

ECOLOGY OF SHALLOW WATER BANK HABITATS
IN FLORIDA BAY

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INTRODUCTION

Florida Bay is a large, shallow, lagoonal estuary between the southern coast of the Florida mainland and the island chain of the Florida Keys (Fig. 1). A unique network of anastomosing, carbonate mud banks runs throughout the Bay, with mangrove islands colonizing emergent portions and seagrass meadows dominating the remainder. The banks, generally less than 0.5 m in depth, slope on either side into large basins up to 3 m in depth. Geological evidence suggests that the banks are persistent, stable features of the Bay (Scholl 1966). The dense beds of seagrass covering the banks provide a rich foraging habitat for wading birds (ten species of herons and egrets), piscivorous raptors (osprey, bald eagle), and numerous species of fishes, including economically important gamefish (red drum, spotted seatrout, bonefish, snook).

Due to their shallow depth, the banks are likely to be exposed to extremes of temperature, salinity, and dessication not encountered in deeper, permanently submerged seagrass systems. The resident grassbed communities may demonstrate very different functional relationships relative to the deeper habitats more thoroughly studied by seagrass investigators (e.g. Livingston 1975, Brook 1978, Thorhaug & Roessler 1977, Weinstein & Heck 1979). We hypothesize that on these shallow banks, physical parameters, such as wind velocity and direction, water turbulence, and variation in water level, play a much greater role in shaping the distribution and abundance of resident species. In addition to its influence on physical stress, water depth also determines the potential impact of predation by wading birds, since the birds cannot feed in water deeper than the length of their legs (Custer and Osborn 1978).

Water depth also influences the ability of predatory fishes to move onto a bank for foraging.

(2) Previous studies of the Florida Bay fish and crustacean fauna have provided qualitative assessments of the species present and their association with broadly defined habitat types. ✓ Tabb *et al.* (1962b) and Schmidt (1979) concentrated their efforts on trawling samples in basin areas, with peripheral examination of bank inhabitants. Hudson *et al.* (1970) sampled primarily on banks, using a variety of methods, but their results are limited to a species list from a single location. There has been no quantitative examination of the bank communities prior to this study.

Florida Bay is a heterogeneous environment. The banks divide the Bay into a number of discrete basins with restricted water circulation, resulting in isolation of water masses and, consequently, wide variations in salinity and tidal flux across the Bay. Ginsburg (1956) divided the Bay into two subenvironments, an outer zone with frequent tidal exchange and an inner zone of restricted circulation, a small range of tidal fluctuation, and a greater range of salinity variation. With additional information on mollusk distributions, Turney & Perkins (1972) divided the Bay into four subenvironments, emphasizing the exchange of bay water masses with Gulf, Atlantic, or fresh water from the Everglades. Based on an extensive analysis of the distribution of seagrass and algae, Zieman and Fourqurean (1985) delimited seven vegetational zones in the Bay.

(3) The physical shape of the banks grades from discrete, narrow strips in the eastern Bay to extensive plateaus in the western Bay. Along this gradient, Zieman and Fourqurean (1985) found a trend of increasing seagrass shoot density and standing crop. In basins, seagrass growth

grades from a thin, sparse covering in the east, where sediment depth is very shallow, to dense beds in the west, where sediment accumulation is much deeper. Under the zonation scheme of Zieman and Fourqurean (1985) the percentage of bank area relative to basins ranges from 4% in their Northeast zone to 44% in their Gulf zone.

Within a continuous seagrass habitat, various physical and biological parameters of microhabitat influence small scale variation in distribution and abundance. While some studies have speculated upon the operation of these factors (Heck and Wetstone 1977, Stoner 1983a, Stoner 1983b, Heck & Orth 1980, Orth *et al.* 1984 and additional references therein), there has been little exploration of microhabitat on a sample by sample basis.

The pattern of bank development in Florida Bay allows us a unique opportunity to examine the influence of variation in microhabitat parameters across short distances. A predominate pattern of easterly trade winds, with a strong northerly component in winter (Schomer and Drew 1982), results in differing water turbulence patterns on either side of a bank, i.e. a windward and leeward side (Ginsburg 1956). Sediment granulometric properties, the growth form of seagrasses, and detrital loads can be expected to vary considerably across a bank. By carefully measuring habitat variables with each sample of organisms collected, we can better determine the influence of microhabitat on species composition and abundance, while maintaining controls for geographically varying factors such as temperature, salinity, dissolved nutrients, and light penetration.

Heck & Orth (1980) concluded that structural complexity of the seagrass habitat is the most influential factor in determining the diversity and abundance of grassbed inhabitants. Structural complexity is

often equated with above ground plant biomass, such that increased biomass leads to increased densities of resident species (Heck & Wetstone 1977, Gore *et al.* 1981, Stoner 1983a, 1983b). With increased seagrass density more cover is available, thus reducing the risk of predation. Experimental evidence has indicated that a predator's efficiency in capturing prey is impaired as the density of seagrass shoots increases (Heck & Thoman 1981, Nelson 1979, Coen *et al.* 1981). The Pacific grass shrimp *Hippolyte californiensis* actively selects dense seagrass in a choice situation (Barry 1974). Stoner (1980) found active selection by three amphipod species of locations with high surface area of seagrass.

In the present study, we examined a variety of microhabitat factors in order to more finely discriminate their individual roles in structuring the grassbed fauna. These parameters included species of grass present, shoot density, standing crop, surface area of the grass blades, height and width of grass blades, and the amount of seagrass detritus present.

While no background data are available on densities of bank organisms, there are some indications that habitat quality in Florida Bay has declined in recent years. Local sport fishing guides have reported lower gamefish catches, particularly in the eastern part of the Bay and Everglades National Park creel censuses have reported decreased catches. Lowered reproductive success of two piscivorous birds, osprey (Poole 1982) and great white heron (Powell 1983) has been linked to an inadequate food supply.

Lowered habitat quality has often been anecdotally linked to alteration of the flow of freshwater into Florida Bay. The restricted water circulation imposed by the banks in Florida Bay, combined with the high rates of evaporation, can result in hypersaline conditions (Tabb *et*

al. 1962b). This situation has been further exacerbated by increased diversion of freshwater from the Everglades by an extensive system of dikes and canals criss-crossing south Florida. Schomer and Drew (1982) provide a succinct description of historical drainage patterns and the chronological development of canal systems. In northeast Florida Bay, Schmidt (1979) found salinities ranging from 8.0 ppt (Little Madeira Bay) to 64.8 ppt (Madeira Bay) over a two year period. In years of severe drought, high salinities may continue for several months (Finucane and Dragovich 1959). Drought conditions have not occurred in the region for several years, but the severely restricted flow of freshwater through the Everglades and into Florida Bay can be expected to induce more extreme salinities in the event of drought.

In addition to moderating salinity, freshwater input may serve two other important functions to the Bay - nutrient addition in the form of particulate detritus and stimulation of some flushing circulation of the northern areas. The effects of freshwater regulation on productivity in Florida Bay are not known. One goal of the present study is to provide detailed base line information on bank communities, allowing for repetition of our sampling methods and testing of the effects of current experiments on water release patterns being conducted by the South Florida Water Management District.

Specific objectives of the present study include the following:

1. Describe the physical environment of Florida Bay's bank habitats, including topography, tidal flux, wind velocity and direction, temperature and salinity regimes, sediment characteristics, and seasonal variations of the above.

2. Compare the distribution and abundance of fishes and decapod crustaceans and variation in seagrass growth on banks in different subenvironments of Florida Bay.

3. Determine the zonation of seagrasses, fishes, and decapods across individual banks.

4. Determine the effects of seagrass microhabitat parameters and variations in physical parameters of tidal variation, temperature, and salinity on species composition and density.

5. Identify and measure the relative distribution across subenvironments of pelagic fish species that move on and off the banks, and determine patterns of occurrence on banks relative to tidal stage and time of day.

STUDY SITES

Sampling sites were selected on the basis of our pilot studies of bank community structure and water level and prior division of the Bay into "subenvironments" (Turney and Perkins 1972). Four sites were chosen (Fig. 1), falling into the more recent Northeast, East Central, Atlantic, and Gulf vegetational divisions of Zieman and Fourqurean (1985). Eagle, in the Northeast zone, had a minor tidal range and a moderate freshwater input from runoff through the Everglades. We divided this site into two stations, one between Lake and Pass Keys (station A) (Fig. 2) and the other between Eagle Key and a mainland peninsula (B) (Fig. 3). Cross Bank, in the East Central subenvironment, had no direct terrestrial freshwater input and a minor tidal range. Cross was also divided into two stations, one near Cowpens Key (A) (Fig. 4) and the other 2 km from the nearest island (B) (Fig. 5). The third site was located on Buchanan Bank, in the Atlantic subenvironment (Fig. 6). This area had a significant tidal range and no freshwater input. The Oyster site, in the Gulf division (Fig. 7), had some terrestrial freshwater input and a marked tidal range. While the first three banks were 140-230 m in breadth, the Oyster bank was 1 km wide at our sampling site.

MATERIALS AND METHODS

We considered the bank inhabitants to belong to two relatively distinct groups: the demersal community and the pelagic community, with pelagic referring to species occurring in the water column. Separate sampling methodologies were developed for the two communities.

We sampled three times a year during the two-year study, with the sampling periods corresponding to three ecologically distinct seasons of Florida Bay (Tables 1, 2). The first sampling period was in the middle of the dry season, with low mean water level, water temperature and salinity. The second period, in the first half of the wet season, was characterized by low mean water level, high water temperatures, and increasing salinities. The last sampling period was in the second half of the wet season, with high mean water level, high temperatures, and falling salinities.

We recognize that three sampling series per year do not allow the same resolution of seasonal cycles provided by monthly or weekly sampling. Some recruitment (particularly of grass shrimp), population peaks, and periodic fluctuations were probably missed. Despite these limitations, we believe that by careful, intensive sampling during ecologically distinct seasons, rather than more limited sampling on a monthly basis, we were better able to evaluate the bank community as an entity.

Demersal Community

The resident community was sampled at each of the four sites during each sampling series. We sampled the Cross and Eagle banks across both of their two stations.

Three transects were established on each bank station, parallel to

the bank's major axis (Fig. 8). Transect 1 was located on the south or southwest side of the bank, transect 2 was on the bank top or crest, and transect 3 was on the north or northeast side. Side transects were approximately 75 cm below the top of the bank. Since banks in northwestern Florida Bay are wide, it was necessary to establish an extra, 1 m deep transect (transect 4, Fig. 7) to adequately sample the different Oyster bank levels. These four transects were perpendicular to a 1 km north-south line that ran between Oyster and Murray Keys. An additional Oyster transect (transect 5) was added in the second year of the study to further analyze a more extreme shallow water habitat. This transect was 29 cm shallower than transect 2.

During a series, we took either six or twelve random samples on each 70 m transect line, for a total of 150 samples (Table 3). All three transects at Buchanan and the two shallowest transects at Oyster (2 and 5) were sampled at both low and high tide in an effort to determine the extent to which animal movements were mediated by tidal flux.

We carried out supplemental sampling at Oyster transects 2 and 5 in January and February, 1985 to examine the effects of a severe cold front on the demersal fauna. This additional sampling also provided further data on differences in density at high and low tide.

Sampling Equipment

A 1 m² throw trap (Kushlan 1981) was the best method available for sampling demersal organisms on the shallow, soft mud banks of Florida Bay. Trawls were impractical because of the shallow depth and their inherent inefficiency in dense vegetation (Stoner 1983a). Setting up large drop nets (Hellier 1958, Gore *et al.* 1981) would have disturbed the soft sediment

during assembly, and shading during the acclimation period could have attracted some species. A throw trap causes no prior disturbance of the site and yields highly quantitative, repetitive samples in 1 m² units. The throw trap also allows comparison with other recent or current work in Everglades National Park (Kushlan in prep., Paul in prep., Robblee in prep).

The effective depth of the trap, a 45 cm deep box without top or bottom, was extended to 1 m via a 3 mm stretch mesh net surrounding the top edges of the trap. A float cord around the top raised the net to the water surface, preventing entry or exit of animals.

To collect a sample, the trap was thrown so that it landed evenly on the bank, and it was immediately pushed into the sediment. Organisms were collected from the trap with a 1 m wide, framed net (bar seine) with a 3 mm stretch mesh. All fish, decapods, stomatopods, seagrass litter, and drift algae were removed from the net after each pass. The initial passes skimmed the grass blades and avoided disturbing the detritus. As scooping continued, the net was forced progressively deeper into the trap, eventually removing 2-4 cm of sediment. With this careful progression, small, easily damaged organisms (e.g. grass shrimp) were removed before they could be lost in the loads of sediment and detritus. Each trap was scooped a minimum of 10 times and until three successive passes encountered no organisms. Xanthids and hermit crabs were excepted from this criterion, as they may burrow into the sediment beyond the reach of the scoop net. These two groups may have been undersampled, but were included in analyses as our sampling criteria allowed relative comparisons.

In conjunction with each throw trap sample, we noted seagrass species

present, percentage of seagrass and drift algae cover, and water depth. Salinity and water temperature were recorded for each transect.

We took seagrass samples with two 15.3 cm diameter cores, from opposite corners outside, but immediately adjacent to, each throw trap. All seagrass short shoots (Zieman 1982) were removed.

At all Buchanan transects and the two shallow Oyster transects, sampling was conducted at both low and high tide. We set out all six traps per transect at the lowest point in the tidal cycle. A minimum depth of 20 cm was required for efficient scooping; sampling was delayed, when necessary, until this depth was attained by the rising tide. At high tide, six additional samples were taken for comparison.

Laboratory Processing

All animals were identified to species and wet weight was determined to the nearest mg on digital Sartorius balances. Standard length of fish, carapace length of shrimp (including rostrum) and carapace width of crabs (including lateral spines) was measured to the nearest 0.1 mm. Seagrass litter and drift algae samples were compressed to remove excess water, allowed to air dry for 30 minutes and weighed to the nearest 10 g.

All seagrass short shoots from each core were identified and counted. We measured the length and width of each blade from each of five short shoots selected by random number tables. All blades from core shoots were clipped to remove basal portions, washed in 1 N HCL to remove epiphytes, and dried 24 hours at 80° C. Dry weight (mg) was used to obtain a measure of standing crop. Calculated grass parameters included shoot density, number of blades per shoot, length of the longest blade per shoot, blade width, leaf area (blade length * blade width), canopy height (mean length

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of the longest blade per shoot), and canopy density (total blades* m^{-2}).
Pelagic Community

We used gillnets to intercept the larger, more mobile fish species moving on and off the banks. Objectives were to: 1) determine relationships between activity and time of day and tidal cycle and 2) compare relative abundance between sites. Nets were set along transect 1 at Eagle station B, Cross Bank station B, and Buchanan. At Oyster, the net was set along transect 3. We sampled during three sampling series in 1984 and the first two in 1985.

Sampling Equipment

Each 69.8 m net was a composite of four sampling panels and three spacer panels. Each sampling panel was 15.2 m in length, with stretch mesh sizes of 13, 19, 25, and 32 mm. Three m spacer sections of 63 mm mesh between sampling panels prevented funneling of larger fish along the net and into the larger meshes (Regier and Robson 1966). Nets used at Eagle, Cross, and Buchanan were 0.9 m in depth; those used at Oyster, with its greater water level range, were 1.2 m deep. The nets thus sampled the water column from surface to sediment at each site.

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Nets were set for 72 hours and cleared of fish every half hour. Time of capture and mesh size was noted for each fish. This frequent clearing provided detailed data on fish movements and minimized shark and blue crab predation on entrapped fish. Water depth was recorded every half hour and water temperature and salinity were noted every two hours.

Lab Processing

All specimens were identified to species and standard length (fork

length for sharks) and wet weight determined.

Physical Parameters

Bank Profiles

At each site, bank topography was determined by measuring water and sediment depths at 10 m intervals along transects perpendicular to the major axis of the bank.

Water Levels

Water levels were recorded continuously from all four sampling sites, and an additional site at Captain Key, with Leupold and Stevens Type F drum units. The recorders were placed in deep water on the edges of islands within 0.5 km of each study site (Figs. 1, 3, 4, 6, 7). The Oyster gauge, subject to the greatest tidal flux, was equipped with an 8:1 gear ratio; all other units had a 2:1 ratio. A staff gauge next to each recording unit was read weekly. These readings were used to relate the recording unit traces to actual water level. Data from traces were digitized for computer entry with a Jandel Corporation Digital Paintbrush System. A data point was entered whenever the trace slope changed.

Mean low tide, monthly tidal range, and mean monthly water level were calculated for each project site and month. Mean low tide was the summation of all low tide values divided by the number of low tides in each month. Monthly tidal range was the difference between mean high and mean low tide. Mean monthly water level was the sum of mean high and mean low tide, divided by 2.

To relate recorder water levels to water levels on the banks, staff

gauges were placed on transect 2 at each sampling station. Simultaneous readings of the staff gauges and water level recorder at each site were collected on 10 to 30 occasions over the course of the study. On the basis of these relationships it was possible to use the recorder at each site to determine actual water level on each transect.

Preliminary field observations at the Oyster study site indicated that some water was retained on the bank at low tide even though water levels in surrounding cuts were below bank level. Since the retention of water on a bank would have major implications for the survival of organisms, we decided to further analyze the temporal and spatial distribution of water on the study site using two procedures. 1) We placed 25 staff gauges at 50 m intervals on the north-south transect that ran through the study area (Fig. 7). The gauges were read simultaneously, at 15 minute intervals, throughout several tidal cycles. 2) Two supplemental water level recorders were placed at transects 2 and 5 for one month.

Water Temperature

We recorded water temperature with five 90-day Ryan J units. Each gauge was secured in a 1.5 m long, 15.3 cm diameter PVC tube that was sunk into the sediment, with the top 10 cm protruding above the bank, and capped. Each gauge was placed on a small platform within the tube to guarantee proper elevation of the sensor relative to sediment and water level. Several large openings were cut in the neck of the housing to allow water exchange. Concurrent measurement of housing and ambient water temperature demonstrated no difference in temperature.

One gauge was placed on transect 2 of each site. A fifth gauge was

alternately positioned in 2 m of water in the basin adjacent to Cross Bank, on the leeward transect (transect 1) of Central Cross Bank (0.8 m depth) and the northern transect of Oyster (transect 4).

Values for peaks and troughs from the recorder traces, with a minimum change of 1° C, were entered into the computer for later analysis.

Mean monthly temperature, monthly temperature range, and mean daily temperature range were calculated for each study site and month. Mean monthly temperature was the sum of all observations for a month divided by the number of observations. Monthly temperature range was the maximum temperature for a month minus the minimum temperature for a month. Mean daily temperature range was calculated by determining the difference between each daily maximum and minimum, summing these differences, and dividing the summation by the number of days in the month.

Weather

Air temperature, wind speed, and wind direction, collected at 3 hr intervals, were obtained from the Marine Coastal Weather Log at the Islamorada Coast Guard Station, Plantation Key, Florida. Monthly wind speed totals were calculated by summing speeds from all observations. These totals were divided into quadrants as follows: northeast, 11° - 101° ; southeast, 101° - 191° ; southwest, 191° - 281° ; northwest, 281° - 11° .

Salinity

Salinity samples were taken every two hours during gillnetting and for each transect during throw trapping. These samples were measured to 0.5 ppt with an American Optical temperature-compensated refractometer.

Sediment Characteristics

Three 100 ml samples of the top 1 cm of sediment were taken from each transect at each site. Large detritus particles were removed and excess water decanted. A portion of the sediment was removed for organic analysis and the remainder dried at 80°C to determine dry weight. It was then wet-seived, retaining three fractions:

< 63 μ	silt-clay
63 μ - 2 mm	sand
> 2 mm	gravel

The sand and gravel portions were dried and weighed and the dry weight of the silt-clay portion determined by subtraction. Organic samples were dried at 100°C and ashed at 500°C. Percentage of organic material present in the sediment was determined by dividing ash free dry weight by dry weight.

Data Analysis

All statistical analyses were performed with the SPSS/PC+ package (Norusis 1986). Because standard deviations typically varied with the mean for seagrass parameters, throw trap densities, and gillnet catches, all data were log-transformed prior to analyses.

ANOVAs

We relied primarily on 1-way ANOVAs and the Student-Newman-Keuls multiple range test to make comparisons among and within sites. For comparisons across stations at Cross and Eagle we used 2-way ANOVAs by

station and series. A similar strategy was used to compare differences in density between high and low tide at Buchanan and Oyster, and to compare vegetation and organisms at transects 2 and 5 of Oyster.

Differences in vegetation and animal densities among seasons and from year to year were tested with 3-way ANOVAs on site, season, and year. By this method we controlled for two of the major factors influencing densities while testing for effects of the third. Because transect 5 of Oyster was an additional location sampled only in the second year of the study, it was not included in statistical analyses of inter-site differences.

Patchiness

The degree of aggregation by individual species on the banks was determined for throw trap catches with Lloyd's (1967) index of patchiness:

$$I.P. = 1 + \frac{s^2 - \bar{x}}{\bar{x}^2} \quad ; \text{ where } s^2 \text{ is the sample variance and } \bar{x}$$

is the sample mean. The index determines how many times as "crowded" an individual is as it would be if the population distribution was random (Lloyd 1967). A value greater than 1.0, then, indicates a patchy or aggregated distribution (Houde and Lovdal 1984). The scale on which patchiness is measured should be smaller than the daily ambit (i.e. range of movement), but large relative to the size of individuals (Lloyd 1967). We assumed that a 1 m² area adequately covered these assumptions for most throw trap species.

Patchiness indices were calculated for each set of six throw traps on a transect. We excluded cases in which less than two individuals were caught among the six traps, as patchiness is a meaningless concept when only one or no individuals are considered. The mean and standard error of

all patchiness indices calculated for a species were then determined.

Multiple Regressions

Multiple regression of habitat parameters with individual species caught in throw traps was performed stepwise, with a $p = 0.01$ criterion of entry into the equation. At each step variables already in the equation were removed if p rose above 0.10 due to entry of other factors. The following habitat variables were available for entry:

Standing Crop = mean dry weight * m^{-2}

Canopy Height = mean length of longest blade of each seagrass shoot

Shoots = density of all seagrass shoots * m^{-2}

Blades = shoot density * mean number of blades per shoot

12) Leaf area = [mean length * mean width] * blades * shoots

Litter = mean wet weight of seagrass litter * m^{-2}

Silt = percentage of sediment in silt-clay fraction

Organics = percentage organic content of sediment, or AFDW * dry weight⁻¹

Depth = mean depth of water at a transect during a series

Tide = monthly tidal range for a site and series

Temp = mean water temperature for a site and series

Temp range = mean daily range in water temperature for a site and series

Salinity = mean salinity for a site and series

Winter = dummy variable set to 1 if sample taken in January-February series, 0 for other series

Spring = dummy variable set to 1 if sample taken in May-June series,

0 for other series (thus September samples are identified by 0 values for both Winter and Spring)

Year = dummy variable set to 0 for 1984 and 1 for 1985

(13) For each species, results of multiple regression analysis were examined for the occurrence of outliers and normality, linearity, and homoscedasticity of residuals (Tabachnick and Fidell 1983). Only those species that did not show obvious violations of assumptions are presented in the results.

Regression equations reported in the results include all variables entered at the final step of stepwise analysis. Along with each regression coefficient (B), the standardized coefficients (Beta), simple correlations (r), and squared semi-partial correlations (sr^2) are reported. Tabachnick and Fidell (1983) state that the latter value is the most useful indicator of the importance of individual independent variables. In the format used in this study, the sr^2 values reveal the percentage of variation in density explained by a microhabitat variable after all other variables in the equation have been taken into account. Squares of the simple correlation coefficients (r) would indicate the percentage explanation of variation when no other independent variables are considered.

The sum of the sr^2 s is the total "unique variance", accounted for by individual factors. The square of the multiple correlation coefficient (R) minus the unique variance is the "shared variance", or that proportion explained by the whole suite of factors entered in the final equation.

Gillnet Catch by Time of Day

The half hour catches from gillnetting were assigned to eight time of day categories, 0500-0730 (dawn), 0800-1030, 1100-1330, 1400-1630, 1700-

1930 (dusk), 2000-2230, 2300-0130, and 0200-0430 EST. For each site on each series, the percentage of fish caught in each time category was calculated. The mean and S.E. of these percentages were then determined, excluding cases in which less than five fish were caught at a site for a single series.

Gillnet Catch by Tidal Stage

Tidal variation in water level was negligible at Cross and Eagle and assumed to have little influence on gillnet catches at these sites. For Buchanan and Oyster, the catch was arbitrarily divided into four stages - the first rise after slack low to about mid-flood, the second rise from mid-flood to slack high, the first fall from slack high to mid-ebb, and the second fall from mid-ebb to slack low. A division of tidal stages into periods of low, rising, high, and falling water level was also attempted, but revealed fewer distinctive patterns in the catch.

The percentage of a species caught in each tidal stage during the day and during the night was then determined for each series and site (Buchanan and Oyster only). The means of these percentages were calculated, excluding cases in which fewer than five fish of a species were caught.

PHYSICAL PARAMETERS - RESULTS AND DISCUSSION

Bank Profiles

Oyster was by far the largest bank investigated, extending 1 km from north to south and 5 km to the east (Fig. 7). The 1.5 m deep Murray Key Cut paralleled our transects 1-4 and separated them from transect 5 near Murray Key. Note that cross section line A on the map was along the north-south bank crest, which was basically flat. The cross section through the transects (B) shows that the bank is sloped to either side, with a slight ridge at transect 1. Oyster had a deep sediment accumulation ($\bar{x} = 205$ cm) at all transects.

Eagle stations A (Lake Key) and B (Eagle Key) had somewhat different profiles (Figs. 2, 3). Station A had a basically flat top with steeply sloping sides, while station B was highest at transect 2 with gradually sloping sides. Both stations were 200 m across at our transect locations and had a mean sediment depth of 140 cm, with an uneven bedrock platform.

Both Cross stations, like Eagle station A, had relatively flat tops with distinct sides (Fig. 4, 5). The bank was 200 m across at station A (Cowpens), and 160 m across at station B (Cross). There was a 230 cm and 190 cm sediment base at stations A and B, respectively, underlain by relatively even bedrock.

Buchanan (Fig. 6) was our narrowest bank (125 m across at our transects). Bank profiles across different portions show various configurations. Our sampling site (profile B) shows a plateau to the south of transect 3, extending midway to transect 2. Profiles C and D indicate a centrally rounded bank, with sides gently pitched away from the longitudinal axis. Profile A shows a crest closer to the northern bank

margin. The bank has only a shallow sediment layer of 80 cm along most of the bank. The bedrock is much deeper along transect 1.

Wind

A number of trends in wind speed and direction were apparent from data collected during our two-year study period. Winds were highest in February (total combined wind speed = 2660 knots), steadily decreased until July (1900 knots), and then increased throughout the fall (Fig. 9). Such a pattern is typical for south Florida (Schomer and Drew 1982). In January, but during no other month, the greatest accumulated wind speed was from the northwest (1300 knots, Fig. 10). This northwest component decreased steadily, reaching a low in July (30 knots), then increased through the fall, thus paralleling total wind speed (Fig. 9). Southwest winds roughly followed this pattern as well. Northeasterly winds dominated in all months except January, reaching a high in October (1730 knots). Southeast winds were greatest in July (670 knots) and were at a minimum in October (180 knots).

Four basic relationships between wind directions occurred:

- | | | |
|--------|-------------------|--|
| Type 1 | NW > NE, SE, SW | January |
| Type 2 | NE > NW > SE > SW | February, March, October, November, December |
| Type 3 | NE > SE > NW > SW | April, September |
| Type 4 | NE > SE > SW > NW | May, June, July, August |

These distinct trends are explained by south Florida climatology. Tradewinds, blowing from the northeast, are prevalent throughout most of the year but are replaced by southeasterlies in the summer (Echternacht 1975). During the dry season (Table 1), cold fronts pass over the area about once a week (Warzeski 1976) and are most frequent and severe in

January (from data in Marine Coastal Weather Log - Islamorada Coast Guard Station). These fronts are characterized by a slow 360° clockwise rotation of wind direction (Warzeski 1976), with winds initially blowing from the northeast or southeast and ultimately from the northwest quadrant. It seems likely that the January Type 1 relationship was a result of increased cold front frequency.

Type 2 relationships were seen immediately before and after January (Fig. 10). The role of northwesterlies (cold fronts) increased before and declined after this pivotal month. The southwesterlies were also reduced during these Type 2 months, relative to January. The Type 3 months (April and September) were transitional between Wind Types 1 and 2 and Wind Type 4. During May, June, July, and August (Type 4), wind velocity was at its lowest. Northeasterlies were lower than at any other time but still predominated, while southeastern winds had increased importance as they swung northward from the Caribbean (Echternacht 1975). During our two years of study a progression of wind types was thus clearly apparent:

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	2	2	3	4	4	4	4	3	2	2	2

With prevailing winds from the northeast quadrant (Fig. 10) and long fetches extending in this direction (Fig. 1), Cross and Buchanan received the most wind stress and associated wave action on the northern sides of the banks. Cross station A was more sheltered than station B, particularly at transect 1 (Figs. 4, 5), which was protected by the adjacent Cowpens Keys and a small shoal to the southeast. Eagle, shielded to the northeast by the mainland (particularly at station B, Figs. 2, 3), and with a large fetch to the south, was most exposed to the

southwest. Oyster was sheltered to the north by the mainland and to the south by extensive banks but received somewhat more wave action from the northeast than other directions. Transects 1 and 5 were most protected, 1 by banks and 5 by Murray Key (Fig. 7). Further reference to the "exposed side" of a bank indicates transect 3 at Cross and Buchanan and transect 1 at Eagle. Likewise, the "sheltered side" refers to transect 1 at Cross and Buchanan and transect 3 at Eagle.

Sediments

16 The size structure of sediments on the banks was nearly identical for the two northern sites (Eagle and Oyster) and the two southern sites (Cross and Buchanan) (Figs. 11-13). Sediments at the northern sites were very fine, with the silt-clay fraction comprising 53% to 71% of the total. At southern sites, the silt-clay fraction had a range from 17% to 56%. Gravel fractions were small at all sites, with a range of 0.2 to 12% at northern sites and 0.1 to 21% at southern sites. Sand fraction percentages mirrored those of silt-clay, with 17 to 39% in the north and 43 to 73% in the south. The finer sediment size in the northern part of the Bay was apparent in the higher turbidity of these waters (personal observation and Zieman and Fourqurean 1985).

Size fractions varied consistently from the sheltered to exposed sides of banks. At Buchanan, both Cross stations, and both Eagle stations, the gravel fraction was nearly absent from, and the ratio of silt-clay to sand fractions was higher on, the sheltered sides. At Oyster, where all four transects were relatively protected, the size structure varied little across the bank.

Ginsburg (1956) also noted that the bank sediments in Florida Bay are

largely in the silt-clay fraction, and found a similar gradient across banks, with sand predominating on exposed sides and silt on sheltered sides.

The percentage of organic content in the sediments also followed a progression from sheltered to exposed sides of banks (Fig. 14). Organic content on the sheltered side averaged 9% at Eagle and 11% at Cross and Buchanan. On the exposed side, means were 8% at Eagle, 6% at Cross, and 5% at Buchanan. At Oyster, organic content was on average higher than at other sites, ranging from 14% at transect 1 to 10% at transects 2 and 3.

Variation in both size structure and organic content across a bank reflected the degree of exposure to wind and wave action. Gradients were stronger at Cross and Buchanan, where windward and leeward sides were pronounced. At Eagle, where the stress of water turbulence was less clearly divided, sediment gradients were less striking. The extensive, relatively protected bank at Oyster revealed little variation in sediments, except for the unusually high organic content of transect 1. In St. Andrew Bay, Florida, greater wave action also results in coarser sediments with a lower organic content (Grady 1981).

The highest percentage of silt-clay was on top of the bank (transect 2) at both Eagle stations, Buchanan, and Oyster. At both Cross stations, the top of the bank had only a slightly smaller proportion of silt than the sheltered sides. Although these shallower portions of the banks were most likely to be exposed by low water levels, the sides of the banks apparently acted as effective buffers to wave action. Thus, even in strong winds, the shallow water on the bank top remained relatively calm.

Previous studies of sediment structure in seagrass beds have found much coarser sediments than those of the banks in Florida Bay. In St.

Andrew Bay, Florida, the silt-clay fraction averages 2.9% (Grady 1981), and in Indian River, Florida (Stoner 1983a), the silt-clay fraction ranges from 3.9 to 5.7%. Sediments in Florida Bay are primarily molluscan carbonate in origin (Ginsburg 1956), while sediments in more northern areas of Florida are likely to have a much greater proportion of quartz.

The organic content of bank sediments was also high relative to values in Indian River grassbeds of 1% to 2% (Stoner 1983a). Finer sediments may enhance the development of a rich microbial community. Sediments at Oyster, however, had a much higher organic content than the similarly-sized sediments at Eagle, suggesting the potential for a more productive benthic community.

Water Levels

15 Water levels on the study banks (Figs. 15-18) followed complex cycles reflecting lunar rhythms modified or superseded by prevailing wind and variations in oceanic water level. Monthly bank water level (Fig. 19) roughly corresponded to seasonal fluctuations in oceanic level. Sea level is lowest at Key West from January through March, reaches a maximum in 15 October, and then falls rapidly (Marmer 1954). All four sites followed this pattern, reaching their highest level in fall, then dropping sharply (Fig. 19). Buchanan and Eagle experienced low levels throughout the winter and spring. Oyster and Cross demonstrated distinct low points in March ($\bar{x}$ 34 cm) and May ($\bar{x}$ = 9) respectively. Thus, while all sites showed a general relationship to oceanic levels, the correspondence was better for yearly maxima than yearly minima.

Regardless of season, mean water level at Oyster ($\bar{x}$ = 48 cm, Fig. 18) was greater than at the other sites (Fig. 19). Buchanan ($\bar{x}$ = 29) was

intermediate, while levels were lowest at Eagle and Cross ($\bar{x} = 20$ and 22, respectively).

Tidal exchange appeared to be a function of access to open ocean. Oyster, close to the Gulf (Fig. 1) had the greatest monthly tidal range ($\bar{x} = 69$ cm, Figs 18, 20). Buchanan, with moderate exchange with the Atlantic and Gulf, demonstrated a tidal range of 17 cm (Figs. 17, 20). Eagle and Cross, separated from the ocean by the latticework of banks to the west and the limestone keys to the south, had restricted water level ranges ($\bar{x} = 3$ and 5, respectively) (Figs. 15, 16, 20). A temporary gauge set in a transitional area at Captain Key (Fig. 1) revealed an intermediate range of 8 cm (Figs. 20, 21). There was little difference in tidal range from month to month at any given site. The greatest tidal range for any month at Eagle was 5 cm; the least tidal range for any month was 3 cm. Thus, yearly variation in Eagle monthly tidal range was only 2 cm. Variation in tidal range at the other sites was as follows: Cross, 3 cm; Captain, 3 cm; Buchanan, 5 cm; Oyster, 17 cm (Fig. 20). Variation in water level range was, therefore, positively related to the degree of oceanic exchange.

Water depth at low tide should be an important factor for organisms residing on these shallow banks. As with mean water level, mean low tide at all four sites (Fig. 22) followed oceanic water level. Eagle, Cross, and Buchanan were remarkably similar with regard to low tide level, with respective yearly means of 21, 20, and 20 cm. While Oyster had the greatest mean water level (Fig. 19), it demonstrated a much lower mean low tide (8 cm) than the other sites. Tides at Oyster transect 2 were theoretically (based on the Murray Key Cut recording gauge) low enough to drop below sediment level, thus the negative water levels (Figs. 18, 22).

In fact, water did not drop below +5 cm on the bank (see below).

Water level at all four sites demonstrated some degree of wind-dependency. Because these wind-induced shifts in water level were largely a function of the intensity and direction of winds during cold fronts, and because winds were generally higher during the dry season ($\bar{x} = 2400$ knots/month, Fig. 9), such effects occurred primarily between November and April. During typical cold fronts, winds slowly rotated 360° , starting from the east (Fig. 23). As winds began shifting to the southwest and west, water was pushed into the Bay. With the mainland and limestone keys presenting a formidable barrier, such influx resulted in a rise in Bay water level. As the fronts progressed, however, and winds rotated through the northwest and northeast, water was rapidly blown out of the Bay, with a corresponding drop in level at all four sites (Fig. 23). Ultimately, as winds shifted to the southeast, water was allowed to return to the Bay from the west. The weak lunar influence on water level at Eagle and Cross (Fig. 20) was completely overridden by these frontal systems. While Buchanan and Oyster maintained their lunar cycles, wind effects were clearly superimposed. During the front pictured in Fig. 23, Eagle suffered a 15 cm drop in bank top water level from the pre-frontal mean of 18 cm - an 83% reduction. Cross saw a low of 6 cm, 22 cm below the pre-frontal mean, or a 78% reduction in bank top water level. Water level at Buchanan dropped to 15 cm, but this decrease was only a 43% reduction. The lowest Buchanan tide during the front was 11 cm. Oyster's mean water level was reduced to 11 cm, a 30 cm drop or a reduction of 73%. Low tides reached a theoretical minimum of -25 cm (actual low was 5 cm, see below). Such fronts should have been particularly stressful for organisms on the Eagle and Cross banks, as mean water levels at these sites were lower than

those of Buchanan and Oyster. More importantly, because of the lack of a lunar cycle, these low levels were maintained for several days; there was no high tide respite (Fig. 23).

Fluctuation in water level during the wet season (Fig. 24) was markedly different from that of the dry season (Fig. 23). With reduced overall wind speeds ($\bar{x} = 2100$ knots/month, Fig. 9) and a greatly reduced northwest component (Fig. 10), major shifts in water level were infrequent. During the period illustrated in Fig. 24, Buchanan and Oyster maintained their lunar cycles (mean level = 24 cm; tidal range = ± 9 cm; and 47 ± 34 cm, respectively) which lacked wind-induced aberrancies. Traces from Eagle and Cross showed little flux throughout the wet season (respective ranges were 13 and 5 cm during the period in Fig. 24).

There was not always a direct relationship between bank water level and that of the surrounding basins. Water levels on the narrow Eagle, Cross, and Buchanan banks closely tracked recording gauge levels. At Oyster, however, low tide levels on the individual transects varied, at any point in time, both with respect to each other and the Murray Key Cut recording gauge. Superimposed traces of the permanent Oyster recording gauge (in Murray Key Cut) and temporary recording gauges on transects 2 and 5 illustrate (Fig. 25) the water-retentive capability of this broad bank. According to the cut gauge, water level should have fallen 7 cm below the sediment surface at transect 2, leaving it completely exposed. Instead, water level only dropped to 14 cm above the sediment. The less extreme low tide resulted in a low of 22 cm at transect 2, instead of the predicted 15 cm. Note that there was also a time lag between low tide in the cut and on the bank: 2 hr for the lower tide and 1 hr for the other.

The difference between water level in the basin and on the bank was

21 even more striking on the shallower transect 5 (Fig. 25). The low tide at 1900 stopped with 7 cm remaining on the bank instead of falling to -28 cm as indicated by the reference gauge. The 0500 low was +9 cm instead of -13 cm. There was a 3 hr time lag on the 1900 low and a 2 hr lag on the 0500 tide. Note that at this transect, but not the deeper transect 2, there was a 30 min time lag before the onset of flood tide as well. At both transects, water level dropped at the same rate as in the cut, up to a certain point, at which time the rate of flow markedly declined. Water level then slowly ebbed until the rising tide reached the top of the bank. High tides were identical on all three traces. Thus, a lens of water was held on these banks at low tide, allowing higher water levels on the bank than in adjacent basins.

Additional evidence of this lens came from concurrently reading staff gauges, set at 50 m intervals across transects 2,3, and 4 and into the northern basin (Fig. 26). At low tide, water level on top of the bank was 25 cm higher than in the basin. As the flood tide began, it piled water against the bank, creating a head that rapidly forced water onto and across the bank crest.

A number of studies report some degree of current velocity reduction by seagrass meadows (Ginsburg & Lowenstam 1958, Scoffin 1970, Zieman 1972 & 1982). Fonseca, *et al.* (1983) emphasize current velocity reduction within the seagrass canopy (but not above the vegetation), particularly in broad shallow meadows subject to relatively slow currents. The Oyster bank clearly fits such a scenario, with an area of several square km and maximum currents of $15 \text{ cm} \cdot \text{s}^{-1}$ (personal observation). As the tide fell, the remarkably tall seagrass canopy (see Vegetation Results) reached the surface of the water column, thus effectively slowing water movement off

the bank and allowing retention of a lens (Figs 25, 26).

Water Temperature

The highest temperature recorded during the study was 37.0°C at Cross in July, 1984, and the lowest was 7.5°C at Eagle in January, 1985. The mean monthly temperatures of the four sites tracked each other and air temperature closely (Fig. 27-31), and yearly means were similar across sites (Table 4). Monthly means for the four sites reached a minimum of 18.3°C in January, and a maximum of 29.8°C in August. Between October and April (dry season, Table 1, Fig. 27), air temperature was an average of 1.7°C higher than bank temperature. During the wet season, water temperatures coincided with air temperature.

The monthly temperature ranges were surprisingly uniform across sites (Figs. 28-32, Table 4) in view of the disparate mean water levels (Fig. 19), low tide levels (Fig. 22), and water level ranges (Figs. 20) of the four banks. Monthly temperature ranges were greatest in February ($\bar{x} = 18.0^\circ\text{C}$), decreased through the summer, and reached a minimum in October ($\bar{x} = 6.3$). Buchanan had the least range of all sites during the wet season and had the least overall mean monthly range (10.4°C). The other three sites had higher wet season and overall ranges. Eagle consistently had the greatest monthly range during the dry season and had the greatest overall monthly range (13.0°C). Cross, Oyster, and Buchanan had low dry season and overall ranges.

The mean daily water temperature ranges of Cross, Eagle, and Oyster were similar, while that of Buchanan was somewhat low ($\bar{x}$ for study = 3.5°C, Table 4, Fig. 33). Buchanan had the lowest mean daily range during all months of the year. Daily ranges, averaged over all sites,

were greatest in February and April ($\bar{x} = 5.7$ and 5.8°C , respectively) and lowest in October ($\bar{x} = 2.3^{\circ}\text{C}$). Seasonality of both monthly (Fig. 32) and mean daily (Fig. 33) water temperature range was probably a function of two factors: air temperature range and water level. Monthly and mean daily air temperature ranges were 20.0 and 6.5°C , respectively, in February. In October, however, these ranges were reduced to a minimal 9.0 and 3.5°C . Water level, in turn, was lowest in February ($\bar{x} = 22.5$ cm) and highest in October ($\bar{x} = 40.5$ cm). Thus, banks were insulated by deeper water from a minimal air temperature range in October; the inverse held in February, enhancing contrasts in the range of bank water temperatures. High February and low October water temperature ranges were the results.

The bank tops were more thermally stressed than the adjacent basins, as shown by concurrent traces of daily water and air temperature maxima and minima during June, 1984 (Fig. 34). Water temperature was recorded for both Cross Bank and the adjacent Cotton Key Basin, with respective June and July depths of 20 cm (Fig. 16) and 1.5 m. The basin showed a very narrow range (daily ranges $\leq 1.5^{\circ}\text{C}$; monthly range = 3.5°C) and little response to air temperature trends. In contrast, bank maxima and minima roughly tracked those of air temperature with daily ranges as great as 11°C . Bank mean daily range was 6.7°C and the monthly range was 15.5°C . Bank minima were lower than basin minima, at times by as much as 8°C . Bank maxima, however, dropped below basin maxima at times, and once even below the basin minimum during a cool spell. While a slow warming trend is apparent in mid-July (Fig. 35), the basin temperature range is again very conservative (daily ranges $\leq 2.0^{\circ}\text{C}$; monthly range = 4.5°C). Now, in the midst of summer, bank maxima and minima bracket those of the basin. Bank mean daily range was 8.1°C and monthly range was 12.5°C ; daily ranges

reached 11.5°C. High temperatures on six days were over 35°C. Roberts *et al.* (1982), with a gauge stationed 0.5 km from our basin station report very restricted basin ranges in January. They record a basin absolute temperature range of $\leq 2^{\circ}\text{C}$ despite an air temperature range of up to 16°C. At Cross bank, we found a mean daily bank top range of 5.0°C during the month of January.

Fig. 36 illustrates the hourly distribution of bank and basin daily maxima and minima during our two month summer period (Figs. 34, 35). Two bimodal distributions are apparent, with one for minima and one for maxima. The modes for bank and basin minima are 0500 and 0800, respectively, while those for maxima are 1400 and 1700. (Note that time of basin maxima occurrence was very conservative, with 80% of the peaks at 1700 and only five hours of the day represented.) Thus, in addition to thermal moderation, there was a 3 h time lag before temperature extremes occurred.

This buffering effect due to water depth was also seen at transect 1 of Cross bank (Fig. 37). This transect had a depth of 1 m, while the bank top (transect 2) was under about 25 cm of water. As in the previous series of traces, bank top water temperature was a direct result of atmospheric forcing. The side transect highs and lows were somewhat more moderate than those of the bank top. Bank top and side absolute ranges for this period were 16.0 and 14.3°C, respectively. Mean daily ranges were 4.1 and 2.0°C. There was a one-day time lag apparent for bank margin maxima and minima compared with those of the bank top and air temperature.

A recording gauge was set for short time periods at Oyster transect 4 (Fig. 7), where mean water level was about 1 m. This deeper transect's maxima and minima were bracketed by those of the shallower bank top (Fig. 38).

Absolute ranges on the bank top were 20.5 and 9.0°C for the February and May periods, respectively, but only 12.5 and 4.0°C at transect 4. Mean daily ranges were 5.9 and 5.1°C on the bank top in February and May and 2.9 and 2.0°C on the deeper transect.

Thus, bank top temperatures were more extreme and/or reached extremes more quickly than those of bank margins and basins. Water depths of only 0.25 m more than the bank tops had a noticeable buffering effect. In the deeper basins, temperature ranges were further decreased. The contrast in monthly and daily temperature range between Buchanan and the other sites (Table 4, Figs. 32, 33) may be related to the source of bank top water. Buchanan is a very narrow bank (Fig. 6) and typically had a rapid flow of water across its surface (personal observation). Water remained on top of this bank for only a short period of time. As a result of strong current and narrow width, the water covering Buchanan Bank would basically have been basin water, thus explaining its conservative daily and monthly temperature range.

12 The temporal distribution of Cross daily maxima and minima approach normal curves and are virtually mutually exclusive (Fig. 39), with 97% of the minima occurring from 2300-1000 hours while of the 99% maxima occurring between 1000 and 1900. Similar distributions were apparent at all four sites (Figs. 40, 41), although the curves defined by the Oyster and Buchanan distributions had a greater spread than those of Eagle and Cross.

Cross and Eagle had both a lower mean water level (Fig. 19) and a lesser tidal range (Figs. 15-18, 20) than Buchanan and Oyster. Because of their shallow depth, the former sites were more rapidly affected by atmospheric forcing than the two deeper sites, and water temperatures did not exhibit tide-induced fluctuations. The minimal temporal spread of

Cross and Eagle water temperature maxima and minima (Figs. 40, 41) was the result.

Buchanan and Oyster, however, had relatively high mean water levels (Fig. 19) and tidal fluctuation (Figs. 17, 18, 20). In turn, water temperature on these two banks responded slowly to air temperature changes at high tide, but rapidly at low tide. For example, at Oyster (Fig. 42) on January 20, air temperature reached a 24°C peak between 1100 and 1400, with the water maximum of 24°C at 1400, in conjunction with a low tide. Air temperature fell throughout the 21st. Water temperature, moderated by warm basin water at high tide, fell slowly at first, then precipitously as the bank was almost exposed at low tide, reaching a minimum of 16°C at 1100. Despite the lower and still plummeting air temperature, water temperature peaked at 1800, in response to the relatively warmer basin water brought onto the bank at high tide. Two similar water temperature minima and a maximum occurred early on the 22nd, each apparently in response to water level. With the onset of higher air temperatures, this relationship was again reversed; water temperature peaks were reached with low tides and troughs with high tides, because of the now relatively cool basin water. Minor low tides (those of short duration) resulted in minor water maxima (e.g. on the 23rd at 2300 and on the 24th at 2400). (Note that because of water temperature depression by the front, air temperature consistently remained above that of the bank water for two days; thus minor water peaks occurred even in darkness.) Higher water temperature peaks, however, occurred in conjunction with major low tides (e.g. on the 23rd at 1400, on the 24th at 1600, and on the 25th at 1600). This pattern was disrupted late on the 25th as air temperature again dropped. While maxima and minima generally occurred during the time of air extremes

(Figs. 42, 43), temporal position within the latter was determined by tide. Occasionally water temperature extremes occurred independently, in the absence of corresponding air temperature maxima or minima (e.g. Fig. 42, on the 23rd and 24th). This increased role of water level in water temperature determination caused a greater temporal spread of daily maxima and minima at Buchanan and Oyster than at Eagle and Cross (Figs. 40, 41).

Salinity

Cross, Buchanan, and Oyster salinities were quite similar (two year $\bar{x}$ = 36.3, 37.4, and 35.3 ppt, respectively) and showed a steady increase in salinity until late summer ($\bar{x}$ = 39.3 ppt), followed by decreasing salinities until the onset of the dry season (Fig. 44). Eagle had the greatest salinity range (20.5 ppt - 42.0 ppt during our sampling) with salinities dropping earlier in the summer and falling more precipitously than at other sites (a 19 ppt drop occurred between July and September, 1985). Eagle's salinity was the lowest of the four sites ($\bar{x}$ = 28.5).

The salinity fluctuations at Cross, Buchanan, and Oyster exemplified the Florida Bay scenario suggested by McCallum and Stockman (1959). While an inverse relationship between local precipitation and salinity would be expected, it does not usually occur. At the beginning of the wet season, salinity continues to rise as a result of several factors: (1) evaporation caused by high summer temperatures usually removes more water than provided by rainfall; (2) southerly winds and high oceanic water level (Ginsburg 1956) confine freshwater influx to the northeastern portion of the Bay; (3) mainland rainfall has not accumulated enough to rise above ground level. However, in late summer and early fall, the Bay becomes less saline, despite reduced precipitation, because: (1) temperatures

fall, reducing evaporation; (2) northerly winds combine with diminishing oceanic water level to respectively push and pull freshwater into the Bay; (3) enough mainland rainfall accumulates to bring the water table above ground level, facilitating sheet flow into the Bay. In their analysis of northwestern Florida Bay, Tabb *et al.* (1962b) do not find a relationship between salinity and local precipitation, but do find a positive salinity relationship with Tamiami Trail run off, with a three month time lag before a salinity reduction in the Bay (near our Oyster site).

Unlike the other three sites, Eagle is adjacent to the source of freshwater. Thus, the initial slow seepage of mainland water has an immediate effect at this northeastern site (Fig. 44), and salinities drop rapidly with the onset of the wet season.

RESULTS - VEGETATION

Thalassia testudinum Konig, *Halodule wrightii* Ascherson, and *Syringodium filiforme* Kützting are the characteristic seagrasses of South Florida (Zieman 1982). While all three species were collected by our study, *Thalassia* was by far the most common.

The 13 vegetation parameters (Fig. 45-57) generated from our grass data showed many significant inter-site differences (Tables 5, 6). Buchanan and, secondarily, Cross were the richest sites in terms of a number of vegetation parameters (Table 5). Buchanan had the greatest standing crop ($\bar{x} = 82.2 \text{ g} \cdot \text{m}^{-2}$) followed by Cross at 54.8 (Fig. 45). Eagle and Oyster were lower yet and not significantly different from each other. Shoot density (Fig. 46) was also greatest at Buchanan and Cross ($\bar{x} = 1135$ and $882 \text{ shoots} \cdot \text{m}^{-2}$, respectively). Eagle and Oyster were lower and not significantly different. Buchanan had the highest canopy density (total blades $\cdot \text{m}^{-2}$ of all seagrass species) ($\bar{x} = 3069 \text{ blades} \cdot \text{m}^{-2}$, Fig. 51), and the greatest leaf area ($\bar{x} = 1.21 \text{ m}^2 \cdot \text{m}^{-2}$, Fig. 52). Cross again followed with respective means of $2167 \text{ blades} \cdot \text{m}^{-2}$ and $0.87 \text{ m}^2 \cdot \text{m}^{-2}$. The two northern sites were again both lower and similar with regard to these two parameters. Number of *Thalassia* shoots $\cdot \text{m}^{-2}$ (Fig. 47), however, was significantly different at all four sites, though the site rankings were similar with a Buchanan mean of 1107; Cross, 866; Eagle, 633; and Oyster much lower with only 101 shoots $\cdot \text{m}^{-2}$.

While Buchanan was highest for the above parameters, Cross had the most seagrass litter ($\bar{x} = 1.24 \text{ kg} \cdot \text{m}^{-2}$, Fig. 56). Eagle followed with a mean of 0.40. Buchanan and Oyster had the least litter build-up and were not significantly different (Table 5).

Oyster had the greatest number of *Halodule* shoots* m^{-2} ($\bar{x}$ = 452, Fig. 48), the only *Syringodium* collected ($\bar{x}$ = 98 shoots* m^{-2} , Fig. 49), tallest canopy height (209 mm, Fig. 50), most *Thalassia* blades per shoot ($\bar{x}$ = 2.86, Fig. 53), and longest *Thalassia* blades ($\bar{x}$ = 231 mm, Fig. 54). There were no significant differences among the other three sites with regard to any of these parameters (Table 5). Oyster also had by far the widest *Thalassia* blades ($\bar{x}$ = 9.3 mm, Fig. 55), but the other sites did have significant differences. Oyster was followed by Buchanan ($\bar{x}$ = 5.8), then by Cross ($\bar{x}$ = 5.0) and Eagle ($\bar{x}$ = 4.4). Although drift algae appeared sporadically at all locations (Fig. 57), there were no significant differences between sites (Tables 5, 6).

For a number of vegetation parameters, there was a gradation in richness from the sheltered to the exposed side of banks. Standing crop (Fig. 45), overall shoot density (Fig. 46), *Thalassia* shoot density (Fig. 47), canopy height (Fig. 50), leaf area (Fig. 52), *Thalassia* length (Fig. 54), and litter (Fig. 56) followed a decreasing progression from transect 1 (sheltered) to transect 3 (exposed) at Buchanan (Table 7). Standing crop, canopy height, leaf area, *Thalassia* length, and litter fit the same pattern at Cross, and canopy height, *Thalassia* length, and litter decreased from transect 3 (sheltered) to transect 1 (exposed) at Eagle (Table 7).

Such clear trends were not evident at Oyster. Transect 1 had the greatest standing crop ($\bar{x}$ = 65.5 g* m^{-2} , Fig. 45), overall shoot density ($\bar{x}$ = 1526 shoots* m^{-2} , Fig. 46), *Halodule* density ($\bar{x}$ = 1168 shoots* m^{-2} , Fig. 48), canopy density ($\bar{x}$ = 3756 blades* m^{-2} , Fig. 51), and litter ($\bar{x}$ = 0.62 kg* m^{-2} , Fig. 56) over the two year study. Transect 5 also had very high overall shoot ($\bar{x}$ = 1934), *Halodule* ($\bar{x}$ = 1847),

and canopy ($\bar{x} = 4867$) densities during the one year (1985) that it was sampled (Table 8). Transect 2, however, had the lowest mean values for these latter three parameters over both the two-year period (341 shoot* m^{-2} , 215 shoots* m^{-2} , and 899 blades* m^{-2} , respectively) and in 1985 alone (414 shoots* m^{-2} ; 292 shoots* m^{-2} , 1157 blades* m^{-2} , respectively, Table 8). Drift algae (Fig. 56) was nearly absent ($\bar{x} = 3.9$ g* m^{-2}) from transect 2. *Syringodium* (Fig. 49) was also virtually absent at transect 2 ($\bar{x} = 44$ shoots* m^{-2}) and was never collected at transect 5; it was most prevalent on the deeper transects 1 and 4 ($\bar{x} = 250$ and 404, respectively), Transect 4 had the sparsest *Thalassia* ($\bar{x} = 3.8$ shoots* m^{-2} , Fig. 47) and least leaf area ($\bar{x} = 0.29$ m^2 * m^{-2} ; Fig. 52) of the five transects.

The representations of Cross and Eagle in the preceding figures are a composite of the two stations at each site (Table 3). These two stations showed some significant differences in vegetation. At Cross, the most prominent differences were apparent at transect 1 (Fig. 58). Transect 1 at the Central (B) station had a much greater standing crop, shoot density, and leaf area than the same transect at Cowpens (A), but a smaller litter load ($\bar{x} = 1.68$ kg at B and 2.79 at A; ANOVA, $p < 0.01$). There was not a significant difference with respect to canopy height and *Thalassia* width at transect 1. While there were some significant differences between vegetation parameters at the other two Cross transects, none were as striking as those at transect 1. Both stations demonstrated the same decreasing gradation in standing crop, canopy height, leaf area, *Thalassia* length, and litter evident in the combined data from the two stations (Figs. 45, 50, 52, 54, 56, Table 7).

At Eagle transect 1, all Pass Key (station A) parameters in Figure 59

were significantly higher than those at Eagle Key (station B) (ANOVA, $p < 0.01$). Of these six parameters, however, only litter showed a significant difference between the bank tops of Pass and Eagle Keys ($\bar{x} = 0.33$ and 0.50 kg, respectively). All parameters were again significantly different at transect 3. Pass Key had a higher standing crop, shoot density, leaf area, and litter weight. Eagle Key had a taller canopy and wider *Thalassia* blades. While the combined data from these two stations only showed canopy height, *Thalassia* length, and litter to follow a decreasing gradation from the sheltered (transect 3) to exposed (transect 1) side, this pattern is more pronounced at the Eagle (B) station. These three vegetation measures, plus standing crop and leaf area followed this trend at Eagle Key, while only canopy height had an analogous progression at Pass Key.

Significant seasonal differences were evident for all vegetation parameters except *Thalassia* and *Syringodium* density and drift algae weight (Table 6). A variety of parameters reached a low in January: standing crop (January $\bar{x} = 38.3$ g*m⁻², Fig. 45), *Halodule* shoot density ($\bar{x} = 106$ shoots*m⁻², Fig. 48), canopy height ($\bar{x} = 105$ mm, Fig. 50), canopy density ($\bar{x} = 1770$ blades*m⁻², Fig. 51), leaf area ($\bar{x} = 0.62$ m²*m⁻², Fig. 52), and *Thalassia* blades per shoot ($\bar{x} = 2.19$ blades*shoot⁻¹, Fig. 53). Accompanying these minima, however, was a corresponding January maximum in litter abundance ($\bar{x} = 0.79$ kg*m⁻², Fig. 56). *Thalassia* blades per shoot ($\bar{x} = 2.96$) and the associated canopy density ($\bar{x} = 2640$) were at their maximum in May, with September intermediate. Two vegetation parameters, *Thalassia* length ($\bar{x} = 113$ mm, Fig. 54) and the closely-linked canopy height ($\bar{x} = 146$, Fig. 50) exhibited maxima during the two September sampling periods. January and May were not significantly different for

these latter two measures.

Seagrass beds at our study sites were denser and richer in 1985 than 1984. Significant increases (Table 6) occurred in standing crop (Fig. 45), shoot density (Fig. 46), *Syringodium* density (Fig. 49), canopy density (Fig. 51), and leaf area (Fig. 52).

DISCUSSION - VEGETATION

Eagle was relatively depauperate in terms of vegetation and did not have the highest value for any of the 13 vegetation parameters (Table 5). It seems reasonable that *Thalassia* parameters in particular, and grass parameters in general, should be low at Eagle. This area occasionally suffers drastic salinity extremes (<10 to >60 ppt; Schmidt 1979) and a 15 ppt change in salinity may also occur in a space of several hours (J. Wagner, personal communication). There was a 20 ppt absolute salinity range at Eagle during 1985 (Fig. 44). This site is also very turbid (Zieman and Fourqurean 1985). Phillips (1960), den Hartog (1970), and Zieman (1975a), report optimum productivity for *Thalassia* in salinities between 24 and 35 ppt, with production decreasing markedly outside this range (Zieman 1975a). *Halodule*, however, is noted as being tolerant of salinity extremes (McMillan and Mosely 1967, Zieman and Fourqurean 1985). Zieman and Fourqurean (1985) also suggest, on the basis of depth limitation work of McMillan and Phillips (1979), that *Halodule* is less light limited than *Thalassia*. It therefore seems that *Halodule* should be prevalent at Eagle. Large bare areas occurred between the patchy meadows of *Thalassia* at this site, and some *Halodule* was present. Thus, space for, and a source of, colonizing plants were available. Nevertheless, *Thalassia* remained dominant (Fig. 47), with *Halodule* of negligible importance (Fig. 48) on this bank.

Buchanan, followed by Cross, had the highest values for several parameters related to, and including, standing crop and *Thalassia* density (Table 5, Figs. 45, 47). Cross, largely as a result of the litter sink at Cowpens (A) transect 1 (Fig. 58), had the greatest amount of dead seagrass blades (Fig. 56, Table 5). Cross and Eagle, with the most litter, also

21 had the lowest water level (Fig. 19) and least tidal range (Fig. 20), perhaps reducing litter export.

Oyster had the greatest *Halodule* (Fig. 48) and *Syringodium* (Fig. 49) densities and had the highest values for a suite of *Thalassia* blade growth parameters (Table 5). Oyster, however, also had a reduced standing crop (Fig. 45), *Thalassia* shoot density (Fig. 47), and leaf area (Fig. 52). The sparse *Thalassia* density resulted in low means for standing crop and leaf area, as these parameters are much more dependent on *Thalassia* densities than on those of *Halodule* or *Syringodium*. *Thalassia* was clearly of reduced importance at Oyster despite the fact that individual shoots were extremely robust. Why should *Thalassia* not be more dense in an environment that encourages such vigorous blade growth? It is possible that the coupling of sparse short shoots with extensive blade growth is a *Thalassia* growth strategy that ameliorates the effects of turbidity. This area is turbid throughout the year, while waters on analogous banks 3 km to the south (but also in the Gulf subenvironment) are generally clear (Zieman and Fourqurean 1985). These authors report the equivalent of a summer standing crop mean of $120 \text{ g} \cdot \text{m}^{-2}$ for these more southern banks (see below) while our Oyster mean (including only May and September sampling) was 44. In turn, the former banks have much denser *Thalassia* growth (personal observation).

Zieman and Fourqurean (1985) calculate total summer standing crop and area for the entire bank system of each of their subenvironments. When converted to values $\cdot \text{m}^{-2}$, the following means result: for the Northeast subenvironment, $33 \text{ g} \cdot \text{m}^{-2}$; East Central, 60; Atlantic, 90; and Gulf, 120. Our mean standing crop values (May and September) for Eagle (Northeast), Cross (East Central), and Buchanan (Atlantic) were 33.4, 60.0, and 90.0,

respectively - thus identical to those of Zieman and Fourqurean (1985). This striking agreement is rather remarkable in view of the intra-site variation present between our transects (Fig. 45) and stations (Figs. 58, 59). Our Oyster (Gulf subenvironment) standing crop ($\bar{x} = 44.1$) was only about 1/3 of Zieman and Fourqurean's value for the Gulf region (120). This dichotomy may be a result of varying turbidity or other factors and is an indication of the heterogeneity of the complex Gulf subenvironment.

At Buchanan, Cross, and Eagle there was, for many vegetation parameters, a progression in richness from one side of a bank to the other. These trends appear to be related to relative exposure to wind-induced wave action. Buchanan fit this pattern best, with 7 parameters, including shoot density, following the gradation (Table 7). Five parameters coincided at Cross, while only canopy height, *Thalassia* length and litter did so at Eagle. How does wave action effect these gradations in grass richness? It seems unlikely that seagrass on the exposed transects was less robust as a result of turbulence-induced breakage. Zieman (1975a) reports that usually less than 1% of *Thalassia* leaves are torn away from their shoots prior to senescence. It may be that the coarser sediments, on the exposed transects (Figs. 11-13), were inappropriate for maximal seagrass growth. Export of nutrients from exposed transects could further inhibit vegetation. It seems likely that litter accumulation was light on the exposed sides because: 1) there was less vegetation present to produce this material, and 2) litter that was produced would have been rapidly exported as a result of wave action. The dead blades would then come to rest on the sheltered transects, adding to the larger amount of litter already present due to lusher vegetation and limited export. A moderate litter accumulation could provide a source of

nutrients for living seagrass that would not occur on the litter-free exposed sides.

While a progression across transects was not apparent at Oyster, transects 1 and 5 generally had the most developed vegetation parameters. Although Oyster was very broad, and relatively sheltered as a whole, these two transects were more sheltered than 2, 3, and 4 (see Wind). It is notable that while transect 5 had high overall (Fig. 46), *Halodule* (Fig. 48), and canopy (Fig. 51) density, transect 2 (the other shallow transect), was lowest of the five for these three measures (Table 8). *Halodule* is typically found in shallow areas which do not support *Thalassia* or *Syringodium* (Zieman 1982). This species was clearly prevalent at transect 5, and it was found almost entirely on transect 2 at the other three sites (Fig. 48). Therefore, we cannot explain its absence from part of the Oyster bank top.

Thalassia was of reduced importance at Oyster in general, but was virtually absent from the deepest transect (4) (Fig. 47), thus explaining the very low leaf area on this transect (Fig. 52). *Syringodium* (Fig. 49) was common on transects 1 and 4 and was almost nonexistent at transects 2 and 5, a reflection of its ability to tolerate lower light levels (Zieman and Fourqurean 1985).

There were some differences apparent between the two stations at both Cross and Eagle. The major differences between the Cowpens (A) and Central (B) stations were at transect 1 (Fig. 58). The Central station had a greater standing crop, shoot density, and leaf area than did Cowpens, while the latter station had much more litter. Cowpens was quite sheltered (Fig. 4) particularly at transect 1. If litter tends to accumulate on the sheltered sides of banks, a particularly quiescent

transect such as this could become a litter sink. A tremendous quantity of litter did occur here. Could this massive accumulation inhibit shoot density? If so, litter accumulation could explain the higher levels of standing crop, shoot density, and leaf area at station B since *Thalassia* length (Fig. 54) and width (Fig. 55) were the same at the two stations.

At Eagle (Fig. 59) transect 1, all major parameters were significantly higher at station A (Pass Key) than at station B (Eagle Key). At transect 2, however, the stations were virtually identical (litter was higher at station B). Station A had higher standing crop, shoot density, leaf area, and litter than station B at transect 3, while the latter station had higher canopy height and wider *Thalassia*. The increasing progression of richness across the bank was very strong at Eagle Key, with standing crop and leaf area (two parameters that did not fit the progression in the combined station data) corresponding. The only measure which followed this gradation at Pass was canopy height. This dichotomy would again appear to be a function of varying wave exposure. Eagle Key was very sheltered (Fig. 3), particularly to the north and east. Pass, though relatively sheltered to the north, was exposed to more easterly wave action (Fig. 2), thus precluding a pronounced west to east (transect 1 to 3) increasing progression of vegetation richness.

Of the 13 vegetation parameters, only 3 failed to demonstrate significant differences between sampling periods: drift algae weight, and *Thalassia* and *Syringodium* density (Table 6). A number of seagrass parameters had their lowest values in January, with a concomitant maximum in litter (Figs. 56, 60). *Thalassia* exfoliates as temperature drops below 20°C (Phillips 1960, Sculthorpe 1967), and all sites had a mean temperature below 20°C during January (Fig. 27). Leaf loss and lower

productivity rates in January provide a likely explanation for the reduction of standing crop, canopy height, canopy density, leaf area, and blades per *Thalassia* shoot. The January maximum in litter accumulation was probably a result of shoot defoliation. *Thalassia* blades per shoot and the resulting canopy density were at their greatest in May, with September intermediate, while September saw the longest *Thalassia* blades and tallest canopy height. From June to September, mean bank temperatures were between 28 and 30°C (Fig. 27), the optimal temperature range for *Thalassia* productivity (Zieman 1975a, 1975b, 1982; Barber and Behrens 1985). Growth rates decline sharply on either side of this narrow range (Zieman 1975a, 1975b). High September blade lengths would therefore be expected.

While increased *Thalassia* growth was expressed in more and longer blades per shoot, *Halodule* increased the number of short shoots during May and September (Fig. 48). Such opportunistic shoot growth may be an adaptation to *Halodule's* role as a colonizer (Zieman 1982).

RESULTS - DEMERSAL COMMUNITY

Species Richness

A total of 57 species of fish, 49 species of decapods, and 2 stomatopod species were collected over the two year period (Tables 9, 10). Dominant fishes on the banks, in order of total abundance, were the gold spotted killifish (*Floridichthys carpio*), the rainwater killifish (*Lucania parva*), the gulf toadfish (*Opsanus beta*), the code goby (*Gobiosoma robustum*), and the fringed pipefish (*Anarchopterus criniger*). Dominant decapods were the grass shrimps *Thor floridanus*, *Periclimenes americanus*, *Hippolyte pleuracanthus*, and *P. longicaudatus*; the snapping shrimp *Alpheus heterochaelis*, the hermit crab *Pagurus mclaughlinae*, and the pink shrimp, *Penaeus duorarum*.

Species richness varied considerably among the four sites (Table 9). Eagle had the lowest number of fish species with only 19; Cross had 21, Buchanan 34, and Oyster 38. For crustaceans, Eagle again had the fewest species (11). Buchanan was the richest site, with 37 species, followed by Oyster with 36 and Cross with 20 (Table 10).

Species richness tended to follow consistent patterns among transects within sites. With fish, there were generally fewer species collected at the top (shallowest) transect of a bank than on the side transects (Fig. 61). At Oyster, the supplemental, shallowest transect (T5) had an average of 7 fish species per series, while transect 2 had an average of 13 species over the same three sampling series. These two transects had twice the sampling effort of the other transects (which could not be sampled at high tide); contrasts between the top and sides of the bank would likely be stronger if sampling effort was equal.

The number of fish species on either side of a bank tended to be similar except at Buchanan, where the exposed side (T3) had fewer species ($\bar{x} = 11$) than the sheltered side (T1, $\bar{x} = 15$), and Oyster, where transect 3 ($\bar{x} = 9$) had fewer species than transects 1 and 4 ($\bar{x} = 12$ at both).

For crustaceans, there were no consistent patterns in richness among transects across a bank (Fig. 62). About the same number of species were caught at each transect of each series at both Eagle ($\bar{x} = 5$) and Buchanan ($\bar{x} = 15$). At Cross, there were generally more decapod species at transect 1 ($\bar{x} = 11$), less at transect 2 ($\bar{x} = 9$), and fewest at transect 3 ($\bar{x} = 8$). At Oyster, transect 4 ($\bar{x} = 17$) generally had the highest decapod richness, while the other transects were similar ($\bar{x} = 14$). Again, the two shallow transects (T2 and T5) had twice the sampling effort.

Density Comparisons

Fish and decapod densities varied widely among sites, sampling series, and transects across a bank (Figs. 63, 64). Densities of 10 fish species and 13 decapod species were high enough at sites where they were present to allow meaningful comparisons. All 13 decapods tested were significantly different among the four sites (ANOVA, all $p < 0.001$, Table 11). A pattern of increasing abundance at the Eagle, Cross, Buchanan, and Oyster sites was observed for half the species tested. Eagle and Cross had significantly lower densities for all 13 species.

All fish species were also significantly different among sites (ANOVA, all $p < 0.001$, Table 12), but distribution patterns were varied. The two most abundant species overall (*Floridichthys carpio*, *Lucania parva*) had their highest densities at Cross bank. Buchanan had the highest densities of *Gobiosoma robustum*, *Anarchopterus criniger*, and

Callionymus pauciradiatus; the highest densities of *Syngnathus scovelli* and *Hippocampus zosterae* were at Oyster. While fewer fish species were caught at Eagle, three of the ten most abundant species had their greatest density here (*Anchoa mitchilli*, *Opsanus beta*, and *Microgobius gulosus*).

2 Fish densities among the transects of a bank followed consistent patterns within each site for many species. In general, the more common fish had lower densities or were absent from bank top transects and were more numerous on either or both sides of the bank. *Floridichthys carpio*, however, was consistently more abundant on top of the banks (Fig. 63a). *Opsanus beta* was more abundant on top of the bank at Buchanan, but was variable across transects at the other sites (Fig. 63b). The three syngnathids, *Syngnathus scovelli* (Fig. 63c), *Anarchopterus criniger* (Fig. 63d), and *Hippocampus zosterae* (Fig. 63e), the goby *Gobiosoma robustum* (Fig. 63f), and the killifish *Lucania parva* (Fig. 63g) were generally most abundant on the sheltered sides (T1 at Cross, Buchanan, and Oyster and T3 at Eagle). *Callionymus pauciradiatus* was caught almost exclusively at Buchanan, with high numbers on both sides of the bank (Fig. 63h). *Anchoa mitchilli* (Fig. 63i) was abundant only on the sheltered side of Eagle, and *Microgobius gulosus* (Fig. 63j) showed no obvious pattern. Multiple range tests showed significant differences across transects within a site for all species abundant enough to test (Table 13).

For the decapods, multiple range tests also showed significant differences across transects (Table 13), but the decapods showed even greater variability across sites. Grass shrimp (Figs. 64a-e), except *Periclimenes americanus* (Fig. 64f), were generally low in number on top of banks, as was the snapping shrimp *Alpheus normanni* (Fig. 64g). *Alpheus*

heterochaelis was generally low in abundance on the exposed sides of banks (Fig. 64h). *Penaeus duorarum* showed an overall decrease from transect 1 to transect 5 at Oyster, but was most abundant on top of the bank at Cross and Buchanan (Fig. 64i). All four crab species were most abundant on top of the bank at Buchanan, but low in abundance on top of banks at other sites (Figs. 64j-m).

Seasonal Differences

From the three sampling series collected during each of the two years it was possible to make limited analyses of seasonal trends (in terms of the three seasons defined for Florida Bay, Table 1) and year-to-year variation. All of the fish species except *Anchoa mitchilli* and *Microgobius gulosus* showed significant differences in population density among seasons (Table 14, ANOVA, $p < 0.05$). The general pattern followed was low abundance in January and high abundance in September. *Callionymus pauciradiatus* and *Gobiosoma robustum*, however, were least abundant in May sampling. Between-year variation was significant in six of the ten fish species (ANOVA, $p < 0.05$, Table 14). Five species increased in density during the second year of the study (1985) while *Gobiosoma robustum* decreased (Fig. 63f). These differences were relatively minor. The average density increase for the five species was by a factor of 2, and the overall densities of *Gobiosoma robustum* decreased by 50% in 1985.

Most of the common decapod species also exhibited both seasonal and between year differences in density (Table 15); for several species the differences were dramatic. Significant differences among the three sampling seasons were found for all the decapods except *Pagurus mclaughlinae*. The grass shrimp species were all most abundant in January,

except *Thor floridanus*. The latter species, along with *Penaeus duorarum*, *Alpheus heterochaelis*, and *Paguristes tortugae*, was most abundant in September. *Neopanope packardii* and *Alpheus normanni* were low in number in May, while *Callinectes ornatus* was most abundant in May.

Densities in 1985 were significantly higher than in 1984 for all grass shrimp species, *Alpheus normanni*, and *Penaeus duorarum* (ANOVA, $p < 0.05$, Table 15). The increase was minor in some cases and pronounced in others. At Eagle, no grass shrimp were collected on the first series. In the second series (May, 1984) a single *Hippolyte pleuracanthus* was caught. By series 6 (September, 1985) mean densities of *Thor floridanus* were as high as 242 m^{-2} (transect 1), comparable to densities at the other sites throughout the study.

During September 1985, conditions must have been optimal for *Thor*, as densities increased dramatically at several locations (Fig. 64a). At the top transect of Buchanan, *Thor* density reached over $1,000 \text{ m}^{-2}$ with a mean of 484 m^{-2} . Densities at Eagle increased to levels higher than at Cross bank, where density increases were moderate. At Oyster, however, *Thor* densities did show any increase.

The two *Periclimenes* species, *Tozeuma carolinense* and *Latreutes fucorum*, also showed dramatic differences in density, and paralleled each other (Fig. 64c-f). All were common only at the Oyster site and only during winter sampling. Densities in January, 1985 of these four species averaged 400% higher than in January, 1984. *Hippolyte pleuracanthus* also increased in January, 1985, but was common throughout the year, particularly at Oyster. Densities of *Alpheus normanni* were almost twice as high overall in 1985, and densities of *Penaeus duorarum* were three times as high, with much of the increase occurring in September.

Station Differences

Comparisons of the two stations within a site revealed several differences (Tables 16, 17, Figs. 65-68). At Eagle the total number of fish collected was significantly lower at Station B on transect 1 (ANOVA, $p < 0.01$), but no different on transects 2 or 3 (Fig. 65). While there were several significant differences between stations for individual species, they were inconsistent among transects. The total number of decapods at Eagle was significantly higher at station A (ANOVA, $p < 0.01$) across all three transects. Individual species were generally more abundant at station A, but again showed inconsistencies among transects. *Thor floridanus*, however, was much more abundant overall at station A ($\bar{x} = 59 \text{ m}^{-2}$) than at station B ($\bar{x} = 11$).

At Cross Bank, the total number of fish caught was higher at Station B on transect 1, no different on transect 2, and higher at station A on transect 3 (ANOVA, $p < 0.01$, Table 17, Fig. 67). Individual species tended to follow the same pattern as total fish. The decapods at Cross Bank also showed a mixture of patterns between the two stations (Fig. 68). Total decapods were higher at station B on transects 1 and 2, and higher at station A on transect 3 (ANOVA, $p < 0.01$, Table 17). On transect 1, *Thor floridanus* densities averaged 53 m^{-2} at station A and 213 m^{-2} at station B, but on transect 3 the means were 98 m^{-2} at station A and only 3 m^{-2} at station B. The increase in *Thor floridanus* densities at Cross throughout the study (Fig. 64a) was due almost solely to increased numbers at station B on transect 1 and station A on transect 3.

Patchiness

All of the fish species tested had mean patchiness indices greater than 1.0 and were thus patchy, except *Syngnathus floridae* (Table 18). The degree of aggregation was very similar and not high except for *Anchoa mitchilli* (I.P. = 3.87), a pelagic species with strong schooling behavior. Among the decapods, *Eucratopsis crassimanus* showed the greatest degree of patchiness, with an index of 2.89 (Table 19). *Portunus depressifrons* was evenly distributed (I.P. = 0.74); *Callinectes sapidus*, with an index of 1.00, was randomly distributed, and all other decapods were patchy. As in the fishes, patchiness indices were not particularly high, suggesting that aggregation within a transect was not intense.

Tidal comparisons

The densities of both fish and decapods captured in throw traps showed little or no response to changes in tide. Almost all species tested (8 fish and 12 decapods) showed no difference in densities between high and low tide at any of the five transects where comparisons were made (three at Buchanan, two at Oyster, Tables 20, 21). Additional sampling in January and February, 1985, designed specifically to test tidal differences, were included in the analysis. In the rare case of a significant difference between the two tide stages, the pattern was often the reverse of that expected, with higher densities on low tide than high tide. While there was typically wide variability among series, densities within a series were remarkably consistent between high tide and low tide (Figs. 69-72).

Oyster Bank Top Comparisons

The very shallow bank at transect 5 of Oyster was considered a special case of the Oyster conditions. Water depth is 29 cm shallower than on transect 2 and the pattern of water level rise and fall results in more extensive stress periods when the bank is "dry" except for a shallow lens less than 10 cm in depth (Fig. 25). Certain vegetation parameters differed between the two transects (Table 8), and most of the individual species were also significantly different (Table 22). The killifishes *Lucania parva* and *Floridichthys carpio* were both more than six times as abundant at transect 5, while transect 2 had higher densities of the other fish species and all the decapods tested except *Alpheus heterochaelis* (which showed no difference).

Effects of Cold Fronts

In January and February of 1985, additional sampling was conducted at transect 2 of Oyster following a cold front to examine the effects of resultant low water temperatures on the bank residents. Temperature profiles show the pattern of decline in water temperature as air temperature dropped (Fig. 43). One-way ANOVAs of the three sampling times (two for grass shrimp species) indicated few significant differences (Table 23). Those species declining in response to the cold front included *Opsanus beta*, *Alpheus normanni*, and *Penaeus duorarum*, while *Hippolyte pleuracanthus* increased following the front (Table 23, Figs. 71, 72). A sign test comparing the direction of change in densities of all species (including less common ones) captured at transect 2 of Oyster showed that more decapod species declined following the cold front (January 22) than can be expected by chance. This was also the case

between the regular January sampling (6 January) and additional sampling a month later, but there was no difference between the January 22 and February 5 densities. For fish species, the sign test did not show any significant trend in densities following the cold front.

Transect 5 at Oyster was sampled on January 9 and February 5. In contrast to transect 2, all species tested except *Gobiosoma robustum* experienced significant declines following the cold front (ANOVA, $p < 0.01$, Table 24, Figs. 71, 72). The shallower water at transect 5 probably resulted in even colder temperatures than at transect 2, with more clear-cut effects on the fauna.

Population Structure

Length-frequency distributions of the more abundant species (except grass shrimp, whose lengths were not measured) were compared among series (Figs. 73, 74). While our sampling regime did not allow comparison of size structure by month, the three sampling series did indicate differential recruitment to the populations.

In all of the fish species examined, smaller individuals were rare in winter. Recruitment in May was apparent for all species, although not consistent across years for *Syngnathus scovelli* (Fig. 73d) and *Callionymus pauciradiatus* (Fig. 73g). Recruitment continued in September sampling for all species, but to a lesser extent for *Anarchopterus criniger* (Fig. 73f). Both *Gobiosoma robustum* (Fig. 73b) and *Opsanus beta* (Fig. 73e) had a bimodal distribution in May but not in September, suggesting that the group of larger individuals had disappeared.

For decapods, recruitment was less apparent. Smaller individuals of *Alpheus normanni* (Fig. 74b) and *Callinectes ornatus* (Fig. 74e) were caught

in May and September but were not a major proportion of the population. *Penaeus duorarum* showed strong recruitment in May and September of 1985, but little recruitment in 1984 (Fig. 74c). In *Alpheus heterochaelis*, size structure varied little across all six sampling series (Fig. 74a). While there was evidence of some recruitment of *Neopanope packardii* (Fig. 74d) in September, 1985, distributions of the other species revealed no patterns.

Regression Analyses

The importance of the habitat parameters available in stepwise multiple regressions varied according to the species being tested (Table 25). In general, each final equation incorporated a large number of independent variables, suggesting a complex relationship of organism densities with microhabitat. The individual contribution of each variable to explanation of variation in the density of the species in question was typically small, but their combined influence generally resulted in a high R^2 value. The shared explanation of variance, based on the independent variables taken as a suite, was usually greater than the summation of the individual explanations of variance unique to each variable. Intercorrelations of variables were generally small, except among closely associated seagrass parameters and among season-related variables (Table 26).

Physical properties of tidal range, season, sediment characteristics, range of temperature, and salinity often figured prominently in the equations. Important grass variables included standing crop, canopy height, and litter weight.

In the equation for all fish species combined, the highest sr^2 was

with litter weight, and the next highest was with the dummy variable "winter", reflecting the overall lower numbers of fish caught in January sampling (Table 25a). The sum of unique contributions of the independent variables in explaining variance was much lower than the shared contribution, suggesting a high intercorrelation of the available variables.

Floridichthys carpio was generally limited to the more shallow areas of the banks, resulting in a strong relationship with water depth, which explained 25.7% of the variation in the fish's density (Table 25b). The sum of unique variances for this species was greater than R^2 , suggesting the operation of a suppressor variable (Tabachnick and Fidell 1983). For example, the dummy variable "spring" had a much higher beta weight than its simple correlation with *Floridichthys carpio*, and may have acted to suppress irrelevant variance in the other independent variables.

For *Lucania parva* (Table 25c) and *Opsanus beta* (Table 25d), the highest sr^2 value was with tide, and the relationship was negative. For both species there was a high simple correlation with litter weight, but the importance of litter decreased after the other independent variables had been taken into account.

For *Anarchopterus criniger* (Table 25e) and *Gobiosoma robustum* (Table 25f), the highest simple correlation and highest sr^2 were with standing crop. The decline of *G. robustum* from 1984 to 1985 was evident in the negative relationship with the dummy variable "year".

Only three independent variables were significant in the equation for *Hippocampus zosterae*: tide, depth, and winter (Table 25g). The resulting R^2 value was relatively low, suggesting that the independent variables available were insufficient in explaining much of the variation in this

species. Tidal range alone, however, explained 10.8 percent of the variance.

Decapods generally had higher R^2 values than those for fish species. For total decapods (dominated by grass shrimp) tidal range explained 14.8% of the variance (Table 25h). Individual species showing tidal range as the most important habitat variable (based on sr^2 values) included *Penaeus duorarum* (Table 25i), *Periclimenes americanus* (Table 25j, *Periclimenes longicaudatus* (Table 25k), *Hippolyte pleuracanthus* (Table 25l, and *Pagurus mclaughlinae* (Table 25m). For the latter species, tidal range explained 27.5% of the variation in its abundance. All of the above species were most abundant at Oyster, where the overall mean change in water level during a tidal cycle was 70 cm.

For *Penaeus duorarum*, a wide variety of variables in addition to tide were included in the final regression equation (Table 25i). Much of the explanation of variance was shared among the variables, but the resulting R^2 was high (.638), indicating that these habitat parameters were the appropriate ones to measure for this species. *Hippolyte pleuracanthus* also had several contributing variables and a high R^2 (.653) (Table 25l).

Equations for the two *Periclimenes* species had only physical parameters entered (Tables 25j, k). The different vegetation parameters apparently had no influence on densities of these two grass shrimp, once physical parameters were considered. For *Thor floridanus*, the highest sr^2 was with year, reflecting the tremendous increase in the density of this species in 1985 over 1984 (Table 25h). The highest simple correlation for *Thor* was with standing crop, but the increase in standing crop from 1984 to 1985 was apparently insufficient to explain the concurrent jump in *Thor* densities.

For *Alpheus heterochaelis*, the highest sr^2 (.11) was with the percentage of silt in the sediment, indicating a preference for finely grained sediments (Table 25o). For both *Alpheus normanni* (Table 25p) and *Neopanope packardii* (Table 25q), the percentage of organic content in the sediment was the most important habitat variable. The relationship was not strong for either species, and both had relatively low R^2 values.

DISCUSSION - DEMERSAL COMMUNITY

Densities of fish and decapods on the banks in Florida Bay far exceeded those reported from some other seagrass habitats. For example, Bauer (1985) found caridean densities of 16m^{-2} by day and 49m^{-2} at night in Puerto Rico seagrass beds, and stated that these levels were much higher than in previous studies. In the present study, the overall mean density of *Thor floridanus* alone was 64m^{-2} , and at the Buchanan site its mean for the entire study was 109m^{-2} . The mean number of fish (all species combined) was 11m^{-2} on Florida Bay banks, but only 1m^{-2} in Australian seagrass beds (Robertson 1980).

Much of the difference in densities may be related to sampling methods. With each throw trap sample, a 1 m^2 area is thoroughly cleared of fish and decapods. Sampling efficiency is as complete as possible, and much greater than that possible with trawls, seines, pushnets, or drop nets covering larger areas. Many of the animals caught were removed only after digging into the sediment with the scoop net. The drawback is that throw trap sampling is time-consuming, and the amount of area that can be sampled is limited. The estimated densities reported here, however, should be very accurate. Campos and Berkeley (1985) tested the efficiency of an electric pulse trawl for sampling pink shrimp (*Penaeus duorarum*), using throw trap samples as a standard. Density estimates based on the electric trawl, were 8.1 times higher than estimates from the catch of a standard roller frame trawl, but 2.7 times lower than estimates based on throw trap samples. For pink shrimp, then, throw traps were almost 22 times more efficient than a standard trawl.

Species Composition

Based on an extensive study of northwestern Florida Bay and associated estuaries, Tabb *et al.* (1962b) concluded that the fauna of the Bay is largely Carolinian (temperate) in nature. Our results show strong support for this conclusion and, in turn, reflect the importance of communication with different water masses. Fish collections by Springer and McErlean (1962) in shallow seagrass meadows on the Atlantic side of the Florida Keys, and studies in shoreline grassbeds of nearby Biscayne Bay (Sogard 1982, Low 1973) reveal a number of more tropical species not found on banks in Florida Bay. Notable among these species are the parrotfishes (Scaridae), scorpionfishes (Scorpaenidae), cardinal fish (*Astrapogon* sp.), surgeonfishes (Acanthuridae), clingfishes (Gobiesocidae), wrasses (Labridae) and additional species of the Gobiidae and Clinidae families.

The dominance of Florida Bay's bank fauna by Carolinian-temperate rather than Antillean-tropical species may be related to two environmental factors - lower water temperatures due to shallow depths and the lack of significant interchange with Atlantic water. The expanse of shallow, minimally flushed water in Florida Bay results in colder winter temperatures for more extended periods of time than adjacent areas exposed to the same air temperatures. Hudson *et al.* (1976) attribute a massive death of corals at Hens and Chickens reef to outwelling of cold water from Florida Bay. Temperature profiles during a cold front, based on satellite imagery, show a sharp increase of over 8°C between Florida Bay and the Gulf Stream (Roberts *et al.* 1982).

The occurrence of several "tropical" species (*Callionymus pauciradiatus*, *Ahlia egmontis*, *Cosmocampus albirostris*, *Sparisoma* sp.,

Paraclinus sp., *Meiosquilla quadridens*, and *Pseudosquilla ciliata*) primarily or exclusively at the Buchanan site, where there is substantial exchange with Atlantic water, suggests that restricted water exchange also limits the pool of species available to colonize more interior parts of the Bay. Of the decapods, several species (*Mithrax forceps*, *Microphrys bicornutus*, *Alpheus armillatus*, and *Calappa* sp.) that are common residents of shallow habitats on the Atlantic side of the Florida Keys occurred exclusively at Buchanan. These areas outside the Bay are a likely source for the rare individuals at Buchanan. At Cross, where there is still some minimal exchange with Atlantic water, tropical species occurred occasionally, but did not become established residents. The Eagle site, which is most isolated in terms of water exchange, had the smallest number of crustacean and fish species, and none of the occasional tropical species. There was no evidence of invasion by more tropical forms during periods of more benign temperatures (the case most of the year), further supporting the importance of water exchange as a dispersal mechanism. At Oyster, exchange with Gulf water was reflected in the high diversity of fishes and decapods, which were dominated by temperate species.

Several other factors contribute to the heterogeneity of bank organisms among the four sites. The low species richness at Eagle may in part be due to the greater range in salinity that the area experiences. Species intolerant of more estuarine salinities would not be expected at this site, where we recorded salinities from 20 to 42 ppt. Species that were abundant primarily at Eagle included the clown goby (*Microgobius gulosus*), bay anchovy (*Anchoa mitchilli*), and the xanthids *Panopeus herbstii* and *Rithropanopeus harrisi*. Tabb *et al.* (1962b) found that the latter species normally occurs only in salinities below 15-20 ppt. While

Rithropanopeus declined in numbers in 1985 compared to 1984 (see Fig. 44 for salinity information), it was still present at Eagle in May, 1985, when the mean salinity was 39 ppt, and was most abundant in May, 1984, at a salinity of 30 ppt. In general, the species present at Eagle did not show predictable responses to variation in salinity over the two year tenure of our study.

The salinity range we recorded, however, was conservative compared to ranges previously reported in Florida Bay. Between September, 1974 and September, 1976, Schmidt (1979) recorded salinities from 8.0 ppt (Little Madeira Bay) to 64.8 ppt (Madeira Bay). In 1965 and 1966, Tabb (personal communication) found salinities as low as 0.5 ppt (northeastern bays adjacent to U.S. 1) and higher than 65 ppt (Snake Bight). By comparison, 1984 and 1985 were both very moderate. Animal populations are probably influenced by prior, long-term salinity regimes as much as current absolute values. With our limited database on salinities, we can speculate that the observed extremes in grass shrimp density at Eagle were due to a recovery from a period of extended low salinities, but need protracted monitoring of both salinity and animal densities to accurately evaluate the impacts of salinity fluctuations and long periods of low or high salinities.

Habitat parameters other than salinity influenced fish and decapod densities both within and across sites. Several parameters indicated lower habitat quality in the Eagle area. Seagrass beds were on the whole less dense than at Cross or Buchanan, and *Thalassia* blades were short and narrow, compared to the long, wide blades present at Oyster. With this reduction in cover, protection from predation was probably also reduced (Heck and Thoman 1981, Nelson 1979, Coen *et al.* 1981). Eagle sediments

were similar to Oyster in physical structure, but the percentage of organic material was much lower, perhaps indicating lower concentrations of detritivorous micro-organisms at the base of the grassbed food web.

Results of multiple regression analyses pointed to several physical parameters as important determinants of animal densities on a Bay-wide basis. On these shallow banks, the physical environment plays as important a role as seagrass parameters in determining animal densities. Range in water level (tide) was a significant factor in the regression equations for all of the species tested except *Floridichthys carpio*. Mean water level (depth) was also an important factor for many species, as was range in water temperature, which was influenced by both depth and tidal flux. Differences in water level of less than 1 m, as between the top and sides of a bank, resulted in significant differences in species composition and densities.

Comparison of the two shallow transects at Oyster (2 and 5) revealed several significant differences in the fauna. While there were some differences in seagrass parameters (Table 8, the major difference between the two areas was mean water level. For *Floridichthys* and *Lucania*, the very shallow depth at transect 5 appeared to provide a refuge, as these species were much denser here than at transect 2. The daily "exposure" of the grassbeds at Transect 5 for several hours at a time either limited or excluded most other species.

The importance of the lens of water retained by the seagrass cover at Oyster (Figs. 25, 26) is obvious. While temperatures can be extreme, the hazards of dessication are greatly decreased, and the more tolerant species can remain on the bank throughout the tidal cycle, avoiding the risks entailed in migrating on and off banks with the tide. Without seagrass

cover to impede water flow, the banks would become dry at low tide, and very few species would be able to inhabit them.

The fact that there was no difference in density between high tide and low tide across all species tested on all transects where comparisons were made (Tables 20, 21; Figs. 69-72), suggests that the risks of migrating on and off the bank are substantial. Those species that cannot tolerate conditions on top of the bank at low tide simply do not occur there at any time. More decapod species than fish species inhabit bank tops relative to bank sides (Figs. 61, 62). Many of these decapods are burrowing species, and may be insulated from temperature extremes by the overlying sediment.

Decapods, however, rather than fish seemed most affected by cold fronts passing through Florida Bay. Our limited amount of post-front sampling did not adequately assess the effects on the bank community, but did demonstrate a trend of decreasing abundance, particularly among some shrimp species. Tabb *et al.* (1962a) also found a decline in *Penaeus duorarum* with decreasing temperature and concluded that pink shrimp move into deeper, warmer water. Severe cold fronts can result in mass mortalities of a variety of fishes in Florida Bay (Tabb *et al.* 1962b), and may stun fish to the point that they become easy prey for piscivorous birds (personal observation). The influence of water level is also apparent, as there were more significant declines in density following the front at transect 5 of Oyster than at transect 2 (Tables 23, 24).

Several studies link species densities to seagrass parameters of shoot density, growth form, species composition, and biomass (Stoner 1983a, Stoner 1983b, Heck and Orth 1980, Heck and Wetstone 1977). In Florida Bay, variation in the physical environment resulted in strong

differences in seagrass growth within close geographical locations (i.e. across a bank). The influence of these differences on densities of demersal fish and decapods are straightforward when comparing the two side transects of a bank (1 and 3 in Figs. 61-64), where depth, temperature, and salinity are the same, but grass density and form is very different. At the two southern Florida Bay sites (Buchanan and Cross) the exposed side of the bank, with its short, sparse grass, was inhabited by far fewer species and individuals than the sheltered side. At station A of Eagle, windward and leeward distinctions were not as apparent as they were at station B. Consequently, differences between transects in seagrass growth and animal densities were not as strong at station A. At Oyster, the broad expanse of bank dampens the influence of wind but a gradient in increasing sediment fineness from north to south is evident. The protected southern end of the bank was a rich area of tall, dense, mixed stands of seagrass, high litter accumulation, and some of the densest animal populations in the Bay.

When examined on a Bay-wide basis, the density of organisms on the banks was related to a suite of physical and biological habitat parameters (Table 25). While individual factors often made only minor contributions to explaining the variation in density of a particular species, several factors were consistently important across species. Among these were the previously discussed factors of water level, standing crop of seagrass, amount of litter present, amount of organic content in the sediment, size composition of sediment, canopy height, and salinity. Leaf area, found to be an important determinant of amphipod density by Stoner (1983a), was rarely incorporated into regression relationships once the influence of other grass parameters had been taken into account.

Standing crop and canopy height were the most important seagrass parameters on an overall basis. With different species of seagrass and different growth forms, a wide variety of shoot densities can result in similar standing crop levels. Heck and Orth (1980) maintain that above ground biomass of seagrass is the most important factor influencing animal densities. For Florida Bay banks we would add litter weight and canopy height and emphasize the initial importance of physical parameters.

RESULTS - PELAGIC COMMUNITY

Species Richness

A total of 71 species of fish were caught by gillnetting over the two years of the study (Table 27). In terms of species present, the two northern Bay sites closely resembled each other, as did the two southern Bay sites. Cross and Buchanan were distinctive in the species that they did not have, or of which few were caught, including catfish (*Arius felis*), striped mullet (*Mugil cephalus*), silver mullet (*Mugil curema*), and all sciaenids. These species were all common at the northern sites.

In contrast to throw trap results, the number of species captured at Eagle, Cross, and Buchanan was about the same (34, 33, and 38 respectively). The results of our first series of gillnetting at Buchanan (March, 1984) surprised us both in the number of species caught and the very low capture rate of all species. We speculated that the presence of another bank parallel to the site was restricting movement of fish onto our bank, and moved the site to a point more open to the adjacent basin. In the July, 1984 series both locations were sampled concurrently. The total catch at the new location was higher, but the species caught differed little; 12 species and 176 individuals were caught at the new location, while 14 species and 65 individuals were caught at the old location. The increased numbers at the new location were due primarily to silver jennys and pinfish. We concluded that the low diversity at Buchanan was an accurate portrayal of the bank.

The Oyster location stood alone in both the number of species (54) and number of individuals caught. Additional species included several species of sciaenids, carangids, and sparids, and occasional large fishes

such as the guitarfish (*Rhinobatos lentiginosus*), bluefish (*Pomatomus saltatrix*), cobia (*Rachycentron canadum*), and gulf flounder (*Paralichthyes albigutta*).

Site and Series Differences

The mean catch per half hour check of the more common species varied widely among sites and sampling series (Fig. 75). In general, Oyster had substantially higher catches than the other sites. The more abundant species are described here in order of abundance. The most common species, the silver jenny (*Eucinostomus gula*), dominated the catch at all four sites. It was particularly abundant in March, 1984 at Cross and March, 1985 at Oyster but was present on the banks year-round (Fig. 75b).

The next most common species, the sea catfish (*Arius felis*), was common at Eagle and very abundant at Oyster, but relatively rare at Cross and Buchanan (Fig. 75c). Catfish declined in summer sampling at Oyster, but increased at Eagle.

The fantail mullet (*Mugil trichodon*) was an important species at all sites except Eagle (Fig. 75d). Like several species, its catch was lower during the two July sampling series.

Atlantic thread herring (*Opisthonema oglinum*) were rare at Eagle and very common at Cross bank (Fig. 75e). They were abundant only during March sampling.

Pinfish (*Lagodon rhomboides*), were important at all sites except Eagle and showed no consistent seasonal trends (Fig. 75f). They declined in number from 1984 to 1985 across all sites.

Striped mullet (*Mugil cephalus*) occurred primarily at Oyster, with minor numbers at Eagle (Fig. 75g). From 1984 to 1985 they increased

substantially at Oyster but decreased at Eagle. They were abundant through all series.

Scaled sardines (*Harengula jaguana*) were abundant at Cross and Buchanan, with high numbers caught in November at Buchanan (Fig. 75h). They were generally low in abundance in July.

The silver perch (*Bairdiella chrysoura*) was strictly an Oyster species (Fig. 75i). The catch was relatively low in July and high in November. While silver perch increased from March, 1984 to March, 1985, they decreased from July, 1984 to July, 1985.

Silver mullet (*Mugil curema*) were rare at Buchanan and common at Oyster, with Eagle and Cross intermediate (Fig. 75j). They were most abundant overall in November.

The redfin needlefish (*Strongylura notata*) occurred at all sites, though in lower numbers at Eagle (Fig. 75k). It was one of the few species with a high catch in July across sites. Few were caught during November sampling.

Gray snapper (*Lutjanus griseus*) occurred at all sites, but were most abundant at Oyster (Fig. 75l). March catches of this species were low, July catches intermediate, and November catches high.

The ladyfish (*Elops saurus*) was also most abundant at Oyster (Fig. 75m). It was relatively low in number during July sampling.

The spotted seatrout (*Cynoscion nebulosus*) was caught primarily at Oyster (Fig. 75n). It was most abundant there in November, and least abundant in July. At Eagle, seatrout were most abundant in July of 1984, but were not caught in either series of 1985.

The bluestriped grunt (*Haemulon sciurus*) was one of two species caught that was more abundant at Buchanan than the other sites (Fig. 75o).

It was also present at Cross, but absent at Eagle and Oyster. It increased at Buchanan from 1984 to 1985 and the highest catch was in November.

Crevalle jacks (*Caranx hippos*) were relatively abundant in March, 1984 at Oyster, but present only in low numbers at other times and other sites (Fig. 75p).

Pigfish (*Orthopristes chrysoptera*) occurred in low numbers at all sites other than Eagle, where they were absent (Fig. 75q). Unlike most of the species, pigfish were most abundant overall in July.

Halfbeaks (*Hyporhamphus unifasciatus*) occurred almost solely at Oyster (Fig. 75r). The catch was low in November, and declined from 1984 to 1985.

Every species tested showed a significant difference in catch among the four sites (ANOVA, $p < 0.01$, Table 28). Oyster was significantly higher than all three other sites (SNK multiple range test, $\alpha = 0.05$) for the following groups: total fish, sea catfish, silver jennys, all three mullet species, silver perch, spotted seatrout, spot (*Leiostomus xanthurus*), pigfish, crevalle jacks, gray snappers, ladyfish, and halfbeaks. The few cases in which the catch was significantly greater at a site other than Oyster included scaled sardines at Cross and Buchanan, thread herring at Cross, barracuda (*Sphyraena barracuda*) at Cross, and bluestriped grunts at Cross and Buchanan.

The number of species captured on each series declined during summer sampling at all sites except Eagle (Fig. 76). Species showing a general decline in July included silver perch, thread herring, scaled sardines, fantail mullet, and silver mullet. Species that contributed to the increased number of fish in summer at Eagle included silver jennys, sea

catfish, and thread herrings (primarily small juveniles).

A general decrease in catch from 1984 to 1985 was observed in pinfish, thread herring, and sea catfish. Catches of striped and fantail mullet, on the other hand, increased in 1985 over 1984. Other species showed inconsistent seasonal and yearly trends.

Diel Activity

Most species showed a diel pattern in their activity on the banks (Fig. 77). For total fish, combining all species, there were slight peaks at dawn, dusk, and just after dusk (Fig. 77a). In general, however, the total catch was evenly distributed throughout day and night. Diurnal species included silver jenny (Fig. 77b), pinfish (Fig. 77c), and striped mullet (Fig. 77d). All three increased in number at dawn and dusk. Those species that were active primarily at night were sea catfish (Fig. 77e), fantail mullet (Fig. 77f), thread herring (Fig. 77g), scaled sardine (Fig. 77h), silver perch (Fig. 77i), gray snapper (Fig. 77j), ladyfish (Fig. 77k), bluestriped grunt (Fig. 77l), halfbeak (Fig. 77m), and pigfish (Fig. 77n). Most of these species showed a sharp increase in number at dusk, high catches continuing through the first hours after dark, and then a decline in catch through the night. Many had a secondary peak at dawn. Several species showed no apparent diel pattern, and were caught both during the day and at night, including silver mullet (Fig. 77o), crevalle jack (Fig. 77p), spotted seatrout (Fig. 77q), and redfin needlefish (Fig. 77r). Except for the needlefish, their catches also increased at dawn and dusk.

Effect of Tidal Stages

Several species showed a pattern of activity related to tidal state (Fig. 78). Pigfish (Fig. 78a), sea catfish (Fig. 78b), and scaled sardine (Fig. 78c) centered around high tide, occurring primarily on the "second rise" and "first fall" stages. Thread herring (Fig. 78d), pinfish (Fig. 78e), silver perch (Fig. 78f), gray snapper (Fig. 78g), crevalle jacks (Fig. 78h), and to a lesser extent, silver mullet (Fig. 78i) and ladyfish (Fig. 78j), occurred primarily on the "first fall" stage, as water began to recede from the bank. The bluestriped grunt (Fig. 78k) concentrated its activity on the bank in the hours before high tide, on the "second rise" stage. Striped mullet (Fig. 78l), fantail mullet (Fig. 78m), and needlefish (Fig. 78n) centered their activity around low tide, occurring primarily on the "second fall" and "first rise" stages. Silver jennys occurred on either side of low tide at night, but did not show any obvious pattern by day (Fig. 78o). Halfbeaks (Fig. 78p) and spotted seatrout (Fig. 78q) occurred primarily on the outgoing tide, on both first and second fall. When the total of all species combined is considered, there is little difference in the percentage caught on each tidal stage and little change between day and night (Fig. 78r).

Population Structure

Size frequency distributions of the ten most common species collected in gillnets are shown in Fig. 79. For most species there was little difference in the size distribution among series. The apparently bimodal distributions of silver jennys (Fig. 79a), pinfish (Fig. 79b), fantail mullet (Fig. 79c), and silver mullet (Fig. 79d) may be due to different capture efficiencies of the four mesh sizes. In general, however, the

size range of most species was adequately covered by the mesh sizes used (Table 29).

Atlantic thread herring were low in number in July (Fig. 75e) and those individuals that were caught were small (Fig. 79e). Smaller individuals of scaled sardine predominated in the July, 1985 catch but were few in number in the July, 1984 catch.

For the other species examined, there was little evidence of recruitment during any season. These fish are present in a similar size distribution (as caught by our nets) throughout the sampling seasons.

DISCUSSION - PELAGIC COMMUNITY

While gillnetting did not allow quantification of densities, as the throw traps did, it did provide a valid means of relative comparison among sites and seasons. Random encounters of fish with the net are likely, but consistent patterns in the catch reflect real patterns in the activity of fish on the banks. The gillnet catch reveals differences in species composition and changes in the relative importance of individual species among sites, but does not indicate relative importance within a site. Different species probably vary considerably in their catchability, due to the mesh sizes used, body morphology, and behavior.

We interpreted the gillnet catches as indicating general movement on and off the banks. Descriptions of diel patterns refer only to the activity of the fish on the sides of the banks (where the nets were positioned). We do not know how far onto the bank individuals move, nor what their activity patterns and abundances are in adjacent basins.

While the smallest mesh size used here (13 mm stretch) may have missed smaller individuals of all species, and the largest mesh (32 mm stretch) missed larger individuals, the four mesh sizes used appeared to adequately cover the size range of the more abundant species occurring on the banks (Table 29). For *Eucinostomus gula* and *Strongylura notata* the majority of individuals was caught in the smallest mesh, suggesting that smaller sizes were under-represented. For *Arius felis* and *Mugil cephalus*, a large number of fish were caught in the largest mesh size, and we may have missed many larger individuals of the population.

Species captured by gillnets reflected a Carolinian-temperate origin to an even greater degree than those captured by throw traps. Fish collected at both Buchanan and Cross banks reflected the influence of

exchange with Atlantic water and the potential source of more tropical species. This influence was minor, however, being apparent only with the greater number of grunt species (*Haemulon* spp.), and the capture of bonefish (*Albula vulpes*), ballyhoo (*Hemiramphus brasiliensis*), hound fish (*Tylosurus crocodilus*), and a single serranid (*Diplectrum bivittatum*). There was no apparent diel migration from offshore areas into Florida Bay at night and little evidence of stray occurrences of ocean side species.

The tremendous difference in both diversity and total catch between Oyster and the other sites may be related to several factors. The much greater tidal flushing (Fig. 19) appears to stimulate activity of pelagic fish, and the proximity of the Oyster bank to the Gulf provides a rich pool of Gulf species. The bank is a wide, extensive foraging ground (approximately 2 km in width), providing much more area than available on narrow banks (40 to 70 m wide at our other three sites). Perhaps one of the most viable hypotheses is the richness of available prey. The pink shrimp (*Penaeus duorarum*) is an important diet item for many of the species caught by gillnets, including gray snapper (Rutherford *et al.* 1983), ladyfish (Darnell 1958), sea catfish (Harris and Rose 1968), spotted seatrout (Tabb 1961, Rutherford *et al.* 1982), red drum (Yokel 1966) and others noted by Odum *et al.* (1982). Pink shrimp were present at Oyster in high densities, especially in early fall and winter (Fig. 64i). While the contribution of small grass shrimp (*Thor*, *Hippolyte*, and *Periclimenes* sp.) to diets of these fishes is unknown, they may be important prey for fishes such as silver perch and some haemulids.

The number of species and abundance of fish at Eagle were much lower than at Oyster, but the two sites were similar in species composition and distribution. Likewise, Cross and Buchanan were more similar to each

other than to Eagle and Oyster. This contrast between northern and southern Florida Bay may in part be due to the proximity of the northern sites (Eagle and Oyster) to the mainland and more estuarine waters along the extensive mangrove coastline. Turbidity at these two sites was typically much greater than at Cross and Buchanan, where water clarity was high (personal observation and Zieman and Fourqurean 1985). The sediment structure also differed between northern and southern Bay sites. At Oyster and Eagle, the sediment was much finer, with a minimum of 53% in the silt-clay fraction (Figs. 11, 13). For bottom feeding detritivores like striped mullet (*Mugil cephalus*) (Odum 1970), this sediment may provide better feeding conditions than coarser sediments of the southern Bay areas. In addition, the higher organic content of sediments at Oyster may be a factor in the greater numbers of mullet at Oyster than at Eagle.

Eagle contrasted with the other three sites with regard to seasonal differences in gillnet catches. While numbers of fish declined in summer elsewhere, they increased at Eagle for several species, and more species were captured at Eagle in summer than at either Cross or Buchanan (Fig. 76). Higher water levels (Fig. 15), and more marine salinities in summer (Fig. 44) may make conditions at Eagle more favorable than at other times of the year. Roessler (1967) found that salinities of less than 25ppt tended to drive off clupeids (*Harengula jaguana* and *Opisthonema oglinum*) and gerreids (*Eucinostomus gula*). The very abundant silver jenny (*E. gula*) was caught in relative high numbers in July at Eagle (Fig. 75b), and forms a major part of the summer increase. *Opisthonema*, while very low in numbers, was caught almost solely in July at Eagle (Fig. 75e), and those caught were a much smaller size than during other series (Fig. 79e), suggesting that the Eagle area serves as a nursery area for young thread

herring. Warmer water temperatures appeared to inhibit fish movement onto the banks at other sites (where water levels were also higher in summer but salinities were comparable to Eagle's).

Length-frequency distributions from gillnet captures gave little indication of seasonal variation in population structure of most species. It should be stressed that most of the species caught in gillnets were present as adults, and these species are permanent Bay residents. Fishes occurring on the banks are present throughout the year, although they may show considerable movement within Florida Bay. Some of the rare species may be considered "occasional" species from other habitats (Kikuchi and Peres 1977), but only a few (*Haemulon* spp. and *Lutjanus griseus*) occurred primarily as juveniles or sub-adults. Seagrass beds on the banks serve as foraging grounds for most of the fish species throughout their lifetimes, and are not acting solely as nursery grounds.

The only apparently "seasonal" species on the banks are the two clupeids, *Harengula jaguana* and *Opisthonema oglinum*. These two species are low in abundance in summer, and those present are relatively small in size. Both spawn in spring and summer (Houde 1977a, 1977b) and both likely move out of the bay to spawn (Martinez and Houde 1975). In nearby Biscayne Bay, *Harengula jaguana* migrated to deeper water from June to September (Martinez and Houde 1975). Low (1973) noted recruitment of juvenile sardines and herrings into grassbeds in spring and summer and a concurrent disappearance of larger individuals. While this was apparently also the case in Florida Bay, the density of these smaller clupeids was low, indicating that the majority of juveniles are not recruiting directly to the banks, but remain in deeper water until temperatures begin to drop in the fall. We have observed large schools of small clupeids in cuts and

in deeper water around mangrove islands.

The analysis of diel activity on the banks revealed several interesting patterns. The hours at dusk and just after darkness were generally the busiest; fish of several species increased during this time. Activity of the planktivorous clupeids may be tied to the vertical migration of planktonic crustaceans that are demersal during daylight and rise in the water column at dusk. While this behavior has not been documented in local seagrass habitats, it has been described in Australian grassbeds (Fancett and Kimmerer 1985, Robertson and Howard 1978). The activity of most species declined through the night with relatively few fish caught just before dawn. The presence of all three *Mugil* species on the banks during daytime is in contrast to anecdotal reports that mullet come onto banks only at night.

Tidal stage was an important factor in determining the activity of several species on the banks at Oyster and Buchanan. After peak water level and the beginning of ebb tide, fish activity is high, presumably due to fish leaving the bank as water level drops. A few species (*Strongylura notata*, *Mugil cephalus*, and to some extent *Eucinostomus gula*) remain on the banks until water level is very low, and return as soon as water level begins to rise after slack low tide. During periods of overall low water level (winter and spring) tide recedes at the Oyster site to such an extent that the bank retains only a 5 to 10 cm lens of water for several hours at a time, even at transect 3 (where gillnet sampling was conducted). At this time the bank is devoid of pelagic fishes. When this low water occurs at night, it may induce activity in species that are otherwise diurnal in behavior. Silver jennys were largely diurnal when all four sites were considered (Fig. 77b) but almost equally divided

between day and night when only Oyster and Buchanan were considered (Fig. 78o). Their activity centered around low tide at night, suggesting that they were driven off the bank by receding water, but return as soon as water level begins to rise.

For fishes moving onto the banks to forage, the daily amount of time available for feeding may vary greatly depending on time of year. In the eastern part of Florida Bay, where tidal flux is minimal, the banks may remain too "dry" for foraging for extended periods of time, especially when a frontal system drives water out of the Bay (Fig. 23). On the extensive banks of western Florida Bay, the banks are always covered with enough water at high tide to allow free movement of pelagic species, but exposure of the banks at low tide varies seasonally and daily, depending on wind conditions.

While activity patterns noted in this study refer only to movement on and off the shallow banks, patterns generally concurred with the limited available literature on activity of these species. In an in-depth study of diel activity in *Arius felis*, Steele (1984) noted a sharp increase in motor activity after the onset of darkness, high levels throughout the night, then a sharp drop at dawn. Daytime peaks of activity from 0600 to 0900 and 1300 to 1500 were consistent from day to day. In the present study, *Arius felis* showed a strong increase in activity at dusk and gradually declined during the night (Fig. 77e). While present at low levels during the day, it did not show the two peaks observed by Steele (1984). In his analysis of *Arius* activity relative to tidal fluctuation, Steele (1985) concluded that tidal stage had no influence on fish activity. He suggested that the small range of tide experienced by fish at that location (Galveston, Texas) was insufficient to entrain a rhythm

that would be maintained in a laboratory situation. In our study, *Arius felis* clearly centered its activity around high tide (Fig. 78b). In a natural situation, water receding off the bank would be an obvious stimulus for movement. The catfish caught by our gillnets might also show a lack of endogenous tidal rhythm if removed from waters actually fluctuating in level, but when low tide represents a potential stranding, the fish respond accordingly.

While the activity of other species has not been as intensively studied, there is some information regarding nocturnal versus diurnal abundance. Pristas and Trent (1977), in a gillnetting study of St. Andrew Bay, Florida, had higher catches at night for all species tested, including sea catfish, striped mullet, and pinfish. The latter two species were diurnal in their activity on the banks in Florida Bay (Figs. 77d, 77c). Our method of clearing the nets every half hour reduces the loss of entrapped fish to sharks and other predators, and allows better resolution of diel patterns than clearing nets only at dawn and dusk, the method used by Pristas and Trent (1977). In Biscayne Bay, using beach seines, Low (1973) collected striped and silver mullet and pinfish throughout the day (sampling every six hours). Silver jennys were caught primarily at mid-day and blue striped grunts primarily at midnight. Our results in general agree with those of Low (1973). In trawling samples of Apalachicola Bay Livingston (1976) found *Bairdiella chrysoura* and sciaenids in general to be nocturnal, again in agreement with the present study.

Consistent patterns of diel activity on the banks of Florida Bay have an important influence on the predators of these fishes. Great white herons (both blue and white morphs) are generally thought to be daytime foragers in shallow water. During winter months, however, we have noted

their presence on the banks throughout the night, and they appear to be foraging heavily on the schools of *Opisthonema* and *Harengula* moving onto the bank. By nesting in winter, the herons can take full advantage of the ready availability of clupeid prey.

While there is a definite change in activity levels from daylight to darkness on the banks, the situation is very different from that of tropical seagrass beds adjacent to coral reefs. In tropical systems, fishes move into seagrass beds at night from other habitats, primarily coral reefs (Ogden and Ehrlich 1977), and these "visitors" may comprise over half the catch (Robblee and Zieman 1984). In Florida Bay the species composition at night is not much different from that by day; there are simply greater numbers of fish on the bank. There is, therefore, little exchange of resources from the bank to other habitats.

SYNTHESIS

One of the major objectives of the present study was to develop a base line data set that would accurately describe the current status of fish and decapod populations on the banks of Florida Bay. This information would include qualification of the species that occur on banks, determination of consistent community differences across the Bay and across individual banks, and recognition of the habitat parameters that most influence the bank community.

With the combined methods of gillnetting and throw trapping we were able to accurately describe the species composition of the bank communities. A few species, however, were absent or under-represented in our results. We often observed, but did not catch, southern stingrays (*Dasyatis americana*), which are likely to have an important impact on banks due to their disturbance of sediments while foraging (Böhlke and Chaplin 1968). Blue crabs (*Callinectes sapidus*) were collected primarily as juveniles in throw traps, although large adults were often seen on banks. They may be more adept at avoiding throw traps than other demersal species are. Because throw trap sampling is intensive rather than extensive, we may have missed additional rare species that occur occasionally on banks and likely underestimated schooling species such as anchovies and silversides. The relatively small mesh sizes of our gillnets limited our catch of larger fishes such as rays, sharks, and tarpons, and non-fusiform fishes such as flounders and puffers. On the whole, however, the results of this study provide a thorough catalog of species utilizing the banks.

Contrasts among the four sites (representing different subenvironments) were clear and consistent across sampling series for both

throw trap and gillnet species and seagrass parameters. Likewise, differences in demersal species across a single bank followed consistent patterns. The physical gradients evident both across a bank and on a Bay-wide basis effect definite and predictable changes in both seagrass and resident animal populations.

Our records of water level, weather, salinity, and water temperature cycles in Florida Bay support a division of the year into three ecological periods or seasons. Seagrass growth on the banks corresponds to these seasons, but patterns are less regular for fish and decapod populations on the banks. Pronounced year-to-year variation, as noted for several species, may mask regular cycles within a year. While we have only limited information on changes in animal populations following a cold front, we would suggest that the influence of winter cold fronts may cause significant fluctuations in density within an ecological period. In our study, contrasts between winter densities in 1984 and 1985 may be due to the number and severity of cold fronts preceding sampling. A two-year data base is inadequate for establishing predictable seasonal trends, especially in an area subject to dramatic shifts in physical parameters.

One important link in our knowledge of the bank ecosystem that we could not fully investigate is salinity. The two years of this study were characterized by moderate salinities. Although values increased in 1985 relative to 1984, they were never close to the hypersaline conditions that can occur in Florida Bay (Schmidt 1979, D. Tabb personal communication). Likewise, salinities never decreased to a level that precluded marine species. The results of this study are, therefore, valid descriptions of the bank community only during periods of benign salinities.

The importance of physical parameters to the bank community was

evident in their prominence in multiple regression equations for demersal species. Seagrass growth and morphology are also significant determinants of animal densities, but are insufficient predictors without concurrent information on the physical environment. The natural variability of animal populations limits our ability to explain density variations, but within the Florida Bay system we have been able to extract a small number of habitat variables important to a large number of species.

Recommendations - Monitoring

Continued monitoring of the bank ecosystem is essential for accurate assessment of the effects of alterations to the physical environment (both natural and human-induced). Because the effects of fluctuating salinities in the Bay (both long term and short term) are unclear, continual monitoring of salinity at several points in the Bay, and particularly in the northeast sections, is vital. The northeast section is in a more precarious position than other areas due to its limited water circulation and low flushing rate. The potential for salinity extremes, and their detrimental effects, is greatest here, and the area will be slowest to recover from declines in either seagrass cover or species densities.

In addition to the influence of immediate salinity levels, animal populations may also vary according to the recent history of salinity patterns. We suspect that the invasion of the Eagle site by *Thor floridanus* in the second year of the study may have been a recovery after a period of relatively low salinities, but do not know what the salinity regime or *Thor* densities were prior to 1984.

Seagrass growth on the banks is an important determinant of species composition and abundances of fish and decapods. We recommend, as a

minimum effort, an annual assessment of grass species composition and standing crops at the four sites of this study on all transects, allowing continual comparison with our results. Due to the sparse distribution of *Thalassia* shoots at Oyster, a larger core or quadrat size would give more reliable estimates of shoot density. This sampling should be conducted in September, when physical conditions are most stable and seagrass beds should be at their prime, following the enhanced growing period of summer. In addition, changes due to extended periods of high salinity during a drought would likely be reflected in September samples, after summer temperatures have caused maximum evaporation rates in the Bay. Any changes in standing crops on the banks would warrant a more in-depth analysis of seagrass parameters, and standing crop, leaf area, shoot density, blades per shoot, and canopy height should all be measured.

Fish and decapod populations should also be monitored on an annual basis, again in September for the above reasons. Because throw trap sampling is very time-consuming, a single transect at each site would probably be sufficient to extend the present base line data. The sheltered sides of banks (transect 1 at Cross, Buchanan, and Oyster and transect 3 of Eagle) would likely provide the most information on non-random fluctuations in densities, due to their more stable environment. Each site provides a unique measure of habitat quality in the Bay. Eagle would best reflect effects of salinity variations. Cross, due to its proximity to the Florida Keys, would likely be the first site to show effects of environmental perturbations in the Keys. Buchanan, with its Atlantic water exchange, would probably be least affected by environmental changes in the Bay, and would best indicate natural fluctuations of individual species. Oyster, with its proximity to Flamingo, would be most

affected by direct human disturbance, such as destruction of grassbeds by boat propellers, increased turbidity, and pollution by gasoline and oil discharge.

While the sides of the banks are more likely to reflect human-induced changes in habitat quality irrespective of natural fluctuations, the tops of the banks will be most affected by changes in patterns of water level and temperature. If extremes in these parameters occur, or the cover of seagrass is significantly altered, a full-scale study of these shallower portions of the banks should be conducted.

Continued monitoring of the pelagic community on the banks, as defined by gillnet catches, is difficult due to the greater movement of these species and more random nature of the catch. Results of annual monitoring of seagrass and demersal species on the banks should indicate the general health of the banks as foraging grounds for pelagic fishes. If the bank community declines, a thorough gillnet sampling of the pelagic community should be conducted to determine the effects.

Recommendations - Further Research

As questions continue regarding the impact on Florida Bay of alterations in freshwater flow, it will be necessary to have better information on water quality, salinity patterns, and circulation of water masses in the Bay. The amount of freshwater actually entering Florida Bay and the character of this input deserve careful study. We need to know levels of nutrient input (both dissolved and in the form of particulate detritus), potentially toxic materials, and chemical constituents. We need to know how these components change as water flows through organically rich mangrove swamps and into open Bay waters. In

conjunction, we need better information on tolerances of, and behavioral responses to, fluctuating salinities.

Based on results of this study, one of the most important factors influencing species composition on the banks is the character of water exchange in each subenvironment. The banks form barriers to water flow, but we do not know to what extent. Our data on water level fluctuations provide only an initial step in comparing the isolation of water masses in different areas. A physical model of residence times, flushing rates, and exchange rates would provide valuable information on how freshwater from upland sources moves through the Bay and the extent of its influence. If interior areas of the Bay are more depauperate because of a lack of interchange with oceanic waters (and, therefore, a planktonic source of potential colonizers), the planktonic community of these areas should vary considerably from western parts of the Bay. Research on planktonic populations communities would be valuable in determining whether eastern Bay communities are influenced more by accessibility of colonizing individuals or by habitat quality.

The four sites examined in the present study represent four of the five major subenvironments described by Zieman and Fourqurean (1985). Analysis of the interior section of the Bay is necessary to more fully characterize bank habitats in Florida Bay. Some differences between our stations on the same bank were significant, and our results do not necessarily characterize all the banks in a given subenvironment. Sports fishermen report that different banks in close geographical proximity may differ considerably in their utilization by gamefish. Further research on several adjacent banks would indicate how well the subenvironment divisions based on seagrasses (Zieman and Fourqurean 1985) apply to fish

and decapod populations.

While results of multiple regression analysis pointed out several important microhabitat parameters, we do not know how they exert their influence. Experimental manipulation of factors such as seagrass density, drift algae load, canopy height, etc. would clarify the direct relationship of microhabitat to animal densities.

Conclusions

The seagrass community inhabiting the shallow banks of Florida Bay is affected by its physical environment to a much greater degree than are continually submerged systems. Water level, water temperature, salinity, wind stress, and water mass exchange play definitive roles in shaping species composition and densities on the banks.

The vegetation parameter most consistently influencing fish and decapod densities is standing crop of seagrasses. Leaf morphology, as it determines canopy height of a grassbed, is also an important microhabitat factor.

Species richness varied markedly across the Bay, and these differences could not be attributed solely to differences in seagrass cover. The restriction of water flow by the banks impedes circulation of water masses, and apparently also impedes the dispersion of grassbed residents.

Regular variations in water level due to seasonal patterns and unpredictable changes due to wind stress have a major impact on the very shallow portions of banks, at times limiting water depth and resulting in greater temperature extremes than in slightly deeper water. The longer these periods of near exposure are, the fewer species become established

residents on the bank, particularly fishes. Those species that do occur, however, may experience greater protection from marine predators, and expand their numbers accordingly.

Florida Bay, despite generally benign temperatures, salinities, pollution input, and human disturbance has heterogeneous seagrass, demersal fish, pelagic fish, and decapod populations on the banks. These four components vary in a generally consistent manner. The northeast section of the Bay, for example, has the least developed grassbeds, a depauperate community of demersal residents, and the least utilization by pelagic species. Most of the heterogeneity among sites appears to be a natural consequence of the suite of physical parameters characterizing individual banks. The high year-to-year variability in some species, particularly *Thor floridanus*, suggests that populations in the Bay may undergo major shifts in abundance. With their rapid turnover rate and apparent ability for rapid expansion, such species may indicate subtle environmental changes.

The seagrass cover on the banks is essential to the community for more than the general benefits of protection from predators and availability of food. Without seagrass, the banks would become completely dry during periods of low water. With seagrass, enough water is retained to allow species to remain on the banks throughout tidal cycles and wind-induced periods of low water. Since migration on and off the banks is apparently a high risk behavior for the demersal residents, banks devoid of seagrass would presumably be devoid of fish and decapods at all times. In turn, the water-retaining capabilities of the grassbed help insure a source of prey for the pelagic fish and wading birds that forage on the banks.

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