CALOOSAHATCHEE RIVER AND ESTUARY COLLABORATIVE RESEARCH PLAN

Field Study – 2003 & 2004

Fourth Quarter Report

MOTE MARINE LABORATORY

Submitted To:

South Florida Water Management District
Under Contract No. C-12109-A2
Charlotte Harbor Research

Submitted By:

Mote Marine Laboratory
1600 Ken Thompson Parkway
Sarasota, FL 34236

And

Florida Gulf Coast University
10501 FGCU Blvd., South
Fort Myers, FL 33965

Mote Marine Laboratory Technical Report #988

INTRODUCTION

The Caloosahatchee River and Estuary (CRE) Collaborative Research Project is one part of the Comprehensive Everglades Restoration Program (CERP) administered by the South Florida Water Management District (District). In 2001 the District engaged Mote Marine Laboratory (Mote), which in turn engaged the Florida Gulf Coast University (FGCU) to develop and then implement a collaborative research program addressing the District's data needs as identified by the Caloosahatchee Estuary Conceptual Model. Objectives of the collaborative CRE program have been to describe present-day conditions of the study area, and to determine and empirically evaluate causal relationships of River flow to the distribution, abundance, and/or condition of selected valued ecosystem components. Specific questions to be answered by the Cooperative Research Plan are presented in hierarchic form below. Each is cross-referenced to corresponding questions in the CRE Conceptual Plan prepared by the District.

- *What is the role of hydrology (discharge) on red tide? (CRE 6)*

- *How do salinity fluctuations affect SAV beds? (CRE 4);*
- *What is the ecological significance (e.g., juvenile fish value) of SAV beds? (CRE 2)*
- *Where is it possible to reestablish SAV beds? (CRE 4)*

- *How do salinity fluctuations affect oysters? (CRE 5);*
- *What is the ecological significance (e.g., juvenile fish value) of oyster bars? (CRE 1)*
- *Where is it possible to reestablish oyster bars? (CRE 4)*

- *How do salinity fluctuations affect juvenile fish populations and densities? (CRE 3)*

- *How do the presence and intensity of red tide blooms affect juvenile fish within the estuary? (CRE 9)*

- *How do manatees use and affect productivity of SAV in the Caloosahatchee River and nearby waters? (CRE 7);*
- *How would loss or reduction of SAV in the area affect manatee health and well- being? (CRE 7)*
- *How do the presence and intensity of red tide blooms affect manatee health, as assessed through immune function? (CRE 8), and are there immunological or other biomarkers that would indicate serious exposure and potential compromises of health? (CRE 8).*

In 2003-04 studies begun in 2001-02 were continued for the subjects of red tide, submerged aquatic vegetation (SAV), SAV-dependent fish communities, oyster growth and condition, oyster disease, and oyster-dependent fish communities. This report is the fourth and final quarterly report of findings for 2003-2004. An appendix of all project data for all years is contained on a CD-ROM provided to the South Florida Water Management District.

Caloosahatchee River and Estuary Collaborative Research Plan

Gary Kirkpatrick[3], Brad Pederson[3], Chris Higham[3] and Barbara Berg[3]

[3]Phytoplankton Ecology Program,
Mote Marine Laboratory,
1600 Ken Thompson Parkway, Sarasota, Florida 34236

INTRODUCTION

Our primary research question from the Conceptual Model was: "What is the role of hydrology (discharge) on red tide?" (CRE 6)

The Phytoplankton Ecology Program at Mote Marine Laboratory has been investigating red tide and the hydrographic conditions associated with bloom development and maintenance along the central West Florida Shelf (WFS). On two annual research cruises in support of the federally funded program known as the Ecology and Oceanography of Harmful Algal Blooms (ECOHAB), red tide was found first in the waters just offshore of Sanibel Island. Surface expressions of those developing blooms were associated with density fronts where freshwater met seawater. Frontal accumulation of red tide at density fronts associated with estuarine inlets is a current hypothesis for the development of red tide along the WFS. These frontal zones form stable areas of converging water that can physically concentrate red tide cells. Additionally, the outflow of terrestrially derived water carries significant amounts of organic nutrients, thought to be important to the development of community dominance by the red tide.

In light of these observations and hypotheses about red tide formation in the GRE region the primary question above was expanded to involve the following more focused issues:

1. How does the discharge of freshwater into near-shore Gulf waters affect water column stability that could control the development and maintenance of red tide?

2. Does the river discharge deliver nutrients to the near-shore Gulf waters of a type and at a level that could influence the development and maintenance of red tide?

3. Does the river discharge of colored dissolved organic material (CDOM) enhance the light environment in the near-shore Gulf waters for red tide development?

APPROACH

Task 3 Hydrology, Red Tide

Task 3.1 Characterize Nutrients

Does the river discharge deliver nutrients to the near-shore Gulf waters of a type and at a level that could influence the development and maintenance of red tide?

Whole water samples were collected at 6 stations along the Caloosahatchee River estuary on January 31, 2003, March 18, 2003, July 30, 2003, August 20, 2003, February 19, 2004, March 17, 2004 and August 19/2004. These samples were split to provide for the determination of nutrient concentrations and phytoplankton community composition using high performance liquid chromatography and chemotaxonomic analysis. Surface hydrography was also monitored using a SeaBird Seacat 19 CTD in flow through mode.

Task 3.2 Describe the biophysical nature of receiving waters

How does the discharge of freshwater into near-shore Gulf waters affect water column stability that could control the development and maintenance of red tide?

A range-finding cruise was conducted on January 22-23, 2002 to evaluate the feasibility of conducting detailed hydrographic surveys of the Sanibel area in conjunction with the regular,

State of Florida funded red tide survey. A limited hydrographic survey was conducted outside of Redfish Pass, but the utilization of resources and time was not optimal. Based on those findings it was determined that individual trips would be necessary to adequately survey both areas. Surveys from San Carlos Bay to Redfish Pass were conducted to characterize the near-shore water structure, and phytoplankton community structure.

On December 18, 2002, August 26,2003 and May 26, 2004 hydrologic surveys were conducted with the R/V Eugenie Clark using the MiniBat, undulating CTD and the underway, surface thermosalinometer in the coastal waters off Sanibel Island. The surveys ran from Red Fish Pass to San Carlos Bay between the 5 m and 10 m isobaths.

Does the river discharge of colored dissolved organic material (CDOM) enhance the light environment in the near-shore Gulf waters for red tide development?

Along with the hydrographic surveys utilizing the MiniBat and thermosalinometer listed above, the Colored Dissolved Organic Material (CDOM) Mapper (Kirkpatrick et al., 2003) was employed to map CDOM light absorption characteristics just below the surface.

RESULTS

Task 3 Hydrology, Red Tide

Task 3.1 Characterize Nutrients

In January 2003 (**Figure 1**) the temperature and salinity structure was classic, warm temperatures and freshwater in the upper reaches with decreasing temperature and increasing salinity toward the mouth. It was interesting that the chlorophyll fluorescence was low in the warm fresh upper reaches, increased dramatically in the mixing mid-section and then decreased to typical coastal marine levels beyond the river mouth. In March 2003 **(Figure 2)** a full hydrographic survey was not collected due to equipment failure. However, the section of the

river that was monitored with the flow-through system showed similar structure to the January survey except the highest chlorophyll fluorescence values occurred in the upper reaches of the estuary. In July and August 2003 **(Figures 3 and 4 respectively)** the river surface waters were uniformly warm and the salinity showed the effects of recent heavy rains. In August the entire survey within the river showed salinity below 3.0. During the dry season 2004 **(Figure 5)** the marine salinity signature moved up the river from the mouth, temperatures were low throughout and chlorophyll fluorescence was more like coastal marine waters. The effects of the dry season were still evident in March 2004 **(Figure 6)** with saline waters progressing further up the river, low chlorophyll fluorescence, but increasing temperatures.

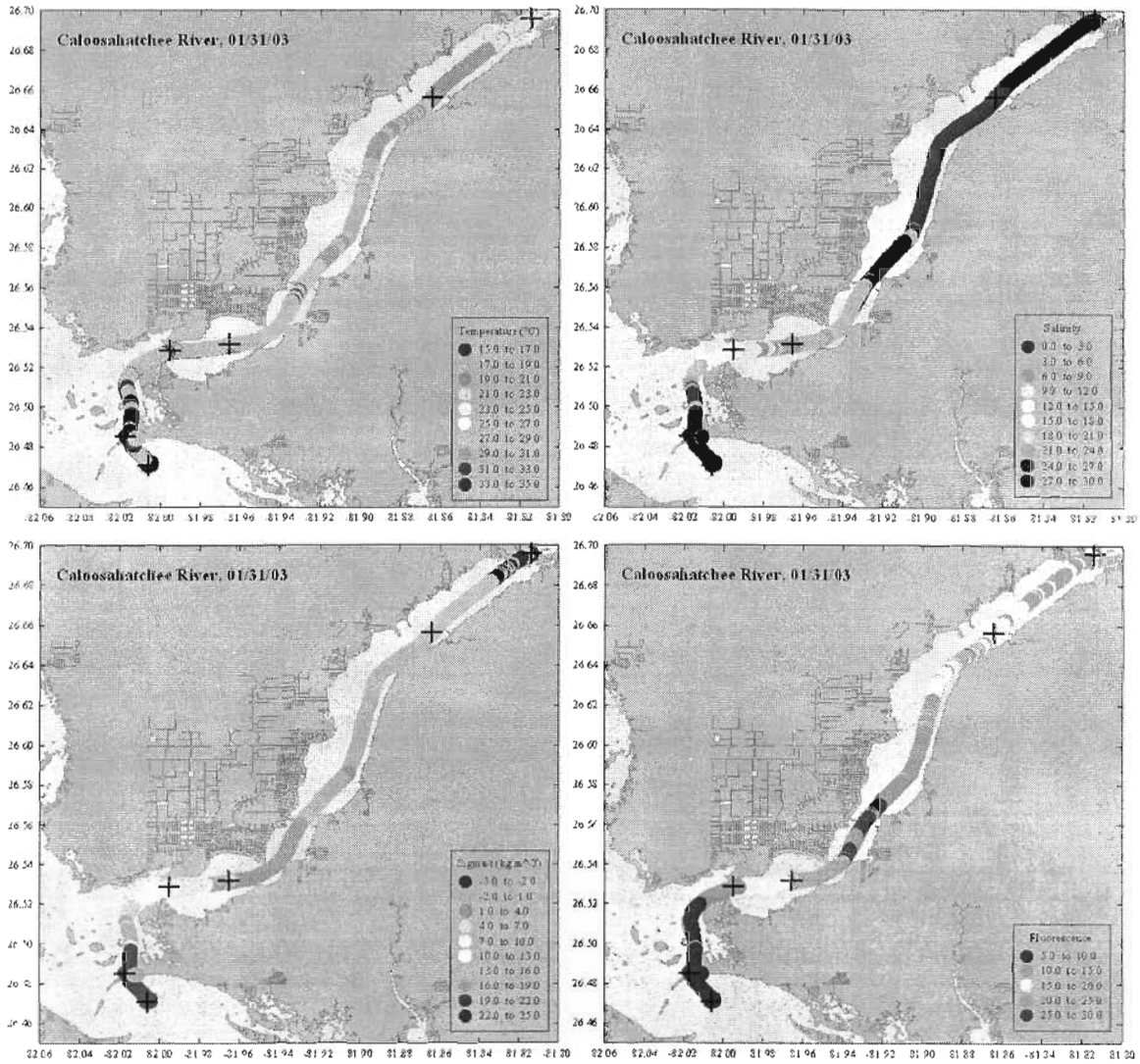

Figure 1. Hydrographic conditions in the surface waters of the Caloosahatchee River on January 31, 2003.

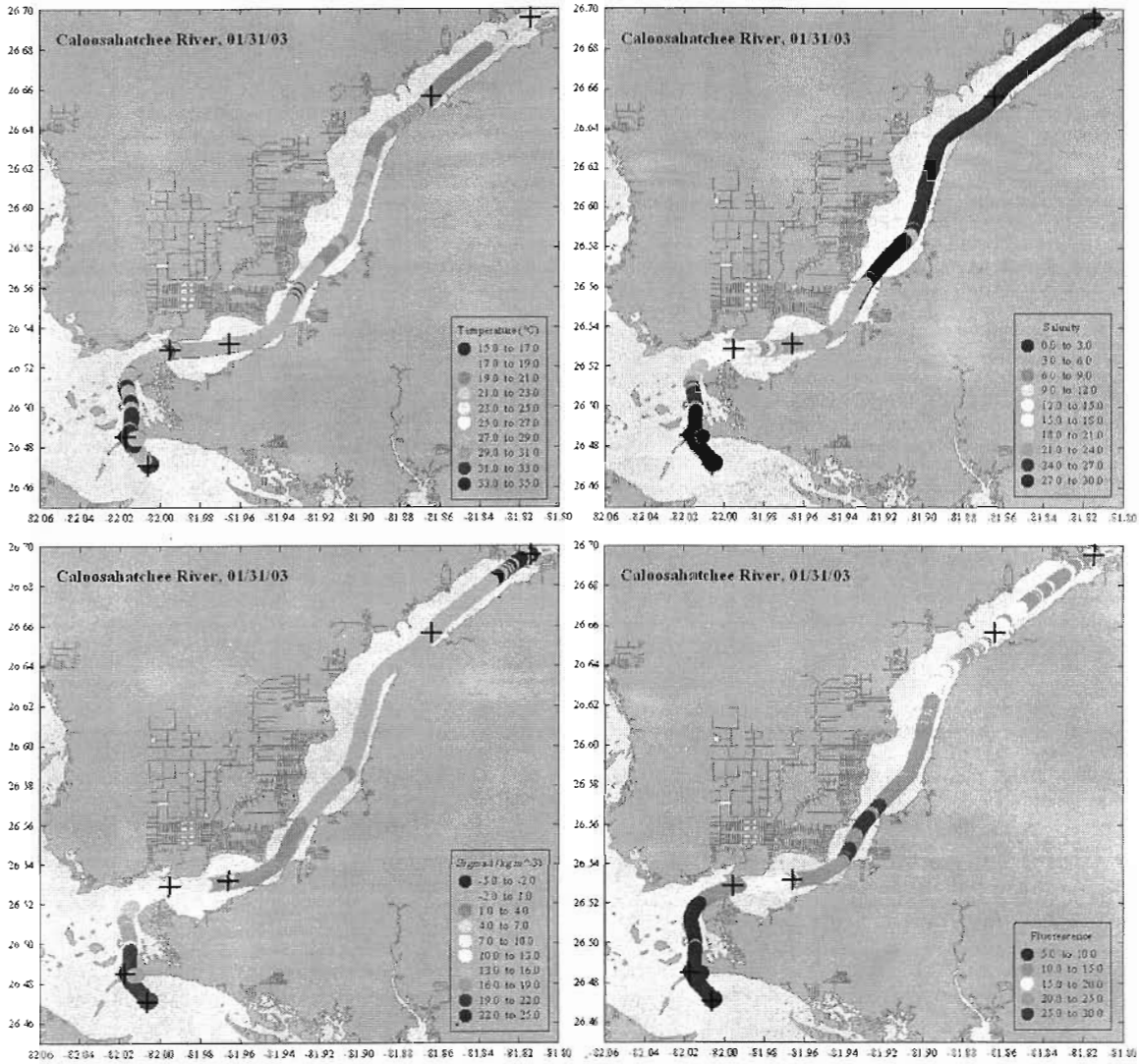

Figure 1. Hydrographic conditions in the surface waters of the Caloosahatchee River on January 31, 2003.

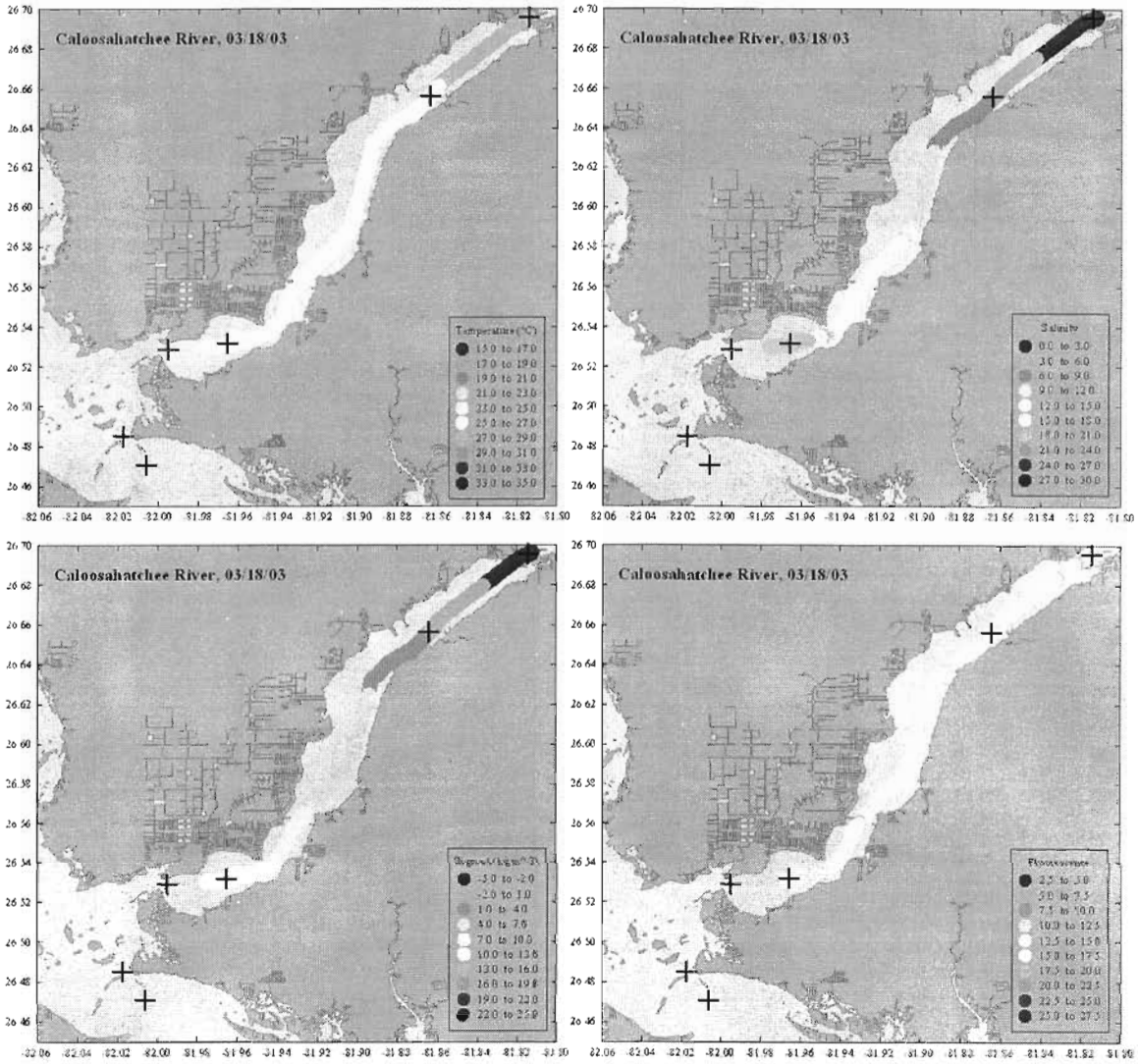

Figure 2. Hydrographic conditions in the surface waters of the Caloosahatchee River on March 18, 2003.

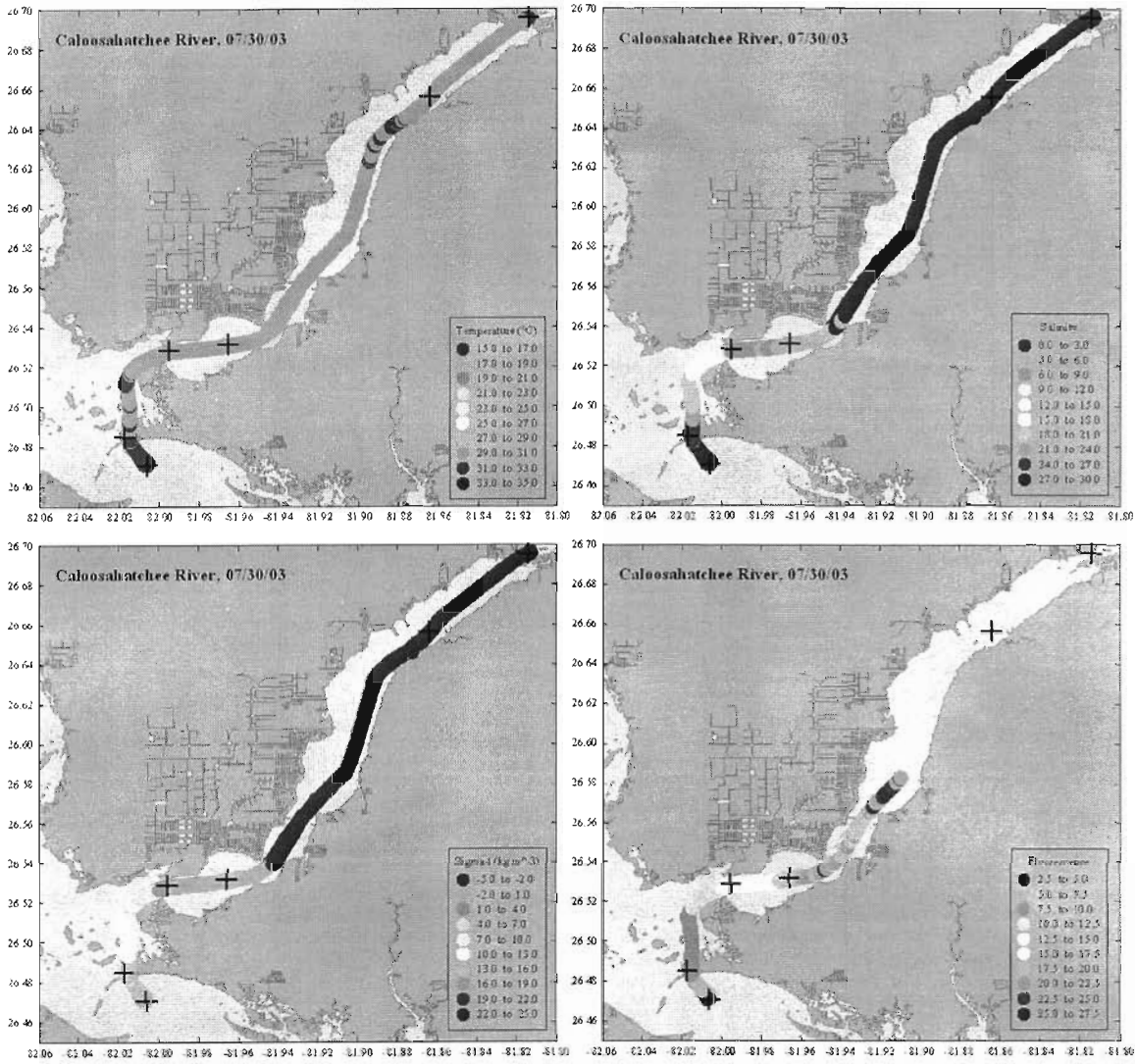

Figure 3. Hydrographic conditions in the surface waters of the Caloosahatchee River on July 30, 2003.

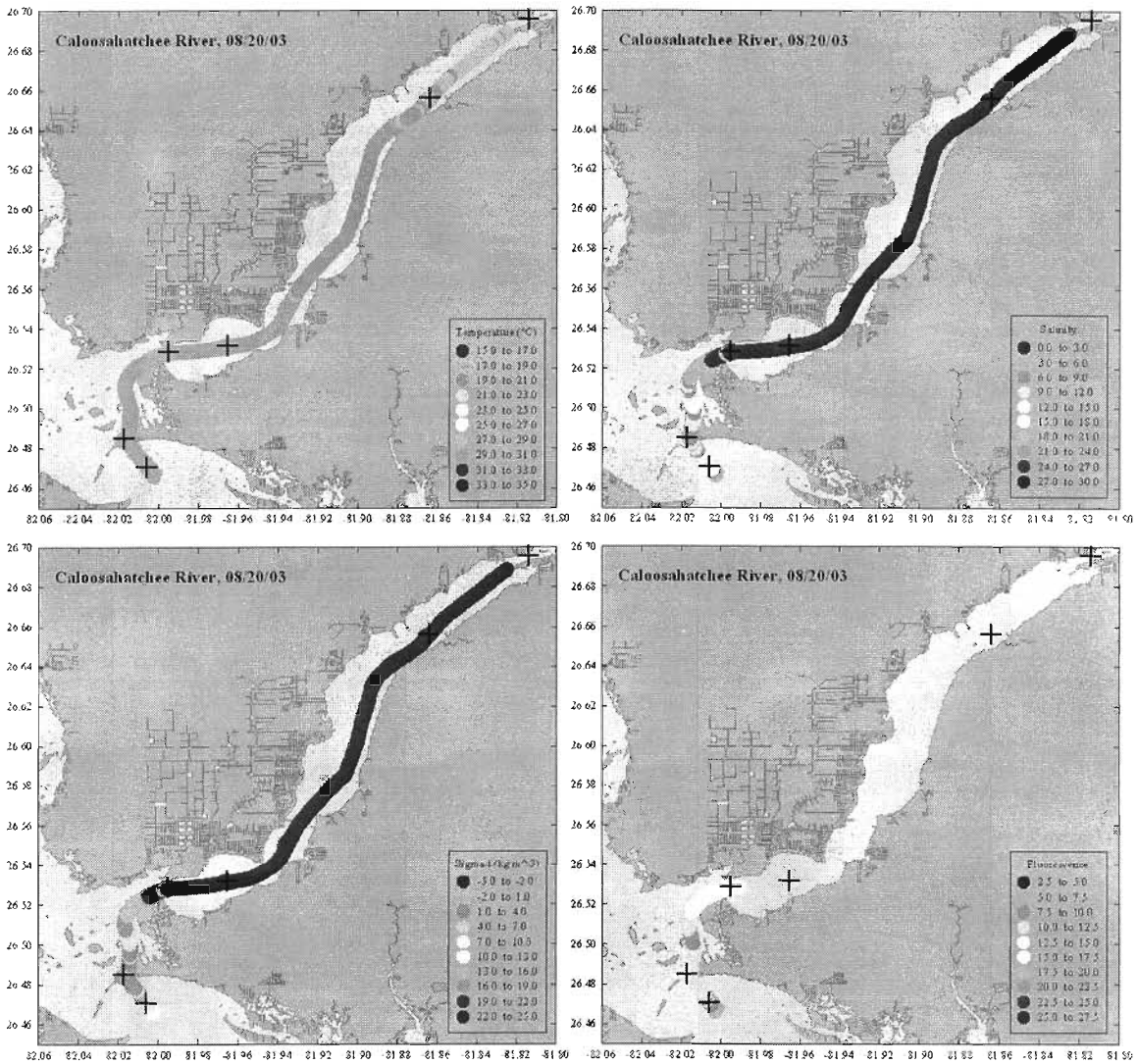

Figure 4. Hydrographic conditions in the surface waters of the Caloosahatchee River on August 20, 2003.

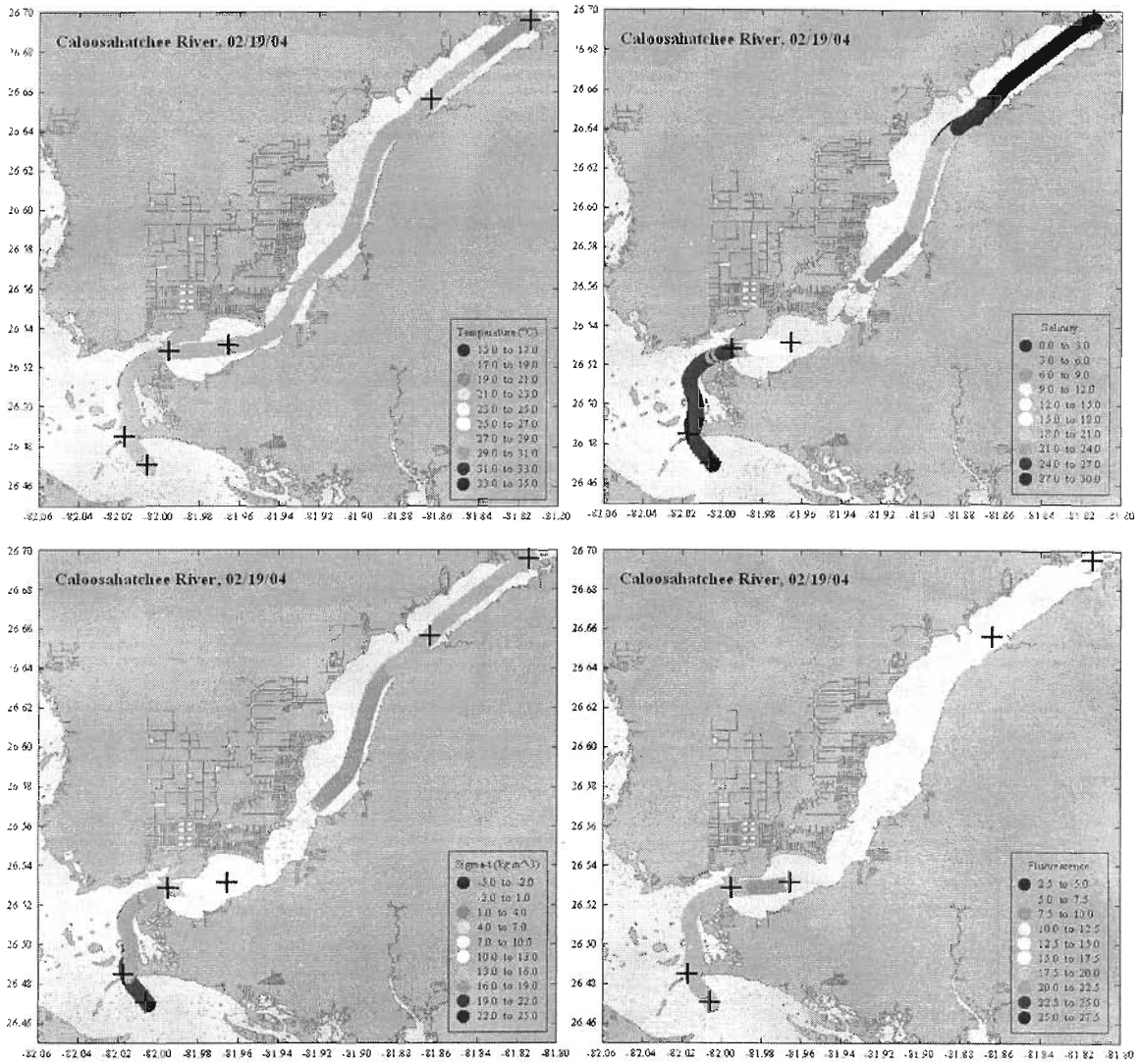

Figure 5. Hydrographic conditions in the surface waters of the Caloosahatchee River on February 19, 2004.

The river survey on August 19, 2004 took place six days after hurricane Charlie impacted the Southwest Florida region. The hydrographic features **(Figure 7)** clearly show the influence of the heavy rains accompanying the storm. The temperatures of the surface waters were uniformly high which would be typical for August **(see Figure 4)**. The salinity was uniformly very low as would be expected from the rains. Chlorophyll fluorescence, though not a complete record, was very high over the entire survey. One unusual condition following the hurricane, compared to a normal wet year, was the projection of the low-salinity and high-chlorophyll out into San Carlos Bay. Presumably this would be the extreme case of high-flow transport of nutrients from the upper river to the coastal waters and should produce the highest direct impact on the coastal phytoplankton community. Low to medium concentrations of *Karenia brevis* cells were detected from San Carlos Bay to Naples more than two months later.

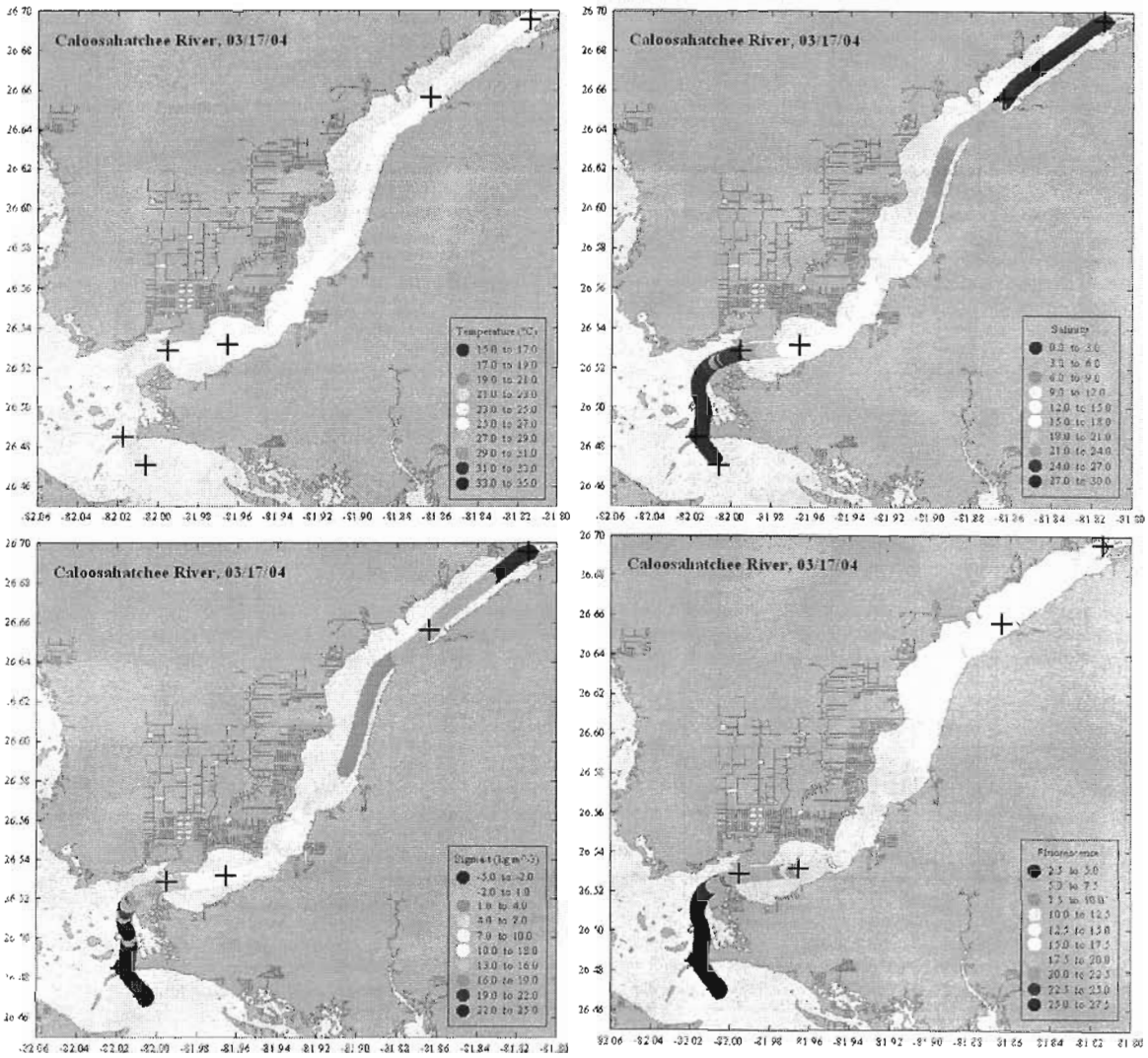

Figure 6. Hydrographic conditions in the surface waters of the Caloosahatchee River on March 17, 2004.

In January 2003 the community structure, as determined by HPLC pigment analyses and ChemTax chemotaxonomic analysis, was quite similar throughout the estuary in both the surface **(Figure 8)** and bottom **(Figure 9)** layers. At the most up-river sample station (BCCR 01) cryptophytes dominated the surface community followed closely by the chlorophytes. Moving downstream diatoms became dominant in the surface and bottom with chlorophytes being second. At the lower end, in San Carlos Bay, the chlorophyll *a* concentration was significantly less than in the estuary and chlorophytes were dominant. Some dinoflagellates were present, but *Karenia brevis* was not. In March the most obvious changes in the upper estuary were the reduced total amount of chlorophyll *a* and the development of a significant population of dinoflagellates at station BCCR 02. Moving down the estuary, diatoms continued to be the dominant group until reaching San Carlos Bay where a bloom of *K. brevis* was taking place. By July the chlorophyll *a* concentration in the upper estuary was significantly reduced and the *K brevis* bloom moved up the estuary, showing reduced levels in San Carlos Bay. In August the surface chlorophyll a content reached a

maximum for all the sample dates, but there was not a single group dominating the community. A notable development in August was the relatively large increase in diatom chlorophyll *a* in San Carlos Bay. Presumably this was due to high river discharge during the rainy season.

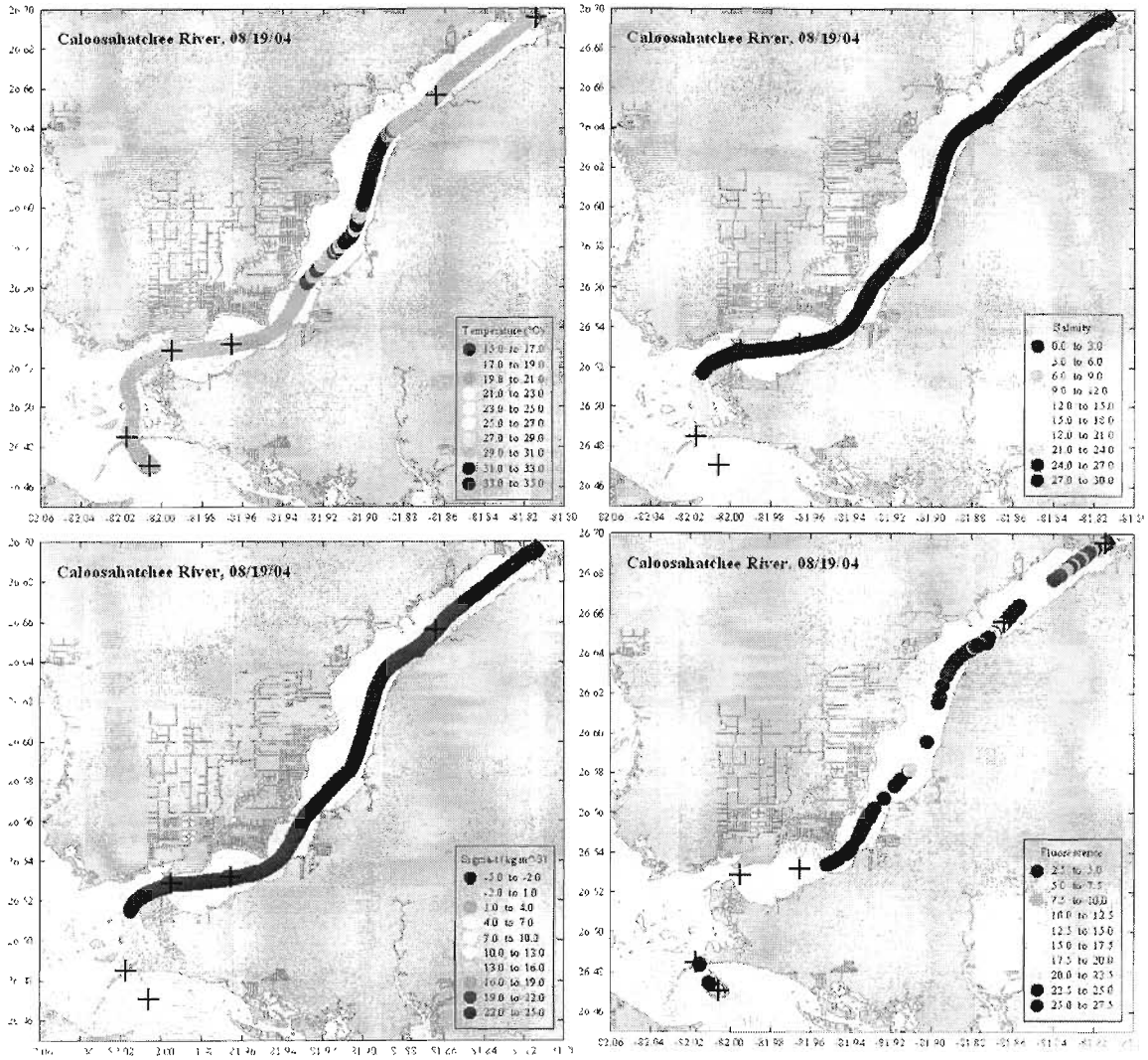

Figure 7. Hydrographic conditions in the surface waters of the Caloosahatchee River on August 19, 2004.

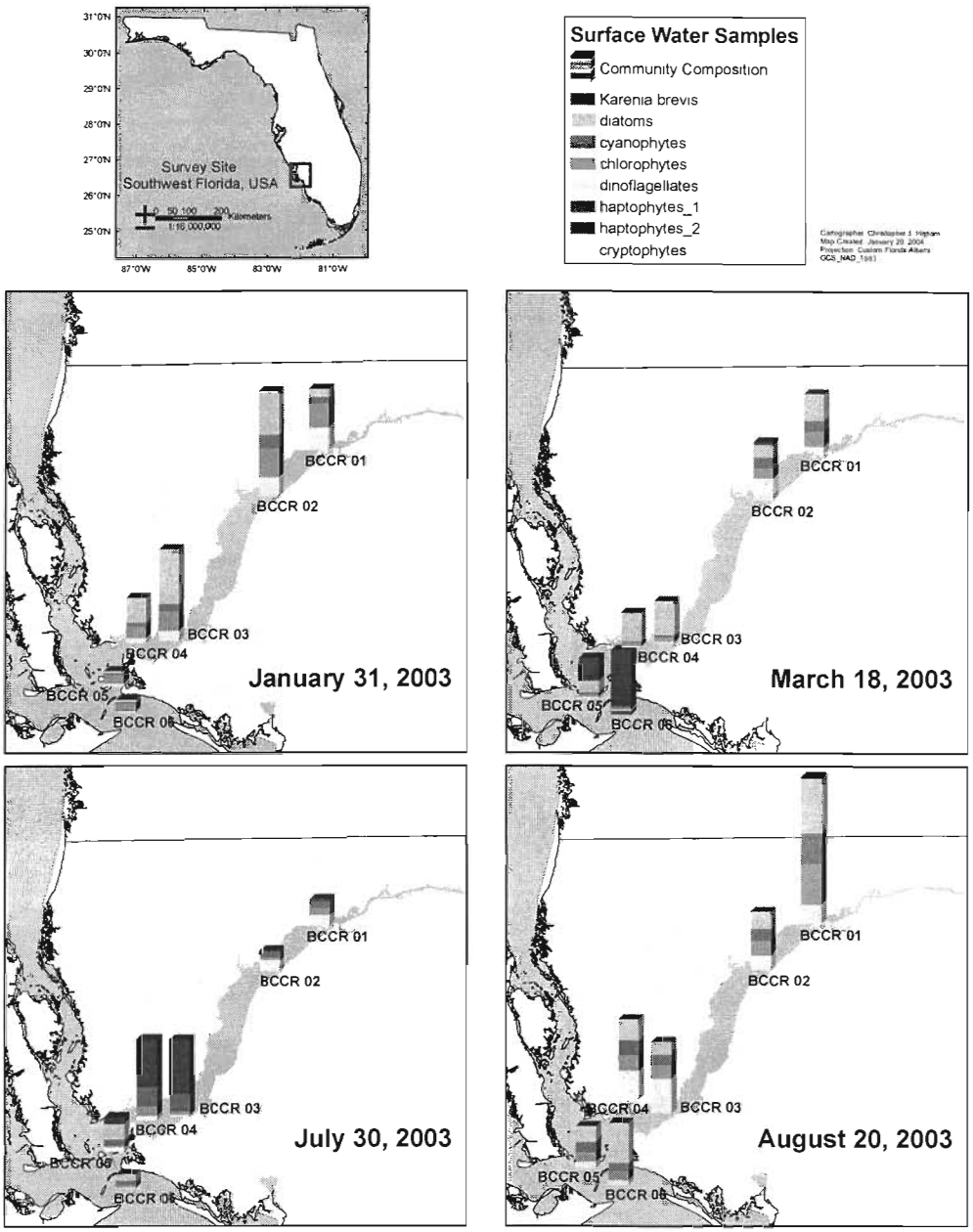

Figure 8. Phytoplankton community structure based on chemotaxonomic pigment analyses for the surface waters of the CRE in 2003. Height of the stacks represents the concentration of chlorophyll a and the height of each band represents the chlorophyll a contribution from each algal group.

CALOOSAHATCHEE RIVER AND ESTUARY COLLABORATIVE RESEARCH PLAN

Brad Robbins[1], Michelle Gittler[1] and Aaron Adams[2].

[1]Landscape Ecology Program,
[2]Fisheries Habitat Program,

Mote Marine Laboratory,
1600 Ken Thompson Parkway, Sarasota, FL 34236

INTRODUCTION

This report provides an evaluation of data collected during the first and second (funding) years. Sampling for funding year 1 (Y1) began in October 2002 and continued through mid-September 2003. Sampling for funding year 2 (Y2) began in October 2003 and continued through mid-September 2004. Sampling of flora and fauna followed protocol established by Robbins in his District funded (RFP C-12836) Caloosahatchee River *Vallisneria americana* study where faunal samples are taken to correspond with three (3) more or less distinct time periods proposed by District staff Bob Chamberlain and Peter Doering: Low productivity (November to March), High Recruitment (March/April to June/July), and High Flow (July to November).

Task 4. Submerged Aquatic Vegetation, Juvenile Fish, & Fisheries Habitat.

Task 4.1: Study Site Selection.

Sites (Figure 1) were chosen using a map of seagrass distribution by category (patchy or continuous) provided by the District. Site choice was based on the presence of both patchy and continuous seagrass allowing us to have two stations at each site. Our initial site survey site in January 2003 (Low Productivity; LP) revealed that seagrass, although present, was very sparsely

distributed with no *Halodule wrightii* seen at any site and *Thalassia testudinum* shoots (~ $10m^2$) seen at only two (2) of the three (3) stations. Because of the time of year, we expected that the paucity of seagrass was typical of Florida seagrass beds that are exposed to (relatively) cold temperatures during winter low tides. Thus our expectation was that as the weather warmed and the seagrasses began to more actively grow they would recover. Of the three (3) sites, two (2): Fisherman's Key (FK) and Big Island (BI) recovered; however, the third site, Ewefish Creek (EC), did not recover and subsequently was dropped from the study. A "new" third site (MA) was selected and sampled during the High Recruitment (HR) sampling period.

A preliminary examination of the data suggested that our inference space would be increased by abandoning our original strategy of sampling a "patchy" and a "continuous" station at each site and instead adopting a strategy of comparing sites defined by the dominant seagrass species across a salinity gradient (when present). As a result, we chose six additional sites (Figure 1) and categorized each by their dominant seagrass species; resulting in three (3) *Halodule*, three (3) *Syringodium*, and three (3) *Thalassia* sites.

A trend, although probably not significant, was seen when comparing mean water depth by site (Figure 2) with *Thalassia* > *Syringodium* > *Halodule*. Subsequently, we will use seagrass species as a surrogate for water depth within this report.

Sites choices were made with the hope that differences could be found in salinity regimes. We found that the salinity pattern was *Thalassia* > *Syringodium* > *Halodule* (Figure 3) although the differences were slight. Because site and salinity were "related" we use site as a surrogate for salinity in this report.

Task 4.2: Monitor seagrass and SAV dispersion and abundance.

Areal extent of seagrass by species as measured by percent cover within a $1m^2$ quadrate (n = 6 per site), confirmed that site-specific species composition was temporally dynamic (Table 1). For example, at site MAH, *T. testudinum,* absent in HR Y1 was present in HF Y1 and LP Y2.

absent again by HR Y2 and present again in HF Y2. Comparatively, *H. decipiens* was found at site MAT in HR of Y1 and LP and HR of Y2 but not recorded on other dates. Changes in seagrass composition are made more evident by examining the grand means of percent cover (Table 2), which illustrates the dynamic of sites dominated by differing seagrass species rather than simply a reflection of seasonal changes at individual sites.

Seagrass shoot density declined over the winter season (HF Y1 through LP Y2) with the exception of *Halodule* site and recovered during the spring season (HR Y2 through HF Y2) (Figure 4). Correspondingly, canopy height also experienced a seasonal decline through LP Y2, recovered by HR Y2 and increased through HF Y2 for all sites (Figure 5) although this pattern was not as clear when examining seagrass biomass (Figure 6); specifically, *S. filiforme*, and *T. testudinum* aboveground biomass did not decline as sharply as did belowground biomass.

Task 4.3: Measure seagrass and SAV production.

A new methodology for measuring seagrass growth was implemented for *T. testudinum* during June 2004. This methodology involves the use of color-coded mini hairclips (SCÜNC1®) attached to each blade (Figure 7). Similar to the hole-punching technique these clips are attached at the base of the blade just above the sheath and left *in situ* for a designated period of time before harvesting and measuring "growth" (a ratio of blade change over time as it relates to the oldest blade). The advantage of this technique is individual blades can be identified thus reducing potential error resulting from the loss of the oldest blade. Our first deployment of our clips was made during LP Y2. Because of slow winter growth displayed by seagrasses marked shoots will be harvested after one month instead of the two-week harvest schedule used during the summer growth season. Seagrass growth was again measured with this technique during the HR Y2.

Using the traditional hole-punch technique growth was seen to be greatest at the *Thalassia* site during HF Y1 (Figure 8). No difference was seen between sites during LP Y2 using the new technique, while the *Syringodium* sites had marginally greater growth than the *Thalassia* sites

(Figure 8). A comparison was not possible for the HR Y1 period because of lost data (an intrinsic problem with marking seagrass in the field regardless of the technique); data were also lost during LP Y2 and HR Y2. Comparing *T. testudinum* growth between HR Y1 and HR Y2 at the *Thalassia* sites revealed growth 1.5 times greater in Y2 then in Y1 (Figure 8).

Task 4.4: Measure macroalgal composition and biomass.

Drift macroalgae was found at two sites (MAH and BIT) during April 2004 and at all sites with the exception of FKH during the June 2004 sampling. However, biomass measures were less than 1g per site.

Task 4.5: Describe epiphytic algal burdens.

On December 22, 2003 a single Epiphyte Collector (EC) was deployed at seven of the nine sites (BIH and FKH were excluded because of water depth limitations). This methodology allows a comparison to be made of epiphyte load with time. Each collector consists of a PVC clip (Figures 9 & 10) with a series (n = 8) of artificial seagrass blades (ASB) attached. This protocol was used successfully by Robbins to estimate *Zostera marina* epiphyte loads in Yaquina Bay, OR. The protocol involves the deployment of the ECs and the harvest of ABS every week for an eight-week period. Harvesting is conducted in such a manner that samples represent 1 week, 2 week, 4 week, and 8-week sampling intervals (*i.e.*, the first week after initial deployment of the eight ABS two representing that week are harvested and then replaced. After Week 2 a second set of two ABS representing two weeks of deployment are harvested along with ABS deployed the previous week. All ABS are replaced. This continues until week 8 when all ABS will be harvested. The data are then analyzed and the ECs again deployed with the length of deployment adjusted to maximize epiphyte load estimates. In addition to harvesting the ABS, a single *T. testudinum* and/or *S. filiforme* shoot (NBS) is also harvested weekly from each site. Data from NBS allow a comparison of maximum epiphyte load (albeit based on unknown blade age) to be considered during our interpretation. For our purposes we found 4-week deployment to be appropriate.

ABS and natural shoots after harvest are placed on ice and returned to the laboratory where they are refrigerated and processed within 24 hrs. Processing ABS and natural shoots is identical with the epiphytes gently scrapped from the surface of each blade (both sides), dried to a constant weight (24hrs @ 70°C), weighed, burned (5hrs @ 500°C) to remove organics and then re-weighed. By subtraction, ash-free dry weights are calculated.

A strong trend was found between sites with *Halodule* sites consistently having a greater epiphyte load than the *Syringodium* or *Thalassia* sites regardless of sampling period (Figure 11). Data for HR Y2 were lost due to vandalism.

Task 4.6: Sample for associated fishes and macroinvertebrates.

Both the number of fish species (Figure 12) and the density of fish (Figure 13) displayed a general trend of increasing from LP to HF in Y1 at *Halodule* and *Thalassia* sites. In Y2, density decreased from LP to HR at *Halodule* and *Thalassia* sites while *Syringodium* sites increased. Density increased at *Halodule* sites during HF Y2 as *Syringodium* sites decreased and *Thalassia* sites leveled off. It is also important to note that the elevated number of fish seen at the *Halodule* and *Thalassia* sites during HF Y1 was caused by a large school of *Lucania parva* and *Anchoa* spp., respectively, and the elevated number of fish seen at the *Syringodium* sites during HR Y2 was caused by a large school of *Lagodon rhomboides* located at one site.

Task 4.8: Describe ambient water quality.

Light attenuation values were much lower in HR for *Halodule* and *Thalassia* sites while *Syringodium* sites showed relatively no change across sampling periods (Figure 14). *Syringodium* sites salinity measures at each site group did not reveal a consistent pattern (Figure 15) and no freshwater pulse were detected.

Table 1. Mean species-specific percent cover at each site during Low Productivity, High Recruitment, and High Flow (LP, HR, and HF) in years 1 & 2. Note addition of *Halophila decipiens* in HR in Y1 from MAT and LP and HR in year 2 samples from FKT and MAT. After an initial decline in Y1, *Halodule*-dominated sites increased as the sampling periods progressed in Y2. *Syringodium*-dominated sites declined from Y1 to Y2 as sampling progressed. *Thalassia*-dominated sites increased through HF Y1, declined and leveled off through LP and HR and increased again in HF of Y2.

Y1

	HR				HF		
Site	*Halodule*	*Syringodium*	*Thalassia*	*Halophila*	*Halodule*	*Syringodium*	*Thalassia*
BIH	75	0	0	0	67	0	0
FKH	100	0	14	0	96	0	0
MAH	82	0	0	0	31	0	43
CIS	0	100	88	0	0	98	85
WKS	0	100	35	0	0	99	29
YIS	0	100	73	0	0	97	88
BIT	13	0	87	0	0	0	92
FKT	30	0	82	6	0	0	95
MAT	74	0	91	100	0	0	89

Y2

	LP				HR				HF		
Site	*Halodule*	*Syringodium*	*Thalassia*	*Halophila*	*Halodule*	*Syringodium*	*Thalassia*	*Halophila*	*Halodule*	*Syringodium*	*Thalassia*
BIH	63	0	0	0	99	0	37	0	97	0	0
FKH	83	0	0	0	84	0	67	0	100	0	2
MAH	72	0	11	0	78	0	0	0	92	0	9
CIS	0	83	83	0	34	61	88	0	35	65	72
WKS	12	85	83	0	66	42	41	0	52	33	30
YIS	0	100	3	0	0	94	36	0	1	91	50
BIT	10	0	71	0	12	0	82	0	0	0	96
FKT	0	0	93	0	29	0	92	2	29	0	85
MAT	30	0	79	7	45	0	68	24	0	0	99

Table 2. Percent cover grand means (±SE) for each site group defined by the dominant seagrass (*Halodule*, *Syringodium*, *Thalassia*) during Low Productivity, High Recruitment, and High Flow (LP, HR, and HF) in years 1 & 2. After an initial decrease, the percent cover of *Halodule* increased as sampling period progressed in each year while *Syringodium* declined. The percent cover of *Thalassia* increased initially in Y1 and decreased and leveled off through HR Y2, and increased again through HF of Y2.

Y1

	HR				HF		
Site	*Halodule*	*Syringodium*	*Thalassia*	*Halophila*	*Halodule*	*Syringodium*	*Thalassia*
Halodule	86(7)	0(0)	5(5)	0(0)	64(19)	0(0)	14(14)
Syringodium	0(0)	100(0)	65(16)	0(0)	0(0)	98(0)	67(19)
Thalassia	39(18)	0(0)	86(3)	35(32)	0(0)	0(0)	92(2)

Y2

	LP				HR				HF		
Site	*Halodule*	*Syringodium*	*Thalassia*	*Halophila*	*Halodule*	*Syringodium*	*Thalassia*	*Halophila*	*Halodule*	*Syringodium*	*Thalassia*
Halodule	73(6)	0(0)	4(4)	0(0)	87(6)	0(0)	34(19)	0(0)	96(2)	0(0)	4(3)
Syringodium	4(4)	89(5)	56(27)	0(0)	33(19)	66(15)	55(16)	0(0)	29(15)	63(17)	50(12)
Thalassia	13(9)	0(0)	81(6)	2(2)	29(10)	0(0)	81(70	9(8)	10(10)	0(0)	93(4)

This page intentionally left blank.

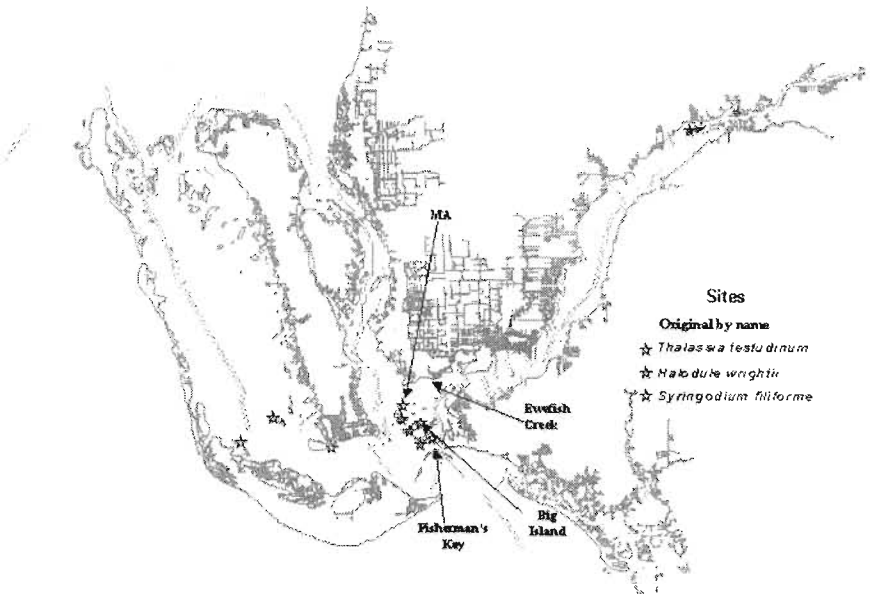

Figure 1. Site map indicating sites as defined by their dominant SAV (seagrass or freshwater grass. The original sites are also identified by name.

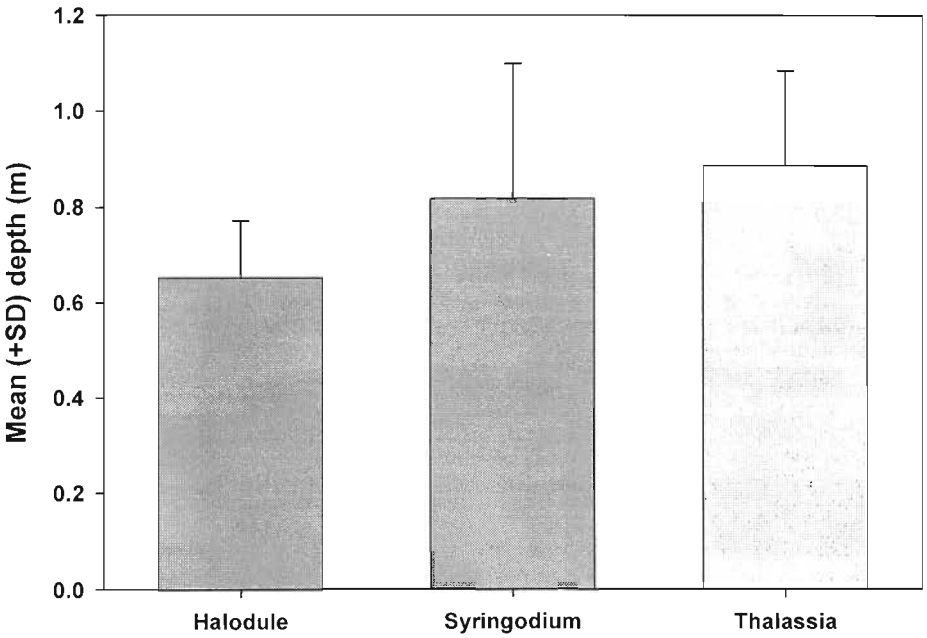

Figure 2. Water depth of each site with site names defined by the dominant SAV.

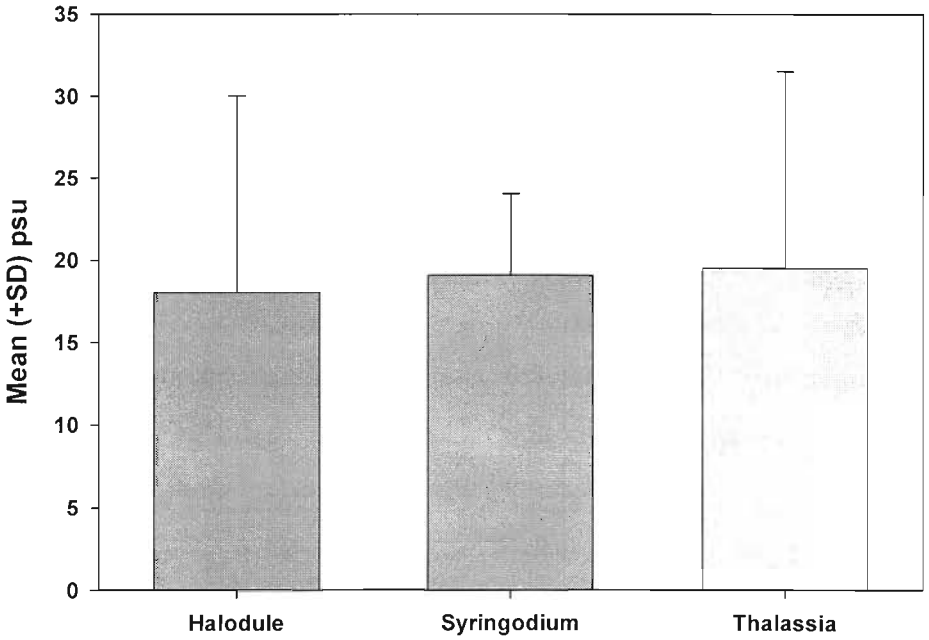

Figure 3. Original salinity regimes with sites defined by dominate seagrass species.

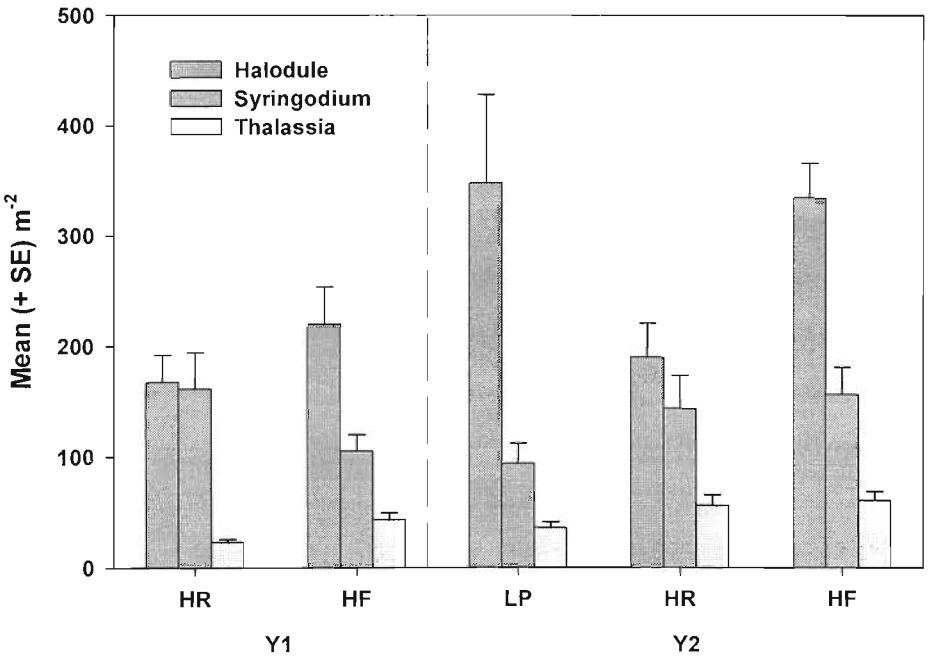

Figure 4. Mean shoot density (m^2) by site group during each sampling period and year.

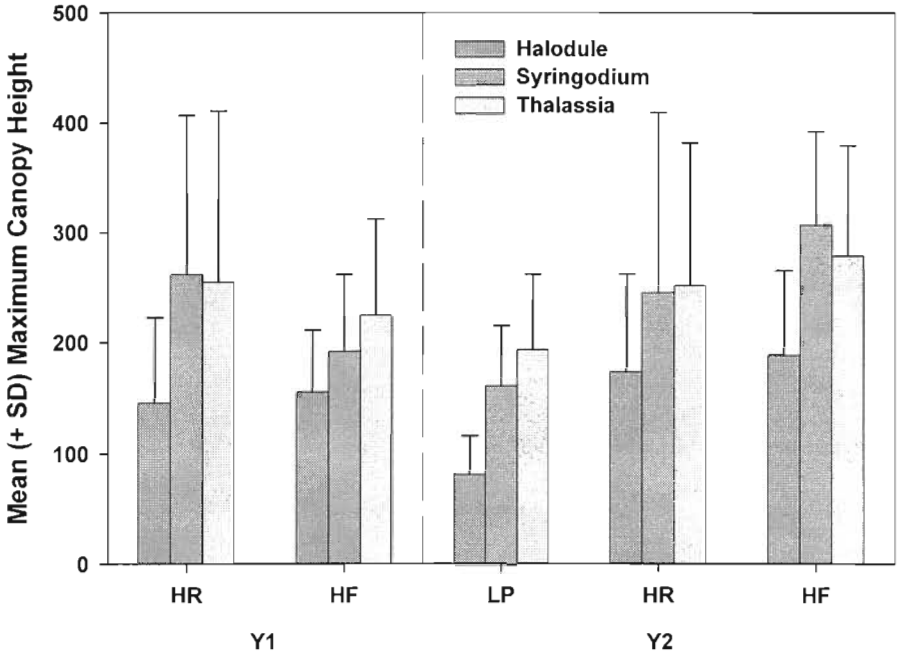

Figure 5. SAV canopy height as a measure of mean maximum blade length for each site group during each sampling period and year.

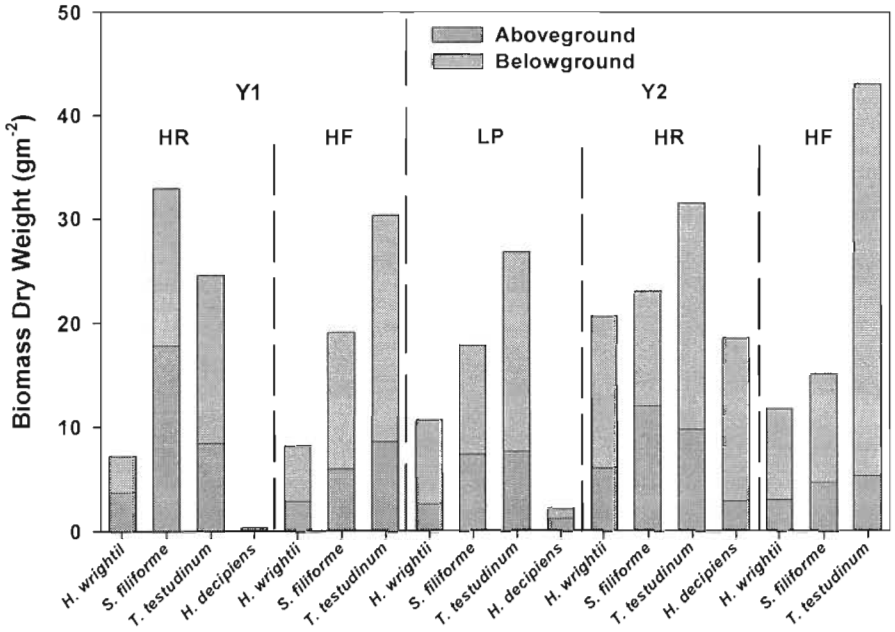

Figure 6. Seagrass biomass (aboveground & belowground) by seagrass species during each sampling period and year. Note the addition of *Halophila decipiens* during LP and HR sampling.

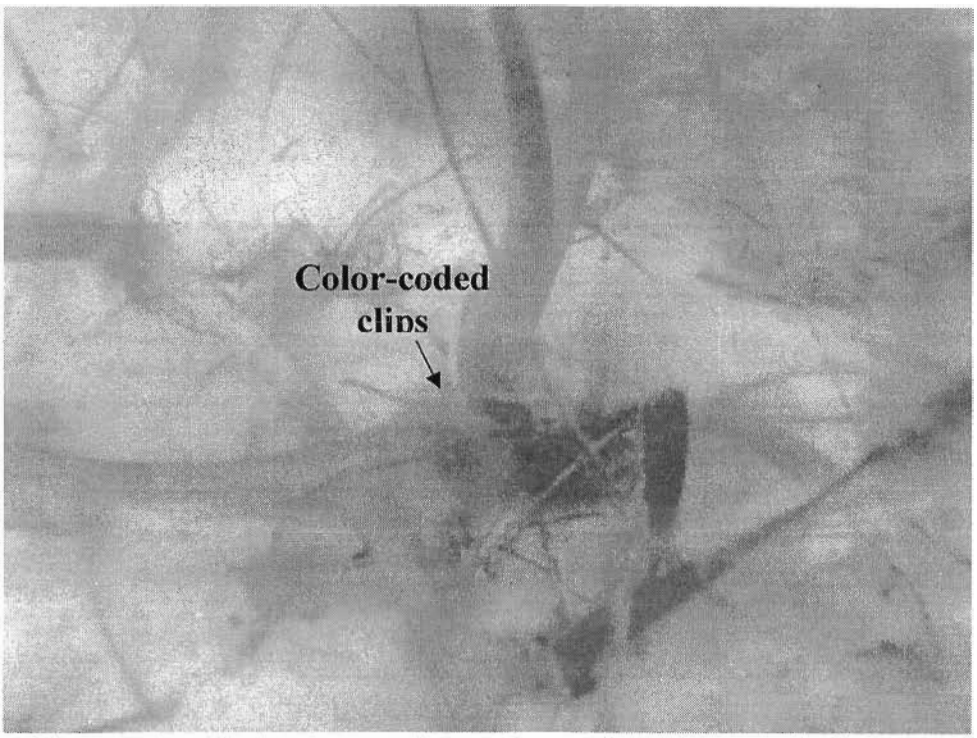

Figure 7. Picture of a *Thalassia testudinum* shoot with color-coded clips attached to each blade.

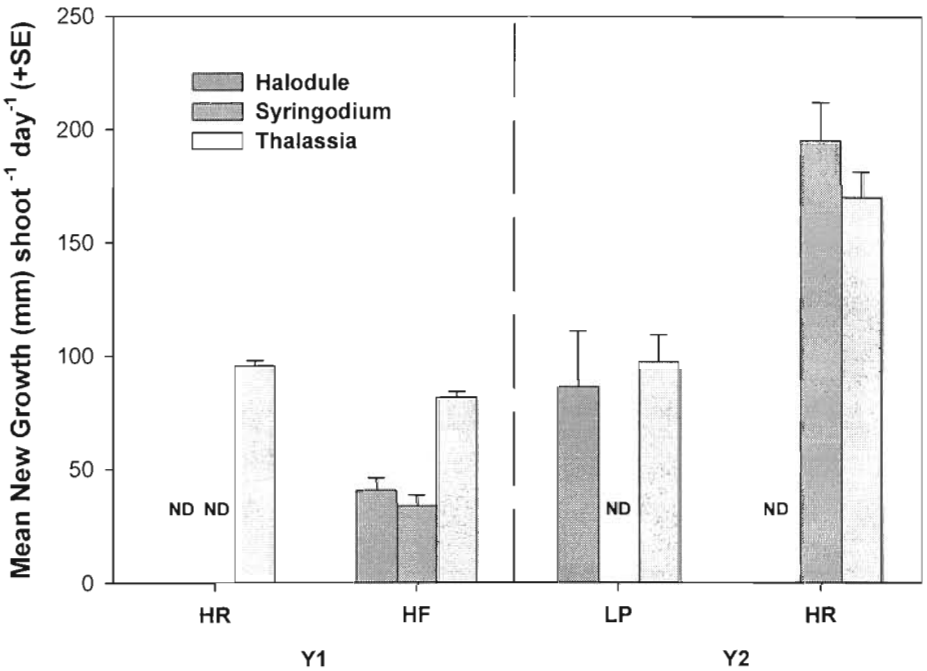

Figure 8. Mean new growth (mm) shoot^{-1} day^{-1} ($\pm$SE) by site group during each sampling period and year.

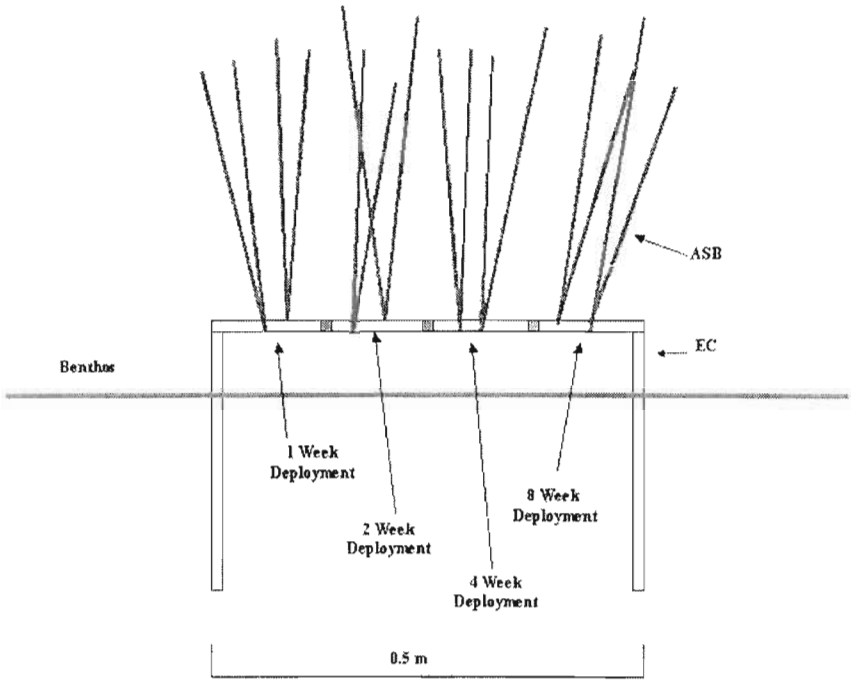

Figure 9. Cartoon depicting an Epiphyte Collector (EC) with attached Artificial Seagrass Blades (ASB) separated by cable ties (range) into deployment periods.

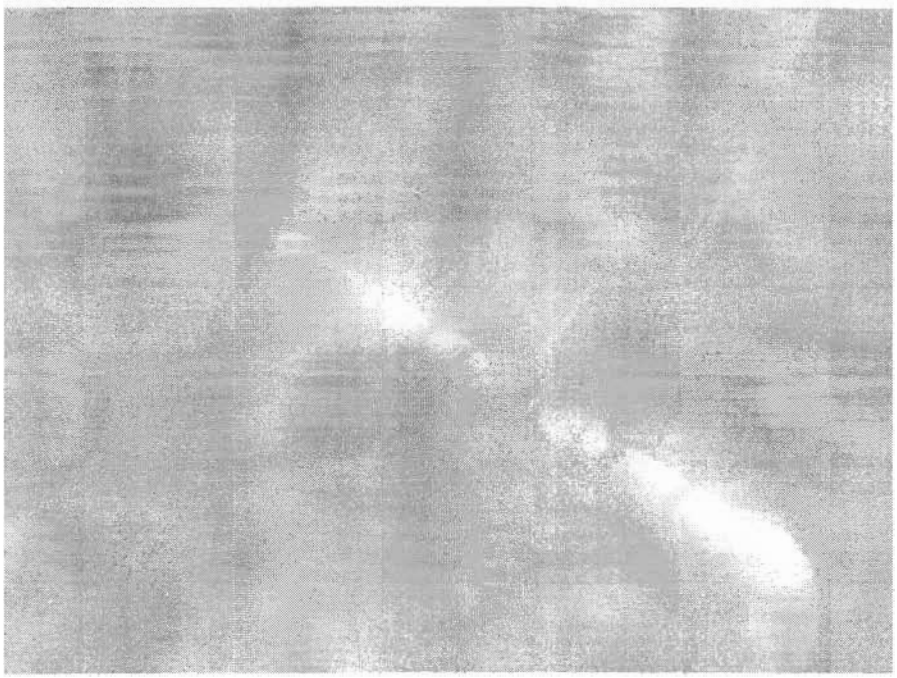

Figure 10. Picture of an Epiphyte Collector (EC) with attached Artificial Seagrass Blades (ABS) *in situ*.

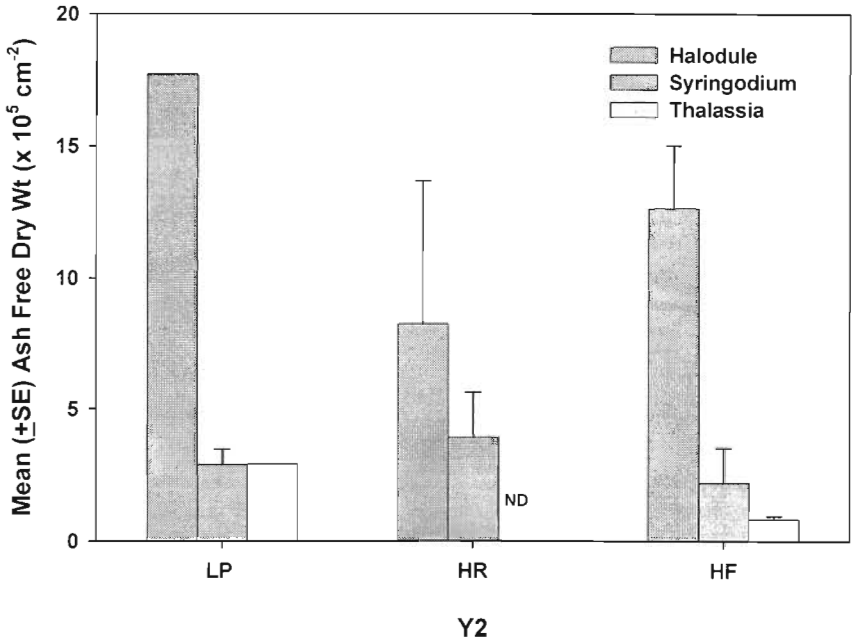

Figure 11. Epiphyte load by deployment interval (4 weeks) at each site. Collectors were lost to vandalism at FKT.

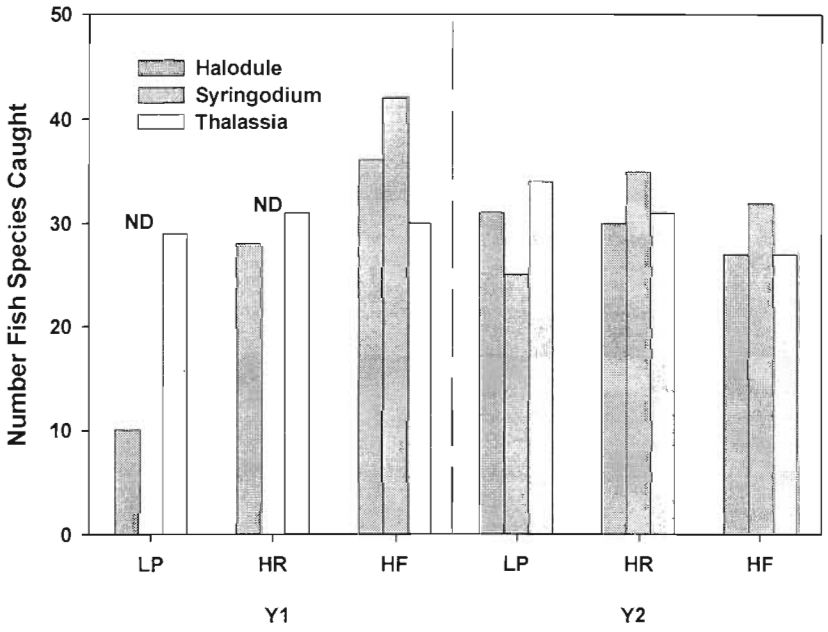

Figure 12. Number of fish species by site group during each sampling period and year. No data were collected at *Syringodium* sites during LP and HR in Y1.

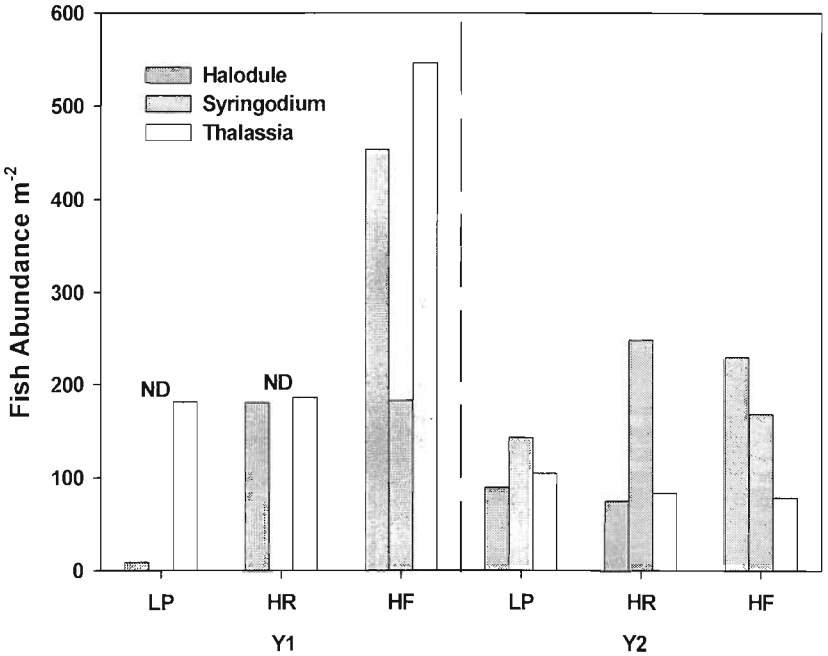

Figure 13. Density (m^{-2}) of fish captured by site group during each sampling period and year. The number of fish captured during HF at the *Halodule* and *Thalassia* sites were inflated by the large number of *Lucania parva* and *Anchoa* spp. (27% and 30%, respectively, of all fish captured) that were caught. No data were collected at *Syringodium* sites during LP and HR in Y1.

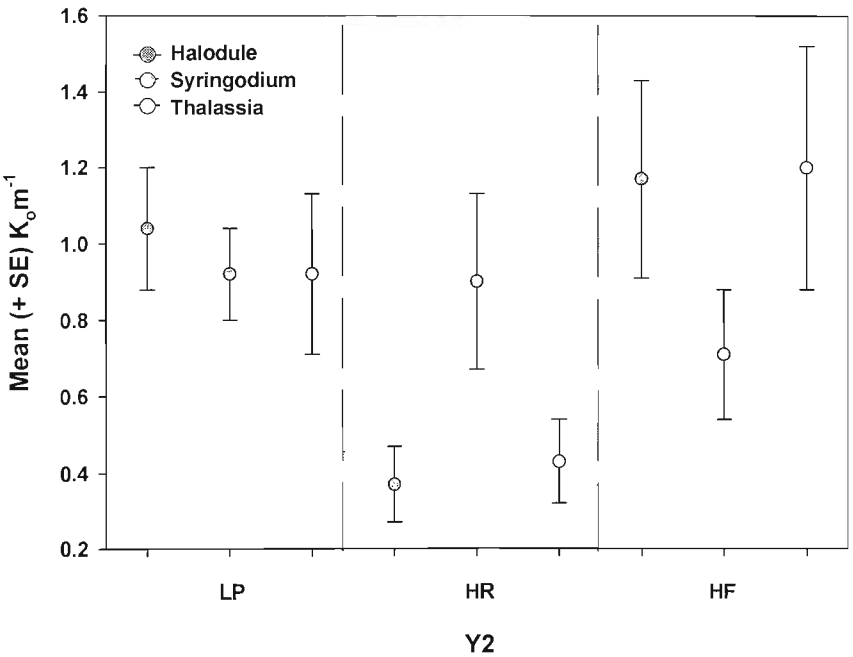

Figure 14. Light attenuation by site group during each sampling period and year.

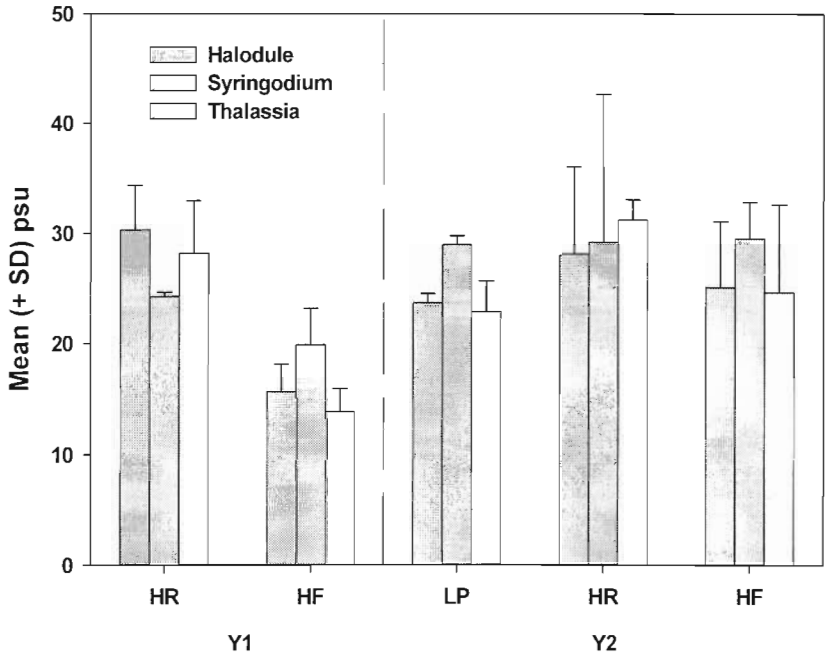

Figure 15. Salinity by site group during each sampling period and year.

Caloosahatchee River and Estuary Collaborative Research Plan

Aswani Volety[4], Greg Tolley[4] and Michael Savarese[4]

[4]Florida Gulf Coast University,
College of Arts & Sciences,
10501 FGCU Blvd. South, Ft. Myers, Florida 33965-6565

INTRODUCTION

The Eastern oyster *Crassostrea virginica* is highly valued as food, yet its ecological significance remains under-appreciated (Coen et al. 1999). Individual oysters filter 5 liters of water h^{-1} g^{-1} dry mass (Newell, 1988) removing phytoplankton, particulate organic carbon, sediments, pollutants, and microorganisms from the water column. This process results not only in greater light penetration downstream but also in the mineralization of nutrients (Dame et al. 1985), thus promoting the growth of submerged aquatic vegetation (see also Peterson and Heck 2001). Oysters assimilate the bulk of the organic matter that they filter; the remainder is deposited on the bottom where it provides food for benthic organisms. Oysters and the complex, three-dimensional, reef structure they form, attract numerous species of invertebrates and fishes.

These "ecosystem engineers" (sensu Jones et al. 1994) attract predators such as mud crab (*Panopeus herbstii*) (Meyer 1994), black drum (*Pogonias cromis*) (Ingle and Smith 1956), and crown conch (*Melongena corona*) (Woodburn 1965), which feed on the living oysters themselves. Oyster shell serves as a site for egg laying and nesting in the crown conch (*M. corona*) (personal observation, Tolley) and Florida blenny (*Chasmodes saburrae*) (Peters 1981), respectively. Oyster reef structure also provides refuge from predation, for such species as the mud crabs *Eurypanopeus depressus* and *P. herbstii* (McDonald 1982), and from environmental stress such as hypoxia (Lenihan et al. 2001) and desiccation (Grant and McDonald 1979).

To date, over 300 species have been identified as depending, either directly or indirectly, on oyster reefs (e.g., Wells 1961; Crabtree and Dean 1982; Abbe and Breitburg 1992; Wenner et al. 1996; Coen et al. 1999). Based on the relative degree of dependence, oyster-reef fauna can be classified as reef residents, facultative residents, and transients (Breitburg 1999). Many of these organisms in turn serve as forage for important fisheries species (e.g., spotted seatrout, *Cynoscion nebulosus*, Tabb and Manning 1961, McMichael and Peters 1989; red drum, *Sciaenops ocellatus*, Peters and McMichael 1987; bluefish, *Pomatomus saltatrix*, Harding and Mann 2001) and birds (e.g., yellow-crowned night-heron, *Nycticorax violaceus*, Watts 1988). Not surprisingly, oyster reefs have been identified as essential fish habitat (Coen et al. 1999) as defined by the Magnuson-Stevens Fishery and Conservation Act, where fish are defined as fin-fish, mollusks, and crustaceans (USDOC 1997).

Although Wells (1961) suggested a role for salinity in determining the composition of oyster-reef communities, limited empirical work has been undertaken to quantify this effect. Only Gorzelany (1986) has since addressed the issue to any real extent by sampling the communities of oyster-reef associated organisms at several points along the salinity gradients of temperate estuaries in the Big Bend region of northwest Florida.

In South Florida, because no commercial harvesting of oysters exists, it is the ecological function of oysters and oyster reefs–the filtration of the water column, the coupling of benthic and pelagic environments through the transfer of organic matter, and the provision of secondary habitat–that is of primary interest. Furthermore, the influence of freshwater inflow on oysters and oyster reef-habitat is of special interest in the region where the Comprehensive Everglades restoration Plan–one of the largest ecosystem restoration projects in the world–is currently underway. This massive project includes the re-routing and reallocation of freshwater from and into many estuaries, including those in Southwest Florida.

This study investigates the influence of salinity on spatial and seasonal patterns of oysters and oyster-reef habitat use by decapod crustaceans and fishes in the Caloosahatchee River and estuary, which will be impacted by Greater Everglades restoration. Special attention is given to examining the potential influence of salinity on the abundance and composition of these organisms. Understanding the relationships between salinity (a proxy for freshwater inflow) and metrics associated with oyster-reef habitat use will provide a valuable tool that can be used to improve coastal resource management and restoration efforts. Resource managers can use this approach to regulate salinity zones within an estuary in order to optimize habitat utilization of oyster reefs by associated organisms. Further, such relationships can be used prior to the commencement of oyster-reef restoration or enhancement efforts to identify those areas within an estuary that are likely to provide an appropriate salinity regime for the development of a robust assemblage of associated organisms.

The overall objectives of this project are as follows: (1) to examine the effects of variation in salinity on oyster condition and health, and on the habitat suitability of oyster reefs for decapod crustaceans and fishes; (2) to identify areas suitable for the development, and therefore potential restoration, of oyster reefs.

The distribution and relative abundance of oyster reefs within the Caloosahatchee River have clearly been altered over recent history. Physical alterations to the river, development of the watershed, and the implementation of water management practices have disrupted both the timing and volume of freshwater delivery into the Caloosahatchee Estuary. These alterations have the capacity to affect oyster health, thereby impacting the distribution and abundance of oyster reefs within the system. As a result, the ecological function of oysters and oyster reefs-the tremendous filtering capacity of oysters, the role of oyster reefs as essential fish habitat, and the over all secondary production associated with oyster reefs-can also be impaired. In addition, Oysters have been identified as "Valued Ecosystem Components" in the Caloosahatchee

Estuary Conceptual Model. The relative health of oysters and the significance of oyster reefs as fish habitat should therefore be examined along the main salinity axis of the estuary in response to a variety of freshwater inflow regimes. Oyster reef development also controls the estuary's geomorphology and its historic change; much of the river's mouth and associated bays and islands have evolved in response to reef growth and subsequent mangrove settlement. Consequently, a comparison of current reef distribution with historic patterns prior to alteration will document the influence of water management (i.e., salinity) on oyster reefs and permit the prediction of the system's geomorphologic response in the future.

Task 7. Oysters, oyster bars and juvenile fish.

Six research tasks were detailed in the proposal.

Task 7.1.1: Living oysters and reefs and Suitability Indicies.

Mapping of oyster reefs in the Caloosahatchee and Estero estuaries. 3 helicopter flights were flown over the 2 systems, and digital images, photographic slides, and video footage were shot to locate and size oyster reefs. The transfer of photographic data to plotted aerial photo mosaics was completed. In addition, we undertook a chopper flight to photograph oyster reefs in lower San Carlos Bay. The data was transcribed into a GIS layer.

Results indicate that Caloosahatchee River and estuary (including San Carlos Bay that forms the estuary portion of the Caloosahatchee River) has an accommodation space of 62,644,983 m2 (6264 Ha or 15,479.36 acres) with oyster reefs comprising of 74,336 m2 (7.43 Ha or **18.37 acres**). Accommodation space is defined as the surface area of the river that has annual mean salinities of greater than 10 ppt, and where oysters are currently found in the estuary. This translates to 0.12% coverage of total surface area available in the estuarine portion (Volety et al., un published results). Of the 18.37 acres of oyster reefs in the Caloosahatchee Estuary, ~**80%** of the reefs (**14.7 acres**) is present

below the Shell Point while ~**20%** (**3.7 acres**) is present above the Shell Point. Percent coverage of oyster reefs along various Gulf of Mexico estuaries (Texas, Coastal Louisiana, Mississippi, Alabama and Florida) ranges between 0 – 5.78%, with areas of intermediate salinities accounting for higher values (Data compiled by the US EPA). Other Florida estuaries that are less influenced by freshwater discharges have oyster reefs ~0.16 – 0.72% of the accommodation space (surface area).

The lower percent coverage of oyster reefs in the Caloosahatchee River is a combination of freshwater inflows into the estuary from Lake Okeechobee and lack of suitable substrate. Most of the benthic habitat in the river is made of silty muds, sand, clay and shell. In the Caloosahatchee River, estuarine conditions suitable for the growth of oyster reefs are normally present at or above shell point (considered the mouth of the river). However, due to freshwater releases from Lake Okeechobee and high amounts of rainfall, estuarine conditions are temporarily shifted downstream towards San Carlos Bay during the peak oyster spawning months (Volety and Tolley 2003) resulting in the recruitment and growth of oyster reefs in the downstream locations of the estuary (i.e. San Carlos Bay). However, upon return of dry months and higher salinities, downstream areas comprising of higher salinities result in lower oyster growth rates and attract significant numbers of predators and diseases that deplete oyster populations.

Task 7.1.2. Determine the quality of oyster-reef substrate.

The relative condition of a reef was assessed by surveying its "living density" (determining the number of living oysters per unit area of a reef). Living oyster density measurements were made for 5 reefs along the estuarine axis. Results from the wet season indicate that living oyster density varies widely among sampling locations. Ranges of living oyster densities ranged from 61 / 0.25 Sq. m (244/sq. m) at Kitchel Key to 407 / 0.25 sq. m (1628 sq. m). Living densities at Iona cove, Bird Island, Kitchel Key, and Tarpon Bay were 332 ± 348, 1628 ± 312, 244 ± 76, and 1172 ± 296 respectively.

Task 7.1.3: Determine the distribution and intensity of disease by Perkinsus marinus.

Oysters were collected monthly for monitoring infection due to *Perkinsus marinus*. Each month 10 oysters were collected from 5 sites (Iona Cove (IC), Cattle Dock (CD), Kitchel Key (KK), Bird Island (BI), and Tarpon Bay (TB) in the Caloosahatchee Estuary. Significant differences were observed due to sampling month and between sampling locations ($P < 0.05$). Mean intensity for the five stations (on a scale of 0 -5) were 0.5 (± 0.102), 0.938 ((± 0.102), 1.11 ((± 0.103), 1.375 ((± 0.103), and 1.306 ((± 0.103) at IC, CD, KK, BI and TB respectively (Fig 1). Prevalence of infection at various sampling stations ranged from 0 – 100%, with infections higher at the downstream stations compared to those at upstream stations. Similar to infection prevalence, infection prevalence increased with increasing salinity (distance) downstream. Trends in both infection intensity and percent oysters infected follow salinity patterns. Both measures tend to be lower at the upstream stations and during intense wet season months, localities and times when salinities are low.

Task 7.1.4: Monitor Oyster Health and Condition Index

The condition index (a measure of dry meat weight / dry shell weight x 100) of each oyster collected for *P. marinus* infection was determined. Similar to *P. marinus* sampling, 10 oysters/site (5 sites) were analyzed for determining the condition index of oysters. Significant differences were observed in the CI of oysters due to sampling month and sampling location ($P < 0.05$). Oysters at Iona Cove had the highest condition index compared to the rest of the sampling locations (4.62 (± 0.077). Mean condition index of oysters at Iona Cove, Cattle Dock, Bird Island, Kitchel Key and Tarpon Bay for the year were 4.62, 2.889, 2.410, 2.978, and 3.496 respectively (Fig 2).

Task 7.1.5. Monitor Oyster Spat Recruitment.

Oyster spat recruitment was monitored at each site monthly using 4 shell strings (12 shells/string) (Haven and Fritz 1985). Significant differences were observed in the spat recruitment due to sampling month and sampling location ($P < 0.05$). Spat recruitment increased with increasing distances downstream (Fig. 3). This could be due to the flushing effect of freshwater releases and inflow due to watershed runoff given regulatory water releases as well as storm events in the Fall. Oyster spat recruitment ranged from 0 – 21 spat/shell/month (Fig. 4). Previous studies suggest that oysters in the Caloosahatchee spawn from May – October.

Task 7.1.6. Determine Juvenile Oyster Growth.

Approximately 70 juvenile oysters were deployed in wire-mesh caged bags at each of the sampling locations. Oysters had limited growth at each of the sampling locations from December to January. However, oysters from Iona Cove, Bird Island, Kitchel Key showed good growth between Mar – Jun. Oysters at Cattle Dock and Tarpon Bay experienced high mortalities (Fig. 5).

Task 7.1.7. Estimate Reproductive Potential and Recruitment.

Histological sections were obtained from ten oysters at each sampling location. Results indicate the oysters in the Caloosahatchee estuary are reproductively active between May – October. The upstream most station (IC) initiated spawning in March, while the oysters from the remaining sampling locations spawned continuously from May. Given the warm water conditions, and abundance of food, it appears that oysters in the Caloosahatchee River continuously spawn during May – October months. This is reflected in the spat recruitment counts, with peak recruitment occurring in the month of September.

Task 7.1.8: Monitoring Water Quality

Physical water quality (salinity, temperature) was characterized at each site during each sampling effort. Temperature showed a distinct seasonal cycle with temperatures ranging from 16°C during the winter months and 35°C during the summer months. Salinity ranged between 0 – 38 ppt (Figures 6 and 7).

Task 7.2.1 Juvenile fishes and associated fauna.

Field Sampling and Analysis

In order to examine the influence of salinity (freshwater inflow) on the habitat use of oyster reefs in the Caloosahatchee Estuary, a spatio-temporal comparison of reef-resident fishes and decapod crustaceans was conducted during the period of October 2003 through September 2004. Three stations were selected for sampling along the salinity gradient of the estuary (Fig. 8): Iona Cove (upper), located within the Caloosahatchee River proper; Bird Island (middle), located just downstream of the mouth of the river; and Tarpon Bay (lower), located even farther downstream in San Carlos Bay.

For each sampling effort (11 months x 3 stations)* salinity and water temperature were recorded and 5 replicate lift nets (Crabtree and Dean 1982) were deployed intertidally, just above mean low water, on living oyster reefs for a duration of approximately 30 d. Previous collections using Hester-Dendy samplers suggested that this period was sufficient for macroinvertebrate recruitment. Lift nets (0.5 m^2) were constructed using 3.2-cm PVC frames and 6.4-mm delta-weave netting dipped in vinyl to minimize wear and tear resulting from constant contact with oyster shell. The bag on each net measured 0.5 m in height and the bottom was made using 1.6-mm netting to prevent the escape of small organisms. Upon deployment, a 1-m^2 area of the substrate was cleared of oyster shell. The net walls were then collapsed as each lift net was pinned to the substrate using 45-cm lengths of PVC attached to a PVC T-fittings. Approximately 3 liters (volume displacement) of live oyster clusters were collected from adjacent portions of the reef and were then placed in each net. Because each net would be deployed for a period of 30 d, no effort was made to remove existing fauna from these

oyster clusters. Upon retrieval of the nets oyster clusters were removed and any associated decapods and fishes were extricated using forceps. Any remaining decapods and fishes were then either removed from the net by hand or by using dip nets to sweep the interior of the lift net. These organisms were then transported on ice back to the laboratory for identification. Specimens were stored in 70% isopropanol for archiving and further analysis.

* No data was collected for the period of mid-August to mid-September 2004 due to the effects of several hurricanes that passed through the state beginning with Hurricane Charley, which destroyed the sampling gear as it passed through the area on August 13th.

Community metrics of the decapods and fishes recruited into the oyster clusters were examined: density, biomass, diversity (Shannon-Wiener Index, H'), dominance (% occurrence of the most abundant species), and species richness. The ratio of the porcelain crab *Petrolisthes armatus* to the mud crab *Eurypanopeus depressus* has also been suggested as a useful metric for comparing oyster-reef communities (Michael Shirley, Rookery Bay National Estuarine Research Reserve, pers. comm.) and was therefore employed in this study. *P. armatus* is a tropical organism that is less tolerant of reduced salinities (Shumway 1983) compared to the more euryhaline *E. depressus*. In the laboratory, organisms were identified, measured to the nearest 0.1 mm (shrimp: carapace length, crabs: carapace width, fishes: standard length) and were weighed to the nearest 0.01 g wet mass (WM). Length-weight regressions were calculated for each species and were subsequently used to estimate biomass based upon the mean size of each species collected in each sample.

Response variables (e.g., density, biomass, diversity, etc.) were examined using one-way analysis of variance with month and station as factors. Homogeneity of variance was tested using the Levene statistic; when variances were deemed unequal, the Welch ANOVA was used. Significant differences detected by ANOVA ($p \leq 0.05$) were resolved using multiple comparison tests (Day and Quinn 1989): Fisher's Least Significant

Difference in cases of equal sample size and equal variance; the GT2 method in cases of unequal sample size but equal variance; and the GH test in cases of unequal variance (regardless of sample size). Unless otherwise specified, data are presented as mean $\pm$ standard deviation.

In order to differentiate potential seasonal effects due to salinity, temperature, or both, metrics were compared with salinity, temperature, and flow values using correlation analysis. Salinity and temperature values represent the average of the measurements recorded at the beginning and at the end of each sampling effort for each station. Flow data were recorded by the U.S. Army Corps of Engineers from the Franklin Locks spillway upstream of the study area (http://www.sfwmd.gov/org/ema/dbhydro/). Flow data were averaged as mean flow for the 30-d period during each sampling effort and were transformed using the natural logarithm. Flow was also lagged for 30-d periods preceding the study to examine the relationship between community metrics and flow measured during the previous 1–6 months.

RESULTS

Density and Biomass

Decapod crustaceans dominated the samples both numerically and in terms of biomass. Ten species of decapods were collected, with the flatback mud crab *Eurypanopeus depressus* and the green porcelain crab *Petrolisthes armatus* being the most abundant (Table 1), and long with the mud crab *Panopeus* sp. occurred in more than 50% of the samples collected. Fishes were slightly more diverse with 13 species (Table 1), but were typically 1–2 orders of magnitude less abundant than decapods. Based on their relative percent occurrence in the samples, the Florida blenny (*Chasmodes saburrae*), the skilletfish (*Gobiesox strumosus*), and the code goby (*Gobiosoma robustum*) were considered common on Caloosahatchee oyster reefs.

Significant spatial and temporal variation in both organism density and biomass was detected (Table 2). Organism density was significantly higher at the middle station (177.1 ± 47.5) compared to the upper (74.3 ± 27.2) or lower stations (120.2 ± 81.7) and densities at both the middle and lower stations were significantly higher than that upstream (Table 2). Biomass was also significantly greater at the middle (29.00 ± 13.51) and lower stations (33.16 ± 30.97) compared with that upstream (17.00 ± 7.28) (Table 2).

Neither density nor biomass varied seasonally when data from all three stations were combined. However, significant seasonal differences were detected in these metrics for each station. For example, densities at the upper station (Iona Cove) were significantly higher in July (112.2 ± 13.7) compared to a number of other months; densities at the middle station were significantly higher in December (213.2 + 37.6) and January (213.2 + 32.0) compared to October (119.0 ± 16.2); and densities at the lower station were significantly elevated in May (337.4 ± 63.1) compared to all other months (March, May, and June densities were also lower those recorded for October at this site) (Fig. 9). Although biomass did not vary seasonally at the upper station, significant differences were detected for the two stations downstream. Biomass in June (36.0 ± 5.0) was significantly higher than in February (21.2 ± 2.7) at the middle station, and was significantly elevated in May (117.72 ± 31.35) compared to all other months at the lower station, reflecting the pattern observed at this site for organism density (Fig. 10).

Biodiversity and Composition

Although species richness did not vary among stations, diversity (H') was lowest at the middle station (0.274 ± 0.211), intermediate at the upper station (0.385 ± 0.250), and highest at the lower station (0.597 ± 0.185) (Table 2). Dominance, which is inversely related to diversity, was reduced at the lower station (79.4% ± 9.8) compared to the two sites farther upstream (upper: 90.7% ± 7.4; middle: 93.3% ± 7.2).

Comparing seasons, data pooled for all three stations indicated that diversity was significantly greater in August (0.643 ± 0.253) than for the months of November (0.323 ± 0.217), December (0.277 ± 0.237), and March (0.270 ± 0.207) (Table 2). August was also characterized by greater species richness (5.5 ± 2.3) than December (3.2 ± 1.2) or March (3.1 ± 1.0) and by lower percent dominance (76.4 ± 15.0) compared to either November (92.5 ± 6.1) or March (92.2 ± 8.8). This August peak in diversity was also apparent when seasonal data were examined for each station: diversity at the middle station was highest in July and August compared to all other months, and diversity at the lower station was significantly higher during August than during December or the period of April through July (Fig. 11). Station-by-station patterns of species richness were less clear: no significant seasonal differences were detected for the upper station, richness was significantly greater in August than in December or January at the middle station, and richness was reduced in November compared to values in March, June, and July at the lower station (Fig. 12). Percent dominance at the middle station was significantly reduced in July and August, and at the lower station was reduced in August compared to values for November through January and for May through July (Fig. 13). Dominance at the lower station was significantly greater during October than for November, December, March, or June.

The ratio of the porcelain crab *Petrolisthes armatus* to the mud crab *Eurypanopeus depressus* increased downstream (upper: 0.001 ± 0.002; middle: 0.046 ± 0.083; lower: 0.227 ± 0.165) (Table 2). Although this ratio was higher during October compared to November or January at the lower station, values calculated for the middle station were highest during July compared to all other stations (Fig. 14). (The mean value for August was even greater but no significant differences were detected for this month due to high associated variance). No individuals of *P. armatus* were found at the upper station during the months of October through June.

Environmental Factors

Salinity increased significantly downstream in the Caloosahatchee with values recorded for the upper station (17.70 ± 8.90) being significantly lower than those recorded for either the middle (24.85 ± 6.66) or lower (31.81 ± 4.84) stations (Table 2). No significant seasonal differences in salinity were detected (Fig. 15).

In contrast, temperature did not vary statistically among stations (Table 2) but exhibited significant seasonal differences with temperatures at all three stations (Fig. 16) dipping below 25°C beginning in November and not rising again above 25°C until April or May (depending upon the station).

Significant correlations were detected between a number of metrics and either salinity, temperature, or freshwater inflow (Table 3). Although organism density was not correlated with environmental variables, biomass was positively related to freshwater inflow lagged at an interval of 4 months. Diversity was positively related to salinity and was negatively correlated with freshwater inflow lagged at 2 months. In contrast to diversity, dominance was negatively correlated with salinity. Species richness did not exhibit any relationships with either salinity or freshwater inflow, but was positively correlated with temperature. Lastly, the ratio of *Petrolisthes* to *Eurypanopeus* was positively correlated with salinity and was negatively related to freshwater inflow occurring at a lag of 2 months (Table 3).

The assemblage of fishes and decapod crustaceans collected in association with oyster clusters during this study is similar to those reported previously from more temperate waters. For example, the skilletfish (*Gobiesox strumosus*), feather blenny (*Hypsoblennius hentz*), and snapping shrimp (*Alpheus heterochaelis*) have all been previously collected from oyster reefs ranging from the Carolinas to Virginia and Maryland (Breitburg 1999; Coen et al. 1999; Posey et al. 1999). Likewise, the mud crab *Eurypanopeus depressus* occurs commonly on North Carolina reefs (Meyer 1994) and was the dominant decapod collected on oyster reefs within the St. Martins Aquatic Preserve on the central Gulf coast of Florida (Glancy et al. 2003). This species was also

the most abundant organism found in the current study. In other cases, more temperate species occurring on oyster reefs from the Carolinas to New York are replaced in Southwest Florida by more tropical to subtropical congeners: the striped blenny *Chasmodes bosquianus* (Breitburg 1999; Coen et al, 1999) is replaced by the Florida Blenny *Chasmodes saburrae*, and the oyster toadfish *Opsanus tau* (Breitburg 1999; Coen et al, 1999) is replaced by the Gulf toadfish *Opsanus beta*. Although the green Porcelain crab *Petrolisthes armatus*, considered an invasive exotic along much of the South Atlantic Bight, has been previously reported throughout the Gulf of Mexico (Knott et al. 1999; Glancy et al. 2003), its range prior to 1994 was apparently limited on the U.S. Atlantic coast to south of Cape Canaveral (Knott et al. 1999). In the Caloosahatchee, *Petrolisthes* was the second most numerically dominant organism collected.

Some of the species collected in this study were found at all stations sampled and occurred in a variety of salinities (e.g., *Alpheus heterochaelis*, *Eurypanopeus depressus*, *Panopeus* sp.); however, other species appeared unsuccessful in colonizing oyster clusters at the uppermost station: the stone crab *Menippe mercenaria* was found only at the lower station and *Petrolisthes armatus* was not collected at the upper station from October through June. Wells (1961) suggested that a majority of species inhabiting oyster reefs are limited in their upstream distribution by the reduced salinities occurring there.

There are two sources of seasonal programming at work in Southwest Florida estuaries: seasonal variation in air and water temperature and seasonal variation in rainfall and water releases. When they interact, salinity and temperature can also confound the interpretation of results: seasonal rains typically occur from mid-June through mid-October in Southwest Florida resulting in reduced salinities at a time of elevated water temperatures. Spatial and seasonal patterns detected in oyster-reef community metrics suggested that salinity might play an important role in structuring the assemblage of decapods and fishes found on Caloosahatchee reefs. Biomass increased from upstream to downstream as did the ratio of the stenohaline porcelain crab *Petrolisthes armatus* to the euryhaline mud crab *Eurypanopeus depressus*. The density

(lower station) and biomass (middle and lower stations) of reef-resident decapods and fishes was highest during the month of May toward the end of the dry season. Diversity was higher in August for the middle and lower stations and may have been largely due to the decrease in species dominance that began in July and continued through August for these two stations. Correlation analysis demonstrated that biomass, diversity, dominance, and the ratio of *Petrolisthes* to *Eurypanopeus* all covaried with either freshwater inflow or with salinity, a proxy for freshwater inflow. Furthermore, significant correlations between community metrics and freshwater inflow occurred at time lags of 2-4 months. Species richness was not related to salinity, but was positively related to temperature, suggesting the potential influence of seasonal recruitment on community metrics.

Water-resource management increasingly involves the identification and conservation of important habitats. From a fisheries perspective, Stalnaker et al. (1995) suggest that for management to be effective, "fishery resource managers must become water and habitat managers." From an ecosystem perspective, Beck and Odaya (2001) proposed that the most effective way to conserve biodiversity in the Gulf of Mexico is to focus on key habitats– including oyster reefs–"and on the ecological processes that affect their variability." Oysters and the reefs they form are managed according to one or both of these perspectives in different parts of the U.S. In Southwest Florida, where oysters are not harvested as a food resource, ecological function is of greater interest.

In terms of managing freshwater flow into estuarine systems, Mattson (2002) reviewed the use of community metrics as a measure of habitat quality that can be compared to such factors as salinity in order to understand the functional relationships involved. Salinity is itself a characteristic of estuarine habitat and is invaluable in the management of freshwater inflows "because it is well-defined and measurable, has ecological significance, integrates a number of important estuarine processes and properties, and is meaningful to a large number of constituencies" (Jassby et al. 1995).

The regulation of freshwater flow into Southwest Florida estuaries can be a useful tool for providing suitable habitat for oysters. For example, La Peyre et al. (2003) proposed the management of freshwater inflow into the Caloosahatchee estuary to reduce infection intensities of the oyster parasite *Perkinsus marinus*. Furthermore, Wilbur (1992) demonstrated the detrimental effects of low flows on oyster productivity in Apalachicola Bay, Florida, suggesting that in the absence of significant freshwater input, high salinities allowed for increased predation on settling spat as well as for increased disease prevalence, both resulting in reduced survivorship. However, salinity fields appropriate for the maintenance of healthy oysters, which tend to favor intermediate salinities, may not necessarily be coincident with salinity fields that maximize density, biomass, or biodiversity of oyster-reef organisms. It is therefore paramount to consider the responses of both oysters and of reef-resident organisms to salinity not only when managing or altering freshwater inflow in estuaries but also when selecting suitable locations for oyster-reef restoration and enhancement.

REFERENCES

Abbe, G. R. & D. L. Breitburg. 1992. The influence of oyster toadfish (*Opsanus tau*) and crabs (*Callinectes sapidus* and Xanthidae) on survival of oyster (*Crassostrea virginica*) spat in Chesapeake Bay: does spat protection always work? *Aquaculture* 107:21–31.

Beck, M. W. & M. Odaya. 2001. Ecoregional planning in marine environments: identifying priority sites for conservation in the northern Gulf of Mexico. *Aquatic Conservation: Marine and Freshwater Ecosystems* 11:235–242.

Breitburg, D. L. 1999. Are three-dimensional structure and healthy oyster populations the keys to an ecologically interesting and important fish community? In: M.W. Luckenbach, R. Mann & J. A. Wesson, editors. Oyster reef habitat restoration: a

synopsis and synthesis of approaches. Virginia Institute of Marine Science Press, Gloucester Point, Virginia, pp. 239–250.

Coen, L. D., M. W. Luckenbach & D. L. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. *American Fisheries Society Symposium* 22:438–454.

Crabtree, R. E. & J. M. Dean. 1982. The structure of two South Carolina estuarine tide pool fish assemblages. *Estuaries* 5:2–9.

Dame, R. F., T. G. Wolaver & S. M. Libes. 1985. The summer uptake and release of nitrogen by an intertidal oyster reef. *Netherlands Journal of Sea Research* 19:265–268.

Day, R. W. & G. P. Quinn. 1989. Comparisons of treatments after an analysis of variance in ecology. *Ecological Monographs* 59:433–463.

Glancy, T. P., T. K. Frazer, C. E. Cichra & W. J. Lindberg. 2003. Comparative patterns of occupancy by decapod crustaceans in seagrass, oyster, and marsh-edge habitats in a northeast Gulf of Mexico estuary. *Estuaries* 26:1291–1301.

Gorzelany, J. 1986. Oyster associated fauna, Volume V: A data collection program for selected coastal estuaries in Hernando, Citrus, and Levy counties, Florida. Report prepared by Mote Marine Laboratory for the Southwest Florida Water Management District.

Grant, J. & J. McDonald. 1979. Desiccation tolerance of *Eurypanopeus depressus* (Smith) (Decapoda: Xanthidae) and the exploitation of microhabitat. *Estuaries* 2:172–177.

Harding, J. M. & R. Mann. 2001. Diet and habitat use by bluefish, *Pomatomus saltatrix*, in a Chesapeake Bay estuary. Environmental Biology of Fishes 60:401–409.

Haven, D. S. and L. W. Fritz. 1985. Setting of the American oyster *Crassostrea virginica* in the James River, Virginia, USA: temporal and spatial distribution. Marine Biology 86:271-282.

Ingle, R. M. & F. G. W. Smith. 1956. Oyster culture in Florida. State of Florida Board of Conservation, Education Series 5, 25 pp.

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel & T. J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. *Ecological Applications* 5:272–289.

Jones, C. G., J. H. Lawton & M. Shachak. 1994. Organisms as ecosystems engineers. *OIKOS* 69:373-386.

Knott, D., C. Boyko & A. Harvey. 1999. Introduction of the green porcelain crab, *Petrolisthes armatus* (Gibbes, 1850) into the South Atlantic Bight. In: J. Pederson, editor. Marine Bioinvasions: Proceedings of the First National Conference. Massachusetts Institute of Technology, Cambridge, Massachusetts, p. 404.

La Peyre, M. K., A. D. Nickens, A. K. Volety, S. G. Tolley & J. F. La Peyre. 2003. Environmental significance of freshets in reducing *Perkinsus marinus* infection in eastern oysters *Crassostrea virginica*: potential management applications. *Marine Ecology Progress Series* 248:165–176.

Lenihan, H. S., C. H. Peterson, J. E. Byers, J. H. Grabowski, G. W. Thayer & D. R. Colby. 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. *Ecological Applications* 11:764–782.

Mattson, R. A. 2002. A resource-based framework for establishing freshwater inflow requirements for the Suwannee River estuary. *Estuaries* 25:1333–1342.

McDonald, J. 1982. Divergent life history patterns in the co-occurring intertidal crabs *Panopeus herbstii* and *Eurypanopeus depressus* (Crustacea: Brachyura: Xanthidae). *Marine Ecology Progress Series* 8:173–180.

McMichael, R. H., Jr. & K. M. Peters. 1989. Early life history of spotted seatrout, *Cynoscion\ nebulosus* (Pisces: Sciaenidae) in Tampa Bay, Florida. *Estuaries* 12:98–110.

Meyer, D. L. 1994. Habitat partitioning between the xanthid crabs *Panopeus herbstii* and *Eurypanopeus depressus* on intertidal oyster reefs (*Crassostrea virginica*) in southeastern North Carolina. *Estuaries* 17:674–679.

Newell, R. I. E. 1988. Ecological changes in Chesapeake Bay: Are they the result of overharvesting the American oyster, *Crassostrea virginica*? In: M. P. Lynch & E. C. Krome, editors. Understanding the Estuary: Advances in Chesapeake Bay Research. Chesapeake Research Consortium, Publication 129. CBP/TRS 24/88, pp. 536–546.

Peters, K. M. 1981. Reproductive biology and developmental osteology of the Florida blenny, *Chasmodes saburrae* (Perciformes: Blenniidae). *Northeast Gulf Science* 4:79–98.

Peters, K. M. & R. H. McMichael, Jr. 1987. Early life history of the red drum, *Sciaenops ocellatus* (Pisces: Sciaenidae), in Tampa Bay, Florida. *Estuaries* 10:92–107.

Peterson, B. J. & K. L. Heck, Jr. 2001. Positive interactions between suspension-feeding bivalves and seagrass–a facultative mutualism. *Marine Ecology Progress Series* 213:143–155.

Posey, M. H., T. D. Alpin, C. M. Powell & E. Townsend. 1999. Use of oyster reefs as habitat for epibenthic fish and decapods. In: M. W. Luckenbach, R. Mann & J. A. Wesson, editors. Oyster reef habitat restoration: a synopsis and synthesis of approaches. Virginia Institute of Marine Science Press, Gloucester Point, Virginia, pp. 133–159.

Shumway, S. E. 1983. Oxygen consumption and salinity tolerance in four Brazilian crabs. *Crustaceana* 44:76–82.

Stalnaker, C., B. L. Lamb, J. Henriksen, K. Bovee & J. Bartholow. 1995. The Instream Flow Incremental Methodology: A Primer for IFIM. Biological Report 29, U. S. Department of the Interior, National Biological Service, Washington, D. C. 44 p.

Tabb, D. C. & R. B. Manning. 1961. A checklist of the flora and fauna of northern Florida Bay and adjacent brackish waters of the Florida mainland collected during the period July, 1957 through September, 1960. *Bulletin of Marine Science of the Gulf and Caribbean* 11:552–649.

USDOC (U. S. Department of Commerce). 1997. Magnuson-Stevens Fishery Conservation and Management Act, as amended through October 11, 1996. National Oceanic and Atmospheric Administration technical memorandum NMFS-F/SPO-23. U. S. Government Printing Office, Washington, D. C.

Watts, B. D. 1988. Foraging implications of food usage patterns in yellow-crowned night-herons. *The Condor* 90:860–865.

Wells, H. W. 1961. The fauna of oyster beds, with special reference to the salinity factor. *Ecological Monographs* 31:239–266.

Wenner, E., H. R. Beatty & L. Coen. 1996. A method for quantitatively sampling nekton on intertidal oyster reefs. *Journal of Shellfish Research* 15:769–775.

Wilbur, D. H. 1992. Associations between freshwater inflows and oyster productivity in Apalachicola Bay, Florida. *Estuarine, Coastal and Shelf Science* 35:179–190.

Woodburn, K. D. 1965. Clams and oysters in Charlotte Co. and vicinity. Florida Board of Conservation, vol. 62-12. 29 pp.

Table 1. Decapod crustaceans and fishes collected on Caloosahatchee oyster reefs from October 2003 through August 2004. Occurrence represents the percentage of the total number of samples containing at least one individual for each species.

Species	Common name	Number collected	Occurrence (%)
Decapods			
Alpheus heterochaelis	bigclaw snapping shrimp	64	17
Calinectes sapidus	blue crab	46	12
Eurypanopeus depressus	flatback mud crab	17,928	100
Libinia dubia	longnose spider crab	12	5
Macrobrachium sp.	freshwater shrimp	4	1
Menippe mercenaria	Florida stone crab	7	4
Palaemonetes pugio	grass shrimp	162	28
Panopeus sp.	mud crab	227	54
Penaeidae	commercial shrimps	6	4
Petrolisthes armatus	green porcelain crab	1,438	59
Fishes			
Archosargus probatocephalus	sheepshead	5	3
Bathygobius soporator	frillfin goby	10	5
Chasmodes saburrae	Florida blenny	56	24
Eucinostomus sp.	mojarra	2	1
Gobiesox strumosus	skilletfish	85	26
Gobiosoma bosc	naked goby	35	18
Gobiosoma robustum	code goby	110	40
Hypsoblennius hentz	feather blenny	4	2
Lagodon rhomboides	pinfish	22	11
Lutjanus griseus	gray snapper	2	1
Opsanus beta	gulf toadfish	29	15

Paralichthys albigutta	gulf flounder	1	1
Syngnathus scovelli	gulf pipefish	1	1

Table 2. Results of One-way Analysis of Variance investigating spatial and seasonal patterns in metrics associated with oyster-reef decapods and fishes.

Response variable	Factor	F-statistic	p-value	Degrees freedom
Density (organisms 0.5 m^{-2})	Station	96.760	0.000	94.611*
Biomass (g WW)	Station	21.417	0.000	91.154*
Diversity (H')	Station	37.690	0.000	163
Species richness (no.)	Station	0.713	NS	163
Dominance (%)	Station	44.545	0.000	163
Petrolisthes : Eurypanopeus	Station	59.258	0.000	73.403*
Salinity (ppt)	Station	9.668	0.001	32
Temperature (°C)	Station	0.276	NS	32
Density (organisms 0.5 m^{-2})	Month	0.806	NS	71.057*
Biomass (g WW)	Month	1.896	NS	71.015*
Diversity (H')	Month	3.175	0.002	71.102*
Species richness (no.)	Month	3.138	0.001	163
Dominance (%)	Month	2.475	0.015	71.099*
Petrolisthes : Eurypanopeus	Month	2.288	0.024	70.676*
Salinity (ppt)	Month	2.133	NS	32
Temperature (°C)	Month	71.206	0.000	32

* Welch ANOVA: reduced degrees of freedom.

Table 3. Relationship between oyster-reef community metrics and environmental parameters. Data represent Pearson's correlation coefficient with significance levels assigned as follows: * ≤ 0.05, ** ≤ 0.01. Flow values (cubic feet per second) are from data collected upstream of the study area and were transformed using the natural logarithm.

Metric	Salinity	Temperature	Ln Flow (cfs)						
	(ppt)	(°C)	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6
Density (0.5 m^{-2})	0.205	-0.042	-0.124	-0.066	0.039	0.028	0.005	-0.134	-0.066
Biomass(g)	0.295	0.083	-0.264	-0.129	-0.041	-0.067	0.523**	-0.318	-0.153
Diversity (H')	0.421*	0.252	-0.138	-0.198	-0.396*	-0.325	-0.311	-0.252	-0.146
Richness (no.)	0.172	0.345*	-0.113	-0.063	-0.289	-0.278	-0.231	-0.303	-0.314
Dominance (%)	-0.443**	-0.231	0.093	0.186	0.396*	0.325	0.322	0.211	0.119
Petro:Eury	0.528**	0.224	-0.054	-0.156	-0.354*	-0.317	-0.323	-0.170	-0.144

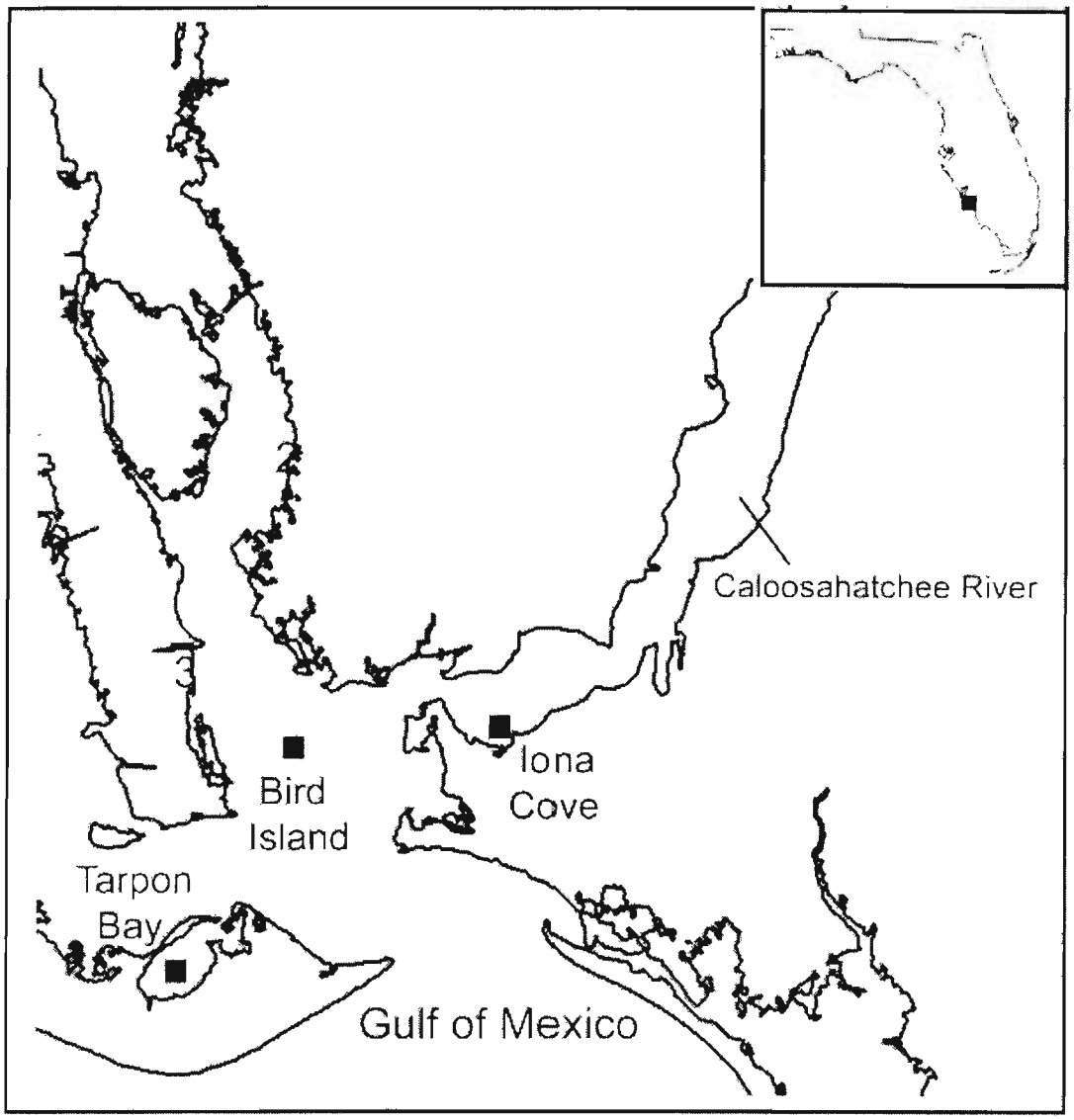

Figure 8. Map of the study area identifying stations along the Caloosahatchee River and Estuary.

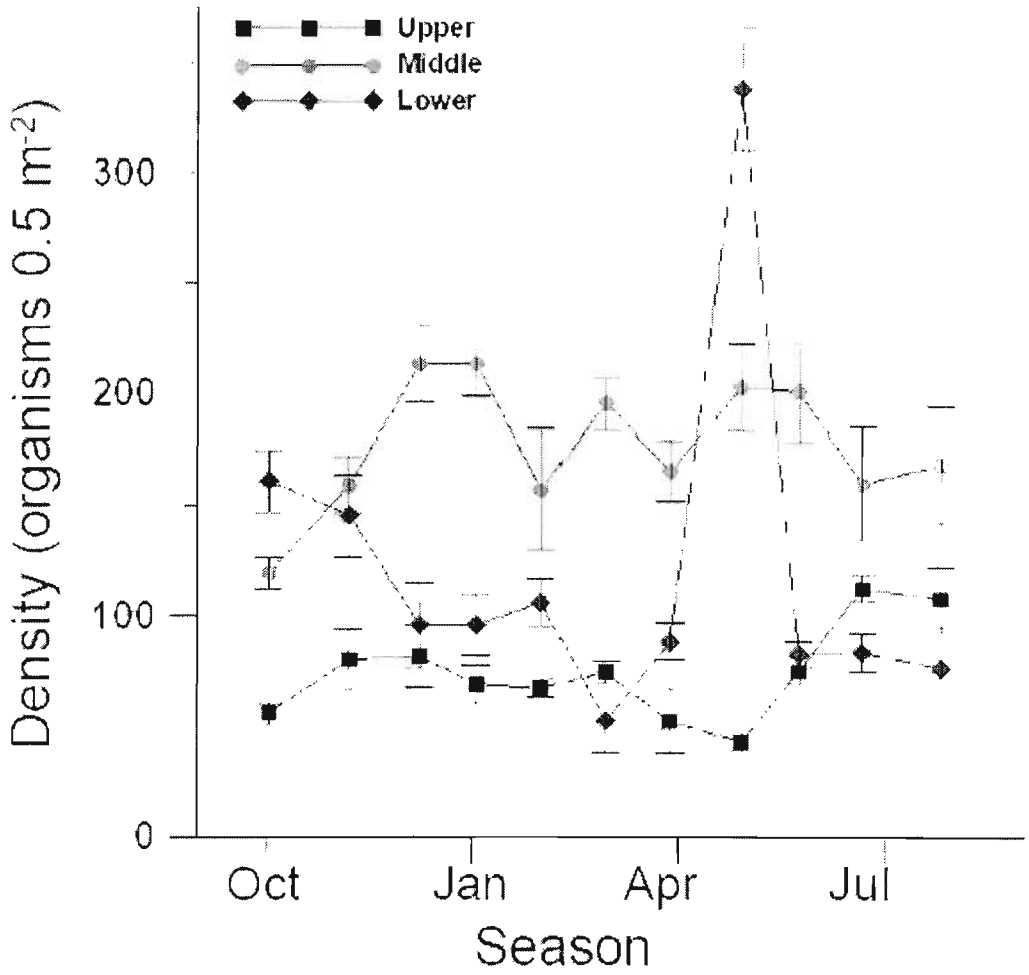

Figure 9. Seasonal patterns in density of oyster-reef associated decapods and fishes monitored at each station. Data are represented as monthly means ± S.E.

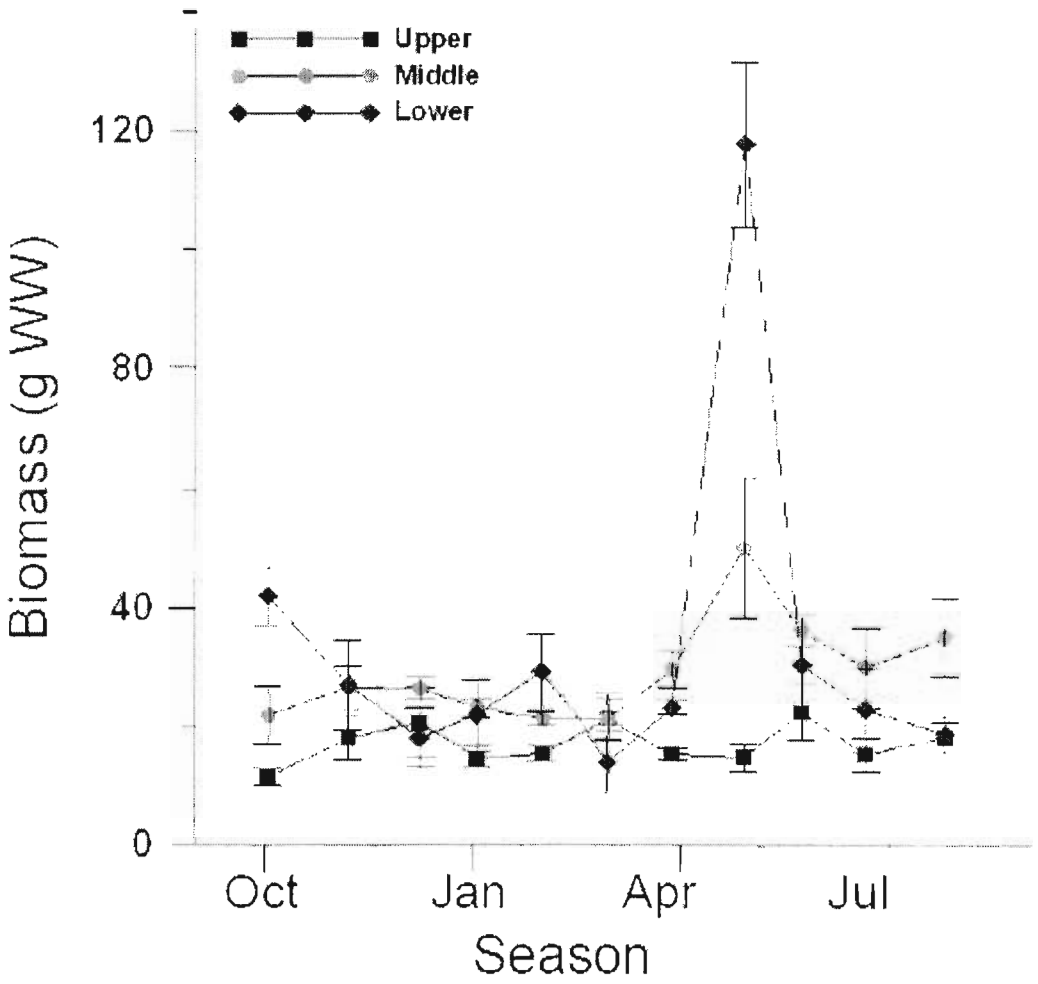

Figure 10. Seasonal patterns in biomass of oyster-reef associated decapods and fishes monitored at each station. Data are represented as monthly means ± S.E.

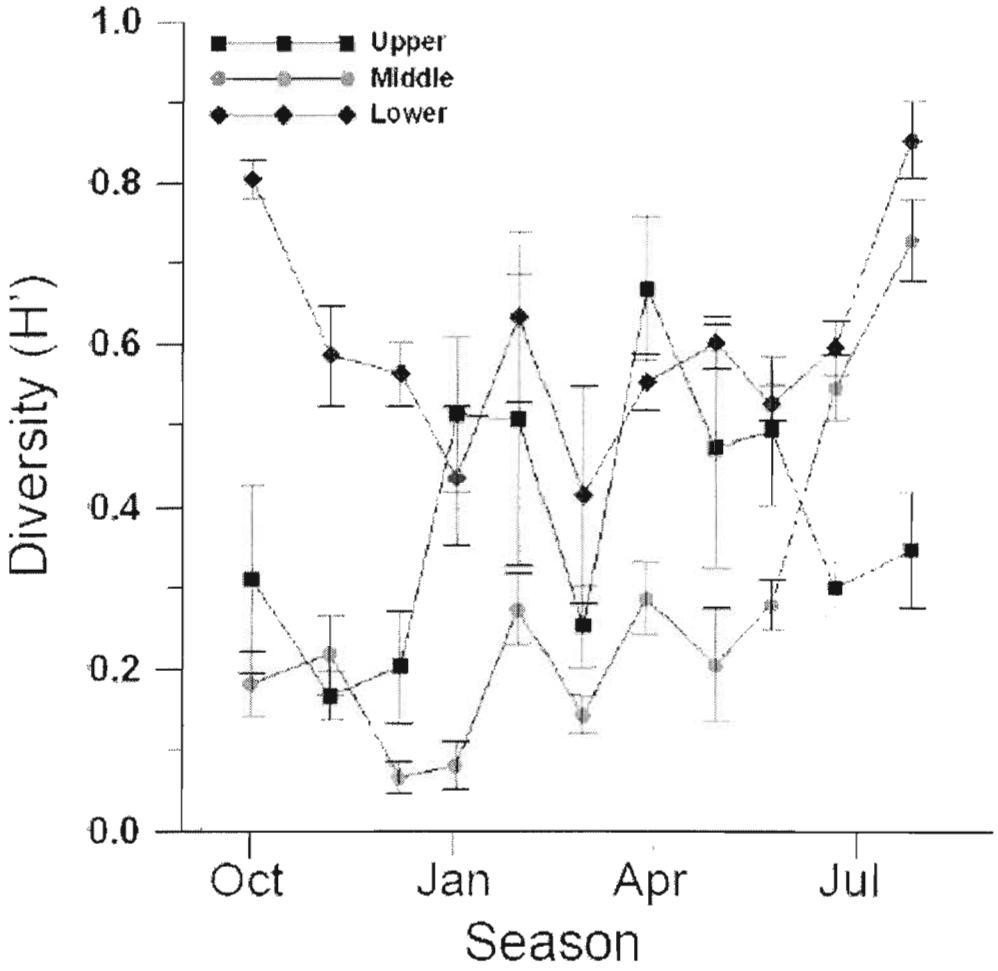

Figure 11. Seasonal patterns in diversity (H') of oyster-reef associated decapods and fishes monitored at each station. Data are represented as monthly means ± S.E.

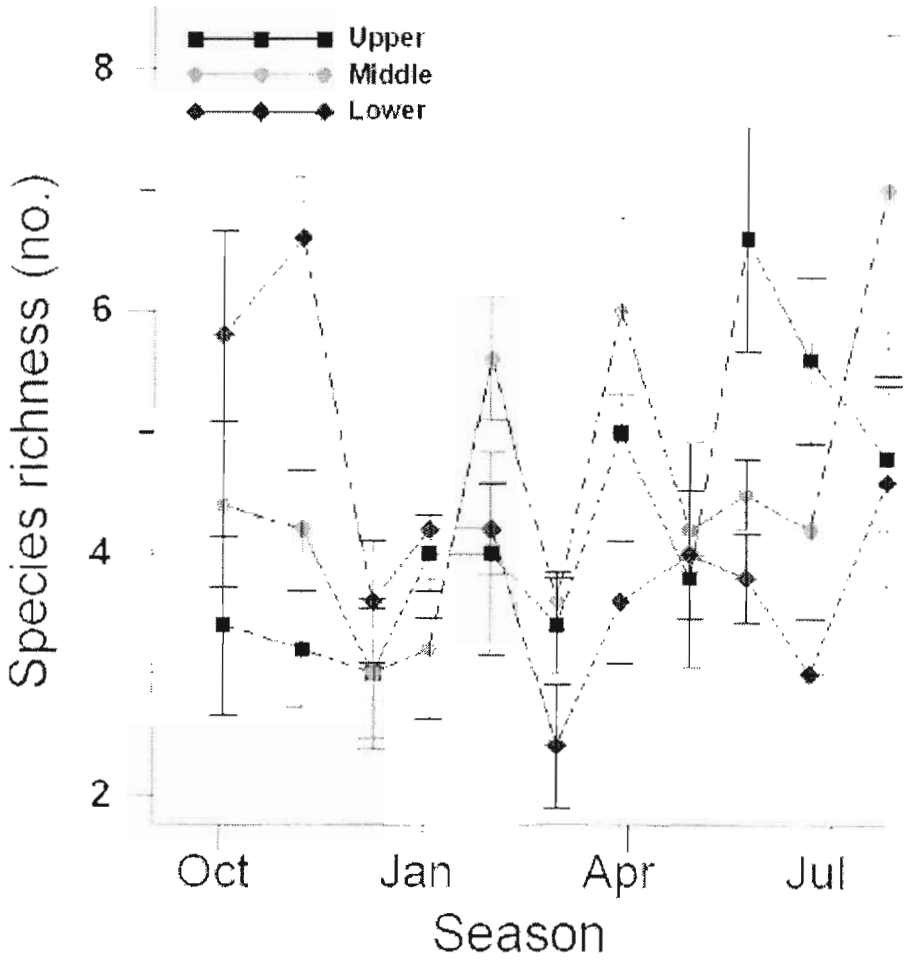

Figure 12. Seasonal patterns in species richness of oyster-reef associated decapods and fishes monitored at each station. Data are represented as monthly means ± S.E.

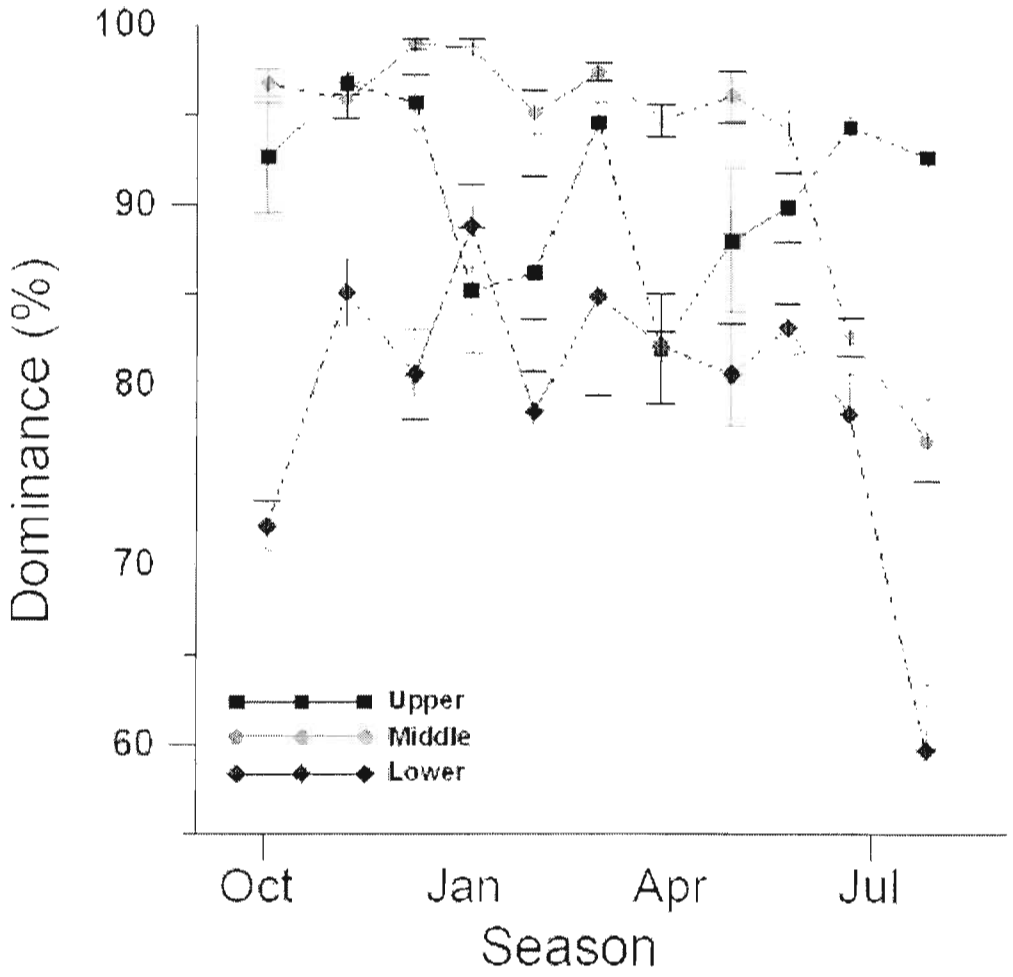

Figure 13. Seasonal patterns in species dominance of oyster-reef associated decapods and fishes monitored at each station. Data are represented as monthly means ± S.E.

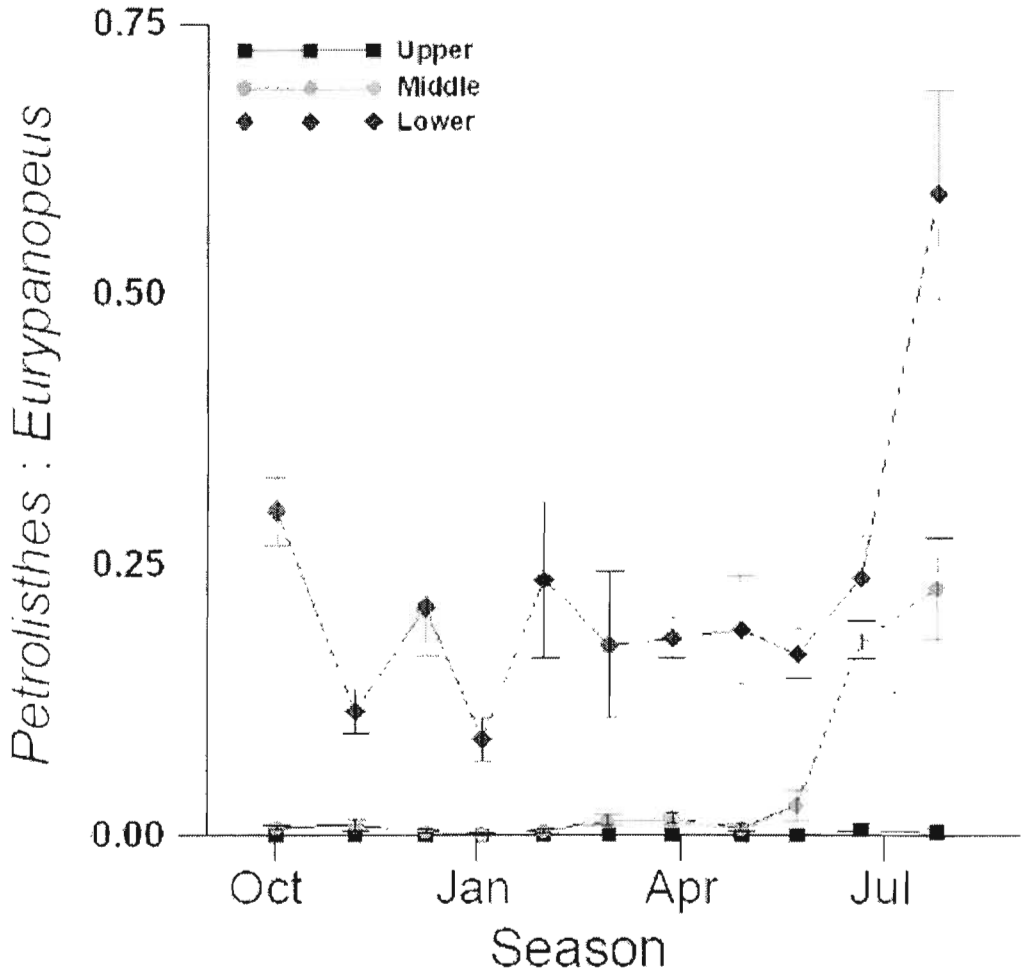

Figure 14. Seasonal patterns in the ratio of the stenohaline porcelain crab *Petrolisthes armatus* to the euryhaline mud crab *Eurypanopeus depressus* calculated for each station. Data are represented as monthly means ± S.E

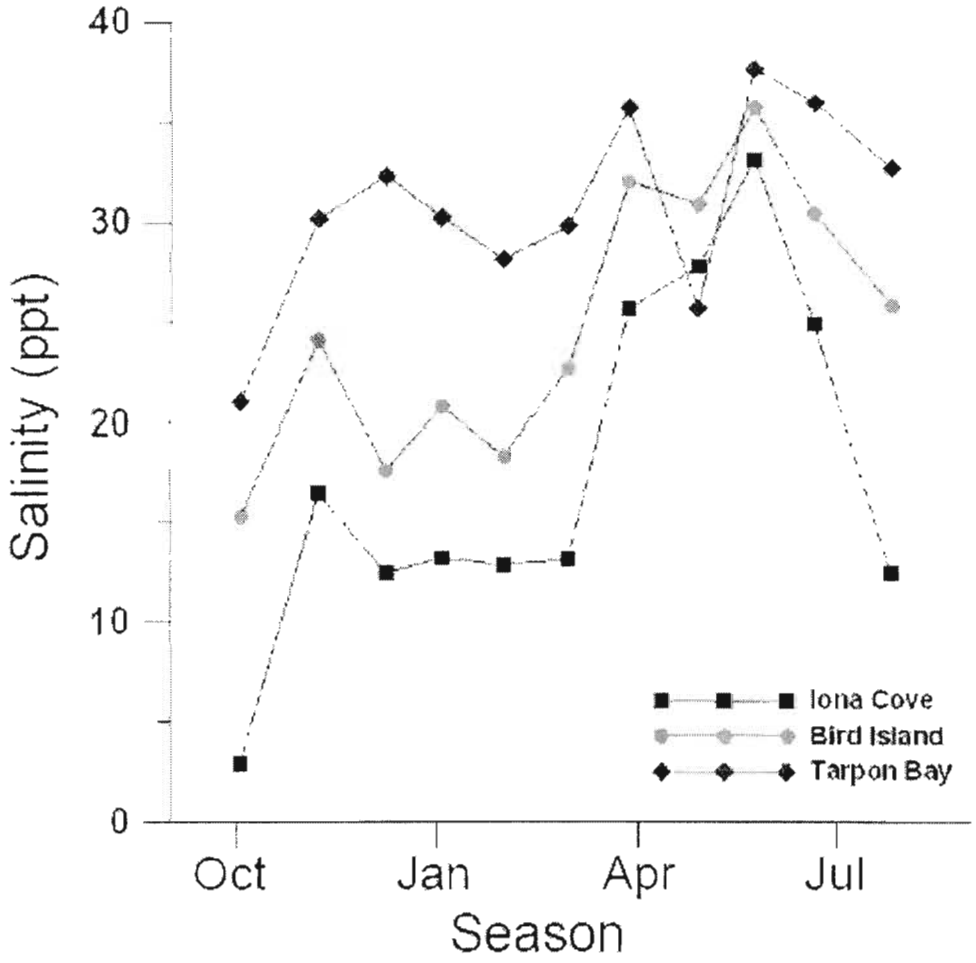

Figure 15. Seasonal patterns in salinity (ppt) monitored at each station in the Caloosahatchee River and Estuary

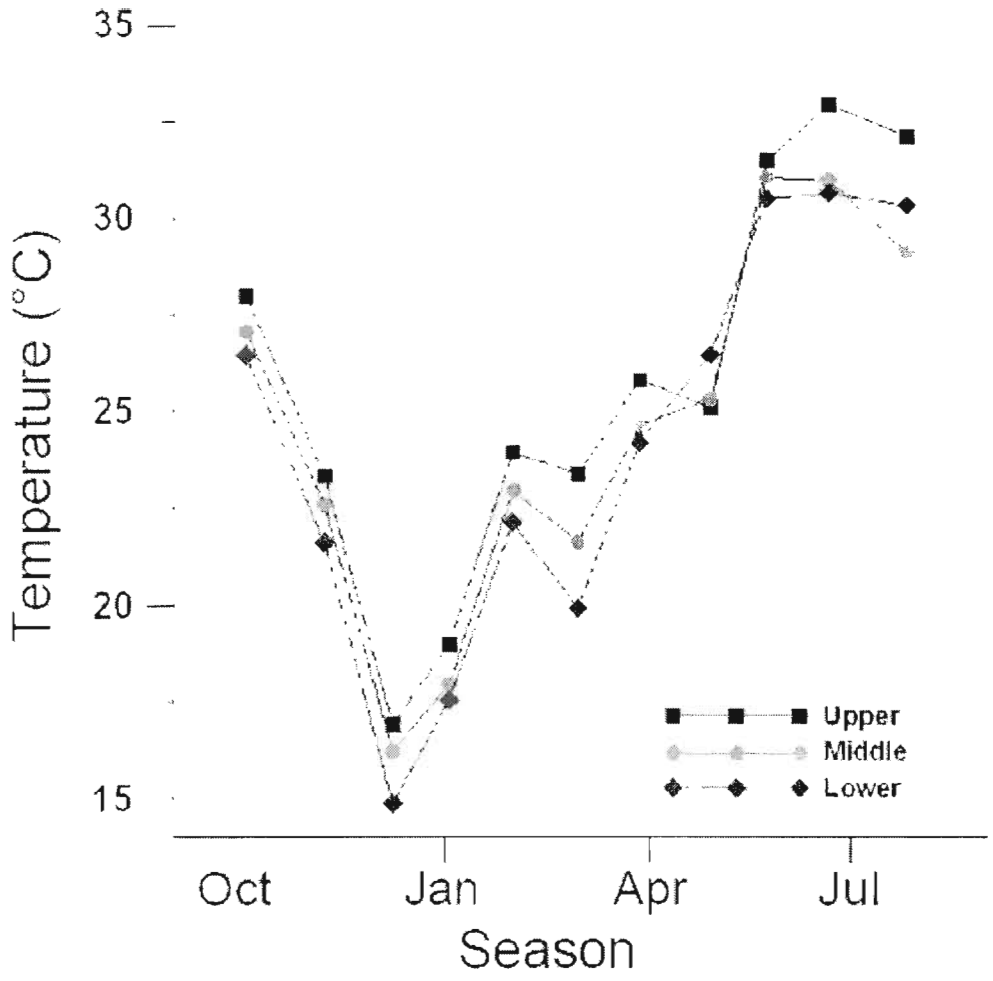

Figure 16. Seasonal patterns in temperature (°C) monitored at each station in the Caloosahatchee River and Estuary