INTERNSHIP REPORT

TEMPORAL AND SPATIAL VARIABILITY IN THE ABUNDANCE OF PENAEID SHRIMP IN BISCAYNE BAY: ENVIRONMENTAL AND ANTHROPOGENIC INFLUENCES

By
Erica McKinley

[Restored and transferred to electronic form by Damon J. Gomez (NOAA/RSMAS) in 2002 as part of the Coastal and Estuarine Data/Document Archeology and Rescue (CEDAR) for South Florida. Sponsored by the South Florida Ecosystem Restoration Prediction and Modeling Program. Original stored at the Library, Rosenstiel School of Marine and Atmospheric Science, University of Miami. Minor editorial changes were made.]

Submitted to the Faculty of the
University of Miami in partial fulfillment
for the requirements for the
Master of Arts degree in Marine Affairs and Policy

February 1995

INTERNSHIP OVERVIEW

My internship began in August of 1994 when I began working with Dr. Joe Serafy, a fisheries ecologist, at the University of Miami, Rosenstiel School of Marine and Atmospheric Science, Division of Marine Biology and Fisheries. My task was to work with a substantial data set on the epibenthic fauna of Biscayne Bay. The project, which began in August of 1993, was designed to provide temporal and spatial information on fishes and decapod assemblages in nearshore habitats and to correlate faunal abundance with water quality, algal and plant communities and selected environmental variables. I participated in the project during the final two months of sampling, (August and September 1994) and up until the present have been performing data entry, quality control, statistical analyses and ecological interpretations.

My goal in this project was to gain a greater understanding of the physico-chemical and environmental factors influencing the temporal and spatial variability of juvenile *Penaeus* (shrimp) populations in the Bay. An assessment of this kind has not been conducted in over a decade.

TABLE OF CONTENTS

I. INTRODUCTION

Penaeid shrimp have been a valuable marine resource in South Florida at least since 1915 (Iversen. 1993). The demand for shrimp is ever expanding and is one of the most valuable export commodities for the region. The Tortugas Dry Grounds, off the southern tip of Florida, has yielded a stable catch of 9.6 million pounds of *Penaeus sp*. (primarily *P*. *duorarum*, the pink shrimp) annually from 1960-1986 (Klima et al., 1986). In 1983, the ex-vessel value of the Florida shrimp fishery was estimated at $22 million (Costello et al., 1986). The live bait fishery, which supports the continually growing recreational fishing industry in South Florida, is also valuable. The live bait fishery of Florida produced 1.38 million pounds of live bait and was valued at $4.7 million in 1990 (Coleman et al., 1993). Biscayne Bay, adjacent to Miami yielded 217,196 pounds of live shrimp valued at $1.07 million in 1993. For the period 1986-1993 the industry average harvest, in Biscayne Bay, has been 238,076 pounds, while the ex-vessel value has fluctuated between $610 thousand and $1.12 million (Florida Department of Environmental Protection [FDEP], 1993).

Penaeid juveniles are also ecologically important in the environments they inhabit. They make up the better part of the food base for many estuarine and bay fishes, including juvenile snapper and other recreationally important game fish (Florida Department of Natural Resources [FDNR], 1992). By burrowing in the sand shrimp also loosen and aerate the sediments creating a more favorable substrate for rooted vegetation, their preferred habitat (Kaplan, 1988).

Since the 1950s, the population of Penaeid shrimp in Biscayne Bay, has received much interest from local marine resource managers, fishermen and scientists. Marine managers are interested in assessing stocks to better manage and monitor this valuable resource as well as preserve critical nursery habitat. Local recreational fishermen and fishing clubs have favored banning live bait shrimping because they believe it degrades seagrass habitat and thus reduces the food and shelter for juvenile gamefish. Scientists have shown interest in the life history and environmental constraints of these warm water shrimp for a variety of reasons, not least of which is the adoption of the genus for aquaculture purposes (Iversen, 1993).

a. Study Area

The focus of this study is on the Penaeids of Biscayne Bay, which is a shallow subtropical bay on the southeast coast of Florida (Map 1). It is approximately 73 km long and 16 km wide with a mean depth of 2 m. (Wilson, 1975). The Bay is a submerged basin bounded to the west by the Atlantic Coastal Ridge made up of Miami limestone, and the low everglades platform; and to the east by a narrow ridge of Key Largo limestone. This ridge underlies Miami Beach and Key Biscayne and rises above sea level to form the Florida Keys farther south (Wanless, 1969). Biscayne Bay, unlike most east coast bays, is not a drown river valley, and so, does not have the drainage and erosional sedimentation common to other bays. The major sedimentary inputs include quartz, carbonate shell sand, carbonate muds and organic material generated within the Bay or brought in by longshore currents and other coastal processes from the ocean (Wanless, 1969). In general, the substrate in the northern section of the Bay is bare mud with patches of red algae and some seagrasses. The southern section, in contrast, is composed mainly of quartz and carbonate sands with well-established seagrass beds.

The hydrology of the Bay is influenced by: 1) tidal flushing and wind driven circulation with ocean waters; 2) freshwater discharge from rivers, canals and groundwater; 3) rainfall; 4) the anthropogenic influences that have altered the Bay, the adjacent wetlands and the underlying aquifer. In the northern section of the Bay, tidal currents and tidal flushing are the principal circulation mechanisms. Ocean water is exchanged with Bay water through Government Cut at the southern end of the north section, and Haulover Cut at the northern end. The southern section of the Bay, by contrast, is bounded on the ocean side by shallow shoals and sand banks exposed to the Atlantic. Wind driven circulation can, at times, be very strong either enhancing or countering any tidal currents (Wilson, 1975).

Rainfall is a significant factor in Biscayne Bay hydrology. There are two seasons in South Florida, a cool, dry season (November - April) and a hot, wet season (May - October). Average annual rainfall for Dade county is 147 cm. with about 64% falling during the wet season (June to Oct.), and an average monthly rainfall of only 5 cm from November through April (National Climatic Data Center, 1994). South Florida, however, is characterized by wide yearly fluctuations in rainfall; about 40 % of the time the annual total rainfall deviates from the yearly average by more than 25 cm. (Surface Water Improvement &Management Plan [SWI&MP] Bisc. Bay, 1994) (Figure 1a).

Much of the ocean exchange with the northern section of the Bay has been restricted by land reclamation, bulkheads, and the construction of artificial islands and causeways. Land development and human population growth have also reduced the aquifer under the Bay, so there are no longer freshwater "springs" in the Bay (Voss, 1969). At the same time freshwater surface inputs into the Bay have increased dramatically. Seventeen canals control the surface water drainage into the Bay's watershed. The primary functions of the canals and water control structures are to: 1) allow discharge and drainage from coastal and inland areas into Biscayne Bay; 2) provide flood protection; and 3) prevent saltwater intrusion in times of drought (SWI&MP Bisc. Bay, 1994).

Freshwater canal discharge into the Bay fluctuates on a seasonal and annual basis corresponding with rainfall. The U.S. Geological Survey monitored the canal discharge into Biscayne Bay from 1980-1989. In the southern section of the Bay, on average, 103 million cubic-meters (83.000 acre-feet) of water were discharged during the dry season and 234 million cubic-meters (189.000 acre-feet) were discharged during the wet season, or 2.27 times that of the dry season. In the northern section of the Bay the recorded dry season average is 132 million cubic-meters (107.000 acre-feet) and the wet season average is 293 million cubic-meters (237.000 acre-feet), or 2.22 times the outflow during the dry season (U.S. Geol. Surv. National Parks Service data, 1990).

I.b. Ecology of Biscayne Bay

Biscayne Bay has a very rich and diverse benthic community sharing characteristics of both the Tropical West Indian Faunal Province and the Carolinian Faunal Province. Over 512 species of fishes

(De Sylva, 1976), and 800 invertebrate species (Schroeder, 1984), have been identified in Biscayne Bay. Voss et al. (1969), identified 150 species of decapods in different Bay habitats. The seagrass beds are among the richest habitats in Biscayne Bay, especially for decapods.

Seagrass habitats provide shelter and food for a variety of fish and invertebrates. The roots stabilize sediments and allow sediment accretion for burrowing organisms, as well as clarifying the water by trapping suspended particulates. For the resident fauna, grass beds provide shelter from strong currents, storms and predators. The epifaunal community associated with seagrass, especially *Thalassia*, with its long broad leaves, provides food for shrimp and other organisms in the community. In the Northern section of Biscayne Bay, *Syringodium* and *Halodule* are more common, while in the southern section *Thalassia* is the predominant routed macrophyte.

c. Biscayne Bay Penaeids

Many workers have addressed the biology, ecology and distribution of *P. duorarum* in South Florida and their dependence on estuarine habitat, specifically seagrass beds (Costello et al., 1986; Costello and Allen 1966, 1969; Bielsa et al., 1983; Broad, 1965; Farfante, 1969; Garcia, 1983; Iversen, et al., 1993). The majority of the Penaeid shrimp in Biscayne Bay are juvenile and subadult *P. duorarum*. On a seasonal basis, other species, particularly *P. brasiliensis* can make up 5-15 % of the population. The exact species composition has not been accurately determined because of the difficulties in distinguishing individual *Penaeus* species during juvenile life history stages (Farfante, 1969).

As juveniles (10 mm Total Length [TL]), *P. duorarum* prefer to inhabit nearshore *Halodule* and *Syringodium* beds, then move into deeper water with *Thalassia* as they mature (Costello et al., 1986). *P. duorarum* spend between 2-6 months in the Bay, reaching a length of 95-100 mm (TL), before moving offshore. The locations of the spawning grounds for the Penaeid populations of Biscayne Bay are not known. Shrimp are difficult to track and tagging them is ineffective because of the molt cycle, some work with dyes has been done, but with poor success (Iversen, 1993). There is speculation, that the Penaeid populations of the Bay come from the Tortugas Dry Grounds, but several biologists believe there is probably another spawning ground to the north (Campos and Allen, 1966; Berkeley, 1985; Iversen, 1993). Some have speculated that the juvenile population in Biscayne Bay may actually recruit from two distinct spawning populations. So far, however, this has been neither proven nor refuted. Peak emigration out of the Bay is in late fall and again to a lesser degree in spring (Costello et al., 1986). The fall emigration correlates with the spawning cycle that peaks when bottom water temperatures are highest in the mid summer.

P. duorarum juveniles are very tolerant of environmental variations, withstanding salinity fluctuations from 5-47 ppt. and surviving temperatures as low as 10°C and as high as 35.5° C. They appear to need higher salinity concentrations if the water is colder (Biesla et al. 1983). As they grow toward adult size, Penaeids seem less tolerant of low salinity (preferring salinities of 25 - 45 ppt.) and more sensitive to temperature changes. Cold fronts moving across South Florida during the Dry season can initiate huge migrations out of the Bay into deeper waters. Biesla et al. (1983), in field and laboratory experiments, found mature shrimp to be least tolerant to salinity fluctuations. They are found almost exclusively in oceanic salinities of 36.2-37.7 ppt.

II. OBJECTIVES

The purpose of this study was to investigate the temporal and spatial variability in the distribution of *Penaeid* shrimp in Biscayne Bay and to correlate abundance and distribution with environmental factors including water quality (temperature, salinity, dissolved oxygen), vegetation quantity and quality, canal discharge, and rainfall. The data set is unique because samples were collected over a 14 month period covering both wet and dry seasons. Also, the entire length of the bay was sampled, rather than only the southern basin, used by the commercial fishery and which has been studied previously. The subject of this study is new to both the literature on Penaeid shrimp and on the Biscayne Bay environment. The 14 month sampling period has allowed for seasonal, as well as spatial assessment of shrimp assemblages and the habitats in which they live.

III. METHODS

a. Study Sites

Eight stations were selected and sampled monthly from August 1993, to September 1994. The station locations spanned much of the north-south axis of Biscayne Bay. All but one (i.e., Sunset Harbor) were located along the western shore of the Bay. All sites except Sunset Harbor and Rickenbacker Causeway (Cswy) were adjacent to fresh water outfalls (canals and rivers). Sampling locations adjacent to fresh water outfalls were chosen to investigate the effects of wide fluctuations in water chemistry parameters, particularly salinity, on the distribution, abundance and composition of *Penaeids*. From north to south, station names were designated as: Biscayne Canal, Little River, Sunset Harbor, Miami River, Rickenbacker Causeway, Matheson Hammock, Black Point, and Turkey Point. Refer to Map 1 for the location of each site.

The northern and southern basins of Biscayne Bay have very different characteristics; therefore, for the purpose of this study the sites were grouped by northern or southern basin. The northern basin extends from the Broward-Dade County line (just north of Baker's Haulover Cut), south to the Rickenbacker Causeway and the southern section extends from there, south into Card Sound. Four sampling sites were selected in each section (Map 1).

Biscayne Bay's northern basin is smaller than the southern basin, with a maximum width of 5 km and characterized by substantial shoreline development and submerged land alterations (Wilson, 1975). Downtown Miami and residential high-rises line the coast from the Rickenbacker Causeway, north to

Haulover cut. Much of this portion of the Bay has been altered by land reclamation, artificial islands and bulkheads. Nearly half (49%) of the northern portion of the Bay has been dredged to a depth of between 10 to 16 feet (SWI&MP Bisc. Bay, 1984). Baker's Haulover Cut provides for the only substantial water exchange with the Atlantic north of Government Cut. The substantial development of the northern basin has further restricted water movement and tidal flushing. Water quality is poor. Nutrients and chlorophyll levels are higher than in the north (Brand et. al., 1991), and rooted vegetation is, in general, less abundant in the north, due partially to poor substrate and high turbidity.

The southern basin is much wider, shallower and has greater exchange with the Atlantic Ocean. A network of mudbanks, mangrove keys and shallow seagrass beds break up the southern portion of the Bay into smaller semi-enclosed shallow basins. The western area of the southern section is characterized by wide banks, smaller basins with deep sediments and dense seagrass growth (Costello, et al., 1986). The shoreline remains relatively unaltered mangrove forest. The water tends to be clear and water quality is good, allowing for greater benthic plant growth. Extensive *Thalassia*, *Syringodium* and *Diplanthera* beds line the bottom of this section of the bay.

b. Rainfall and Canal Discharge

Rainfall data for the months of the study, as well as average monthly rainfall data for the area, were obtained from the National Climatic Data Center, which operates a precipitation monitoring station at the Miami International Airport. Canal outflow data was obtained from the South Florida Water Management District. The data was collected from 1980 to 1989 and compiled into monthly mean outflow expressed in 1000's of acre-feet. The monthly flow rates from canals adjacent to six of the sample sites are listed in Table 1. The other two study sites, Sunset Harbor and Rickenbacker Cswy, are not adjacent to canals. Refer to Map 2 for the location of the canal outflow monitoring stations.

c. Physico-Chemical Measurements

Water quality data including, salinity, dissolved oxygen, temperature and depth were collected during each sampling regime (Map 3). During all tows, a surface water sample was obtained and temperature, salinity and dissolved oxygen (DO) were determined. The shallow nature of Biscayne Bay makes vertical stratification rare and a single layer circulation system prevails (Wilson, '75), allowing accurate measurements of the entire water column to be taken using surface water samples. Depth was measured at the beginning and end of each tow using an electronic depth sounder. Environmental data collected by the South Florida Water Management District (SWI&MP BISC BAY) and the Dade Department of Environmental Resource Management (DERM), which has been monitoring water quality in the Bay since 1979, was also used when correlating environmental factors with the distribution and shrimp abundance.

DERM monitored the water quality in Biscayne Bay from 1979 to 1992. Water Temperature (°C) and dissolved oxygen (mg/L) measurements were taken in the field and salinity (ppt) and turbidity (NTU) measurements were conducted in the laboratory. The long duration of the DERM monitoring and their greater sample size offers a truer description of the water quality parameters in the area of the sample sites. Water quality parameter averages and variations (standard deviation [s.d.]) were computed by DERM for the twelve year monitoring period. Both the DERM monitoring stations closest to the sample sites and the corresponding stations at the mouths of adjacent canals were used. The only available DERM monitoring station near the Black Point site was at the mouth of Black Creek canal, there was no station located farther out in the bay near the Black Point sample site.

d. Benthic Vegetation Sampling

During July 1994, the bottom flora of each site was evaluated. This tends to be the peak growing season for rooted macrophytes in the region. All eight sites were visited by day. Once on location, three one-meter quadrats constructed of 1 inch PVC pipe and divided into 25 equal sections (20 x 20 cm) with nylon cord, were tossed overboard in random directions and allowed to sink. Once they reached the bottom, all of the flora in two randomly selected sections of each quadrat were removed and placed in plastic bags. The sampling process provided a total of six vegetation samples for each site. The bags were then sealed, marked and returned to the lab for processing. In addition to the quadrat samples a "diversity sample" was also taken. The diversity sample was a collection of all plant species observed within a 15 meter radius of the vessel. All were then taken back to the lab for positive identification and measurement of biomass.

Laboratory processing of the vegetation samples involved several steps. For each sample, every species present was identified using Marine Plants of the Caribbean by Littler et. al., 1989. Total wet weight of each species was measured directly. These were converted to dry weights after determining species specific water content for 14 of the predominant species.

e. Shrimp Collection

The standard gear used to harvest live shrimp from the coastal bays in South Florida is the "rollerframe" trawl. In the present study, this gear was towed from a licensed, operating commercial vessel. Paired trawls were towed from a 10.1 m vessel with a shallow draft (i.e. 0.3 m). The trawls measured 3 meters in width, 1 meter in height, and the attached net was 7 meters in length. As the name suggests, each rollerframe trawl consisted of a steel frame with one or more slotted rollers along the entire bottom edge. The net mesh size was 10 mm. As the primary contact point with the bottom, the rollers were designed to allow the frame to roll over, rather than drag through, the substrate. The trawls also possessed fiberglass bars, called "finger bars" which were spaced 30 mm apart and extended vertically across the trawl mouth. The finger bars functioned to prevent large objects, such as coral rubble, large animals (e.g., turtles), and unattached benthic vegetation (e.g., *Laurencia*) from damaging the live catch.

Sampling was conducted exclusively at night, in full darkness. For each month, two paired trawl samples were obtained at each site. For any given tow, trawl catches on either side of the vessel were kept separate, thus the monthly number of samples equaled four (N = 4), for each site. At the beginning and end of each tow, location coordinates (i.e., latitude-longitude) were obtained using a GPS unit. Nominal tow time and speed were 10 minutes at 1.5 knots; actual trawl bottom time and speed measurements were recorded for each tow.

Catches were first placed onto sorting tables and fishes and invertebrates separated from plant debris. All shrimps and crabs were placed directly in plastic bags and put on ice. In the laboratory retained shrimps 1) were examined to confirm identification, 2) counted and 3) measured (carapace length [CL]). Individual weights of the shrimp catch were estimated using a weight-length relationship determined from 1500 individuals.

f. Data Analyses

Statistical analyses were performed using SAS (1985) on an IBM-compatible PC. Dependent variables were examined on a per tow basis. These included: Penaeid density, mean size, and total biomass. Independent (habitat) variables including water temperature, salinity, dissolved oxygen, depth and season were also compared. Before statistical analyses, residuals were examined and, when necessary, values were $\log_e$-transformed to reduce problems of non-normality and heteroscedasticity (Sokal and Rohlf 1987).

To estimate the weight (W) of individuals from their carapace length (CL), a nonlinear, least squares regression analysis was performed using the equation $W=aCL^b$ (Ricker, 1975). Once the coefficients a and b were determined, the model was employed to estimate the weight of each shrimp from its (empirically determined) length.

$$W = 0.001527\ (CL)^{2.7788}$$

The relative abundance and mean size of *Penaeus sp*. was compared at each site for each of the two seasons recognized in this subtropical region. Two measures of relative abundance were investigated: mean numbers of Penaeus sp. per tow; and mean biomass of Penaeus sp. per tow. Variations in spatial and seasonal abundance were compared using an analysis of variance (ANOVA) model consisting of the factors site, season and site x season. Site and seasonal abundance means were compared using t-tests in which "experimentwise" error rate was held at the $p<0.1$ level using the Bonferroni method (Sokal and Rohlf 1982).

IV. RESULTS

a. Rainfall and Canal Discharge

In 1993, 103 cm of precipitation was recorded, by the National Climatic data Center, during the wet season (May - Oct.), with 45 cm of that falling during Aug. and Sept. (the first two months of the study period). In the 1993-1994 dry season (Nov. 93 - Apr. 94) 49 cm of precipitation were recorded. During the wet season of 1994 (May-Sept.) 109 cm of rain have been recorded (National Climatic Data Center, 1994) (Figure 1b). The precipitation during the 1993-1994 study period was slightly higher than typical for south Florida with an average of 21.5 cm per month falling in the wet season and 8.2 cm per month falling in the dry season. Rains in January, August and September of 1994 were heavier than normal. See Figures la & 1b for rainfall data.

Canal discharge closely follows the seasonal rainfall pattern, but has a lag time of a few weeks. Therefore, canal outflow in May is minimal because of the light precipitation during the preceding months and outflow in November is still high due to the heavy rains during the month of October. The southern most canal observed, canal F (Map 2), has the greatest outflow during both seasons because of its location adjacent to the swamp environment of Everglades National Park (Table 1).

b. Physico-Chemical Parameters

Physico-chemical data was analyzed by site, season and north/south section of the Bay. Temperature fluctuations, at all sites, were fairly uniform, showing no distinguishing pattern to differentiate the northern or southern section of the Bay. Temperatures were lower during the cooler dry season and highest during the wet season (Figure 2).

Dissolved Oxygen concentrations at all sites during the 13 month sampling period showed similar fluctuations, ranging between 4.5 and 11 ppt. Turkey Point generally had higher dissolved oxygen concentrations than the other sites (Figure 3). DERM, because of the long duration of its monitoring efforts (1979-1992) was able to develop means and standard deviation (s.d.), measurements for dissolved oxygen, salinity and turbidity at their monitoring stations. Mean dissolved oxygen was fairly uniform ranging from 4.4-6.4 ppt. Little River is shown to have a high degree of fluctuation with a standard deviation (s.d.), in dissolved oxygen of 7.6. The other sites have a s.d. ranging from 0.6 at Turkey Point to 1.3 at Matheson Hammock and Black Point (Table 2).

Large differences in salinity among sites were recorded during the study period (Figure 4). Little River had the greatest variation in salinity ranging from 8.0-32.0 ppt, followed by Turkey Point and Biscayne Canal (Map 3). The Miami River, Rickenbacker Cswy and Matheson Hammock all had less than 10 ppt variation in salinity recorded. Data compiled by DERM suggests that, of the canals adjacent to the study sites, 8C, 7, 6C and IC have the highest variation in salinity, with the standard deviation from the means being 10.2, 8.8, 7.4 and 7.2 respectively. Of the monitoring stations located in the bay, near the study sites, station 2 showed the greatest variation with a s.d. of 5.1, which is similar to the data collected during sampling (Table 2).

Turbidity was not measured during sampling but, the data collected by DERM shows higher turbidity in the northern basin and a marked reduction in turbidity in the southern basin, with the Rickenbacker Cswy being a transitional area (Table 2).

Depth at all sites ranged between 1.42 and 4.17 m during sampling, and the tidal variation for all sites ranged between .47 mat the southern most site to 2.04 mat the northern most site. Tidal range increases northward in the Bay. At the Port of Miami, for example, the tidal fluctuation averages 76 cm. but tapers to only 23 cm. in Card Sound (Wilson, '75). There is also a seasonal difference in sea level in the Bay. Sea level in Biscayne Bay begins to rise in April with the onset of the rainy season and reaches maximum height in October at the end of the wet season.

c. Benthic Vegetation

Appendix D contains a graph and individual pie charts showing the total dry biomass (g) of benthic vegetation per square meter and the species composition for each site. Miami River, Rickenbacker Cswy and Matheson Hammock all had a majority of *Thalassia*, with Matheson Hammock the most densely vegetated. The vegetation at Sunset Harbor and Black Point was comprised mainly of *Syringodium* although Black Point was very sparsely vegetated with only 59.60 g/m^2, as compared to Sunset Harbor with a total benthic vegetation of 331.63 g/m^2. Little River had a thick covering of red algae with 73.07% of the 653.99 g/m^2 of vegetation being Amphiroa. Biscayne Canal also was mainly vegetated by Amphiroa (70.57%), but much less densely (90.71 g/m^2 total vegetation).

d. Shrimp Abundance

The trawl data shows a strong seasonal distribution with the dry season having a higher shrimp abundance in all cases except Biscayne Canal and Little River which had abundance peaks at the end of the wet season (Figure 5). Turkey Point, Miami River and Matheson Hammock all showed a very similar distribution. Black Point does not conform to a seasonal pattern, and has a fairly uniform low density throughout the year. Sunset Harbor had the greatest numbers of shrimp in both seasons (Appendix E).

The shrimp abundance data was $\log_e$-transformed for statistical analysis to reduce problems of non-normality and heteroscedasticity, and allowed us to determine the standard error and Probability values for site and seasonal data (Table 3). Figures 6a & 6b show the $\log_e$-transformed mean abundance data for each site by season. The sites sharing the same letter value (A,B,C) for each season, are statistically similar and those not sharing a letter value are significantly different from each other. (The letter values cannot be compared between the wet season and dry season figures.)

In Table 3, the differences in seasonal abundance per site are shown. The sites with a significant difference in seasonal abundance are, Biscayne Canal, Miami River, Rickenbacker Cswy, Matheson Hammock and Turkey Point ($P < 0.0125$). Biscayne Canal has significantly more shrimp during the wet season than the dry. Little River has a greater number of shrimp during the wet season as well, but it is not statistically significant. The other sites have a greater abundance during the dry season.

e. Shrimp Biomass

The data shows a strong seasonal trend in shrimp biomass, with the greatest biomass occurring during the cooler, dry season and less shrimp biomass during the wet season. Sunset Harbor, Miami River, Rickenbacker Cswy, Matheson Hammock and Turkey Point all showed a similar pattern of low biomass during the wet season and higher biomass during the dry season (Map 4). Sunset Harbor had a relatively late peak in biomass occurring in March. Biscayne Canal had a constant low biomass throughout the year. During the dry season the Rickenbacker site, followed by Sunset Harbor had the greatest biomass. In the wet season Sunset Harbor had the greatest biomass (Figure 7).

Figure 8a & 8b show the ($\log_e$-transformed) mean biomass values for each site by season. The sites sharing the same letter value (A,B,C,D) for each season, are statistically similar and those not sharing a letter value are significantly different from each other. (The letter values cannot be compared between the wet season and dry season figures.)

Table 4 shows the differences in seasonal biomass per site. The sites which have significantly different shrimp biomass per season are Biscayne Canal, Little River, Miami River, Rickenbacker Cswy, Black Point and Turkey Point. Biscayne Canal has a significantly higher biomass during the wet season. All other sites have greater shrimp biomass during the dry season.

f. Correlations

Correlation matrices were generated to relate shrimp abundance and shrimp biomass data and the environmental parameters. Site specific correlation matrices suggested that, at all sites, except Black Point, shrimp biomass is more closely related to temperature than any other parameters (Table 5 & 6). At the Biscayne Canal site, which was the only site to have a higher abundance during the wet season, little correlation was found with any of the water quality parameters.

In general, shrimp abundance correlations were weaker than those of shrimp biomass. Miami River, Rickenbacker Cswy, Matheson Hammock and Turkey Point, however, all showed a significant correlation between shrimp abundance and temperature, showing similar seasonal trends. All four sites show a significant difference in seasonal abundance (Table 3), suggesting that temperature may be more significant than other parameters, in seasonal fluctuations in shrimp quantity and size. Both Biscayne Canal and Little River showed little correlation between abundance and any of the environmental parameters. Unlike the other sites, they both had greater shrimp abundance in the wet season.

Abundance and biomass were also analyzed against rooted and non-rooted vegetation and turbidity levels. Table 7 is a matrix of correlation coefficients for the above parameters by site. As expected, abundance and biomass were highly correlated, at .866. Abundance and biomass were also significantly correlated with the amount of rooted vegetation (*Thalassia*, *Halodule*, and *Syringodium*). And rooted vegetation is negatively correlated with non-rooted vegetation.

In Table 8, habitat variables were correlated against each other and vegetation composition. The first correlation matrix uses the mean values for salinity, dissolved oxygen and turbidity. The second matrix compares the variation (s.d.) in each water chemistry parameter. In both cases, salinity and D.O. are significantly correlated. Turbidity and vegetation are also closely correlated. High turbidity and a high variation in turbidity levels both have a significant negative influence on rooted vegetation, and are positively correlated with higher quantities of non-rooted vegetation. Table 7 and 8 show that *P. dourarum* are found in greater abundance at sites with rooted vegetation and low turbidity.

V. DISCUSSION

None of the water quality parameters measured during the study alone are extreme enough to negatively affect juvenile Penaeid shrimp populations. Penaeid shrimp are often referred to as eury-everything because of their wide tolerance to many environmental parameters. The variance in temperature, salinity, and dissolved oxygen all are within known tolerance levels for Penaeid species.

As Witzell and Allen (1983) point out, however, the relationship between shrimp and salinity-temperature regimes are not limited to direct physiological effects but indirectly affect the stock by altering habitat, making it more or less favorable for settlement and survival. It is of interest to note, that while drastic changes-in the hydrology and ecology of the Bay have taken place over the last twenty years, little fluctuation in bait shrimp (mainly juvenile *P. duorarum*) landings (there has been little increase in per unit effort by fishermen), have been recorded (Berkeley, et al., 1985).

Salinity is often a limiting factor in the distribution and abundance of juvenile Penaeid shrimp, because the estuarine nursery grounds frequently experience wide salinity fluctuations. Salinity tolerance regimes of both *P. setiferus* and *P. aztecus* have been studied by a number of workers (Gunter, 1964; Iversen, 1993; Hughes, 1969a; Broad, 1965). Extensive work on *P. duorarum*, the primary species in Biscayne Bay, however, is absent in the literature. The workers that have looked at the salinity regimes of juvenile *P. duorarum* often refer to *P. duorarum* as euryhaline (Gunter et al., 1954, 1964, 1961; Bielsa, 1983; Witzell and Allen, 1982;) being found in waters ranging from 4-47 ppt., but they prefer salinities higher than the other commercial species of Penaeid shrimp. They are found in greatest abundance in salinities between 18-20 ppt. Gunter (1964) found 97.5% of *P. duorarum* sampled, were taken in salinities greater than 18 ppt. How salinity actually limits the population is still largely unknown. There may be physiological constraints, changes in habitat, the availability of appropriate food, or a complex combination of a number of environmental and physiological factors. This would suggest that the salinity of Biscayne Bay today, is higher than optimal for juvenile Penaeid species. And, in fact, salinity variation between sites had very little significant correlation with shrimp abundance or biomass (Table 5 & 6).

The significant correlation between vegetation type and shrimp abundance and biomass in Biscayne Bay supports other workers findings that juvenile *Penaeid* shrimp prefer seagrass habitat, to other bottom communities (Iversen, et al., 1993; Garcia and Reste, 1981; Costello, et al., 1986). Costello et al. (1986) noticed a positive correlation between blade density of *Halodule* and *Thalassia* to shrimp density. And that shrimp density is higher in grass beds near shore than beds in open water (Costello et al., 1986). Van Lopik et al. (1979) and others (Zimmerman and Livingston, 1976; Dugan and Livingston 1982) report that healthy seagrass habitat appears essential for stable invertebrate communities. Polluted or denuded sections of estuaries monitored by these workers had a marked reduction in invertebrate diversity and biomass (Bielsa et al., 1983). The findings of this study seem to be in agreement with this previous work. The sample sites which had the highest shrimp biomass, Sunset harbor, Miami River, Rickenbacker Cswy and Matheson Hammock, all had more than 50 percent rooted vegetation.

Shoreline alterations have been cited by other workers. Van Lopik et al. (1979) have described several shoreline development practices that severely degrade shrimp habitat. The most obvious and highly publicized of these being the flow of polluted waters into estuaries. Other practices that negatively alter shrimp nursery habitat include (1) direct saltwater intrusion (or diversion of natural freshwater discharge), which causes unfavorable salinity regimes; (2) impounding of natural waterways, which prevents the influx of immigrating shrimp; and (3) bulkheading of shorelines, which removes the critical marsh or mangrove water interface. Mock's (1967) findings emphasized the consequences of shoreline modifications; he found 2.5 times as many brown shrimp and 14 times more white shrimp along a natural shoreline than along a bulkheaded shoreline.

If the work of Bielsa and Van Lopik is applied to Biscayne Bay a greater number of shrimp should be found in the less developed southern basin. In interviews with shrimp fisherman from Biscayne Bay, they agree that a greater number of shrimp are available in the Southern Basin, and very rarely do they trawl north of the Rickenbacker Cswy. Campos and Berkeley (1986), in their population assessment of bait shrimp in Biscayne only surveyed the southern basin. Our data does not support this, but it may be due to the fact that our sampling regime did not select sites for their high shrimp content, but for their proximity to canals and other manmade shoreline infrastructure. The Sunset Harbor site, which is located on the eastern side of the bay and surrounded by manmade islands, downtown Miami, and a marina, had the highest abundance and biomass of any site. Other factors appear to be more important in the distribution of juvenile shrimp than shoreline alteration alone.

Shoreline alteration, especially the creation of artificial islands and bulkheads which restrict or alter water flow patterns in and out of the northern basin may be a significant factor in recruitment. At present, very precise current flow measurement techniques are being perfected using VHF radar. To date this high quality vector current mapping has only been done for a small portion of Biscayne Bay (Map 5). VHF radar mapping could be used to produce very accurate vector current maps of the Bay and adjacent ocean areas to provide clues to current transport regimes which control the recruitment of larval shrimp into the Bay and adults out to the spawning grounds. Discovering the spawning grounds and thus gaining a better understanding of the Biscayne Bay population and management plans for it, would be a significant addition to the work on *P. dourarum* in Biscayne Bay.

VI. REFERENCES

Allen, D.A., J.A. Hudson and T.J. Costello. 1980. *Post Larval shrimp (Penaeus) in the Florida Keys: species, size, and seasonal abundance*. Bull. Mar. Science. 30(1): 21-33.

Berkeley, Steven a., Donald W. Pybas and Wilfredo l. Campos. 1985. *Bait shrimp fishery of Biscayne Bay*. Florida Sea Grant Extension Program. Technical Paper No. 40. Project No. IR-83-9. Grant No. NA80AA-D-00038.

Bielsa, Lourdes M., William H. Murdich and Ronald F. Labisky. 1983. *Species profiles: life histories and environmental requirements of coastal fisheries and invertebrates (South Florida), Pink Shrimp*. National Coastal Ecosystems Team, Division of Biological Services, Research and Development. Fish and Wildlife Service, U.S. Department of the Interior, Fish and Wildlife Service. FWS/OBS--82/11.17. TR EL-82-4.

Bishop, J.M., J.G. Gosselink and J.H. Stone. 1980. *Oxygen consumption and hemolymph osmolarity of brown shrimp, Penaeus aztecus*. U.S. Fish and Wildlife Service. Fish. Bull. 78. 741-757.

Brand, Larry E., et al. 1991. *Spatial and temporal distribution of phytoplankton in Biscayne Bay, Florida*. Bulletin of Marine Science. 49(1-2): 599-613.

Broad, A.C. 1965. *Environmental Requirements of shrimp*. Pobl. Hlth. Serv. Pobls Wash. (999-WP-25). 86-91.

Campos, Wilfredo L. and Steven a. Berkeley. 1986. *Impact of the Commercial Fishery on the Population of Bait Shrimp (Penaeus spp.) in Biscayne Bay*. Final Report to Dade County Department of Environmental Resources Management.

Coleman, Falicia C., C. Koenig and William F. Hernkind. 1993. *Survey of Florida inshore shrimp trawler bycatch*. Both first and second annual reports. Submitted to Florida Department of Natural Resources, Florida Marine Research Institute. (DNR contract #C-7779).

Coleman, Falicia C., C. Koenig and William F. Hernkind. 1991-1992. *Survey of Florida inshore shrimp trawler by-catch and preliminary tests of by-catch reduction devices*. Annual Report, Submitted to Florida Department of Natural Resources, Florida Marine Research Institute. (DNR contract #C-6953).

Costello, T.J.. 1964. *Field Techniques for staining-recapture experiments with commercial shrimp*. Special Scientific Report-Fisheries No. 484. United States Department of the Interior, Fish and Wildlife Service. Washington, D.C.

Costello, T.J. 1963. *Pink shrimp life history*. U.S. Fish. Wildl. Serv. Circ. 161. 35-37.

Costello, T.J. and Donald M. Allen. 1969. *Ecology of pink shrimp in Florida Bay*. In M.J. Lindner and R.E. Stevenson (eds.). "Report of the Bureau of Commercial Fisheries Biological Laboratory", Galveston, Texas. U.S. Fish and Wildlife service. Circ. 325.

Costello, T.J. and Donald M. Allen. 1960. *Notes on the migration and growth of pink shrimp (Penaeus duorarum).* Proc. Gulf Caribb. Fish. Inst. 12. 5-9.

Costello, T.J, Donald M. Allen and J. Harold Hudson. 1986. *Distribution, seasonal abundance, and ecology of juvenile northern pink shrimp Penaeus duorarum, in the Florida Bay area*. NOAA Technical Memorandum NMFS-SEFC-161.

Dade County Landings of Bait Shrimp unedited data from Batches 223-301, 1986 -1993. 1994. Florida department of Environmental Protection, Marine Fisheries Information System.

Dobkin, S. 1961. *Early development stages of pink shrimp, Penaeus duorarum, from Florida waters*. U.S. Fish and Wildlife Service. Fish, Bull. 1961.

Dugan and Livingston. 1982. *Long-term variation of macro-invertebrate assemblages in Apalachee Bay, Florida*. Estuarine Coastal Shelf Science. 14:391-403.

Farfante, Isabel Perez. 1969. *Western Atlantic shrimps of the genus Penaeus*. Fisheries Bulletin. U.S. Fish and Wildlife Service. 67(3).

Fish, J.E. and M. Stewart. 1991. *Hydrology of the surficial aquifer system, Dade Cty., FL*. Water resource Investigations Report 90-4108. U.S. Geol. Sur. Tallahassee, FL.

Fontaine, C.T. and R.A. Neal. 1986. *Relation between tail length and total length in three commercially important species of Penaeid shrimp*. U.S. Fish Wildl. Serv. Bull. 67. 125-126.

Fuss, C.W., Jr., and L.H. Ogren. 1966. *Factors affecting activity and burrowing habits of the pink shrimp, Penaeus duorarum Burkenroad*. Biol. Bull. (Woods Hole, Mass.) 130. 179-191.

Garcia, S. and Lee Reste, L. 1981. *Life cycles, dynamics, exploitation and management of coastal Penaeid shrimp stocks*. FAO Fish Tech. Pap. 203.

Gulland, J.A. and B.J. Roghschild (eds.). 1981. *Penaeid shrimp - their biology and management. Selected papers presented at the workshop on the scientific basis for the management of Penaeid shrimp*. Held in Key West, FL. November 1981.

Gunter, G., J.Y. Christmas, and R. Killebrew. 1964. *Some relations of salinity to population distribution of motile estuarine organisms, with special reference to Penaeid shrimp*. Ecology. 45. 181-185.

Gunter, Gordon and Henry H. Hildebrand. 1954. *The relation of total rainfall of the state and catch of the marine shrimp (Penaeus setiferus) in Texas waters*. Bulletin of Marine Science of the Gulf and Caribbean. 2(2). 95-103.

Hughes, D.A. 1968. *Factors controlling emergence of pink shrimp (Penaeus duorarum) from the substrate*. Biol. Bull. (Woods Hole, Mass.) 134. 48-59.

Hughes D.A. 1969a. *Responses to salinity change as tidal transport mechanism of pink shrimp, Penaeus duorarum*. Biol. Bull. (Woods Hole, Mass.) 136. 43-53.

Inversen, E.S., D.M. Allen and J.B. Higman. 1993. *Shrimp Capture and Culture Fisheries of the United States*. Halsted Press. New York.

Jones, A.C., D.E. Dimitriou, J.J. Ewald and J.H. Tweedy. 1970. *Distribution of early developmental stages of pink shrimp Penaeus duorarum, in Florida water*. Bull. Mar. Science. 20. 634-661.

Lee, T. and C. Rooth. 1976. *Circulation and exchange processes in Southeast Florida's coastal lagoons*. In A. Thorhaug and A. Volker. (eds.). Biscayne Bay: Past/ Present/Future. 51-64.

Lindner, Milton J. 1957. *Survey of shrimp fisheries of Central and South America*. Special Scientific ReportFisheries No. 235. United States Department of the Interior, Fish and Wildlife Service. Washington.

Littler, M.M. and DS. Littler, eds. 1985. Handbook of Physiological Methods. Ecological Methods. Macroalgae. Cambridge University Press. Cambridge.

Littler, D.S. et al. 1989. Marine Plants of the Caribbean: A Field Guide from Florida to Brazil. Smithsonian Inst. Press. Wash. D.C.

Local Climatological Data. 1994. National Climatic Data Center. NOAA. Wash. D.C.

Maharaj, Vishwanie and Corrad Recksiek. 1991. *The by-catch from the artisanal shrimp trawl fishery, Gulf of Paria, Trinidad*. Marine Fish. Review. 53(2). 9-15.

Meese, R.J., P.A. Tomich. 1992. *Dots on the rocks: a comparison of percent cover estimation methods*. J. Exp. Mar. Bio. Ecol. 59-73.

Mock, C.R. 1967. *Natural and altered estuarine habitats of Penaeid shrimp*. Proc. Gulf Caribb. Fish, Inst. 19:86-98.

Roller-frame trawl bait shrimp fishery impacts on by-catch, seagrass meadows, and habitat quality in Pine Island Sound, Florida. 1992. Final Draft, submitted to Florida Department of Natural Resources, Marine Research Institute.

Skop, Richard A., H.S. Graber and D.B. Ross. 1995. *VHF radar measurements of flow patterns in bays and estuaries*. Proc. of the IEEE Fifth Working Conference on Current Measurement, St. Petersburg, FL., Feb. 1995.

Surface water improvement and management plan for Biscayne Bay, technical supporting document. Draft. 1994. Lower East Coast Planning Division. South Florida Water Management District.

Geol. Surv. 1990. *Water resources data for Florida, surface water records*. USGS. Tallahassee, FL.

Van de Kreeke, J. and J.D. Wang. 1984. *Hydrology of north Biscayne Bay*. Dade Cty Dept. of Environ. Res. magmt. and Florida Seagrant report.

Van Lopik, et al. 1979. *Draft environmental impact statement and fishery management plan for the shrimp fishery of the Gulf of Mexico, United States waters*. Cent. Wetland Resources. La. State University, Baton Rouge. 227.

Voss, G.L. et al. 1969. *The marine ecology of Biscayne National Monument; a report to the National Park Service*. Department of the Interior. Miami Institute of Marine and Atmospheric Science. University of Miami.

Voss, G.L. 1976. *Invertebrates of Biscayne Bay*. in Thorhaug and Volker (eds.). *Biscayne Bay*: *past/present/future; papers prepared for Biscayne Bay Symposium 1*. University of Miami Sea Grant report, 5. Coral Gables: University of Miami.

Williams, A.B. 1960. *The influence of temperature on osmotic regulation in two species of estuarine shrimps (Penaeus*). Biol. Bull. (Woods Hole, Mass.) 119.560-571.

Wilson, Susan Uhl. 1975. *Biscayne Bay: Environmental and Social Systems*. University of Miami Sea Grant, Special Report Number 1. March 1975.

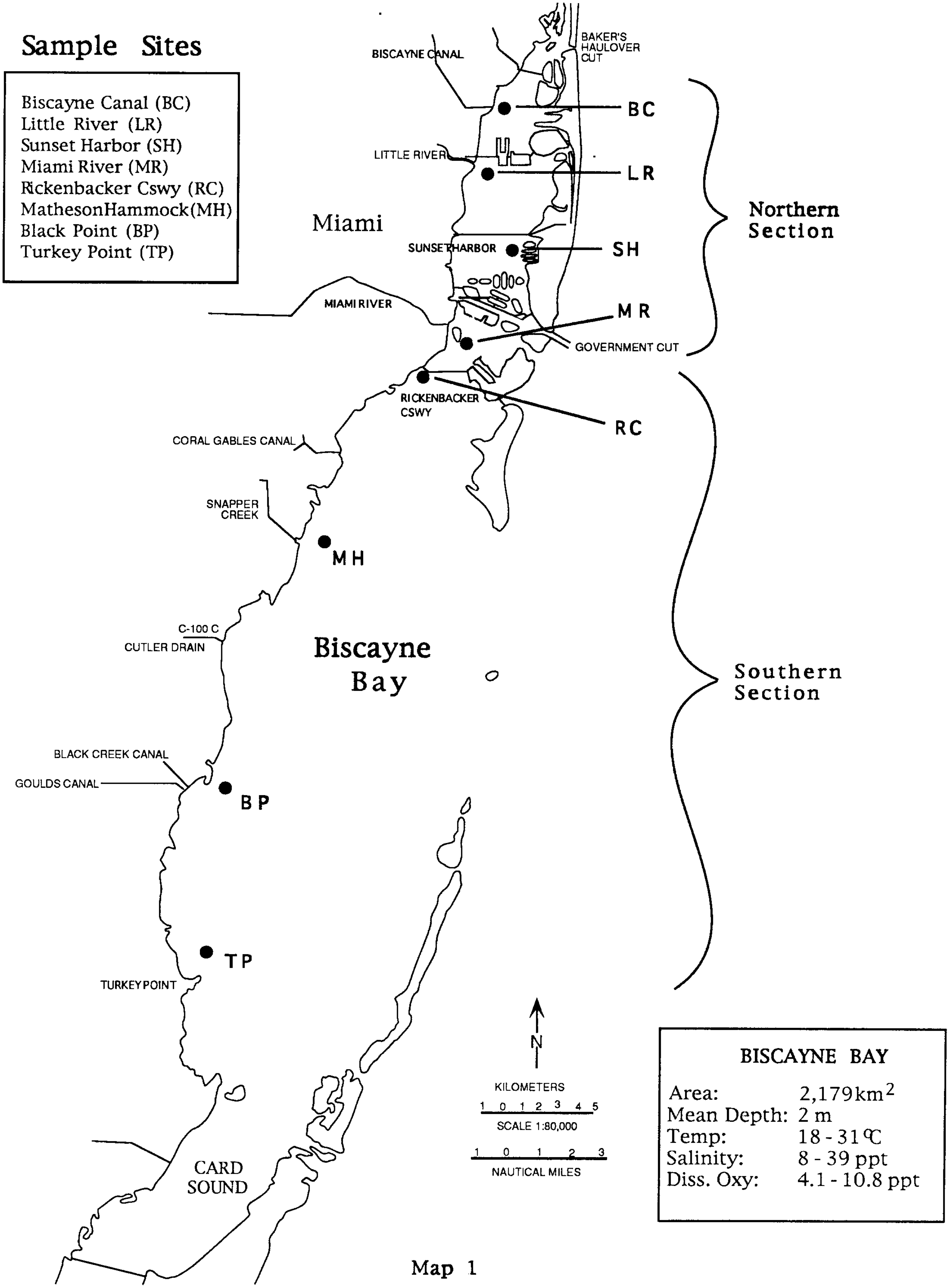
Witzell, W.N. and D.M. Allen. 1983. *Summary of studies relating coastal climatological factors and commercial shrimp production, southeastern United States*. FAO Fish. Rep. 278 Suppl. 111-19.

Zimmerman and Livingston. 1976. *Effects of kraft-mill effluents on benthic macrophyte assemblages in a shallow-bay system (Apalachee Bay, north Florida).* Mar. Biol. 34:297-312.

Appendix A

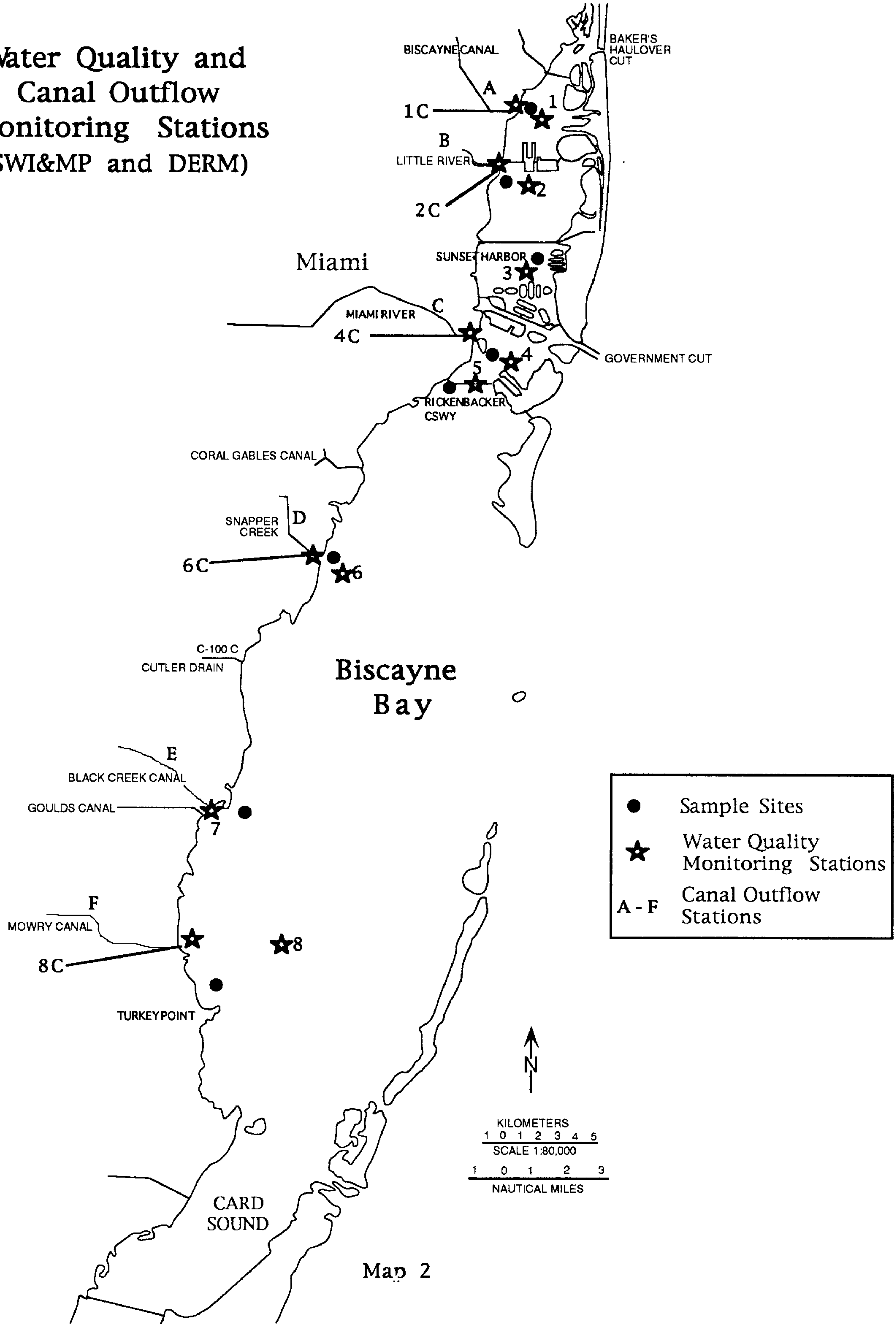
Maps

* Map 1: Sample Sites
* Map 2: Water Quality and Canal Outflow Monitoring Stations
* Map 3: Site Specific Environmental Data
* Map 4: Monthly Shrimp Biomass Per Site
* Map 5: Current Flow Patterns In Biscayne Bay


Sample Sites
Biscayne Canal (BC)
Little River (LR)
Sunset Harbor (SH)
Miami River (MR)
Rickenbacker Cswy (RC)
MathesonHammock(MH)
Black Point (BP)
Turkey Point (TP)
BISCAYNE CANAL
BAKER'S HAULOVER CUT
BC
LITTLE RIVER
LR
Miami
Northern Section
SUNSET HARBOR
SH
MIAMI RIVER
MR
GOVERNMENT CUT
RICKENBACKER CSWY
RC
CORAL GABLES CANAL
SNAPPER CREEK
MH
C-100 C
CUTLER DRAIN
Biscayne Bay
Southern Section
BLACK CREEK CANAL
GOULDS CANAL
BP
TP
TURKEY POINT
N
KILOMETERS
1 0 1 2 3 4 5
SCALE 1:80,000
1 0 1 2 3
NAUTICAL MILES
CARD SOUND
BISCAYNE BAY
Area: 2,179km²
Mean Depth: 2 m
Temp: 18 - 31 °C
Salinity: 8 - 39 ppt
Diss. Oxy: 4.1 - 10.8 ppt

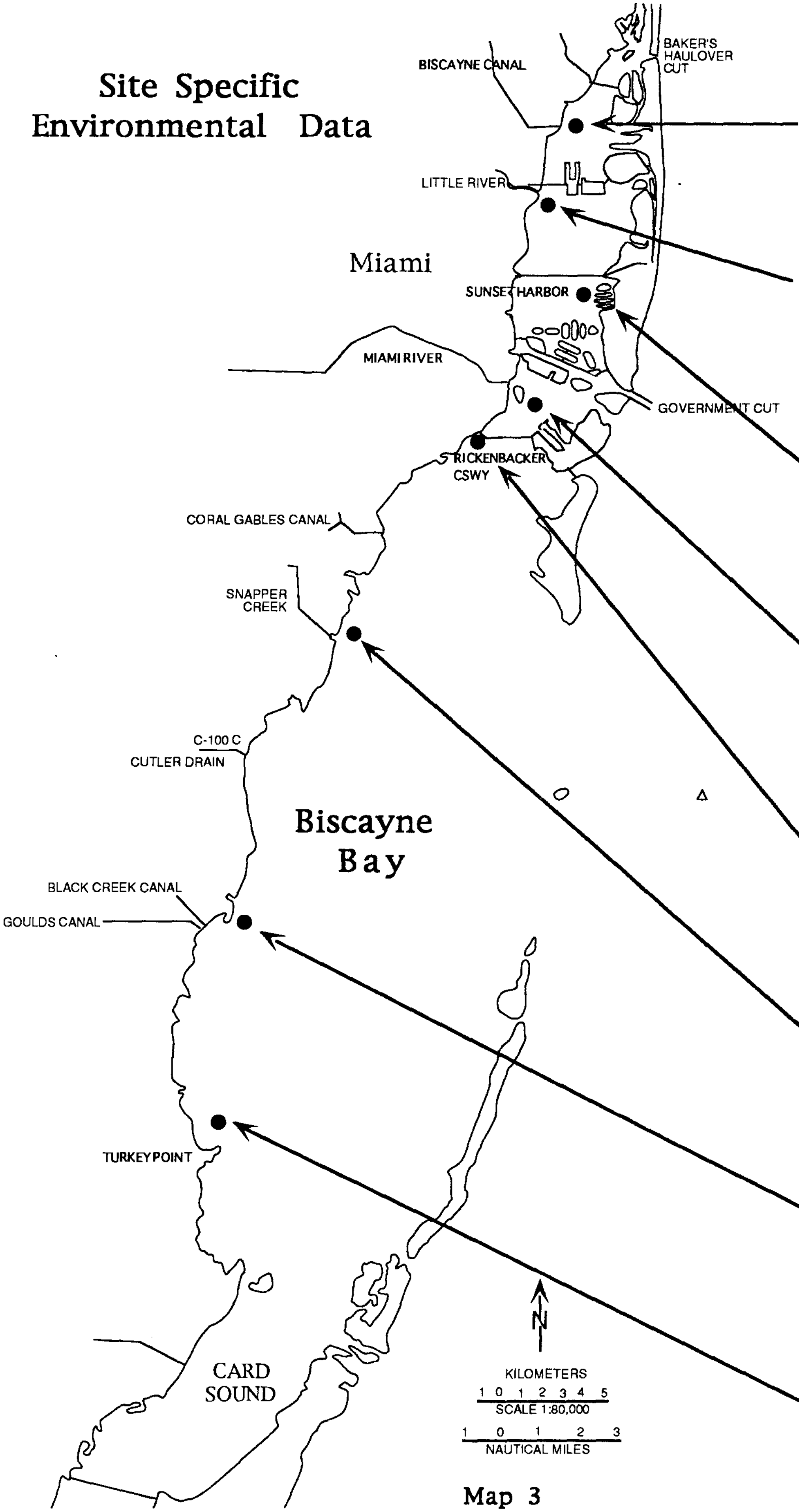
Map 1

Water Quality and Canal Outflow Monitoring Stations (SWI&MP and DERM)



Map 2

Site Specific Environmental Data



Biscayne	Canal
Depth (m):	2.13-4.17
Salinity (ppt):	15.0-34.0
D.O. (ppt):	5.81-8.82
Temp (C):	21.9-30.0
Primary Veg.:	Amphiroa

Little	River
Depth (m):	2.13-3.98
Salinity (ppt):	8.0-32.0
D.O. (ppt):	4.54-9.73
Temp (C):	22.0-30.6
Primary Veg.:	Amphiroa

Sunset	Harbor
Depth (m):	1.77-3.35
Salinity (ppt):	20.1-34.0
D.O. (ppt):	5.53-8.39
Temp (C):	25.0-31.3
Primary Veg.:	Syringodium

Miami	River
Depth (m):	1.57-3.26
Salinity (ppt):	27.0-35.0
D.O. (ppt):	4.27-8.25
Temp (C):	21.8-30.6
Primary Veg.:	Thalassia

Rickenbacker	Cswy
Depth (m):	1.42-2.39
Salinity (ppt):	28.0-35.0
D.O. (ppt):	4.68-8.63
Temp (C):	19.9-30.0
Primary Veg.:	Thalassia

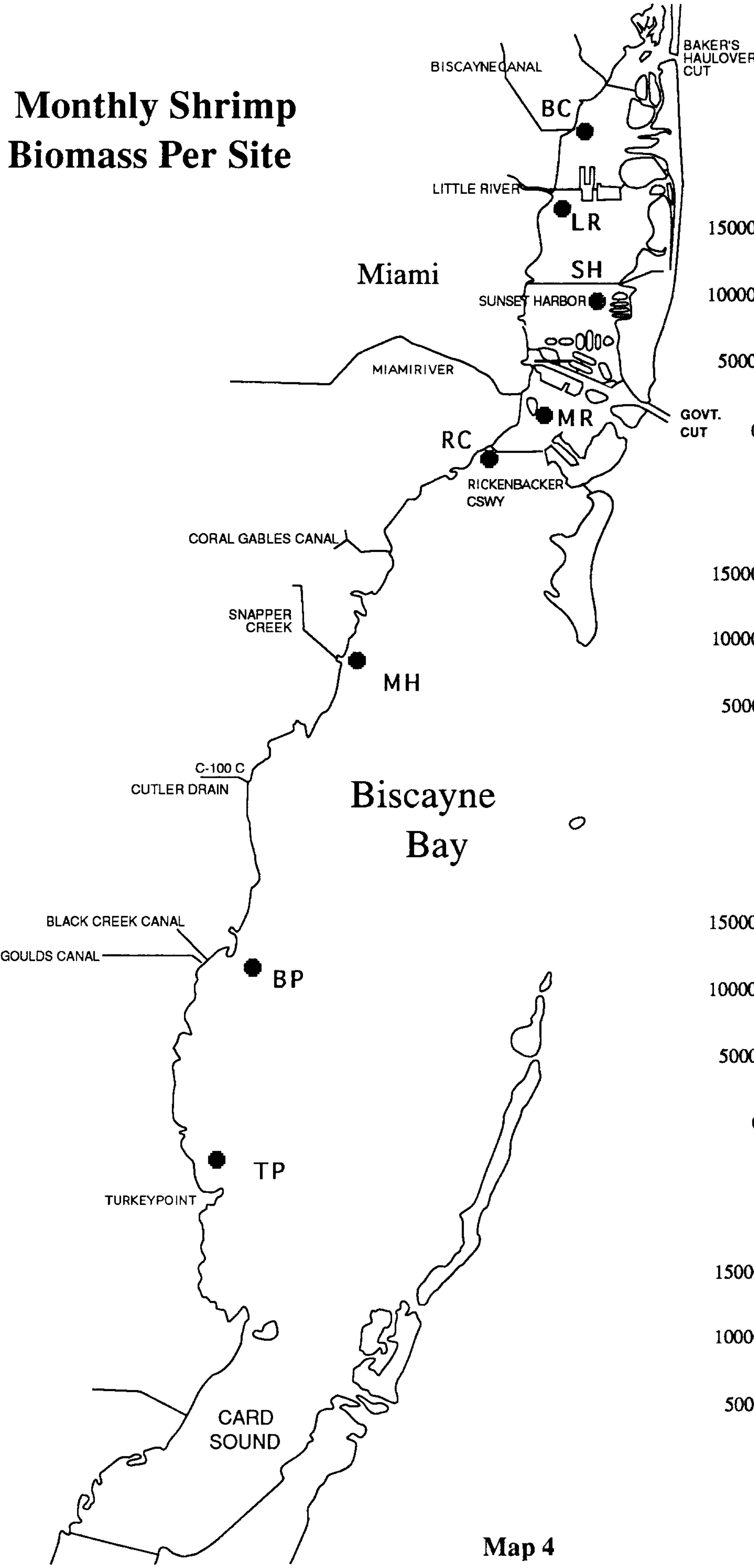
Matheson	Hammock
Depth (m):	1.49-2.62
Salinity (ppt):	25.0-34.0
D.O. (ppt):	4.12-9.15
Temp (C):	19.2-30.5
Primary Veg.:	Thalassia

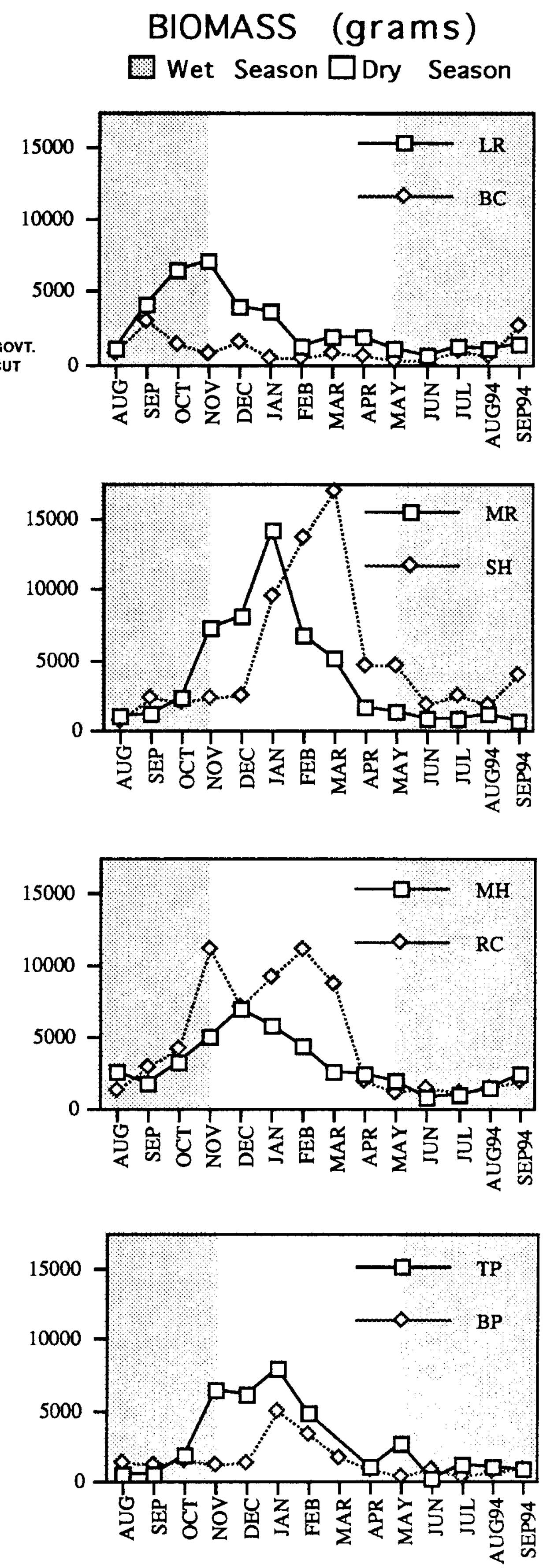
Black	Point
Depth (m):	1.88-2.73
Salinity (ppt):	15.0-32.0
D.O. (ppt):	6.04-10.13
Temp (C):	18.9-31.2
Primary Veg.:	Syringodium

Turkey	Point
Depth (m):	1.56-2.03
Salinity (ppt):	15.0-39.0
D.O. (ppt):	6.30-10.80
Temp (C):	19.6-31.6
Primary Veg.:	Laurencia

Map 3

Monthly Shrimp Biomass Per Site

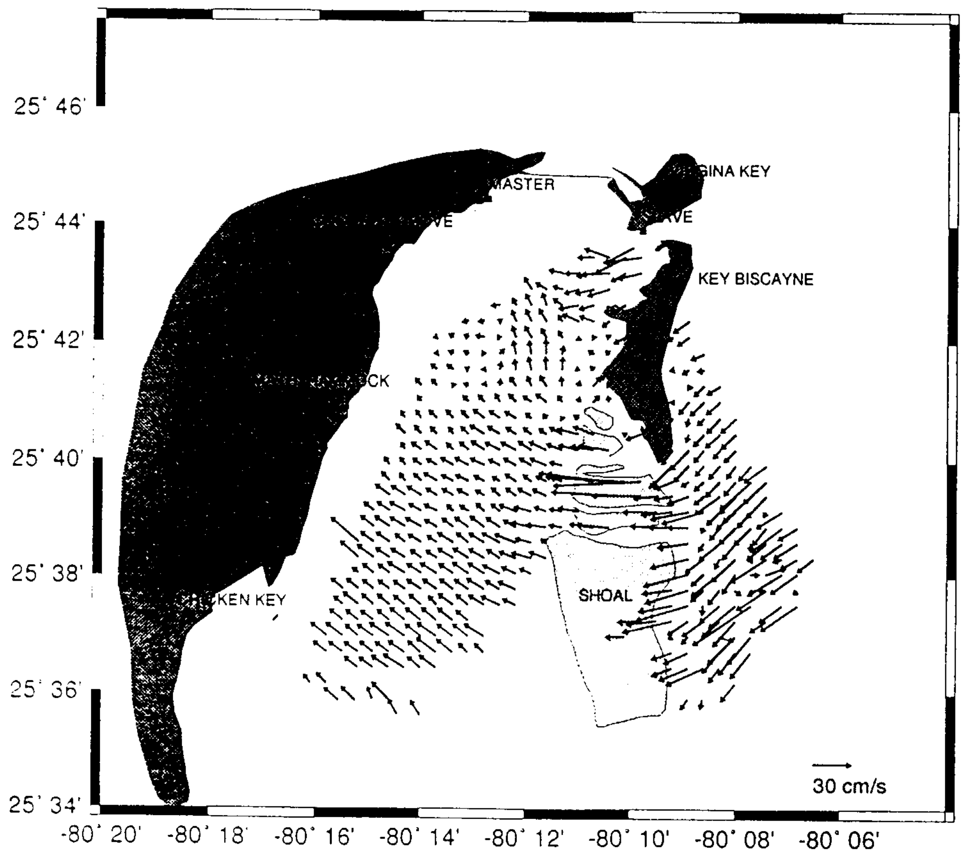




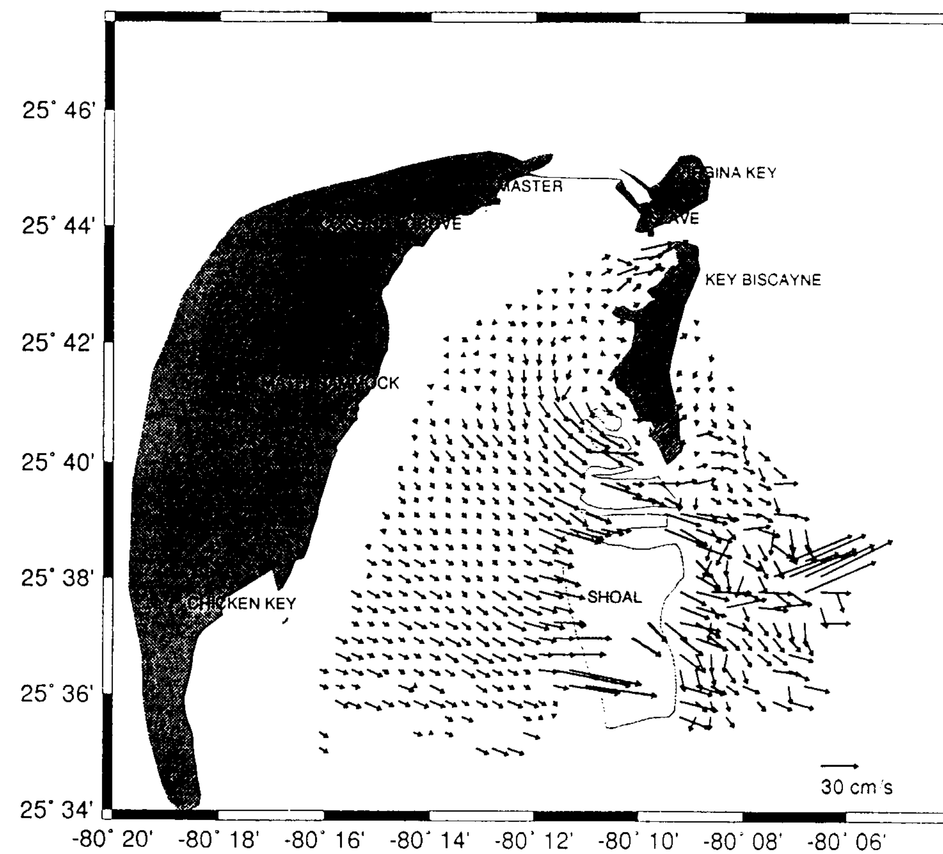
Map 4

Current Flow Patterns in Biscayne Bay

Max Flood Tide: 11:40 hrs. May 1, 1994



Max Ebb Tide: 18:20 hrs. May 1, 1994



Richard A. Skop, et al. Division of Applied Marine Physics, Rosenstiel School of Marine and Atmospheric Science, University of Miami

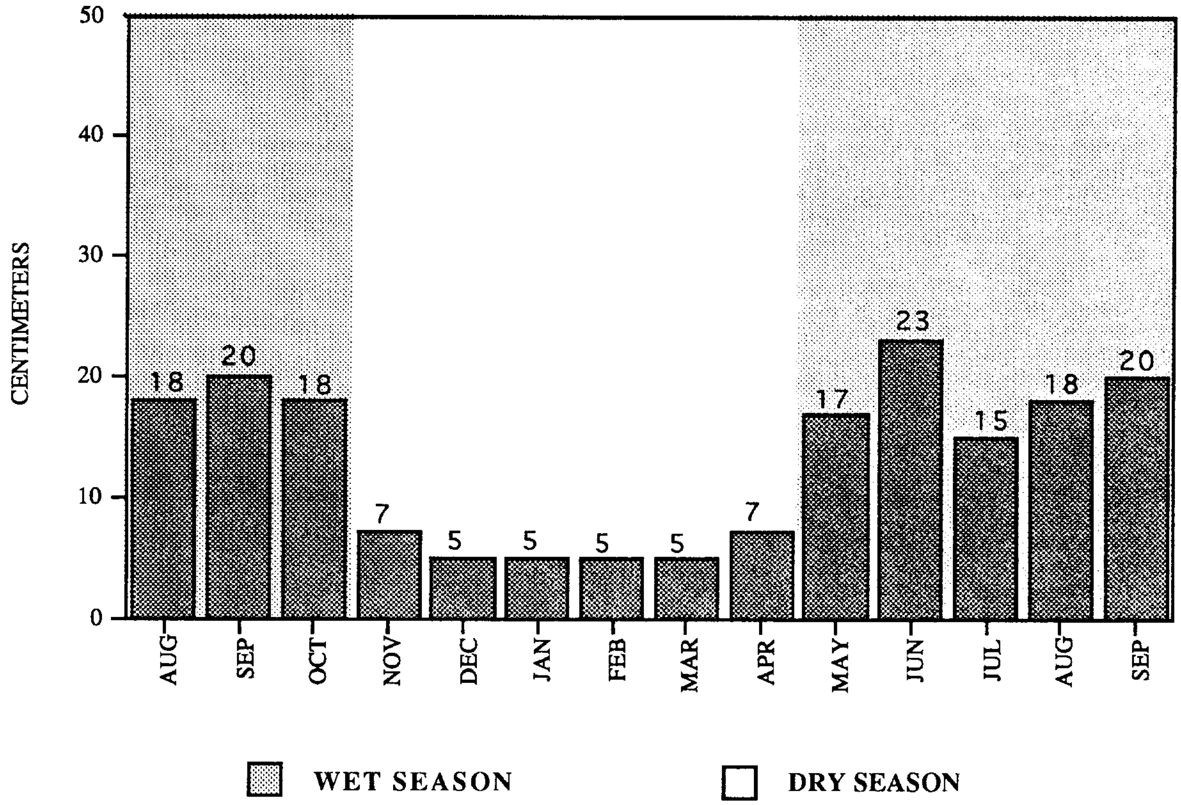
Map 5

Appendix B

Figures

* Figure 1a & 1b: Rainfall
* Figure 2: Temperature
* Figure 3: Dissolved Oxygen
* Figure 4: Salinity
* Figure 5: Total Shrimp Abundance
* Figure 6a & 6b: Seasonal Log-Transformed Abundance
* Figure 7: Total Shrimp Biomass
* Figure 8a & 8b: Seasonal Log-Transformed Biomass

30 YEAR MEAN MONTHLY RAINFALL



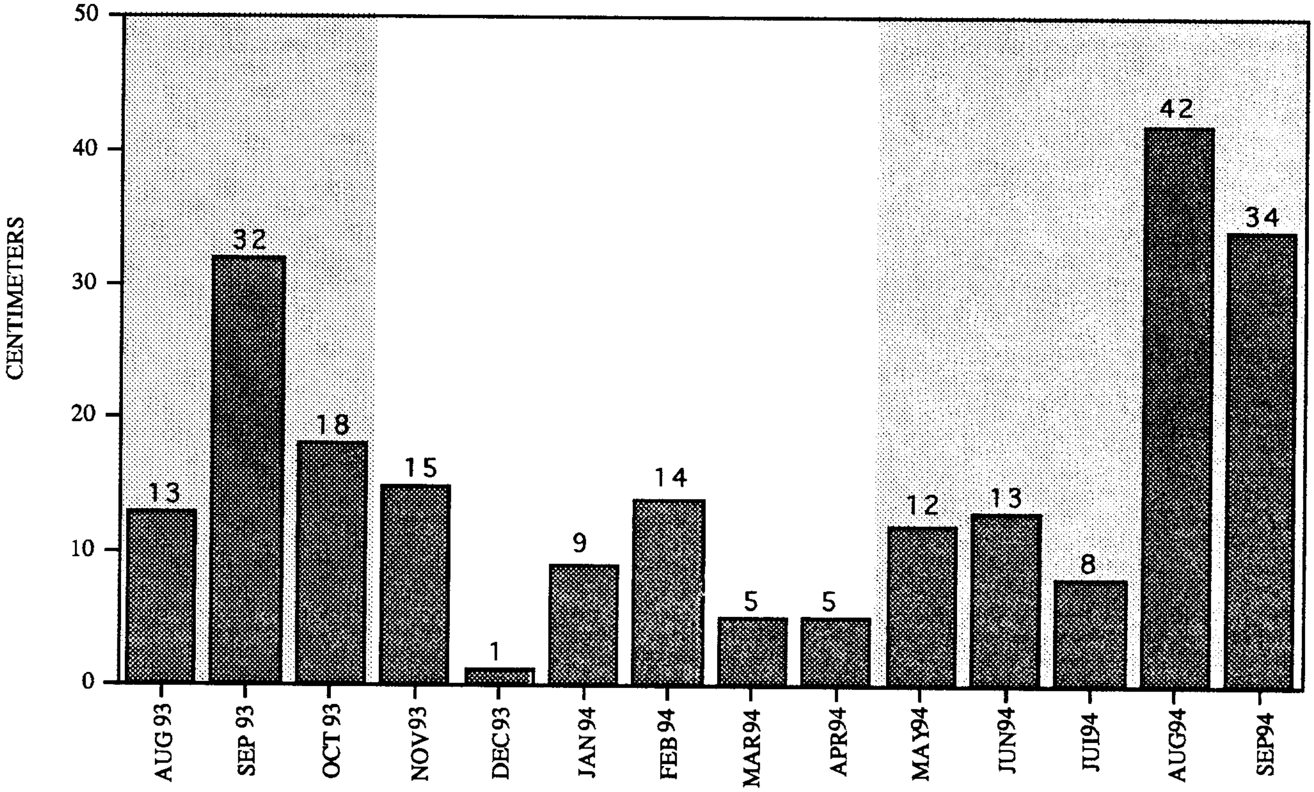
Total Seasonal Rainfall (six month): 111 cm.

Total Seasonal Rainfall: 34 cm.

Monthly Mean Rainfall Data from: NOAA comparative Climatic Data for the U.S. through 1989. Mean data was calculated from rainfall data collected from 1951-1980.

Figure 1a

RAINFALL



WET SEASON

TOTAL RAINFALL: 172 cm. or 112 cm. (with the overlapping months averaged in order to calculate a six month season total.)

DRY SEASON

TOTAL RAINFALL: 49 cm.

Rainfall Data From: The National Climatic Data Center collected at the Miami International Airport. (National Climatic Data Center, 1994).

Figure 1b

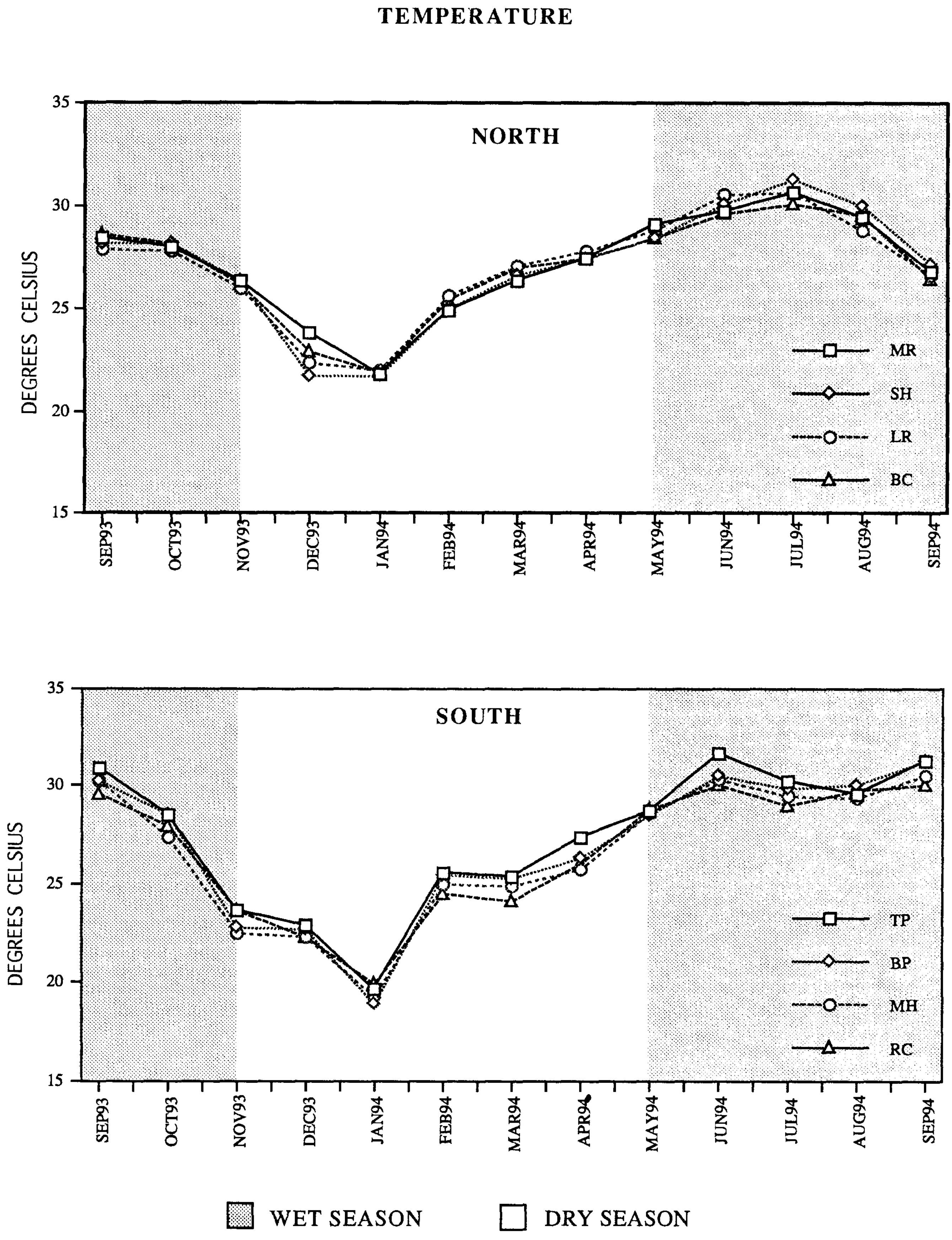
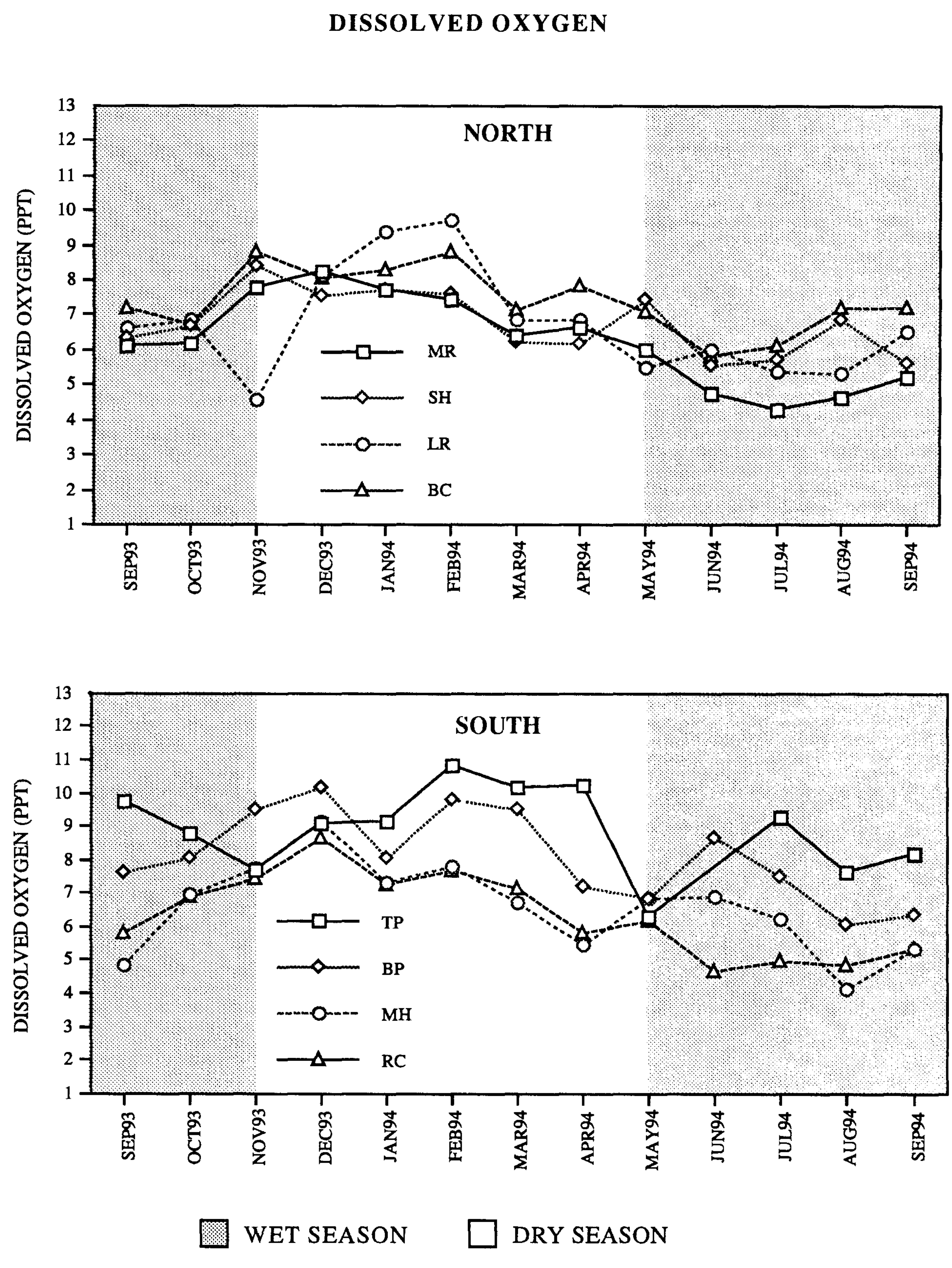

TEMPERATURE
NORTH
DEGREES CELSIUS
35
30
25
20
15
MR
SH
LR
BC
SEP93
OCT93
NOV93
DEC93
JAN94
FEB94
MAR94
APR94
MAY94
JUN94
JUL94
AUG94
SEP94
SOUTH
DEGREES CELSIUS
35
30
25
20
15
TP
BP
MH
RC
SEP93
OCT93
NOV93
DEC93
JAN94
FEB94
MAR94
APR94
MAY94
JUN94
JUL94
AUG94
SEP94
WET SEASON
DRY SEASON

Figure 2



DISSOLVED OXYGEN
NORTH
DISSOLVED OXYGEN (PPT)
13
12
11
10
9
8
7
6
5
4
3
2
1
MR
SH
LR
BC
SEP93
OCT93
NOV93
DEC93
JAN94
FEB94
MAR94
APR94
MAY94
JUN94
JUL94
AUG94
SEP94
SOUTH
DISSOLVED OXYGEN (PPT)
TP
BP
MH
RC
WET SEASON
DRY SEASON

Figure 3

SALINITY

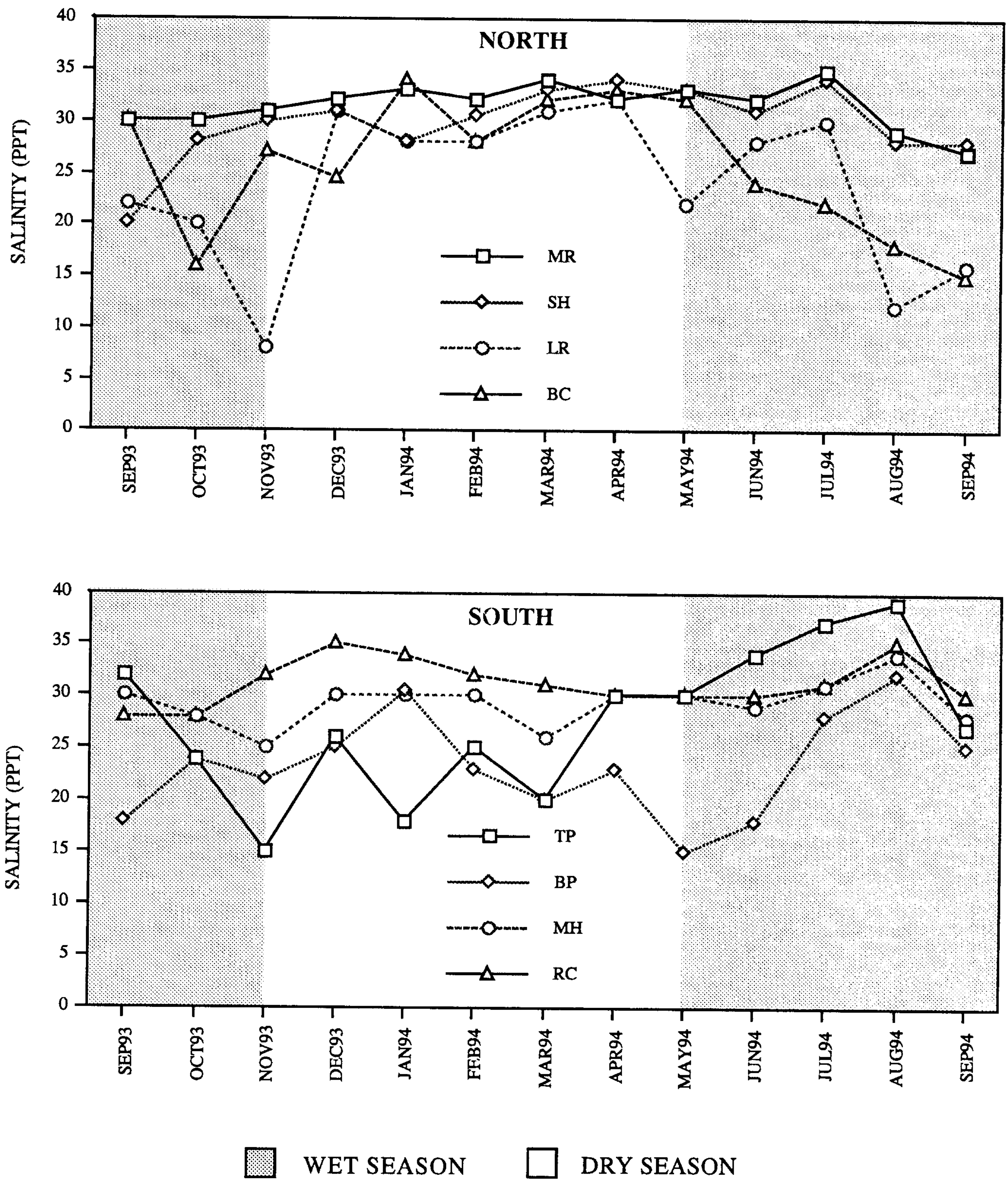


Figure 4

TOTAL SHRIMP ABUNDANCE

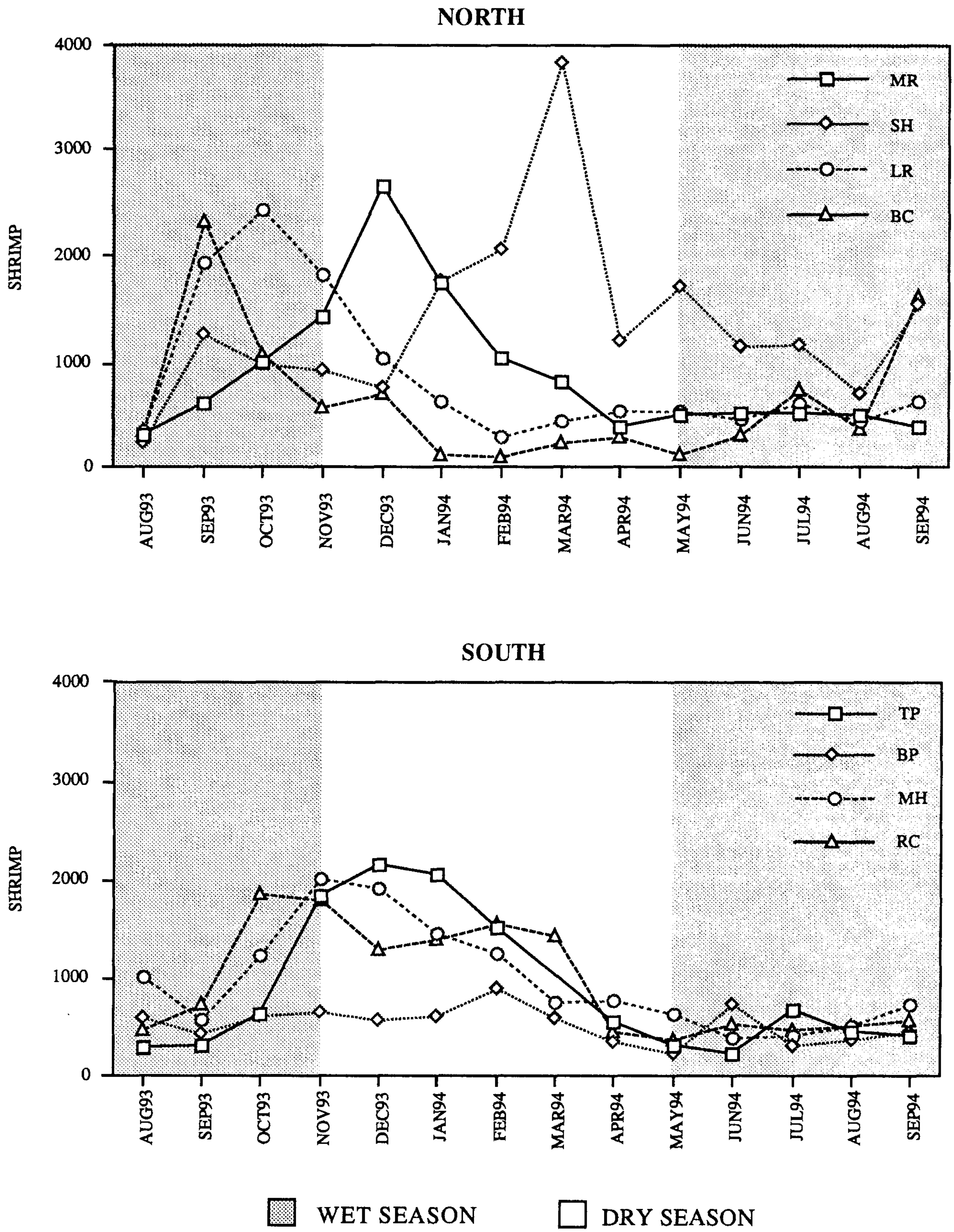
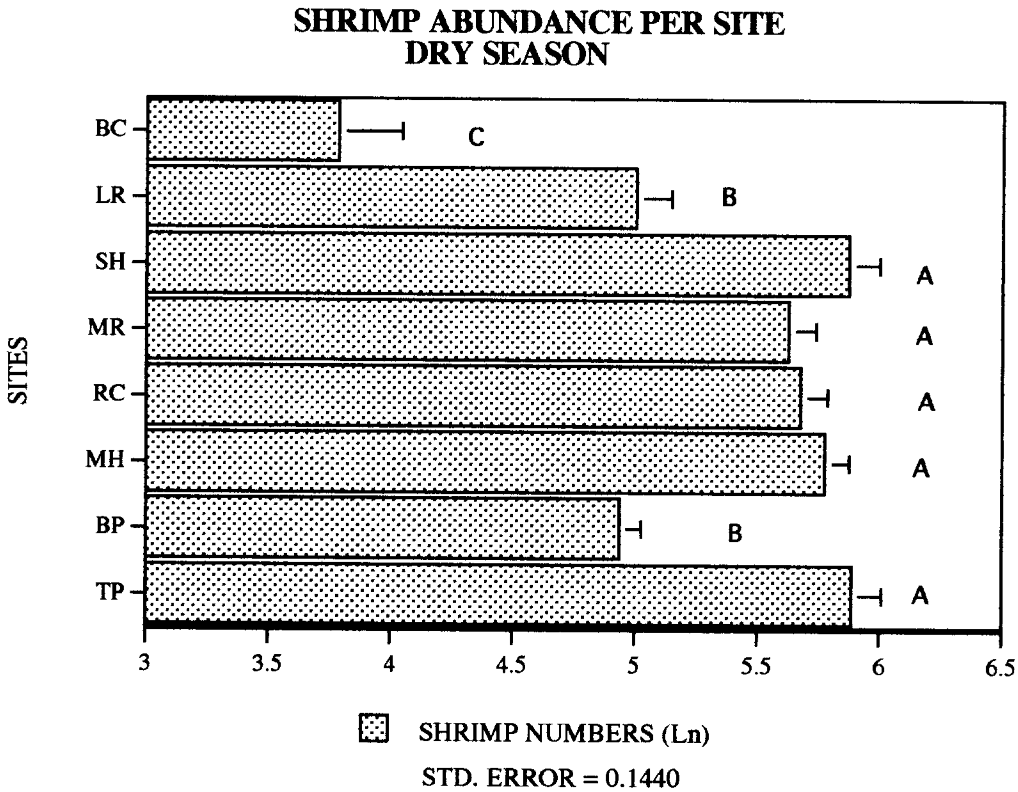


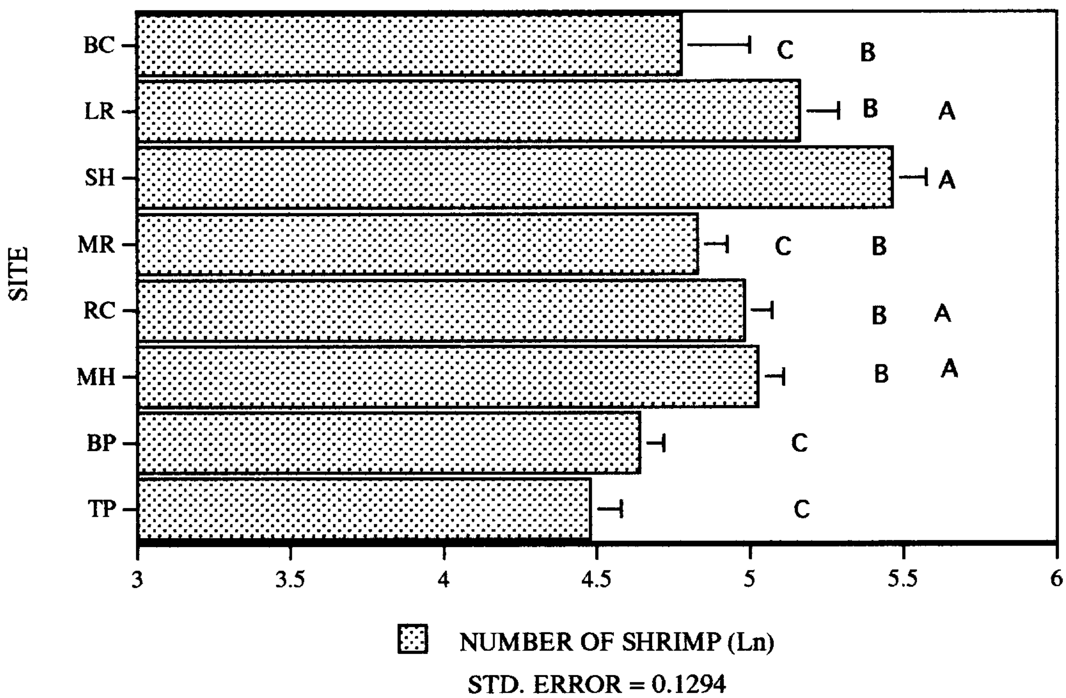
Figure 5



Sites sharing a common letter (A,B,C) have statistically similar shrimp abundance during the dry season.

Figure 6a

SHRIMP ABUNDANCE PER SITE
WET SEASON



Sites sharing a common letter value (A,B,C,) have statistically similar shrimp abundance during the wet season.

Figure 6b

TOTAL SHRIMP BIOMASS

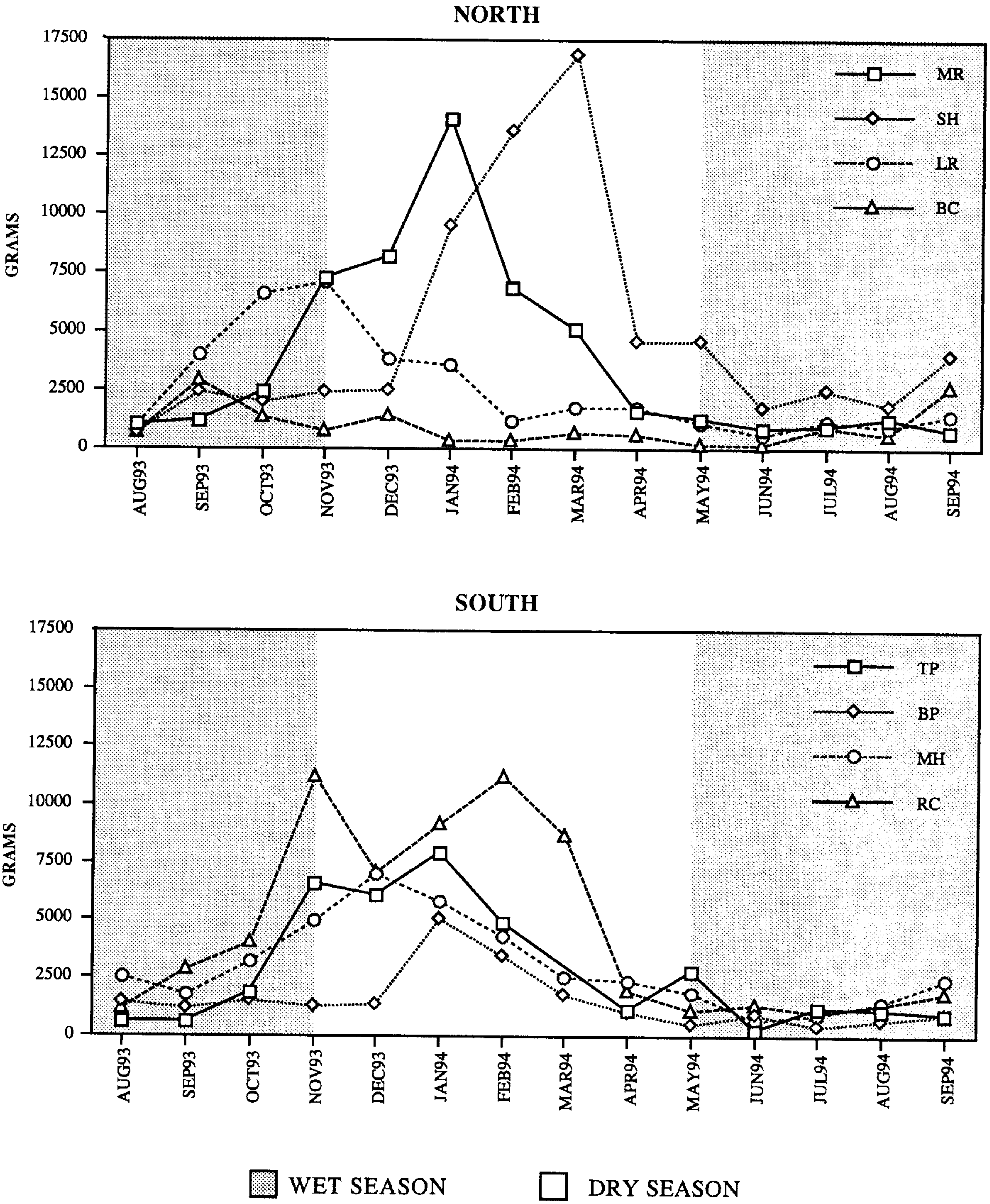
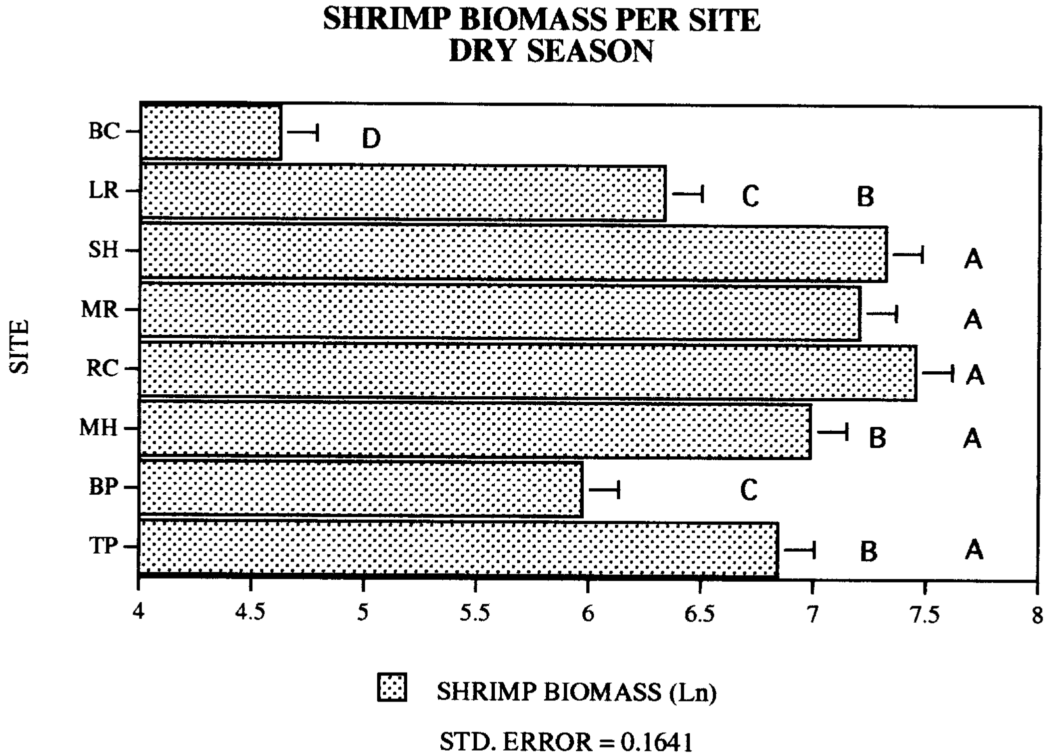
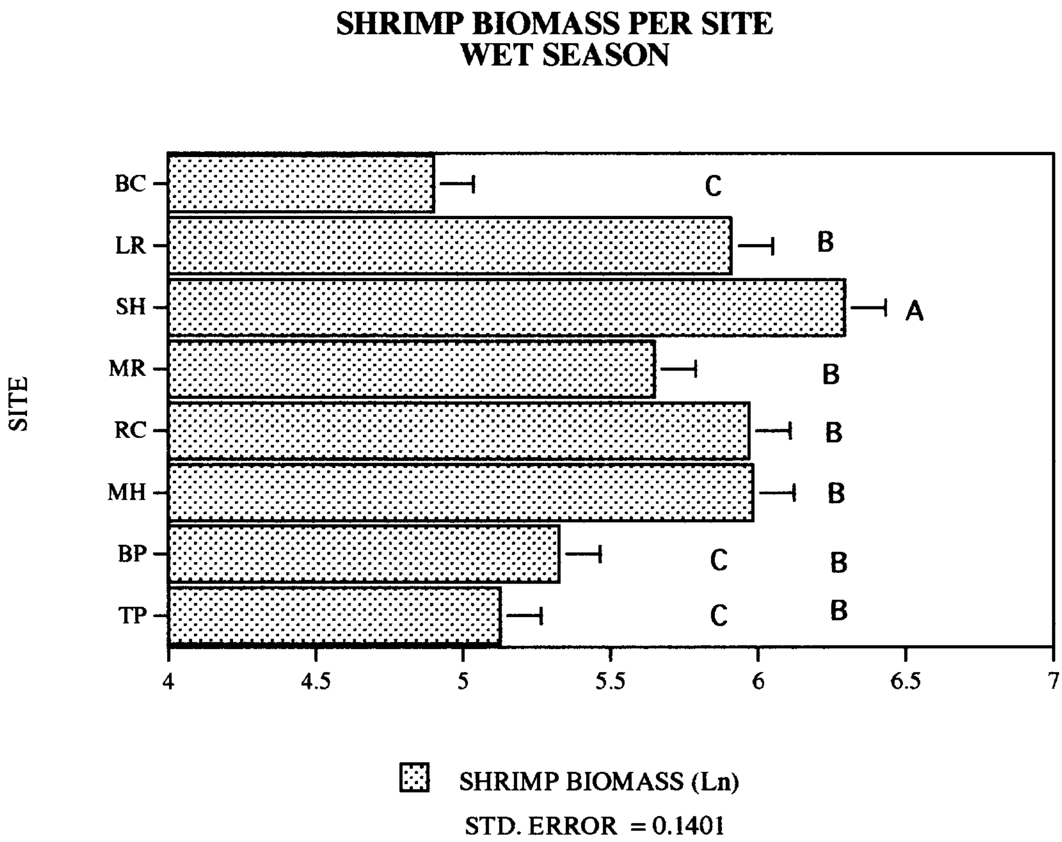


Figure 7



Sites sharing a common letter (A,B,C,D), have statistically similar biomass levels during the dry season.

Figure 8a



Sites sharing a common letter (A,B,C), have statistically similar biomass levels during the wet season.

Figure 8b

Appendix C

Tables

AVERAGE MONTHLY FRESHWATER OUTFLOW DATA FOR CANALS ADJACENT TO STUDY SITES

CANALS

MONTH	A	B	C	D	E	F
DRY SEASON						
NOVEMBER	4.0	6.7	6.3	5.4	7.1	17.6
DECEMBER	2.1	4.7	4.3	0.8	3.9	13.3
JANUARY	1.8	3.4	4.2	2.0	3.6	9.9
FEBRUARY	2.7	3.8	5.1	2.9	4.2	6.8
MARCH	3.3	4.2	6.3	2.3	5.0	8.9
APRIL	2.9	5.1	6.9	2.8	3.5	4.0
TOTAL	16.8	27.9	33.1	16.2	27.3	60.5
WET SEASON						
MAY	2.8	4.7	2.4	1.4	4.3	5.8
JUNE	7.9	10.4	7.0	10.4	18.2	14.2
JULY	6.2	9.6	12.9	7.4	10.5	15.6
AUGUST	7.1	8.8	16.0	10.8	18.2	20.9
SEPTEMBER	6.4	10.1	15.0	11.9	18.5	18.9
OCTOBER	6.7	9.1	10.7	10.0	13.3	19.3
TOTAL	37.1	52.7	64.0	51.9	83.0	94.7
AVERAGE MONTHLY OUTFLOW FOR EACH SEASON						
DRY SEASON	2.8	4.7	5.5	2.7	4.6	10.1
WET SEASON	6.2	8.8	10.7	8.7	13.8	15.8

UNITS = 1000 acre-feet (1 cubic acre-foot = 1233 cubic meters)

See Map 2 for location of canal monitoring stations.

The average monthly outflow was calculated by the South Florida Water Management District using data collected from 1980-1989. (SWI&MP Bisc. Bay, 1994).

Table 1

DERM WATER QUALITY DATA FOR EACH SAMPLE AREA AND ADJACENT CANALS (WHEN AVAILABLE)						
	SALINITY (ppt)		DISS. OXYGEN (mg/L)		TURBIDITY (NTU)	
STATIONS	**MEAN**	**ST. DEV.**	**MEAN**	**ST. DEV.**	**MEAN**	**ST. DEV.**
BC (1)	33.3	4.1	5.9	0.7	4.2	2.6
BC (1C)	30.8	7.2	5.3	1.0	4.3	2.9
LR (2)	32.9	5.1	5.7	0.9	4.2	4.9
LR (2C)	30.9	5.2	6.4	7.6	5.7	3.9
SH (3)	33.8	4.0	5.8	1.1	5.1	4.4
MR (4)	34.9	3.7	5.6	1.1	4.0	4.0
MR (4C)	33.5	4.6	5.2	1.1	5.6	3.8
RC (5)	34.4	3.7	5.6	1.1	3.6	5.0
MH (6)	34.1	4.3	5.8	0.8	1.3	1.4
MH (6C)	30.0	7.4	4.4	1.3	1.9	2.7
BP (7)	25.6	8.8	5.1	1.3	2.5	1.6
TP (8)	36.4	3.4	6.1	0.6	1.2	0.7
TP (8C)	25.2	10.2	5.6	1.1	1.6	0.9

See Map 2 for the location of each monitoring station.

The data was collected and calculated by the South Florida Water Management District and DERM from 1979 to 1992 (SWI&MP Bisc. Bay, 1994).

Table 2

SITE SPECIFIC SEASONAL COMPARISON OF SHRIMP ABUNDANCE					
	DRY SEASON		WET SEASON		
SITE	**MEAN**	**ST. ERROR**	**MEAN**	**ST. ERROR**	**SIGNIFICANCE**
BC	3.7849	0.2593	4.7753	0.2246	*
LR	5.0034	0.1446	5.1021	0.1279	NS
SH	5.8742	0.1244	5.4646	0.1099	NS
MR	5.6275	0.1113	4.8283	0.0964	*
RC	5.6776	0.1094	4.9810	0.0913	*
MH	5.7763	0.0982	5.0260	0.0832	*
BP	4.9366	0.0903	4.6397	0.0782	NS
TP	5.8851	0.1251	4.4792	0.0989	*

Significance is measured at the P=0.0125 level.
* = Significant difference between seasons
NS = No significant difference between seasons

Table 3

SITE SPECIFIC SEASONAL COMPARISION OF SHRIMP BIOMASS					
	DRY SEASON		WET SEASON		
SITE	MEAN	ST. ERROR	MEAN	ST. ERROR	SIGNIFICANCE
BC	4.6230	0.2920	4.9008	0.2453	*
LR	6.3350	0.1560	5.9088	0.1360	*
SH	7.3186	0.1381	6.2930	0.1220	NS
MR	7.2028	0.1208	5.6492	0.1046	*
RC	7.4540	0.1260	5.9690	0.1090	*
MH	6.9860	0.1188	5.9819	0.1029	NS
BP	5.9713	0.1087	5.3247	0.9400	*
TP	6.8427	0.1537	5.1244	0.1331	*

Significance is measured at the P=0.0125 level.
* = Significant difference between seasons
NS = No significant difference between seasons

Table 4

Correlations Between Shrimp Abundance and Environmental Parameters Collected During Sampling

Biscayne Canal

Dependent Var.	R-squared
Salinity	0.0523
Temp.	0.0337
D.O.	0.0229
Depth	0.0000

Little River

Dependent Var.	R-squared
Depth	0.0974
Salinity	0.0875
D.O.	0.0835
Temp.	0.0000

Sunset Harbor

Dependent Var.	R-squared
Salinity	0.1733
D.O.	0.0540
Temp.	0.0476
Depth	0.0000

Miami River

Dependent Var.	R-squared
Temp.	0.5028
D.O.	0.4819
Depth	0.0693
Salinity	0.0000

Rickenbacker Cswy

Dependent Var.	R-Squared
D.O.	0.4430
Temp.	0.4266
Depth	0.2507
Salinity	0.0000

Matheson Hammock

Dependent Var.	R-squared
Temp.	0.5011
D.O.	0.3786
Depth	0.2438
Salinity	0.0000

Black Point

Dependent Var.	R-squared
D.O.	0.3713
Temp.	0.0655
Depth	0.0459
Salinity	0.0000

Turkey Point

Dependent Var.	R-squared
Temp.	0.6850
Salinity	0.2961
D.O.	0.0915
Depth	0.0000

Table 5

Correlations Between Shrimp Biomass and Environmental Parameters Collected During Sampling

Biscayne Canal

Dependent Var.	R-squared
Salinity	0.0193
Depth	0.0046
Temp.	0.0023
D.O.	0.0000

Little River

Dependent Var.	R-squared
Temp.	0.1254
Depth	0.0484
Salinity	0.0424
D.O.	0.0000

Sunset Harbor

Dependent Var.	R-squared
Temp.	0.2191
D.O.	0.1279
Depth	0.0961
Salinity	0.0000

Miami River

Dependent Var.	R-squared
Temp.	0.7334
D.O.	0.6477
Depth	0.1505
Salinity	0.0000

Rickenbacker Cswy

Dependent Var.	R-squared
Temp.	0.6459
D.O.	0.5333
Salinity	0.1430
Depth	0.0000

Matheson Hammock

Dependent Var.	R-squared
Temp.	0.5435
D.O.	0.2721
Depth	0.2604
Salinity	0.0000

Black Point

Dependent Var.	R-squared
D.O.	0.3299
Temp.	0.2034
Depth	0.0001
Salinity	0.0000

Turkey Point

Dependent Var.	R-squared
Temp.	0.6926
Salinity	0.2910
D.O.	0.0846
Depth	0.0000

Table 6

Correlation Matrix For Shrimp Abundance and Biomass With Vegetation and Turbidity parameters

	ADUND.	BIOMASS	ROOTED	NON-R.	TURBIDITY
ADUNDANCE	1				
BIOMASS	.866	1			
ROOTED VEG.	.66	.557	1		
NON-ROOTED VEG.	.114	-.071	-.415	1	
TURBIDITY	.361	.331	-.262	.157	1

(See App. D & E and Table 2 for data)

Table 7

Habitat Variables Correlation Matrix

computed using mean values for
water quality parameters (SWI&MP).

	SALINITY	D.O.	TURB.	ROOTED	NON-R.	CANAL
SALINITY	1					
D.O.	.479	1				
TURBIDITY	.175	-.185	1			
ROOTED VEG.	.189	.06	-.728	1		
NON-ROOTED VEG.	-.041	.317	.216	-.523	1	
CANAL OUTFALL	.083	.062	-.526	.052	.143	1

Habitat Variables Correlation Matrix

computed using the variation (s.d.),
in water quality parameters.

	SAL. (s.d.)	D.O. (s.d.)	TUR. (s.d.)	ROOTED	NON-R.	CANAL
SALINITY (s.d.)	1					
D.O. (s.d.)	.557	1				
TURBIDITY (s.d.)	-.095	-.191	1			
ROOTED VEG.	-.15	.01	-.522	1		
NON-ROOTED VEG.	-.16	-.143	.457	-.523	1	
CANAL OUTFALL	.036	.745	-.436	.052	.143	1

Water quality variables from SWI&MP data,
and vegetation data from on site samples.
(See Tables 1 & 2 and App. D for data.)

Table 8

Appendix D

Vegetation

* Chart 1: Vegetation Biomass Per Site
* Chart 2: Vegetation Species Composition, Northern Sites
* Chart 3: Vegetation Species Composition, Southern Sites

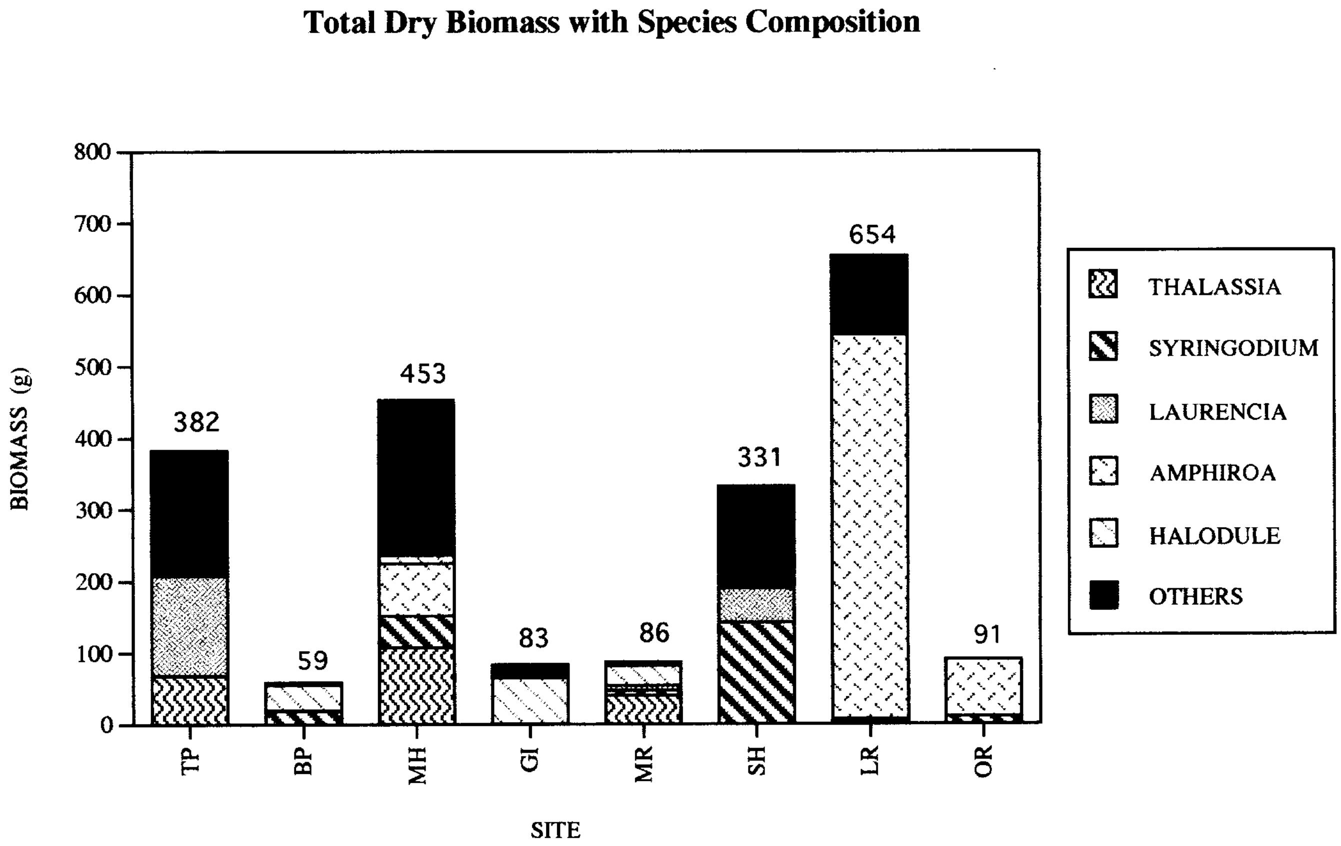

Total Dry Biomass with Species Composition
800
700
600
500
400
300
200
100
0
BIOMASS (g)
382
59
453
83
86
331
654
91
TP
BP
MH
GI
MR
SH
LR
OR
SITE
THALASSIA
SYRINGODIUM
LAURENCIA
AMPHIROA
HALODULE
OTHERS

Figure V1

VEGETATION
NORTHERN SITES

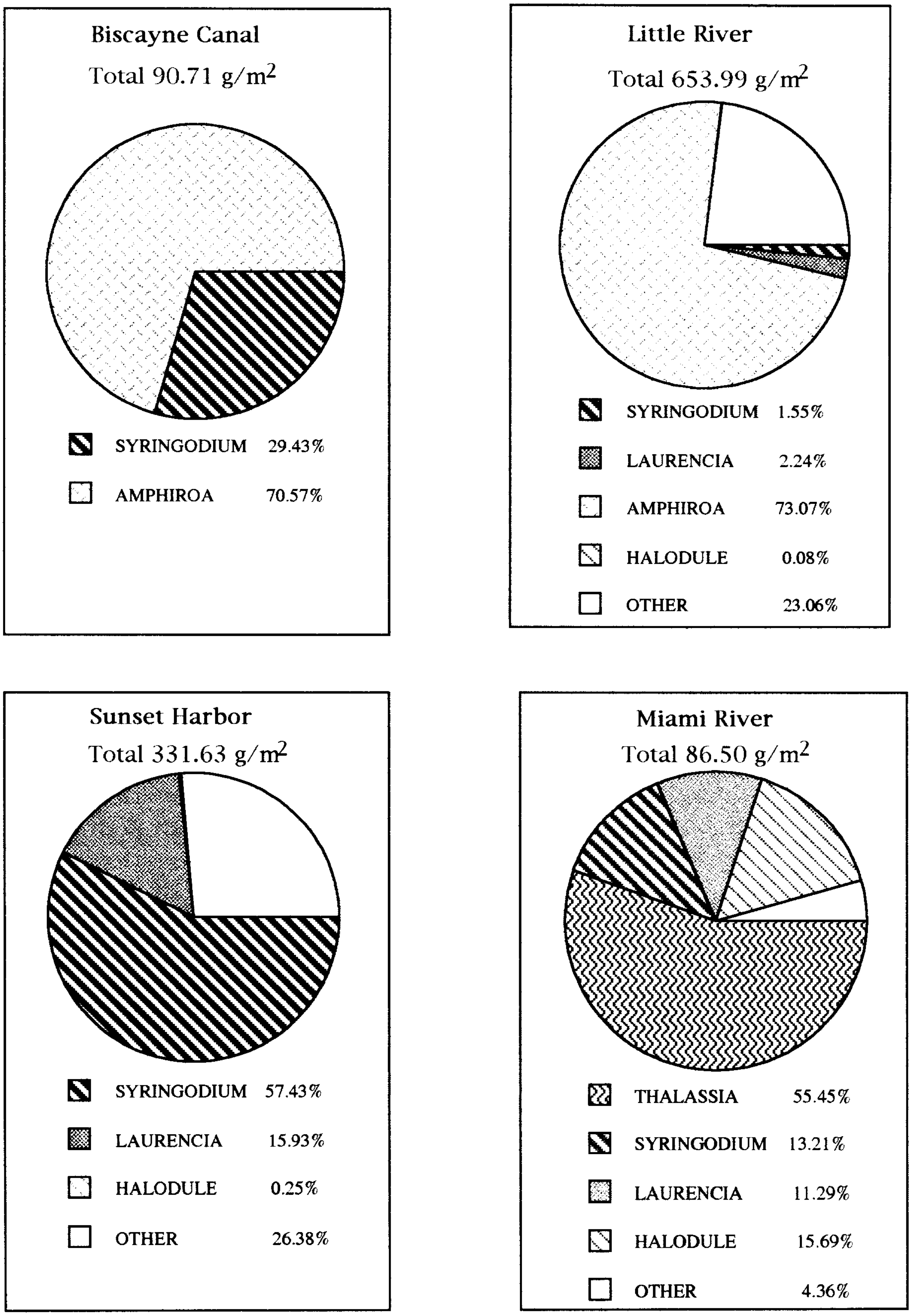


Figure V2

VEGETATION
SOUTHERN SITES

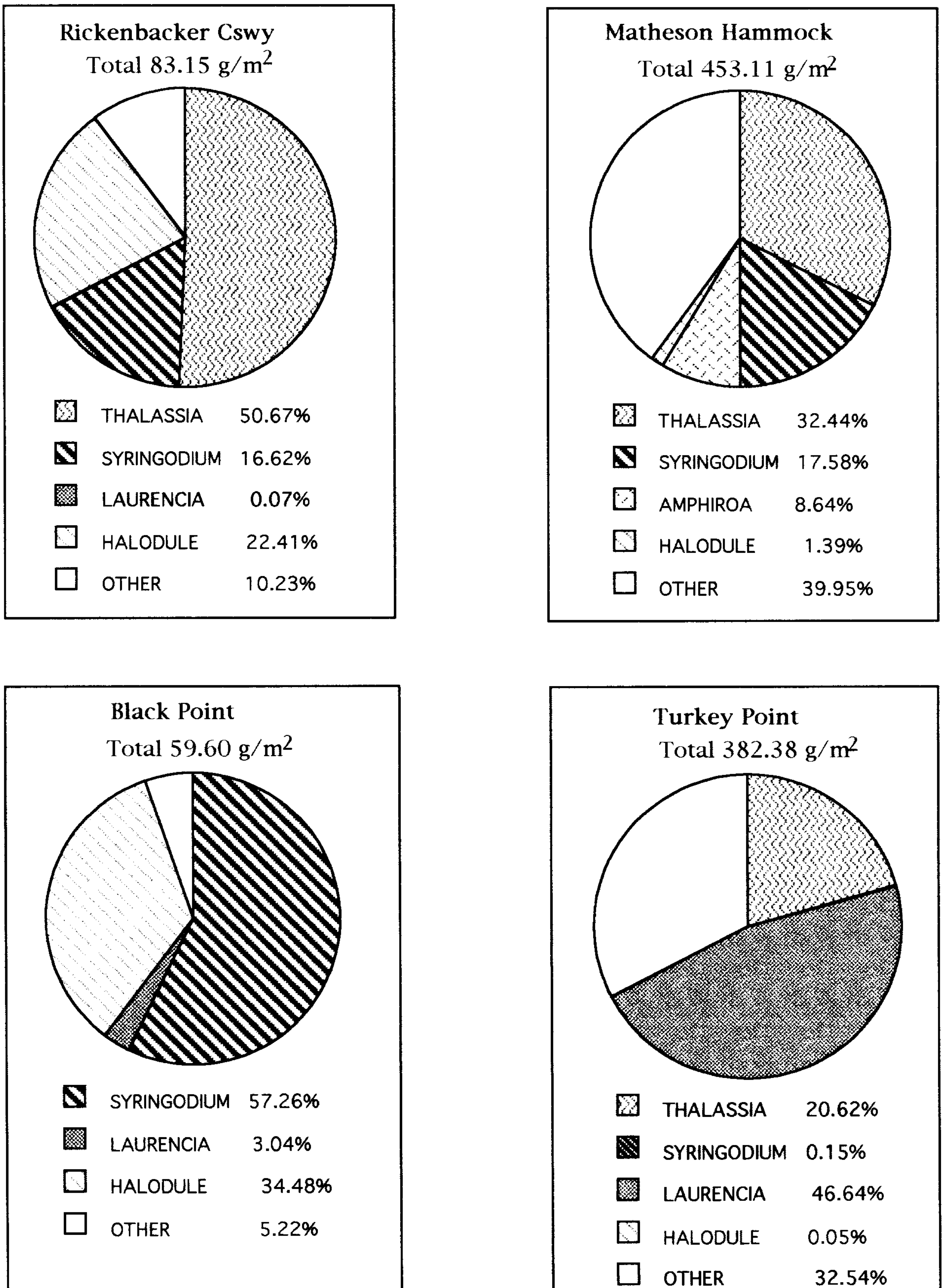


Figure V3

Appendix E
Shrimp Abundance and Biomass Data
and Environmental Data For Each Site
by Month

* Biomass is given in grams
* Temperature is given in Degrees Celsius
* Salinity is given in ppt
* Dissolved Oxygen (D.O.) is given in ppt
* Depth is given in Meters
  (Environmental Data was not collected during the first sampling month (August, 1993).)

Biscayne Canal

Month	Abundance	Biomass	Tempurature	Salinity	D.O.	Depth
Aug93	341	701.9755				
Sept 93	2317	2954.7137	28.6	30.0	7.19	12.30
Oct93	1071	1396.7811	28.2	16.0	6.72	10.95
Nov93	573	769.4347	26.2	27.0	8.82	9.50
Dec93	695	1481.7957	22.9	24.5	8.07	8.35
Jan94	114	324.5456	21.9	34.0	8.30	12.50
Feb94	101	357.6741	25.4	28.0	8.82	12.55
Mar94	225	733.2753	27.0	32.0	7.13	10.25
Apr94	282	633.1628	27.4	33.0	7.86	9.40
May94	117	163.1022	28.4	32.0	7.07	9.50
Jun94	308	214.1445	29.6	24.0	5.81	11.20
Jul94	740	937.7015	30.1	22.0	6.12	10.75
Aug94	372	596.2148	29.5	18.0	7.18	11.05
Sept94	1618	2708.6485	26.4	15.0	7.20	10.10

Little River

Month	Abundance	Biomass	Tempurature	Salinity	D.O.	Depth
Aug93	339	994.4230				
Sept 93	1917	4014.3284	27.9	22.0	6.65	12.87
Oct93	2436	6570.5193	27.8	20.0	6.86	10.70
Nov93	1821	7151.6816	26.0	8.0	4.54	10.10
Dec93	1039	3885.4303	22.3	31.0	8.11	7.00
Jan94	623	3622.6193	22.0	28.0	9.38	9.85
Feb94	297	1227.8984	25.6	28.0	9.73	9.40
Mar94	432	1769.0942	27.1	31.0	6.86	10.15
Apr94	524	1805.6681	27.8	32.0	6.88	9.45
May94	525	1103.7832	28.8	22.0	5.48	10.10
Jun94	461	601.0775	30.5	28.0	5.97	10.95
Jul94	608	1188.5298	30.6	30.0	5.35	10.25
Aug94	432	972.6431	28.8	12.0	5.28	9.70
Sept94	618	1440.3168	26.6	16.0	6.52	11.45

Sunset Harbor

Month	Abundance	Biomass	Tempurature	Salinity	D.O.	Depth
Aug93	225	665.4988				
Sept 93	1253	2451.8594	28.2	20.1	6.35	9.5
Oct93	974	2068.0940	28.2	28.0	6.71	9.3
Nov93	912	2449.6320	26.3	30.0	8.39	6.2
Dec93	758	2502.8023	21.7	31.0	7.57	6.5
Jan94	1763	9530.1141	21.7	28.0	7.69	9.4
Feb94	2056	13606.6594	25.0	30.5	7.63	7.3
Mar94	3819	16902.1779	26.6	33.0	6.20	5.8
Apr94	1196	4624.1247	27.4	34.0	6.16	7.0
May94	1703	4596.2863	28.4	33.0	7.45	6.0
Jun94	1136	1808.1454	30.1	31.0	5.53	10.4
Jul94	1162	2505.3318	31.3	34.0	5.70	9.1
Aug94	704	1883.4478	30.0	28.0	6.87	9.0
Sept94	1533	3996.7035	27.2	28.0	5.59	9.8

Miami River

Month	Abundance	Biomass	Tempurature	Salinity	D.O.	Depth
Aug93	301	997.8391				
Sept 93	601	1196.4199	28.4	30.0	6.13	7.30
Oct93	997	2419.9436	28.0	30.0	6.19	9.15
Nov93	1431	7295.0377	26.3	31.0	7.76	9.00
Dec93	2650	8164.6101	23.8	32.0	8.25	6.55
Jan94	1748	14126.3790	21.8	33.0	7.71	7.15
Feb94	1039	6866.2211	24.9	32.0	7.41	8.55
Mar94	806	5079.2367	26.3	34.0	6.38	7.10
Apr94	384	1641.5569	27.4	32.0	7.09	6.65
May94	500	1312.5800	29.1	33.0	6.00	7.80
Jun94	514	869.2955	29.7	32.0	4.71	5.65
Jul94	513	914.7315	30.6	35.0	4.27	5.15
Aug94	501	1270.3489	29.4	29.0	4.60	6.30
Sept94	384	781.8140	26.8	27.0	5.22	6.25

Rickenbacker Cswy

Month	Abundance	Biomass	Tempurature	Salinity	D.O.	Depth
Aug93	466	1150.3803				
Sept 93	717	2859.6971	29.5	30.0	5.83	6.70
Oct93	1835	4060.6435	27.9	28.0	6.87	7.85
Nov93	1777	11166.9168	23.6	32.0	7.47	6.50
Dec93	1272	7056.7221	22.3	35.0	8.63	6.70
Jan94	1386	9131.7684	19.9	34.0	7.27	6.05
Feb94	1536	11158.1568	24.5	32.0	7.67	4.80
Mar94	1412	8614.5202	24.1	31.0	7.12	5.60
Apr94	441	1937.9728	26.0	30.0	5.80	5.20
May94	368	1084.5195	28.8	30.0	6.20	5.70
Jun94	515	1329.6450	30.0	30.0	4.68	5.30
Jul94	454	981.4977	29.0	31.0	4.95	5.20
Aug94	497	1315.8330	29.7	35.0	4.84	4.70
Sept94	559	1849.6209	30.0	30.0	5.33	5.20

Matheson Hammock

Month	Abundance	Biomass	Tempurature	Salinity	D.O.	Depth
Aug93	1006	2482.4987				
Sept 93	551	1728.2164	30.2	30.0	4.83	6.90
Oct93	1220	3208.1974	27.3	28.0	6.98	6.50
Nov93	2010	4959.1798	22.5	25.0	7.74	8.25
Dec93	1906	6964.0237	22.3	30.0	9.15	6.55
Jan94	1441	5794.9671	19.2	30.0	7.34	4.85
Feb94	1235	4278.9230	25.0	30.0	7.79	5.10
Mar94	904	2531.3040	24.9	26.0	6.70	6.00
Apr94	762	2343.1481	25.7	30.0	5.44	4.90
May94	625	1823.8147	28.6	30.0	6.82	7.00
Jun94	378	671.8791	30.3	29.0	6.90	5.90
Jul94	409	904.0840	29.4	31.0	6.24	6.10
Aug94	491	1428.7912	29.3	34.0	4.12	5.40
Sept94	730	2386.1528	30.5	28.0	5.32	7.15

Black Point

Month	Abundance	Biomass	Tempurature	Salinity	D.O.	Depth
Aug93	589.0	1449.0231				
Sept 93	420.0	1177.2817	30.2	18.0	7.62	6.30
Oct93	603.0	1532.3810	28.5	24.0	8.04	7.50
Nov93	631.0	1215.9566	22.8	22.0	9.52	7.10
Dec93	568.0	1334.7621	22.7	25.0	10.13	6.15
Jan94	595.0	5020.9617	18.9	30.5	8.02	6.55
Feb94	885.0	3397.0836	25.4	23.0	9.77	8.30
Mar94	588.0	1731.4616	25.2	20.0	9.47	7.85
Apr94	338.0	960.8827	26.3	23.0	7.23	7.75
May94	216.0	451.9856	28.5	15.0	6.84	6.55
Jun94	713.0	938.8558	30.5	18.0	8.62	8.30
Jul94	292.0	431.5224	29.8	28.0	7.51	8.45
Aug94	353.0	698.2154	30.0	32.0	6.04	7.35
Sept94	437.0	926.2456	31.2	25.0	6.35	6.35

Turkey Point

Month	Abundance	Biomass	Tempurature	Salinity	D.O.	Depth
Aug93	289	550.6752	•	•	•	•
Sept 93	293	575.3049	30.9	32	9.76	5.5
Oct93	611	1805.5561	28.5	24	8.79	5.7
Nov93	1825	6517.5449	23.6	15	7.69	5.25
Dec93	2134	6073.1933	22.9	26	9.06	5.6
Jan94	2032	7936.3773	19.6	18	9.14	5.45
Feb94	1491	4831.0226	25.5	25	10.8	5.4
Mar94	•	•	25.3	20	10.18	6.5
Apr94	548	1088.0962	27.3	30	10.24	5.15
May94	309	2756.6237	28.7	30	6.3	5.4
Jun94	218	220.8498	31.6	34	•	5.15
Jul94	658	1146.844	30.2	37	9.25	6.15
Aug94	435	1073.7324	29.5	39	7.61	6.65
Sept94	406	945.6136	31.2	27	8.19	5.45