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**Characteristics of reef fish assemblages relative to aspects of
adjacent seagrass meadows and other peripheral communities**

Buckley, Lorraine Madsen, Ph.D.

City University of New York, 1994

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A

**Characteristics of Reef Fish Assemblages
Relative to Aspects of Adjacent Seagrass Meadows
and Other Peripheral Communities**

by

Lorraine Madsen Buckley

**A dissertation submitted to the Graduate Faculty in Biology in partial
fulfillment of the requirements for the degree of Doctor of Philosophy, The
City University of New York**

1994

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This manuscript has been read and accepted for the Graduate Faculty in Biology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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ABSTRACT

Characteristics of Reef Fish Assemblages Relative to Aspects of Adjacent Seagrass Meadows and Other Peripheral Communities

by Lorraine Madsen Buckley

Advisor: C. Lavett Smith, Curator Emeritus, American Museum of Natural History

Video transects of four natural reefs and their peripheral habitats in shallow water off South Caicos Island, B. W. I., revealed significant differences in species density, diversity, evenness, structure of size classes and biomass of fishes. These differences were correlated with density and height of contiguous seagrass meadows.

To test correlative relationships for causality, twenty-seven artificial reefs were constructed of conch shells and located in areas surrounded by sparse and dense seagrass meadows of differing shoot height, and non-seagrass habitats such as soft coral flats, sand flats, and halo zones. Density of fishes, species density, recruitment rates, species composition, and relative abundances of juveniles and adults varied with type of peripheral habitat.

Data from natural and artificial reefs revealed species-specific relationships between abundance of reef fish and contiguous habitat types. These associations were sometimes different between adults and juveniles.

Patterns observed in this study suggest that reef fish assemblages have predictable structures that are in dynamic equilibrium and that peripheral communities such as seagrass meadows are critical to processes which determine structure of these reef fish assemblages. Processes of community interaction include nutrient transfer, migrations of adult fish, habitat selection by settlement-stage fish from plankton, and secondary colonization of reefs by juveniles from nursery habitats.

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CHAPTER 1. GENERAL INTRODUCTION

Coral reefs are among the most diverse communities on the planet.

Although species density is not as high as in rain forests, species richness across phyla is highest on coral reefs. As living laboratories, coral reefs are valued for this faunal variety, as well as for the antiquity of their complex community structure (Hodgson and Smith, 1990), their circumtropical distribution, and their natural division into habitat isolates. Habitat fragmentation has recently received considerable research emphasis because of the number of terrestrial communities that are being subdivided by development and because of the utility of patches in modular experimental design.

The inherent beauty of a coral reef community is unsurpassed, but is virtually unknown to most of humanity. And yet, reefs and other shallow-water tropical habitats are degrading at an accelerating rate due to their vulnerability to human impacts such as pollution and over-fishing (Hatcher *et al.*, 1989; LaPointe, 1989). Although reef communities include members of most phyla of algae and animals, fishes are an especially conspicuous component that has considerable economic value in the tropics. Finfish have been the most important dietary protein resource for Caribbean people for over 100 years (Brownell and Stevely, 1981). Economic value of fishes also results from tourism and the aquarium trade. Apparently, marine fish communities associated with coral reefs need protection since their habitat is degrading, they are vulnerable to human impact, and selected species are over-exploited (Randall, 1980). Further, understanding processes that encourage development and maintenance of highly diverse fish assemblages on coral reefs is necessary to design appropriate protected areas and management

programs.

Equilibrium models of community structure dominated theoretical ecology over the last several decades. Early discussions of process emphasized competitive exclusion (Gause 1943; Hardin, 1960) and resulted in development and testing of ideas such as resource partitioning (MacArthur, 1958). The concept of a dynamic equilibrium (Huston, 1979 and 1985) between competition and disturbance was developed principally from research in marine systems. These views all stressed biotic interactions, or a combination of biotic and abiotic factors in structuring communities.

In discussions specific to reef fishes, Smith and Tyler (1972, 1973, 1975) and Smith (1978) emphasized the role of resource partitioning in maintenance of stable assemblages. Although habitat selection and predation were also considered integral processes in structuring reef assemblages by Smith and Tyler (1975), labels such as space limitation hypothesis or competition hypothesis have been assigned to these views (Sale, 1991b). Other studies have supported the prediction that resource partitioning will be exhibited in reef fishes (Parrish and Zimmerman, 1977; Gladfelter and Johnson, 1983; Neudecker, 1985; Ebersole, 1985; Hourigan *et al.*, 1989).

Much time and paper has been devoted to variations of the recruitment limitation hypothesis. This alternative suggests that presettlement mortality results in such low recruitment that competition is precluded (Williams, 1980; Doherty, 1981; Victor, 1983; Victor, 1986). Nonequilibrium models such as this, stress random fluctuations in availability of recruits and chance settlement as the most important determinants of reef fish community structure (Sale, 1977, 1980 and 1991b). The predation hypothesis, which states that adult patterns of abundance

are a result of postsettlement piscivory, has received less attention (Glynn, 1988; Hixon, 1991).

If biotic processes of settlement, postsettlement interactions, and/or resource limitations affect reef fish community structure, then resultant patterns of recruitment and fish assemblage structure should be discernable; and nonequilibrium models of reef fish community structure must be rejected. This project tests effects of biotic processes linked to peripheral habitats on characteristics of reef fish assemblages.

Despite the habitat limitation suggested by their name, many reef fishes occupy more than one habitat. As Smith and Powell (1971) explain, a community of fishes can occupy more than one habitat and a habitat type can support more than one community of fishes in different regions. Habitats used by coral reef fishes include mangroves, sand flats, mud flats, algal flats, soft coral flats, and seagrass meadows.

Interactions between fish assemblages of coral reefs and the communities in adjacent habitats have been widely studied; however, the effect of these interactions on the characteristics of reef fish assemblages remains unclear (Sale, 1981; Parrish, 1989). It has been suggested that the presence of shallow, vegetated habitats enhances diversity, stability, and/or productivity of fishes on adjacent coral reefs (Randall, 1963; Connell, 1978; Gladfelter, 1979; Bohnsack and Talbot, 1980). Such effects on species composition are contrary to the notion of stochastic determination of community structure (Talbot *et al.*, 1978; Sale, 1980).

Elucidation of community interactions as processes that control species composition or other structural patterns of reef fish assemblages has broad implications in resource conservation and management. Recognition of influences

of peripheral communities affects our understanding of response of reef fish assemblages to disturbance (Ogden, 1987). Most reef preservation efforts have targeted organisms only in areas with coral coverage (Salm, 1984). Evidence of peripheral community importance to coral reef systems would suggest protection of entire ecosystems including all relevant peripheral habitats.

Seagrass meadows are of interest because of their high productivity, their utilization by reef fishes, and the frequency with which seagrass habitat is found in association with reefs (Randall, 1965). Seagrass meadows are declining because of increases in direct impacts by dredging and filling operations of development projects and because of their vulnerability to indirect human impacts. Specific ecological linkages of selected reef fishes with seagrass communities have been identified to include trophic interactions (Randall, 1965), shelter from predation (Baelde, 1990), and recruitment (Ogden and Gladfelter, 1983; Heck and Weinstein, 1989; Parrish, 1989).

According to Randall (1965), several reef fishes eat seagrasses and the epiphytic and epifaunal growth associated with seagrass blades. Bare sand between reef areas and adjacent seagrass meadows (halo or Randall zone) is caused by heavy grazing by scarids and acanthurids as well as herbivorous invertebrates (Randall, 1965). Bite marks on seagrass blades within meadows are evidence of grazing by surgeonfishes and parrotfishes (Zieman, 1974; Young and Young, 1982). Recent studies indicate considerable nutrient import to the reef from reef fishes such as haemulids feeding on benthic invertebrates and juvenile fishes of seagrass meadows (Kikuchi and Peres, 1977; Shulman and Ogden, 1987). Interestingly, Young and Young (1982) found no relationship between standing crop of seagrasses and species density or diversity of macrobenthic invertebrates. They

suggested that intense predation limited invertebrate abundance in seagrass habitat as compared to bare sand habitat. Heavier predation may result from feeding by reef fishes which use refuge afforded by seagrasses during foraging.

Value of a peripheral habitat for feeding and refuge of reef fishes is likely linked to density and variety of shelter sites. Communities peripheral to coral reefs, such as seagrass meadows, soft coral flats and sand/rubble flats, vary in density and complexity of shelter. Shulman (1985b) demonstrated that presence of shelter provided by seagrasses increases density of selected species on artificial reefs. Alevizon and Gorham (1989) showed a relationship between shelter complexity and fish density. It is not clear if these effects result from preferential settlement by larvae or from differential predation.

Reef fish assemblages are unique ecological communities because species composition and abundance of recruits are unrelated to reproductive success of adult residents of a particular reef (Shulman, 1985a). This phenomenon results from extended planktonic larval stages (Brothers *et al.*, 1983; Smith *et al.*, 1987; Wellington and Victor, 1989) in irregular current patterns (Shapiro *et al.*, 1988; Lobel, 1989) which separate new recruits from parental populations. That adult population growth is more affected by characteristics of ephemeral planktonic communities than reproductive success of residents emphasizes the importance of understanding processes associated with settlement from the planktonic stage.

Seagrass meadows act as pools of juvenile recruits for reefs due to their advantages as postlarval habitats compared to predator-laden reefs (Ogden and Gladfelter, 1983; Shulman and Ogden, 1987; Parrish, 1989). Larvae of some species display preferential settlement in high density seagrass beds (Bell *et al.*, 1987). Therefore, reefs where seagrass meadows are sparse or absent may have

limited recruitment of selected species as compared to reefs bordered by dense stands of seagrasses.

If proximal seagrass habitats are critical for some species of coral reef fishes and if density of seagrasses affects degree of community interaction, then reef fish assemblages with adjacent seagrass may have unique characteristics. The purpose of this study is to test the null hypothesis that characteristics of reef fish assemblages do not vary relative to densities of adjacent seagrasses. In chapter two, I describe the regional characteristics and specific habitats of the study site. My dissertation research includes both observational and experimental approaches. The third chapter discusses methods and results of surveys of four natural reef sites and habitats peripheral to the reef sites. An experimental test of effects of peripheral habitat on reef fish community structure that employed artificial reefs is described in chapter four. Chapter five examines selected species by analysis of data from natural and artificial reefs. A comprehensive review of major conclusions of this work is given in chapter six, including implications of results for conservation and management of reef fish communities.

CHAPTER 2. SITE DESCRIPTION

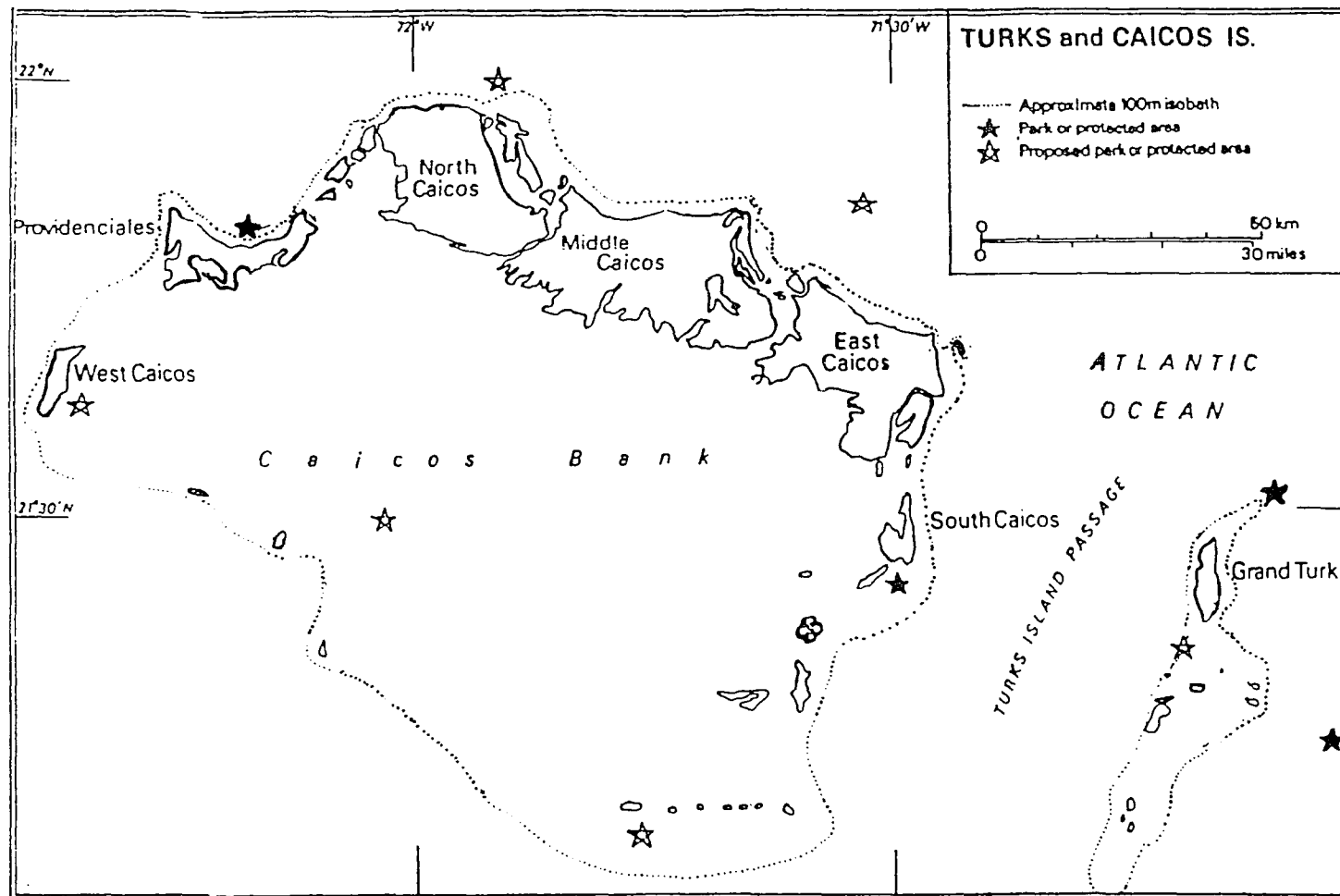
STUDY AREA

GENERAL LOCATION. The Turks and Caicos Islands (TCI) are at the southeastern extent of the 600-mile Bahamian archipelago and comprise a total of 490 km² dry land. Thirty islands and cays are arranged on three geologic platforms: the Mouchoir Bank, the Turks Bank, and the Caicos Bank (Figure 2.1). Caicos Bank consists of 6140 km² of submerged area (244-km perimeter) which is primarily barren sandy bottom, averaging 2-3 m in depth and sloping gently from north to south. Data in Table 2.1 summarize estimates of abundance of substrate types on Caicos Bank (Olsen, 1985).

Table 2.1 - Estimate of Abundance of Selected Benthic Associations on the Caicos Bank, T.C.I. (Olsen, 1985)

<u>Benthic Habitat</u>	<u>Area in sq. km.</u>	<u>Relative Abundance</u>
Sand	3946	64%
Mixed coral and vegetation	1134	18%
Coral	425	7%
Tidal flats	296	5%
Mangroves	235	4%
Seagrass meadows	104	2%
Total	6140	100%

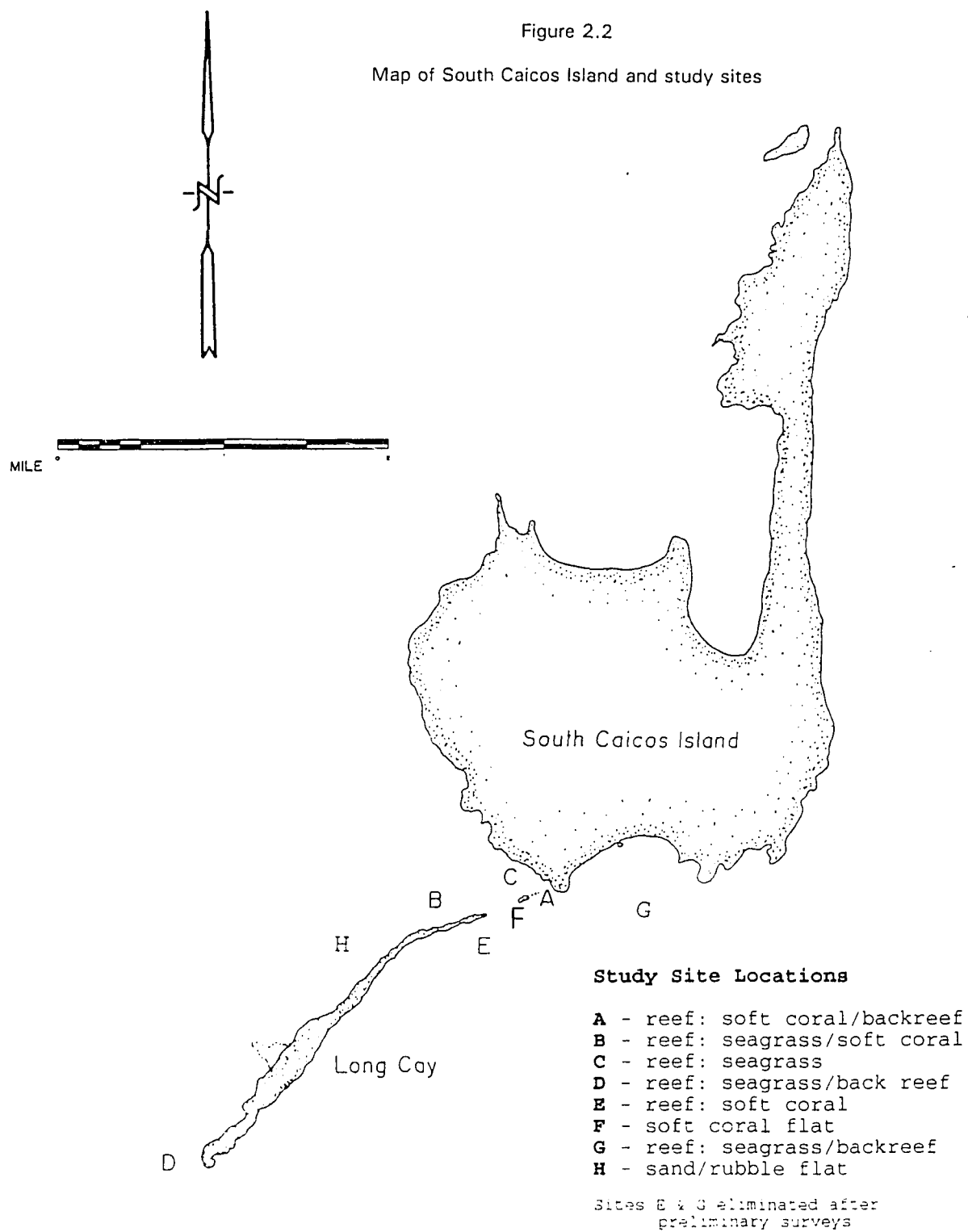
Figure 2.1 - Map of Turks and Caicos Islands, British West Indies



Well-developed coral reef is found adjacent to islands and cays and at the shelf edge. Most remaining coral areas are interspersed with benthic vegetation. Tidal flats and mangrove habitats are nearer to land while seaward-facing shallows contain seagrass meadows. Most seagrass meadows have at least one margin adjacent to coral reef.

Turks and Caicos Islands are a British Crown Colony with a population of approximately 8500 persons on six inhabited islands. Since decline of the salt production industry in 1964, the major employer has been the fishing industry. Major fisheries are lobster, conch, and finfish, in decreasing order of importance (Brownell and Stevely, 1981). Tourism is the only other industry of considerable economic value.

STUDY SITE. South Caicos Island (Figure 2.2) is on the windward (eastern) margin of the Caicos Bank. Its population ranges between 800-1100 dependent upon the fishing season. Surrounding three sides of South Caicos is shallow water of Caicos Bank dotted with many uninhabited cays and mangrove islets. The eastern side of the island faces trade winds and the Atlantic Ocean and is protected by a barrier reef. Strong, wind-driven currents are normal with occasional shifts in current direction due to tidal flow. The southeastern portion of the barrier reef and several islets and cays south of the island are included in a proposed national park. A few hundred meters beyond the barrier reef is a wall that begins in 15-20 meters of water and plummets to over 2000 meters.



TARGET COMMUNITIES

CORAL REEFS. Corals off South Caicos are primarily east and south of the island in barrier reefs, patch reefs, and fringing reefs and in scattered coral heads on sandy flats dominated by soft corals. Barrier reefs of South Caicos are not included in this study because of inaccessibility because of windward exposure to Atlantic swells. Habitats adjacent to coral reefs include seagrass meadows, soft coral flats, backreef, and sand flats. Mangroves are not found adjacent to coral reefs off South Caicos.

Six shallow reefs (depth < 10 m) southeast of the island and within the boundaries of a national marine park were selected for study; however, two of them (sites E and G) were often inaccessible due to strong currents and wave action. Therefore, surveys at sites E and G are incomplete, and data are excluded. Locations of study sites are depicted in Figure 2.2. Habitats at the remaining four sites are characterized by continuous reef bordered by dome-like patch reefs shaped by very large single colonies of *Montastrea annularis*.

Each of the study reefs has a different pattern of adjacent communities:

Site A - backreef, sand, and soft coral flat (Figure 2.3)

Site B - sparse seagrass and soft coral flat (Figure 2.4)

Site C - sand and seagrass (Figure 2.5)

Site D - backreef, sand, and dense seagrass (Figure 2.6)

SEAGRASS MEADOWS. Seagrass meadows surround South Caicos.

Dominant species are *Thalassia testudinum* of the family Hydrocharitaceae and *Syringodium filiforme* of the family Potamogetonaceae (Hartog, 1977). Seagrass

Figure 2.3 - Site A: Natural reef with adjacent backreef, sand, and soft coral habitats

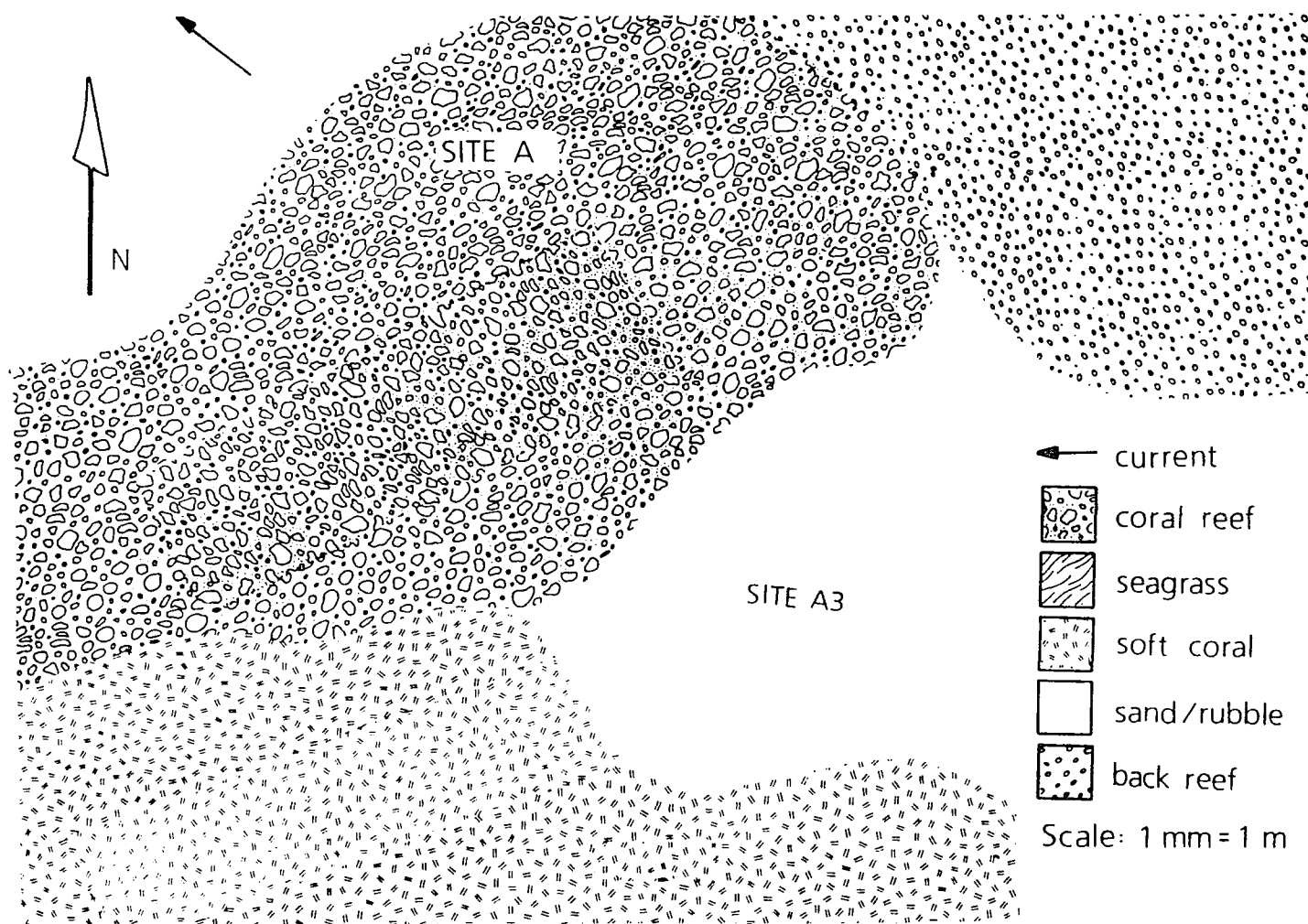


Figure 2.4 - Site B: Natural reef with adjacent seagrass, sand, and soft coral habitats

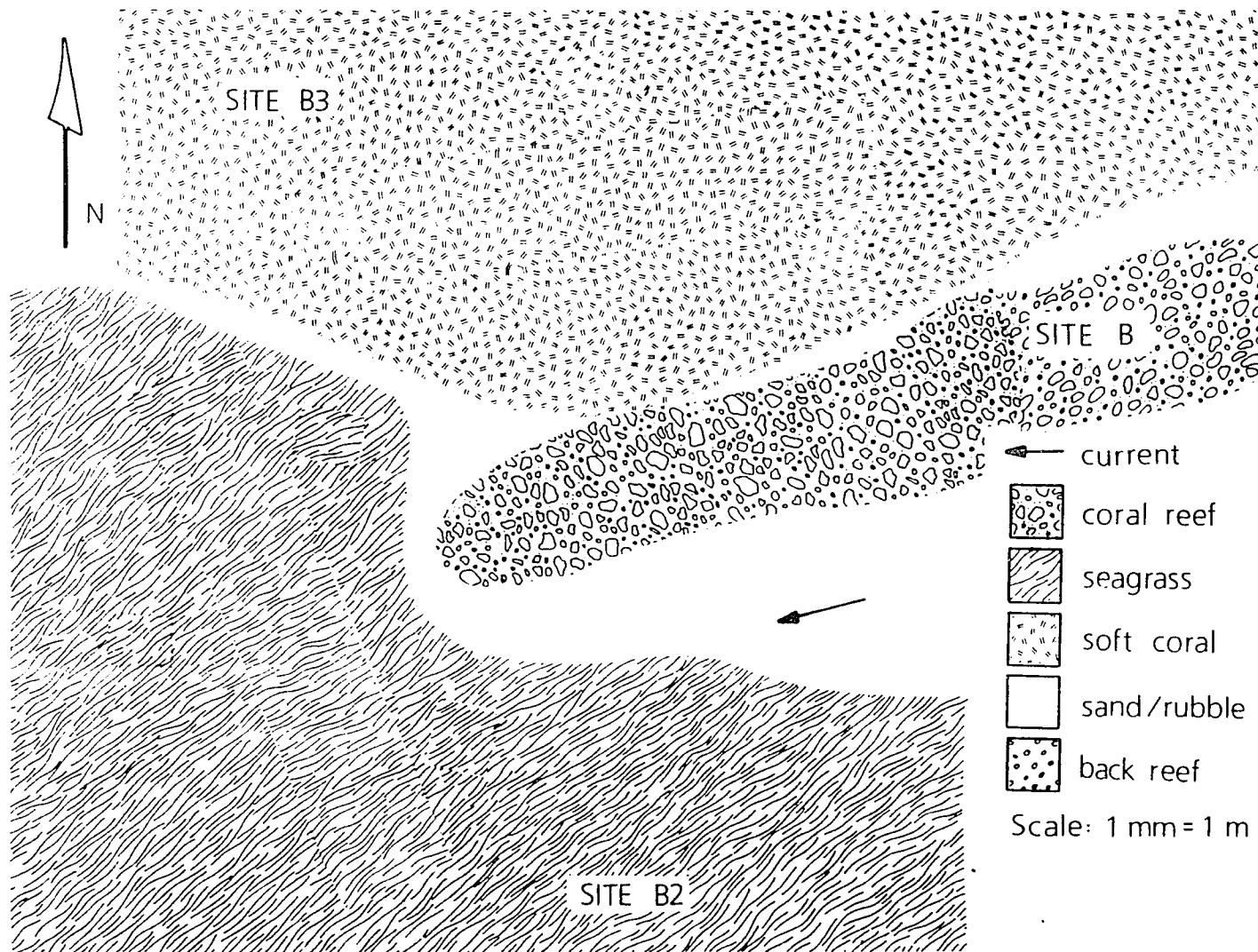


Figure 2.5 - Site C: Natural reef with adjacent seagrass and sand habitats

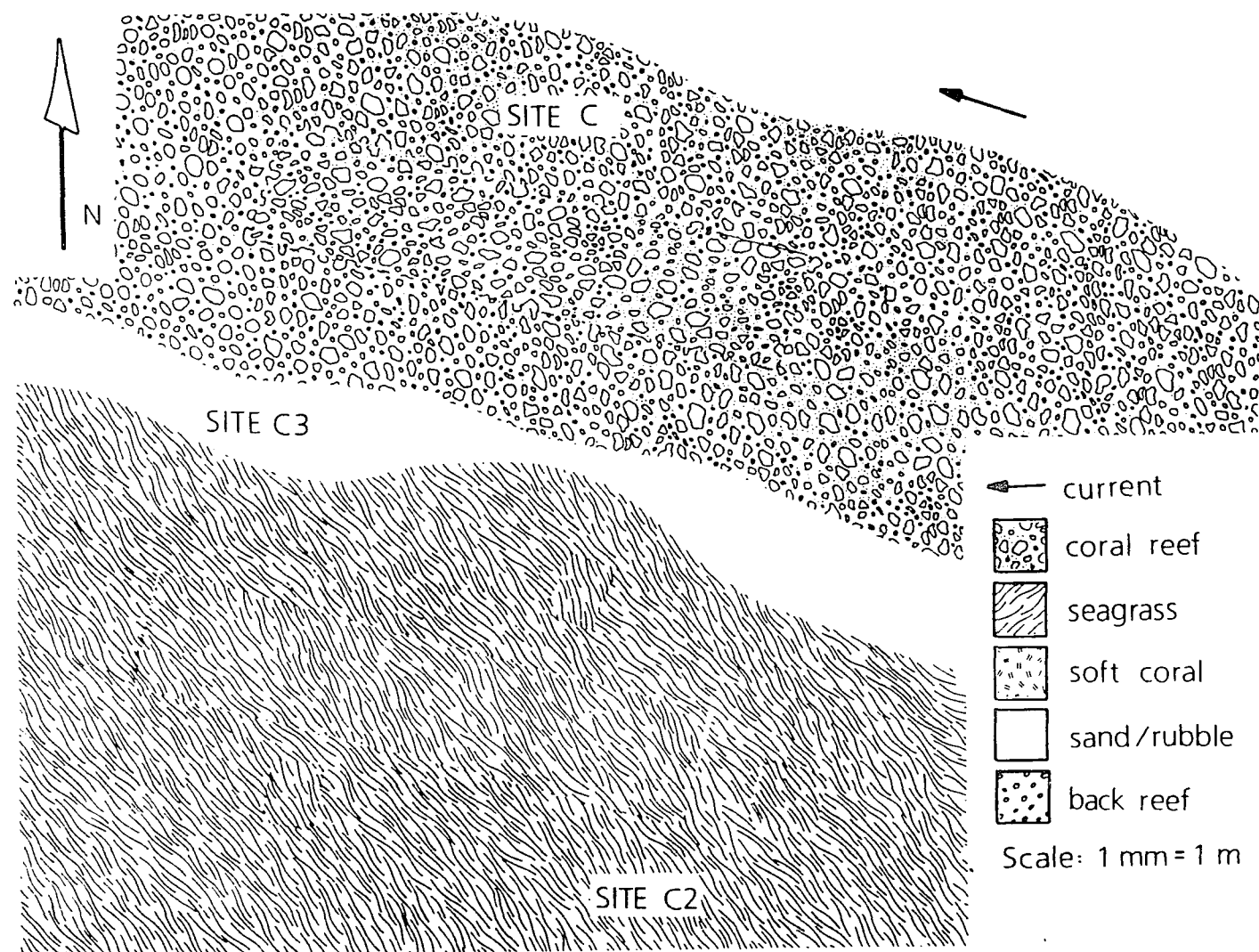
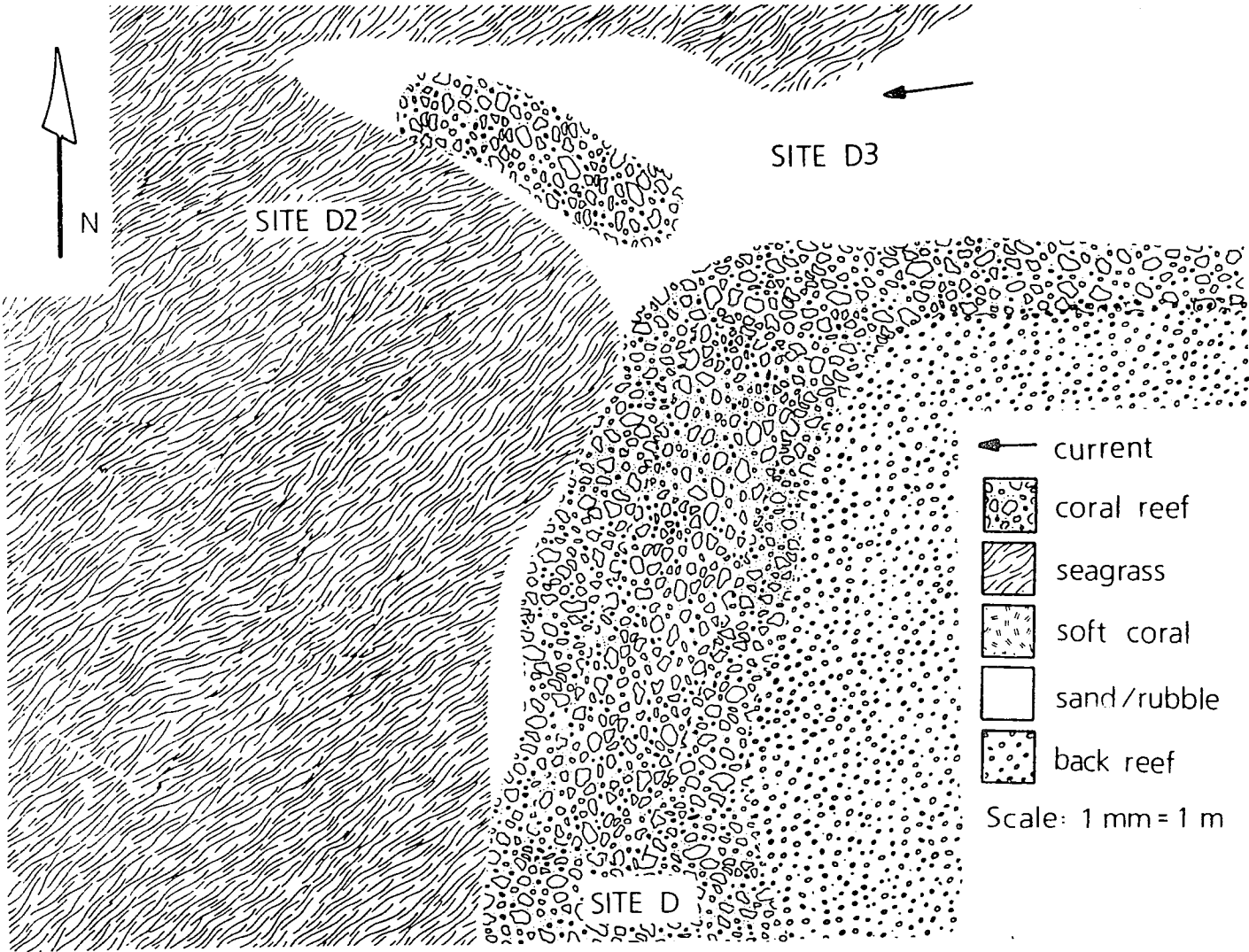


Figure 2.6 - Site D: Natural reef with adjacent seagrass, sand, and backreef habitats



meadows next to reef study sites (B, C and D in figure 2.2) have varying densities ranging from sparse grass (with more sand visible than grass) to dense grass (capable of complete concealment of the largest parrotfish). The meadow of site D, at the southwestern tip of Long Cay, has occasional bare patches of sand, called blowouts, discussed in more detail in Chapter 4.

Each seagrass site has a different height and density of seagrass:

Site B2 - sparse, short seagrass (Figure 2.4)

Site C2 - moderately dense, moderately tall seagrass (Figure 2.5)

Site D2 - dense, tall seagrass (Figure 2.6)

SAND FLATS and SOFT CORAL FLATS. Sand-bottomed habitats found between the periphery of coral reefs and seagrass meadows are called halo or Randall zones. Other sand flats with little or no shelter are found as channels and patches within or between other habitat types. In addition, extensive areas of shallow sandy habitat are found on Caicos Bank. Carbonate plains where sand is shallow are characterized by soft corals, hydrozoans (*Millepora* sp.), sponges, macroalgae, and small scattered coral heads. Soft coral flats are abundant seaward of the fringing and barrier reefs off South Caicos.

Study sites in sand and soft coral habitats include:

Site A3 - sandy area between natural reef and soft coral habitats
(Figure 2.3)

Site B3 - sparse soft coral (Figure 2.4)

Site C3 - halo between natural reef and seagrass meadow
(Figure 2.5)

Site D3 - halo between natural reef and seagrass meadow (Figure 2.6)

Site F3 - dense soft coral

Site H3 - sand flat of the banks

REEF FISHES. Noncryptic reef fishes off South Caicos can be observed in well-developed coral reefs, seagrass meadows of varying densities, and on soft coral and sand flats. A single coral patch less than three meters in diameter may have up to 75 species (Smith and Tyler, 1972). This study targets noncryptic, demersal and pelagic fishes of the reef assemblage because they are most likely to rely on one or more linkage between reef and seagrass meadow. Also, noncryptic fishes are economically important because they provide the base for the tourist-dive industry and finfish fisheries of the region. Small, cryptic reef fishes rarely have a home range that includes another habitat; however, the importance of seagrasses as nursery grounds for small and cryptic fishes remains unclear. Unfortunately, sampling of cryptic fishes requires poison techniques that are ineffective in areas of strong currents like the waters off South Caicos, and are not allowed within the national park boundaries.

CHAPTER 3. SURVEYS OF NATURAL HABITATS

INTRODUCTION

To answer the central question of this project I began with a search for characteristics of natural reef fish assemblages which vary among reefs relative to the type of peripheral habitat. Such a search is complicated by the myriad of influences on natural fish assemblages other than peripheral habitat. Detailed habitat descriptions are necessary to examine as many of these other influences as possible. Habitat surveys of study sites include measurement of abiotic factors and biotic characteristics of substratum communities as described below. Fish assemblages at each study site were surveyed on the reef and in each accessible peripheral habitat. Since study sites were windward, shallow backreef habitats were inaccessible due to wave action and were therefore excluded from surveys.

Video records of transects (cinetransects) were used to make most efficient use of field time, to sample without density bias, and to sample in an area in which poisons such as rotenone would be ineffective or not feasible. Use of video transects for estimating species abundance was reviewed by Sale (1981). In some ways, video surveys assess fish communities more accurately than traditional methods of visual survey and concurrent data recording on slates. Records written on underwater slates during fish surveys are density biased in that more data points are missed as fish density increases (Greene and Alevizon, 1989). In the time it takes to record one individual by visual survey, several other fishes can swim by unrecorded (Brock, 1982). Video surveys, on the other hand, offer slow motion, stop action, and rewind options of fish movements. In addition, the video tape

becomes a permanent record of habitat and fishes for reevaluation or future research (Smith and Tyler, 1973).

METHODS

CINETRANSECTS. Video tapes of three 100-meter linear transects arranged parallel and at least 5 meters apart in each accessible habitat at each site were recorded diurnally 0900 - 1500 hrs. at least once each summer for three years, 1990-1992. Figures 3.1 - 3.6 delineate transect locations at each site. A video camera (Nikon VN-300 or JVC 2000) in an Ikelite underwater housing recorded each transect on 8 millimeter videotape as a diver held the camera in front while swimming approximately one meter above the substratum following the contours of the bottom. A constant camera angle was maintained to include a consistent percentage of the bottom and water column. The field of view was adjusted with a zoom control to include a swath of the bottom of consistent width.

ABIOTIC FACTORS. Maximum depth was determined at each of 12 sites in June and July, 1990. Depth from surface to sand (between coral heads, soft corals, or seagrass shoots) was measured three times and averaged for maximum site depth. At each reef site (A, B, C, D) data were recorded in June and July of 1990 to determine coral height and topographic complexity. Topographic relief was measured along one of the three 100-meter transects at each site using a measuring tape with a float attached to one end. Distance from substratum to surface was recorded at every other meter mark resulting in 50 depth measurements. Each record was then subtracted from the maximum depth at that site and the results were used to determine mean coral height. Topographic complexity was calculated by subtracting each datum from the previous one

Figure 3.1 - Transect positions at natural reef site A and sand/soft coral site A3

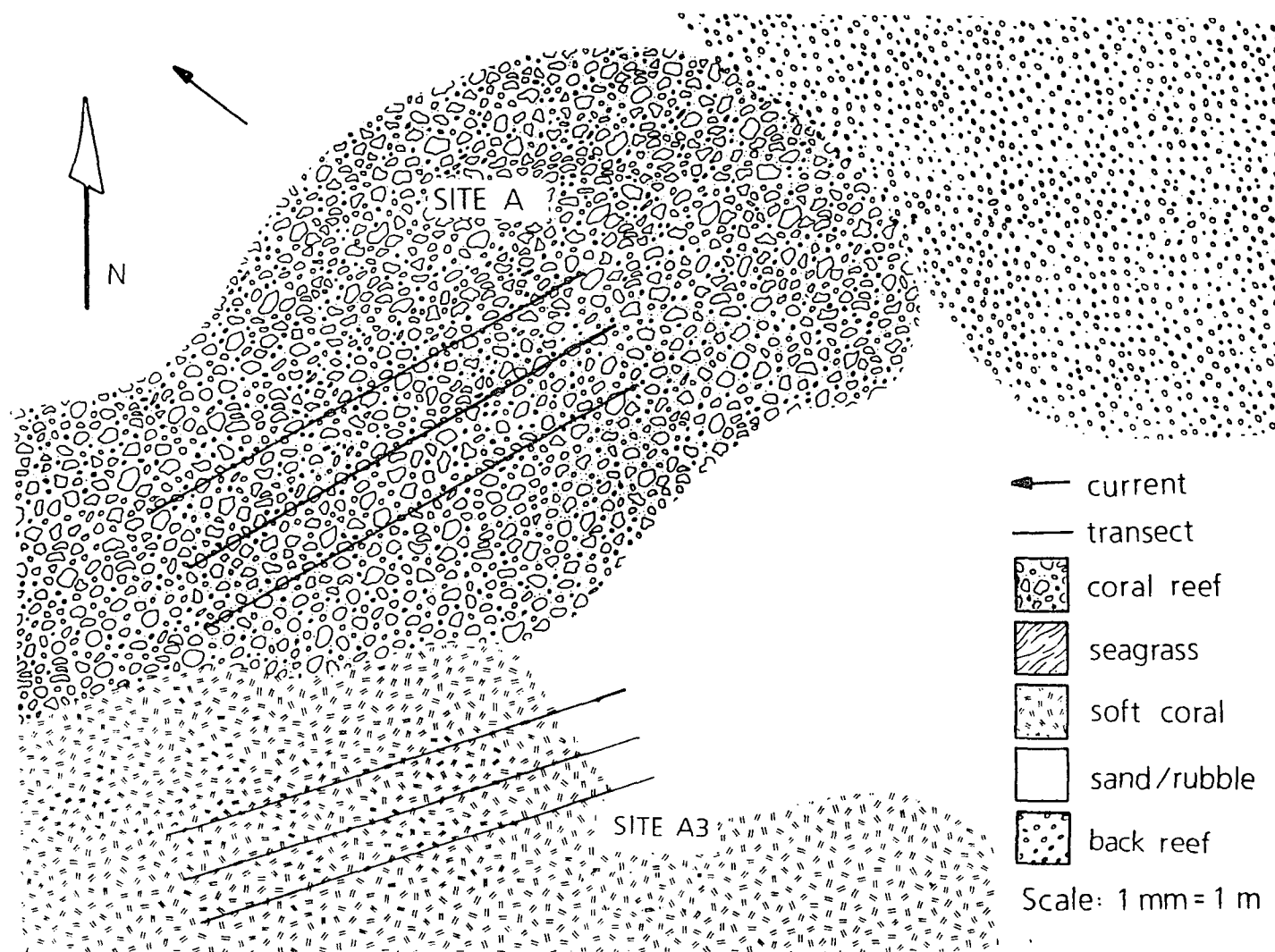


Figure 3.2 - Transect positions at natural reef site B, seagrass site B2, and soft coral site B3

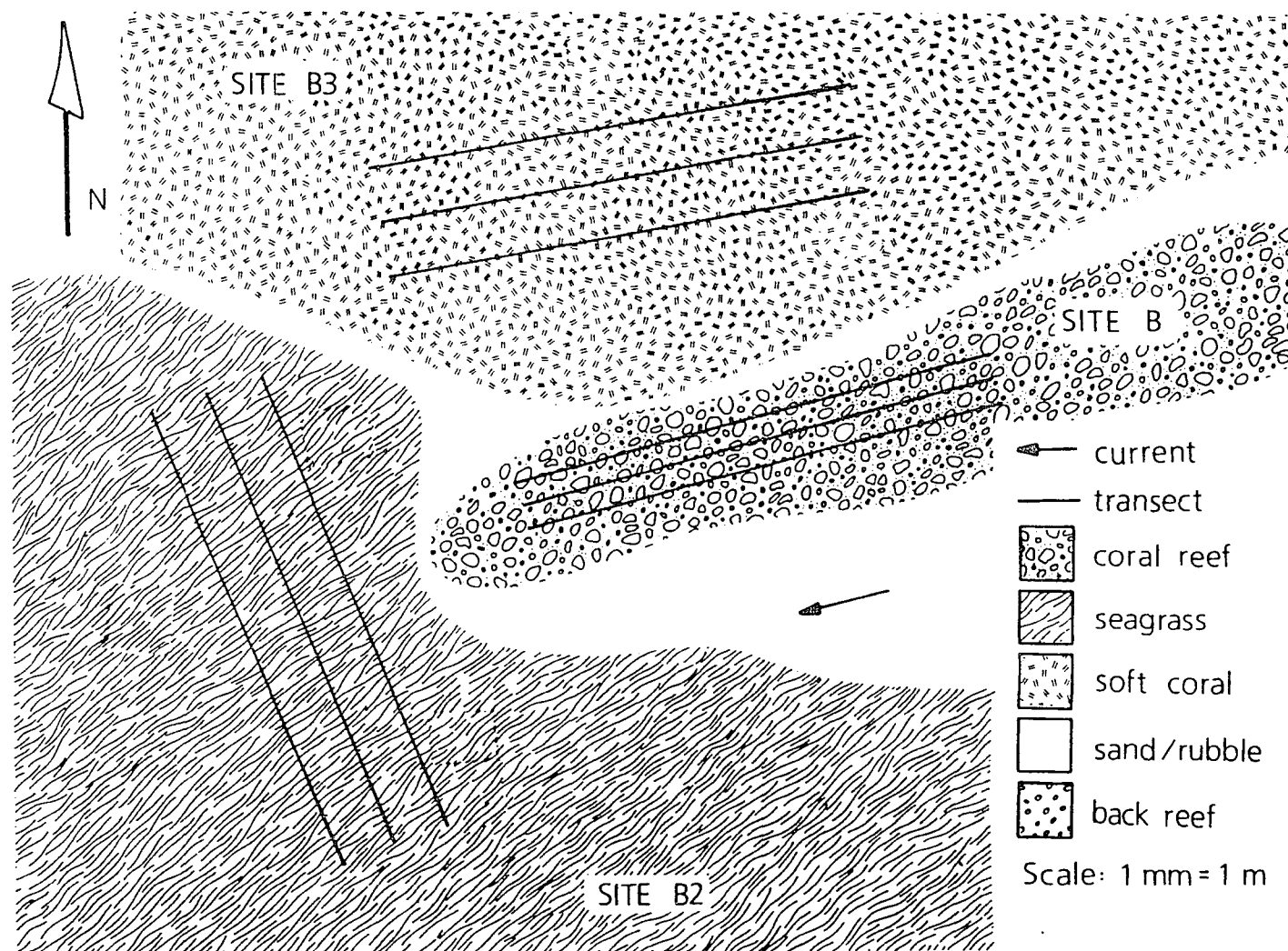


Figure 3.3 - Transect positions at natural reef site C, seagrass site C2, and sand site C3

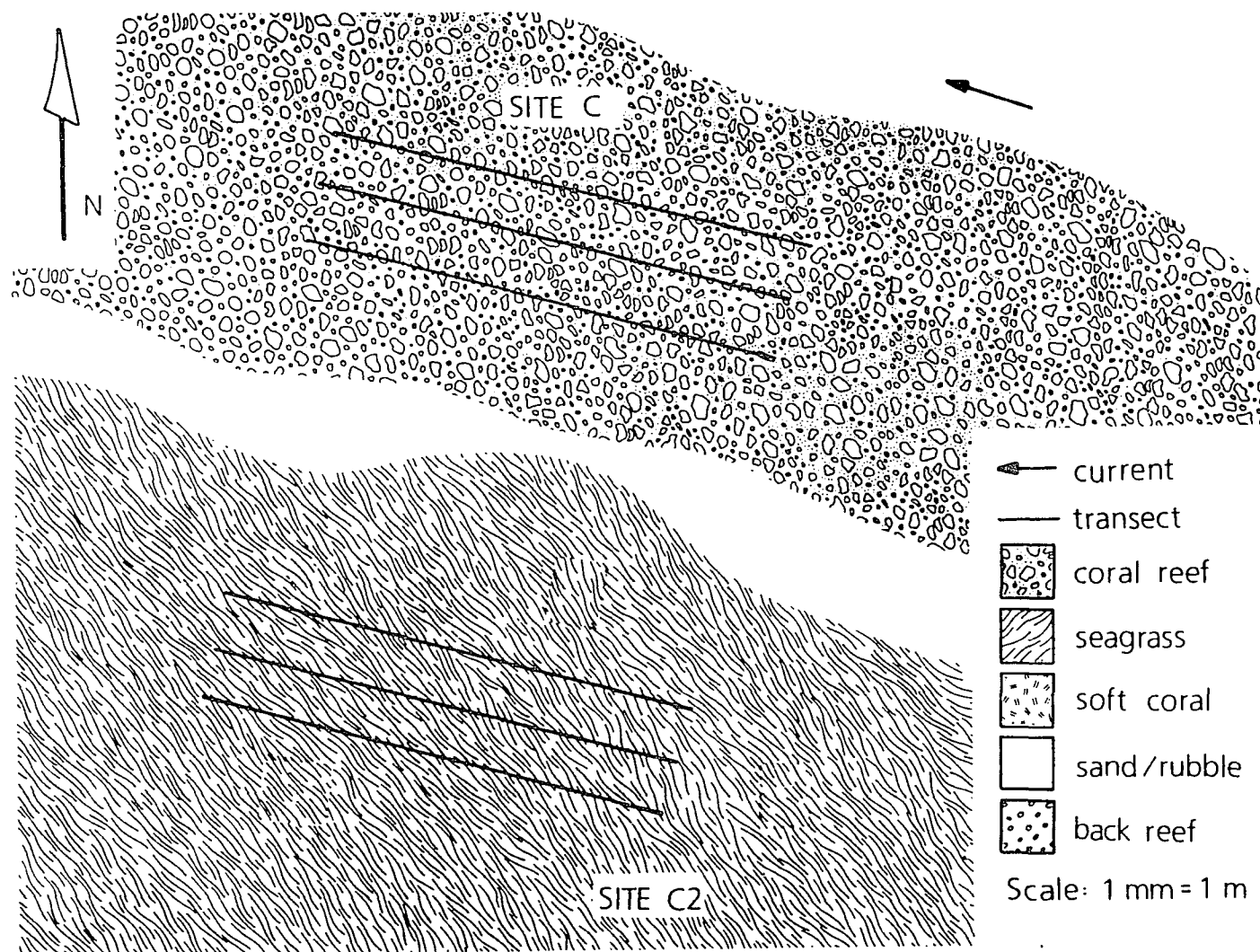


Figure 3.4 - Transect positions at natural reef site D, seagrass site D2, and sand site D3

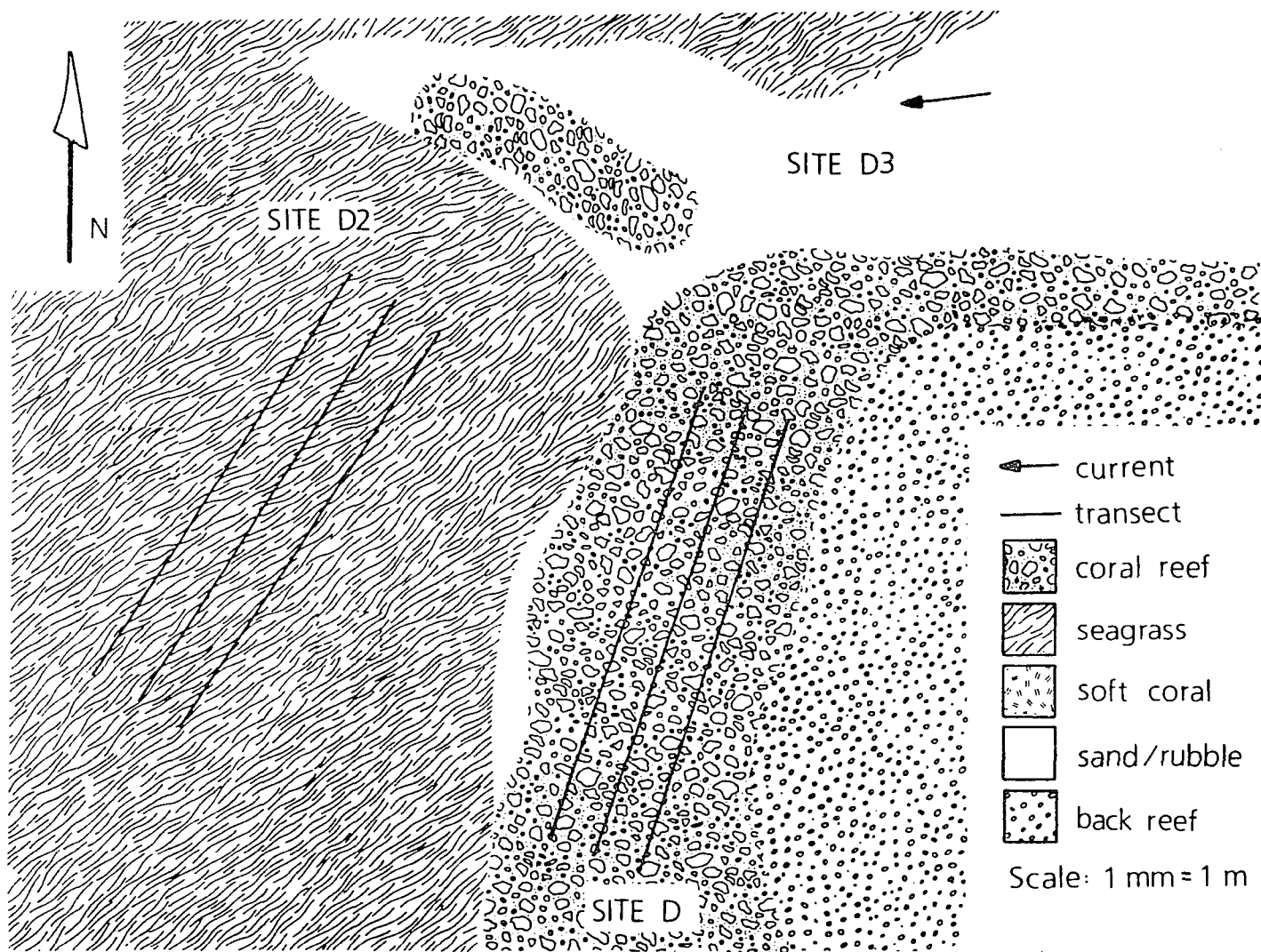


Figure 3.5 - Transect positions at soft coral site F3

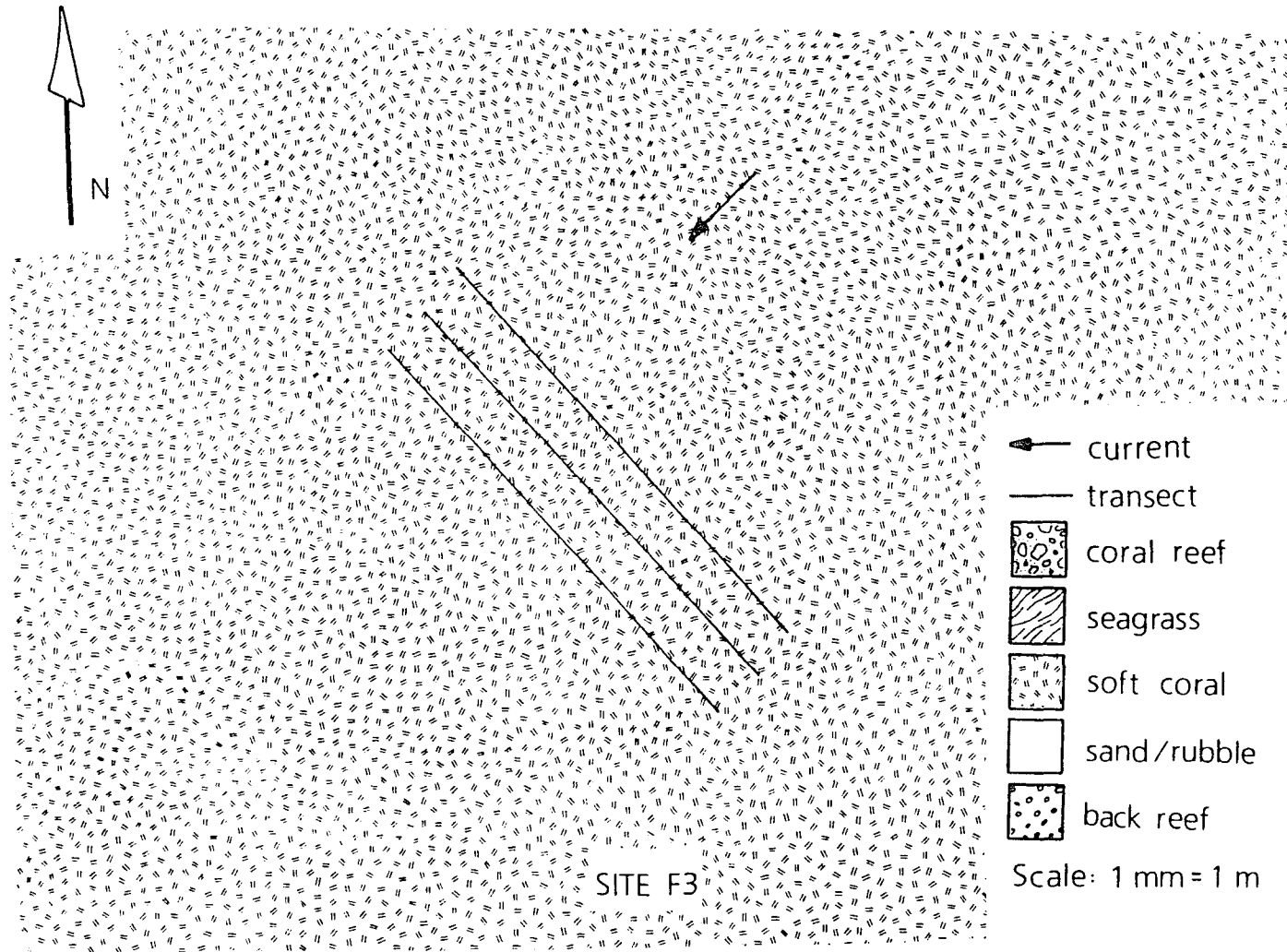
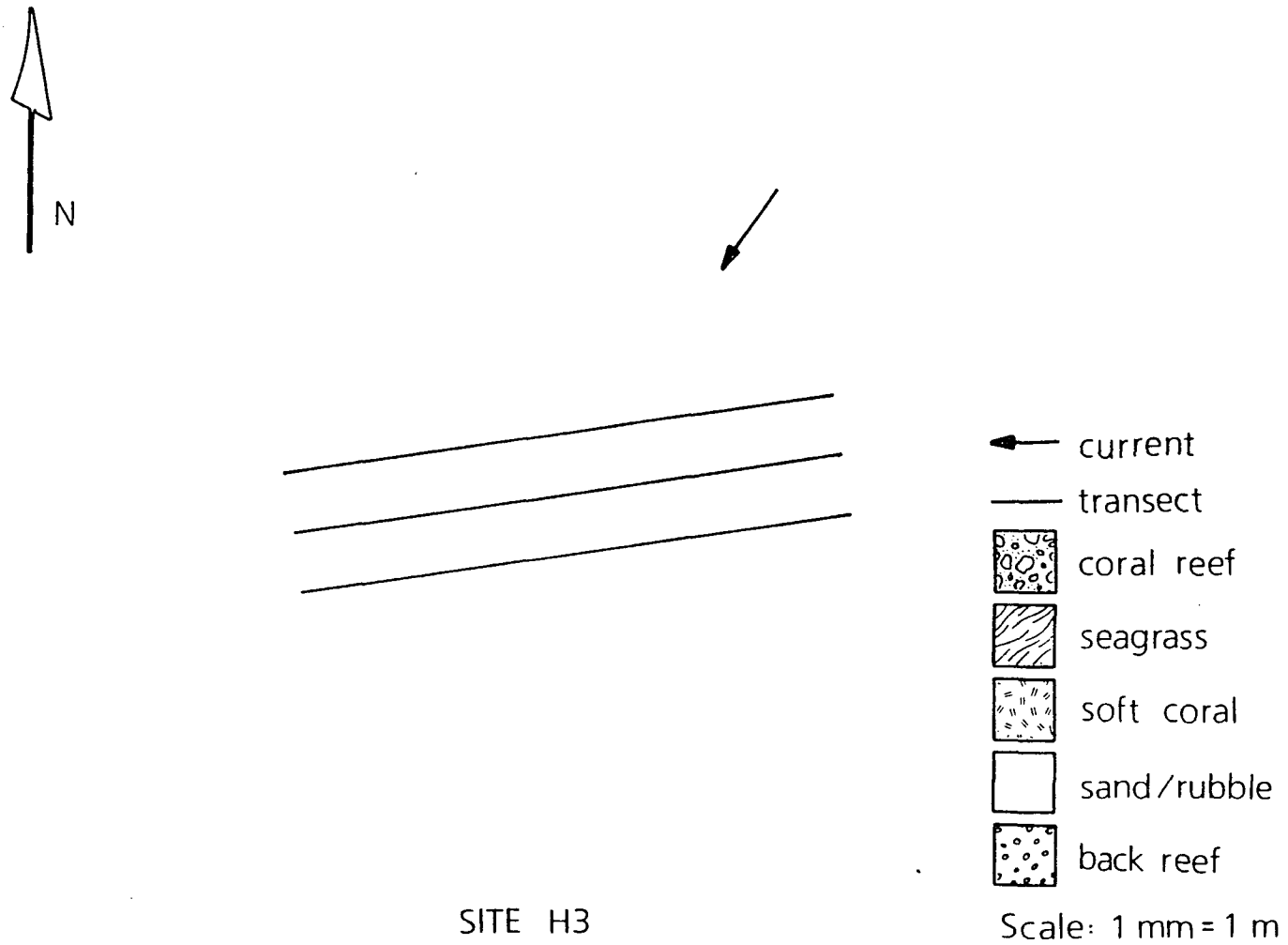


Figure 3.6 - Transect positions at sand and rubble site H3



resulting in 49 measurements of change in depth. The mean of these data was calculated for each natural reef site.

Other physical characteristics were measured each summer at each site, including turbidity, temperature, and current velocity for three years (1990, 1991, and 1992). Turbidity was measured using a secchi disk attached to a measuring tape that was extended horizontally approximately one meter above the bottom. The secchi disk was moved away from the observer slowly until it disappeared and the tape measurement was recorded. Then the disk was moved toward the observer until it reappeared as the observer reeled in the slack tape, and again the measurement was recorded. The average of these two data was recorded for comparison of turbidity at each site near slack tide between 0900 and 1500 hours on three days in consecutive years for a total of three repetitions.

Temperature was recorded midway between surface and bottom with a field thermometer. Temperatures were recorded at each site near slack tide between 0900 and 1500 hrs on each of three summer days in consecutive years. Current velocity was measured by repeatedly recording time and distance to the bottom of a slightly negatively buoyant object dropped from three meters above the bottom. The object was a 50 ml. plastic bottle partially filled with sand and water and capped. Ten repetitions were recorded and averaged at each site between 0900 and 1500 hours near slack tide on three occasions in summers of consecutive years.

SUBSTRATA. Shoot densities were recorded in each seagrass meadow by tossing a circular quadrat (0.25 m diameter) at random intervals during a timed swim. Data from ten tosses at each of three habitats were recorded in June or July of 1991 and 1992 for a total of twenty repetitions at each site. Time between

tosses on each dive was determined using a table of random numbers to select number of kick cycles between tosses (0-99). Shoots were identified to species and counted at the point where they emerged from the sand. Thalli of algae were also identified and counted. Shoot height was measured on the first three shoots of each quadrat for a total of 60 measurements. Height of each shoot or thallus was measured from the sand to the end of the longest blade or tip of the thallus.

In habitats without seagrass, percent coverage of live coral and other sessile invertebrates (soft coral, sponge, dead coral, or sand/coral rubble) was determined from cinetransects. During viewing of cinetransects, a 0.5 m² square plastic grid subdivided into 25 equal squares was hung over the monitor screen. Using a table of random numbers to determine elapsed time, 1-10 seconds passed while the cinetransect played at normal speed. Then the tape was paused and the next clear frame was used to record bottom coverage. The amount of substratum coverage of each type was estimated for each of the 25 0.1-m² grid squares to a resolution of 0.05 m². Percentages of each substratum type in that frame were then calculated. Data were recorded from 25 frames on each of three 100-meter cinetransects for each site from tapes recorded in June and July of 1991.

FISH ASSEMBLAGES. Fish surveys were conducted by a strip cinetransect method modified from Brock (1954) using tapes recorded along three 100-meter transects in each study habitat at each site (figures 3.1-3.6) each summer for three years (June and July of 1990, 1991, and 1992). Identification and maturity (juvenile or adult) of each fish were determined from cinetransects viewed on a color monitor (Sony Trinitron: diameter = 75 cm). All fishes in the camera's field of view were counted even when only part of the animal's body was visible. If

identification was not possible the fish was recorded as "unidentified." Fish size was estimated using the smaller category when size was marginal between two categories. Categories included small (< 10 cm), medium (10 - 25 cm), large (25 - 50 cm), and extra large (> 50 cm).

Frequency and relative abundance of each size and maturity category were determined for each species. Relative abundance of each species at each site and each maturity category of each species at each site was determined using

$$\text{Relative Abundance} = n/N$$

where n = number of individuals per species

N = total number of individuals per site.

Density of fishes, species density, diversity and evenness were determined for each assemblage. The Shannon index of diversity (Shannon and Weaver, 1949) was calculated according the following formula:

$$H = - \sum (n_i/N \log(n_i/N)) \text{ or } \sum P_i \log P_i$$

where n_i = importance value for each species

N = total of importance values

P_i = importance probability for each species = n_i/N .

The Shannon index is independent of sample size and is normally distributed which allows more flexibility in choices of additional statistical tests. Pielou's evenness index (Pielou, 1966) was calculated using the formula:

$$e = H/\log S$$

where H = Shannon index

S = number of species.

Natural logarithms ($\log e$) were employed in both the Shannon index of diversity and Pielou's evenness index.

RESULTS AND DISCUSSION

Differences among means were tested with one-way analysis of variance (ANOVA), and significance was determined within a 95% confidence interval ($P < 0.05$) unless otherwise stated. Least significant difference (LSD) values were determined to scrutinize pairs of means within groups found to be significantly different. After analysis of variance revealed no significant difference among transects within sites, data on fishes from cinetransects within sites were pooled each year resulting in three repetitions at each site for determination of community characteristics such as relative abundance, density and diversity.

CORAL REEFS. Characteristics of natural reef sites have been summarized in Table 3.1. No significant difference among sites was found based on topographic complexity, temperature, or current velocity. However, there was significant difference among sites based on the data recorded for depth, coral height, and secchi disk visibility. Mean coral height and depth were greatest at site A and least at site B. Although not significantly different among the four sites, topographic complexity was also highest at site A and lowest at site B. Turbidity was lowest at site B and highest at site D.

Types of peripheral habitats directly adjacent to the four natural reefs included seagrass meadows, soft coral flats, backreefs, and sand/rubble flats. The types of adjacent habitats and density of seagrasses present are described in Table 3.1. Sites C and D had the most dense seagrass in the adjacent meadow. Site A had no seagrass peripherally, but did have some shelter in adjacent habitats in the form of coral and rubble on the backreef and soft coral on the soft coral flat.

Table 3.1 - Characteristics of Four Natural Reefs off South Caicos Island

SITE	A	B	C	D
Adjacent Seagrass Description	none	sparse	moderate	dense
Other Peripheral Habitats	backreef sand/soft coral	soft coral sand/rubble	sand/rubble	backreef sand/rubble
ABIOTIC FACTORS				
Maximum Depth (m), n = 3 *	5.4	3.8	4.5	4.1
Mean Coral Height (m), n = 50 *	1.8	1.4	1.2	1.5
Topographic Complexity, n = 49	1.5	1.2	1.1	1.4
Secchi Disk Visibility (m), n = 3 *	24.5	26.5	20.2	18.7
Temperature (degrees C), n = 3	22.0	25.0	27.0	24.0
Current Velocity (m/sec), n = 3	0.6	0.7	1.1	0.9
SUBSTRATES				
Live Coral (% coverage) *	43.8%	33.1%	36.5%	24.7%
Dead Coral (% coverage)	9.4%	12.0%	6.1%	10.5%
Soft Coral (% coverage) ***	5.7%	0.1%	9.0%	1.9%
Sponges (% coverage)	2.1%	0.8%	1.8%	0.3%
Macroalgae (% coverage) ***	2.2%	16.0%	2.7%	11.1%
Hydrozoans (% coverage)	0.8%	0.2%	0.1%	0.3%
Sand and Coral Rubble (% cov.)	36.8%	37.7%	43.9%	51.3%
FISH ASSEMBLAGES				
Fish Density (#/1000 m2)	636	728	447	742
Species Density (#/1000 m2) **	28	29	37	41
Species Evenness ***	0.5	0.7	0.8	0.8
Species Diversity ***	1.6	2.5	2.9	2.8

* P < 0.05

** P < 0.01

*** P < 0.001

Measurements of amount and type of bottom coverage at each of four natural reef sites are compared in Table 3.1 and Figure 3.7. Categories of substratum included live coral, dead coral, soft coral, sponges, macroalgae, sand/coral rubble, and hydrozoans. Hydrozoans were represented only by species of *Millepora*. A one-way ANOVA revealed significant differences in amount of coverage by live coral, soft coral, and macroalgae at the four sites. Site A had significantly more live coral than the other three sites, and site B had significantly more macroalgae and less soft coral than the other three sites.

Characteristics of fish assemblages on natural reef appear in Table 3.1. Significant differences in species density, evenness, and diversity were found among the fish assemblages at the four sites. Although there was no significant difference in density of fishes, values were highest at site D. Species density, diversity, and evenness were significantly higher at sites C and D than at reefs with sparse or no seagrass. Examination of relative abundances of species by site (Tables 3.2 - 3.5) reveals that data from Site A is strongly influenced by two resident schools, one of *Gerres cinereus*, the other of *Sphyræna picudilla*. With these two species excluded, density of fishes at Site A was the lowest with 209 individuals per 1000 square meters.

Although *Gerres cinereus* and *Sphyræna picudilla* were the most abundant species at Site A and accounted for 67% of the fishes recorded, the pomacentrids were the most abundant nonschooling fish and comprised 11% of total fish density (Table 3.2). Damselfishes were also the largest percentage of the fish assemblage at Site B (Table 3.3). Whereas, the fish assemblages at sites C and D were dominated by haemulids, followed by pomacentrids and lutjanids (Tables 3.4 and 3.5).

Figure 3.7 - Percent Coverage of Substrate Types on Four Natural Reef

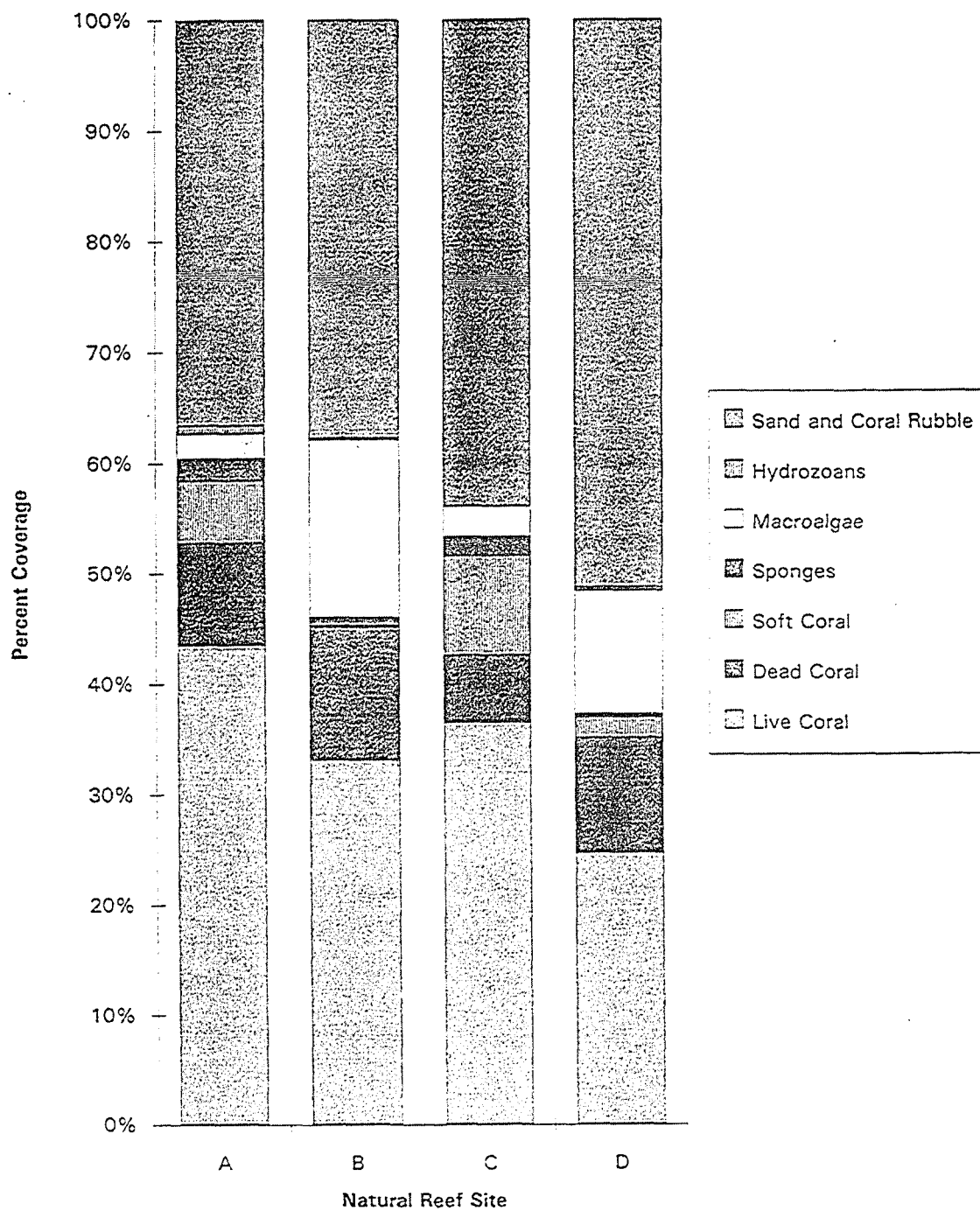


Table 3.2 - Maturity, Size, and Relative Abundance of Fishes at Natural Reef Site A

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Gerres cinereus</i>	0	365	0	365	0	0	365	57.5%
<i>Sphyræna picudilla</i>	0	62	0	62	0	0	62	9.7%
<i>Chromis cyanea</i>	0	39	39	0	0	0	39	6.0%
<i>Thalassoma bifasciatum</i>	23	15	38	0	0	0	38	6.0%
<i>Lutjanus mahogoni</i>	0	22	0	0	22	0	22	3.4%
Unidentified	0	16	10	5	1	0	16	2.5%
<i>Stegastes dorsopunicans</i>	0	13	13	0	0	0	13	2.0%
<i>Chromis multilineata</i>	0	10	10	0	0	0	10	1.5%
Labrid	2	6	7	1	0	0	8	1.3%
<i>Acanthurus bahianus</i>	0	8	0	8	0	0	8	1.2%
<i>Mulloidichthys martinicus</i>	0	6	0	6	0	0	6	1.0%
<i>Halichoeres garnoti</i>	< 1	5	< 1	5	0	0	6	0.9%
<i>Haemulon sciurus</i>	0	5	0	5	0	0	5	0.7%
<i>Sparisoma aurofrenatum</i>	0	3	0	3	0	0	3	0.5%
<i>Haemulon flavolineatum</i>	0	3	0	3	0	0	3	0.5%
<i>Haemulon parrai</i>	0	3	0	0	3	0	3	0.5%
<i>Sparisoma viride</i>	1	2	1	0	2	0	3	0.5%
<i>Microspathodon chrysurus</i>	0	3	0	3	0	0	3	0.4%
<i>Myripristis jacobus</i>	0	2	0	2	0	0	2	0.4%
<i>Acanthurus coeruleus</i>	0	2	0	2	0	0	2	0.3%
<i>Grama loreto</i>	0	2	2	0	0	0	2	0.3%
<i>Halichoeres radiatus</i>	1	< 1	1	0	<1	0	1	0.2%
<i>Scarus taeniopterus</i>	0	1	0	0	1	0	1	0.2%
<i>Abudefduf saxatilis</i>	0	1	0	1	0	0	1	0.2%
Scarid	0	1	0	0	1	0	1	0.2%
<i>Chaetodon capistratus</i>	0	1	0	1	0	0	1	0.2%
<i>Ocyurus chrysurus</i>	0	1	0	1	0	0	1	0.2%
<i>Lutjanus griseus</i>	0	1	0	0	1	0	1	0.2%
<i>Melichthys niger</i>	0	1	0	1	0	0	1	0.2%
<i>Sphyræna barracuda</i>	0	1	0	0	0	1	1	0.2%
<i>Chaetodon striatus</i>	0	1	0	1	0	0	1	0.1%
<i>Sparisoma rubripinne</i>	0	1	0	0	1	0	1	0.1%

Table 3.2 Continued - Maturity, Size, and Relative Abundance of Fishes at Natural Reef Site A

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Holocentrus rufus</i>	0	1	0	1	0	0	1	0.1%
<i>Caranx ruber</i>	0	1	0	0	1	0	1	0.1%
<i>Holacanthus tricolor</i>	0	1	0	1	0	0	1	0.1%
Lutjanid	0	1	0	0	1	0	1	0.1%
Pomacentrid	0	1	1	0	0	0	1	0.1%
<i>Scarus vetula</i>	0	1	0	0	1	0	1	0.1%
<i>Stegastes planifrons</i>	0	1	1	0	0	0	1	0.1%
Striped scarid	< 1	0	< 1	0	0	0	< 1	0.1%
<i>Ginglymostoma cirratum</i>	0	< 1	0	0	0	< 1	< 1	0.1%
<i>Aulostomus maculatus</i>	0	< 1	0	0	< 1	0	< 1	0.1%
<i>Bodianus rufus</i>	0	< 1	0	< 1	0	0	< 1	0.1%
<i>Cephalopholis fulvus</i>	0	< 1	0	0	< 1	0	< 1	0.1%
<i>Halichoeres bivittatus</i>	0	< 1	< 1	0	0	0	< 1	0.1%
Total (per 1000 m2)	28	27	609	123	477	35	1	636
Relative Abundance	4.2%	95.8%	19.3%	75.0%	5.5%	0.2%		

Table 3.3 - Maturity, Size, and Relative Abundance of Fishes at Natural Reef Site B

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Chromis cyanea</i>	0	172	172	0	0	0	172	23.6%
<i>Thalassoma bifasciatum</i>	8	73	81	0	0	0	81	11.2%
<i>Stegastes dorsopunicans</i>	0	81	81	0	0	0	81	11.1%
<i>Lutjanus apodus</i>	0	52	0	0	52	0	52	7.2%
Scarid (gray)	51	0	49	2	0	0	51	7.0%
<i>Haemulon flavolineatum</i>	0	42	0	42	0	0	42	5.7%
<i>Abudefduf saxatilis</i>	0	32	0	32	0	0	32	4.4%
<i>Acanthurus coeruleus</i>	1	24	1	24	0	0	25	3.5%
<i>Halichoeres garnoti</i>	0	25	0	25	0	0	25	3.4%
Unidentified	3	22	18	7	0	0	25	3.4%
<i>Holocentrus rufus</i>	0	17	0	17	0	0	17	2.4%
Scarid (striped)	17	0	17	0	0	0	17	2.4%
<i>Acanthurus bahianus</i>	0	12	0	12	0	0	12	1.6%
<i>Microspathodon chrysurus</i>	1	9	1	9	0	0	10	1.4%
<i>Halichoeres bivittatus</i>	4	5	9	0	0	0	9	1.3%
<i>Sparisoma viride</i>	5	4	5	0	4	0	9	1.3%
<i>Chromis multilineata</i>	0	9	9	0	0	0	9	1.2%
<i>Stegastes planifrons</i>	2	6	8	0	0	0	8	1.1%
<i>Stegastes leucostictus</i>	2	5	7	0	0	0	7	1.0%
<i>Sparisoma aurofrenatum</i>	0	6	0	6	0	0	6	0.8%
<i>Haemulon sciurus</i>	0	5	0	5	0	0	5	0.7%
<i>Halichoeres maculipinna</i>	4	1	5	0	0	0	5	0.7%
<i>Lutjanus mahogoni</i>	0	5	0	0	5	0	5	0.6%
<i>Scarus vetula</i>	0	4	0	0	4	0	4	0.5%
<i>Stegastes variabilis</i>	0	3	3	0	0	0	3	0.4%
<i>Mulloidichthys martinicus</i>	0	3	0	3	0	0	3	0.4%
<i>Halichoeres radiatus</i>	0	2	0	2	0	0	2	0.3%
<i>Caranx ruber</i>	0	2	0	0	2	0	2	0.3%
<i>Pseudupeneus maculatus</i>	0	1	0	1	0	0	1	0.2%
<i>Holocentrus ascensionis</i>	0	1	0	1	0	0	1	0.1%
<i>Scarus iserti</i>	0	1	0	1	0	0	1	0.1%
<i>Myripristis jacobus</i>	0	1	0	1	0	0	1	0.1%

Table 3.3 Continued - Maturity, Size, and Relative Abundance of Fishes at Natural Reef Site B

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Pomacanthus arcuatus</i>	0	1	0	1	0	0	1	0.1%
<i>Diodon hystrix</i>	0	1	0	0	1	0	1	0.1%
<i>Cephalopholis fulvus</i>	0	1	0	1	0	0	1	0.1%
<i>Cantherhines pullus</i>	0	1	0	1	0	0	1	0.1%
<i>Chaetodon capistratus</i>	0	1	0	1	0	0	1	0.1%
<i>Sphyraena barracuda</i>	0	< 1	0	0	0	< 1	< 1	< 0.1%
<i>Holacanthus tricolor</i>	0	< 1	0	< 1	0	0	< 1	< 0.1%
<i>Balistes vetula</i>	0	< 1	0	< 1	0	0	< 1	< 0.1%
<i>Chaetodon striatus</i>	0	< 1	0	< 1	0	0	< 1	< 0.1%
<i>Stegastes diencaeus</i>	< 1	0	< 1	0	0	0	< 1	< 0.1%
Total (per 1000 m2)	29	98	630	466	194	68	0	728
Relative Abundance	13.5%	86.5%	64.0%	26.6%	9.3%	0.0%		

Table 3.4 - Maturity, Size, and Relative Abundance of Fishes at Natural Reef Site C

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Haemulon flavolineatum</i>	0	62	0	62	0	0	62	14.0%
<i>Chromis cyanea</i>	0	38	38	0	0	0	38	8.5%
<i>Thalassoma bifasciatum</i>	6	27	33	0	0	0	33	7.3%
Unidentified	0	25	20	5	0	0	25	5.5%
<i>Lutjanus apodus</i>	0	21	0	0	21	0	21	4.7%
<i>Acanthurus bahianus</i>	0	21	0	21	0	0	21	4.7%
<i>Stegastes dorsopunicans</i>	0	20	20	0	0	0	20	4.5%
<i>Haemulon parrai</i>	0	19	0	19	0	0	19	4.2%
<i>Lutjanus mahogoni</i>	0	19	0	0	19	0	19	4.2%
<i>Haemulon sciurus</i>	0	17	0	17	0	0	17	3.7%
Scarid (striped)	16	0	7	9	0	0	16	3.5%
<i>Halichoeres garnoti</i>	0	13	0	13	0	0	13	2.8%
<i>Holocentrus rufus</i>	0	13	0	13	0	0	13	2.8%
<i>Lutjanus griseus</i>	0	11	0	0	11	0	11	2.4%
<i>Pseudupeneus maculatus</i>	0	10	0	10	0	0	10	2.3%
<i>Halichoeres bivittatus</i>	0	8	7	1	0	0	8	1.8%
<i>Stegastes planifrons</i>	0	7	7	0	0	0	7	1.6%
<i>Caranx ruber</i>	0	7	0	0	7	0	7	1.6%
<i>Sparisoma viride</i>	0	7	0	0	7	0	7	1.6%
<i>Sparisoma aurofrenatum</i>	0	6	0	6	0	0	6	1.4%
<i>Stegastes partitus</i>	0	6	6	0	0	0	6	1.4%
<i>Acanthurus coeruleus</i>	2	4	2	4	0	0	6	1.4%
<i>Chromis multilineata</i>	0	6	6	0	0	0	6	1.3%
<i>Myripristis jacobus</i>	0	6	0	6	0	0	6	1.2%
Lutjanid	0	5	0	3	2	0	5	1.1%
<i>Scarus iserti</i>	0	5	0	0	5	0	5	1.1%
Labrid	2	3	5	0	0	0	5	1.1%
<i>Stegastes leucostictus</i>	1	3	4	0	0	0	4	1.0%
<i>Scarus vetula</i>	0	4	0	0	4	0	4	0.8%
<i>Halichoeres radiatus</i>	0	3	0	1	2	0	3	0.8%
<i>Scarus taeniopterus</i>	0	3	0	0	3	0	3	0.6%
Scarid (gray)	2	0	1	1	0	0	2	0.5%

Table 3.4 Continued - Maturity, Size, and Relative Abundance of Fishes at Natural Reef Site C

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Ocyurus chrysurus</i>	0	2	0	1	1	0	2	0.5%
Gobiid	0	2	2	0	0	0	2	0.4%
<i>Chaetodon capistratus</i>	0	2	2	0	0	0	2	0.4%
<i>Bodianus rufus</i>	1	1	1	1	0	0	2	0.4%
<i>Lutjanis analis</i>	0	1	0	1	0	0	1	0.3%
<i>Mulloidichthys martinicus</i>	0	1	0	1	0	0	1	0.2%
<i>Aulostomus maculatus</i>	0	1	0	0	1	0	1	0.2%
<i>Microspathodon chrysurus</i>	0	1	0	1	0	0	1	0.2%
<i>Holacanthus tricolor</i>	0	1	0	1	0	0	1	0.2%
<i>Stegastes variabilis</i>	0	1	1	0	0	0	1	0.2%
<i>Gramma loreto</i>	0	1	1	0	0	0	1	0.2%
<i>Sparisoma rubripinne</i>	0	1	0	< 1	1	0	1	0.1%
<i>Sparisoma chrysopteron</i>	0	1	0	1	0	0	1	0.1%
<i>Diodon hystrix</i>	0	1	0	0	1	0	1	0.1%
<i>Sphraena barracuda</i>	0	< 1	0	0	0	< 1	< 1	< 0.1%
<i>Ginglymostoma cirratum</i>	0	< 1	0	0	0	< 1	< 1	< 0.1%
<i>Malacanthus plumieri</i>	0	< 1	0	0	< 1	0	< 1	< 0.1%
<i>Aleuterus scriptus</i>	0	< 1	0	0	< 1	0	< 1	< 0.1%
<i>Haemulon album</i>	0	< 1	0	< 1	0	0	< 1	< 0.1%
<i>Bothus lunatus</i>	0	< 1	0	< 1	0	0	< 1	< 0.1%
Pomacentrid	0	< 1	< 1	0	0	0	< 1	< 0.1%
<i>Canthigaster rostrata</i>	0	< 1	< 1	0	0	0	< 1	< 0.1%
<i>Amblycirrhitos pinos</i>	0	< 1	< 1	0	0	0	< 1	< 0.1%
Total (per 1000 m2)	37	30	417	163	198	85	1	447
Relative Abundance	6.7%	93.3%	36.5%	44.3%	19.0%	0.2%		

Table 3.5 - Maturity, Size, and Relative Abundance of Fishes at Natural Reef Site D

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Haemulon sciurus</i>	0	158	0	158	0	0	158	21.3%
<i>Lutjanus mahogoni</i>	0	78	0	10	68	0	78	10.6%
Unidentified	0	65	49	16	0	0	65	8.7%
<i>Haemulon parrai</i>	0	57	0	0	57	0	57	7.7%
<i>Chromis cyanea</i>	0	44	44	0	0	0	44	5.9%
<i>Acanthurus bahianus</i>	1	36	2	35	0	0	37	5.0%
<i>Thalassoma bifasciatum</i>	24	9	33	0	0	0	33	4.4%
<i>Haemulon flavolineatum</i>	0	27	0	27	0	0	27	3.6%
<i>Holocentrus rufus</i>	0	26	0	26	0	0	26	3.5%
Scarid (striped)	20	0	20	0	0	0	20	2.7%
<i>Halichoeres bivittatus</i>	9	8	17	0	0	0	17	2.3%
<i>Stegastes dorsopunicans</i>	0	15	15	0	0	0	15	2.0%
<i>Halichoeres garnoti</i>	0	14	6	8	0	0	14	1.8%
<i>Cephalopholis fulvus</i>	0	13	0	0	13	0	13	1.7%
<i>Ocyurus chrysurus</i>	0	11	0	4	7	0	11	1.5%
<i>Lutjanus griseus</i>	0	9	0	0	9	0	9	1.3%
<i>Lutjanus apodus</i>	0	8	0	0	8	0	8	1.1%
<i>Stegastes leucostictus</i>	2	5	7	0	0	0	7	1.0%
<i>Sparisoma viride</i>	0	7	0	0	7	0	7	0.9%
<i>Acanthurus coeruleus</i>	0	6	0	6	0	0	6	0.9%
<i>Pseudupeneus maculatus</i>	0	6	0	6	0	0	6	0.8%
Labrid	1	5	6	0	0	0	6	0.8%
<i>Caranx ruber</i>	0	5	0	0	5	0	5	0.7%
<i>Stegastes planifrons</i>	2	3	5	0	0	0	5	0.7%
<i>Mulloidichthys martinicus</i>	0	5	0	5	0	0	5	0.7%
<i>Melichthys niger</i>	0	4	0	4	0	0	4	0.6%
<i>Gerres cinereus</i>	0	4	0	4	0	0	4	0.6%
<i>Haemulon carbonarium</i>	0	4	0	4	0	0	4	0.5%
<i>Epinephelus striatus</i>	0	4	0	1	3	0	4	0.5%
<i>Sparisoma rubripinne</i>	0	3	0	0	3	0	3	0.5%
<i>Scarus iserti</i>	0	3	0	0	3	0	3	0.5%
<i>Scarus vetula</i>	0	3	0	1	2	0	3	0.4%
Scarid (gray)	3	0	3	0	0	0	3	0.4%

Table 3.5 Continued - Maturity, Size, and Relative Abundance of Fishes at Natural Reef Site D

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Myripristis jacobus</i>	0	3	0	3	0	0	3	0.4%
<i>Stegastes partitus</i>	0	3	3	0	0	0	3	0.4%
<i>Aetobatus narinari</i>	0	3	0	0	0	3	3	0.4%
<i>Sparisoma aurofrenatum</i>	0	3	0	3	0	0	3	0.4%
<i>Halichoeres maculipinna</i>	2	0	2	0	0	0	2	0.2%
<i>Bodianus rufus</i>	1	1	0	2	0	0	2	0.2%
<i>Holocentrus ascensionis</i>	0	1	0	1	0	0	1	0.2%
<i>Sparisoma chrysopterum</i>	0	1	0	0	1	0	1	0.2%
<i>Malacanthus plumieri</i>	0	1	0	0	1	0	1	0.2%
<i>Pomacanthus arcuatus</i>	0	1	0	0	1	0	1	0.2%
<i>Scarus taeniopterus</i>	0	1	0	0	1	0	1	0.2%
<i>Microspathodon chrysurus</i>	0	1	0	1	0	0	1	0.2%
<i>Holacanthus tricolor</i>	0	1	0	1	0	0	1	0.1%
<i>Lachnolaimus maximus</i>	0	1	0	0	1	0	1	0.1%
<i>Aulostomus maculatus</i>	0	1	0	0	1	0	1	0.1%
<i>Lutjanus jocu</i>	0	1	0	0	1	0	1	0.1%
<i>Mycteroperca bonaci</i>	0	1	0	0	1	0	1	0.1%
<i>Ginglymostoma cirratum</i>	0	< 1	0	0	0	< 1	< 1	< 0.1%
<i>Caranx bartholomaei</i>	0	< 1	0	0	0	< 1	< 1	< 0.1%
<i>Epinephelus guttatus</i>	0	< 1	0	0	< 1	0	< 1	< 0.1%
<i>Gymnothorax moringa</i>	0	< 1	0	0	< 1	0	< 1	< 0.1%
<i>Cephalopholis cruentata</i>	0	< 1	0	0	< 1	0	< 1	< 0.1%
<i>Balistes vetula</i>	0	< 1	0	< 1	0	0	< 1	< 0.1%
Acanthurid	0	< 1	< 1	0	0	0	< 1	< 0.1%
<i>Stegastes variabilis</i>	0	< 1	< 1	0	0	0	< 1	< 0.1%
<i>Cantherhines pullus</i>	0	< 1	< 1	0	0	0	< 1	< 0.1%
Total (per 1000 m2)	42	65	676	213	329	195	4	742
Relative Abundance	8.8%	91.1%	28.7%	44.3%	26.3%	0.5%		

Size and maturity of fishes varied by site also. Site B had the largest percentage of juveniles and small fishes (Table 3.3). Site D had the largest percentage of large and extra large fishes (Table 3.5). Since Site D also had the highest density of fishes, it follows that biomass was highest at this site.

The absence of blennid and gobiid fishes from cinetransects of reef communities is due to lack of resolution of the camera and its inability to record small, cryptic fishes and infauna at the chosen distance from the bottom. Therefore, this study is limited in its comparison of communities to the larger, demersal reef fishes. Use of rotenone or other poison in combination with cinetransects would better describe the reef fish assemblage.

SEAGRASS MEADOWS. Peripheral habitat summaries are subdivided by presence or absence of seagrass. Data from sites with seagrasses are summarized in Table 3.6. No significant difference was found among sites regarding secchi disk visibility, temperature, current velocity, or characteristics of fish assemblages. Significant differences were found among sites regarding depth, secchi disk visibility, percent coverage of substratum types, seagrass shoot density, shoot height, and relative abundance of plants and algae.

Seagrass shoot height at site D2 was significantly taller than the other two sites, and seagrass shoots at B2 were significantly shorter and sparser than at the other two sites. Seagrass meadow at site B2 was also unique in that relative abundances of *Thalassia testudinum* and macroalgae were higher than at other sites, and that of *Syringodium filiforme* was significantly lower than at other sites.

No significant differences were discovered among fish assemblages at the three seagrass sites when comparisons were made of density of fishes, species

Table 3.6 - Characteristics of Three Seagrass Meadows off South Caicos Island

SITE	B2	C2	D2
Habitat Description	sparse grass	moderate grass	dense grass
ABIOTIC FACTORS			
Depth (m), n = 3 *	3.8	4.7	5.2
Secchi Disk Visibility (m), n = 3 *	26.2	21.6	19.1
Temperature (degrees C), n = 3	25.0	27.0	24.0
Current Velocity (m/sec), n = 3	0.7	1.1	0.9
SUBSTRATES			
Seagrasses (% coverage) ***	43.1%	100.0%	100.0%
Macroalgae (% coverage) ***	5.3%	0.0%	0.0%
Sand/rubble (% coverage) ***	51.6%	0.0%	0.0%
Shoot Density (#/m2), n = 20 ***	667	3544	3775
Shoot Height (cm), n = 60 ***	8.4	19.6	28.3
<u>RELATIVE ABUNDANCE (n = 20):</u>			
<i>Syringodium filiforme</i> ***	19.8%	78.2%	83.0%
<i>Thalassia testudinum</i> **	63.4%	21.8%	15.5%
Macroalgae *	16.8%	0.0%	1.4%
FISH ASSEMBLAGES			
Fish Density (#/1000 m2)	100	28	78
Species Density (#/1000 m2)	6	5	10
Species Evenness	0.8	0.7	0.8
Species Diversity	1.3	1.2	1.7

* P < 0.05

** P < 0.01

*** P < 0.001

density, diversity and evenness. Species density and diversity varied similarly to the density and height of sheltering seagrass and were highest at site D2 (Table 3.6). Tables 3.7 - 3.9 summarize data on maturity, size, and relative abundance of fishes from seagrass surveys. Site D2 had the highest relative abundance of fishes categorized as large and extra large. Site C2 had the highest number of juveniles which was due, in part, to a large school of juvenile *Pseudupeneus maculatus* on one cinetransect. Species at the three sites overlapped and surveys at site D2 included most of the species represented at the other two sites with the exceptions of *Microspathodon chrysurus* and *Mulloidichthys martinicus* at site B2.

Cinetransects of fish assemblages in seagrass meadows revealed inadequacies of the method due to variations in fish behavior among habitats. Fishes of seagrass meadows sought shelter from approaching danger (a diver) at a smaller threshold distance than fishes on coral reefs. Even fishes of the same species exhibited this exaggerated sheltering response in seagrass as compared to reef habitat. Most fishes which swam above dense seagrass were hidden within the grass before the camera's field of view reached them. Cinetransects of sparse seagrass meadows demonstrated the lack of shelter provided by sparse grass, in that, fishes were recorded swimming away from the camera at a speed equivalent to the divers' approach. Records of such fish sometimes extended up to 25 meters. The size of these fishes prevented them from utilizing the minimal shelter provided by short, scattered seagrass and algal thalli. Based on these observations, use of ichthiocide or nets would provide a more accurate assessment of fish density and community structure in seagrass.

Table 3.7 - Maturity, Size, and Relative Abundance of Fishes at Seagrass Meadow Site B2

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Halichoeres bivittatus</i>	11	21	32	0	0	0	32	32.1%
Labrid	0	25	25	0	0	0	25	24.7%
Unidentified	0	24	22	2	0	0	24	24.1%
<i>Acanthurus bahianus</i>	0	8	0	8	0	0	8	7.5%
Pomacentrid	1	3	4	0	0	0	4	3.5%
<i>Sparisoma radians</i>	0	2	2	0	0	0	2	2.1%
Scarid (gray)	2	0	2	0	0	0	2	2.1%
<i>Sphyaena barracuda</i>	0	1	0	< 1	0	< 1	1	1.4%
<i>Mulloidichthys martinicus</i>	0	< 1	0	< 1	0	0	< 1	0.7%
<i>Sparisoma chrysopterum</i>	0	< 1	0	< 1	0	0	< 1	0.7%
<i>Thalassoma bifasciatum</i>	0	< 1	< 1	0	0	0	< 1	0.7%
<i>Microspathodon chrysurus</i>	0	< 1	< 1	0	0	0	< 1	0.4%
<i>Sparisoma rubripinne</i>	0	< 1	0	0	< 1	0	< 1	0.3%
Total (per 1000 m2)	6	14	88	88	11	0	< 1	100
Relative Abundance	14%	88%	88%	11%	0%	< 1%		

Table 3.8 - Maturity, Size and Relative Abundance of Fishes at Seagrass Meadow Site C2

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Pseudupeneus maculatus</i>	14	0	14	0	0	0	14	48.6%
<i>Halichoeres bivittatus</i>	1	3	4	0	0	0	4	14.3%
<i>Caranx ruber</i>	0	3	0	0	3	0	3	9.5%
Unidentified	3	0	3	0	0	0	3	10.7%
<i>Acanthurus bahianus</i>	0	1	0	1	0	0	1	4.0%
<i>Ocyurus chrysurus</i>	0	1	0	1	0	0	1	3.6%
<i>Sparisoma radians</i>	0	1	1	0	0	0	1	3.6%
Labrid	0	1	1	0	0	0	1	3.6%
<i>Sphyraena barracuda</i>	0	< 1	0	0	0	< 1	< 1	1.2%
Total (per 1000 m2)	5	18	10	23	2	3	< 1	28
Relative Abundance	64.3%	35.7%	82.1%	7.1%	10.7%	1%		

Table 3.9 - Maturity, Size, and Relative Abundance of Fishes at Seagrass Meadow Site D2

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Acanthurus sp.</i>	0	21	0	21	0	0	21	26.5%
Unidentified	3	15	8	10	0	0	18	23.2%
<i>Halichoeres bivittatus</i>	5	3	8	0	0	0	8	10.1%
<i>Acanthurus bahianus</i>	0	7	0	7	0	0	7	9.4%
<i>Caranx ruber</i>	0	4	0	0	4	0	4	5.0%
<i>Caranx bartholomaei</i>	0	4	0	0	0	4	4	4.7%
<i>Ocyurus chrysurus</i>	0	3	0	3	0	0	3	3.8%
Scarid (striped)	2	0	0	2	0	0	2	3.1%
<i>Pseudupeneus maculatus</i>	0	2	0	2	0	0	2	3.0%
<i>Thalassoma bifasciatum</i>	0	2	2	0	0	0	2	2.7%
<i>Sparisoma chrysopterum</i>	0	1	0	0	1	0	1	1.3%
<i>Acanthurus coeruleus</i>	0	1	0	1	0	0	1	1.3%
<i>Epinephelus striatus</i>	0	1	0	0	1	0	1	1.0%
<i>Sparisoma radians</i>	0	1	1	0	0	0	1	0.9%
<i>Sparisoma rubripinne</i>	0	1	0	0	1	0	1	0.9%
<i>Sphyræna barracuda</i>	0	1	0	0	0	1	1	0.9%
<i>Aetobatus narinari</i>	0	< 1	0	0	0	< 1	< 1	0.5%
<i>Malacanthus plumieri</i>	0	< 1	0	< 1	0	0	< 1	0.5%
Total (per 1000 m2)	10	68	19	46	7	5	78	
Relative Abundance	12.8%	87.2%	24.4%	59.0%	9.0%	6.4%		

SAND/SOFT CORAL FLATS. Characteristics of six flat, sandy habitats are summarized in Table 3.10. No significant difference among sites was found in secchi disk visibility, temperature, or current. Significant differences were identified among sites in depth, type of substratum, fish density, species density, and diversity.

Figure 3.8 depicts percentage coverage by several common types of sessile invertebrates. Halo zones (sites C3 and D3) had flat sandy bottoms virtually devoid of epibenthic growth. Site F3 had the highest coverage by soft coral and site B3 had the highest coverage by live coral. Macroalgae coverage was highest on the dense soft coral flats (site F3) and on the banks (site H3). Sponges were most dense at sites F3 and B3, but were of distinctly different types. At site F3, sponges were mostly of the flat, encrusting shape; whereas sponges at site B3 were primarily large, tubular or vase-like shapes. Both sites had tall, finger-like sponges.

Significant differences were found among sites A3, B3, F3, and H3 in density of fishes, density of species, and diversity. Density of fishes was highest in the dense soft coral flats of site F3, but density of fishes, density of species and diversity at site H3 on the banks was significantly lower than at other sites. Cinetransects of sites C3 and D3 were of variable length (some less than 25 meters) and were not on linear paths because they followed the shape of the halo zone. For these reasons, cinetransects of sandy sites in halos were not comparable with surveys of fishes at other sites, therefore data was not included in Table 3.10. However, no fishes were recorded in halo zones. Relative abundances, maturity, and sizes of fishes at four sites are given in Tables 3.11 - 3.14. Density of fishes was significantly higher at soft coral flat site F3 than at other sandy sites.

Table 3.10 - Characteristics of Six Sandy Habitats off South Caicos Island

SITE	A3	B3	F3	H3	C3	D3
Habitat Description	sand/ soft coral	sparse soft coral	dense soft coral	sand/ rubble	sand halo	sand halo
ABIOTIC FACTORS						
Depth (m), n = 3 *	6.8	3.4	7.1	3	4.5	4.2
Secchi Disk Visibility (m), n=3 *	22.9	26.5	26.8	25	21.2	20.1
Temperature (degrees C), n=3	23	25	22.5	25	26.0	24
Current Velocity (m/sec), n=3 *	0.5	0.7	0.4	1.1	1.1	0.9
SUBSTRATES						
Live Coral (% coverage) ***	1.3%	4.4%	1.3%	0.0%	0.0%	0.0%
Dead Coral (% coverage)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Soft Coral (% coverage) ***	10.9%	6.3%	30.1%	0.0%	0.0%	0.0%
Sponges (% coverage) *	0.7%	1.8%	2.5%	0.3%	0.0%	0.0%
Macroalgae (% coverage) **	0.3%	1.0%	3.7%	3.3%	0.0%	0.0%
Hydrozoans (% coverage) *	1.3%	0.1%	1.7%	0.0%	0.0%	0.0%
Sand & Rubble (%coverage) *	85.5%	86.4%	60.8%	96.5%	100.0%	100.0%
FISH ASSEMBLAGES						
Fish Density (#/1000 m2) **	75	114	161	34		
Species Density (#/1000 m2) **	9	14	16	2		
Species Evenness	0.8	0.8	0.6	0.5		
Species Diversity ***	1.8	2.1	1.6	0.5		

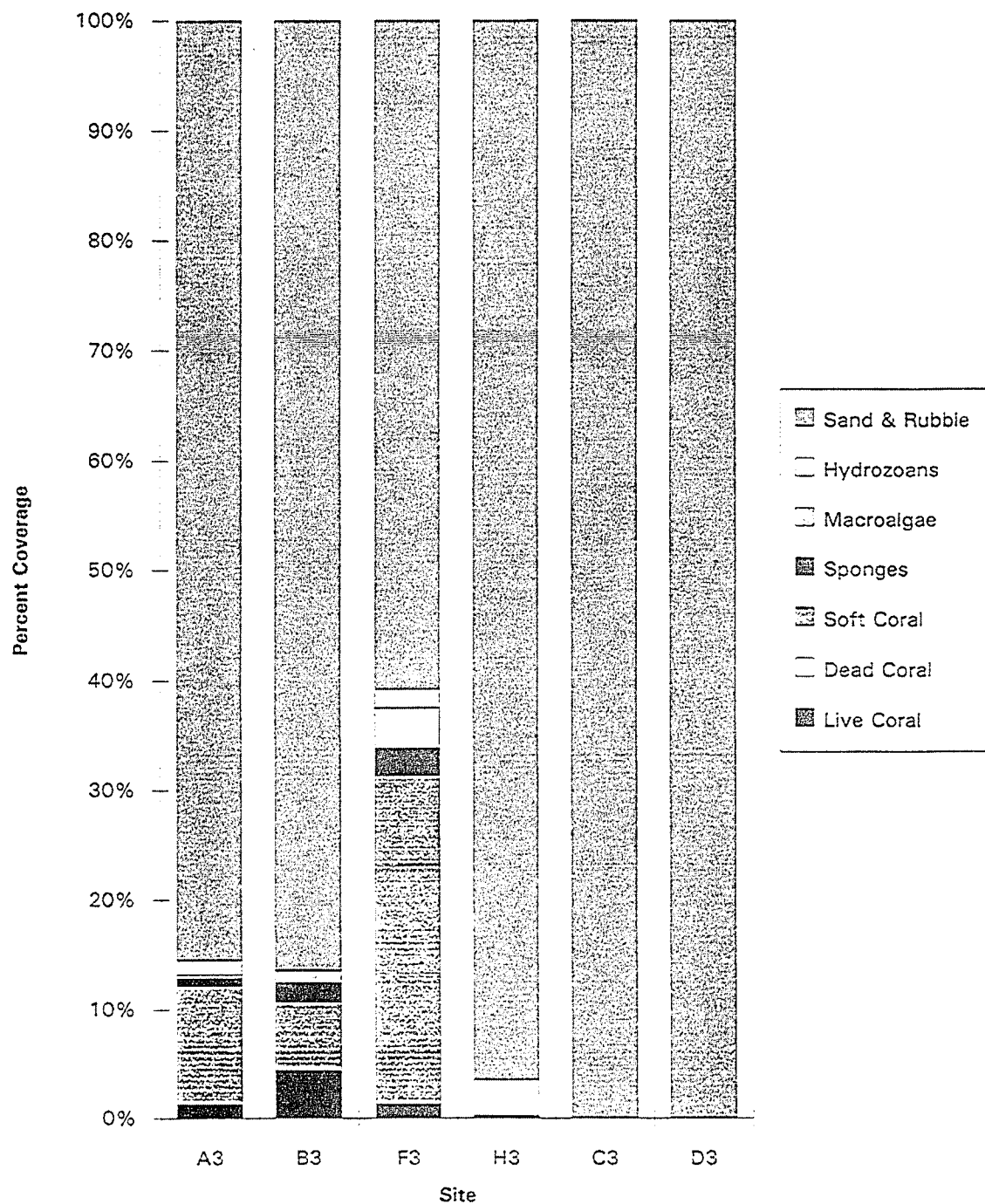
Percent coverage data from sites C3 and D3 were omitted from analysis of variance among sit

* P < 0.05

** P < 0.01

*** P < 0.001

Figure 3.8 - Percent Coverage of Substrate Types at Six Sites off South Caicos



SITES: A3 - sand/soft coral; B3 - sand/sparse soft coral; F3 - sand/dense soft coral; H3 - sand flat; C3 - sand halo; D3 - sand halo

Table 3.11 - Maturity, Size, and Relative Abundance of Fishes at Sand/Soft Coral Flat Site A3

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Thalassoma bifasciatum</i>	12	2	14	0	0	0	14	18.7%
Unidentified	0	14	11	3	0	0	14	18.3%
<i>Acanthurus bahianus</i>	0	10	0	10	0	0	10	13.3%
Labrid	7	3	10	0	0	0	10	13.0%
<i>Acanthurus coeruleus</i>	0	6	0	6	0	0	6	8.0%
<i>Halichoeres garnoti</i>	0	5	0	5	0	0	5	6.4%
<i>Halichoeres bivittatus</i>	2	2	4	0	0	0	4	5.3%
Scarid	0	2	0	0	2	0	2	2.7%
<i>Malacanthus plumieri</i>	0	2	0	1	1	0	2	2.3%
Pomacentrid	0	2	2	0	0	0	2	2.3%
<i>Mulloidichthys martinicus</i>	0	1	0	1	0	0	1	1.9%
<i>Scarus viride</i>	0	1	0	0	1	0	1	1.8%
<i>Stegastes partitus</i>	0	1	1	0	0	0	1	1.4%
Acanthurid	0	1	0	1	0	0	1	1.3%
<i>Cephalopholis fulvus</i>	0	1	0	0	1	0	1	0.9%
<i>Scarus vetula</i>	0	< 1	0	0	< 1	0	< 1	0.4%
Total (per 1000 m2)	9	21	54	42	27	6	75	
Relative Abundance	28.0%	72.0%	56.0%	36.0%	8.0%	0.0%		

Table 3.12 - Maturity, Size and Relative Abundance of Fishes at Soft Coral Flat Site B3

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Acanthurus bahianus</i>	0	30	0	30	0	0	30	26.4%
Unidentified	8	9	14	3	0	0	17	14.9%
<i>Halichoeres bivittatus</i>	6	10	14	2	0	0	16	13.8%
<i>Stegastes dorsopunicans</i>	0	9	9	0	0	0	9	8.1%
<i>Thalassoma bifasciatum</i>	0	9	9	0	0	0	9	7.5%
<i>Mulloidichthys martinicus</i>	0	7	0	7	0	0	7	6.0%
Labrid	0	4	4	0	0	0	4	3.6%
<i>Chromis cyanea</i>	0	4	4	0	0	0	4	3.2%
<i>Calamus calamus</i>	0	3	0	3	0	0	3	3.0%
<i>Ocyurus chrysurus</i>	0	1	0	2	0	0	2	2.2%
<i>Sparisoma aurofrenatum</i>	0	2	0	2	0	0	2	1.8%
<i>Haemulon melanurum</i>	0	2	0	2	0	0	2	1.5%
<i>Acanthurus coeruleus</i>	0	1	0	1	0	0	1	1.2%
<i>Halichoeres garnoti</i>	0	1	1	0	0	0	1	1.2%
<i>Caranx ruber</i>	0	1	0	1	0	0	1	1.0%
<i>Haemulon flavolineatum</i>	0	1	0	1	0	0	1	1.0%
<i>Haemulon sciurus</i>	0	1	0	1	0	0	1	0.9%
<i>Sphyraena barracuda</i>	0	1	0	0	0	1	1	0.6%
<i>Sparisoma chrysopterum</i>	0	1	0	0	1	0	1	0.6%
<i>Microspathodon chrysurus</i>	0	1	1	0	0	0	1	0.6%
<i>Sparisoma viride</i>	0	< 1	0	0	< 1	0	< 1	0.3%
Scarid (striped)	< 1	0	0	< 1	0	0	< 1	0.3%
<i>Chaetodon capistratus</i>	0	< 1	0	< 1	0	0	< 1	0.3%
<i>Holocentrus rufus</i>	0	< 1	0	< 1	0	0	< 1	0.3%
Total (per 1000 m2)	14	14	99	56	56	1	1	114
Relative Abundance	12.3%	86.8%	49.1%	49.1%	0.9%	0.9%		

Table 3.13 - Maturity, Size, and Relative Abundance of Fishes at Soft Coral Flat Site F3

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Thalassoma bifasciatum</i>	27	65	92	0	0	0	92	56.9%
<i>Halichoeres bivittatus</i>	11	5	16	0	0	0	16	10.2%
<i>Acanthurus coeruleus</i>	0	13	0	13	0	0	13	7.9%
<i>Acanthurus bahianus</i>	0	8	3	5	0	0	8	5.2%
<i>Stegastes partitus</i>	0	6	6	0	0	0	6	3.7%
<i>Malacanthus plumieri</i>	0	4	0	3	1	0	4	2.7%
<i>Chromis cyanea</i>	0	4	4	0	0	0	4	2.3%
<i>Cephalopholis fulvus</i>	0	3	0	3	0	0	3	2.1%
<i>Pomacanthus arcuatus</i>	0	2	0	0	2	0	2	1.3%
<i>Halichoeres garnoti</i>	0	2	0	2	0	0	2	1.3%
<i>Caranx ruber</i>	< 1	2	< 1	< 1	2	0	2	1.2%
<i>Scarus coelestinus</i>	0	2	0	0	0	2	2	1.2%
<i>Sparisoma viride</i>	0	1	0	0	1	0	1	0.8%
<i>Sparisoma aurofrenatum</i>	0	1	0	1	0	0	1	0.8%
<i>Mulloidichthys martinicus</i>	0	1	0	1	0	0	1	0.6%
<i>Chaetodon striatus</i>	0	1	0	1	0	0	1	0.6%
<i>Sphyræna barracuda</i>	0	1	0	0	0	1	1	0.4%
<i>Haemulon album</i>	0	< 1	0	0	< 1	0	< 1	0.2%
<i>Lutjanus mahogoni</i>	0	< 1	0	0	< 1	0	< 1	0.2%
<i>Cantherhines pullus</i>	0	< 1	0	< 1	0	0	< 1	0.2%
<i>Rypticus saponaceus</i>	0	< 1	0	< 1	0	0	< 1	0.2%
Total (per 1000 m2)	16	38	123	121	29	6	3	161
Relative Abundance	23.6%	76.4%	75.2%	18.0%	3.7%	1.9%		

Table 3.14 Maturity, Size, and Relative Abundance of Fishes at Sand and Soft Coral Site H3

Species	Juv	Adults	Small	Med	Large	XL	Total	Rel Abun
<i>Halichoeres bivittatus</i>	5	8	13	0	0	0	13	38.7%
Unidentified	4	5	9	0	0	0	9	27.6%
Pomacentrid	0	3	3	0	0	0	3	9.3%
<i>Stegastes dorsopunicans</i>	0	3	3	0	0	0	3	8.1%
Gobiid	0	2	2	0	0	0	2	6.1%
Labrid	0	2	2	0	0	0	2	5.2%
<i>Stegastes leucostictus</i>	0	1	1	0	0	0	1	4.0%
Total (per 1000 m2)	2	9	25	34	0	0	34	
Relative Abundance	26.5%	73.5%	100%	0.0%	0.0%	0.0%		

Site F3 also had the highest numbers for both maturity categories and all sizes except medium. Sites A3 and B3 had higher numbers of medium size fishes. The medium size class was dominated by acanthurids at sites A3, B3, and F3. This is consistent with observations of large acanthurid schools traversing soft coral flats.

Cinetransects of sand flats on the banks (site H3) recorded *Halichoeres bivittatus* as the most abundant fish (39%) and unidentified fishes as second in abundance. This underscores the inadequacy of the cinetransect method for records of cryptic and sheltering fishes since *Gnatholepis thompsoni*, and *Coryphopterus glaucofraenum* were observed repeatedly at each visit but did not appear on the tapes. These species quickly hide in defended shelter when a swimmer approaches. Such behavior biases the cinetransect results.

In conclusion, tests of data on characteristics of fish assemblages regarding effects of physical factors revealed no relevant patterns. Although some characteristics of fish assemblages varied among reef sites relative to presence of seagrass in peripheral habitats, causality is not attributable since the peripheral habitat type was a random variable. In the next chapter, an experimental manipulation incorporates peripheral habitats as fixed variables to test causality.

CHAPTER 4. EXPERIMENTAL MANIPULATION

A direct measure of the hypothesis in question can be accomplished by manipulation of seagrass densities. That is, do characteristics of a coral reef fish assemblage of a coral reef change with addition or removal of seagrasses? Two problems exist with this approach: logistical problems of creating or removing a natural seagrass community and the lack of replicate treatments.

Transplantation of seagrasses has been attempted by a variety of methods for many species (seventeen species in nine genera of twelve worldwide) with disappointing results (Kirkman and Kuo, 1990). Few of these resulted in shoot survival, but most research failed to establish a true meadow even years after initial planting with repeated planting or reseeded. Although underlying problems with transplantation are unresolved, indications of the magnitude of the problem are provided by data on blowouts. Blowouts are bare patches of sand within healthy seagrass meadows. They result from activities such as rays feeding, boats mooring, anchor damage, and seismic testing that cause shot holes up to 50 meters in diameter (Macintyre *et al.*, 1982; Kirkman and Kuo, 1990). Even bare spots as small as anchor scars resist recolonization (Patriquin, 1973; Zieman, 1976). Experimental clearings of small patches of seagrass were bare after 35 months (Larkum, 1976).

In light of the foregoing, addition of a seagrass meadow to an existing reef was not attempted. The reverse manipulation--to remove seagrass from an area extensive enough to affect a natural reef fish assemblage--was prohibited by national park regulations at the study site and was excessively labor intensive; therefore, it was not attempted. Even if a seagrass meadow could be readily

juxtaposed or removed from a coral reef, the changes noted could not be repeated. Each natural community represents a unique set of biotic and abiotic characteristics that are also temporally and spatially distinct from all other natural communities. However, repetition can be achieved by constructing artificial reefs small enough to share abiotic conditions, mobile enough to place in a variety of natural communities, and inexpensive enough to replicate. Limitations on this mode of experimentation include time to reach climax community, habitat completeness (e.g., lack of live coral, or other required food sources), and size effects.

Artificial reefs constructed in seagrass meadows and on sand flats would provide a comparison of the effects of peripheral seagrass on reef fish community structure. However, it has been suggested that the differences observed in recruitment to artificial reefs between sandy habitats and seagrass meadows were due to shelter afforded by the adjacent seagrass (Shulman, 1985b). To account for the effect of shelter, artificial reefs constructed in sandy habitats with soft coral as shelter would have to be tested simultaneously with those in seagrass and those in sand flats.

Artificial reefs have been used extensively in research relevant to natural reef systems and in fisheries management (Seaman *et al.*, 1989; Ambrose and Swarbick, 1989). Small isolated artificial reefs attract a fish fauna similar to that found on small isolated patch reefs (Talbot *et al.*, 1978). However, some differences between natural reef fauna and artificial reef fauna is expected. Recruitment of juveniles of some species is expected to be higher on these small habitats due to lower encounter rates with reef-associated predators (Shulman, 1982). Certain reef fishes rarely colonize isolated artificial reefs (Shulman, 1982). Differences in size of the openings and texture of structure compared with natural

reefs may affect size and role of fishes attracted (Smith, 1975; Hixon and Beets, 1989). Although there is evidence that artificial habitats in the same area are not colonized consistently by the same species or the same numbers of fishes (Smith, 1977), a comparison of fish assemblages attracted by similar artificial habitats at different sites has revealed fundamental differences in habitat utilization in cold-water fishes (Matthews, 1990).

Smith and Tyler (1973) discussed utility of concrete blocks as fish habitats: Other studies have used materials as diverse as PVC, bamboo, sunken ships, rocks, and palm fronds (Matthews, 1985 and 1990; Ambrose and Swarbick, 1989). Use of natural materials reduces negative effects of reef construction. Some artificial materials require "aging" in seawater to allow toxins to leach out of the material. Shulman (1982) constructed artificial modules with queen conch shells (*Strombus gigas*) in the Virgin Islands. These shells are an advantageous material for artificial reefs because of their availability and similarity to natural reefs in composition (CaCO_3) and complexity of shape. Artificial reefs of conch shells constructed in seagrass meadows and nonseagrass habitats were used in this study to test effects of peripheral seagrass on structure of reef fish assemblages.

METHODS

Artificial reefs were constructed of empty queen conch shells (*Strombus gigas*) in June and July of 1991. Conch shells were collected from middens on South Caicos and Long Cay. A hole was knocked into the lip of each shell with a hammer. Shells were strung on multistrand monofilament or braided polypropylene line. Strings of twelve to fifteen conch shells per string were transportable by one person. To account for varying shell sizes, each string was constructed from the

quantity of shells that would fill a large plastic measuring basket.

Four strings of conch shells comprised one artificial reef. The first three strings were arranged on the bottom so that each string was at the angle of an equilateral triangle with approximately ten centimeters between each pile. Each string was piled on itself to provide vertical relief. The fourth string was piled in the center of the first three forming a broad-based cone shape. Resulting artificial reefs covered approximately one square meter of substratum to a height of 0.5 - 0.8 m.

A total of 27 artificial reefs were constructed in nine habitats. Three replicate artificial reefs were placed in each of three seagrass meadows (sites B2, C2, and D2; Figures 4.1 - 4.3), two sandy habitats near seagrass (sites C3 and D3; Figures 4.2 and 4.3), two sandy habitats without seagrass (sites A3 and H3; Figures 4.4 and 4.5), and two sandy habitats with soft coral as shelter (sites B3 and F3; Figures 4.1 and 4.6). Replicates in each habitat were arranged in a rough triangular formation and at least 50 meters apart. Distance between artificial reefs was chosen to sufficiently isolate each reef so that fish did not move between them because statistical independence was critical to my experimental design. In a recent tagging study (Hixon and Beets, 1993), 50 meters was sufficient distance to achieve independent fish assemblages at artificial reefs.

Artificial reefs were monitored after one week, two weeks, three weeks, four weeks, four months, eight months, and one year (June, 1991 to July, 1992). Monitoring periods were between 1000 and 1600 hrs and comprised observation of each reef for fifteen minutes from a distance of at least one meter. Subsequently, the artificial reef was closely scrutinized from all angles to observe fishes hiding between shells. Identification and maturity (juvenile or adult) of each fish within a 0.5-meter perimeter were recorded.

Figure 4.1 - Artificial reef positions at seagrass site B2 and sand site B3

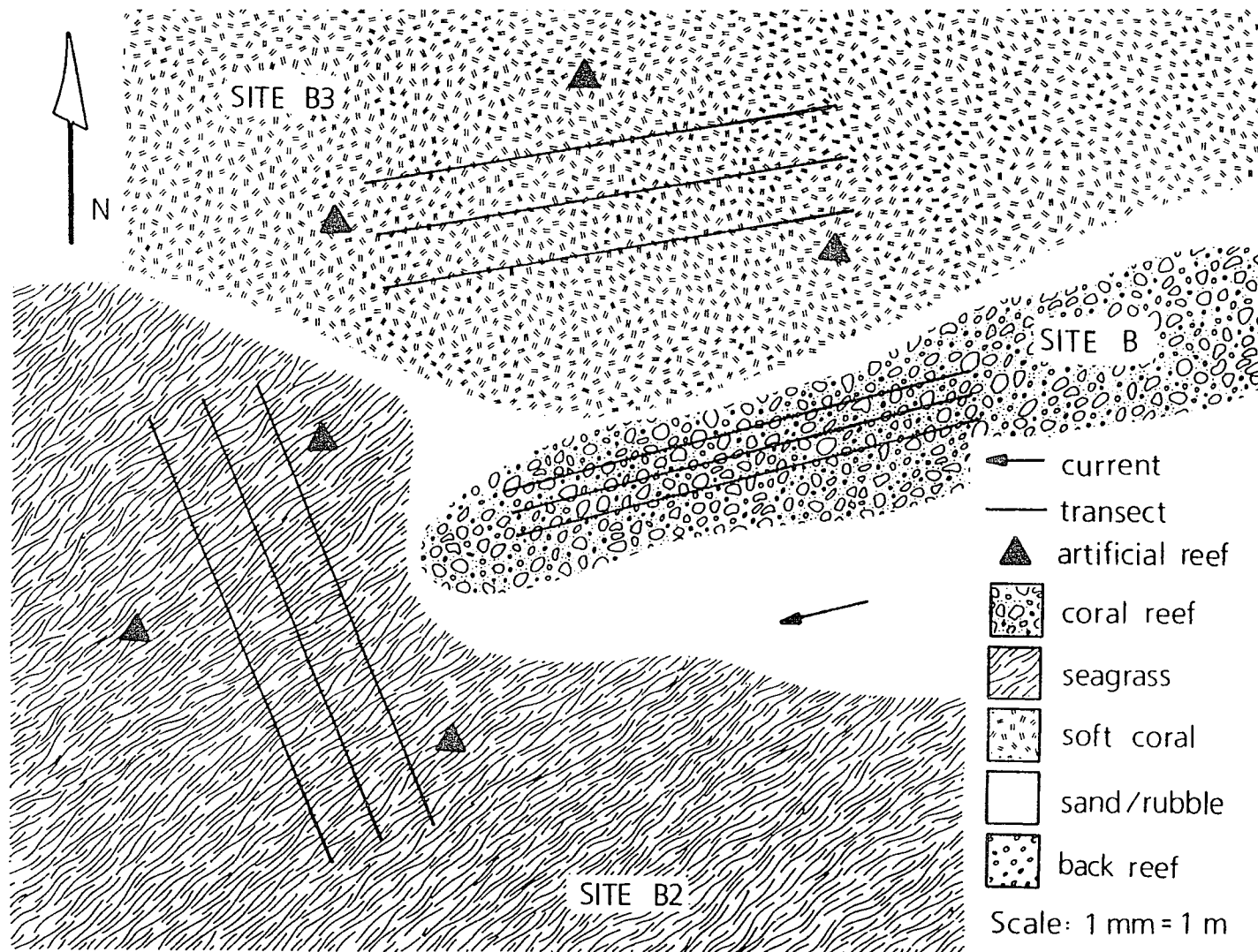


Figure 4.2 - Artificial reef positions at seagrass site C2 and sand site C3

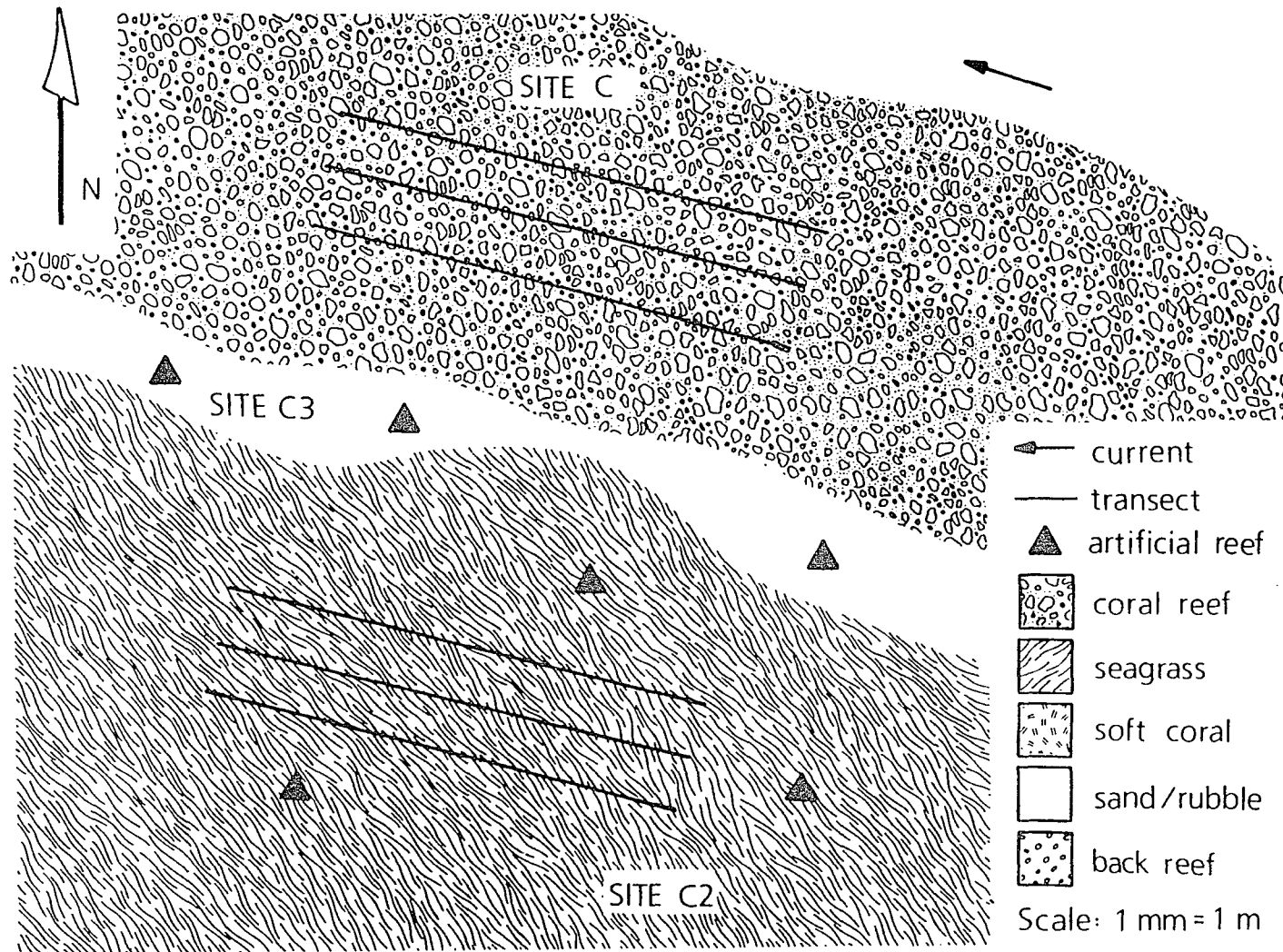


Figure 4.3 - Artificial reef positions at seagrass site D2 and sand site D3

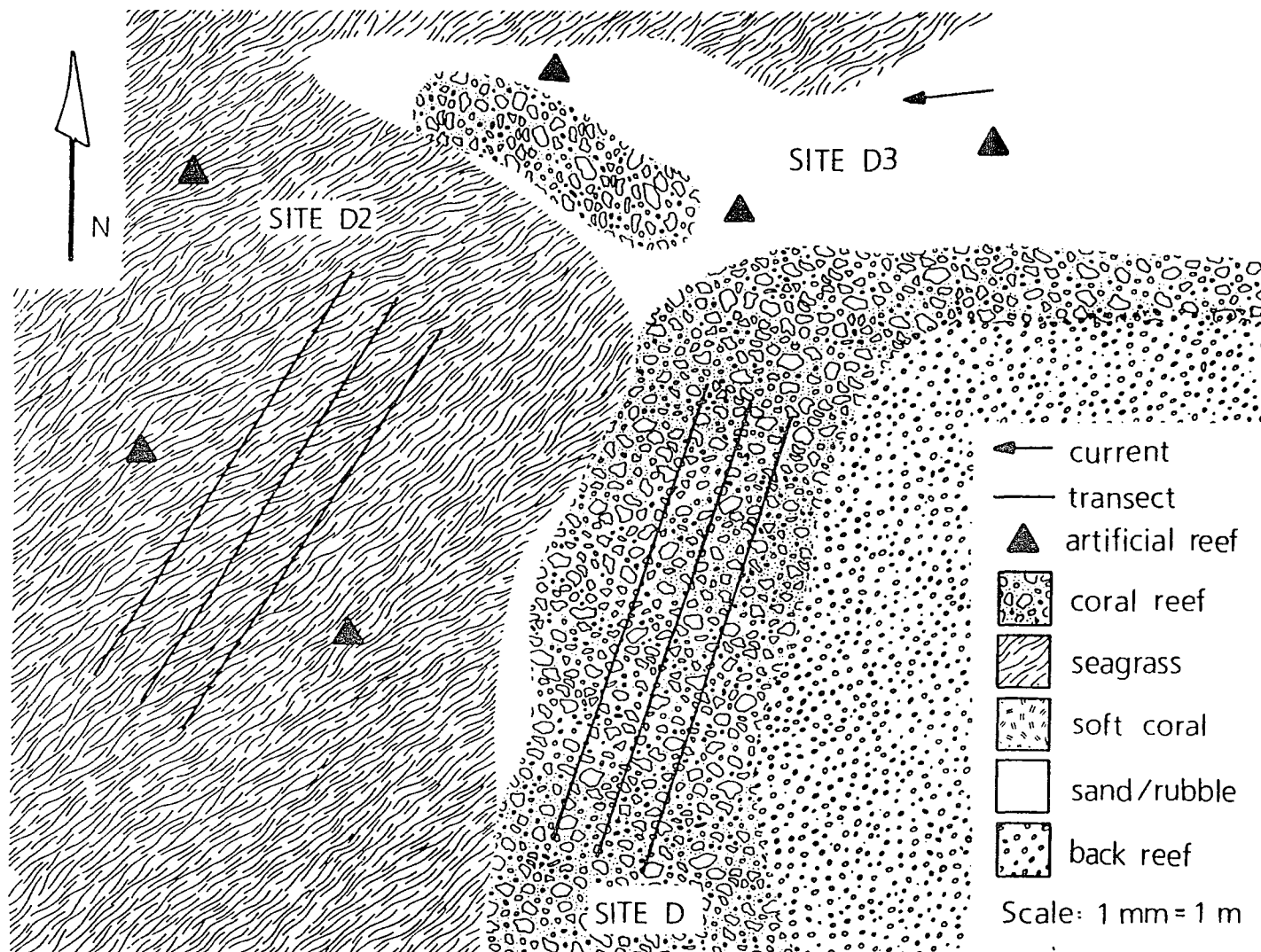


Figure 4.4 - Artificial reef positions at sand site A3

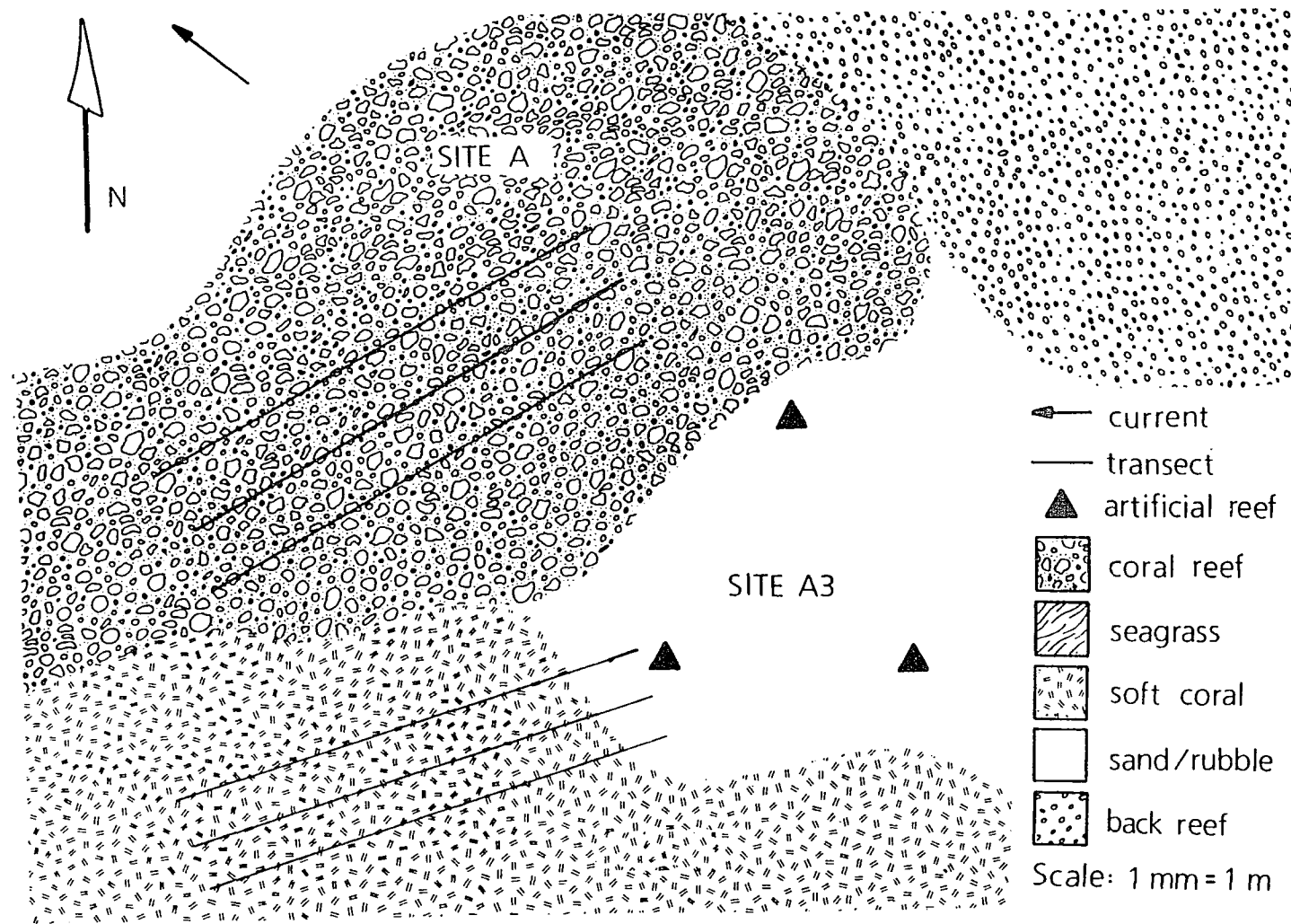


Figure 4.5 - Artificial reef positions at sand and rubble site

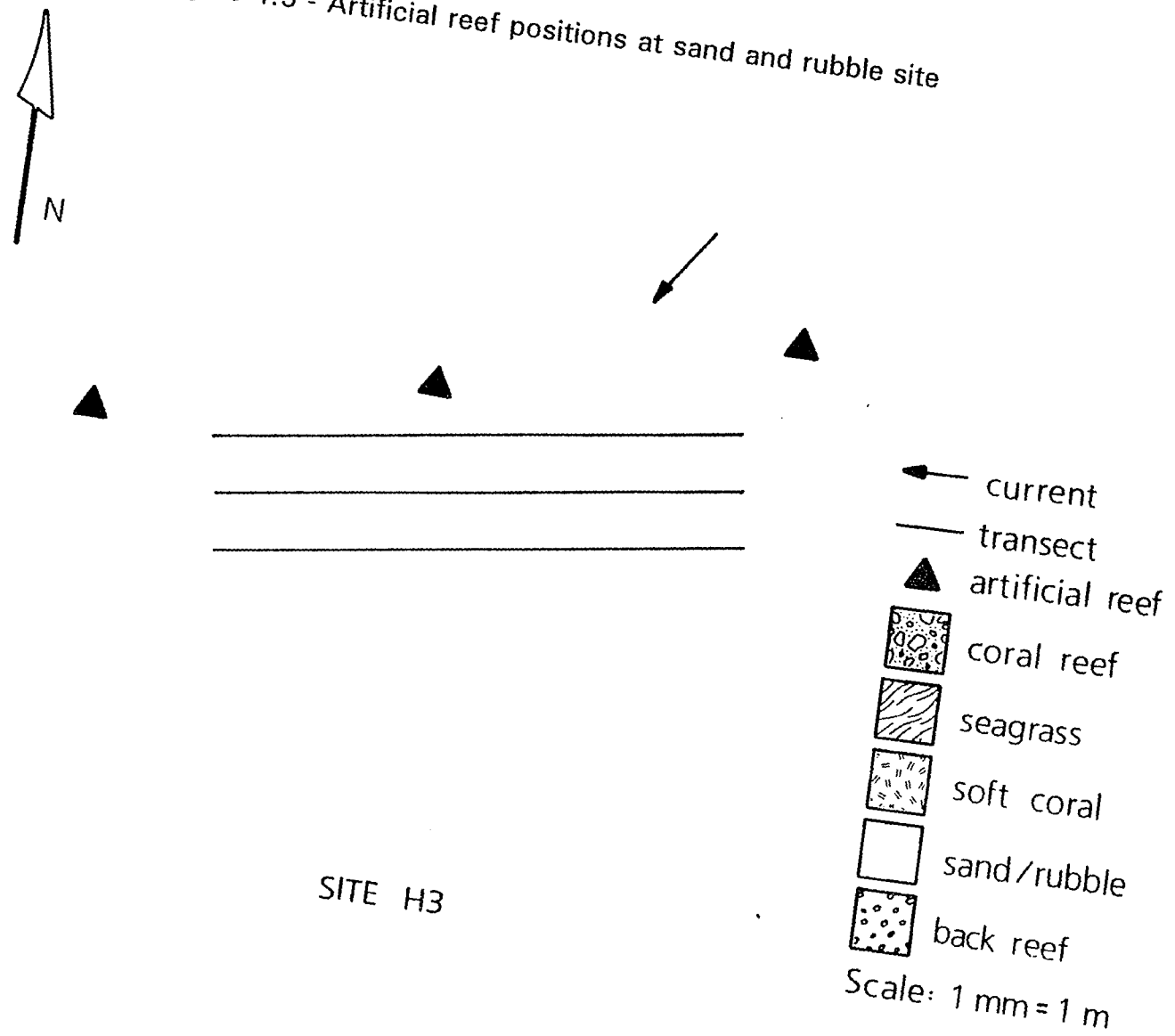
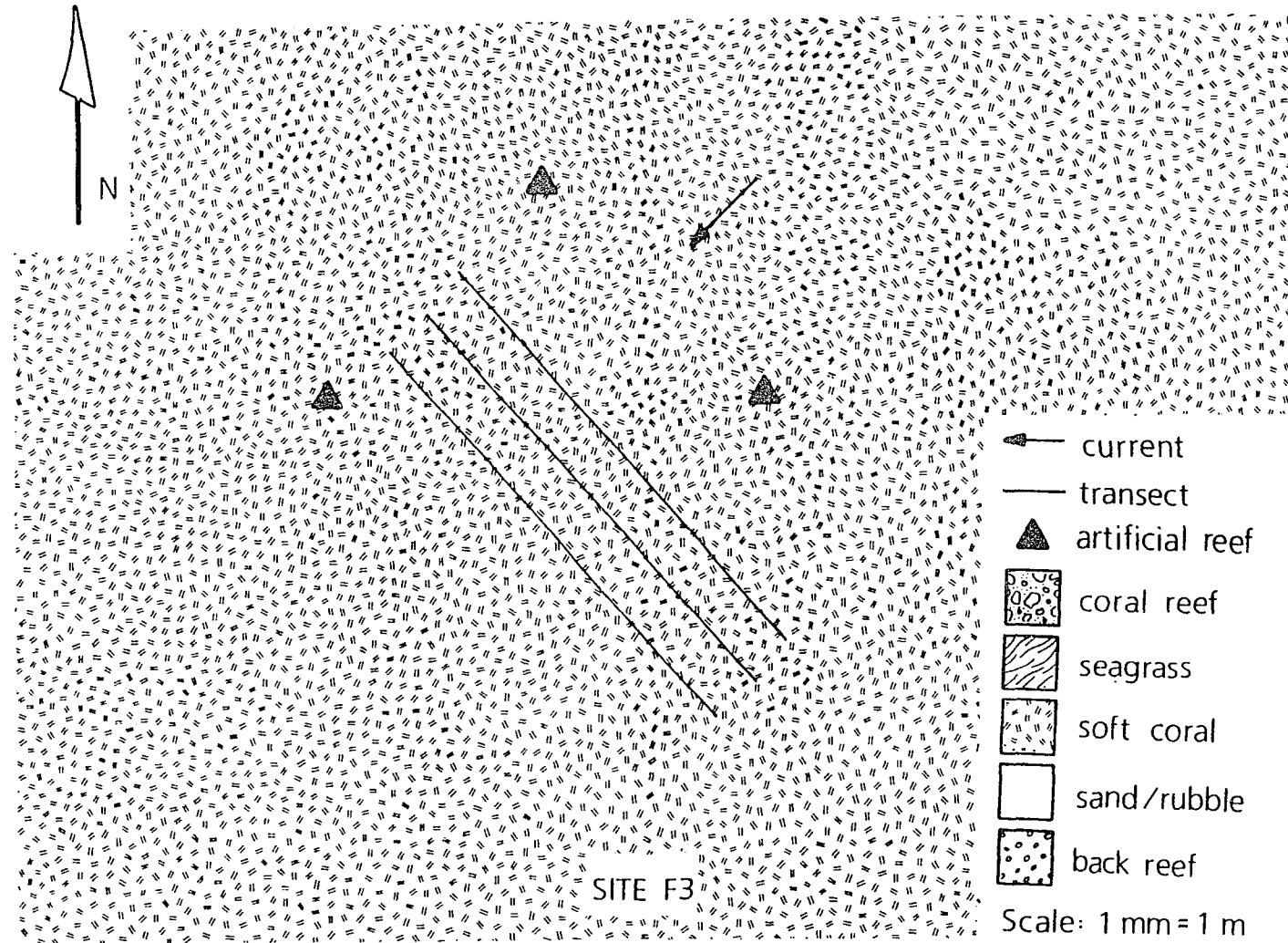


Figure 4.6 - Artificial reef positions at soft coral site F3



RESULTS

Recruitment data for artificial reefs in Figures 4.7 and 4.8 include density of fishes and species, respectively. Apparent differences among the curves include rate of initial recruitment, maximum number of fishes per reef, and time to approach asymptote. Initial recruitment was highest on reefs with adjacent soft coral flats and lowest in sandy halo zones. Highest numbers of fishes and species recorded at a single visit were on artificial reefs surrounded by sand/rubble flats or dense seagrasses; lowest numbers of fishes and species were on artificial reefs constructed in sandy halos near natural reefs. Rate of recruitment to one-year asymptote was fastest on reefs surrounded by soft coral flats and slowest on reefs surrounded by tidal flats.

To explore recruitment differences more carefully, the first month of recruitment data are plotted for fishes in Figure 4.9 and for species in Figure 4.10. Although artificial reefs surrounded by sand/rubble flats had the highest numbers of fishes and species after several months, examination of short-term recruitment reveals these reefs among the lowest in density of fishes. Other patterns in short-term recruitment data are similar to those of long-term recruitment.

For statistical analysis of recruitment, data were subdivided into initial recruitment and long-term recruitment. Because asymptotes of curves were approached by the second week of observations, initial recruitment figures represent means of values recorded during the first two weeks. Long term recruitment values were calculated based on observations from six to twelve months after construction of artificial reefs.

Characteristics of habitats surrounding artificial reefs are summarized by site with recruitment data in Table 4.1. No significant differences were found among

Figure 4.7 - Long-Term Recruitment of Fishes to Artificial Reefs

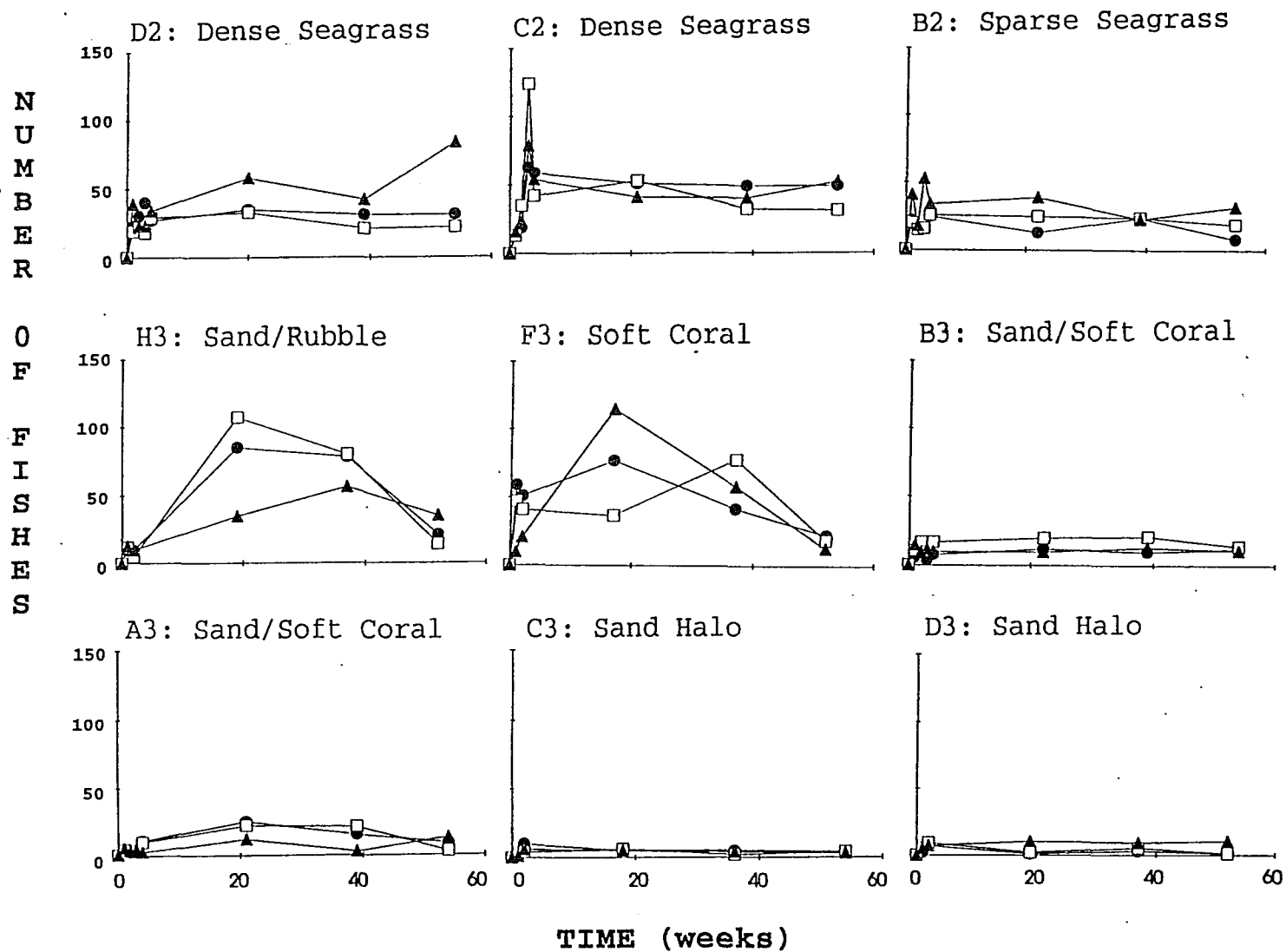


Figure 4.8 - Long-Term Recruitment of Species to Artificial Reefs

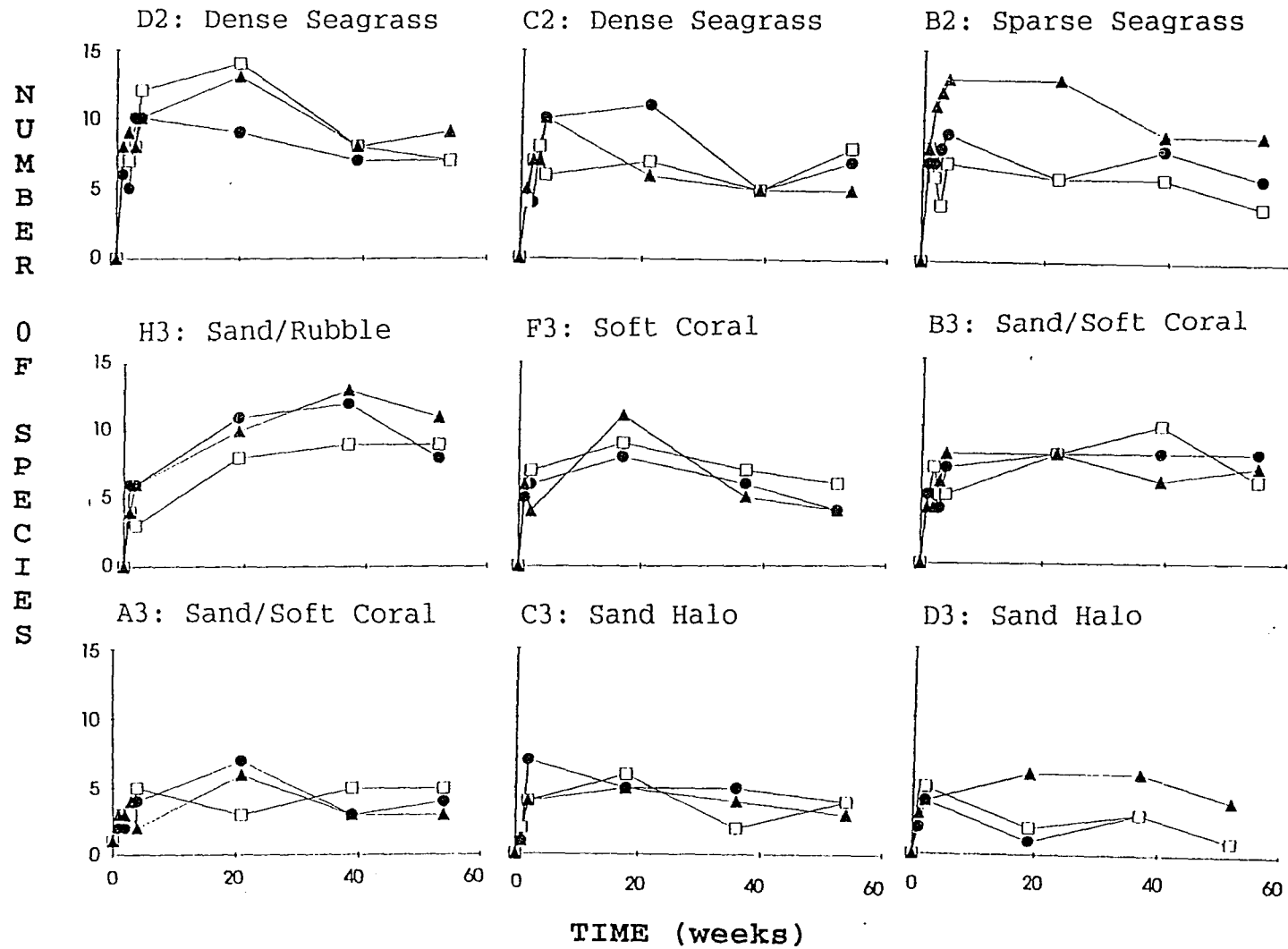


Figure 4.9 - Initial Recruitment of Fishes to Artificial Reefs

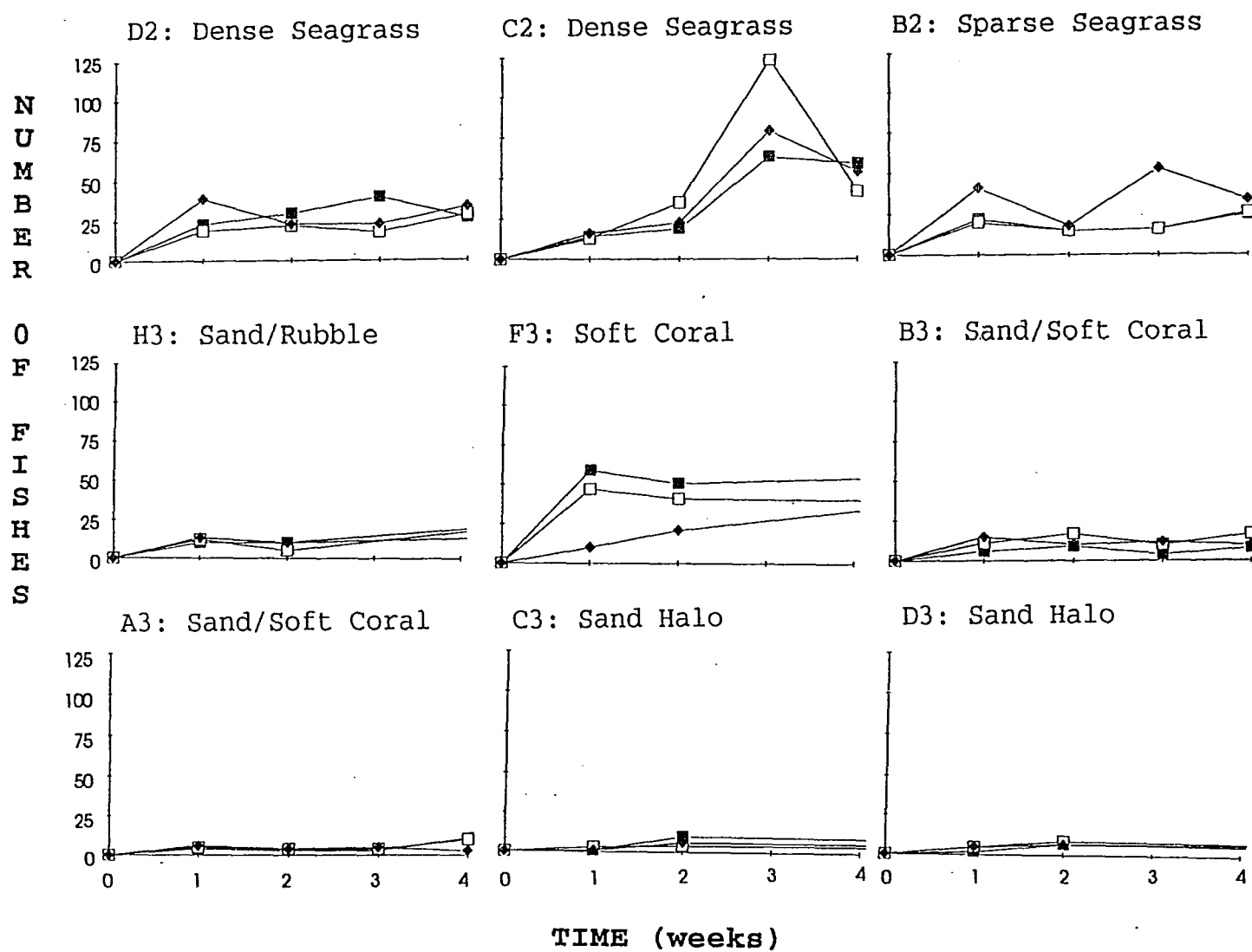


Figure 4.10 - Initial Recruitment of Species to Artificial Reefs

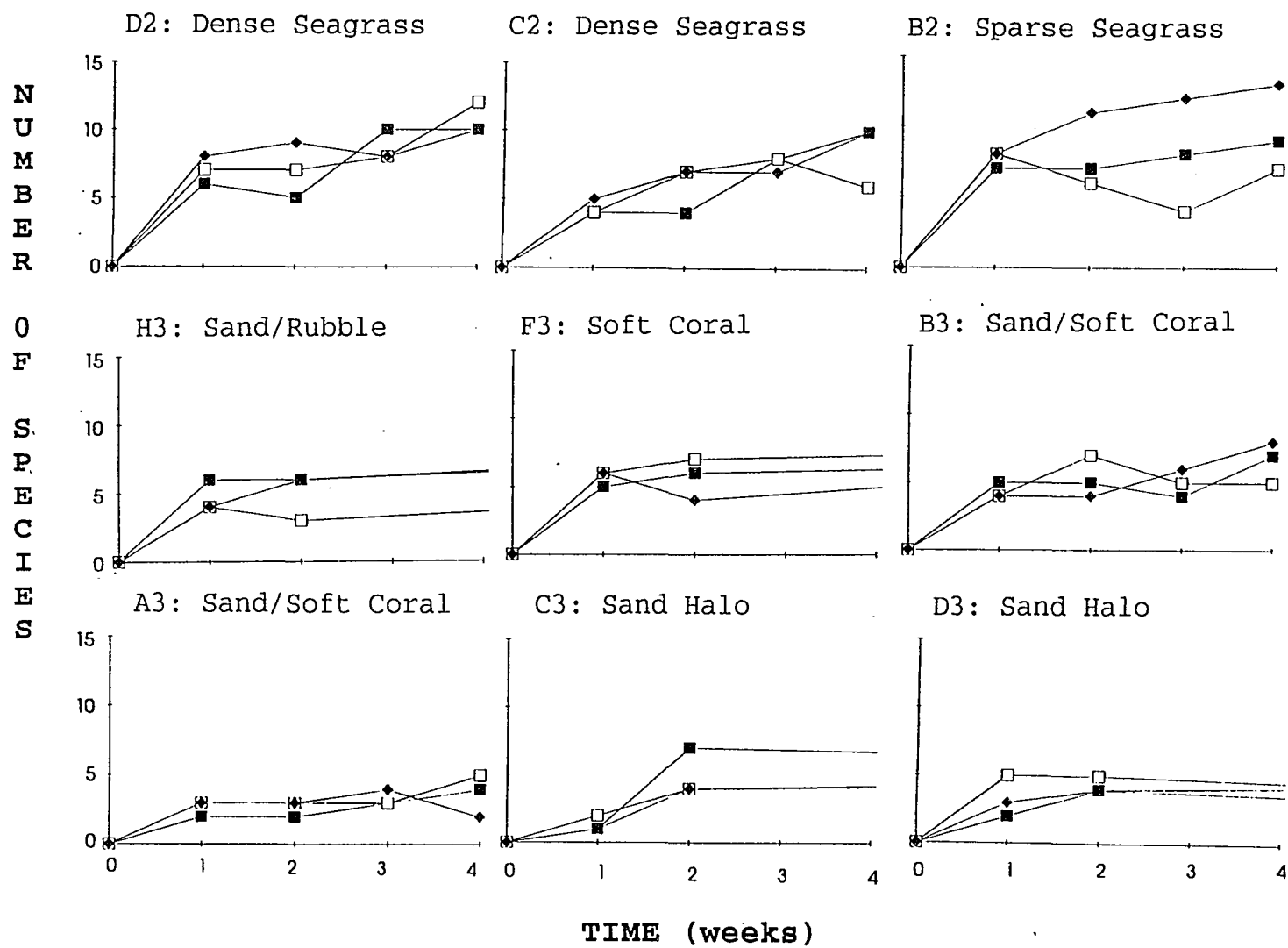


Table 4.1 - Recruitment of Fishes to Artificial Reefs Relative to Habitat Characteristics

SITE	A 3	B 2	B 3	C 2	C 3	D 2	D 3	F 3	H 3
Peripheral Habitat Description	sand and soft coral	sparse seagrass	sparse soft coral	dense seagrass	sand halo	dense seagrass	sand halo	dense soft coral	sand and rubble flat
ABIOTIC FACTORS									
Depth (m), n = 3**	6.8 +/-0.4	3.8 +/-0.2	3.4 +/-0.3	4.7 +/-0.8	4.5 +/-1.2	5.2 +/-0.2	4.2 +/-0.5	7.1 +/-1.3	3 +/-0.3
Visibility (m), n = 3	22.9 +/-2.0	26.2 +/-2.5	26.5 +/-1.4	21.6 +/-2.3	21.2 +/-3.6	19.1 +/-3.7	20.1 +/-1.3	26.8 +/-1.7	25 +/-2.1
Distance to Reef (m), n = 3*	28.7 +/-21	37.1 +/-20	46.3 +/-24	48.2 +/-28	4.4 +/-1.3	75.3 +/-31	10.9 +/-6	>100	>100
Distance to Seagrass (m), n = 3**	>100	<0.1	66.4 +/-39	<0.1	2.2 +/-0.3	<0.1	10.1 +/-8.7	>100	>100
Seagrass (shoots/m ²), n = 20**	0	667	0	3544	0	3775	0	0	0
Soft Coral (% coverage), n = 60**	10.9 %	0.0 %	6.3 %	0.0 %	0.0 %	0.0 %	0.0 %	30.1 %	0.0 %
Sand/Rubble (%coverage) n = 60**	85.5 %	78.4 %	86.4 %	0.0 %	100.0 %	0.0 %	100.0 %	60.8 %	96.5 %
FISH ASSEMBLAGES AT ARTIFICIAL REEFS									
Species Density (#/site) +	18	24	28	28	16	28	16	21	24
Evenness +	0.6	0.7	0.7	0.6	0.8	0.7	0.8	0.3	0.6
Diversity +	1.7	2.2	2.5	2.0	2.3	2.4	2.2	1.0	1.8
INITIAL RECRUITMENT (0 - 2 weeks)									
Fish Density (#/reef)**	4.3 +/-1.0	21.8 +/-9.8	11.3 +/-4.0	20.0 +/-8.2	4.2 +/-3.4	26.0 +/-7.3	5.8 +/-2.4	38.2 +/-18.	10.0 +/-2.8
Recruitment Rate (fish/wk/reef)**	5.5 +/-0.3	24.0 +/-0.9	18.0 +/-2.2	38.5 +/-4.2	10.0 +/-1.5	37.5 +/-2.2	11.5 +/-0.6	56.5 +/-7.6	12.5 +/-1.4
Species Density (#/reef)**	2.7 +/-0.5	7.8 +/-1.7	4.8 +/-1.2	5.2 +/-1.5	3.2 +/-2.3	7.0 +/-1.4	3.8 +/-1.2	5.7 +/-1.0	4.8 +/-1.3
Recruitment Rate (sp/wk/reef)	1.3 +/-0.3	4.0 +/-1.3	2.7 +/-0.8	3.0 +/-0.9	2.5 +/-0.9	3.5 +/-1.0	2.2 +/-0.3	2.8 +/-0.8	2.5 +/-0.9
LONG-TERM RECRUITMENT (6 - 12 months)									
Fish Density (#/reef)**	11.7 +/-0.	21.7 +/-5.8	12.5 +/-4.8	42.2 +/-9.4	3.7 +/-0.8	38.5 +/-21.	4.8 +/-4.0	38.8 +/-8.5	47.2 +/-2.1
Species Density (#/reef)**	3.8 +/-1.0	7 +/-2.0	7.5 +/-0.9	7.2 +/-0.8	3.7 +/-0.8	7.7 +/-0.8	3.0 +/-1.7	5.3 +/-1.0	10.2 +/-1.8

* Significant difference at P < 0.05

** Significant difference at P < 0.01

+ Indices calculated from data pooled after twelve months of observations at three artificial reefs per site.

reefs within each site regarding density of fishes or number of species from the first two weeks of data (mean of observations 0 - 2 weeks) or from data collected from six to twelve months. Significant differences among sites were revealed in numbers of fishes per reef and numbers of species per reef after initial recruitment (0-2 weeks) and after long-term recruitment (6-12 months).

Analysis of initial recruitment data revealed that fish densities were higher at artificial reefs at site F3 than at any other site. High fish density of site F3 was primarily due to schools of *Thalassoma bifasciatum*. Artificial reefs surrounded by seagrasses were significantly lower in fish density initially than those at F3 but higher than artificial reefs surrounded by sand and/or rubble (sites C3, A3, D3, H3). Initial species densities were highest on reefs with peripheral seagrasses (sites B2 and D2) and were lowest on reefs with peripheral sand (sites A3, C3, D3).

Rates of recruitment for each site were calculated by determining the mean of slopes of recruitment curves for each artificial reef at that site. No significant differences were found among sites in long-term (0 - 12 months or 6-12 months) recruitment rates of fishes or species nor among sites in initial (0-2 weeks) recruitment rates of species. However, initial recruitment rates of fishes were different ($P < 0.01$) among sites. Site F3, where artificial reefs were surrounded by dense soft coral, had recruitment rates higher than at any other site. Artificial reefs surrounded by dense seagrass (sites C2 and D2) had recruitment rates higher than all but F3.

Long-term recruitment data were similar in some respects to initial recruitment, but also have distinct differences worth evaluation. Although fish densities at reefs at site F3 (dense soft coral) remained significantly higher than at reefs surrounded by sand (A3, C3, D3), they were no longer different from reefs

surrounded by dense seagrasses. Reefs with peripheral seagrasses continued to have greater densities of species and fishes than their counterparts with peripheral sand (A3, C3, D3). Artificial reefs at site H3 (sand/rubble) had significantly higher numbers of species than reefs at any other site. In addition, H3 reefs had the highest mean fish density which was significantly higher than reefs in sandy sites (A3, C3, D3) and higher than those with sparse soft coral or sparse seagrass (B3, B2). Reefs surrounded by seagrass (sites B2, C2, and D2) had significantly more species after six months than reefs at sandy sites A3, C3 or D3.

Plotting data on each habitat characteristic (Table 4.1) against number of species or against number of fishes after initial recruitment or after six months failed to reveal any significant pattern. In addition, comparison of recruitment data to characteristics of fish assemblages of the peripheral habitats resulted in no significant patterns which could be helpful in understanding the differences in fish assemblages on artificial reefs. An examination of data arranged by species did reveal some patterns of interest which are described in the following chapter.

That fish assemblages at artificial reefs surrounded by seagrasses shared more species of juveniles with reefs at seagrass sites (sites B2, C2, and D2) than with reefs in other habitats suggests two hypotheses:

1. Planktonic larvae selectively settle on reefs with peripheral seagrass instead of reefs with other surrounding habitats.
2. Artificial reefs aggregate the fish fauna from surrounding benthic habitats.

If the first hypothesis is correct, then larval habitat selection is a deterministic component of settlement and recruitment from plankton cannot be considered random. If the second hypothesis is correct, then juveniles on artificial reefs originated from the seagrass meadow rather than the plankton. Therefore,

seagrass meadows provide nursery habitat for a larger number of reef species than has been thought. In either case, presence of seagrass in the peripheral habitat is a causal factor in structure of fish assemblages. The following chapter considers selected species distributions among sites for further analysis of these hypotheses.

CHAPTER 5. SPECIES ACCOUNTS

Patterns of abundance of juveniles and adults of reef fish by species provide information useful in analysis of data on characteristics of fish assemblages. A list of species observed during this study arranged by adult trophic niche is provided in Table 5.1. Trophic classification was based on observation and data provided by Randall (1967) and Smith and Tyler (1973). Trophic categories were modified from Smith and Tyler (1973) to include a distinction of pickers such as grunts which forage primarily off the reef since this essentially separates their niche from reef pickers. In addition, benthic pickers such as gobies were segregated to emphasize limitations on their access to food sources because of their tendency to remain on the bottom or within crevices for foraging. In general, pickers are fishes which feed on whole organisms, such as wrasses which feed on crustaceans; whereas browsers, like acanthurids, are less specific and their bites often include both algae and epiphytic invertebrates. Browsers, like terrestrial grazers, crop the prey close to the substratum without completely denuding the surface.

Other categories included suprabenthic and benthic predators, scrapers, planktivores, and sand sifters. Scrapers such as parrotfishes remove biota completely to reveal exposed carbonate or rock. This feeding technique finely separates them from browsers which feed on similar prey with a different technique. Goatfishes and other sand sifters stir up sand and feed on previously hidden invertebrates. Within each category, especially pickers, browsers, and scrapers, some overlap of preferred prey exists; however, when mouth size, teeth structure, prey preference, body size, and microhabitat selection are considered, separate hyperniches are apparent among most fishes.

Table 5.1 - Species List by Habitat and Adult Trophic Niche

	NATURAL REEFS				PERIPHERAL HABITATS								ARTIFICIAL REEFS									
SUPRABENTHIC REEF PICKERS	A	B	C	D	B2	C2	D2	A3	H3	B3	F3	b2	c2	d2	a3	h3	c3	d3	b3	f3		
<i>Aluterus scriptus</i>			A																			
<i>Balistes vetula</i>		A		A								J	J									
<i>Bodianus rufus</i>	A		JA	JA																		
<i>Calamus calamus</i>										A												
<i>Canthigaster rostrata</i>			A									J	J									
<i>Cantherhines pullus</i>		A		A							A		J							A		
<i>Diodon hystrix</i>		A	A																			
<i>Equetus acuminatus</i>														J								
<i>Equetus punctatus</i>														J								
<i>Gerres cinereus</i>	A			A																		
<i>Ginglymostoma cirratum</i>	A		A	A																		
<i>Halichoeres bivittatus</i>	A	JA	A	JA	JA	JA	JA	JA	JA	JA	JA	JA	JA	JA	JA	JA	A	JA	JA	JA		
<i>Halichoeres garnoti</i>	JA	A	A	A				A		A	A	J	J	J	JA		JA		A			
<i>Halichoeres maculipinna</i>		JA		J								J				J		J	J			
<i>Halichoeres radiatus</i>	JA	A	A	A										J			J	J				
<i>Holocentrus ascensionis</i>		A		A																		
<i>Holocentrus rufus</i>	A	A	A	A						A			J			J		A	J	A		
<i>Lachnolaimus maximus</i>				A																		
<i>Malacanthus plumieri</i>			A	A			A	A			A											
<i>Monacanthus ciliatus</i>														J								
<i>Sargocentron coruscus</i>												J	J		J	JA	A		JA			
<i>Serranus tigrinus</i>																			A			
<i>Thalassoma bifasciatum</i>	JA	JA	JA	JA	A		A	JA		A	JA	JA	JA	JA	JA	JA	A	JA	JA	JA		

Table 5.1 Continued - Species List by Habitat and Adult Trophic Niche

	NATURAL REEFS				PERIPHERAL HABITATS							ARTIFICIAL REEFS									
SUPRABENTHIC OFF-REEF PICKERS	A	B	C	D	B2	C2	D2	A3	H3	B3	F3	b2	c2	d2	a3	h3	c3	d3	b3	f3	
<i>Haemulon album</i>											A										
<i>Haemulon carbonarium</i>				A																	
<i>Haemulon flavolineatum</i>	A	A	A	A						A						JA					
<i>Haemulon melanurum</i>										A		A				JA					
<i>Haemulon parrai</i>			A	A																	
<i>Haemulon sciurus</i>	A			A						A											
<i>Halichoeres poeyi</i>													J	J							
<i>Lutjanus apodus</i>		A	A	A																	
<i>Lutjanus analis</i>			A																		
<i>Lutjanus griseus</i>	A		A																		
<i>Lutjanus jocu</i>				A																	
<i>Lutjanus mahogoni</i>	A	A	A	A							A										
BENTHIC PICKERS																					
<i>Apogon binotatus</i>																A					
<i>Coryphopterus glaucofraenum</i>															A	A	A		A		
<i>Coryphopterus sp</i>															A	A	A		A		
<i>Gnatholepis thompsoni</i>															A	A	A		A		
<i>Gramma loreto</i>	A		A																		
<i>Malcoctenus triangulatus</i>																				A	
<i>Sparisoma radians</i>					A	A	A					JA	JA	JA	A	A	A			A	

Table 5.1 Continued - Species List by Habitat and Adult Trophic Niche

	NATURAL REEFS				PERIPHERAL HABITATS								ARTIFICIAL REEFS									
	A	B	C	D	B2	C2	D2	A3	H3	B3	F3	b2	c2	d2	a3	h3	c3	d3	b3	f3		
SCRAPERS																						
<i>Scarus coelestinus</i>											A											
<i>Scarus iserti</i>		A	A	A															A			
<i>Scarus taeniopterus</i>	A		A	A																		
<i>Scarus vetula</i>	A	A	A	A				A														
<i>Sparisoma rubripinne</i>	A		A	A	A		A															
<i>Sparisoma aurofrenatum</i>	A	A	A	A						A	A	J		A					J			
<i>Sparisoma chrysopteron</i>			A	A	A		A			A		JA	J	A		J		J	J	A		
<i>Sparisoma viride</i>	JA	JA	A	A				A		A	A	J	J	J		J			J	J		
Gray juvenile scarids		J	J	J	J							J	J	J		J		J	J	J		
Striped juvenile scarids	J	J	J	J			J	J		J		J	J	J			J			J		
PLANKTIVORES																						
<i>Chromis cyanea</i>	A	A	A	A						A	A	A			A				A			
<i>Chromis multilineata</i>	A	A	A																			
<i>Melichthys niger</i>	A			A																		
SAND SIFTERS																						
<i>Aetobatus narinari</i>				A			A															
<i>Mulloidichthys martinicus</i>	A	A	A	A	A			A		A	A											
<i>Pseudupeneus maculatus</i>		A	A	A		J	A					J	JA	JA	A	J			A			

Table 5.1 Continued - Species List by Habitat and Adult Trophic Niche

	NATURAL REEFS				PERIPHERAL HABITATS						ARTIFICIAL REEFS									
	A	B	C	D	B2	C2	D2	A3	H3	B3	F3	b2	c2	d2	a3	h3	c3	d3	b3	f3
SUPRABENTHIC PREDATORS																				
<i>Aulostomus maculatus</i>	A		A	A									J	J						
<i>Caranx bartholomaei</i>				A			A													
<i>Caranx ruber</i>	A	A	A	A		A	A			A	JA	A	A	A						
<i>Ocyurus chrysurus</i>	A		A	A		A	A			A			J	A					A	
<i>Rypticus saponaceus</i>											A									
<i>Sphyraena barracuda</i>	A	A	A		A	A	A			A	A	A	A			A				A
<i>Sphyraena picudilla</i>	A																			
BENTHIC PREDATORS																				
<i>Amblycirrhitos pinos</i>			A																	
<i>Bothus lunatus</i>			A																	
<i>Cephalopholis cruentata</i>				A																
<i>Cephalopholis fulvus</i>	A	A		A				A			A				JA		JA	JA		JA
<i>Epinephelus striatus</i>				A			A							A		J	A			
<i>Epinephelus guttatus</i>				A										A						
<i>Gymnothorax moringa</i>				A									A						A	
<i>Gymnothorax vicinus</i>																				A
<i>Mycteroperca bonaci</i>				A																

Table 5.1 Continued - Species List by Habitat and Adult Trophic Niche

	NATURAL REEFS				PERIPHERAL HABITATS						ARTIFICIAL REEFS									
	A	B	C	D	B2	C2	D2	A3	H3	B3	F3	b2	c2	d2	a3	h3	c3	d3	b3	f3
BROWSERS																				
<i>Abudefduf saxatilis</i>	A	A																		
<i>Acanthurus bahianus</i>	A	A	A	JA	A	A	A	A		A	A	J A	J	J A	J A		J A	J A	J A	J A
<i>Acanthurus coeruleus</i>	A	JA	JA	A			A	A		A	A		J	J	J		A	J	A	J
<i>Chaetodon striatus</i>	A	A									A			J						A
<i>Chaetodon capistratus</i>	A	A	A							A				J						
<i>Holacanthus tricolor</i>	A	A	A	A											J					
<i>Microspathodon chrysurus</i>	A	JA	A	A	A					A										
<i>Pomacanthus arcuatus</i>		A		A							A					J				
<i>Stegastes dorsopunicans</i>	A	A	A	A					A	A		A				A	A	JA	JA	
<i>Stegastes dienceus</i>		J													J			J	A	
<i>Stegastes leucostictus</i>		JA	JA	JA					A			JA	JA		A	JA	JA	A	JA	JA
<i>Stegastes partitus</i>			A	A				A			A		A		A		A		A	JA
<i>Stegastes planifrons</i>	A	JA	A	JA								A						A	J	
<i>Stegastes variabilis</i>		A	A	A																
Total Species-Juveniles	5	11	6	9	2	2	2	3	1	2	3	16	21	18	9	15	7	10	13	10
Total Species-Adults	39	38	48	54	9	6	15	11	3	21	21	13	9	11	14	15	16	8	20	14
Total Species-Juv + Adlt	44	41	49	57	11	8	17	14	4	23	24	29	30	29	23	30	23	18	33	24

Totals in Table 5.1 reflect density of ecological units rather than taxonomic units since trophic niche is different between adult and juvenile stages of a species. Even in the rare instance that adults and juveniles utilize the same prey type, size categories will be different. Totals of adults plus juveniles were highest at natural reefs with adjacent seagrass (sites C and D), in peripheral habitats with soft coral as shelter (site F3) and on artificial reefs surrounded by soft coral (site B3), seagrasses (sites B2, C2, and D2), and sand/rubble flats (site H3). Results regarding species density in peripheral habitats are biased by experimental error in that cinetransects were inadequate measures of fishes in seagrasses. Many residents of seagrasses swim between seagrass blades and are impossible to record with video. A net or rotenone technique would have produced a more accurate assessment of seagrass assemblages, but not comparable to measures by cinetransect. Site B3 had the highest species density of adults, and high totals of adults plus juveniles were due to the larger number of adult fishes. Densities at artificial reefs with adjacent seagrass were due more to juveniles; whereas artificial reefs in sand/rubble habitat had equal numbers of juveniles and adults.

Fishes not recorded on natural reef sites nor on artificial reefs were low in abundance off South Caicos or inadequately sampled by methods used in this study. Examples include species of *Hypoplectrus* and *Labrisomus* that are known to be rare off South Caicos. Genera such as *Hippocampus*, *Pempheris*, *Opistognathus*, and *Gobiosoma* were undoubtedly present off South Caicos, but were not sampled by the methods utilized in natural habitats.

Some species known from natural reefs were not observed on the artificial reefs. Even fishes difficult to detect on a natural reef, such as cryptic or nocturnal species, were observed, if present, on the artificial reefs. However, fishes may

have colonized artificial reefs between visits and, subsequently, may have been lost to disease, predation, or emigration. Time between visits to the artificial reefs was 1-12 weeks; therefore, new recruits were subject to considerable predation and other causes of mortality between visits. Thus, absence of species on artificial reefs that appeared on natural reefs could have been attributed to low recruit abundance, recruitment patterns that excluded use of habitats such as the artificial reefs, or increased vulnerability to predation on artificial reefs.

Species recorded on artificial reefs but not on reef transects were characteristic of the peripheral habitat in which the artificial reef was constructed, difficult to observe on natural reefs with the methods in this study, or low in abundance on natural reefs. *Gnatholepis thompsoni* and species of *Coryphopterus* were residents of the sand flats and colonized to artificial habitats as adults. Muraenids and apogonids were not recorded on natural reefs due to their cryptic diurnal behavior. *Serranus tigrinus* was only occasionally noted on natural reefs at times other than video transects.

Examination of data collected for fishes on natural and artificial reefs revealed patterns relative to peripheral habitat type. Separate accounts follow of abundance and recruitment data by habitat for selected species that appeared on artificial reefs and natural reef transects. Species are grouped by family, and families are arranged in alphabetical order. Data from each group of three artificial reefs at one site were pooled for all visits and summarized in tables of frequency, relative abundance, and recruitment for juveniles and adults of each species.

ACANTHURIDAE

Surgeonfishes settle from plankton as transparent metamorphosing presettlement achronous stage and acquire pigmentation within a few days (Shulman, 1985a). Acanthurids recorded off South Caicos include three species in the genus *Acanthurus*. The blue tang, *Acanthurus coeruleus*, is morphologically distinct as a juvenile and as an adult. All three species feed in schools that are sometimes monotypic; but more frequently, particularly when juveniles, they feed schooling with congeners and/or parrotfishes (Scaridae). Reinthal and Lewis (1986) suggested that schools increased foraging efficiency especially on reefs with territorial damselfishes. Schools observed in this study were most often on sandy flats where predator avoidance would be the most likely function of schooling.

Ocean surgeonfish, *A. bahianus*, and doctorfish, *A. chirurgus*, are morphologically similar both as adults and as juveniles. Resolution in video transects was usually not adequate for positive distinction between these two species. Similar problems distinguishing these two species has also been reported for visual transect methods (Alevizon *et al.*, 1985). Although ranges of both species include South Caicos reefs (Randall, 1983), *A. bahianus* is more common; *A. chirurgus*, if present at all, is restricted to inshore shallows in fringing reef, rock, and rubble. Therefore, individuals of both species were recorded as *A. bahianus* and will be referred to as surgeonfish in the following discussion.

Acanthurus bahianus group

Frequency and relative abundance of surgeonfishes recorded on natural and artificial reefs appear in Table 5.2. Data on recruitment of surgeonfish to artificial reefs is summarized in Table 5.3. Most (98%) of the surgeonfish observed on

Table 5.2 - Frequency and Relative Abundance of *Acanthurus bahianus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	2	8.7%	3	5.1%	5	6.1%
Artificial Reef -sand halo	D3	2	5.4%	9	22.5%	11	14.3%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	7	5.1%	5	8.5%	12	6.1%
Artificial Reef -sparse soft coral	B3	1	1.5%	2	1.1%	3	1.2%
Artificial Reef -dense soft coral	F3	4	1.0%	22	7.6%	26	3.8%
Artificial Reef -sparse grass	B2	11	4.6%	23	8.0%	34	6.5%
Artificial Reef -dense seagrass	C2	228	35.5%	0	0.0%	228	24.4%
Artificial Reef -dense seagrass	D2	96	18.7%	3	1.8%	99	14.5%
Natural Reef -soft coral	A	0	0.0%	8	1.3%	8	1.3%
Natural Reef -sparse seagrass	B	0	0.0%	12	1.9%	12	1.6%
Natural Reef -dense seagrass	C	0	0.0%	21	5.0%	21	4.7%
Natural Reef -dense seagrass	D	1	1.5%	36	5.3%	37	5.0%

Table 5.3 - Recruitment of *Acanthurus bahianus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.1	1	0.2	2	3 of 3	2	18	27%
sand halo	D3	0.1	1	0.6	3	3 of 3	3	7	20%
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0%
sand/soft coral	A3	0.3	2	0.2	1	2 of 3	1	39	43%
soft coral	B3	< 0.1	1	0.1	1	2 of 3	2	39	14%
soft coral	F3	0.3	4	1.5	6	3 of 3	1	52	60%
seagrass	B2	0.5	4	1.1	5	3 of 3	1	55	71%
seagrass	C2	10.9	32	0.0	0	3 of 3	1	54	100%
seagrass	D2	4.6	10	0.1	3	3 of 3	1	54	86%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

natural reefs were adults. The only juvenile recorded on a natural reef was near a dense stand of seagrass at site D. The number of surgeonfishes recorded on natural reef transects increased with increasing density of seagrass in the adjacent habitat.

On artificial reefs most surgeonfish were juveniles. The juvenile surgeonfish were always arranged in a tight school if more than two were present on a single reef. Artificial reefs surrounded by seagrass meadows at sites C and D had the highest number of juvenile surgeonfishes. Among artificial reefs surrounded by sparse seagrass, soft coral or sand, there was no significant difference in numbers of juveniles. Metamorphosis and development to the size juveniles observed on artificial reefs occurs postsettlement over a 1-2 week period of time (Thresher, 1984). Presettlement acronous stage are primarily found well offshore. This suggests selective preference for dense seagrass by settling surgeonfish.

Adult surgeonfish were most common on artificial habitats surrounded by sparse seagrass or soft coral. This observation may be a function of the tendency of surgeonfish to move through such habitats in groups that are a part of large schools of blue tang. Upon encountering an artificial reef, surgeonfish observed on one occasion separated from the school and began feeding on algal growth on the conch shells.

Acanthurus coeruleus

As juveniles, blue tang are bright yellow and transform to a blue adult stage gradually. In this study, if any part of the body was yellow, an individual was recorded as a juvenile. Frequency and relative abundance of tang are summarized by habitat in Table 5.4 and recruitment data in Table 5.5. Although adult blue tang

Table 5.4 - Frequency and Relative Abundance of *Acanthurus coeruleus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	1	1.7%	1	1.2%
Artificial Reef -sand halo	D3	2	5.4%	0	0.0%	2	2.6%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	4	2.9%	0	0.0%	4	2.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	1	0.5%	1	0.4%
Artificial Reef -dense soft coral	F3	4	1.0%	0	0.0%	4	0.6%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	7	1.1%	0	0.0%	7	0.8%
Artificial Reef -dense seagrass	D2	11	2.1%	0	0.0%	11	1.6%
Natural Reef -soft coral	A	0	0.0%	2	0.3%	2	0.3%
Natural Reef -sparse seagrass	B	1	1.0%	24	3.8%	25	3.5%
Natural Reef -dense seagrass	C	2	6.7%	4	1.0%	6	1.4%
Natural Reef -dense seagrass	D	0	0.0%	6	0.9%	6	0.9%

Table 5.5 - Recruitment of *Acanthurus coeruleus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.1	1	1 of 3	1	1	7%
sand halo	D3	0.1	1	0.0	0	1 of 3	2	19	13%
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0%
sand/soft coral	A3	0.2	3	0.0	0	2 of 3	21	21	10%
soft coral	B3	0.0	0	< 0.1	1	1 of 3	4	4	5%
soft coral	F3	0.3	2	0.0	0	2 of 3	17	17	13%
seagrass	B2	0.0	0	0.0	0	0	0	0	0%
seagrass	C2	0.3	2	0.0	0	3 of 3	3	54	24%
seagrass	D2	0.5	2	0.0	0	3 of 3	1	54	38%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

were most abundant on natural reefs with adjacent seagrass, their abundance did not appear correlated with density of seagrass. Juveniles were only observed on natural reefs with adjacent seagrass. Spotte *et al.* (1992) also reported a significant association of blue tang with sites having seagrass.

Adult blue tang were rare on artificial reefs. Adults were observed at the 1-week visit to site C3 and the 4-week visit to site B3. Both times adults were observed on artificial reefs, they were solitary individuals that paused briefly at a reef and nipped at the conch shell. Presumably, this was an attempt to scrape off what little algal growth may have been present.

Frequency of observations of juvenile blue tangs were highest on artificial reefs surrounded by seagrass of at least moderate density. Observations at these reefs spanned the full year and included 100% of the reefs. In contrast to juvenile surgeonfish, juvenile blue tang remained solitary even when more than one juvenile was present on the same artificial reef.

APOGONIDAE

A single species of apogonidae was recorded in this study, *Apogon binotatus*, barred cardinalfish. Although apogonid spawning is demersal and oral incubation of eggs is common to most, if not all, apogonids (Smith *et al.*, 1971), larval stages are generally planktonic (Dale, 1978; Thresher, 1984). It is, therefore, not surprising that apogonids colonized artificial reefs at a considerable distance from natural reefs. However, it is noteworthy that only one species of the six to twelve species in the region was observed on artificial reefs. Since natural reef transects in this study were diurnal and apogonids shelter in crevices diurnally, cinetransect methods would not sample apogonids. Therefore, insufficient

information is available on apogonid distribution to evaluate data from artificial reefs as it compares to apogonid abundance in natural habitats.

Apogon binotatus

Barred cardinalfish were observed on 9 separate occasions (Table 5.6) on artificial reefs at site H3, shallow sand flats from the nineteenth to the fifty-second week. Two or three individuals were observed on each of three artificial reefs at that site. When first observed (nineteenth week), barred cardinalfish were small, but had no characteristics to mark them as juveniles. They were, therefore, recorded as small adults. In fact, it was apparent that they were several weeks beyond the postlarval stage of development. All individuals observed on the nineteenth week were of approximately the same size, and all were similarly larger on each subsequent visit (thirty-seventh and fifty-second week visits). It is presumed that they colonized artificial reefs directly from a planktonic larval phase and continued to reside there.

That cardinalfish settle on artificial reefs surrounded by sand in shallows leeward of the islet Long Cay is consistent with observations of a similar species in the Pacific. Leis and Goldman (1984) found strong windward/leeward differences in abundance of larvae of numerous taxa. Their data on cardinalfish larvae show a distinct leeward distribution of both young and old larvae.

AULOSTOMIDAE

Aulostomus maculatus

Trumpetfish are described as common by Randall (1983). On natural reefs off South Caicos, trumpetfish were observed occasionally. Tables 5.7 and 5.8

Table 5.6 - Recruitment of *Apogon binotatus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	1.1	3	3 of 3	19	52	60%
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.7 - Frequency and Relative Abundance of *Aulostomus maculatus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	1	0.2%	0	0.0%	1	0.1%
Artificial Reef -dense seagrass	D2	2	0.4%	0	0.0%	2	0.3%
Natural Reef -soft coral	A	0	0.0%	0.5	0.1%	0.5	0.1%
Natural Reef -sparse seagrass	B	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	C	0	0.0%	1	0.2%	1	0.2%
Natural Reef -dense seagrass	D	0	0.0%	1	0.1%	1	0.1%

Table 5.8 - Recruitment of *Aulostomus maculatus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	< 0.1	1	0.0	0	1 of 3	4	4	5%
seagrass	D2	0.1	2	0.0	0	1 of 3	4	4	5%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

summarize data collected on trumpetfish. Adult trumpetfish were recorded on natural reefs with and without adjacent seagrass. Juvenile trumpetfish were not observed on natural reefs, they were seen only on artificial reefs with surrounding seagrass of at least moderate density (Table 5.7). Although Munro *et al.* (1973), suggested that trumpetfish spawn during the winter off Jamaica, juveniles were observed in this study only at the four-week visit which was late summer (Table 5.8).

BALISTIDAE

Triggerfishes are represented off South Caicos by three species: *Balistes vetula*, queen triggerfish; *Melichthys niger*, black durgon; and *Xanthichthys ringens*, sargassum triggerfish. Of these, only queen triggerfish and black durgon were observed during this study.

Balistes vetula

Adult queen triggerfish were observed often on natural reefs at sites B and D. Data on frequency and relative abundance of queen triggerfish by habitat are in Table 5.9. Juvenile queen triggerfish were observed on two of the nine artificial habitats with adjacent seagrass. They colonized artificial reefs in weeks 1 and 4 as described in Table 5.10. Both juveniles selected artificial reefs surrounded by seagrass.

Although most triggerfishes reportedly have demersal eggs (Fricke, 1980), Thresher (1984) suggested that queen triggerfish may have pelagic eggs based on the position of spawning pairs high in the water column. Pelagic larvae have more opportunity for selectivity of habitat at settlement than demersal larvae. Similarity

Table 5.9 - Frequency and Relative Abundance of *Balistes vetula* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	1	0.4%	0	0.0%	1	0.2%
Artificial Reef -dense seagrass	C2	1	0.2%	0	0.0%	1	0.1%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	0	0.0%	0	0.0%
Natural Reef -sparse seagrass	B	0	0.0%	0.3	< 0.1%	0.3	< 0.1%
Natural Reef -dense seagrass	C	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	D	0	0.0%	0.3	< 0.1%	0.3	< 0.1%

Table 5.10 - Recruitment of *Balistes vetula* to artificial reefs in nine habitats off South Caicos

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0%
sand halo	D3	0.0	0	0.0	0	0	0	0	0%
sand /rubble	H3	0.0	0	0.0	0	0	0	0	0%
soft coral	B3	0.0	0	0.0	0	0	0	0	0%
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0%
soft coral	F3	0.0	0	0.0	0	0	0	0	0%
seagrass	B2	0.2	1	0.0	0	1 of 3	4	4	5%
seagrass	C2	0.1	1	0.0	0	1 of 3	1	1	5%
seagrass	D2	0.0	0	0.0	0	0	0	0	0%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits on which at least one individual was observed on the artificial reef

of habitats surrounding artificial reefs colonized by juvenile queen triggerfish supports the hypothesis of pelagic eggs and larvae of queen triggerfish.

Melichthys niger

Adult black durgon were recorded on natural reef transects at sites A and D. Table 5.11 details frequency and relative abundance of black durgon at these sites. The pattern of observations may be explained by proximity of these two sites to deeper water since these fish are most common in outer-reef areas of 30 meters or more (Randall, 1983).

BLENNIIDAE

Blennies were observed on two occasions, but were not identifiable on video records. They were likely *Ophioblennius atlanticus* since this species was observed on natural reefs most often during visual surveys. Other species of blennies were observed at the study site during preliminary visual surveys, but none was visible on the recorded transects of natural reefs.

CARANGIDAE

Caranx ruber

Frequency of observations of bar jack was highest at natural and artificial reefs with bordering seagrass of at least moderate density (Table 5.12). Bar jack at artificial reefs fed on resident schools of juvenile acanthurids and small wrasse. Bar jack were most often observed in small tight schools, whether on natural or artificial reefs. Occasional and temporary presence of predators such as bar jack at artificial reefs is similar to their transient status on natural reefs.

Table 5.11 - Frequency and Relative Abundance of *Melichthys niger* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	1	0.2%	1	0.2%
Natural Reef -sparse seagrass	B	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	C	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	D	0	0.0%	4	0.6%	4	0.5%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.12 - Frequency and Relative Abundance of *Caranx ruber* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	1	0.3%	1	0.2%
Artificial Reef -dense seagrass	C2	0	0.0%	6	2.1%	6	0.6%
Artificial Reef -dense seagrass	D2	0	0.0%	1	0.6%	1	0.1%
Natural Reef -soft coral	A	0	0.0%	1	0.2%	1	0.2%
Natural Reef -sparse seagrass	B	0	0.0%	2	0.3%	2	0.3%
Natural Reef -dense seagrass	C	0	0.0%	7	1.7%	7	1.6%
Natural Reef -dense seagrass	D	0	0.0%	5	0.7%	5	0.7%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

CHAETODONTIDAE

Of families of reef fishes, one of the most characteristic is butterflyfishes. Two species of butterflyfishes were observed in this study, *Chaetodon capistratus*, foureye butterflyfish, and *Chaetodon striatus*, banded butterflyfish. White (1988) suggests that surface relief and live coral coverage are positively correlated with successful recruitment of most species of butterflyfishes. This study also reveals a positive relationship between live coral coverage and adult butterflyfish abundance which were both highest at natural reef site A.

Though peaking in early summer, spawning activity of butterflyfish appears to occur year-round (Thresher, 1980). In this study, juveniles were observed only in mid-summer. In both species, juveniles were only observed on artificial reefs surrounded by dense seagrass; however, adults were observed on natural reefs with and without adjacent seagrass. That adults were not recorded on natural reefs closest to artificial reefs where juveniles were observed may be explained by: (1) predation being higher in route to or on site D natural reef; (2) migration of older juveniles to distant natural reef sites. The latter process may be related to the small percentage of live coral coverage (Figure 3.7) at site D. Both species feed on coral polyps and their abundance has been correlated with live coral coverage in other studies (White, 1988; Pitts, 1991).

Chaetodon capistratus

Juvenile foureye butterflyfish are common in very shallow inshore areas, often no more than two feet deep. They are strongly site attached and associate as solitary individuals with some particular shelter in rocky habitats or on isolated coral heads on shallow, sandy bottoms (Thresher, 1980). Adult foureye butterflyfish are

associated with the reef crest and other shallow reef zones (Alevizon *et al.*, 1985; Pitts, 1991).

Foureye butterflyfish were observed at natural reef sites A, B, and C; but juveniles were recorded only on artificial reefs at site D2 (Table 5.13). Although not commonly described as seagrass fishes, juvenile foureye butterflyfish have been previously recorded from seagrass beds in the West Indies (Baelde, 1990). Spotte *et al.* (1992) also reported a significant correlation of foureye butterflyfish with sites having turtle grass. Thresher (1980) suggests that butterflyfish have some sort of irregular migration offshore as they mature. All individuals recorded on natural reefs were solitary and, on artificial reefs, only one juvenile occurred per reef (Table 5.14).

Chaetodon striatus

Tables 5.15 and 5.16 summarize data on banded butterflyfish. Not as common as foureye butterflyfish, banded butterflyfish were recorded only on natural reef site A which has contiguous soft coral. Adults were also recorded on artificial reefs with surrounding dense soft coral. Only one juvenile was observed, and it was present on an artificial reef surrounded by dense seagrass.

CIRRHITIDAE

Amblycirrhitus pinos

Redspotted hawkfish, the single western Atlantic cirrhitid, were recorded only on natural reef at site C and colonized artificial reefs as adults at site F3 (dense soft coral) and in a juvenile stage at sites C2 and D2 (dense seagrass)(Table 5.17). Based on size, juveniles were postsettlement and immigrated from seagrass

Table 5.13 - Frequency and Relative Abundance of *Chaetodon capistratus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	5	1.0%	0	0.0%	5	0.7%
Natural Reef -soft coral	A	0	0.0%	1	0.2%	1	0.2%
Natural Reef -sparse seagrass	B	0	0.0%	1	0.2%	1	0.1%
Natural Reef -dense seagrass	C	0	0.0%	2	0.5%	2	0.4%
Natural Reef -dense seagrass	D	0	0.0%	0	0.0%	0	0.0%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.14 - Recruitment of *Chaetodon capistratus* to artificial reefs in nine habitats off South Caicos

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0%
sand halo	D3	0.0	0	0.0	0	0	0	0	0%
sand /rubble	H3	0.0	0	0.0	0	0	0	0	0%
soft coral	B3	0.0	0	0.0	0	0	0	0	0%
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0%
soft coral	F3	0.0	0	0.0	0	0	0	0	0%
seagrass	B2	0.0	0	0.0	0	0	0	0	0%
seagrass	C2	0.0	0	0.0	0	0	0	0	0%
seagrass	D2	0.2	1	0.0	0	2 of 3	2	4	23.8%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits on which at least one individual was observed on the artificial reef

Table 5.15 - Frequency and Relative Abundance of *Chaetodon striatus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	2	0.7%	2	0.3%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	1	0.2%	0	0.0%	1	0.1%
Natural Reef -soft coral	A	0	0.0%	1	0.2%	1	0.2%
Natural Reef -sparse seagrass	B	0	0.0%	0.3	0.0%	0.3	0.0%
Natural Reef -dense seagrass	C	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	D	0	0.0%	0	0.0%	0	0.0%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.16 - Recruitment of *Chaetodon striatus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.1	1	1 of 3	17	17	7%
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	< 0.1	1	0.0	0	1 of 3	4	4	5%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.17 - Recruitment of *Amblycirrhitis pinos* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.1	1	1 of 3	2	2	7%
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	< 0.1	1	0.0	0	1 of 3	4	4	5%
seagrass	D2	< 0.1	1	< 0.1	1	1 of 3	20	39	10%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

surrounding artificial reefs. At site D2, a large juvenile was recorded in November; and apparently the same individual was observed in March when it was recorded as a small adult. In June, it was no longer present.

CLINIDAE

Malacoctenus triangulatus

The saddled blenny was the only member of the family Clinidae recorded on artificial reefs, and no clinids were recorded on natural reef transects. This was the most common of the scaled blennies (Clinidae) observable on preliminary visual surveys. Its apparent commonness is partially due to its perching behavior and its relatively fearless demeanor. Six observations of saddled blennies were recorded from the soft coral flat at site F3 (Table 5.18). The first observation was at the seventeenth week, and individuals were full size (Table 5.18). Based on dates and sizes at first records, saddled blennies most likely immigrated to the artificial reefs from nearby territories as adults. Artificial reefs of conch shells on soft coral flats offer a considerable advantage as sheltered sites.

GOBIIDAE

Gobies were of two distinct groups segregated by surveys of natural reefs vs. artificial reefs. Those recorded on natural reefs were of the genus *Gobiosoma*, but species were not distinguishable by the survey methods. *Gobiosoma* spp. were in surveys only at site C, although they were observed at all natural reef sites (Table 3.4). Gobies observed on artificial reefs included *Gnatholepis thompsoni*, *Coryphopterus glaucofraenum*, and some individuals that may have represented other species of *Coryphopterus* but were not identifiable (Table 5.1).

Table 5.18 - Recruitment of *Malacoctenus triangulatus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.4	2	3 of 3	17	37	33%
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Coryphopterus glaucofraenum and *Gnatholepis thompsoni*

These two species of gobies colonized all artificial reefs surrounded by sandy-bottomed habitats with a notable exception (Tables 5.19 and 5.20), gobies did not colonize artificial reefs at site F3 (dense soft coral) despite its apparent similarity to other habitats where gobies were present. Each species, and gobiids as a group, were significantly more abundant on artificial reefs at site H3 (sand flats on banks).

Gnatholepis thompsoni, goldspot goby, were repeatedly observed chasing *C. glaucofraenum*, bridled goby, from artificial reefs at site H3. Shulman (1982) described similar aggressive encounters between these species on *Strombus* artificial reefs. She demonstrated an inverse relationship between population densities of these two species. Thus, interspecific competition may explain the significantly higher relative abundance of *G. thompsoni* at all artificial reefs where one or both were present. A juvenile of *G. thompsoni* colonized an artificial reef at site C3 on week 2, but was absent one week later (Table 5.20). Since C3 reefs were constructed in the halo zone, predation is presumed as the cause for its absence. Juveniles of other gobiid species were not observed. Eight individuals per reef was the maximum population size on an artificial reef.

HOLOCENTRIDAE

Adult squirrelfishes and soldierfishes are reef dwellers that feed in seagrass meadows by night. Most species hide in crevices of the reef by day. This behavior may have biased data resulting from video tape from natural reefs if concealment within crevices differed significantly among sites. *Holocentrus ascensionis*, *H. rufus*, *Myripristis jacobus*, and *Sargocentron coruscus* were observed in this study.

Table 5.19 - Recruitment of *Coryphopterus glaucofraenum* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.1	1	1 of 3	2	2	7%
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.5	4	2 of 3	2	2	13%
sand/soft coral	A3	0.0	0	< 0.1	1	1 of 3	21	21	5%
soft coral	B3	0.0	0	0.1	1	2 of 3	4	4	10%
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.20 - Recruitment of *Gnatholepis thompsoni* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.1	1	0.1	2	2 of 3	2	2	13%
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	1.4	6	3 of 3	1	19	60%
sand/soft coral	A3	0.0	0	0.1	1	2 of 3	4	54	14%
soft coral	B3	0.0	0	0.2	1	3 of 3	4	54	19%
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Juveniles were observed of *Holocentrus rufus*, *Myripristis jacobus* and *Sargocentron coruscus*. The pelagic stage of *H. rufus* and *H. ascensionis* is protracted with an average age at settlement of over nine weeks compared to four to five weeks for *S. coruscus* and seven weeks for *M. jacobus* (Tyler *et al.*, 1993). Ogden and Zieman (1977) describe squirrelfish settlement in seagrass meadows and suggest that most of the juvenile stage of these fishes is spent in seagrass.

Holocentrus ascensionis

Longjaw squirrelfish were recorded on natural reefs at sites B and D. Adults were observed only as occasional visitors on artificial reefs in dense soft coral and dense seagrass (Table 5.21). They represent transient components of the artificial reef fish assemblage.

Holocentrus rufus

Adults and juveniles of the common squirrelfish colonized artificial reefs at different sites and were present on natural reefs (Table 5.22). Adults were on reefs surrounded by dense soft coral and on reefs in an halo zone (sites F3 and D3). Adults were significantly more numerous on natural reefs surrounded by seagrasses (sites B, C, and D).

Juvenile squirrelfish were recorded on artificial reefs encompassed with sand/rubble (H3), sparse soft coral (B3), and dense seagrass (C2). These data apparently represent recruitment from a single reproductive cycle in that juveniles were only recorded on the November visit (Table 5.23). This is consistent with reports of year-round spawning off Jamaica by Munro *et al.* (1973) and reports of settlement in October off St. Croix by Tyler *et al.* (1993). That all seven of the

Table 5.21 - Recruitment of *Holocentrus ascensionis* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.2	2	1 of 3 0	1	2	13%
seagrass	B2	0.0	0	0.0	0		0	0	0
seagrass	C2	0.0	0	< 0.1	1	1 of 3	4	4	5%
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.22 - Frequency and Relative Abundance of *Holocentrus rufus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	1	2.5%	1	1.3%
Artificial Reef -sand/rubble	H3	2	0.5%	0	0.0%	2	0.4%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	3	4.4%	0	0.0%	3	1.2%
Artificial Reef -dense soft coral	F3	0	0.0%	1	0.3%	1	0.1%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	2	0.3%	0	0.0%	2	0.2%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	1	0.2%	1	0.1%
Natural Reef -sparse seagrass	B	0	0.0%	17	2.7%	17	2.4%
Natural Reef -dense seagrass	C	0	0.0%	13	3.1%	13	2.8%
Natural Reef -dense seagrass	D	0	0.0%	26	3.8%	26	3.5%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.23 - Recruitment of *Holocentrus rufus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.1	1	1 of 3	52	52	7%
sand/rubble	H3	0.1	2	0.0	0	1 of 3	19	19	7%
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.1	1	0.0	0	1 of 3	22	22	14%
soft coral	F3	0.0	0	0.1	1	1 of 3	37	37	7%
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.1	2	0.0	0	1 of 3	21	21	5%
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

juveniles were absent on the succeeding visit (March) is evidence of predation or migration to another shelter site.

Myripristis jacobus

Adult black-bar soldierfish were recorded on all natural reefs and on artificial reefs at sites B2 (sparse seagrass) and A3 (sand/sparse soft coral). Juveniles were observed on one artificial reef within seagrass, site C2, and all artificial reefs in sand/rubble habitat, site H3, (Table 5.24). Juvenile soldierfish small enough to have settled directly from the pelagic rhynchichthys stage were observed only at the November (4 month) visit at both sites (Table 5.25). Thereafter, juveniles were only at site H3, and were increasingly larger at each visit. Eight months later (52 week visit) soldierfish were large enough to be recorded as small adults. At smaller sizes, soldierfish remained within artificial reef perimeters; but as they grew larger, soldierfish hovered above or to the side of a reef and darted in and out of the space protected by the conch shells.

Sargocentron coruscus

Reef squirrelfish are distinguished by a black spot at front of dorsal fin which is apparent in juveniles and adults. Although none were recorded on surveys of natural reefs, reef squirrelfish were observed on artificial reefs in sites of all habitat types (Table 5.26). Adults colonized artificial reefs surrounded by sparse soft coral (site B3) at least three times and one artificial reef in the halo zone at site C3 (Table 5.27). Adults were not observed on the same reef on consecutive visits; however juveniles were always observed on second and sometimes third consecutive visits which represented as much as three months in time.

Table 5.24 - Frequency and Relative Abundance of *Myripristis jacobus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	35	9.3%	13	7.0%	48	8.5%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	3	1.0%	3	0.6%
Artificial Reef -dense seagrass	C2	1	0.2%	0	0.0%	1	0.1%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	2	0.3%	2	0.4%
Natural Reef -sparse seagrass	B	0	0.0%	1	0.2%	1	0.1%
Natural Reef -dense seagrass	C	0	0.0%	6	1.4%	6	1.2%
Natural Reef -dense seagrass	D	0	0.0%	3	0.4%	3	0.4%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.25 - Recruitment of *Myripristis jacobus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	2.3	11	0.9	6	2 of 3	19	52	60%
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.1	2	2 of 3	39	39	10%
seagrass	C2	< 0.1	1	0.0	0	1 of 3	21	21	5%
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.26 - Frequency and Relative Abundance of *Sargocentron coruscus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	11	2.9%	1	0.5%	12	2.1%
Artificial Reef -sand/soft coral	A3	1	0.7%	0	0.0%	1	0.5%
Artificial Reef -sparse soft coral	B3	3	4.4%	8	4.3%	11	4.4%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	4	1.7%	0	0.0%	4	0.8%
Artificial Reef -dense seagrass	C2	2	0.3%	0	0.0%	2	0.2%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	0	0.0%	0	0.0%
Natural Reef -sparse seagrass	B	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	C	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	D	0	0.0%	0	0.0%	0	0.0%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.27 - Recruitment of *Sargocentron coruscus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.1	1	1 of 3	18	18	7%
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.7	6	0.1	1	3 of 3	19	37	33%
sand/soft coral	A3	< 0.1	1	0.0	0	1 of 3	54	54	5%
soft coral	B3	0.1	1	0.4	4	3 of 3	3	39	29%
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.2	1	0.0	0	2 of 3	3	4	19%
seagrass	C2	0.1	1	0.0	0	1 of 3	3	4	10%
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Juveniles colonized artificial reefs at five sites representing all peripheral habitat types except halo zones (sites A3, B2, B3, C2, and H3). Reef squirrelfish remained deep within the artificial reefs. Reef squirrelfish, which were observed from juvenile stages on artificial reefs, were not recorded after attaining a small adult size. Most likely these individuals migrated to a more suitable habitat--a natural reef. Although they may have been removed from the population by predation.

LABRIDAE

Seven species of wrasses of the genera *Bodianus*, *Doratonotus*, *Halichoeres*, *Lachnolaimus*, and *Thalassoma* were recorded on natural or artificial reefs where their characteristic "pectoral fin" swimming style and unique color patterns were easily identifiable.

Doratonotus megalepis

Dwarf wrasse are seagrass fish and are so well camouflaged when in their preferred habitat that they are rarely seen. Only one dwarf wrasse was observed in this study, and it was on an artificial reef surrounded by sparse seagrass at site B2. This adult individual was not observed on subsequent visits.

Halichoeres bivittatus

Adult slippery dick were recorded on all natural and artificial reefs (Table 5.28). Adults were most abundant at site B2 (sparse seagrass) and C2 (dense seagrass) and least abundant on natural reefs and at artificial reefs surrounded by sand (A3, C3, and D3).

Table 5.28 - Frequency and Relative Abundance of *Halichoeres bivittatus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	1	4.3%	13	22.0%	14	17.1%
Artificial Reef -sand halo	D3	9	24.3%	11	27.5%	20	26.0%
Artificial Reef -sand/rubble	H3	16	4.2%	21	11.4%	37	6.6%
Artificial Reef -sand/soft coral	A3	43	31.4%	10	16.9%	53	27.0%
Artificial Reef -sparse soft coral	B3	22	32.4%	25	13.6%	47	18.7%
Artificial Reef -dense soft coral	F3	15	3.7%	27	9.3%	42	6.1%
Artificial Reef -sparse grass	B2	72	30.3%	123	43.0%	195	37.2%
Artificial Reef -dense seagrass	C2	129	20.1%	90	30.9%	219	23.5%
Artificial Reef -dense seagrass	D2	60	11.7%	35	20.5%	95	13.9%
Natural Reef -soft coral	A	0	0.0%	0.3	0.0%	0.3	0.1%
Natural Reef -sparse seagrass	B	4	4.1%	5	0.8%	9	1.2%
Natural Reef -dense seagrass	C	0	0.0%	8	1.9%	8	1.8%
Natural Reef -dense seagrass	D	9	13.8%	8	1.2%	17	2.3%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Juveniles were only recorded on artificial reefs (Table 5.29) and were present at least once on all artificial reefs at all sites. Juveniles were noted on most natural reefs on sight surveys and likely comprised a significant portion of the unidentified small fish on video surveys. Recruitment was lowest on reefs in halo zones and highest on reefs in seagrass meadows; however, reefs surrounded by sand and sparse soft coral (site A3) had numbers of juveniles that were not significantly different than the number per reef at site D2 in dense seagrass. *H. bivittatus* is an inshore species most commonly associated with breakwaters, piers, and other sheltered shallow water (Thresher, 1980) and this data demonstrates that both juveniles and adults may have immigrated to artificial reefs from adjacent seagrass.

Halichoeres garnoti

Juvenile yellowhead or "T" wrasse are bright yellow/orange with an electric blue stripe on each side. Yellowhead wrasse were observed on artificial reefs with contiguous sand and seagrass (Table 5.30). Yellowhead juveniles were significantly more abundant on artificial reefs surrounded by seagrass (sites B2, C2, D2). Juveniles are generally solitary fish although are occasionally seen in small groups (Thresher, 1980). Twice in this study groups of juveniles (9 - 12 fish per group) were observed on artificial reefs with adjacent dense seagrass (sites C2 and D2). Others were always seen singly even when more than one was observed on the same artificial reef.

Table 5.31 shows that adults were most common on natural reef B which has sparse peripheral seagrass and is the most shallow site. Based on depth alone, this is unexpected since Thresher (1980) describes their distribution as peaking at

Table 5.29 - Recruitment of *Halichoeres bivittatus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.1	1	0.9	3	3 of 3	2	51	47%
sand halo	D3	0.6	2	0.7	7	3 of 3	1	52	47%
sand/rubble	H3	1.1	6	1.4	7	3 of 3	1	52	87%
sand/soft coral	A3	2.0	7	0.5	3	3 of 3	1	54	86%
soft coral	B3	1.0	4	1.2	3	3 of 3	1	54	90%
soft coral	F3	1.0	4	1.8	9	3 of 3	1	52	80%
seagrass	B2	3.4	10	5.9	15	3 of 3	1	55	100%
seagrass	C2	6.1	34	4.3	18	3 of 3	1	54	100%
seagrass	D2	2.9	10	1.7	8	3 of 3	1	54	90%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.30 - Frequency and Relative Abundance of *Halichoeres garnoti* Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	3	13.0%	9	15.3%	12	14.6%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	2	1.5%	1	1.7%	3	1.5%
Artificial Reef -sparse soft coral	B3	0	0.0%	3	1.6%	3	1.2%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	8	3.4%	0	0.0%	8	1.5%
Artificial Reef -dense seagrass	C2	15	2.3%	0	0.0%	15	1.6%
Artificial Reef -dense seagrass	D2	21	4.1%	0	0.0%	21	3.1%
Natural Reef -soft coral	A	0.6	2.2%	5	0.8%	5.6	0.9%
Natural Reef -sparse seagrass	B	0	0.0%	25	4.0%	25	3.4%
Natural Reef -dense seagrass	C	0	0.0%	13	3.1%	13	2.8%
Natural Reef -dense seagrass	D	0	0.0%	14	2.1%	14	1.8%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.31 - Recruitment of *Halichoeres garnotito* Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.2	1	0.6	2	1 of 3	1	51	53%
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.1	1	< 0.1	1	1 of 3	3	21	14%
soft coral	B3	0.0	0	0.1	1	1 of 3	1	4	14%
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.4	2	0.0	0	2 of 3	1	55	29%
seagrass	C2	0.7	12	0.0	0	2 of 3	21	54	14%
seagrass	D2	1.0	9	0.0	0	3 of 3	3	54	38%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

10 - 30 meters. Some other habitat characteristic must influence their abundance at this reef. Adult yellowheads were also recorded on artificial reefs at sites C3, A3, and B3.

Halichoeres maculipinna

Clown wrasse are described as moving about in large feeding aggregations of intermediate phase fish within a home range of a hundred square meters or so (Thresher, 1980). However, in this study the largest group of clown wrasse were five juveniles on an artificial reef at site B3 (Table 5.32). Juveniles were also recorded on natural reefs at sites B and D. Adults were only on artificial reefs at site D3 (halo) and on natural reef site B.

Halichoeres poeyi

Black-ear wrasse inhabit seagrass meadows in which its uniformly lime green coloring offers excellent camouflage. This species was observed on two occasions on artificial reefs surrounded by seagrass (sites C2 and D2). Both individuals were large juveniles and darted into seagrass when disturbed. This behavior was characteristic of fishes that were not residents of artificial reefs; therefore, black-ear wrasse were categorized as transient members of the artificial reef fish assemblage.

Halichoeres radiatus

The puddingwife is the largest Caribbean species of this genus. Juveniles and adults are vibrantly colorful yet distinct from each other. Recruitment of juveniles to artificial reefs occurred in both summer and late fall (Table 5.34). Adults were most abundant on natural reefs with peripheral seagrass. Juveniles

Table 5.32 - Recruitment of *Halichoeres maculipinna* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.5	4	0.2	3	1 of 3	2	19	27%
sand/rubble	H3	0.1	1	0.0	0	1 of 3	19	19	7%
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.4	5	0.0	0	2 of 3	22	54	14%
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.5	3	0.0	0	3 of 3	22	55	24%
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.33 - Frequency and Relative Abundance of *Halichoeres radiatus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total	Relative	Total	Relative	Total	Relative
		Observed	Abund.	Observed	Abund.	Observed	Abund.
Artificial Reef -sand halo	C3	1	4.3%	0	0.0%	1	1.2%
Artificial Reef -sand halo	D3	2	5.4%	0	0.0%	2	2.6%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	5	1.0%	0	0.0%	5	0.7%
Natural Reef -soft coral	A	1	3.7%	0.3	0.0%	1.3	0.2%
Natural Reef -sparse seagrass	B	0	0.0%	2	0.3%	2	0.3%
Natural Reef -dense seagrass	C	0	0.0%	3	0.7%	3	0.7%
Natural Reef -dense seagrass	D	0	0.0%	3	0.4%	3	0.4%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.34 - Recruitment of *Halichoeres radiatus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.1	1	0.0	0	1 of 3	18	18	7%
sand halo	D3	0.1	1	0.0	0	1 of 3	1	2	13%
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.2	1	0.0	0	2 of 3	1	4	24%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

were recorded on artificial reefs with peripheral seagrass (site D2) or with seagrass nearby (sites C3 and D3) (Table 5.33). This pattern can be explained by initial settlement in seagrass and secondary recruitment to reef. Spotte *et al.* (1992) also reported an association of *H. radiatus* with sites having seagrass.

Thalassoma bifasciatum

Bluehead wrasse are the most abundant of the Caribbean wrasses (Thresher, 1980) and were more abundant than other wrasse species on natural reefs. Highest relative abundance of wrasse on artificial reefs varied between *Thalassoma bifasciatum* and *H. bivittatus*. *Thalassoma bifasciatum* was most abundant on reefs at sites C3, A3, B3, F3, D2, and all natural reefs (Table 5.35); whereas, *H. bivittatus* was most abundant at all others (site D3, H3, B2, C2). It is unclear whether competition or habitat selection was the cause of abundance patterns; this topic warrants additional study.

Juveniles were observed at all sites except artificial reefs within halo zone at site D3. Juveniles were significantly more abundant at site F3 artificial reefs (dense soft coral) where as many as 90 individuals were on one artificial reef (Table 5.36). Juveniles were observed throughout the year with no detectable peak in recruitment.

LUTJANIDAE

Snappers observed on natural reefs include *Lutjanus analis*, *L. apodus*, *L. griseus*, *L. jocu*, *L. mahogoni*, and *Ocyurus chrysurus*. On most video transects one or more lutjanids were recorded that were not identifiable despite their medium to large size especially when in mixed species schools in which individuals in the

Table 5.35 - Frequency and Relative Abundance of *Thalassoma bifasciatum* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	5	21.7%	14	23.7%	19	23.2%
Artificial Reef -sand halo	D3	0	0.0%	3	7.5%	3	3.9%
Artificial Reef -sand/rubble	H3	6	1.6%	12	6.5%	18	3.2%
Artificial Reef -sand/soft coral	A3	73	53.3%	15	25.4%	88	44.9%
Artificial Reef -sparse soft coral	B3	19	27.9%	48	26.1%	67	26.6%
Artificial Reef -dense soft coral	F3	361	89.8%	157	54.3%	518	75.0%
Artificial Reef -sparse grass	B2	5	2.1%	12	4.2%	17	3.2%
Artificial Reef -dense seagrass	C2	17	2.6%	14	4.8%	31	3.3%
Artificial Reef -dense seagrass	D2	48	9.4%	54	31.6%	102	14.9%
Natural Reef -soft coral	A	23	85.2%	15	2.5%	38	6.0%
Natural Reef -sparse seagrass	B	8	8.2%	73	11.6%	81	11.1%
Natural Reef -dense seagrass	C	6	20.0%	27	6.5%	33	7.4%
Natural Reef -dense seagrass	D	24	36.9%	9	1.3%	33	4.5%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.36 - Recruitment of *Thalassoma bifasciatum* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.3	1	0.9	4	3 of 3	1	51	73%
sand halo	D3	0.0	0	0.2	1	1 of 3	1	52	20%
sand/rubble	H3	0.4	2	0.8	3	3 of 3	1	52	73%
sand/soft coral	A3	3.5	16	0.7	8	3 of 3	1	54	71%
soft coral	B3	0.9	3	2.3	8	3 of 3	1	54	86%
soft coral	F3	24.1	92	10.5	57	3 of 3	1	52	100%
seagrass	B2	0.2	2	0.6	3	2 of 3	1	55	43%
seagrass	C2	0.8	6	0.7	4	3 of 3	4	54	48%
seagrass	D2	2.3	10	2.6	10	3 of 3	1	54	90%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

background were partially obscured by other fishes. In some cases ambiguous characteristics were noted which may have been the result of field hybridization (Domeier and Clarke, 1992; Chow and Walsh, 1992).

Ocyurus chrysurus

Yellowtail snapper was the only species of lutjanid to frequent artificial reefs as adults. Apparently nonresident, adult yellowtail snapper appeared attracted to resident fishes as potential prey. Adults were recorded at sites B3 and D2 on six and two occasions, respectively (Table 5.37). Adults were most abundant on natural reefs with dense seagrass in the adjacent habitat (sites C and D). A single juvenile was observed on an artificial reef surrounded by seagrass (site C2)

MONACANTHIDAE

Filefishes (monacanthids) are now generally considered a separate family from the triggerfishes (balistids). Although not commonly used in the Caribbean as foodfish (except for the most creative fish soup lovers), filefishes are cherished by sport divers and aquarists. Due to their relatively slow swimming, filefishes are easily approached and some species are curious enough to follow a diver. Other features of interest are their ability to change color patterns and independent eye movements. Two species of filefishes colonized artificial reefs--*Cantherhines pullus* and *Monacanthus ciliatus*.

Cantherhines pullus

Adult orangespotted filefish (tail-light filefish) were observed on natural reefs at sites B and D (Table 3.3 and 3.5), soft coral flat site F (Table 3.13), and on

Table 5.37 - Recruitment of *Ocyurus chrysurus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.5	3	2 of 3	1	4	29%
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	< 0.1	1	0.0	0	1 of 3	21	21	5%
seagrass	D2	0.0	0	0.5	4	3 of 3	2	20	10%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

artificial reef sites B3 and F3 (Table 5.38). Since adults were found in habitats peripheral to artificial reefs and were recorded only once at each artificial reef, it is likely that they were residents of the peripheral habitats and transient visitors to artificial reefs.

The only juvenile observed in this study appeared on an artificial reef at site C2 (dense seagrass) in early July and was absent one week later (Table 5.38). Most filefishes produce demersal eggs with no parental care and juvenile recruitment to an artificial reef deep within a seagrass meadow suggests planktonic larvae.

Monacanthus ciliatus

Fringed filefish, *Monacanthus ciliatus*, are usually in turtle grass and algae where they are well-camouflaged. A single observation of fringed filefish in this study was of a juvenile in early August on an artificial reef surrounded by dense seagrass. It already exhibited the head-down hiding posture characteristic of adults.

MULLIDAE

Both species of Caribbean goatfishes were recorded on natural reefs--yellow goatfish, *Mulloidichthys martinicus*, and spotted goatfish, *Pseudupeneus maculatus*. However, only spotted goatfish colonized artificial reefs.

Pseudupeneus maculatus

Adult spotted goatfish were most abundant on natural reefs with peripheral seagrass. They were present on artificial reefs at sites A3, B3, C2, and D2 and on

Table 5.38 - Recruitment of *Cantherhines pullusto* Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	< 0.1	1	1 of 3	4	4	5%
soft coral	F3	0.0	0	0.1	2	2 of 3	17	17	13%
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	< 0.1	1	0.0	0	1 of 3	3	3	5%
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

natural reefs at sites B, C, and D (Table 5.39). With the exception of an adult on A3, all other observations occurred on reefs with seagrass within ten meters. Adults were apparently only transient visitors to artificial reefs. At sites A3 and B3 they swam away from the artificial reef before the observation was complete. Although adults stayed longer at artificial reefs surrounded by seagrass (sites C2 and D2), they did not seek shelter within the reef when threatened. Instead, they darted away into seagrass.

Juvenile spotted goatfish were observed in a tight school at seagrass site C2 on two occasions which is consistent with their description as abundant residents of seagrass by Heck and Weinstein (1989). On artificial reefs, juveniles were most abundant at site C2 (dense seagrass), but were also found at sites B2, D2 and H3 (Table 5.40). Observations of juveniles in summer and fall support the reportedly long spawning season (February-October) described by Munro *et al.* (1973). Based on recruitment data, spotted goatfish display preferential settlement near dense seagrass. When more than one juvenile was observed on an artificial reef, they were always in a relatively well-organized school and would disperse only to dart into reef holes for shelter from large predators such as *Caranx ruber* or a curious SCUBA diver.

MURAENIDAE

Muraenid eels are piscivorous reef fishes hidden from the casual observer of a coral reef fish assemblage. Secretive behavior explains their absence in natural reef surveys. Adults of two species were on artificial reefs -- *Gymnothorax moringa* and *Gymnothorax vicinus*.

Table 5.39 - Recruitment of *Pseudupeneus maculatus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0.0%
sand halo	D3	0.0	0	0.0	0	0	0	0	0.0%
sand /rubble	H3	0.1	1	0.0	0	1 of 3	37	37	6.7%
						0			
soft coral	B3	0.0	0	0.0	1	1 of 3	4	4	4.8%
sand/soft coral	A3	0.0	0	0.0	1	1 of 3	2	2	4.8%
soft coral	F3	0.0	0	0.0	0	0	0	0	0.0%
						0			
seagrass	B2	0.0	1	0.0	0	1 of 3	4	4	4.8%
seagrass	C2	3.4	31	0.1	3	1	1	4	47.6%
seagrass	D2	0.5	3	0.1	2	2 of 3	1	20	23.8%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits on which at least one individual was observed on the artificial reef

Table 5.40 - Frequency and Relative Abundance of *Pseudupeneus maculatus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	1	0.3%	0	0.0%	1	0.2%
Artificial Reef -sand/soft coral	A3	0	0.0%	1	1.7%	1	0.5%
Artificial Reef -sparse soft coral	B3	0	0.0%	1	0.5%	1	0.4%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	1	0.4%	0	0.0%	1	0.2%
Artificial Reef -dense seagrass	C2	72	11.2%	3	1.0%	75	8.0%
Artificial Reef -dense seagrass	D2	10	1.9%	2	1.2%	12	1.8%
Natural Reef -soft coral	A	0	0.0%	0	0.0%	0	0.0%
Natural Reef -sparse seagrass	B	0	0.0%	1	0.2%	1	0.1%
Natural Reef -dense seagrass	C	0	0.0%	10	2.4%	10	2.2%
Natural Reef -dense seagrass	D	0	0.0%	6	0.9%	6	0.8%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Gymnothorax moringa

Adult spotted moray were present on an artificial reef surrounded by seagrass (site C2) and one surrounded by sparse soft coral flats (site B3). Both were observed one year after construction of the artificial reefs. Presence of a large predator at such a habitat is of interest for several reasons. An artificial reef fish assemblage is more similar to a natural reef fish assemblage when it includes a top carnivore. In addition, predation by the piscivore may have had an impact on the reef's fish assemblage, although species density and fish density were similar to the other two reefs at each of the two sites.

Gymnothorax vicinus

A purplemouth moray was observed on two occasions, four months apart, on an artificial reef on the sand/rubble flats. Identification of the individual was possible due to a mark on the side of the head. That the purplemouth moray remained in residence for four months suggests a steady food supply. This species was observed consuming small resident fish on artificial reefs in a project by Hixon and Beets (1993). A decline in *Haemulon flavolineatum* from artificial reefs at that site occurred after the arrival of the moray (Figure 5.1); however, the reef inhabited by the moray had no greater decline than other reefs at that site. It is impossible, therefore, to determine if the decline was due to predation by the moray, mortality from other causes, or migration.

POMACANTHIDAE

Angelfishes observed in this study included two morphologically similar genera: *Holacanthus*, with one species represented, and *Pomacanthus*, with two.

Unlike the adults, juvenile pomacanthids are site-attached. In this study juveniles appeared to orient to a single conch shell of the pile comprising an artificial reef.

Holacanthus tricolor

Rock beauty are one of the most striking species of reef fishes because of their bold color pattern. Adults were in video transects on all four natural reef sites, but only one juvenile was observed (Table 5.41). It was present on an artificial reef at site A3 on the last visit to that site (week 54). The juvenile evidently settled directly from plankton based on its size and the proportionate size of the dorsal spot.

Pomacanthus arcuatus

Adult gray angelfish were observed on video transects of natural reef site D and dense soft coral flat F3 (Tables 5.5 and 5.13). Adults at site F3 were observed swimming as a pair. A juvenile was observed on an artificial reef at site H3 (sand/rubble flat). It was present on three consecutive visits that spanned eight months from November to July.

POMACENTRIDAE

Damselfishes of the family Pomacentridae are one of the most evolutionarily successful and well-studied taxonomic groups of reef fishes. At least fifteen of the 250 species worldwide have ranges which include the study area (Randall, 1983). Six of these colonized artificial reefs--*Chromis cyanea*, *Stegastes diencaeus*, *S. dorsopunicans*, *S. leucostictus*, *S. partitus*, and *S. planifrons*--and will be discussed further below. Video transects of natural reefs included these and four additional

Table 5.41 - Frequency and Relative Abundance of *Holacanthus tricolor* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	1	0.7%	0	0.0%	1	0.5%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	1	0.2%	1	0.1%
Natural Reef -sparse seagrass	B	0	0.0%	0.3	< 0.1%	0.3	< 0.1%
Natural Reef -dense seagrass	C	0	0.0%	1	0.2%	1	0.2%
Natural Reef -dense seagrass	D	0	0.0%	1	0.1%	1	0.1%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

species--*Abudefduf saxatilis*, *Chromis multilineatus*, *Microspathodon chrysurus* and *Stegastes variabilis* (Tables 3.2 - 3.5 and 5.1).

Chromis cyanea

Adding a sparkling burst of electric blue above select coral heads or artificial reefs, blue *Chromis* were abundant in the study area. Although blue *Chromis* prefer deeper water habitats (Randall, 1968; Schmitt *et al.*, 1994), highest densities in this study were at the shallowest natural reef (site B) where they comprised over 20% of the recorded fish assemblage. Blue *Chromis* colonized artificial reefs at sites A3, B3, and B2 (Table 5.42). All were adults at first observation, but may have immigrated as juveniles as there were up to four months between visits.

Highest densities on artificial reefs occurred at site B3 which is adjacent to the natural reef with highest *C. cyanea* density, and the minimum number of fish per reef was two. An unusual larval development pattern was described by de Boer (1978) who suggested that newly hatched *C. cyanea* move directly into the reef as planktivores and omit the planktonic stage entirely. Thresher (1984) described *C. cyanea* as having aggregative juveniles that become site-attached only in the presence of conspecifics. The bypass of planktonic stage and tendency to wander until conspecifics are encountered could explain high densities of young adults near a well-established adult population.

Stegastes diencaeus and *S. dorsopunicans*

Stegastes dorsopunicans and *Stegastes diencaeus*, dusky damselfishes, are distinguished by characteristics that are largely useless in the field, unless the two are side-by-side. The anal fin of a mature *S. diencaeus* extends to the caudal

Table 5.42 - Frequency and Relative Abundance of *Chromis cyanea* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	4	6.8%	4	2.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	17	9.2%	17	6.7%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	2	0.7%	2	0.4%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	39	6.4%	39	6.1%
Natural Reef -sparse seagrass	B	0	0.0%	172	27.3%	172	23.6%
Natural Reef -dense seagrass	C	0	0.0%	38	9.1%	38	8.5%
Natural Reef -dense seagrass	D	0	0.0%	44	6.5%	44	5.9%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

extent of the caudal peduncle, and the longest anal ray is 20-25% of total length; by contrast, the anal fin of *S. dorsopunicans* reaches only the middle of the caudal peduncle, and the longest anal ray is only 10-20% of body length. There are habitat differences between these two species; *S. diencaeus* prefers shallow, high energy areas, and *S. dorsopunicans* prefers calmer and deeper areas. This study includes natural reef sites with both habitats types; therefore, adults of these two species were lumped into a single category named *S. dorsopunicans* based on a greater abundance of that species in preliminary surveys of the study area.

Juveniles were distinguishable with survey methods employed based on descriptions by Bohlke and Chaplin (1968). Tables 5.43 and 5.44 summarize recruitment of juveniles to artificial reefs. Juveniles of these two species were not observed on natural reefs. Juveniles of both species colonized artificial reefs surrounded by sand/rubble (sites A3, B3, and D3). *Stegastes diencaeus* colonized prior to the March visit, but *S. dorsopunicans* juveniles colonized prior to the November visit as well as the March visit. March colonization represents a winter spawning which is consistent with reports of year-round reproduction, but is prior to the expected late spring and summer peak in spawning activity (Robertson, 1990).

Table 5.45 summarizes data for juveniles and adults of both species. Adults were recorded on all natural reefs surveyed. However, a significantly higher number of adults were present on natural reef at site B than on other natural reefs; and significantly higher numbers of adults colonized artificial reefs that were surrounded by sparse soft coral (B3) and by sparse grass (B2) at the same general location. Adults were observed on 100% of the artificial reefs at every visit to these two sites. Adults were also observed on artificial reefs at sites C3 and D3

Table 5.43 - Recruitment of Juvenile *Stegastes diencaestu* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.1	1	0.0	0	1 of 3	37	37	7%
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	< 0.1	1	0.0	0	1 of 3	21	21	5%
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.44 - Recruitment of Juvenile *Stegastes dorsopunicans* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.1	1	0.0	0	1 of 3	19	19	7%
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	< 0.1	1	0.0	0	1 of 3	22	22	5%
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.45 - Frequency and Relative Abundance of *Stegastes diencaeus* and *S. dorsopunicans* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	1	1.7%	1	1.2%
Artificial Reef -sand halo	D3	2	5.4%	2	5.0%	4	5.2%
Artificial Reef -sand/rubble	H3	0	0.0%	20	10.8%	20	3.6%
Artificial Reef -sand/soft coral	A3	1	0.7%	0	0.0%	1	0.5%
Artificial Reef -sparse soft coral	B3	1	1.5%	24	13.0%	25	9.9%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	22	7.7%	22	4.2%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	13	2.1%	13	2.0%
Natural Reef -sparse seagrass	B	0.3	0.3%	81	12.9%	81	11.2%
Natural Reef -dense seagrass	C	0	0.0%	20	4.8%	20	4.5%
Natural Reef -dense seagrass	D	0	0.0%	15	2.2%	15	2.0%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

(halo zones). This pattern may be explained by adults moving from a densely populated natural reef habitat to a less competitive environment on an artificial reef.

Stegastes leucostictus

Beaugregory were distinguishable from other brownish damselfishes by the pale to yellowish tail and lack of spot on the peduncle (such a spot is present in *S. variabilis*). Beaugregory are common in sand, grass, and rubble areas and are occasionally seen on reef-tops. The only natural reef on which beaugregory were not recorded during video surveys was site A (Table 5.46). Beaugregory were most common on artificial reefs at sites H3, B3 and B2 in descending order of abundance. These sites share the combined characteristics of shallow water (less than four meters deep) and sand/rubble on a hard substratum (rather than deep sand as in halo zones).

There was no significant difference in the number of juvenile beaugregory on artificial reefs among sites. Juveniles were observed at settlement stage throughout the year which is consistent with reports of year-round spawning (Robertson, 1990) on a lunar cycle (Itzkowitz, 1985).

There was a significant difference among sites regarding number of adults per artificial reef (Table 5.47). It is likely these adults immigrated to artificial reefs from surrounding habitats despite their absence in surveys of those habitats. Shulman (1985a) found that beaugregory colonize randomly with respect to conspecifics but exhibit a negative correlation between population density and change in population size.

Although beaugregory are territorial and defend against egg eaters such as bluehead wrasse (Draud *et al.*, 1990), *Stegastes dorsopunicans* was repeatedly

Table 5.46 - Frequency and Relative Abundance of *Stegastes leucostictus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	2	8.7%	4	6.8%	6	7.3%
Artificial Reef -sand halo	D3	0	0.0%	1	2.5%	1	1.3%
Artificial Reef -sand/rubble	H3	4	1.1%	31	16.8%	35	6.2%
Artificial Reef -sand/soft coral	A3	0	0.0%	2	3.4%	2	1.0%
Artificial Reef -sparse soft coral	B3	4	5.9%	14	7.6%	18	7.1%
Artificial Reef -dense soft coral	F3	1	0.2%	3	1.0%	4	0.6%
Artificial Reef -sparse grass	B2	3	1.3%	31	10.8%	34	6.5%
Artificial Reef -dense seagrass	C2	1	0.2%	1	0.3%	2	0.2%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	0	0.0%	0	0.0%
Natural Reef -sparse seagrass	B	2	2.0%	5	0.8%	7	1.0%
Natural Reef -dense seagrass	C	1	3.3%	3	0.7%	4	0.9%
Natural Reef -dense seagrass	D	2	3.1%	5	0.7%	7	0.9%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.47 - Recruitment of *Stegastes leucostictus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.1	1	0.3	2	3 of 3	1	51	33%
sand halo	D3	0.0	0	0.1	1	1 of 3	19	19	7%
sand/rubble	H3	0.3	3	2.1	7	3 of 3	1	52	80%
sand/soft coral	A3	0.0	0	0.1	1	2 of 3	39	54	10%
soft coral	B3	0.2	1	0.7	2	3 of 3	1	54	52%
soft coral	F3	0.1	1	0.2	1	3 of 3	17	52	27%
seagrass	B2	0.1	1	1.5	2	3 of 3	1	55	95%
seagrass	C2	< 0.1	1	< 0.1	1	2 of 3	2	21	10%
seagrass	D2	0.0	0	0.0	0	0	0	0	0%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

observed chasing smaller *S. leucostictus* from artificial reefs at site H3. It is, therefore, presumed that juvenile beaugregory would have been more abundant at these reefs in the absence of dusky damselfish. In one instance, a single dusky damselfish successfully defended an artificial reef against five small but persistent beaugregory at site H3. It has been suggested that negative associations between these two species may be a result of differing size preferences for shelter sites (Spotte *et al.*, 1992)

Stegastes partitus

Bicolor damselfish adults were recorded on video transects of natural reefs at sites C and D (Table 5.48) and on artificial reefs at sites A3, B3, C2, C3, and F3. Adults were significantly more numerous on artificial reefs at site F3 where individuals established residence within the first month and were present on all subsequent visits (Table 5.49). Juveniles were only observed on artificial reefs at sites C3 and F3.

Stegastes planifrons

Threespot damselfish were recorded at all natural reef sites among which there was no significant difference in their abundances (Tables 3.2 - 3.5). On artificial reefs, threespot damselfish were rare appearing on one reef at sites B2 and B3. A juvenile colonized an artificial reef at site B3 in November, and apparently the same individual remained through the last visit in June at which time it was counted as an adult due to its color change and increased size (Table 5.50).

Threespot damselfish are territorial (Robertson *et al.*, 1981) and Williams (1978) documented that *S. planifrons* competitively excluded dusky damselfish

Table 5.48 - Frequency and Relative Abundance of *Stegastes partitus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	2	8.7%	3	5.1%	5	6.1%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	10	16.9%	10	5.1%
Artificial Reef -sparse soft coral	B3	0	0.0%	1	0.5%	1	0.4%
Artificial Reef -dense soft coral	F3	4	1.0%	39	13.5%	43	6.2%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	2	0.7%	2	0.2%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	0	0.0%	0	0.0%
Natural Reef -sparse seagrass	B	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	C	0	0.0%	6	1.4%	6	1.3%
Natural Reef -dense seagrass	D	0	0.0%	3	0.4%	3	0.4%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.49 - Recruitment of *Stegastes partitus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.1	2	0.2	2	3 of 3	18	51	20%
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.5	2	3 of 3	21	54	33%
soft coral	B3	0.0	0	< 0.1	1	1 of 3	54	54	5%
soft coral	F3	0.3	2	2.6	7	3 of 3	1	52	100%
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.0	0	0.1	1	1 of 3	21	54	10%
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.50 - Recruitment of *Stegastes planifrons* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.1	1	< 0.1	1	1 of 3	22	54	14%
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	< 0.1	1	1 of 3	55	55	5%
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

from preferred habitats. On artificial reefs where *S. planifrons* was observed (Table 5.46); *S. dorsopunicans* were present at the first observation and at later visits. Based on Williams' hypothesis, these data suggest that shelter sites were not limited on the reef at site B3 from week 22 - 54 (November - June).

POMADASYIDAE

Grunt are common in large mixed groups on natural reefs where they shelter by day. At night grunts forage over nearby sand and grass flats for crustaceans and fishes. Pomadasyid eggs are pelagic (Courtenay, 1961) and larvae are among inshore plankton (Smith *et al.*, 1987).

Juveniles of three species were observed on artificial reefs: *Haemulon flavolineatum*, *H. melanurum*, and *H. sciurus*. Adults recorded on natural reefs included *Haemulon album*, *H. carbonarium*, *H. flavolineatum*, *H. parrai*, and *H. sciurus* (Table 5.1).

Haemulon flavolineatum

Adult French grunt were observed at all natural reef sites. However, they were more abundant on reefs with peripheral seagrass, which is most likely related to their feeding habits (Table 5.51). French grunt are among several species that find shelter on coral reefs by day and feed in seagrass meadows nocturnally (Kikuchi and Peres, 1977; Ogden and Ehrlich, 1977). Spotte *et al.* (1992) also reported a positive association of French grunt with sites having seagrass.

The preference of juvenile French grunt for sandy bottoms (Brothers and McFarland, 1981) may explain the exclusive occurrence of juveniles on artificial reefs at site H3 where reefs are surrounded by sand (Table 5.52). Juvenile French

Table 5.51 - Frequency and *Haemulon flavolineatum* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	282	74.8%	7	3.8%	289	51.4%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	4	0.7%	4	0.6%
Natural Reef -sparse seagrass	B	0	0.0%	41	6.5%	41	5.6%
Natural Reef -dense seagrass	C	0	0.0%	45	10.8%	45	10.1%
Natural Reef -dense seagrass	D	0	0.0%	16	2.4%	16	2.2%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.52 - Recruitment of *Haemulon flavolineatum* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	18.7	82	0.5	4	3 of 3	19	52	53%
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

grunt colonized all three artificial reefs in this habitat type. They were first observed at week 19, and some were still present at the last visit (week 52). Individuals observed at weeks 37 and 52 were assumed to be from the week 19 recruits because their size was appropriate for their presumed age.

Shulman (1985a) also found French grunt to be abundant recruits on *Strombus* reefs in the Virgin Islands and suggested that they subsequently migrate to the main reef (natural reef) for diurnal shelter. Declines in populations on artificial reefs may also have been due to emigration to a natural reef; however, predation may also have been a factor.

Haemulon melanurum

Cottonwick were seen only on artificial reefs. Juveniles colonized all three reefs at site H3 as observed at week 37. Small adults were subsequently seen at week 52 and were assumed to be from the week 37 recruits (Table 5.53). A single adult was observed at an artificial reef at site B2 on week 22 and was not seen on subsequent visits.

Haemulon sciurus

Bluestriped grunt were significantly more abundant on natural reef site D than other natural reefs. Juveniles were observed only on artificial reefs at site D2 (Table 5.54). Based on the proximity of seagrass at site D2 to natural reef D, this data suggests seagrass at site D2 is a nursery for the adult population at site D2.

Juvenile bluestriped grunt were first observed in a large tight school of newly settled postlarvae at a single artificial reef on week 20 (November). They were fewer in number and progressively larger at the March and June visits. In

Table 5.53 - Recruitment of *Haemulon melanurum* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.0	0	0.0	0	0	0	0	0
sand/rubble	H3	0.4	3	0.1	1	3 of 3	37	52	27%
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	< 0.1	1	1 of 3	22	22	5%
seagrass	C2	0.0	0	0.0	0	0	0	0	0
seagrass	D2	0.0	0	0.0	0	0	0	0	0

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.54 - Frequency and Relative Abundance of *Haemulon sciurus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	112	21.8%	0	0.0%	112	16.4%
Natural Reef -soft coral	A	0	0.0%	5	0.8%	5	0.8%
Natural Reef -sparse seagrass	B	0	0.0%	5	0.8%	5	0.7%
Natural Reef -dense seagrass	C	0	0.0%	17	4.1%	17	3.8%
Natural Reef -dense seagrass	D	0	0.0%	158	23.4%	158	21.3%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

addition, small adults were seen on two of the three artificial reefs in June. As they mature, grunt increase their nocturnal foraging range; therefore, by June some may have encountered the other artificial reef and began using it as their diurnal shelter. Decline of the juvenile population on a small artificial reef was expected since grunts move from shelter in seagrass to natural reefs as they mature (Ogden and Zieman, 1977).

SCARIDAE

Parrotfishes, like wrasses, are protogynous hermaphrodites and display different color patterns with each life stage. Parrotfishes form mixed species feeding aggregations which further complicates field identification. Species observed in this study included *Scarus coelestinus*, *S. iserti*, *S. taeniopterus*, *S. vetula*, *Sparisoma rubripinne*, *S. aurofrenatum*, *S. chrysopteron*, and *S. viride*.

Juveniles of two groups of species are so similar to one another that field identification is often impossible. These groups are characterized by either a striped juvenile or a solid gray juvenile. Striped juvenile stages are present in four species of parrotfishes: *Scarus iserti*, *S. guacamaia*, *S. vetula*, and *Sparisoma taeniopterus*. However, since adult *S. guacamaia* were not observed at the study site, this species was not considered in the following discussion. Juveniles of *Scarus iserti*, *S. vetula*, and *S. taeniopterus* were considered as a group and are referred to as striped juvenile scarids. Juveniles of *Sparisoma chrysopteron* and *S. rubripinne* comprised another group called gray juvenile scarids. Juvenile *Sparisoma aurofrenatum*, *S. radians*, and *S. viride* were identifiable and are included with adult accounts.

Striped juvenile scarids

Striped juvenile parrotfishes were most abundant on artificial (sites B2, C2, D2) and natural reefs surrounded by seagrasses (sites C and D) (Table 5.55). In Table 5.56, the pattern of abundance as linked to presence of nearby seagrass is also apparent in the percentage of visits and percentage of reefs per site with juvenile striped parrotfishes.

Parrotfishes are herbivorous throughout their life cycle and often form feeding aggregations, but such groups are usually segregated by size. Smallest striped juveniles were observed in groups on artificial reefs surrounded by seagrasses and in seagrass meadows. Groups of striped parrotfish juveniles observed on natural reefs were always greater than 10 cm in length and were likely in transition to adulthood.

Scarus iserti

Striped parrotfish have an ontogenetic sequence of social units which includes stationary groups, roving groups, and territorial groups (Warner and Downs, 1977). However, in this study, striped parrotfish were observed singly or paired. Adult striped parrotfish have a pattern of abundance that reiterates the striped juvenile parrotfish on a smaller scale (Table 5.57). Adults were most abundant on natural and artificial reefs surrounded by dense seagrasses (sites C, D, C2, D2).

Scarus vetula and *Scarus taeniopterus*

Queen parrotfish (*Scarus vetula*) and princess parrotfish (*S. taeniopterus*) were observed as adults on natural reefs with no apparent pattern among the four

Table 5.55 - Frequency and Relative Abundance of Striped Juvenile Scarids on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	3	13.0%	0	0.0%	3	3.7%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	2	1.5%	0	0.0%	2	1.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	2	0.5%	0	0.0%	2	0.3%
Artificial Reef -sparse grass	B2	40	16.8%	0	0.0%	40	7.6%
Artificial Reef -dense seagrass	C2	129	20.1%	8	2.7%	137	14.7%
Artificial Reef -dense seagrass	D2	75	14.6%	8	4.7%	83	12.1%
Natural Reef -soft coral	A	0.6	2.2%	0	0.0%	0.6	0.1%
Natural Reef -sparse seagrass	B	17	17.3%	0	0.0%	17	2.3%
Natural Reef -dense seagrass	C	16	53.3%	0	0.0%	16	3.6%
Natural Reef -dense seagrass	D	20	30.8%	0	0.0%	20	2.7%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.56 - Recruitment of Striped Juvenile Scarids to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.2	1	0.0	0	2 of 3	18	36	20%
sand halo	D3	0.0	0	0.0	0	0	0	0	0%
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0%
sand/soft coral	A3	0.1	1	0.0	0	2 of 3	2	21	10%
soft coral	B3	0.0	0	0.0	0	0	0	0	0%
soft coral	F3	0.1	2	0.0	0	1 of 3	17	17	7%
seagrass	B2	1.9	8	0.0	0	3 of 3	1	39	48%
seagrass	C2	4.8	14	0.0	0	3 of 3	1	54	76%
seagrass	D2	3.6	12	0.0	0	3 of 3	1	54	90%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.57 - Frequency and Relative Abundance of *Scarus iserti* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	1	0.5%	1	0.4%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	0	0.0%	0	0.0%
Natural Reef -sparse seagrass	B	0	0.0%	1	0.2%	1	0.1%
Natural Reef -dense seagrass	C	0	0.0%	5	1.2%	5	1.1%
Natural Reef -dense seagrass	D	0	0.0%	3	0.4%	3	0.4%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

natural reefs surveyed. Adults of these two species were not observed on artificial reefs. Data on relative abundances appear in Tables 3.2 - 3.5.

Sparisoma aurofrenatum

Adult redband parrotfish were observed on all natural reefs in approximately similar abundances (Table 5.58). Although redband parrotfish are territorial as young females and reproductive males (Shapiro, 1991), no territorial behavior was observed in this study. Juvenile redband parrotfish were observed on artificial reefs at sites B2 and B3 in spring and summer.

Gray juvenile scarids

Data collected on gray juvenile parrotfishes, summarized in Tables 5.59 and 5.60, include *Sparisoma chrysopterum* and/or *S. rubripinne*. These juveniles were observed in small numbers at a variety of sites and were present throughout the year. Natural reef at site B and adjacent seagrasses (site B2) had greater abundances than other sites. Gray juvenile parrotfishes observed at these sites were in large feeding groups. Sizes of fishes were similar between the natural reef and artificial reefs. In one instance, a large feeding group was observed to move from an artificial reef in seagrass meadow B2 to the natural reef (site B). Site B and its adjacent seagrass may be a nursery for adults of these species which live on more extensive reefs in deeper water.

Sparisoma chrysopterum and *S. rubripinne*

Large adult redband parrotfish (*S. chrysopterum*) were recorded on natural reefs at sites C and D; and large adult redband parrotfish (*S. rubripinne*) were recorded

Table 5.58 - Frequency and Relative Abundance of *Scarus aurofrenatum* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	2	2.9%	0	0.0%	2	0.8%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	2	0.8%	0	0.0%	2	0.4%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	1	0.6%	1	0.1%
Natural Reef -soft coral	A	0	0.0%	3	0.5%	3	0.5%
Natural Reef -sparse seagrass	B	0	0.0%	6	1.0%	6	0.8%
Natural Reef -dense seagrass	C	0	0.0%	6	1.4%	6	1.3%
Natural Reef -dense seagrass	D	0	0.0%	3	0.4%	3	0.4%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.59 - Recruitment of Gray Juvenile Scarids to artificial reefs in nine habitats off South Caicos

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0%
sand halo	D3	0.1	1	0.0	0	1 of 3	37	37	7%
sand /rubble	H3	0.3	4	0.0	0	2 of 3	37	37	13%
soft coral	B3	0.0	0	0.0	0	0	0	0	0%
sand/soft coral	A3	0.0	1	0.0	0	1 of 3	2	2	5%
soft coral	F3	0.2	2	0.0	0	1 of 3	17	17	13%
seagrass	B2	3.0	12	0.0	0	3 of 3	1	39	67%
seagrass	C2	0.9	12	0.0	0	2 of 3	2	2	10%
seagrass	D2	0.1	2	0.0	0	1 of 3	4	4	5%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits on which at least one individual was observed on the artificial reef

Table 5.60 - Frequency and Relative Abundance of Gray Juvenile Scarids on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	1	2.7%	0	0.0%	1	1.3%
Artificial Reef -sand/rubble	H3	5	1.3%	0	0.0%	5	0.9%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	1	1.5%	0	0.0%	1	0.4%
Artificial Reef -dense soft coral	F3	3	0.7%	0	0.0%	3	0.4%
Artificial Reef -sparse grass	B2	64	26.9%	0	0.0%	64	12.2%
Artificial Reef -dense seagrass	C2	19	3.0%	0	0.0%	19	2.0%
Artificial Reef -dense seagrass	D2	2	0.4%	0	0.0%	2	0.3%
Natural Reef -soft coral	A	0	0.0%	0	0.0%	0	0.0%
Natural Reef -sparse seagrass	B	51	52.0%	0	0.0%	51	7.0%
Natural Reef -dense seagrass	C	2	6.7%	0	0.0%	2	0.4%
Natural Reef -dense seagrass	D	3	4.6%	0	0.0%	3	0.4%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

on natural reefs at sites A, C, and D (Tables 5.61 and 5.62). Redfin adults were not recorded on artificial reefs, but small adult redbtail parrotfish were recorded on artificial reefs at several different sites (F3, B2, and D2) and a single large adult was found on an artificial reef at site D2.

Site D2, in dense seagrasses, is also the location that a feeding aggregation of large redbtail and redfin parrotfishes was observed on several occasions but never recorded on a transect. The mixed feeding aggregation frequented the seagrass meadow at site D2 and moved slowly through it without apparent direction. This observation and the pattern of abundance of redbtail and redfin parrotfishes on natural reefs with adjacent seagrasses is consistent with these species preference for shallow areas of coral rubble and seagrass (Baelde, 1990).

Sparisoma radians

Bucktooth parrotfish were not observed on natural reefs and were significantly more abundant on artificial reefs at sites with seagrass (Table 5.63). Although bucktooth parrotfish prefer seagrass habitats (Randall, 1965; Targett *et al.*, 1986), they were observed in small numbers on all artificial reefs at site F3 where the surrounding habitat is dense soft coral. Juvenile bucktooth parrotfish were only seen on artificial reefs at seagrass sites (B2, C2, D2); and were observed throughout the year. Numerous studies have been cited by Thresher (1984) that describe year-round spawning in most of the Caribbean parrotfishes.

Sparisoma viride

Adult stoplight parrotfish were observed only on natural reefs and were most abundant on reefs with adjacent seagrass - sites B, C, and D (Table 5.64). Spotte

Table 5.61 - Frequency and *Sparisoma chrysopterum* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	2	0.7%	2	0.3%
Artificial Reef -sparse grass	B2	0	0.0%	11	3.8%	11	2.1%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	2	1.2%	2	0.3%
Natural Reef -soft coral	A	0	0.0%	0	0.0%	0	0.0%
Natural Reef -sparse seagrass	B	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	C	0	0.0%	1	0.2%	1	0.2%
Natural Reef -dense seagrass	D	0	0.0%	1	0.1%	1	0.1%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.62 - Frequency and *Sparisoma rubripinne* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	1	0.2%	1	0.1%
Natural Reef -sparse seagrass	B	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	C	0	0.0%	1	0.2%	1	0.1%
Natural Reef -dense seagrass	D	0	0.0%	3	0.4%	3	0.5%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.63 - Recruitment of *Sparisoma radians* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.1	1	1 of 3	36	36	7%
sand halo	D3	0.0	0	0.0	0	0	0	0	0%
sand/rubble	H3	0.0	0	0.1	1	1 of 3	1	1	7%
sand/soft coral	A3	0.0	0	0.1	2	1 of 3	4	21	10%
soft coral	B3	0.0	0	0.0	0	0	0	0	0%
soft coral	F3	0.0	0	1.3	4	3 of 3	1	52	53%
seagrass	B2	0.1	1	2.2	7	3 of 3	1	55	81%
seagrass	C2	0.5	2	5.4	16	3 of 3	1	39	86%
seagrass	D2	0.2	3	2.3	10	3 of 3	1	52	38%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Table 5.64 - Frequency and *Sparisoma viride* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total	Relative	Total	Relative	Total	Relative
		Observed	Abund.	Observed	Abund.	Observed	Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	3	0.8%	0	0.0%	3	0.5%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	1	1.5%	0	0.0%	1	0.4%
Artificial Reef -dense soft coral	F3	1	0.2%	0	0.0%	1	0.1%
Artificial Reef -sparse grass	B2	13	5.5%	0	0.0%	13	2.5%
Artificial Reef -dense seagrass	C2	4	0.6%	0	0.0%	4	0.4%
Artificial Reef -dense seagrass	D2	20	3.9%	0	0.0%	20	2.9%
Natural Reef -soft coral	A	1	3.7%	2	0.3%	3	0.5%
Natural Reef -sparse seagrass	B	5	5.1%	4	0.6%	9	1.2%
Natural Reef -dense seagrass	C	0	0.0%	7	1.7%	7	1.6%
Natural Reef -dense seagrass	D	0	0.0%	7	1.0%	7	0.9%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

et al. (1992) also found a significant correlation between abundance of stoplight parrotfish and sites having seagrass. Although Koltes (1993) reported schools of adults at Grand Turk (TCI), adults off South Caicos were observed as solitary individuals or in pairs.

Juveniles were recorded on artificial and natural reefs, but were most abundant on natural reefs with sparse grass adjacent to it (site B2) and on artificial reefs with surrounding seagrass (sites B2 and D2). Juvenile stoplight parrotfish were significantly more numerous on natural reef B than other natural reefs comprising 9% of the juvenile fishes recorded at that site. Juvenile stoplight parrotfish were observed throughout the year (Table 5.65). The size at recruitment (< 10 mm) indicated direct settlement onto artificial reefs. Juveniles were observed on artificial reefs on consecutive visits. Unlike gray and striped parrotfishes, stoplight juveniles were not observed on artificial reefs beyond a size of 30 mm. Larger juveniles were seen only on natural reefs. In this species, initial settlement of postlarvae may be to seagrass or rubble such as conch middens; shallow coral reefs may serve as a secondary nursery before adults move to more extensive reefs in deeper water.

SCIAENIDAE

Jackknife fish of the genus *Equetus* in the drum family are spectacular reef predators that are not common and are often overlooked since they are nocturnal and hover in sheltered, dark areas by day. This characteristic makes them unlikely to be captured on video transect even if they were present on a natural reef.

Juveniles on artificial reefs were the only representatives of this family recorded in this study. However, several adult spotted drum and an adult highhat

Table 5.65 - Recruitment of *Sparisoma viride* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0%
sand halo	D3	0.0	0	0.0	0	0	0	0	0%
sand/rubble	H3	0.2	1	0.0	0	2 of 3	19	37	13%
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0%
soft coral	B3	< 0.1	1	0.0	0	1 of 3	22	22	5%
soft coral	F3	0.1	1	0.0	0	1 of 3	17	17	7%
seagrass	B2	0.6	2	0.0	0	3 of 3	1	55	38%
seagrass	C2	0.2	1	0.0	0	2 of 3	3	21	14%
seagrass	D2	1.0	4	0.0	0	3 of 3	1	54	57%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

were observed on natural reefs near site D. Newly settled juveniles appear as tiny black dots with four streaming, black and white fins many times the length of the body. Accurate identification of newly settled juveniles was difficult due to the similarity of the three local species and due to the behavior of juveniles, in that they remain deep within the shelter of the shells of the artificial reef. For these reasons juveniles of *Equetus acuminatus*, *E. lanceolatus*, and *E. punctatus* are considered as a group.

Equetus spp.

Juveniles of the genus *Equetus* were observed on all artificial reefs at site D2 where seagrass is dense. Newly settled postlarvae were observed in summer, fall, and spring. Based on sizes of fishes at consecutive visits, juveniles remained on artificial reefs up to four months before moving to a coral reef or being lost to disease or predation. A total of seven separate recruitment events occurred with as many as three juveniles present simultaneously on the same artificial reef. No other adults nor juveniles were recorded in this study on natural or artificial reefs.

SERRANIDAE

Groupers and hinds are considered one of the most important reef fish families due to their role as piscivorous predators. This portion of the family is also valuable to reef fisheries and are taken by spear, hook and line, and trap off South Caicos. Other serranids such as the harlequin bass and chalk bass are economically important to the aquarium trade. In addition, their presence on the reef enhances species diversity and thereby the value of a reef for sport diving and ecotourism. Species of serranids observed in this study included *Cephalopholis cruentata*, *C.*

fulvus, *Epinephelus guttatus*, *E. striatus*, *Mycteroperca bonaci* and *Serranus tigrinus*.

Cephalopholis fulvus

Coney are very common predatory seabass which prefer coral reef habitat and are unusually gregarious compared to other serranids. Adult coney were seen on all natural reef sites, but were recorded on video transects at only three (sites A, B, and D). Abundance was highest at site D where dense seagrasses are adjacent to the reef (Table 5.66).

Data summarized in Table 5.67 display a pattern of summer recruitment of juvenile coney to artificial reefs surrounded by sand with soft coral or deep sand including 100% of reefs (6 of 6) in halo zones. Coney did not colonize any artificial reefs surrounded by seagrass. Apparently, this pattern was not related to abundance of prey on the artificial reefs since density of small fishes was highest on those artificial reefs without coney. Therefore, habitat selectivity was the most likely explanation for the pattern observed. Absence of recruits from reefs at sites B3 and H3 which have bottom types similar to F3 may be explained by water depth because sites B3 and H3 are the most shallow sand-bottomed sites.

Early summer recruitment of juveniles is consistent with reports of spring spawning by Thompson and Munro (1978) and up to a 40-day planktonic larval stage (Thresher, 1984). Thresher (1984) also reports newly settled individuals in sizes from 20 to 35 mm. Juvenile recruits on artificial reefs were at the high end of that scale with initial sizes from 30 to 50 mm. At the time of their initial recruitment, reefs were visited weekly; therefore initial sizes represent a maximum of seven days of growth after recruitment.

Table 5.66 - Frequency and *Cephalopholis fulvus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	3	13.0%	4	6.8%	7	8.5%
Artificial Reef -sand halo	D3	6	16.2%	5	12.5%	11	14.3%
Artificial Reef -sand/rubble	H3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/soft coral	A3	3	2.2%	1	1.7%	4	2.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	6	1.5%	2	0.7%	8	1.2%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	0.6	0.1%	0.6	0.1%
Natural Reef -sparse seagrass	B	0	0.0%	1	0.2%	1	0.1%
Natural Reef -dense seagrass	C	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	D	0	0.0%	13	1.9%	13	1.8%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.67 - Recruitment of *Cephalopholis fulvus* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.2	1	0.3	2	3 of 3	2	51	40%
sand halo	D3	0.4	1	0.3	1	3 of 3	1	52	73%
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0%
sand/soft coral	A3	0.1	1	0.1	1	3 of 3	3	54	24%
soft coral	B3	0.0	0	0.0	0	0	0	0	0%
soft coral	F3	0.4	2	0.1	1	3 of 3	1	52	47%
seagrass	B2	0.0	0	0.0	0	0	0	0	0%
seagrass	C2	0.0	0	0.0	0	0	0	0	0%
seagrass	D2	0.0	0	0.0	0	0	0	0	0%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

Adult coney were small and were observed on artificial reefs only at sites where juveniles had been observed previously. Based on body size changes and consistency of observation, coney apparently settled onto an artificial reef and remained site attached through early adult life. All artificial reefs on which juveniles were found by spring, still had resident coney at the last visit in June. Further research would be necessary to determine if the adults remained site attached into their sexual maturity since most require three to five years of development to attain maturity (Nagelkerken, 1979).

Epinephelus guttatus

Two adult red hind were observed on a single occasion at an artificial reef at site D2. This pattern may have resulted from adults utilizing artificial reefs as temporary shelters or as feeding sites because of concentrated prey.

Epinephelus striatus

Nassau grouper are important as a food fish for islanders and as an export product that is sold as frozen fillets and steaks. Although many aspects of the biology of this species are fairly well understood (Randall, 1963; Randall, 1967; Smith, 1972; Parrish, 1987; Ralston, 1987), little is known about their early life history (Grover, 1993; Tucker *et al.*, 1993). Juvenile Nassau grouper were only observed on artificial reefs at site H3. These individuals were apparently several weeks post-settlement in size (80 - 100 mm) when first observed in June. This suggest early spring spawning which is consistent with reports that indicate Nassau grouper spawning seasons are progressively later in the year with more distance from the equator--December through March near Grand Cayman (Powell and

Tucker, 1992), January through April near Jamaica (Thompson and Munro, 1983), May through August near Bermuda (Smith, 1971).

Adults were recorded only on natural reef site D and on artificial reefs at sites D2 and D3 (Table 5.68). The proximity of these observations indicates a pattern of abundance higher in this area associated with an extensive dense seagrass meadow. An association of adult Nassau grouper with sites having seagrass has previously been reported by Spotte *et al.* (1992), and Heck and Weinstein (1989) documented the use of seagrass meadows as nurseries for juvenile Nassau groupers near Panama.

Serranus tigrinus

A single adult harlequin bass was present on an artificial reef at site B3 in March and was still present at the June observation. It was most likely a recruit from the assemblage of the surrounding soft coral flat. This record and data on recruitment of other adult serranids and pomacentrids to artificial reefs supports Alevizon and Gorham's (1989) suggestion that artificial reefs redistribute local fish by aggregating them at the artificial structure. No other harlequin bass were observed at study sites.

SPHYRAENIDAE

Sphyraena barracuda

Barracuda were observed regularly at all natural reef sites but were recorded on video transects only at sites A and B (Table 5.69). Although this likely indicates a greater abundance at those sites, it should also be noted that barracuda behavior usually prevents their presence on the video record. Barracuda tend to swim high

Table 5.68 - Frequency and *Epinephelus striatus* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	1	2.5%	1	1.3%
Artificial Reef -sand/rubble	H3	2	0.5%	0	0.0%	2	0.4%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse grass	B2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	C2	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense seagrass	D2	0	0.0%	3	1.8%	3	0.4%
Natural Reef -soft coral	A	0	0.0%	0	0.0%	0	0.0%
Natural Reef -sparse seagrass	B	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	C	0	0.0%	0	0.0%	0	0.0%
Natural Reef -dense seagrass	D	0	0.0%	4	0.6%	4	0.5%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

Table 5.69 - Frequency and *Sphyraena barracuda* on Artificial and Natural Reefs

Habitat Description	Site	JUVENILES		ADULTS		ALL	
		Total Observed	Relative Abund.	Total Observed	Relative Abund.	Total Observed	Relative Abund.
Artificial Reef -sand halo	C3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand halo	D3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sand/rubble	H3	0	0.0%	1	0.5%	1	0.2%
Artificial Reef -sand/soft coral	A3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -sparse soft coral	B3	0	0.0%	0	0.0%	0	0.0%
Artificial Reef -dense soft coral	F3	0	0.0%	1	0.3%	1	0.1%
Artificial Reef -sparse grass	B2	0	0.0%	2	0.7%	2	0.4%
Artificial Reef -dense seagrass	C2	0	0.0%	2	0.7%	2	0.2%
Artificial Reef -dense seagrass	D2	0	0.0%	0	0.0%	0	0.0%
Natural Reef -soft coral	A	0	0.0%	1	0.2%	1	0.2%
Natural Reef -sparse seagrass	B	0	0.0%	0.3	0.0%	0.3	< 0.1%
Natural Reef -dense seagrass	C	0	0.0%	0.3	0.1%	0.3	< 0.1%
Natural Reef -dense seagrass	D	0	0.0%	0	0.0%	0	0.0%

Total Observed = number per year

Relative Abundance = abundance of a species relative to abundance of all fishes at a given habitat

in the water column out of vertical field of the camera. Once they are aware of a diver, barracuda often remain to the side of the divers path. Barracuda were also observed at artificial reefs where they were sometimes observed feeding on small resident fishes, but were more often hovering just above the artificial reef. They were only recorded on artificial reefs when they remained within one meter of reef throughout 5 minutes of observation.

TETRAODONTIDAE

Canthigaster rostrata

Sharpnose puffers were recorded only on natural reef site C and juveniles colonized artificial reefs at several sites (Table 5.70). Juveniles were observed on most artificial reefs (83%) surrounded by dense seagrass (sites C2 and D2) and on the artificial reef at site D3 which was closest to dense seagrass habitat (< 3 meters). Sharpnose puffer are known to frequent seagrass habitat and have been observed to nibble on grass blades (Thresher, 1980), therefore their presence on artificial reefs at seagrass sites is not surprising. It is noteworthy, however, that they colonized artificial reefs directly from their planktonic stage based on their minute size at first observation. In some cases juveniles were observed on consecutive visits for up to three weeks, but there was no evidence for site attachment into adulthood. In fact, none were observed beyond juvenile size on artificial reefs. They may have utilized the shelter of the artificial reef until they attained adequate size to survive among seagrasses or on the natural reef.

Table 5.70 - Recruitment of *Canthigaster rostrata* to Artificial Reefs at Nine Sites

Habitat	Site	Mean Jv/Reef	Maximum Jv/ Reef	Mean Adlt/Rf	Maximum Adlt/Rf	# of Reefs*	First Obs (week #)	Last Obs (week #)	% Visits**
sand halo	C3	0.0	0	0.0	0	0	0	0	0
sand halo	D3	0.3	2	0.0	0	1 of 3	1	19	40%
sand/rubble	H3	0.0	0	0.0	0	0	0	0	0
sand/soft coral	A3	0.0	0	0.0	0	0	0	0	0
soft coral	B3	0.0	0	0.0	0	0	0	0	0
soft coral	F3	0.0	0	0.0	0	0	0	0	0
seagrass	B2	0.0	0	0.0	0	0	0	0	0
seagrass	C2	0.2	2	0.0	0	2 of 3	4	54	14%
seagrass	D2	0.3	2	0.0	0	3 of 3	1	39	29%

* # Reefs - number of reefs with at least one individual on one occasion

** % Visits - percentage of visits at which at least one individual was observed on the artificial reef

CHAPTER 6. PATTERNS AND PROCESSES

PATTERNS

The central question of this project was: *Do characteristics of reef fish assemblages differ relative to the presence of seagrass adjacent to the coral reef?* Data described in previous chapters provide evidence that the answer to this question is--yes, some characteristics of reef fish assemblages varied relative to the type of habitat adjacent to the coral reef. In addition, data demonstrated that peripheral habitats such as seagrass meadows were important in primary and secondary recruitment and in post-settlement processes.

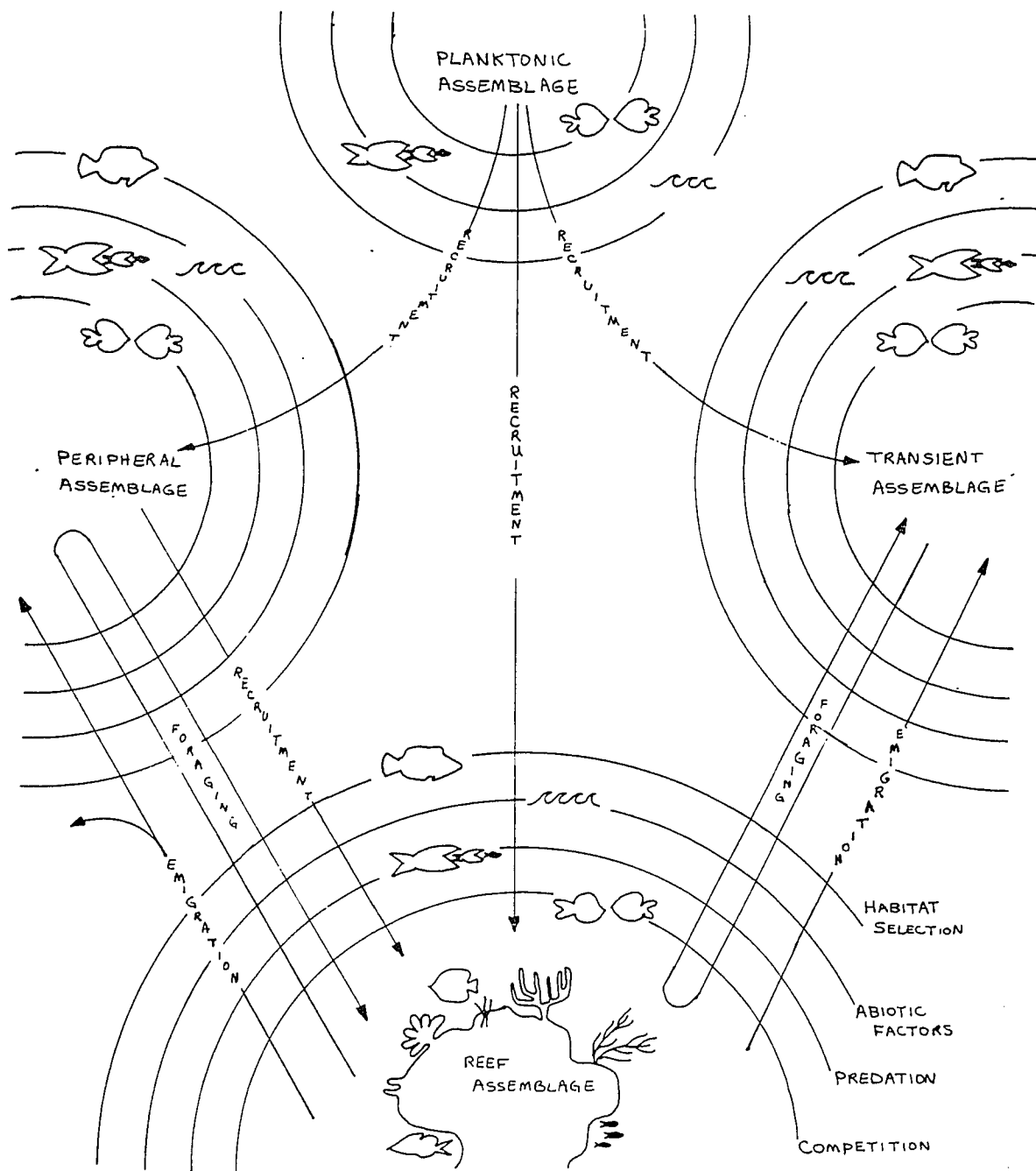
Surveys of natural reefs provided comparative information on characteristics of reef fish assemblages in the study area (chapter 3). Fish assemblages on reefs surrounded by dense seagrass included larger fish at higher densities and with more snappers and grunts than reefs with sparse grass or no seagrass peripherally. Damselfishes were proportionately higher in fish assemblages at reefs without seagrass. Experimental use of artificial reefs provided sites in modular form for comparison of fish assemblages with fixed peripheral habitats and with repetition (Chapter 4). Artificial reefs surrounded by dense seagrass had highest densities of juveniles, fishes, and species.

PROCESSES AND PROXIMAL CAUSES

Conceptualization of influences on structure of reef fish assemblages (Figure 6.1) is derived from Smith's (1978) depiction of screens, which filter potential recruits from regional fauna. This project emphasized effects of resources and recruits from peripheral communities on reef fish assemblages (Figure 6.1).

Figure 6.1

Conceptualization of processes affecting reef fish community structure



Peripheral communities such as seagrass meadows or soft coral flats also have selectively permeable screens which affect community composition and emigration of potential recruits or transients to adjacent reefs. Screens reflect stochastic and deterministic mechanisms affecting structure of fish assemblages. In this project no distinction was made between residents and transients on natural or artificial reefs because transients are an integral component of the fish assemblage.

Piscivorous transients, such as *Sphyraena barracuda* and carangids, increase predation pressure. Competition is heightened by herbivorous visitors such as large schools of foraging acanthurids. Transients add to the nutrient load of the reef by defecation as well as by frequenting cleaner stations and, on occasion, by becoming prey to reef predators.

Results of this study indicate that Hixon's (1991) pluralistic perspective toward determinants of reef fish community structure provides more information than hypotheses based on a single process. Patterns such as those observed in this study are interpreted as results of 1. random settlement, 2. recruit availability, 3. postlarval habitat selection during or after settlement, and/or 4. other postsettlement processes.

Random settlement is rejected as a generalized explanation of the data based on the mere presence of repeated patterns. That characteristics of fish assemblages were repeated among artificial reefs with similar peripheral habitats, within and among sites, is evidence of non-random causal process.

Recruit availability is controlled by reproduction and by dispersal, survival, and consequent distribution of eggs, larvae, and juveniles. Reproductive rates were not significant to local community structure in this study for several reasons. High fecundity of marine fishes, apparently extensive dispersal of reef fish larvae, extent

of reef habitat, and poor stock-recruitment relationships suggest that reproductive output of parental populations is insignificant to local distribution of fishes (Williams, 1991).

Planktonic larval distribution is often not directly proportional to local reproductive rates. Typical lengths of larval stages of reef fishes are approximately three weeks to three months (Thresher, 1984), which are times sufficient for larvae to be moved between islands by currents. Larval movement between reefs within island groups was suggested by Williams, *et al.* (1984). Adults of few species of shallow-water reef fish are likely to move between reefs separated by kilometers or by depths greater than 100 meters. Hence, availability of recruits from planktonic larvae are more likely influenced by reproductive rates of distant populations.

The notion that larval mortality is a major determinant of year class strength has been a part of fisheries theory since before the turn of the century. During the planktonic larval stage, major portions of a fish fauna share prey, predator, and abiotic variables (Moser, 1984). Since species from all depths and habitats supply larvae to surface waters, nowhere else in the life histories of these species is there so great a potential for interaction.

Virtually unstudied interactions, such as competition and selective predation during planktonic stages, must alter plankton communities. Several mechanisms that are non-deterministic also affect the planktonic fish assemblage, including patchy distribution of food, indiscriminate predation, and abiotic factors such as temperature and currents. These factors may impact a wide diversity of species simultaneously.

That recruit availability affects recruitment to natural reefs is undeniable, and the degree of this effect is species specific. Species whose habitat requirements

were met by artificial reefs but were not observed as juveniles during this study, or were observed rarely, may have had limited numbers in the plankton; examples include pomacanthids and chaetodontids. Limited recruit availability is indicated for species that were observed on only one or two artificial reefs of the three in each grouping.

For other species observed in this study, however, larval recruit availability was not limiting. If larval distribution in the plankton had strong effects on recruitment, similarities would exist among artificial reefs within the same vicinity irrespective of surrounding habitat type. However, this was not the case, recruitment patterns were repeated among artificial reefs with similar habitat types at differing sites and were therefore not attributable to recruit availability from plankton. This may relate to recruit availability from surrounding habitats.

Recruit availability for coral reef fish assemblages also is affected by juvenile abundance in nursery habitats. In some species, two or more recruitment episodes occur. For reef fishes which utilize peripheral habitats such as seagrass meadows as nurseries, settlement into seagrass from plankton is the first, or primary, recruitment and migration from seagrass to reef is a secondary recruitment. Therefore, recruit availability for the reef assemblage may be limited by proximity and extent of nursery habitat. Species with recruitment patterns that suggest such an effect include *Pseudupeneus maculatus*, *Aulostomus maculatus*, and *Acanthurus bahianus*.

Postlarval habitat selection can occur during either direct settlement from plankton or recruitment from a habitat immediately adjacent to artificial reefs. Since each artificial reef was surrounded by a single habitat type, the community of origin was limited to two, plankton or the peripheral habitat. Peripheral habitats

varied among artificial reefs and included sand flats, sand and rubble flats, soft coral flats, or seagrass meadows. Recruitment to an artificial reef from a peripheral habitat may have represented acquisition of shelter within an adult habitat or transition from a nursery to an adult or intermediate habitat. A distinction between these is discerned by knowledge of preferred adult habitat. Artificial reefs served as shelter within adult habitat for species such as *Sparisoma radians* in seagrass meadows and *Stegastes dorsopunicans* on sand and soft coral flats.

For other species, artificial reefs provided a facsimile of an adult habitat and their presence represented recruitment from a nursery. For example, striped scarid juveniles of *Scarus iserti*, *Scarus taeniopterus* or *Scarus vetula*, and juveniles of *Pseudopeneus maculatus* were residents of seagrass meadows and would eventually seek a natural reef as adult habitat. Behavior repertoires of most juveniles include shelter-seeking strategies whether they utilize a nursery habitat or recruit directly to adult habitat from plankton. In some species, shelter-seeking behavior is an important causal mechanism for movement from nursery to adult habitat.

Shulman (1985b) postulated that if coral reef species recruit to seagrass beds, it is only for very short periods (days to weeks). The advantage to minimal nursery residence time would be maximization of shelter and minimization of predation during the vulnerable postlarval period. However, some juveniles that recruited to artificial reefs surrounded by dense seagrasses were of a size that suggested a lengthy seagrass residence; e.g., *Aulostomus maculatus* and *Pseudopeneus maculatus*. Larger size at recruitment and longer residency of some species, such as holocentrids and lutjanids, is consistent with results of Ogden and Zieman (1977), who found that some coral reef species (e.g., *Holocentrus rufus*,

Ocyurus chrysurus, and *Diodon holacanthus*) recruit to seagrass beds and spend most of their juvenile stage there prior to recruitment to reef habitat.

Some species are thought to recruit directly onto reefs from the plankton and remain within the reef habitat for their entire postsettlement life cycle. These fishes include scarids, acanthurids, chaetodontids, pomacanthids, and many labrids and pomacentrids (Choat and Bellwood, 1991). For species such as these, recruitment to artificial reefs represents termination of the planktonic stage and selection of a habitat for their adult lives. After analysis of results of this study, some species of these groups appear to rely on habitats peripheral to coral reefs as nurseries; e.g., *Acanthurus bahianus* settled in schools on artificial reefs in seagrass.

Fishes observed on artificial reefs that were believed to have recruited directly from plankton due to their size at first observation include *Acanthurus bahianus* and *Sparisoma viride* at seagrass sites and *Haemulon flavolineatum* and *Stegastes leucostictus* on sand and soft coral flats. Since larval distribution has been ruled out as the cause of settlement patterns, these species evidently had some degree of habitat selection in the settlement process based on the consistency of their appearance on artificial reefs surrounded by a specific habitat type. Patterns of distribution on artificial reefs of these species may reveal preferences for reefs with specific peripheral habitats.

Others have examined influence of habitat structure and complexity on community structure of reef fishes, both on natural reefs (Gladfelter and Gladfelter, 1978; Luckhurst and Luckhurst, 1978) and artificial reefs (Alevizon and Gorham, 1989). Extent of habitat selectivity during settlement of planktonic larvae is unknown. Larvae may be competent to settle for some time before they leave the

plankton (Leis, 1991). Length of this time period undoubtedly differs among taxa. Chaetodontids have flexibility in duration of their pelagic stage (Leis, 1989; Victor, 1986). This flexibility is coupled with a high degree of habitat selectivity in *Chaetodon capistratus*.

Settlement strategy may be labile in some species and dependent on habitats encountered during a critical period at the end of the larval stage. For example, a planktonic larva nearing the end of the larval stage would normally recruit to preferred habitat such as seagrass if available. If at the end of a critical settlement period, no seagrass is available, then settlement would occur in a less desirable habitat such as sand/rubble substrata. Since the artificial reefs surrounded by shallow sandy habitat (site H3) were farthest from natural reefs, their high diversity indices may be a result of larvae becoming increasingly less selective about settlement sites as they near the end of a competency period.

Postsettlement survival is related to competition, predation, prey abundance, and a myriad of species specific behavioral mechanisms. Interference competition among postrecruits is not of significance in determining distribution of most species among reefs, according to recent studies reviewed by Williams (1991). However, Shulman (1985a) found that interference competition contributes to community structure of reef fishes. Interspecific competition was attributed to species pairs in this study which demonstrated inversely proportional density curves and aggressive behavior between individuals such as *Coryphopterus glaucofrenum* and *Gnatholepis thompsoni*.

Shulman (1985b) studied recruitment on artificial reefs placed at varying distances from a natural reef. That recruitment rates increased with proximity to the reef except within the halo zone prompted further work. Ultimately, low

recruitment rates on artificial reefs in the halo zone was attributed to predation by piscivorous reef-dwellers. Predation pressure presumably diminished immediately outside the halo.

In this study, postsettlement mortality due to higher predation pressures was not indicated as a process on artificial reefs in sandy habitats for two reasons. First, predators were most abundant on artificial reefs surrounded by seagrass where recruitment rates were highest. Secondly, artificial reefs in sandy habitats other than halo zones had similarly low recruitment. These results can be explained by habitat selection by recruits. This process can occur prior to settlement as larvae and postlarvae search for a suitably complex substrate and avoid the absence of visual cues in a sandy habitat. In addition, new recruits to sandy sites may be forced to find a new site due to low prey abundance peripheral to the artificial reef.

Data on natural reefs is suggestive of predation pressure control over selected community characteristics. The site with the highest number of juveniles also had the lowest number of extra large and large fishes and, therefore, probably had lower predation pressure (site B). It is suggested that some small, shallow reefs and their adjacent habitats may function as nurseries for deeper, more extensive reefs. This concept was discussed in chapter 5 related to the use of site B by gray juvenile scarids.

A relationship between recruitment and food availability was rejected by Shulman (1982) after a series of experimental manipulations in which the amount of food available on artificial reefs varied with no apparent correlation in rates of recruitment. No direct test of effect of prey abundance on characteristics of fish assemblages was made in this study. However, an effect of varying peripheral habitats on reef fish community structure was apparent. Moreover, in some

instances these effects may have been related to prey abundance. It is likely that prey abundance in habitats peripheral to reef of residence may also have effects on selection mechanisms in the evolutionary development of habitat preferences.

That haemulids and lutjanids were more abundant on natural reefs with dense peripheral seagrass is related to the value of seagrass meadows as foraging grounds. Both families of fishes are characterized by nocturnal feeding in seagrass meadows and diurnal sheltering on nearby coral reefs. In some species, nocturnal foraging extends over several kilometers (Brothers and MacFarland, 1981), which could explain how individuals might shelter at one reef and then another until a reef was located with adequate prey abundance in the peripheral habitat.

Other evidence that high prey abundance in seagrass meadows affects reef fish community structure is that greater fish densities and biomass were found on reefs with peripheral seagrass. If a large number of reef fishes such as haemulids or lutjanids are feeding in the peripheral habitat, then nutrients from the peripheral habitat will be transported to the reef by these fishes. Nutrients from the peripheral habitat are made available to the reef community from the waste of these fishes or from migrant fishes becoming prey for larger fish. Thus, a reef where the peripheral habitat is utilized for its high prey abundance will be able to support more biomass.

Structure of a shallow-reef fish assemblage also is affected by transients from peripheral habitats such as seagrass meadows, soft coral flats, midwater habitats, and deep reefs. Transients to the reef often are predators and in this study were most common on reefs with contiguous dense seagrass peripherally, such as carangids at site D. If biomass is higher on such reefs, as it was in this study, then it is advantageous for transient predators to expend more foraging effort on reefs with peripheral seagrass.

PROCESSES AND ULTIMATE CAUSES

Natural and artificial reefs are patchy environments and, therefore, function as isolated or insular communities. Island biogeography theory (MacArthur and Wilson, 1963, 1967) predicts that species densities in insular communities are controlled by the number of species in source areas, by distance of source areas, by the island's size, and by variety and types of habitats. In this project, artificial reefs were constructed with an attempt to keep all of these variables except habitat type constant. MacArthur and Wilson (1963, 1967) further suggest that most islands support as many species as possible, with rates of extinction of existing species approximately equal to immigration rates of new species. Stable species densities after the first month of initial recruitment to artificial reefs in this study support this hypothesis. Although species density changes little in such a dynamic equilibrium, species composition can change constantly. Further, species turnover increases long-term diversity within a community.

Habitat selection during primary or secondary recruitment events appears to be the single most significant process affecting structure of reef fish assemblages in this study. Data evaluated from the Great Barrier Reef also indicate that larger scale patterns of community structure (tens to hundreds of meters) arise because of habitat preferences of settling larvae (Sale, 1991b). Evolutionary development of such preferences has been suggested as a consequence of interspecific competition or adaptation independent of other species (Sale, 1991a). It is conceivable that seagrass or other peripheral habitats of preference may represent ancestral adult habitats. Retention of ancestral patterns in juvenile behavior is only one of several processes that may affect evolution of habitat selection in reef fishes.

Avoidance of halo zones and other deep sand habitats also is a predictable result of selection. One study estimated that in one day, reef fish defecate as much as a ton of calcareous sand particles per acre of reef. In addition, erosion of limestone occurs from a variety of other biological and physical forces. The halo represents a primary sink for the transport of this sand from the reef. Therefore, copious sand added daily inhibits plant and algal growth, as well as settlement and growth of corals or sponges. Herbivory of reef dwellers has also been demonstrated to have significant detrimental effect on plant and algal growth in the halo (Randall, 1965). In other sandy sites farther from natural reefs, currents play a more important role in accumulating sand and preventing growth of sessile organisms. Without sessile organisms or rubble of some kind to diversify the habitat, prey abundance is low and what prey exist are relatively inaccessible endofauna of the benthos. With low prey abundance, no vegetation, and no shelter, the sand flats are the least preferable habitat choice for new recruits. Sand flats are virtually devoid of visual cues compared with visually diverse habitats that have shelter and more abundant prey. Therefore, selection would favor an avoidance reaction, or inhibition of settlement, in response to habitats devoid of visual patterns.

Predation plays a role in evolution of preference for settlement in seagrass prior to movement to a reef. Larvae seeking the visual cues of seagrass meadows would find immediate shelter from predation, whereas those in other habitats are more vulnerable. Moreover, settlement onto the adult habitat--a coral reef--would place postlarvae in a predator-laden environment. Thus, selection pressures based on predation mold larval habitat preferences and utilization of seagrasses as a nursery.

In descriptions of processes that affect reef fish community structure, recruitment is usually defined as settlement from a planktonic larval phase (Sale, 1991b). This study points to the importance of recruitment from juvenile habitats or nurseries such as seagrass meadows. Although addition of yet another process to the list of initial recruitment from plankton, competition, predation, and biotic or physical disturbances adds to the complexity of the system, it does not preclude a dynamic equilibrium. Many now refer to reef fish assemblages as nonequilibrium (Sale, 1991a), but this characterization does not fit a system with repeatable patterns in natural surveys and experimental manipulations. Perhaps dynamic equilibrium is still the best terminology for a community where predictability of structural outline is high and of specific detail is low. It offers an intermediate position between random process and the theoretical stable equilibrium, and emphasizes the evolution of a myriad of stable interspecific associations between and within habitats which have developed over millennia.

IMPLICATIONS FOR MANAGEMENT

Since conch is second only to lobster in economic value in the Turks and Caicos Islands and other regions of the Caribbean, use of conch middens as artificial reefs has immediate applicability for local resource management. Annually, three to five million conch are harvested from waters of the TCI including processed and exported conch (Olsen, 1985). Innumerable conch are harvested that are too small or that are taken for immediate consumption. For each harvested conch, an empty shell results. Fishers discard shells in middens 1-100 meters in diameter throughout their fishing day. Conch shell middens appear on shores of cays, at

harbors, and in every conceivable shallow-water marine habitat including coral reefs and seagrass meadows. Conch shells may be a significant resource that has, thus far, received little research or management attention.

Use of conch shells as artificial reefs has provided information on the effects of continual addition of conch middens to existing communities. But, perhaps more importantly, results from this project have provided more information on the long-debated topic of whether artificial reefs aggregate fishes from the local populations or increase recruitment to the surrounding populations, and thereby productivity. The recruits to small conch middens, or artificial reefs, in this study were adults aggregated from the existing community as well as juveniles attracted from the planktonic community. The extent of recruitment of local fishes compared to immigrants was dependent on the habitat in which the reef was constructed.

This issue is especially critical when artificial reefs are utilized as fishing sites. Bohnsack and Sutherland (1985) speculated that increasing net production of fishes with artificial reefs may be more effectively achieved with reefs designed to recruit and improve survival of juvenile fishes rather than reefs designed to increase harvest of adults. Although some have found artificial reefs to recruit primarily adult fishes (Matthews, 1985; Alevizon and Gorham, 1989), in this study artificial reefs were colonized mainly by juveniles which is consistent with results described by Randall (1965) and Talbot, *et al.* (1978). Data presented here suggest that habitat in which an artificial reef is constructed influences age structure, species composition, species density and fish density of the resulting fish assemblage. This implies that location of artificial reefs relative to surrounding habitat will determine whether artificial structures serve to increase local fish populations or merely redistribute them.

Based on results of this study, effects of middens can range from habitat destruction when middens are placed on natural reef to recruitment enhancement for selected reef fishes when middens are constructed on banks or in seagrass. Since shells will continue to be discarded by fishers and their effects may be destructive or constructive to the local fishery, selective placement of shells by fishers is recommended. Future fisheries plans should address the issue of preferable middens location and methods of communicating the plan to all facets of the industry.

Although general trends for conch reefs in several habitats are recognizable from this study, generalizations to other regions or other artificial structures may not be valid. Structural features of artificial reefs such as hole size and construction material have been demonstrated to affect recruitment in a species specific and size specific manner (Bohnsack and Sutherland, 1985). Therefore, specific type of structure should be tested in all feasible habitats to determine which location will provide maximal yield for species of interest in a given location.

Of particular interest for fisheries management decisions regarding selection of habitats for deposition of shells is the similarly high diversity indices of fish assemblages on artificial reefs at sites in dense seagrass (site D2) and on sand/rubble habitats (site H3). That extensive area is covered by habitat similar to H3 on the banks in TCI is especially promising when coupled with its accessibility to conch fishers. With minimal effort, fishers could establish middens along travel routes across the banks and thereby increase recruitment of selected species of reef fishes.

Another, more general management consideration resulting from this project is the importance of protection of peripheral habitats in conservation of coral reef

systems. Coral reefs will be important to the future of tropical island nations such as TCI because major industries are based on healthy coral reefs, including tourism, fisheries, and the less-developed aquarium trade. Results of this study emphasize the importance of peripheral seagrass meadows as nurseries and foraging grounds for reef fishes important for all of those industries. Finfish fisheries include grouper, grunt, some snappers, and parrotfishes which were described in chapter five as affected by proximity of specific peripheral habitats such as seagrass. Therefore, protection of such habitats from impacts of development ultimately benefits the economy.

Ecotourism targets coral reefs for recreational snorkeling, SCUBA diving, submarine and glass-bottom boat cruises. Tourists recognize healthy, diverse reef fish communities as opposed to stressed, less diverse assemblages; therefore, careful management of coral reef systems is important for maintenance and growth of ecotourism. Reef fishes valued by sport divers and ecotourists have been described in this paper as utilizing seagrass meadows and other peripheral habitats for critical phases of their life cycles. Industry can capitalize on this information by adding educational components to ecotourism programs targeting habitats other than coral reefs and emphasizing linkages between habitats. Coordinated campaigns to include displays, brochures, tours, T-shirts, and giftware can reduce tourist load on reefs while increasing understanding as well as profits.

In recognition of the value of coral reefs for the education, economy, and general welfare of the nation's people, The Turks and Caicos Islands recently established several national parks on coral reefs. Regulatory programs currently being proposed consider habitats peripheral to coral reefs. Other island communities should emulate this system in which a coordinated management plan

for marine parks and fisheries includes actions to protect and monitor all habitat types, to educate and provide recreational opportunities, and to adjust fisheries activities to enhance conservation efforts for the benefit of fisheries, tourism, and health of natural resources.

CONCLUSION

Recognition that reef fish assemblages are uniquely different from other communities because of long distance dispersal of planktonic larvae from highly fecund parental populations was a first and necessary step toward understanding processes affecting reef fish community structure. Although it is now clear that stochastic influence on settlement is not the sole key to understanding what structures these systems, Sale's work (1977, 1980) sparked a renewed effort to reveal patterns and processes of recruitment that are critical to reef fish community structure (Smith, 1978; Doherty, 1981; Shulman, 1982).

Patterns observed in this study suggest that reef fish assemblages have predictable structures that are in dynamic equilibrium and that peripheral habitats such as seagrass meadows are critical to processes which determine structure of reef fish assemblages. These processes include habitat selection, post-settlement survival, and intercommunity interactions. That habitat selection is a process affecting recruitment in this project emphasizes the influence of species-specific characteristics.

Broad generalizations and single theme hypotheses regarding processes determining reef fish community structure do not account for interactions of the

variety of mechanisms that differentially affect each life stage of each cohort of each species. This project underscores the need for study of each species regarding effects on presettlement recruit availability and processes of habitat selection during and after settlement from plankton. Only then will community structure of reef fishes come within the realm of accurate predictability and effective management.

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