Final Report

DEVELOPMENT OF HABITAT SUITABILITY MODELS FOR BISCAYNE BAY AREA FISHES: ASSESSING SALINITY AFFINITY FROM ABUNDANCE DATA

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Final Report

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EXECUTIVE SUMMARY

The central objective of this project was to examine for patterns of fish abundance across salinity gradients, from which researchers and managers can draw inferences about the salinity-affinities of individual taxa inhabiting Biscayne Bay. Major project elements included: conducting a literature review; acquiring and preparing datasets for analysis; performing habitat suitability index model fitting and community analyses; and interpreting and integrating analytical results. The literature review focused on determining the range of salinities inhabited by 12 fish species and one invertebrate. Data analyses were conducted in an unconventional way, primarily due to the general tendency for taxon-specific fish abundance data to be zero-inflated. Specifically, we adopted the delta approach to generate a triad of habitat suitability index (HSI) models per species, sampling technique, and habitat combination. The approach allowed for the testing of three HSI models per combination because three "abundance metrics" are considered: frequency of occurrence, concentration (density when present, exclusive of zeros) and "delta-density" (occurrence x concentration). In the present project, we fit 150 HSI models for 13 fish and invertebrate taxa (i.e., 12 fishes and pink shrimp) and provide results in both graphic and mathematical form. This was achieved via scrutiny of 16 studies which were conducted from 1976 to the present and involved five distinct sampling techniques: visual census, trawling, seining, throw-trapping and drop-trapping. Six of the data sets were products of studies conducted in Biscayne Bay and 10 were from studies in Florida Bay.

We detected statistically-significant trends across salinity gradients in one or more abundance metrics of 12 of the 13 taxa for a total of 60 significant relationships (i.e., 60 of the 150 HSI models emerged as statistically significant). Where observations under hypersaline conditions were available, most of the statistically-significant salinity trends for individual taxa showed abundance declines beyond 36 psu. Several apparent differences in salinity relationships were found for the same taxon in Biscayne versus Florida Bay. In most cases, however, other confounding factors (i.e., size-class, gear and/or sampling time-of-day differences) accompanied these apparent inter-Bay differences. We found few significant relationships between salinity and taxonomic

richness; the strength and direction of these relationships were not consistent within or among Bays. Multivariate community-level analyses were restricted to the Biscayne Bay visual census data using cluster and canonical correlation techniques (the latter are also known as redundancy analysis). Both analyses suggested that 20 psu as a "pivot point" with respect to community composition and structure. Although data were limited, our community-level analyses showed patterns of decreased diversity and reduced assemblage structure when waters were hypersaline (i.e. > 36 psu).

To more directly evaluate the importance of salinity variability along the Biscayne Bay mainland, the shoreline was divided into 31 segments and an index of salinity variability (salinity range across years) was developed for each of the segments. The three abundance metrics of the selected species were calculated for each segment of shoreline and plotted against the salinity range index. A trend line (linear or parabolic) was assessed for each metric. In addition, digital maps of the three abundance indices were made for the seven most abundant species to identify spatial patterns of fish and salinity variability.

To conclude, in the absence of quantitative historical data, or large-scale field experiments, there are few options but to examine for fish-habitat relationships as has been conducted here. Because all these relationships are correlative, they should be used in a "decision tool", rather than a predictive capacity, when considering the setting of minimum flows or for gaining insight into the effects of implementing wetlands restoration scenarios. Further progress in HSI development requires that we examine salinity-organism relationships at increasingly realistic time/space scales. For such advances, we recommend: (1) future research examine animal correlations with the empirical or modeled "salinity histories" of sampling locations; and (2) increased emphasis on designing and implementing integrated field, laboratory and modeling activities that test the validity of the animal-salinity relationships presented here. However, until spatially-explicit salinity time series data from both empirical and model-based sources have been compiled and made fully accessible, the approach taken here will remain among the most logical and easily-communicated means of generating HSI models for our region's living resources.

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BACKGROUND

The South Florida Water Management District (SFWMD) is charged with establishing minimum flows for all surface waters and minimum levels for all aquifers and surface water courses within its jurisdiction. Minimum flows and levels are defined as threshold values below which "significant harm" can be expected to water-dependent ecosystems and their biological components. Therefore, one goal of the present project is to provide scientific support to the SFWMD in their effort to establish minimum freshwater flows for central and southern Biscayne Bay. A second project goal is to provide local and regional scientists and managers, including those at SFWMD and NOAA, with insight into the possible impacts of the Biscayne Bay Coastal Wetlands Project (BBCWP), a $300 million component of the Comprehensive Everglades Restoration Plan (USACE and SFWMD 2002). The BBCWP comprises numerous large-scale engineering projects designed to re-hydrate existing coastal wetlands that are now drained by the canal system, and to redistribute freshwater flow to the Bay across a broad front using pump stations, spreader swales, culverts, and other means. These efforts will modify the timing, location and volume of freshwater inflows to Biscayne Bay, and likely change salinity regimes, contaminant loads and nutrient dynamics, which, in turn, could have consequences on the Bay's habitats, fishes and fisheries.

Under ideal circumstances, the scientific and management communities would have reliable, prior knowledge regarding: (1) precisely when, where and by how much freshwater flows and salinity regimes will change; (2) what the relevant ecological metrics are; and (3) how they should be measured and interpreted. Unfortunately, there is a dearth of quantitative, spatially-explicit historical data on fishes in the area of interest and many uncertainties remain regarding the timing and magnitude and form that restoration will take. The present study seeks to address the shortcomings above via utilization of existing empirical datasets which include information on fish species, abundance, salinity, and other habitat measures, but that have not been examined in the context of determining habitat suitability.

With the overall objective of determining patterns of fish abundance across salinity gradients, we present habitat suitability index (HSI) models in both graphical and

mathematical form. HSI models represent correlations between salinity and abundance metrics, rather than statements of cause-and-effect. In the absence of quantitative historical data, or large-scale field experiments, there are few options but to examine for fish-habitat correlations as has been conducted here. Therefore, the relationships presented should be used in a "decision tool" rather than a predictive capacity, when considering the setting of minimum flows or for gaining insight into the effects of implementing wetlands restoration scenarios.

PROJECT ELEMENTS

This project comprises four main elements and eight associated tasks. General descriptions of the elements and associated tasks follow.

Element A: Literature Review and Synthesis

We performed a literature review and synthesis which entailed gathering previous reports and published papers relevant to freshwater flow impacts on the fishes of Biscayne Bay and/or similar coastal water bodies. A synthesis of these studies with descriptions of their respective objectives, methods, findings and potential usefulness in the context of developing HSI models is provided in tabular and narrative form.

Element B: Data Acquisition and Preparation

Data acquisition and preparation entailed communicating with individual researchers and/or agency representatives to gauge the strengths and limitations of candidate datasets in their possession; to facilitate the transfer of the appropriate datasets to this project's research team; and to address any additional concerns on the part of those that collected and have managed the data thus far. Data preparation involved placing the various datasets in a common format and performing basic data diagnostic and error-checking routines.

Element C: Data Analyses

Data analyses was conducted at both species-specific and community-levels and with an emphasis on responses to changes in salinity. The former involved applying the delta approach per Serafy et al. (2007). Patterns in these metrics along a salinity gradient were evaluated using standard regression techniques (Serafy et al. 2007). The resulting species-specific HSI models are presented both graphically and mathematically and the emerging relationships discussed in terms of their generality and precision. Community-level analysis entailed multivariate techniques to analyze matrices of species/samples abundance together with associated salinity data. Hierarchical clustering into sample (or species) groups and ordination by non-metric multidimensional scaling (MDS) was used to summarize patterns in community species composition.

Element D: Interpretation and Integration of Results

Results of the above data analyses are discussed in terms of their accuracy and precision and relation to the findings of previous studies. Finally, results are integrated via multivariate, multispecies analyses (ordination) of the species-specific salinity affinities determined in the first part of the analysis. From these results, we speculate on possible future impacts of freshwater changes on the commercial and recreational fisheries of Biscayne Bay.

TASKS

Eight tasks were specified in the statement of work associated with this project: Task 1.1 Initial Meeting; Task 1.2 Work Plan; Task 2.1 Literature Review; Task 2.2 Meeting Summary; Task 3.0 HSI Model Analysis; Task 4.1 Draft Report; Task 4.2 Presentation; and Task 4.3 Final Report. At the initial meeting (Task 1.1) the Principal Investigators met with the South Florida Water Management District (SFWMD) personnel to discuss general approaches and details of project execution. This resulted in the development of a work plan (Task 1.2), which was subsequently approved on July 3, 2007. The next set of deliverables were a literature review (Task 2.1), submitted November 13, 2007, a Meeting Summary (Progress Report, Task 2.2), submitted

December 13, 2007, and a Letter Report (Task 3.0), submitted February 27, 2008. Remaining deliverables are the Draft Final Report, Presentation, and Final Report (Tasks 4.1 – 4.3).

LITERATURE REVIEW (TASK 2.1)

General

A literature review and synthesis was conducted that was relevant to freshwater flow (salinity) impacts on a mix of economically- and ecologically-important fishes that inhabit Biscayne Bay. Fishes selected for review were those for which appropriate data were available for HSI model development. Salinity affinities were assessed for 13 species of fish/invertebrate (*Cynoscion nebulous* (spotted seatrout), *Eucinostomus sp*., *Farfantepenaeus duorarum* (pink shrimp), *Floridichthys carpio* (goldspotted killifish), *Gerres cinereus* (yellowfin mojarra), *Gobiosoma robustum* (code goby), *Haemulon parra* (blue striped grunt), *Lagodon rhomboides* (pinfish), *Lucania parva* (rainwater killifish), *Lutjanus griseus* (gray snapper), *Opsanus beta* (Gulf toadfish), *Sphyraena barracuda* (great barracuda), and *Syngnathus scovelli* (Gulf pipefish). Table 1 shows a summary of optimum salinity and salinity range for each species. Species-specific accounts follow.

Cynoscion nebulosus

The spotted seatrout is a major recreational species in Florida estuaries and throughout the southeastern United States (Johnson and Seaman 1986). It is a carnivorous fish that lives near the top of the estuarine food web and tends to spawn and live in their natal estuaries and bays where salinities range from brackish to hypersaline. It has been found to move only short distances during its lifetime (Johnson and Seaman, 1986; Johnson et al. 1999). In Florida Bay, the spatial distribution of seatrout larvae and juveniles suggest that both spawning and the early life history of spotted seatrout occur mainly in the northwestern Bay and adjacent estuaries waters (Thayer et al. 1987a; Powell et al. 1989, Rutherford et al. 1989b). Trawl collections in Biscayne Bay suggest higher densities of juveniles in northern versus southern seagrass beds (Serafy et al. 1997).

Salinity Effects

1. Spawning

The time of spotted seatrout spawning is controlled largely by a combination of temperature and salinity and occurs in spring and late summer/fall in Everglades National Park and Florida Bay (Stewart 1961, Jannke 1971, Rutherford et. al. 1982, Powell 2003). Stewart (1961) correlated spawning peaks, in Everglades National Park, with water temperatures between 28° and 30°C, and Jannke (1971) found that temperatures above 30°C reduced intensity of spring spawning. In south Florida, Tabb (1958) reported that spotted seatrout spawned when water temperatures were near 25°C but ceased when temperatures reached 8°C. He suggested that spawning usually peaked in the spring (dry season) when salinities were highest (30-35 psu).

Spawning has been reported in non-tidal portions of estuaries and lagoons (Pearson 1929; Miles 1950; Tabb 1961), near tidal passes (Stewart 1961; Tabb et al. 1962b; Roessler 1967), and outside estuaries (Pearson 1929; Jannke 1971; King 1971). This suggests a wide range of conditions in which spawning occurs. Optimal spawning salinities for an area seem to be related to the hydrographic conditions of a specific area (Holt and Holt 2002). In freshwater-dominated systems such as Louisiana and Mississippi (Saucier and Baltz 1993; Brown-Peterson and Warren 2001) optimal spawning was found to be at salinities ranging 10-18 psu. Brown-Peterson (2002) noted that in marine-dominated systems off Texas, Georgia, and Florida, spawning was not observed below 20 psu, 26 psu, and 28 psu, respectively (Brown-Peterson et al. 1988; Music and Pafford 1984; Tucker and Faulkner 1987). In a comparison of five estuarine systems in the Gulf of Mexico, Brown-Peterson et al. (2002) reported that in female spotted seatrout, populations varied by spawning season, time of peak gonadosomatic index, size at sexual maturity, mean batch fecundity, and spawning frequency. These responses were attributed to variations in ambient salinities among estuaries. Baltz et al. (2003) found that courtship drumming occurred at 7-25.8 psu, but that 81% of the observations occurred at 15-18 psu. No drumming was detected at salinities greater than 25.8 psu, although a wide range of salinities were sampled, up to 31 psu.

Studies of preflexion larvae less than 7 days old (< 3.0 mm notochord length) caught in plankton samples (McMichael and Peters, 1989; Powell et al. 1989; Holt et al. 1990) suggest that spawning occurs exclusively within the estuaries – assuming the occurrence of preflexion larvae is a proxy for spawning (Holt and Holt 2002). Extreme salinity patterns (rapid changes/or fresh water fronts) that occur in estuaries may harm newly hatched offspring when their osmoregulatory organs are poorly developed (Holt and Holt 2002).

Based catches of preflexion larvae in the western Florida Bay, Powell et al. (1989) concluded that spawning occurred primarily in intermediate to high salinities (25-35 psu). Rutherford et al. (1989b) also suggested that most spawning (during 1982-1983) was in the western part of the Bay, where salinities ranged during this period, 33-50 psu. Few larvae were caught in the eastern Bay, which led both researchers to conclude that spawning did not occur in the brackish areas of the Bay. Subsequent studies by Thayer et al. (1999) confirmed that larvae occurred primarily in the western Bay. Thayer et al. (1999) also found spotted seatrout larvae in the north central Bay, but only found young juveniles there during 1994-1995, when high rainfall eliminated the hypersaline conditions often present. In the Ten Thousand Islands, larvae were found to be more abundant where salinities were slightly higher than in nearby Fakahatchee Bay (Peebles and Tolley, 1988). Studies in Tampa Bay have indicated that spawning occurs in the lower and middle bays where salinities range from 18 to 36 psu (McMichael and Peters 1989). Bioacoustics have been used to locate spawning aggregations (Mok and Gilmore 1983; Alshuth and Gilmore 1993) in the Indian River Lagoon. Spawning was identified at salinities from 18-33 psu, but ceased when salinities dropped to 14 psu.

2. Eggs

Spotted seatrout eggs have been collected from 15-50 psu (Holt and Holt 2002). Eggs have been reported to be both demersal (Tabb 1966) and pelagic (Fable et al. 1978) depending upon salinity. Salinity can affect eggs through a variety of means: through reduced fertilization rates, reducing hatch rates, and changing buoyancy (Holliday 1969). Most studies on the effects of salinity and its effects on spotted seatrout eggs have been conducted in the laboratory, due to the difficulty of separating their eggs from other

sciaenid species (Holt and Holt 2002). Alshuth and Gilmore (1993) reported that eggs sink at salinities 0-15 and float at salinities > 20 psu. They also found that the diameter of the egg was dependent upon salinity, with bigger eggs at lower salinities. Optimum salinity for the survival of eggs and larvae has been suggested at about 28 psu based on laboratory studies (Taniguchi 1980; Killam et al. 1992). Eggs had a significantly lower hatch rate at 5 psu and all eggs died at any temperature when salinity was 45 psu (Killam et al. 1992). Gray and Colura (1988) reported that spotted seatrout eggs (Texas fish) exposed to temperatures of 20, 23, 26, 29, and 32°C died at salinities between 35 and 45 psu. They found that eggs hatched at salinities above 45 psu had a 0% hatch rate. Eggs stripped from adults collected in Texas at 32 psu did not hatch when placed in salinities of 10-20 psu but did hatch in salinities 25-40 psu (Holt and Holt 2002). Egg diameters were the same for all salinities, and eggs were negatively buoyant at < 25 psu. A critical minimum (0 psu) and a critical maximum (50 psu) has been determined corresponding to 0% embryo survival at 28° (Shephard 1986). The discrepancies between Killam et al. (1992) who studied fish in Tampa Bay and Shepherd (1986) who studied fish from Louisiana may be related to geographic differences.

Taniguchi (1980) found that when adults (fish from Laguna Madre) were acclimated to ambient salinities (33 psu), eggs could be fertilized at salinities of 5 to 60 psu, but embryos died after the 2-8-celled stages of development at 5 psu and at >50 psu. Optimum temperature and salinity based on 100% survival of yolk sac larvae was 28°C and 28.1 psu. The range of optimum conditions for hatching were suggested to be 18.6-37.5 psu depending upon temperature. The highest hatch rates for experimental incubated eggs have been reported to occur at 15-25 psu from Louisiana (Shephard 1986) and 19-38 psu from Texas at 28° C (Gray and Colura 1988).

Alshuth and Gilmore (1994) reported that laboratory spawned spotted seatrout from the Indian River Lagoon acclimated at 24-27.5 psu produced eggs that hatched in 5-45 psu and were negatively buoyant at 20 psu. Poor hatching rates occurred at salinities 0-5 psu, but an 80% survival of 24 hr larvae occurred at 10-40 psu (30° C). Temperature was also found to affect hatching success at high salinities, and 26° C was suggested by Gray et al. (1991) as the optimum temperature for hatching of eggs from Matagorda Bay, Texas fish in hypersaline conditions. They suggested that seatrout living in hypersaline

waters may spawn successfully at higher salinities, but that spawning success may be reduced when salinities exceed 40 psu.

Holt and Holt (2002) reviewed laboratory studies of different salinity tolerance levels of early egg development from adults from low and high salinity systems and acclimated to different spawning salinities and concluded that the early development of eggs is limited to salinities of the prevailing spawning condition. Tolerance increases after the formation of the embryonic axis (> 12 hrs) after which the eggs are tolerant of a broad range of salinities, but are negatively buoyant in salinities below that of spawning. The size of eggs was closely linked to the spawning salinity, but also the natal estuary. Spotted seatrout from a hypersaline lagoon could not produce buoyant eggs at low salinity, even after acclimation for 6 months at that salinity. This suggests salinity tolerance may be linked to spawning salinity. It also suggests that spotted seatrout may be adapted to the salinity of a particular estuarine system that is reflected in physiological responses of eggs and larvae to salinity (Holt and Holt 2002). Kucera et al. (2002b) reported that the response of spotted seatrout eggs and larvae to changes in salinity is dependent upon the prevailing salinity regime within the bay. The tolerance of eggs and larvae to very low salinity increased with decreasing spawning salinity. The time to 90% yolk depletion was significantly longer for low salinity bay fish kept at 20 psu, but not for high salinity bay fish at 20 psu.

3. Larvae

Spotted seatrout larvae are considered the most euryhaline of all sciaenid larvae (Killam et al. 1992). Seatrout larvae were captured in Florida Bay throughout the year except during November and December (Powell et al. 1989). The majority of larvae were captured during late spring and throughout the summer. These authors suggested that older larvae may be able to avoid collecting gear. In the high salinity Laguna Madre of Texas, larvae have been collected from 22-48 psu (Holt et al., 1990; Tolan et al., 1997; Holt and Holt 2002). Holt et al. (1990) reported that they were relatively abundant up to 45 psu.

Preflexion seatrout larvae hatched 18 hours after fertilization and ranged 1.3-1.6 mm under laboratory conditions (Fable et al. 1978). Planktonic larvae have been

collected in open waters of estuaries and occasionally in nearshore waters at salinities from 15-45 psu (Jannke 1971; Peebles and Tolley 1988; McMichael and Peters 1989; Powell et al. 1989; Rutherford et al. 1989; Holt et al. 1990; Tolan et al. 1997; Thayer et al. 1999). They have been collected in Florida from 8-40 psu (Rutherford et al. 1989a, Killam et al. 1992), and optimal salinity has been reported to range from 20-35 psu in hatchery conditions (Arnold et al. 1976; Killam et al. 1992; Patillo et al. 1997). Mean salinity of larval catches in Everglades National Park was 29.8±1.3 psu (Rutherford et al. 1989b). No difference in larval growth rates was found between two Florida estuaries that differed in mean salinity (33.1 and 29.3 psu) by Peebles and Tolley (1988). Mortality rates, however, were lower for the estuary with the greater access to seagrass meadows.

Killam et al. (1992) reported that spotted seatrout larvae tolerate brackish water or salinities lower than seawater better than hypersaline conditions. Salinity tolerance of seatrout larvae was reported to be age-linked by Banks et al. (1991). They found in laboratory studies that the maximum and minimum salinities tolerated by larvae spawned at 32 psu decreased initially from day 1 (4-40 psu) to day 3 (8-32 psu) but increased after day 3. For larvae spawned at low salinity (24 psu), the highest salinity tolerated decreased with time; it was 37 psu on day 1 and 27 psu on day 3. It was possible to acclimate larvae to lower salinity but not higher salinity. This suggests a parental or habitat influence on salinity tolerance in newly hatched larvae.

Brown-Peterson et al. (2002) suggested that salinities from 20-29 psu (which corresponds to freshwater-dominated estuaries and marine-dominated estuaries) should be optimal for spotted seatrout growth, maturation, spawning, and survival of larvae, and be the least energetically costly. Powell (2003) reported collection of spotted seatrout larvae mainly at salinities between 25 and 40 psu, although larvae were collected in salinities as low as 12 psu at the Little Madeira Bay entrance.

4. Juveniles

Spotted seatrout juveniles have been collected in waters with salinities from 0-48 psu (Gunter 1945; Wang and Raney 1971; Peterson 1986; Rutherford et al. 1989a; Killam et al. 1992). Juveniles seem to prefer mesohaline and polyhaline waters where salinities range from 8-25 psu (Peterson 1986). In Florida Bay, juvenile spotted seatrout were

caught in salinities 24-48 psu (Rutherford et al. 1989b). In the summer, when spotted seatrout are 10-15 mm SL (standard length), they are more easily collected in shallow vegetation and grassbeds in bays and lagoons (Tabb 1966; Perret et al. 1980). In winter, juveniles and adults migrate to deeper, more thermally stable waters (Tabb 1966).

However, Chester and Thayer (1990) reported that salinity was not a significant factor in the distribution of juveniles among sites throughout Florida Bay. However, Thayer et al. (1999) found the distribution of spotted seatrout expanded into the central and northeastern portions of Florida Bay in the 1990's when average salinities throughout the Bay were 4 psu lower. Baltz et al. (1998) reported that salinity was a significant variable explaining the daily growth of Louisiana juvenile spotted seatrout. Other significant explaining variables were otolith radius (fish size), prey density, and a salinity-DO interaction term.

Powell (2003) determined that Central Florida Bay is a major spawning ground for spotted seatrout. However, bioenergetic models suggest that at salinities >45 psu survival and growth of larval and juvenile spotted seatrout could be diminished (Wuenschel 2002). Furthermore, Thayer et al. (1999) reported collecting young juvenile spotted seatrout in Central Florida Bay only in 1994-1995 when high rainfall eliminated the hypersaline conditions often found there. The frequency and duration of hypersaline events were suggested be important in affecting survival and growth of young seatrout and, consequently, the abundance of this species. However, in Laguna Madre, Gunter (1967) lists spotted seatrout as a fish normally caught in hypersaline waters based on work of Simmons (1957) and notes that small seatrout are collected in salinities up to 60 psu. However, Serafy et al. (1997) reported that spotted seatrout were very intolerant of rapid changes in salinity, and there was a 100% mortality when exposed to a freshwater pulse after being acclimated to full seawater.

Johnson et al. (2002) developed multivariate GAM models for the spotted seatrout for Florida Bay and found a negative linear relationship between density and salinity.

5. Adults

Rutherford et al. (1989b) found a weak relationship (two-year lag) between rainfall records from an upland marsh north of Florida Bay (closest rain gauge) and the

spotted seatrout harvest rate. He suggested that low rainfall and resulting hypersaline conditions were detrimental to the survival of young-of-the-year, while increased rainfall and lower salinity may increase growth and survival of larvae and juveniles. Trends in age structure (strong year classes) were used to support the hypothesis. Higman (1967) reported a weak positive relationship between catches and 3-year lagged rainfall. Rutherford et al. (1989b) suggested that declines in spotted seatrout landings were due to prolonged dry periods and controlled water delivery during the 1970's. They reported that fishing effort did not appear to explain declines in Florida Bay, as harvest rates were stable over the period of record.

The salinity tolerance of adult spotted seatrout has been reported as broad. Adults are considered euryhaline and have been collected over a salinity range of 0.2 to 75 psu (Simmons 1957; Perret et al. 1971; Mercer 1984; Killam et al. 1992). In Laguna Madre, Gunter (1967) lists spotted seatrout as a fish commonly caught in hypersaline waters based on work of Simmons (1957) and Breuer (1957). Tabb (1966) suggested that abundance is greatest at moderate salinities, 15-35 psu, and that those areas with seasonally fluctuating salinities are the most productive habitats. In the Indian River system where a wide range of salinities were sampled, Johnson et al. (1999) reported that densities were negatively related to salinity with highest numbers in waters less than 20 psu. Wakeman and Wohlschlag (1977) and Wohlschlag and Wakeman (1978) reported that the salinity optimum as judged by swimming performance occurred at 20-25 psu for fish 174-438 mm. They noted that spotted seatrout were rarely collected below 10 psu or above 45 psu in south Texas waters. They suggested that optimal salinity was about 20 psu for spotted seatrout in south Texas waters. In Florida Bay, Powell et al. (2007) observed that spotted seatrout were most common in the western part of the bay, but noted that their distribution had extended into the north central part of the bay where hyperhaline conditions can occur. They noted that there was an absence of hyperhaline conditions during the period when this extension occurred.

Other factors

Thayer et al. (1987a) collected the smallest juvenile spotted seatrout in Florida Bay in June and July, and were taken associated with seagrass meadows. Larval and

juveniles were collected in similar areas: primarily in northwestern Florida Bay, in areas with mixed *Thalassia, Syringodium* and *Halodule* meadows having lush growth of *Syringodium* rather than any single monotypic seagrass habitat type (Thayer et al. 1987a). Thayer et al. (1987a) found that those taken in the channels were larger than those in basin seagrass beds suggesting changes in habitat with size. Kerchner et al. (1985) reported that in the Indian River, spotted seatrout were most frequently taken in *Halodule* (size range 10-109 mm). Johnson et al. (2005) developed multivariate GAM models from multiple data sets for the spotted seatrout collected by trawl and seine for Florida Bay and found that a positive relationship to *Halodule* and *Syringodium* and a negative relationship with depth. In the Indian River System, Johnson et al. (1999) found the most important variable predicting subadult/adult spotted seatrout density was sampling depth with greatest catches at depths less than 1.5 m.

Clarke (1970) reported that there was little relation between spotted seatrout catch rates and changes in environmental factors for Whitewater Bay fish. Differences in catches rates appear associated with habitat factors such as vegetation density, although salinity, substrate conditions, and other factors were believed important. Fraser (1997) found Biscayne Bay densities related to dissolved oxygen/temperature, lunar cycle, and freshwater flow/salinity using principal component analyses. They were rarely caught below 3.1-4 mg/liter dissolved oxygen. Rydene and Matheson (2003) found density in Little Manatee River related to seagrass cover and temperature, while peaks in abundance at Marco Island coincided with maximum salinity and water temperatures.

Eucinostomus gula

The mojarras are among the most speciose and ecologically diverse families. The silver jenny (*Eucinostomus gula*) is abundant in open water lagoons often near seagrass beds from the Carolinas to Texas (Matheson and Gilmore 1995). It is one of the most abundant mojarras in the waters of Florida (Reid 1954; Springer and Woodburn 1960; Tabb and Manning 1961; Gunter and Hall 1965; Roessler 1967). Matheson and Gilmore (1995). In Florida Bay, silver jenny was the most abundant species collected in basins (Thayer et al. 2007) and Roessler (1967) reported that it was the second most abundant species in Buttonwood Canal. It is also abundant in mangrove prop root habitat (Thayer

et al., 1987b). In Jamaica, Aiken et al. (2000) reported it as the second most abundant species in shallow nearshore areas associated with mangrove roots and mud. It is important as a bait fish or forage fish for other larger sport species.

Salinity

In a multivariate analysis, Campos (1985) found that silver jenny were negatively correlated with salinity in Biscayne Bay. GAM models for Florida Bay silver jenny suggested a flat relationship between 20 psu and 38 psu, and a sharp negative slope after 38 psu (Johnson 2002). Sogard et al. (1987) reported that in Florida Bay, highest silver jenny catches were at stations nearest to the Gulf of Mexico followed by those closest to the Atlantic and Interior sites. Fewest occurred in the northeast part of the Bay where salinities were the lowest and most variable. Florida Bay densities in 1990's were one third that for the 1980's when salinities were reduced 4 psu (Thayer et al. 1999). Schmidt (1993) found mean size in Florida Bay decreased with distance and with salinity from the opening to the Gulf of Mexico. Powell et al. (2007) reported that silver jenny in Florida Bay was found in waters mesohaline (5-19) to hyperhaline (>40) with highest densities in hyperhaline.

Faunce et al. (2004) found no difference in Biscayne Bay silver jenny densities between inland sites and barrier island mangrove sites for 3 of the 4 seasons (wet and dry) examined even though large differences in mean seasonal salinities (inland always lower) and salinity variation were evident. Although, barrier island sites had larger fish (> 60 mm) than inland sites (20-60 mm). Serafy et al. (1997) reported silver jenny were very tolerant when exposed to a freshwater pulse for 24 hours after being acclimated to full seawater.

Other factors

Charles (1975) reported that recruitment in Biscayne Bay, based on smallest fish (16 mm) caught, was in May, but catches of 18 mm fish in June-July and November suggested two spawning cohorts. However, he suggested that spring was the strongest spawning period. Powell et al. (2007) found silver jenny recruited into Florida Bay throughout the year with peak recruitment in the fall. Weinstein et al. (1977) considered

the silver jenny a permanent resident of the Marco Island ecosystem because it did not exhibit any seasonal migration into the open Gulf.

In North Florida Bay, Tabb and Manning (1961) reported that silver jenny abundance peaks from September to November. In the Buttonwood Canal, Rosessler (1967) found them present during all months with highest catches in summer and fall. Subsequent analyses of the data by Waldinger (1968) reported catches were highest in September followed by August and July in 1963 and in July, followed by August and June in 1964. In Whitewater Bay, Clarke (1970) reported juveniles less than 20 mm were taken from May to January with a peak May-July. He reported that there was evidence of seaward movement with increased size especially in the late summer and fall. Schmidt (1993) collected the species year around in Florida Bay. In seasonal sampling, Sheridan (1992) reported that they were found associated with mangroves in December and April, but none were collected in September. Larger individuals were mostly frequently caught in gill nets in March (Sogard 1989c). In Biscayne Bay, Charles (1975) found silver jenny most abundant on the flats in August and September. Spring recruitment was considered most important. Larger fish (> 70 mm) were not captured after July suggesting migration from study area or reduced efficiency of gear. No mature fish were captured based on examination of gonads. In the Indian River System, Brown-Peterson and Eames (1990) reported that *Eucinostomus spp.* did not display a marked seasonality in capture frequency. Subsequent studies suggested that *Eucinostomus spp*. was common during all seasons, with highest numbers in the fall in the first year of the study and summer and fall during the second year (Brown-Peterson et al. 1993). Stoner (1983) reported abundance was highest in October and January. Kerchner et al. (1985) also reported highest numbers in October. In fall/spring sampling, Tremain and Adams (1995) reported that they were common in both seasons with highest numbers in the fall.

Weinstein et al. (1977) reported that smaller individuals at Marco Island were prominent during late spring and early fall (October) and larger fish dominated samples in winter and early spring. Yokel (1975) hypothesized spawning in March or April based on young entering the Rookery Bay/Marco Island estuary and observed that the largest fish left in the late winter and spring possibly moving into the Gulf to spawn. Highest abundance was in the summer and early fall (June/July through September) with variable

catches in the fall and early winter and lowest levels in March and April. Sheridan (1992) found that they were associated with mangroves in Rookery Bay in December and April in seasonal sampling, but none were collected in September. In Charlotte Harbor, Fraser (1997) reported highest abundance in fall and early winter (peak abundance in December) and uncommon in late winter through the summer. In inland canals in Tampa Bay, Lindall et al. (1973) caught them from November to January (a few in March). Smaller silver jenny were reported more abundant in seagrass and larger fish were more abundant near the inlet. In Jamaica, it was found associated with areas near mangrove prop-roots and mud (Aiken et al. 2000). Sheridan (1997) also reported that highest densities in Florida Bay were in *Halodule*, followed by mud and algae habitats, and least in *Thalassia.* In the Indian River, Stoner (1983) found highest density associated with *Halodule*, followed by *Syringodium*, and lowest density in *Thalassia*, while Rydene and Matheson (2003) reported that density in Little Manatee River was highest in moderate seagrass density. In Apalachee Bay, Stoner (1983) reported that density was not correlated to seagrass biomass. In Charlotte Harbor, distribution was linked to dense algal concentrations (Wang and Raney 1971). In multivariate GAM models using multiple studies data, Johnson et al. (2002) related Florida Bay *Eucinostomus spp.* (mainly silver jenny) densities to seagrass density although no significant difference was found among seagrass type. In a multivariate analysis of Biscayne Bay silver jenny, Campos (1985) found the most important variables were water clarity, water color, turbidity (negative), shrimp density, salinity (negative), and grass blade density.

Farfantepenaeus duorarum

The pink shrimp (*Farfantepenaeus duorarum*) is found along the Atlantic coast of North America from lower Chesapeake Bay to southern Florida and throughout the Gulf of Mexico (Perez-Farfante 1969). Adult pink shrimp are exploited commercially over much of the geographic range, but the largest commercial fisheries for pink shrimp occur in South Florida on the Tortugas shelf. The multi-million dollar Tortugas shrimp fishery receives recruits from Florida Bay and other south Florida estuaries (Costello and Allen 1966; Upton et al. 1992). Locally, throughout its range, juvenile pink shrimp support significant live bait shrimp fisheries (Higman, 1952; Tabb and Kenny 1961).

Pink shrimp in south Florida spawn in marine waters near the Dry Tortugas about 150 km southwest of Florida Bay. Pink shrimp immigrate to Biscayne and Florida Bays as postlarvae and spend several months as juveniles feeding and growing before leaving the bay and recruiting to the commercial fishery (Costello and Allen 1966). Juvenile and subadult pink shrimp marked and released in Florida Bay and the Ten Thousand Islands were primarily recaptured on the Tortugas grounds, but some were caught on the northern Sanibel grounds or remained in Florida Bay for extended periods (Costello and Allen 1966; Gitschlag 1986; Iversen and Idyll 1960). Shrimp tagged in Biscayne Bay were not recovered in the Dry Tortugas. Only postlarvae and early to late juvenile pink shrimp occur in inshore waters; adults move to deeper waters to spawn.

Salinity

1. Postlarvae

Pink shrimp postlarvae were observed to be most abundant at night on the flood tide entering Coot Bay from Buttonwood Canal. Postlarvae were most abundant on the flood tide entering Florida Bay through Middle Ground and Sandy Key channels (Criales et al. 2006). Postlarvae drop to the substrate and become inactive in response to decreasing salinity. Laboratory experiments (Hughes 1969a; 1969b) suggest that the mechanism used by postlarvae to discriminate between the tides is based on changes in salinity. Pink shrimp enter inshore nursery habitats as postlarvae at about 8 mm total length (Copeland and Truitt 1966; Perez-Farfante 1969) and settle to the bottom becoming benthic at about 10 mm (Costello and Allen 1970). Postlarval immigration to Florida Bay and the Everglades estuaries occurs throughout the year with peaks of abundance generally in spring, April-May, and summer/fall, July-October, (Allen et al. 1980; Idyll and Roessler 1968; Roessler et al. 1969; Browder et al. 2002).

Postlarvae can survive in waters having a wide salinity range (12-43 psu, Tabb et al.1962a). In the laboratory at a constant temperature of 24 ^{o}C, postlarvae showed no difference in growth at salinities ranging from 2-40 psu (Zein-Eldin 1963). Teinsongrusmee (1965) observed maximum growth of postlarval pink shrimp (7.8-10.1 mm TL) at 30 ^{o}C to 35 ^{o}C under constant salinity conditions (28 psu to 32 psu). Laboratory experiments suggest that postlarvae respond to a decrease in salinity by

descending to the substrate and in an estuarine setting avoiding the ebb tide and displacement out of the nursery habitat (Hughes 1969a; 1969b).

2. Juveniles

Juvenile pink shrimp can survive in waters having a wide salinity range (0-70 psu, Tabb et al.1962a), although the optimum salinity range is narrower, but still broad, and relatively high compared with those of white and brown shrimp (Gunter 1961; Gunter et al. 1964). Hoese (1960) observed that salinity is not very important to juvenile pink shrimp if other environmental factors are ideal. Dall et al. (1990) concluded that nursery ground selection is unlikely to be related to a salinity optimum determined by osmoregulatory ability. Salinity-temperature interactions are important to penaeid shrimp (Williams 1960). In the laboratory, Browder et al. (2002) established for juvenile pink shrimp that optimal growth occurred at 30 psu. The survival response curve was broad and nearly flat between about 20 psu and 40 psu and showed a strong salinity-temperature interaction. Juvenile production and potential harvests from regions of Florida Bay were simulated using these laboratory-developed salinity-temperature relationships and observed daily temperature and salinity. These simulations predict that juvenile production and potential harvests might differ among years, seasons, and regions of Florida Bay based solely on observed salinity and temperature (Browder et al., 2002). With this exception little research on effects of hypersalinity on pink shrimp is available.

In Florida Bay and other south Florida estuaries juvenile pink shrimp are present throughout the year with peaks of abundance in late summer, fall and early winter; greatest numbers of shrimp typically occur between September and December (Robblee et al. 1991; Schmidt 1993; Idyll and Yokel 1970; Costello et al. 1986). A close relationship is evident between the abundance and timing of immigrating postlarvae and the abundance of juvenile pink shrimp in Florida Bay (Allen et al. 1980; Criales, Browder and Robblee unpublished data). Costello and Allen (1966) state that juvenile pink shrimp spend 2-6 months in Florida Bay and other shallow nursery areas before emigrating to the Tortugas grounds. Kutkuhn (1966) estimated that juveniles spend 10 to 11 weeks on the nursery ground before recruitment to the offshore fishery. Estimates of pink shrimp size at emigration vary from 78.4 mm TL (Nichols 1982) to 100 mm TL (Joyce 1965; Kutkuhn 1966). In a long-term study of pink shrimp in Florida Bay, size frequency

distributions suggest shrimp are leaving the Johnson Key Basin nursery ground when as small as 10 mm and 17 mm carapace length (CL) (≈84 mm TL) (Robblee et al. 1991; Robblee unpublished data). Only 1.4% of shrimp captured in routine throw-trap collections exceeded 17 mm CL. Laboratory experiments suggest that juvenile pink shrimp, which are positively rheotactic, will switch and swim downstream in response to decreasing salinity and, in an estuarine setting, ensure that they will exit the estuary (Hughes 1969a; 1969b).

Juvenile pink shrimp have occurred in salinities ranging between 0 psu and 70 psu in Florida Bay and other south Florida waters with highest abundance from 25 psu to 40 psu and in temperatures from 11 ^{o}C to 40 ^{o}C (Tabb et al. 1962a; Tabb et al. 1962b; Costello et al. 1986; Robblee et al. 1991; Robblee unpublished data). Young shrimp tolerate low salinities (Burkenhead 1939) but not for long periods of time (Joyce 1965). Hildebrand (1955) summarizing available data at the time concluded that juvenile pink shrimp prefer salinities above 20 psu. Large shrimp (28-32 mm CL) may exhibit a preference for higher salinities, 25 to 45 psu (Tabb et al. 1962a). Costello et al. (1986) suggested that maximum recruitment and survival, but not necessarily optimum osmoregulation, occurred within the ranges of highest abundance in Florida Bay and adjacent waters. They reported highest juvenile densities at salinities from 33 psu to 41 psu in Florida Bay. Tabb, as cited in Costello and Allen (1970), reported highest juvenile densities in Florida Bay in salinities ranging from 30 psu to 50 psu. In Johnson Key Basin, western Florida Bay, where a 16 year record of juvenile pink shrimp annual peak abundance exists, lowest peak annual shrimp abundance has occurred in 2 of 3 years when Basin salinities were above 40 psu (Robblee et al. 1991; Robblee unpublished data).

The effects of temperature and salinity on pink shrimp should be evaluated together. At low temperatures, all shrimp have difficulty adjusting to changes in salinity; survival rates are higher at moderate to high salinities under conditions of low water temperatures (Williams 1960). In the laboratory Browder et al. (2002) found a significant relationship of juvenile pink shrimp growth to salinity with the salinity optimum at 30 psu. Survival was low at high (>45 psu) and low (<15 psu) salinities,

especially at low temperatures. Conditioning did not improve survival at low salinities. Survival showed a strong salinity-temperature interaction.

Juveniles were reported to leave Florida Bay on the ebb tide (Beardsley 1970; Tabb et al. 1962, Yokel et al. 1969, Roessler and Rehrer 1971). Laboratory experiments (Hughes 1969a; 1969b) suggest that the mechanism used by juveniles to discriminate between the tides is based on changes in salinity.

3. Adults

Pink shrimp production in the Tortugas fishery is likely linked to survival and growth of juveniles in Biscayne Bay and adjacent estuarine waters. Browder (1985) observed a relationship between landings of pink shrimp on the Tortugas grounds and freshwater conditions in Everglades National Park as indexed by water levels in Everglades National Park; high water levels during October-December and January-March were associated with subsequent high pink shrimp catches in January-March and April-June, respectively. Sheridan (1996) forecasted landings in the Tortugas fishery within $\pm$ 20% for five of eight years using models that included indices of fishing activity as well as variables characterizing hydrologic conditions upstream from Florida Bay and the Everglades estuaries, ground water levels, rainfall and surface water inflow to the Park. The apparent dependence of tide-associated pink shrimp movements on changes in salinity provides one explanation for the positive correlations that have been found between freshwater conditions upstream of nursery habitats and commercial harvest (Hughes 1969a; 1969b).

A few pink shrimp remain in south Florida estuaries after they become adults, but most move offshore (Iversen and Idyll 1960; Costello and Allen 1966). The size of shrimp on the Tortugas grounds increases with depth (Iversen and Jones 1960) and greatest concentrations are between 9 and 45 m (Kutkuhn 1966). Temperature rather than salinity appears to be the major factor influencing the distribution of adults or controlling spawning activity on the Tortugas grounds (Roessler et al. 1969). Adults have been found on the Tortugas grounds where salinities range from about 36 psu to 38 psu (Iversen and Idyll 1960).

Floridichthys carpio

The goldspotted killifish (*Floridichthys carpio*) is a small common fish of estuaries and bays. Sheridan (1992) reported that the goldspotted killifish was the most important fish in Rookery Bay mangroves. It is an annual fish, with sexual maturity attained during the first year of life (Powell et al. 2007). They are benthic spawners , laying eggs one at a time which are attached to the substrate. Multiple spawning occurs in this species (Nordlie 2000).

Salinity

Goldspotted killfish have been reported to tolerate salinities from 0.5-90 psu (Simpson and Gunter 1956). Based on osmoregulatory patterns, Nordlie and Haney (1998) reported that the most consistent osmotic regulation occurred at salinities of 25-70 psu and that it had limited freshwater tolerance. Lorenz (1999) found that goldspotted killifish were highest at high salinity/intermediate variability sites and 19% lower in the northern part of Florida Bay which had lower salinities. However, lowest densities were in areas with intermediate salinity variation (intermediate and high salinity). Sogard et al. (1987) reported goldspotted killifish most abundant in the north central area of Florida Bay which has relatively high salinities and often hypersalinities, but found no significant relationship with salinity. Robbins (2005) found no evidence that the rate of salinity change and the direction of change affected mortality in experiments. He slowly introduced goldspotted killifish which had been acclimated at full seawater to salinities of 0 psu (fresh water) and 56 psu over a 7-day period, then acclimated for 7-days at the high and low salinities. Although, mortality was greater in the high to low treatment than the low to high treatment, the treatments were not significantly different from each other or the zero mortality of the control. These fish were then instantaneously exposed to salinities of 56 psu and 0 psu, respectively. Mortality only occurred in the low to high salinity treatment, but this was not significantly different than the zero mortality of the high to low treatment or the control. Ley et al. (1994) found that goldspotted killifish ingested low quality food (algae) in areas where salinity was highly variable, whereas in areas with less variability, high quality food (benthic invertebrates) was ingested. However, using multiple data sets for Florida Bay, Johnson et al. (2002) developed GAM

models predicted goldspotted killifish densities were significantly higher at lower salinities (20 psu) than salinities in the 22-38 psu range when adjusting for multiple variables. There was a negative response from lowest salinity to 34 psu then a positive trend from 35-46 psu, then a negative response at yet higher salinities.

Other Environmental Factors

Sogard et al. (1987) reported that goldspotted killifish was most common on top of the banks and had a strong negative relationship with depth and seagrass litter. Johnson et al. (2002) investigated factors affecting Florida Bay goldspotted killifish using GAM models pooled across three gears. The models predicted that gear, month, temperature, seagrass type, seagrass density, depth, salinity, sea level, wind forcing, rainfall, and freshwater flow were important factors. Standardized densities when adjusted for other variables predicted that throw-trap values were greater than seine values which were greater than trawl values. Predicted densities were significantly higher in *Halodule* than mixed seagrasses, but there were no significant differences between mixed seagrasses, *Thalassia* or samples without seagrass. Significantly higher densities were correlated with increased rainfall but negatively correlated with 2-month lagged freshwater flow. Densities were positively correlated with sea levels. Predicted densities were highest at moderate seagrass densities. All seagrass densities had higher predicted densities than sparse seagrass. Sheridan et al. (1997) reported that mean densities of goldspotted killifish were lower in *Thalassia* than other vegetation types. Thayer et al. (1987b) reported that in Florida Bay and adjacent estuarine waters this species prefers the mangrove root habitat rather than adjacent seagrass beds. Nordlie (2006) has studied physicochemical tolerances in cyprinodont fishes for several decades, and reported that goldspotted killifish was the only species that was highly sensitive to hypoxia and showed stress at DO levels of 6-8 mg/kg.

Gerres cinereus

The yellowfin mojarra (*Gerres cinereus*) is an important mangrove and coral reef species in the subtropical of Florida and tropical waters of the Caribbean. Juveniles are common in mangrove creeks and adults are seen frequently in sandy areas and near coral reefs (Matheson and Gilmore 1995). In Florida, it is only common in southeastern Florida and the Florida Keys (Matheson and Gilmore 1995). It was not listed among the top 30 most numerous species in Florida Bay trawls (Thayer et al. 1999) nor in collections by Tabb and Roessler (1987). It was not taken in Biscayne Bay trawls (Serafy et al. 1997), but Serafy et al. (2003 and 2007) found that it is one of the common fishes in the mangroves of Biscayne Bay. Densities have been found to be higher at the inland mangrove sites of Biscayne Bay than in the mangroves of the keys in the wet season and no consistent pattern has been found between sites during the dry seasons when salinities were more similar. Modal sizes were similar for the two shorelines, and there were equal proportions of mature and immature life stages. Eggleston et al. (2004) found increases in the size-frequency of yellowfin mojarra, from backreef habitats such as seagrass and mangroves, to channels and eventually patch and offshore reefs which were suggestive of ontogenetic patterns of habitat use around the Key West National Wildlife Refuge.

Gobiosoma robustum

The code goby (*Gobiosoma robustum*) is a benthic resident of bays and estuaries. It is a small annual fish that spawns year around with peak spawning in May, and sexual maturity is achieved within a few month old (Patillo et al. 1997). The eggs are usually attached to the underside of sponges and shells, and the male guards the eggs (Breder 1942). Larvae are pelagic and adults are benthic (Schofield 2003a). There is little information on the larval stages of this species (Patillo et al. 1997).

Salinity

Patillo et al. (1997) suggested based on a review of the literature that although adult code goby have been found from 2-38 psu, this species seems to prefer intermediate to moderate salinities (22-32 psu). Schofield (2003b) reported collection salinities from 1-37.6 psu based on Florida Museum of Natural History Collections (University of

Florida), and Tagatz (1967) collected code goby at salinities as low as 0 psu in the St. Johns River. In Florida Bay, highest densities have been reported in areas closest to the Gulf of Mexico and Atlantic Ocean where salinities are in the range 27-44 psu (Sogard et al. 1989b, Schofield 2003b). However, experiments found that growth was higher at 5 psu than at 35 psu even though greater abundance was found in habitats with stable, high salinities (Schofield 2004). In experiments where fish were transferred from 30 psu to 0, 10, 15, 30, 50, and 60 psu, survival was significantly lower at extreme salinities (0, 55, 60 psu) than the control (Schofield 2003b). No mortality occurred at 10-30 psu, but mortality was more than 80% at 0 psu, 50% at 60 psu, 20% at 55 psu, and 5% at 4 psu. Lorenz and Serafy (2006) classified the code goby as oligohaline in a study of northeastern Florida Bay, but this was based on a sample size of 6 fish, but they pointed out that it is generally reported to be polyhaline.

Johnson et al. (2002) modeled the code goby using GAM techniques (Florida Bay data) for a variety of environmental factors and found that when densities were standardized by other variables, there was not a significant difference in code goby density at salinities between 20 and 40 psu. However, densities at 42-46 psu were significantly higher than those at 20 psu. There was a parabolic relationship with rainfall and a with the previous month's freshwater flow. Lorenz (1999) sampled lower-salinity mangrove areas of Florida Bay and found code goby absent in areas with intermediate and high salinity variability and rare at the site of lowest salinity variation .

Other Environmental Factors

Schofield (2003a) found that it was more abundant in seagrass than bare mud habitats, while Sheridan et al. (1997) reported that abundance of code goby was never related to plant type. Patillo et al (1997) review of the literature suggests that code goby is found in a variety of shallow water habitats, especially *Thalassia* beds, but is uncommon in deep habitats. Kulczycki et al. (1981) found a significant relationship between abundance and drift algae biomass. Stoner (1983) reported that the code goby was only abundant in *Syringodium* in the Indian River system. In the laboratory, Schofield (2003a) found that code goby preferred artificial seagrass over sand but in the presence of a predator (toadfish) selected sand.

Johnson et al. (2002) developed GAM models for the code goby in Florida Bay using multiple data sets. The code goby model suggested that gear, month, seagrass type, salinity, seagrass density, depth, habitat, tidal amplitude, wind, rainfall, and freshwater flow were important factors in predicting abundance. Compared to banks, densities were significantly higher at basin/channel and mainland shoreline habitats and lower at island habitats. There was a negative relationship with depth, with highest predicted abundance at depths less than 0.5 m. Highest densities were associated with sparse seagrass coverage, although this was not significantly different than dense or moderately dense seagrass sites. Density was lowest in *Syringodium* which was significantly lower than mixed or *Thalassia* vegetation. However, there was no significant difference in densities between *Halodule* or unvegetated sites and mixed/*Thalassia* seagrass. Predicted densities were significantly greater in throw-trap than other gears. Densities were significantly higher in late winter and spring and lowest in the late fall and early winter (November-January). The modeled data suggested that they prefer shallow open areas, vegetated or unvegetated. There was a positive relationship with code goby density and tidal amplitude. Density was also highest during periods of low wind forcing.

Haemulon sciurus

The blue striped grunt (*Haemulon sciurus*) is commonly found in mangrove, seagrass, and coral reef habitats through south Florida estuaries and the Caribbean. Juveniles and small adults have been found to inhabit both estuarine and non-estuarine mangroves (Faunce and Serafy 2007, Nagelkerken and van der Velde 2002). In the Caribbean, they spawn from November to April with peak spawning in January-February (Powell et al. 2007). Females mature at 220 mm FL (Gaut and Munro 1983). Powell et al. (2007) found all juvenile stages present in Florida Bay with recruitment occurring throughout the year. Adults and sexually mature females were rare or absent.

Salinity

Only three studies were found that related blue striped grunt and salinity. It was not a commonly collected species in those studies that sampled across salinity gradients.

In Biscayne Bay, Campos (1985) found a negative relationship between density and salinity. However, in a salinity challenge experiment, Serafy et al. (1997) found blue striped grunt from Biscayne Bay to be highly tolerant when exposed to freshwater for 24 hours after being acclimated to full seawater. Faunce and Serafy (2007) reported that no blue striped grunts were found in mainland shoreline during the dry season, but subadults and mature blue striped grunts were found there during the wet season when salinities are lower and more variable. However, densities along the mainland shoreline was less than in the higher salinity mangroves of the barrier islands. Powell et al. (2007) reported that blue striped grunt was found in waters polyhaline (19-29 psu) to hyperhaline (>40 psu). Densities were similar over the salinity groupings.

Other Factors

In a multivariate analysis of Biscayne Bay, Campos (1985) found that the most important variables in predicting blue striped grunt density was seagrass blade density, temperature, and salinity. Faunce and Serafy (2007) reported that juveniles recruitment to seagrass beds in Biscayne Bay occurs in February where they spend their first year of life, then expand into mangrove habitats at 10-12 cm TL as subadults and mature fish. Depth and distance from an inlet were the best predictors of abundance. Serafy et al. (2003) observed blue striped grunts in coral reef habitats offshore of Biscayne Bay barrier islands, and Springer and McErlean (1962) found them common in grassy shore habitat on the Atlantic side of the Florida Keys. Ley and McIvor (2001) found blue striped grunts in Florida Bay related to mangrove tree height and water depth, and Cocheret de la Moriniere et al. (2004) and Verwej et al. (2006) reported that abundances increased as a function of habitat complexity and shading. Powell et al. (2007) reported that bluestriped grunt was uncommon in otter trawl collections in basin habitats.

Lagodon rhomboides

The pinfish (*Lagodon rhomboides*) is a common inhabitant of seagrass meadows and marginal tidal wetlands (Gilmore 1995). Pinfish are commonly caught in recreational fishing and are a bycatch of some commercial fisheries (e.g., bait shrimp, hook and line, cast net), although due to its small size is rarely targeted. Ecologically, it

is important, because it is so abundant that they are believed to alter the composition of estuarine epifaunal communities (Orth and Heck 1980; Coen et al. 1980; Stoner 1980; Stoner 1982, Muncy 1984). It is typically non-schooling but has been reported to sometimes form aggregations. Juveniles are voracious predators on amphipods, but also feed on plants and detritus. Other reported food items include fish eggs, insect larvae, decapod crabs, bivalve mollusks, and polychaetes. Pinfish greater than 110 mm are mostly herbivorous (Darnell, 1958; Carr and Adams 1973; Stoner 1980). Pinfish are an important prey species of spotted seatrout, ladyfish (*Elops saurus*), red drum (*Sciaenops oscellatus*), Gulf flounder (*Paralichthys albigutta*), southern flounder (*Paralichthys lethostigma*), and bottlenose dolphin (*Tursiops truncatus*) (Pattillo et al. 1996).

Spawning is thought to take place in the fall and winter (Sabins and Truesdale 1974, Darcy 1985, Ditty 1986). Eggs are marine and neritic. The distribution of larvae suggests offshore spawning. Larval pinfish occur in the Gulf of Mexico from October through April with peak abundance in December through February. Larvae move into estuaries at 10-20 mm TL (Tabb and Manning 1961; Darcy 1985). Larval development is complete by 13 mm SL (Zieske 1989). Juveniles move up the estuary during spring and summer, while growing from 15 mm TL (12 mm SL) to 100 mm TL. Sexual maturity occurs between 80 mm and 100 mm TL (Schmidt 1993).

Salinity

In general, pinfish are euryhaline, and without regard to life stage tolerate salinities from 0-45% (Roessler 1970, Pineda 1975). Larvae are marine and estuarine, and juveniles and adults are marine, estuarine and riverine (Patillo et al. 1997). There may be ontogenetic changes in salinity preference, with juveniles at lower salinities than adults, which may prefer euhaline conditions.

Heavy rains reducing salinities to 4 psu have been reported to decrease the abundance of pinfish in a seagrass bed (Cameron 1969). A study by Subrahmanyam and Coultas (1980) positively correlated pinfish abundance with salinity in northern Florida salt marshes. Colby et al. (1985) classified pinfish as a species inhabiting intermediate

to high salinities in Faka Union Bay and eight collateral bays. Zimmerman et al. (1990) sampled fishes along a salinity gradient in Galveston Bay and found highest numbers of pinfish in mesohaline and polyhaline sites. Nelson (1998) compared densities of young-of the-year pinfish from three Florida estuaries and found that salinity was only a factor at Charlotte Harbor. Fraser (1997) classified pinfish as a species preferring higher salinities (24-32 psu) in Charlotte Harbor, while Gelwick et al. (2001) classified pinfish as an upper brackish water inhabitant (10-20 psu) in Matagorda Bay, Texas. Wang and Raney (1971) reported that adult pinfish prefer higher salinity waters in the Gulf and stay mainly in the Gulf or close to passes.

Carrier and Evans (1976) found that tolerance of freshwater survival was dependent on the quantity of environmental calcium in the water. They found that the presence of high calcium levels in fresh water reduces epithelial permeability to sodium. Shervette et al. (2007) found that juvenile growth in the laboratory (36-80 mm TL) was significantly higher at 15 psu than 0 psu and at 30 psu than 60 psu in Texas, suggesting that the 15-30 psu range may be optimum. Serafy et al. (1997) found a 12.5% mortality when pinfish were exposed to a freshwater pulse after being acclimated to full seawater. Kloth and Wohlschlag (1972) found that a salinity range of 20-45 psu did not significantly affect the respiratory metabolism of large or small pinfish in unpolluted water. However, sustained swimming velocities (maximum performance) were found at 20 psu, for both large and small pinfish, and the velocities decreased as salinity increased. Sustained swimming velocities of large pinfish decreased more than those of small pinfish in polluted waters and salinity only significantly affected larger pinfish. Johnson et al. (2002) standardized catches of pinfish against an array of environmental factors for Florida Bay and found a parabolic relationship between pinfish densities and salinity with optimum density at 32 psu. No significant difference was found between low and high salinities.

Other Environmental Factors

Salinity effects may be secondary. Vegetation rather than salinity is thought to have a greater affect on pinfish distribution (Weinstein 1979, Stoner 1982, Jordan 1996). Campos (1985) found using a multivariate analysis of Biscayne Bay pinfish that seagrass

blade density, depth, shrimp density, temperature, and then salinity were the most important variables predicting pinfish density. In Florida Bay, pinfish were found associated with *Thalassia* (Thayer and Chester 1989). Powell et al. (2007) reported that densities were low following a seagrass die-off. Johnson et al. (2002) developed a multivariate GAM model for the pinfish in Florida Bay and found that temperature, seagrass type, seagrass density, depth, tidal amplitude, rainfall, and freshwater flow were also important factors in predicting abundance of this species. There was a parabolic relationship with predicted densities and temperature optimum density at 32° C. Pinfish densities were positively correlated with seagrass density, and were higher in *Syringodium* than other grass types. Pinfish densities were significantly higher for depths under 0.5 m and depths greater or equal to 1 m. Densities were positively correlated with tidal amplitude. Nelson (1998) reported that young-of-the-year pinfish were caught in waters less that 5 m and associated with seagrass in Choctawhatchee Bay, Tampa Bay, and Charlotte Harbor. Higher abundance of pinfish was found in Choctawhatchee Bay and was attributed to higher densities of *Halodule* and patchy vegetation in contrast to continuous seagrass beds in the other two systems. Stoner (1982, 1983) found that pinfish predation on amphipods was highest in *Halodule*, least in *Syringodium*, and *Thalassia* was intermediate. Nelson (1998) suggested that seagrass patchiness may be preferred as it offers protection from predators while providing close access to alternative feeding areas. One study found that vegetation density was negatively related to the growth rate of juvenile pinfish (Spitzer et. al. 2000), and suggested that dense seagrass made it more difficult to find food.

Lucania parva

The rainwater killifish (*Lucania parva*) is the smallest fish found in saltmarshes and estuaries along the Atlantic and Gulf coasts of the United States. It is ecologically important prey item for larger fishes. Crawford and Balon (1994b) consider it a small r-selected species that produces many low quality eggs (little yolk investment) and reported it to spawn year around and matures as small as 23 mm (<2 months). They also note that phenotypic variation is greater for L. parva compared to its freshwater relative, *Lucania goodei* a characteristic that is associated with colonizing and early successional species,

and while these phenotypes are less competitive under stable environmental regimes, they are very successful in harsh environments with few other species. Rainwater killifish deposit their eggs on submerged vegetation, and larvae tend to remain in the vegetated habitat in which they are spawned (Foster 1967).

Salinity

Rainwater killifish has been reported to occur in freshwater to full seawater, but is common in brackish water (Hildebrand and Schroeder 1928; Crawford and Balon 1994a). Crawford and Balon (1994b) suggested that the ability of rainwater killifish to successfully invade certain freshwater rivers in Florida may be related to the chemical composition of the water in those rivers, especially in springs which are high in calcium salts. Lorenz (1999) found that rainwater killifish in northern Florida Bay were highest at sites with low salinity but low variability, while Jordan (2002) reported that the abundance of rainwater killifish increased with salinity as long as vegetated habitat was available. Lorenz and Serafy (2006) classified rainwater killifish as an oligohaline fish. but noted that other studies report high abundances in mesohaline and polyhaline waters. Dunson and Travis (1991) reported that the rainwater killifish was tolerant of a wide range of salinity from freshwater to 80 psu, but that its relative competitive ability was related to salinity along a gradient, and was replaced by freshwater species even when vegetation was present. Nordlie and Haney (1998) based on osmotic regulatory patterns classified rainwater killifish as a species with extensive populations frequenting both freshwater and brackish waters but not marine. Most of their work was based on fishes that inhabited north Florida salt marshes and estuaries. However in Florida Bay, Sogard (1987) reported that rainwater killifish was most abundant in the north central part of the bay (an area subject to annual hypersaline conditions).

Laboratory experiments by Dunson et al. (1993) suggested that the growth of rainwater killifish was not affected by salinities within the range 3.5-35 psu. Serafy et al. (1997a) however classified this species as intolerant of salinity variation in Biscayne Bay when they observed mean abundances higher at stable salinity sites and found a 50% mortality rate when subjected to a 2-hour rapid pulse event where the salinity changed from 33 to 0 psu. What this seems to indicate, is that the rainwater killifish, while

intolerant of freshwater or rapid freshwater pulses, probably still has the ability to tolerate a wide range of salinities if it has time to adapt to them and is able to colonize areas that have been subject to these extremes (both high and low), where potential competitors and predators are excluded. While able to tolerate full seawater, it loses its competitive advantage and may even, because of its small size, be subject to higher rates of predation. Fuller et al. (2007) raised rainwater killifish at 0 and 8 psu, and found that survival and adult body size increased with salinity, while Dunson and Travis (1991) reported that rainwater killifish grew faster at 0 psu than in 15 psu. Powell et al. (2007) reported that rainwater killifish in Florida Bay was found in waters mesohaline (5-18) to hyperhaline (>40) with highest densities in mesohaline.

Johnson et al. (2005) developed a multivariate GAM model for rainwater killifish caught in Florida Bay and found that salinity was one of the most important predictors of abundance. Predicted density when adjusted for other factors tended to be flat at salinities of 10-35 psu, but increased from 35-50 psu. Perhaps these differing patterns of abundance in different estuaries are reflective of its phenotypic diversity and short lifespan that allows it to survive and quickly adapt to a variety of salinity regimes (Crawford and Balon 1994b).

Other Environmental Factors

Numerous researchers have observed that rainwater killifish are associated with vegetation (Duggins 1980, Sogard et al. 1987, Harrington and Harrington, 1961, Tremain and Adams 1995), although Sogard noted a lack of association between abundance and seagrass structural complexity. Jordan (2002) found based on field and laboratory experiments that rainwater killifish use vegetation to reduce their risk of predation, and found that sites supported few when vegetation beds were poorly developed.

Depth, *Syringodium* standing crop, and salinity were found to be the most important predictors of abundance in Johnson et al. (2005) multivariate model for Florida Bay rainwater killifish. Serafy et. al. (1997a) also found highest densities of rainwater killifish associated with *Syringodium* vegetation in Biscayne Bay. However, Sheridan et al. (1997) reported that mean densities of rainwater killifish in Florida Bay were nearly always higher in *Thalassia* than *Halodule*. Sogard (1987) reported that rainwater killifish

was correlated with seagrass litter, vegetation height and standing crop. Tolan et al. (1997) noticed the average biomass of fishes were lower in *Syringodium* than other seagrasses, and suggested that the average size of fishes were smaller.

Lutjanus griseus

The gray snapper is common in south Florida estuaries and supports an important sport fishery (Rutherford et al. 1989b). Gray snapper is the most common snapper in the waters of Biscayne Bay and is collected in all areas of Everglades National Park from the fresh water of river tributaries to Whitewater Bay and the Shark River estuary to the highest salinities of Florida Bay (Tabb and Manning 1961).

There is no evidence of spawning within south Florida bays. No larvae were taken in plankton sampling in Florida Bay in 1982-83 (Rutherford et al. 1989b). The presence of large juvenile gray snapper in July and August in northwestern Florida Bay (Hettler 1989, Starck 1970) but the absence of larvae and small juveniles suggests that gray snapper in northwestern Florida Bay may be recruited from adults spawning in June-July over reef areas south and east of northwestern Florida Bay (Powell et al. 1989). Thayer et al. (1987) reported catching juveniles during 1984-1985 in every sampling trip with largest numbers in September, March, and May suggesting that spawning may occur in late spring and extend into the fall. Rutherford et al. (1989b) suggested that reefs off the middle and lower Florida Keys probably supply much of the recruitment.

Salinity

1. Spawning/Eggs/Larvae

Eggs and larvae are pelagic (Thayer et al. 2007). Gray snappers enter estuaries as advanced larvae, thus this life stage is not affected by salinities in estuarine systems. McIvor et al. (1994) stated that enhanced recruitment occurs in years of higher salinity in Florida Bay. The presence of postflexion larvae and juveniles at near-inlet stations indicated that snappers enter Florida Bay as advanced larvae (Powell et al.1989). No larvae were caught in ENP samples, but 26 larvae were caught by NMFS (1984-1985) in southeast Florida Bay (Rutherford et al. 1983). Smallest larvae (<4.2 mm SL) were

caught at Alligator Reef (Atlantic side of the Keys), while larger larvae were caught inshore of this station. Larvae were caught June-August and September indicating a summer spawning period. Collins and Finucane (1984) caught only 8 larvae in Everglades National Park inshore waters, but found higher catches further offshore in the eastern Gulf of Mexico. Powell et al. (1989) suggests that they may not be available to the collecting gear, due to their habitat preferences (i.e. bottom, oyster bars, crevices, and channel edges).

2. Juveniles and Subadults

Rutherford et al. (1989b) reported catching juvenile gray snapper in Florida Bay at salinities 8-48 psu. Thayer et al. (1987) reported that juveniles were taken in greatest numbers in higher salinity areas in the western bay and were rare in the low salinity stratum. In the St. Lucie area, subadult gray snapper (120-170 mm) are commonly caught on hook and line in the St. Lucie estuary (Browder, unpublished data, pers. comm.) in salinity from 2-22 psu. Serafy et al. (1997a) reported gray snapper were very tolerant when exposed to a freshwater pulse for 24 hours after being acclimated to full seawater. Recent laboratory experiments by Xaymara Serrano (RSMAS, University of Miami, unpublished data) found no difference in blood osmolality in the gray snapper at salinities 5-50 psu when exposed to salinities 0-60 psu. There were significant changes at 0 psu and 60 psu. Results after 192 hours of exposure suggest gray snapper may possess an extraordinary capacity to osmoregulate in such salinity extremes. Field measurements of osmolality across the salinity gradient show a similar pattern to that observed in the laboratory. Preliminary behavioral results (n = 5) suggest that gray snapper has a salinity preference that may be in the range of 12-22 psu.

3. Adults

Starck (1964) stated that adults are less tolerant of salinity fluctuations and generally inhabit offshore waters. Higman (1967) hypothesized a weak inverse correlation between catch rates of gray snapper and annual rainfall of the previous year. He suggested that survival and growth of juveniles was favored by conditions resulting from lower rainfall. He suggested that high catch rates during periods of high rainfall, high temperature, and/or poor oxygen conditions within the upper reaches of the estuary

may be due to aggregation of gray snapper in channels and outer banks to avoid the adverse upstream conditions. Aggregation in open waters may increase their availability to fishermen. Harvests of gray snapper were reported by Rutherford et al. (1989a) to be highest during the season of highest rainfall each year, but they did not find a correlation between high rainfall years and gray snapper production. They suggested a 3-year lag between rainfall (or water levels) and catch rates. They reported that recruitment levels of 1-year-old fish were inversely correlated with water levels in Taylor Slough marshes. They suggested that, during low rainfall years and higher salinity conditions in the estuaries, sub-adult fish may tend to remain within the estuaries longer, thereby temporarily increasing densities and availability to fishermen.

Other Environmental Factors

Authors are divided on the most important habitat for gray snapper but this may be due to ontogenetic changes in habitat. Faunce and Serafy (2007) reported that juvenile gray snapper initially recruit to seagrass habitats and the mangroves of the barrier islands in the fall and winter where they spend their first year, then expand into inland mangroves at 100-120 mm TL as subadults. Higher densities were reported during the dry season in the mangroves. Average size and density was correlated with distance from inlet. In Florida Bay, Chester and Thayer (1990) suggested that gray snapper recruit mainly to channels where seagrass communities are more diverse and luxuriant than adjacent basins. Older juveniles prefer mangrove habitats to adjacent seagrass sites (Thayer et al. 1987b). Cocheret de la Moriniere et al. (2002) had similar findings in the Caribbean.

Rutherford et al. (1989b) reported that most successful gray snapper catches were in *Halodule* and *Syringodium*-dominated grassbeds, while in a cluster analysis, Thayer et al. (1987a, b) found that gray snapper grouped with fishes taken in large numbers in the northwestern part of the Bay associated with channels in areas where mixtures of S*yringodium* and *Thalassia* or *Syringodium* and *Halodule* were prevalent. These authors suggested that smaller juveniles used seagrass beds and larger juveniles were more characteristic in channels in the southeastern Bay that contained mixtures of *Thalassia* and *Halodule*. Thayer et al. also suggested that the channels may be the only suitable

habitat (as other open areas contain only sparse *Thalassia* which are less suitable) in the bay besides the mangrove prop root habitats. Serafy et al. (2003) also reported that gray snapper are found in coral reef habitats east of Biscayne Bay barrier islands, but were smaller and that the modal length was one (5 cm) size-class less than that observed along the mangrove shorelines. Ley and McIvor (2001) correlated gray snapper abundance with mangrove fringe width, height, prop root density and water depth. Thayer et al. (1999) found habitat was an important factor in Florida Bay as densities (were higher in the basin/bay habitats than in channels.

Opsanus beta

The Gulf toadfish (*Opsanus beta*) is a common benthic fish that spends most of its time near or even buried in the bottom. They attach their eggs to hard substrate and have no free-swimming larval stages (Hoese and Moore 1987). It is common component of seagrass communities in Florida and the Gulf of Mexico. It is ecologically a top predator consuming shrimp and small fishes and in turn is a common of the bottlenose dolphin (Barros 1987).

Salinity

Serafy et al. (1997b) reported Gulf toadfish were very tolerant when exposed to a freshwater pulse 24 hours after being acclimated to full seawater. They also found that abundance was higher in areas with higher salinity variation than in areas with more stable salinities. Campos (1985) found that densities were negatively related to salinity in Biscayne Bay trawls. Johnson et al. (2002) developed modeled Gulf toadfish and found that Gulf toadfish densities when standardized for other environmental variables predicted that Gulf toadfish densities had a parabolic relationship with salinity increasing over the interval 20-30 psu, peaking at 30 psu, and negatively related at higher salinities. Powell et al. (2007) reported that Gulf toadfish in Florida Bay was found in waters mesohaline (5-19 psu) to hyperhaline (>40 psu) with highest densities in hyperhaline.

Other Environmental Factors

In a multivariate analysis, Campos (1985) found that densities were (in order of importance) positively related to seagrass blade density and number of crustaceans, negatively related to salinity, and positively related to water temperature in Biscayne Bay. Johnson et al. (2002) modeled the Gulf toadfish from Florida Bay and found that the most important factors in predicting abundance were gear, month, temperature, seagrass density, habitat, tidal amplitude, sea level, wind, and freshwater flow into the Bay. Throw- trap densities were significantly greater than seine/trawl densities. Highest predicted densities were in January and December, and lowest in June and August. All months were significantly lower than January except December, March, and April. Densities showed a parabolic relationship to temperature, although there was no significant difference between temperatures 18° and those $\geq 30^{o}$. Habitat type was a significant factor, and predicted densities for basin and channel habitats were significantly higher than banks and island and mainland shorelines. no significant differences between seagrass types. Gulf toadfish densities in moderate seagrass were significantly higher than in dense seagrass while Gulf toadfish densities at moderately dense seagrass and sparser seagrass were significantly lower.

Serafy et al. (1997a) reported that *O. beta* was negatively correlated with depth. The Gulf toadfish has been reported in other studies to inhabit a variety of habitats including shallow basins and channels, mudflats, sand and under rocks or oyster bars and linked to seagrass beds (Reid 1954; Kilby 1949; Berkeley and Campos 1984; Sogard et al 1987; Serafy et al. 1997b). Serafy et al. (1997b) reported densities of Gulf toadfish in all vegetation types, with slightly higher densities in *Thalassia* than *Halodule* vegetation in Biscayne Bay, although density was also related to a north-south distribution (higher in the southern bay). Both Powell et al. (2007) and Sheridan et al. (1997) also reported mean densities of Gulf toadfish in Florida Bay were significantly higher in *Thalassia* beds than in *Halodule*. Sogard et al. (1987) reported abundance in Florida Bay (using a subset of our data) related to *Thalassia* density, but total seagrass shoot density was reported to be insignificant. Serafy et al. (1997a) reported that Gulf toadfish related to *Thalassia* biomass, while Matheson et al. (1999) reported increases in the benthic predatory Gulf toadfish when the above ground standing crop of lush seagrass seagrass meadows declined. Serafy et al. (1997a) also found changes in seasonal abundance by

sites in Biscayne Bay, and suggested that cool season increases of toadfish in shallow *Thalassia* beds may reflect a concentration of reproductive individuals in these areas (where the males create nesting sites and "sing" to attract females). They also suggested that nocturnal dissolved oxygen may be an important factor. Perhaps the dense seagrass prevents burrowing in the substrate of this species, while seasonal (winter) declines in shallow seagrass areas provide a place both where mating burrows can be dug and accessibility by predators is reduced. This species may be subject to high predation by diving birds, dolphins, and sharks (Schmidt 1986; Barros 1987; Cummings 1987). Serafy et al. (1997b) found that the distribution of Gulf toadfish in Biscayne Bay was correlated with dissolved oxygen.

Sphyraena barracuda

The great barracuda (*Spyraena barracuda*) is a common fish found in the mangroves and coral reefs. It has been reported to be a top predator foraging on fish schooling at the mangrove/seagrass interface (Nagelkerken and Velde 2002). Spawning was reported from April through October in the Miami area (DeSylva 1963), although Powell et al. (2007) suggested that spawning occurs year-around in Florida Bay based on hatch-date distribution of juveniles. Sheridan et al. (1996) suggested that barracuda enter Florida Bay at a size of about 20 mm and an age of 27 days. Males mature at 423-460 mm SL (age 2) and females mature at 533-606 mm SL (age 3-4) (DeSylva 1963). Eggs are pelagic and transform to juveniles at 12 mm SL (Ditty et al. 1999). Schmidt (1979) reported that goldspotted killifish and rainwater killifish were the most common dietary items of juvenile barracuda collected in Florida Bay seagrass beds.

Little has been published on salinity effects on great barracuda. Powell et al. (2007) reported that great barracuda in Florida Bay was found in waters mesohaline (5-19) to hyperhaline (>40) with highest densities in hyperhaline. Serafy et al. (2007) found higher densities in Biscayne Bay inland shoreline habitats during the wet season. Multiple regressions suggested that depth and temperature were important factors affecting frequency, occurrence, and delta density. However, salinity was not significant. Wet season fish were smaller than dry season suggesting that maximum recruitment occurs during this time. No north-south trend was evident in occurrence. Consistently

low concentrations suggested that individuals distance themselves from one another to reduce hunting interference and/or cannibalism.

Serafy et al (2003) reported that densities were higher in barrier island mangroves than from inland mangroves in Biscayne Bay. Modal lengths were similar in the two habitats, although barrier island mangroves tended to harbor larger barracuda. They also observed great barracuda in coral reef habitats east of Biscayne Bay barrier islands. Powell et al. (2007) reported that great barracuda were uncommon in trawl collections in Florida Bay and that were first collected in their gear at approximately 23-26 mm SL (30 days) and grew about 2 mm/day. Increases in the size-frequency of great barracuda from backreef habitats such as seagrass and mangroves, to channels and eventually patch and offshore reefs were suggestive of ontogenetic patterns of habitat use (Eggleston et al. 2004). Adult great barracuda have been characterized as typically solitary and highly territorial as adults (Gudger, 1918**;** de Sylva, 1963; Johannes, 1981). Although Starck and Davis (1966) observed groups of up to 30 barracuda congregating during both day and night in the Florida Keys and Paterson (1998**)** suggested that it was common for mature barracuda to form schools.

Syngnathus scovelli

Pipefish are extremely slender and elongated with armored bodies. The Gulf pipefish is a short-snouted seahorse-like species that grows to 175 mm. The Gulf pipefish is the most common pipefish along the Gulf of Mexico and eastern Florida (Brown-Peterson 1972). It is also the commonest pipefish in the Tampa Bay (Springer and Woodburn 1960) and Indian River (Brown-Peterson and Eames 1990) although not in Florida Bay (Matheson et al. 1999, Thayer et al. 1999). The female lays her eggs in the brood pouch of the male where the eggs are fertilized and incubated. Sheridan (1997) reported that it was most abundant from April-June in Florida Bay. In the Indian River, they were reported as being most abundant in the spring during only spring/fall sampling (Tremain and Adams 1993) and during the summer during seasonal sampling (Brown-Peterson et al. 1993). Dokken et al. (1984) reported that based on larval collections, spawning occurs in summer and fall and that no larvae were collected in the winter.

Salinity

Gulf pipefish have been reported common in freshwater to hypersaline waters up to 45 psu (Whatley 1962; Simmons 1957; Roessler 1967). An isolated freshwater population has been reported from Lake St. John, which is 150 miles inland from the Louisiana coast by Whatley (1962; 1969) and a population has also been found in the St. Johns River in northern Florida (McLane 1955). In a survey by Carter et al. (1973) of the Ten Thousand Islands/Fakhatchee Strand, they were reported in four habitats that include beaches and adjacent water, bays , tidal streams, and tidal canals, but they were not found in freshwater canals or freshwater lakes. Quast and Howe (1980) reported the brood pouch osmolality is regulated near osmolality of the father through incubation, perhaps to protect developing embryos from osmotic extremes. This allows the larvae to develop efficiently in any aquatic environment acceptable to the adults. Density was found to be negatively correlated to salinity in a multivariate analysis of Florida Bay (Johnson et al. 2002). Powell et al. (2007) reported that Gulf pipefish in Florida Bay was found in waters mesohaline (5-19) to hyperhaline (>40) with highest densities in hyperhaline.

Other Environmental Factors

The usual habitat for Gulf pipefish is shallow seagrass beds. Highest densities in the Laguna Madre (Texas), Indian River, and Florida Bay have been reported in *Syringodium* and *Halodule* (Tolan et al. 1997; Stoner 1983; Sheridan 1997). Several studies in the Indian River have found them positively associated with drift algae biomass (Snelson 1980; Kulczycki et al. 1981). A shift in habitat may occur seasonally or life stage. Tolan et al. (1997) found that densities in winter and fall were in *Syringodium* dominated/mixed seagrass beds compared to *Halodule* or unvegetated sites but in the summer, highest numbers were in *Halodule*. They are also found in *Thalassia* and are caught in mud habitats (Sheridan 1997). They were reported absent in mangrove areas of Florida Bay (Sheridan 1992; Lorenz 1999), although Ley et al. (1999) reported catching them in the northeast part of the Bay but they were not one of the dominant species of this habitat.

In the Indian River, Snodgrass (1992) reported that Gulf pipefish density was determined by (in order of importance) vegetation biomass, depth, dissolved oxygen, pH, and salinity. Rydene and Matheson (2003) reported that in the Little Manatee River, density was highest in a seagrass habitat with moderate seagrass cover followed by temperature and salinity and in a drift algae habitat by moderate algae biomass. Clark (1970) reported that abundance was higher in higher salinity areas and that the most important variables in predicting abundance were runoff, temperature, rainfall, and vegetation.

In a multivariate GAM analysis using multiple datasets, Johnson et al. (2002) found that month, temperature, seagrass type, salinity, seagrass density, and depth were the most important predictors of Gulf pipefish density. Density was highest in dense seagrass beds and there was no significant difference among seagrass types. Density was positively related to temperature.

HSI MODEL DEVELOPMENT (TASK 3.0)

The main objective of our HSI data analyses is to examine for patterns of fish abundance and/or diversity across gradients in salinity. Details of data acquisition and methodology are described below. These are followed by the results that emerged and how we interpret them.

Data Acquisition and Treatment

Researchers who have conducted or are conducting major fish studies in Biscayne Bay were contacted for permission to use their data in our meta-analyses of salinity-related faunal trends. Virtually everyone we contacted responded to our request by providing us with their raw data. Similarly, we obtained permission to use data sets from Florida Bay researchers to allow inter-bay salinity–affinity comparisons. Table 2 lists the 16 data sets that we used for this study. We were requested not to use the Florida Bay spotted seatrout data collected by the NOAA National Ocean Service group as they were in the process of publishing it. However, because we had Florida Marine Research Institute and Everglades National Park spotted seatrout trawl data for Florida Bay, this request did not interfere with our analyses on this species.

Data were screened and reviewed for data entry and recording errors and outliers. There were six data sets for Biscayne Bay and nine for Florida Bay. Biscayne Bay data covered the period 1993-2007 and three sampling techniques (visual census, trawl, and throw-trap). Florida Bay data covered the period 1974-2004 and five sampling techniques (trawl, seine, drop net, throw-trap, and visual census). In many instances, data were converted to numbers per hectare to standardize fish abundance values collected using different gears and/or techniques.

Sampling Technique Considerations

The HSI models and community analyses detailed in this report derive from data collected using a variety of fish and invertebrate sampling techniques in a variety of habitats. Sampling characteristics of these methods have a profound influence on the species and size composition of catches as well as magnitude of abundance estimates.

Therefore, all results are presented on a gear-specific basis. Pros and cons of the five gear types are outlined below. Additional sampling consideration information (habitat, time-of-day, size-bias and water depth) as it pertains to the data sets examined in the present study is detailed in Table 3.

Visual surveys are one of the few techniques that are effective for gathering fish assemblage data in rigid, complex habitats, such as coral reefs and mangroves. In addition to being non-destructive of fish and habitat, data collection by visual means is relatively rapid because all taxonomic determination and quantification of fish numbers and size structure is conducted at time of sampling, obviating sample preservation and transport for subsequent sorting, counting and measurement of specimens in the laboratory. A disadvantage of visual fish survey techniques is that sufficient visibility (e.g., 2 m) is required; thus the technique is generally ineffective at night and highly bias when turbidity levels are high, or if organisms have a propensity to hide in dense foliage. Personnel skilled in underwater species identification, enumeration and size estimation are required.

Perhaps the most-commonly used method for fish and invertebrate assemblage characterization and quantification is trawling. This method has the advantage of covering far greater areas than virtually any other sampling technique and tends to be most effective at night over soft substrates. It can be employed at most water depths, except the very shallowest. Trawling can be highly size- and species-selective, depending on such factors as bottom disturbance (amounts of noise, vibration), mesh size and towing speed. It can be destructive of both target organisms and the benthos. Trawling vessels must have sufficient size, configuration and equipment to deploy and retrieve the net(s).

Seining is also a commonly-used nekton sampling method. This technique is most appropriate for sampling shallow, soft-substrate habitats and can be conducted by individuals with minimal training. Seining shares many pf the same selectivity problems as trawling, but differs in that it is limited to sampling waters < 1.5 meters. It is one of the most cost-effective methods for sampling nekton. Throw-traps and drop-traps are active enclosure sampling devices. These gear types are either thrown or triggered to rapidly enclose organisms within a known quadrat of substrate. They are most effective

for collecting small fishes and invertebrates in relatively shallow (< 3 m) environments and allow for simultaneous quantification of benthic species composition and coverage. Enclosure techniques yield highly accurate density animal density estimates, but are highly size-selective due to the relatively small areas that they sample.

Analytical Methodology

We followed a data analysis procedure known as the delta approach. The Delta Approach is not new (Aitchison and Brown, 1957; Seber, 1982; Pennington, 1983) and is often used in fisheries applications (e.g., Lo et al., 1992) and in ecological studies of niche overlap (Krebs, 1999). It is virtually absent, however, in the wetlands fish literature (Faunce and Serafy, 2006). As described by Serafy et al. (2007), the approach entails analyzing three "abundance metrics" for each taxon of interest: frequency of occurrence (occurrence), concentration (i.e., density when present, exclusive of zeros) and "delta-density" (product of occurrence x concentration). Initially, salinity-frequency and fish abundance-frequency distribution plots were generated as a basic data diagnostic step and also to aid defining salinity bins. Next, using standard regression techniques, we examined patterns in these abundance metrics along a salinity gradient.

Following Serafy and Valle (2006), salinity gradients were constructed via 5-psu binning of salinity measurements made at time of fish sampling. Salinities recorded during each study were classified into as many of the following nine 5-psu salinity (S) bins that the data would allow: (1) $S \leq 5$; (2) $5 < S \leq 10$; (3) $10 < S \leq 15$; (4) $15 < S \leq 20$; (5) $20 < S \leq 25$; (6) $25 < S \leq 30$; (7) $30 < S \leq 35$; (8) $35 < S \leq 40$; and (9) $S > 40$. Taxon-specific fish abundances were expressed in terms frequency of occurrence, concentration (density when present), and delta density. These three "abundance metrics" were calculated for each selected species-gear-bay combination. Analyses were conducted across all years and seasons within each combination. Data were plotted against a salinity gradient along with a trend line, regression equation and associated p-value. Our salinity-binning approach does not require the assumption that the abundance metric patterns are driven solely by salinity -- numerous other factors (e.g., seagrass density, mangrove coverage, water depth) combine with salinity to define and influence the habitats sampled as well as their fish assemblages. Rather, the appropriate perspective is that the method reveals

correlation trends (or lack thereof) along salinity gradients, with the combined influence of all other factors expressed as variability around these trends.

Twelve species of Biscayne Bay fishes and one invertebrate (pink shrimp) had sufficient data to analyze density by means of our salinity-binning approach (Table 4). Biscayne Bay visual census data had sufficient data for six species, while individual trawl studies had adequate data for between five and eight species. There were sufficient throw-trap data for five Biscayne Bay species. One visual census studies allowed examination of six Biscayne Bay taxa. Grouping the Biscayne Bay trawl studies across the three trawl data sets allowed us to increase positive samples within salinity bins and estimate abundance metrics for nine species. However, we did not group those data sets when a species was extremely rare. Table 4 shows the salinity range by species for each individual study. A minimum of at least eight positive "catches" were required within a salinity bin to be considered adequate in terms of sample size. Previous studies have found that concentration estimates tend to be suspect (either too high or too low) when sample size is too low, which tends to occur at the tails of the sampling distribution.

Table 5A shows the number of models developed for each species by gear. In general, collections in Biscayne Bay had lower salinities than for Florida Bay. Hence, while several Florida Bay studies contained sufficient data to plot trends in abundance by salinity; data were insufficient in some cases to examine abundance trends at lower salinities. Pooled Florida Bay trawl data was used to estimate a salinity trend for 11 selected Biscayne Bay species, while seine data was adequate for nine species. Florida Bay drop-net data were adequate for two species, visual census for three species and the throw-trap was for five species. The Florida Bay visual census and drop-net gear sampled the lowest salinities (≤ 2.5 psu).

Community-level Analyses

Community-level analyses entailed examining species diversity (i.e., taxonomic richness) and conducting canonical correlation analysis. In both cases, we employed our salinity binning approach. For the former, we examined for patterns of mean taxonomic richness across our salinity bin gradient (i.e., in a univariate fashion). Taxonomic richness values are highly dependent upon gear and the size of the sample area. We did

not pool data sets by gear due to inconsistencies in sampling areas within or among gear types. Therefore, while area standardization is adequate for inter and intra-habitat abundance comparisons, such standardization is inappropriate for taxonomic richness.

Canonical correlation analysis is a multivariate technique which is concerned with determining the relationships between groups of variables in a data set (Legendre and Legendre 1998); we this analysis to the Biscayne Bay visual census data. A Bray-Curtis dissimilarity matrix was constructed using 4th root-transformed abundances of 89 fish taxa from 544 wet season mainland shoreline transects. The dissimilarity matrix was used in a permutation-based MANOVA (Anderson 2001) to test differences in species composition and abundance among salinity bins. Distance-based redundancy analysis (Legendre and Anderson 1999; McArdle and Anderson 2001) of the Bray-Curtis matrix was used to visualize the variability in community composition among salinity bins. Taxon-specific responses to salinity were identified for the 12 species that contributed the most to the variation in community composition by overlaying bi-plot vectors on the canonical plot. Cluster analyses were also conducted using the species occurrence-salinity bin matrix for Biscayne Bay's mainland shoreline. One cluster analysis grouped the salinity bins and a second grouped the species. Table 5B lists the community-level models that were developed.

Salinity Variability Analysis

In Biscayne Bay, salinity variability is greatest in those areas that have the most freshwater flow and these areas also tend to have the lowest salinities. In other words, salinity variation increases as the mean decreases, thus the two are confounded. We addressed salinity variability as a factor by developing a "salinity range index" and examining for fish abundance patterns along a salinity-variability gradient. This was performed using the Biscayne Bay visual census data set. Specifically, we divided Biscayne Bay's mainland shoreline from Matheson Hammock to Turkey Point into a series of contiguous segments and focused on wet season salinity measurements. Wet season samples were sorted by latitude (across years) and a 21-sample running average of the salinity range (10 samples before and 10 samples after) was calculated (maximum salinity within 21 samples minus minimum salinity within 21 samples). Each sample was

assigned a range index value of low (<20 psu), medium (20-29 psu), and high (>30 psu) variability and samples were grouped into variability segments of approximately 20 samples based on the similarity of their index values. Frequency of occurrence, concentration, and delta density of the top seven species were calculated for each segment and a regression model was used to test the relationship between the salinity variability index and each of the abundance indices of the segments. Table 5C shows the salinity variation models developed.

Maps of the occurrence, concentration, and delta density of the seven most important species (*Eucinostomus sp., G. cinereus, S. barracuda, L. griseus, L. apodus, F. carpio,* and *H. sciurus*) in the visual census studies were constructed in Arc-GIS using the above salinity-range segments along the mainland shoreline. The leeward shoreline segments were also divided into latitudinal segments with approximately 25 samples each. As above, occurrence, concentration, and delta density were calculated and mapped on a taxon-specific basis.

Final Synthesis (Task 4.0)

Results

HSI Model Assessment

Salinity HSI models were developed for 12 Biscayne Bay fishes and one invertebrate (pink shrimp). These models were compared to those derived from throw-trap, trawl, seine, drop-net, and visual census data collected from Florida Bay. Using our "salinity bin" application of the delta approach, we have examined three indices of abundance per taxon: frequency of occurrence, concentration (density of positive catches), and delta density (product of occurrence x concentration). We detected significant trends in one or more abundance metrics along salinity gradients for 12 of the 13 taxa examined (Table 6). Plots of significant models for the three metrics are presented in Figures 1-6 and plots of all species/bay/gear/metric combinations are presented in the Appendix. Taxon specific abundances were gear-dependent with larger individuals tending to be sampled in the visual census and seine studies and smaller individuals in trawl, throw-trap and drop-net studies. Trend analyses were conducted for each species/bay/gear/metric combination, and the strength of the trend (R^2), equation of

the relationship (i.e., linear, parabolic or exponential) and significance (p-value) were determined for each. A significance level less than 90 % was considered, because of the limited number of salinity bins in several of the data sets (4-7).

Sixty metric trends (40%) out of 150 combinations (species/bay/gear/metric) examined were found to be significant at the 90% level (Table 6). Twenty-one significant relationships (nine species) were found with salinity using the frequency of occurrence metric, which included seven species in Biscayne Bay and eight species in Florida Bay. There were 17 significant relationships for the concentration metric (11 species), and 22 significant relationships for the delta density metric (12 species). Seven species showed significant trends using the concentration metric in Biscayne Bay and seven species in Florida Bay. For the delta density metric, 11 Biscayne Bay species and seven species in Florida Bay species showed significant trends.

The general pattern of the trends in the abundance metrics with salinity across species (with a few exceptions) differed between the two bays. The metric relationships tended to be negative or parabolic for Biscayne Bay fishes, and positive or parabolic for Florida Bay fishes. The exceptions were visually-quantified gray snapper (*L. griseus*) occurrences (Figure 1) in Biscayne Bay, rainwater killifish (*L. parva)* captured with drop-nets (Figures 4 and 6), and pink shrimp (*F. duorarum)* captured by throw-trap in Florida Bay (Figure 4). Trends for Biscayne Bay gray snapper (*L. griseus*) probably indicate size-dependent differences. The gray snapper quantified in visual surveys were mostly subadults (about two years of age) occurring along the mainland mangrove fringe, which had the lowest salinities (minima of less than 2 psu). In contrast, trawl sampling encountered almost exclusively smaller, young-of-the-year gray snapper inhabiting seagrass beds, which had higher salinity minima (12 psu). Most rainwater killifish trends were either insignificant or negative. The exception was that throw-trap-derived trends whereby Biscayne Bay trends were negative, but Florida Bay trends were positive. Because the Biscayne and Florida Bay sampling efforts encountered different salinity ranges, it is difficult to interpret these results. On possibility consistent with these results is that this species has an affinity for salinity extremes. No significant relationships with salinity were found for any of the abundance metrics for the gulf toadfish (*O. beta*) in Biscayne Bay, but there was a parabolic trend in Florida Bay for trawl occurrence and

delta density with highest densities in the 20-30 psu range. There was a positive trend in *O. beta* concentrations in Florida Bay and for *O. beta* for all of the throw-trap metrics. There were not enough data to plot yellowfin mojarra (*G. cinereus*) and no significant relationships were found for other small mojarras (*Eucinostomus spp.*) in Florida Bay. No relationships were found for bluestriped grunt (*H. sciurus*), possibly due to small sample sizes.

Delta density and occurrence metrics had greater number of significant relationships than concentration. This roughly corresponds with the notion that a given fish's school size is more variable and difficult to predict than its occurrence or density. The trawl gear (both bays) provided the greatest number of significant relationships for the occurrence metric (five for both bays); probably because more data were available for this gear and that it sampled the largest areas. For the concentration metric, the trawl data produced five significant relationships in Biscayne Bay, while throw-trap gear had the greatest number of significant trends (four) in Florida Bay. The trawl had six significant relationships for the delta-density metric in Biscayne Bay, while the throw-trap had the most significant relationships (four) in Florida Bay.

Data were adjusted for area sampled and extrapolated to number/hectare. There were density differences between the two bays. At the species level, Florida Bay had higher estimated densities of smaller species such as *F. carpio*, *L. parva*, *G. robustum*, *L. rhomboides*, and *O. beta*, while Biscayne Bay estimated densities were greater for larger species, such as *H. sciurus*, *G. cinereus*, and *L. griseus*. Similar densities were found for *C. nebulosus*, *Eucinostomus* spp. mojarras, and *S. scovelli* for the two bays. In Biscayne Bay, mangroves (visual census) had higher densities of *G. cinereus*, *H. sciurus*, *L. griseus*, and *S. barracuda* than the open-bay areas sampled with the trawl, although this may be due to difference in sampling efficiencies, which were not taken in account. A critical factor to consider when comparing trawl-based studies conducted in Biscayne *versus* Florida Bay is that trawling Biscayne Bay has been exclusively nocturnal and that in Florida Bay has been exclusively diurnal. It is possible, therefore, that each species may have differing salinity affinities by day versus night, hence the different relationships that emerged between bays. For example, gray snapper are known to forage widely by night, but spend much of the day hovering near structure, thus, we might

expect an individual to experience a wider array of salinities as it searches for food nocturnally.

An example of the potential utility of the HSI models that we have generated is illustrated in Figure 7. First, for a fictitious location in Biscayne Bay, a hypothetical time series of salinities was generated using a random number generator. Next, we used our HSI models to generate predicted occurrences of young of year spotted seatrout and gray snapper. Figure 7A shows the salinity-affinity relationships found for the two species. Figure 7B is a plot of the randomly-generated (hypothetical) salinity time series. And Figure 7C shows the predicted time series of species occurrences at that location, thus depicting of how the suitability of our fictitious location varies over time for each species. The above approach, of course, should be taken with great caution, but may have utility when other means of addressing habitat suitability are lacking.

Community-Level Analyses

Taxonomic richness (average number of fish taxa per sample) was evaluated using our salinity-binning approach. In Biscayne Bay, taxonomic richness showed a positive relationship with salinity in the visual census study conducted along the mangrove shoreline, while the throw-trap study conducted offshore of the mangroves suggested a parabolic relationship (Figure 8A). There were differences between the trawl studies in Biscayne Bay. A negative trend between taxonomic richness and salinity was found in the trawl study conducted in the Browder studies (2002-2004) (Figure 8B); corresponding relationships in two of the three Biscayne Bay trawl studies were not significant. It was not possible to combine trawl studies because of different trawling distances among studies. Throw-trap richness showed a parabolic relationship with salinity with highest richness at intermediate salinity (Figure 8C). The average number of taxa per sample was higher in the trawl studies, which obviously sampled a greater area compared to the throw-trap as well as the visual census studies which sampled areas of $60m^2$. Even within the individual trawl studies, trawling distance was not uniform, which probably contributed to some of the variation in the taxonomic richness. In general, highest taxonomic richness in Biscayne Bay occurred at salinities from 35-45 psu.

Taxonomic richness was found to be highest at salinities of 30-40 psu in both Biscayne and Florida Bays. Driving this was the presence of reef-associated species along mainland shoreline when higher salinities prevailed. Taxonomic richness and/or diversity are poor metrics when evaluating the suitability of a habitat for estuarine species. Taxonomic richness is highest in environmentally stable areas, and species diversity would be expected to be negatively related to estuarine fish production. Estuaries which contain low salinity habitats are important in maintaining overall species diversity for an ecosystem by providing high diversity of habitats.

In Florida Bay (Figure 9), there was a negative relationship between salinity and taxonomic richness in the Everglades National Park trawl study conducted by Schmidt (1974-1976) and a parabolic relationship in the Florida Marine Research Institute trawl study conducted by Colvocoresses (1993-1997). The Everglades National Park trawl study did not sample areas with salinities less than 30 psu. No significant relationship was found between salinity and taxonomic richness in the National Oceanographic Survey trawl study conducted by the grouped trawl studies (Powell 1984-1986, 1996-2001). Neither was there a significant relationship in the Florida Marine Research Institute seine study (Figure 10) conducted by Colvocoresses (1993-1997), while the Everglades National Park seine study conducted by Schmidt (1974-1976) suggested a weak parabolic relationship ($p=0.07$). In general, Florida Bay studies suggested that highest taxonomic richness occurred at salinities around 35-45 psu which was similar to that found in Biscayne Bay. No significant relationship was found for species richness and salinity in the Florida Bay visual census surveys. We were unable to conduct a taxonomic richness analyses on Florida Bay throw-trap or drop net samples because we did not have a complete data sets, but were only provided data for the most common species.

The distance-based redundancy analysis was conducted on 544 wet season visual census transects along the mainland shoreline. Permutation-based MANOVA found significant differences in species composition among salinity bins ($F=2.14$, $p=0.001$) between salinity bins and Axis 1 which represented salinity and accounted for 65% of the variability. The transect data projected in multivariate space as defined by the dissimilarity in species composition, constrained by nine 5-psu salinity bins is shown by

the canonical plot in Figure 11. Salinity vectors (red arrows) indicate the relative magnitude and direction of the gradient of each of the 9 salinity bins in defining the variation in species composition among transects. The salinity vectors were nearly perfectly ordered in a clockwise direction (i.e., the ordination space is parsed into 9 ordered subspaces) and transect similarity was divided into two main groups -- a low salinity space on the left of the central Axis (arrows 1-4 which correlate to salinity bins, 0-20 psu) and a high salinity space on the right of the central axis (arrows 5-9 which correlates with salinity bins, 20-45 psu). Post-hoc comparisons of the dissimilarity matrix indicated that significant ($P<0.05$) changes in community composition and structure emerged between the high and low salinity categories beginning with the 20 -25 psu category (Table 7). Although grouped together, the slight distortion in ordering the salinity bins 7-9 may be the result of the small sample size of salinity bin 9 which consisted of only four transects. Similar groupings of transects by salinity were found using cluster analysis based on presence/absence species data except, that salinity bin 9 (> 40 psu) was found to be distinctly different than both salinity bins 1-4 (0 – 20 psu) and salinity bins 5-8 (21 - 40 psu) (Figure 12).

Species vectors (green arrows) in Figure 10 indicate the relative strength (length) and direction (heading) of the gradient in abundance of the 12 species that contributed the most to the variation among transects. Both gerrid groups show very similar patterns of composition and abundance and preferred intermediate salinities (16-25 psu) along with *F. carpio* and *Sphoeroides testudineus* (checkered puffer). *S. barracuda* appeared to prefer transects between 26-30 psu. Snappers (*Lutjanus apodus* (schoolmaster) and *L. griseus*), grunts (*Haemulon parra*, sailors choice), *Abudefduf saxatilis* (sergeant major) and *L. rhomboides* were very similar to each other and gravitated towards higher salinities (>30 psu). In general, most species with the exception of the *Diapterus plumieri* (striped mojarra) avoided extremely low salinities. The silversides (which represents numerous schooling forage species of the herring/sardine/anchovy/silverside families displayed the strongest variance of all 89 species, which might have been expected as this group is composed of both low-salinity affinity and high-salinity affinity species. It was not possible using visual census to identify this group to species (without handling them) because the individual species are so similar in appearance.

Salinity bin groupings from the redundancy analysis were similar to those obtained using a cluster analysis of species similarity based on presence/absence data (Figure 13). This suggested that the greatest structural changes occur at about 20 psu. Below 20 psu, occurrences of mojarras (*Eucinostomus* spp.), snook (*Centropomus undecimalis*), striped mojarra (*Diapterus plumieri*) and marsh killifish (*Fundulus confluentus*) tend to be higher, whereas snappers (Lutjanidae), grunts (Haemulidae), pinfish (*Lagodon rhomboides*) and sergeant major (*Abudefduf saxatilis*) tend to be lower. Figure 14 shows the top 10 species based on frequency of occurrence for salinities, 0-20 psu, 21-40 psu, and 40 psu.

Salinity Variability Assessment

To evaluate the importance of salinity variability along the Biscayne Bay mainland shoreline, the shoreline was divided into 31 segments and an index of salinity variability was developed from wet season visual census transects (across years). The seven most common visual census species within these segments were examined. Three species showed a significant ($P < 0.10$) trend for occurrence versus salinity variability, three with concentration, and four with delta density (Table 8). A negative relationship was found for one or more metrics for *H. sciurus*, *L. apodus*, and *L. griseus*. All of the above species are typical reef or known higher salinity species. In contrast, the mojarras, *Eucinostomus* spp. showed a positive relationship to salinity variability, while the majority of typical estuarine species showed no significant relationships.

Figures 15-17 show the results of the wet season salinity range plots for frequency of occurrence, concentration, and delta density for the mainland shoreline. Table 7 shows the significance of the relationships. The salinity range approach provides further insight to our salinity bin results. All three of the abundance metrics for *H. sciurus*, *L. griseus*, and *L. apodus* showed a negative relationship with salinity range. Small mojarra concentration and delta density showed a positive relationship with salinity range, but there was no relationship with frequency of occurrence. *S. barracuda*, *F. carpio*, and *G. cinereus* did not show a significant relationship with any of the abundance metrics and salinity range. This suggests high tolerance to salinity variability for these species.

Figures 18-24 show wet and dry season maps of frequency of occurrence, concentration, and delta density for *Eucinostomus* mojarras, *F. carpio*, *G. cinereus*, *H. sciurus*, *L. apodus*, *L. griseus*, and *S. barracuda*. Concentration and delta density values are shown on a log-10 scale.

Figures 25-26 show the salinity range for the 31 segments and the location of major freshwater canals. Note that sampling sites are restricted to the lower end of Biscayne Bay south of the Rickenbacker Causeway. Salinity variability within segments ranged 3-38 psu during the wet season and 3-24 psu in the dry season (Figures 25-26). During the wet season, greatest variability occurred in the northern area near C-100A and Military Canals and Florida Bay. Variability was low (<16 psu) along the offshore keys during both seasons.

The maps show that the mojarras occur in relatively high frequency (> 45%) throughout all of the shorelines of Biscayne Bay during the wet season (Figure 18). During the dry season, both *Eucinostomus* mojarra occurrence and concentrations in the southernmost part of the bay are lower than the central and northern parts of the bay, which coincided with higher salinity range (Figure 26). The magnitude of *Eucinostomus* mojarra occurrence and concentration along the Leeward Keys shoreline were similar to that of the mainland shoreline. *F. carpio* was found to occur most often in the northern and central parts of the bay especially during the dry season (Figure 19). Densities were lower in wet season *F. carpio* and occurrence tended to be patchier. *F. carpio* concentration and delta density showed similar patterns as occurrence. Occurrence and density of *F. carpio* along the Leeward Key shoreline were of a similar order of magnitude as that of the southern mainland shoreline. Highest occurrence of *G. cinereus* was found along the Leeward Keys shoreline, although the order of magnitude of the concentration and delta density suggest that it is relatively uniform throughout the bay (Figure 20). It was found to be absent in portions of the southern most bay which may be related to recruitment or the high salinity variability (Figures 25-26). *H. sciurus* tended to be absent along the northern and central parts of the bay (Figure 21). It occurred with highest frequency along the Keys shoreline and in moderate occurrence levels in the southern part of the bay except in the southernmost portion where recruitment may be

limiting its distribution. *H. sciurus* concentration showed similar distribution patterns as occurrence.

L. apodus occurred with highest frequency along the Leeward Keys shoreline in the wet season (Figure 22). *L. apodus* occurrence along the Mainland shoreline in the wet season was highly variable, while in the dry season it tended to be patchy. Wet season *L. apodus* delta density tended to be of a similar order of magnitude throughout most of the bay. Dry season *L. apodus* occurrence along the Leeward Keys shoreline varied between medium to high. The *L. apodus* tended to be absent from the northern and southern parts of the bay. Absence from the southern part of the bay may be related to recruitment. Frequency of occurrence of *L. griseus* was high along the Keys shoreline during both seasons (Figure 23). Highest *L. griseus* occurrence and concentration along the Mainland shoreline was in the southern part of the bay. The *L. griseus* delta density along the Mainland shoreline tended to be relatively stable and was an order of magnitude lower than the Leeward Keys shoreline. There were a few places along the northern most part of the Mainland shoreline where the *L. griseus* was absent during both seasons. The *S. barracuda* was found throughout the bay in both seasons. Highest *S. barracuda* frequency of occurrence was found along the Leeward Keys shoreline and in the central portion of the Mainland shoreline during the wet season (Figure 24). Dry season *S. barracuda* occurrence tended to be more variable. *S. barracuda* concentration and delta density tended to be of a similar order of magnitude throughout the bay during both seasons. There were a few spots along the Leeward Keys where delta densities were very low during the dry season. Salinity variability may have contributed to the absence of *G. cinereus*, *H. sciurus*, and *L. apodus* in the southern part of the bay.

Conclusions

Predicting the response of fish communities to large-scale estuarine restoration efforts can be extremely challenging, especially when the timing, magnitude and quality of anticipated changes are unclear and when quantitative historical data on fishes are limited. The metrics that have been developed appear to have utility for gauging species and community response to the large-scale ecosystem restoration activities currently

underway. The approach and methods may also be useful for gaining insight into possible CERP effects on flora and other fauna.

The general trends in abundance metrics with salinity across species differed between the two bays. The metrics tended to be negative or parabolic for Biscayne Bay fishes, and positive or parabolic for Florida Bay fishes. The exceptions were visual census *L. griseus* frequency in Biscayne Bay which showed a size-dependent selection of habitat (smaller in the bay and larger along the mangrove shoreline), and the dropnet *Lucania parva*, trawl *Cynoscion nebulosus* and throw-trap *F. duorarum* concentrations in Florida Bay. In most cases, however, other confounding factors (i.e., size-class, gear and/or sampling time-of-day differences) accompanied these apparent inter-Bay differences.

There were obvious differences in magnitude of the metrics calculated for the two bays, some of which may be explained by the nocturnal versus diurnal trawl sampling conducted in Biscayne and Florida Bay, respectively. At the species level, Florida Bay had higher estimated densities of smaller species such as *F. carpio*, *L. parva*, *G. robustum*, *L. rhomboides*, and *O. beta*, while Biscayne Bay-estimated abundances were greater for larger species, such as *H. sciurus*, *G. cinereus*, and *L. griseus.* Higher densities of *F. duorarum* were found in nocturnal Biscayne Bay trawls compared to diurnal Florida Bay trawls. However, similar numbers of *F. duorarum* in both bays were collected using the throw-trap when sampling only occurred in the daytime which tends to confirm that sampling time is a factor. Similar densities were found for *C. nebulosus*, *Eucinostomus* mojarras, and *S. scovelli* for the two bays. In Biscayne Bay, visual census (mangrove) sampled areas estimated higher densities of *G. cinereus*, *H. sciurus*, *L. griseus*, and *S. barracuda* than the seagrass-dominated areas sampled with the trawl. Again, because sampling protocols differed among Bays, additional research is required to address the notion that different salinity-affinities apply in Biscayne and Florida Bays.

Multivariate community-level analyses were restricted to the Biscayne Bay visual census data using cluster and canonical correlation techniques (the latter are also known as redundancy analyses). Both analyses suggested that 20 psu as a “pivot point” with respect to community composition and structure, with the occurrences of snapper and

grunt species diminishing at salinities below 20 psu and those of snook and small mojarras increasing.

This report contains several examples of negative abundance or diversity relationships as waters were increasingly hypersaline (i.e., > 36 psu) conditions. In fact, where high-salinity observations were available, most of the statistically-significant salinity trends for individual taxa showed abundance declines beyond 36 psu. Similarly, our community-level analyses showed patterns of decreased diversity and reduced assemblage structure when waters were hypersaline. This is or particular relevance in the assessment of minimum flows and levels, whereby an objective may be to reduce the magnitude, duration and frequency of hypersaline events at a particular location. We recommend behavioral and physiological laboratory investigations as a means of directly testing the apparent nekton abundance-hypersalinity relationships obtained in the present study.

Our salinity variability evaluation, *H. sciurus, L. griseus*, and *L. apodus* showed negative relationships with salinity range. *Eucinostomus* mojarras concentration was positively correlated with salinity range and no relationship was found for *S. barracuda, F. carpio*, and *G. cinereus.*

Future Directions

We consider the results presented in this report as hypotheses about relationships between various size-classes of selected organisms and salinity. These are hypotheses because the patterns found derive from: (1) "snapshot", versus semi-continuous, salinity data; and (2) studies that, in several cases, were not specifically designed to examine relationships with salinity. The logical "next step", therefore is to design and implement a series of field, laboratory and modeling activities that test the validity of the animal-salinity relationships presented here. Optimal would be studies that entail adaptive animal sampling along a gradient of empirically-measured salinity regimes. This would necessitate flexibility on the part of the research teams to deviate, when the opportunity presents itself, from their fixed sampling schedules (and locations) to sample across a gradient of natural or anthropogenic freshwater flow events. Such an approach would require heavier investment salinity recording instruments than is currently in place in

Biscayne Bay, but would lead to more robust HSI models. Provided they are reasonably representative of true conditions, hydrodynamic models also represent a potentially useful source of salinity regime data against which fluctuations in animal abundance and diversity may be examined. Even if modeled salinity estimates are uncertain, we recommend their use in the near-term so that progress can be made in dealing with the inevitable complexities of identifying and analyzing those salinity regime properties that are of highest ecological relevance. Finally, laboratory studies that directly investigate (on a size- and species-specific basis) how animals respond (in terms of tolerance, preferences, growth and possibly reproduction) to changes in the magnitude, duration and frequency of salinity change. Such laboratory studies would be particularly helpful for testing candidate species as indicators of salinity regime change.

Reliance on "salinity snapshot data" (i.e., discrete, non-continuous salinity measurements) is useful, but not optimal, especially for organisms that live months to years. Ideally, we would have access to the hourly "salinity histories" of every sampling location allowing investigation of correlations of faunal abundance measures with salinity means, medians, modes, ranges and perhaps some ecologically-relevant salinity exceedences per relevant time period (e.g., weeks for small invertebrates, months for medium-sized fishes, etc.). Obviously, instrumentation (with salinity recorders) of each of the thousands of locations that have been sampled in Biscayne Bay is not feasible, hence the universal need for assistance from accurate or at least somewhat "salinity-regime-realistic" hydrodynamic models. In the future, there needs to be a concerted effort to bring together and make fully accessible: (1) all available empirical salinity time series data; and (2) all available model-simulated salinity time series data. In practice, we will probably be relying heavily on item (2) in the future to make sense of salinity-organism relationships at more ecologically realistic time/space scales, which will likely differ according to the life stage (size) of the taxon in question. We contend, however, that until spatially-explicit salinity data from both empirical and model-based sources have been compiled and made accessible, the approach taken here will remain among the most logical and easily-communicated means of generating HSI models for Biscayne Bay's fauna.

Synopsis

- A literature review of 12 ecologically and economically important fishes and one invertebrate (pink shrimp) in Biscayne Bay was conducted.
- Sixty statistically significant HSI models pertaining to 12 taxa were developed for Biscayne and Florida Bay fauna and these are presented in both graphical and mathematical form.
- Trend analyses were conducted for each species/bay/gear/metric combination, and the strength of the trend (r^2), equation of the relationship and significance (p-level) were determined for each trend.
- A hypothetical example of the potential utility of our HSI models is illustrated for young of the year seatrout and gray snapper during their residence in Biscayne Bay seagrass beds.
- We have examined community-level relationships using univariate and multivariate techniques. Trends of species richness across salinity gradients were generally inconsistent. In contrast, multivariate methods suggested significant community changes occur in the region of 20 psu.
- We found several statistically-significant salinity trends for individual taxa that showed abundance declines beyond 36 psu. Similarly, our community-level analyses showed patterns of decreased diversity and reduced assemblage structure when waters were hypersaline.
- We have included information on possible salinity variability effects on Biscayne Bay fishes along the mainland shoreline and have provided maps showing spatial trends.
- While somewhat simplistic and imperfect, the approach taken here may serve as heuristic tool for hypothesis testing as well as for relating to non-scientists the possible outcome of salinity change for a given taxon.

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Table 1. Salinity optima and ranges for selected Biscayne Bay species as reported in the literature. Note: Only life stages of species that live in nearshore areas are included.

Scientific name	Common name	Life stage in bay	Optimum salinity psu	Salinity range occur psu	Source
Cynoscion nebulosus	Spotted seatrout	larvae	20-29; 20-35		Brown-Peterson et al. 2002 Arnold et al. 1976; Killam et al. 1992; Patillo et al. 1997
		larvae		15-45	Jannke 1971; Peebles and Tolley 1988; McMichael and Peters 1989; Powell et al. 1989; Rutherford et al. 1989; Holt et al. 1990; Tolan et al. 1997; Thayer et al. 1999
		juvenile	8-25		Peterson 1986
		juvenile		0-48	Gunter 1945; Wang and Raney 1971; Peterson 1986; Rutherford et al. 1989a; Killam et al.
		adult	20-25		Wohlschlag and Wakeman 1978
		adult		0.2-75	Simmons 1957; Perret et al. 1971; Mercer 1984; Killam et al. 1992
Eucinostomus gula	Silver jenny	juvenile	Considered to be very tolerant; FL bay highest density at hyperhaline	mesohaline (5-19)-hyperhaline (>40)	Serafy et al. 1997; Powell et al. 2007
*Farfantepenaeus duorarum**	Pink shrimp	postlarvae	No info	12-43; 2-40	Tabb et al. 1962a; Zein-Eldin 1963
		juvenile	30; 25-40		Browder et al. 2002 (laboratory); Tabb et al. 1962a; Tabb et al. 1962b; Costello et al. 1986; Robblee et al. 1991; Robblee unpublished data (based on highest abundance)
		juvenile		0-70	Tabb et al.1962a
Floridichthys carpio	Gold-spotted killifish	all	25-70		Nordlie and Haney 1998 (osmoregulation)
				0.5-90	Simpson and Gunter 1956
Gerres cinereus	Yellowfin mojarra	juvenile/subadult	No info		
Gobiosoma robustum	Code goby	all	growth higher at 5 psu than 35 psu; 80% mortality at 0 psu		Schofield 2004
		all		2-38	Patillo et al. (1997)
*Haemulon sciurus**	Blue striped grunt	juvenile/subadult	densities are similar from polyhaline to hyperhaline	polyhaline (19-29)-hyperhaline (>40)	Powell et al. 2007
Lagodon rhomboides	Pinfish	all	15-30; 20		Shervette et al. 2007; Kloth and Wohlschlag 1972
				0-45	Rosessler 1970; Pineda 1975
Lucania parva	Rainwater killifish	all	highest density at mesohaline (5-18)	0-80	Dunson and Travis 1991; Powell et. al. 2007
*Lutjanus griseus**	Gray snapper	juvenile/subadult	12-22		Serrano (unpublished data)
		juvenile		8-48	Rutherford et al 1989b
		subadult		2-22	Browder (unpublished data)
Opsanus beta	Gulf toadfish	all	30; highest density >40		Johnson et al. 2002 (based on gam models); Powell et al. 2007
		all		mesohaline (5-19)-hyperhaline (>40)	Powell et al. 2007
*Sphyraena barracuda**	Great barracuda	juvenile	highest density at hyperhaline (>40)	mesohaline (5-19)-hyperhaline (>40)	Powell et al. 2007
Syngnathus scovelli	Gulf pipefish	all	highest density at mesohaline (5-18)	0-45	Whatley 1962; Simmons 1957; Roessler 1967; Powell et al. 2007

**spawn outside bay*

Table 2. List of data sets examined in the present meta-analysis (SEFSC=Southeast Fisheries Research Center, NMFS= National Marine Fisheries Service, USGS= United States Geological Service, FMRI= Florida Marine Research Institute, NOS= National Oceanographic Service, NOAA=National Oceanographic And Atmospheric

Researcher	Affiliation	Time frame	Sampling method	Species with adequate data
Biscayne Bay Studies				
Joseph Serafy	SEFSC/NMFS	1998-2007	Visual census	*Eucinostomus spp., Floridichthys carpio, Gerres cinereus, Haemulon sciurus, Lutjanus griseus, Sphyraena barracuda*
Joseph Serafy	University of Miami[1]	1993-1994	Trawl	*Cynoscion nebulosus, Eucinostomus gula, Floridichthys carpio, Haemulon sciurus, Lucania parva, Lutjanus griseus, Opsanus beta*
Joan Browder	SEFSC/NMFS	2002-2004	Shrimp trawl	*Cynoscion nebulosus, Eucinostomus gula, Floridichthys carpio, Gerres cinereus, Haemulon sciurus, Lucania parva, Lutjanus griseus, Opsanus beta*
Joan Browder	SEFSC/NMFS	2005-2006	Throw-trap	*Floridichthys carpio, Gobiosoma robustum, Lagodon rhomboides, Lucania parva, Opsanus beta, Syngnathus scovelli*
Guillermo Diaz	University of Miami[1]	1996-1997	Trawl	*Cynoscion nebulosus, Eucinostomus gula, Floridichthys carpio, Haemulon sciurus, Lucania parva, Lutjanus griseus, Opsanus beta*
Michael Robblee	USGS	2002-2005	Throw-trap	*Floridichthys carpio, Gobiosoma robustum, Lagodon rhomboides, Lucania parva, Opsanus beta, Syngnathus scovelli*
Florida Bay Studies				
Michael Robblee	USGS	1984-2002	Throw-trap	*Floridichthys carpio, Gobiosoma robustum, Lucania parva, Opsanus beta, Syngnathus scovelli*
Richard Matheson	FMRI, State of Florida	1994-1996	Throw-trap	*Floridichthys carpio, Gobiosoma robustum, Lucania parva, Opsanus beta, Syngnathus scovelli*
Susan Sogard	Audubon Society[1]	1984-1986	Throw-trap	*Floridichthys carpio, Gobiosoma robustum, Lucania parva, Opsanus beta, Syngnathus scovelli*
Thomas Schmidt	Everglades National Park	1974-1976	Trawl	*Cynoscion nebulosus, Eucinostomus spp., Floridichthys carpio, Lagodon rhomboides, Lucania parva, Lutjanus griseus, Opsanus beta, Sphyraena barracuda, Syngnathus scovelli*
Thomas Schmidt	Everglades National Park	1974-1976	Seine	*Cynoscion nebulosus, Eucinostomus spp., Floridichthys carpio, Lagodon rhomboides, Lucania parva, Lutjanus griseus, Opsanus beta, Syngnathus scovelli*
James Colvocoresses	FMRI, State of Florida	1994-1997	Trawl	*Cynoscion nebulosus, Eucinostomus spp., Floridichthys carpio, Lagodon rhomboides, Lucania parva, Lutjanus griseus, Opsanus beta, Sphyraena barracuda, Syngnathus scovelli*
James Colvocoresses	FMRI, State of Florida	1994-1997	Seine	*Cynoscion nebulosus, Eucinostomus spp., Floridichthys carpio, Lagodon rhomboides, Lucania parva, Lutjanus griseus, Opsanus beta, Syngnathus scovelli*
Allyn Powell	NOS/NOAA	1984-1985; 1994-2001	Trawl	*Eucinostomus spp., Floridichthys carpio, Lagodon rhomboides, Lucania parva, Lutjanus griseus, Opsanus beta, Sphyraena barracuda, Syngnathus scovelli*
Jerry Lorenz	Audubon Society	1990-2004	Drop net	*Floridichthys carpio, Lucania parva*
Craig Faunce	FMRI, State of Florida	1996-1999	Visual census	*Lucania parva, Lutjanus griseus, Gerres cinereus*

[1] Currently with NMFS

Table 3. Gear differences and biases

Gear	Bay	Time of day	Depth	Habitat	Size bias	Area sampled
Visual census	Biscayne	Day	0.1-1.4 m	Mangrove shoreline	Medium-largest subadults	60 m^2
Visual census	Florida	Day	0.2-1.6 m	Mangrove shoreline	Medium-largest subadults	4 m^2
Trawl	Biscayne	Night	0.8-3.0 m	Seagrass	Small-medium	646-3684 m^2
Trawl	Florida	Day	0.5-4.2 m	Seagrass	Small-medium	252-1500 m^2 (NOS) 480-960 m^2 (ENP)
Seine	Florida	Day	0.1-1.9 m	Shoreline, island, and bank seagrass	Small-medium	78-450 m^2 (ENP)
Throw trap-Browder	Biscayne	Day	0.3-1.2	Seagrass	Smallest	3 m^2 (3 replicates combined)
Throw trap-Robblee	Biscayne	Day	0.37-3.1 m	Seagrass	Smallest	1 m^2
Throw trap-Robblee	Florida	Day	0.1-2.3 m	Seagrass	Smallest	1 m2
Dropnet	Florida	Day	Not available	Nearshore	Smallest	Not sure data given in m^2

Table 4. Synopis of salinity ranges for selected species by study. At least 8 positive samples in a salinity bin.

Scientific name	Common name	BB serafy visual census	BB combined trawl studies	BB Serafy trawl	BB Diaz trawl	BB Browder trawl	BB Browder throw trap	FB Faunce visual census	FB combined trawl studies	FB combined seine studies	FB Lorenz drop net	FB Robblee throw trap
Farfantepenaeus duorarum	Pink shrimp	**	12.5-37.5	12.5-37.5	17.5-37.5	22.5-37.5	12.5-37.5	**	17.5-47.5	17.5-42.5	**	17.5-47.5
Haemulon sciurus	Blue striped grunt	22.5-37.5	12.5-37.5	12.5-37.5	**	22.5-37.5	**	**	22.5-42.5	**	**	**
Lutjanus griseus	Gray snapper	12.5-37.5	12.5-37.5	12.5-37.5	27.5-37.5	22.5-32.5	**	2.5-27.5	22.5-42.5	17.5-37.5	**	**
Opsanus beta	Gulf toadfish	**	12.5-37.5	12.5-37.5	17.5-37.5	22.5-32.5	**	**	12.5-42.5	7.5-42.5	**	**
Lagodon rhomboides	Pinfish	**	12.5-37.5	12.5-37.5	17.5-37.5	22.5-37.5	**	**	22.5-47.5	17.5-42.5	**	**
Lucania parva	Rainwater killifish	**	12.5-32.5	12.5-32.5	**	22.5-32.5	7.5-37.5	2.5-32.5	22.5-47.5	2.5-42.5	2.5-32.5	17.5-47.5
Cynoscion nebulosus	Spotted seatrout	**	17.5-37.5	17.5-27.5	**	**	**	**	22.5-42.5	17.5-42.5	**	**
Gerres cinereus	Yellowfin mojarra	7.5-37.5	22.5-37.5	**	**	22.5-37.5	**	**	**	**	**	**
Eucinostomus gula	Silver jenny	7.5-37.5	**	**	**	**	**	2.5-12.5	7.5-57.5	2.5-47.5	**	**
Sphyraena barracuda	Great barracuda	7.5-37.5	**	**	**	**	**	**	22.5-42.5	27.5-37.5	**	**
Syngnathus scovelli	Gulf pipefish	**	**	**	**	**	12.5-37.5	**	7.5-47.5	2.5-42.5	**	12.5-47.5
Gobiosoma robustum	Code goby	**	**	**	**	**	7.5-37.5	**	22.5-47.5	**	**	17.5-47.5
Floridichthys carpio	Gold-spotted killifish	7.5-37.5	27.5-32.5	**	27.5	27.5-32.5	12.5-37.5	**	7.5-47.5	2.5-47.5	2.5-32.5	7.5-47.5

** insufficient data

Table 5A. Number and description of HSI models fitted by species, gear and bay. Number of models per species/gear/bay combination is three (3) to indicate that the full triad of abundance metrics (i.e., occurrence, concentration and delta density) was regressed against salinity.

Species	Visual census		Trawl		Seine	Throw-trap		Drop Net	Total		
Bay	BB	FB	BB	FB	FB	BB	FB	FB	BB	FB	Both
Cynoscion nebulosus			3	3	3				3	6	9
Eucinostomus sp.	3	3	3	3	3				6	9	15
Farfantepenaeus duorarum			3	3	3	3	3		6	9	15
Floridichthys carpio	3			3	3	3	3		6	9	15
Gerres cinereus	3		3						6	0	6
Gobiosoma robustum						3	3		3	3	6
Haemulon sciurus	3		3						6	0	6
Lagodon rhomboides			3	3	3	3			6	6	12
Lucania parva	3		3	3	3	3	3	3	9	12	21
Lutjanus griseus	3	3	3	3					6	6	12
Opsanus beta			3	3	3	3	3		6	9	15
Sphyraena barracuda	3			3					3	3	6
Syngnathus scovelli				3	3	3	3		3	9	12
Totals	21	6	27	30	24	21	18	3	69	81	150

Table 5B. Number and listing of community-level analyses conducted by gear and bay.

Analyses	Visual census		Trawl		Seine	Throw-trap		Drop net	Total		
Bay	BB	FB	BB	FB	FB	BB	FB		BB	FB	Both
Richness	1	1	3	3	2	1	0	0	4	6	11
Cluster	1								1		1
Canonical	1								1		1
Total	3	1	3	3	2	1	0	0	6	6	13

Table 5C. Number of HSI models fitted by species in salinity range analyses conducted using Biscayne Bay visual census data. Number of models per species is three (3) to indicate that the full triad of abundance metrics (i.e., occurrence, concentration and delta density) was regressed against salinity range.

Species	Number of models
Eucinostomus sp.	3
Floridichthys carpio	3
Gerres cinereus	3
Haemulon sciurus	3
Lucania parva	3
Lutjanus griseus	3
Sphyraena barracuda	3
Total	21

Table 6. Results of statistically significant relationships with salinity by species, bay, gear, and metric. Shown are type of relationship, fitted equation, r^2, and p-value. Units for occurrence is proportion of positives, and concentration and delta density

Species	Bay	Gear	Metric	Relationship	Equation	r^2	p-value
Cynoscion nebulosus	BB	trawl	occurrence	linear	$y = -0.009x + 0.3089$	0.90	0.04
Cynoscion nebulosus	BB	trawl	concentration	linear	$y = -2.0672x + 71.157$	0.80	0.01
Cynoscion nebulosus	BB	trawl	delta density	exponential	$y = 147.75e^{-0.2025x}$	0.96	0.004
Cynoscion nebulosus	FB	seine	occurrence	linear	$y = 0.0038x + 0.0218$	0.58	0.08
Eucinostomus spp	BB	trawl	concentration	linear	$y=-28.947x + 1089$	0.91	0.0009
Eucinostomus spp	BB	trawl	delta density	linear	$y = -26.667x+947.21$	0.60	0.004
Farfantepenaeus duorarum	BB	trawl	occurrence	linear	$y = -0.0015x + 1.019$	0.77	0.02
Farfantepenaeus duorarum	BB	trawl	concentration	linear	$y = -59.377x+2661.6$	0.93	0.002
Farfantepenaeus duorarum	BB	trawl	delta density	linear	$y = -59.923x+2661.3$	0.94	0.002
Farfantepenaeus duorarum	FB	trawl	occurrence	parabolic	$y = -0.0009x^2 + 0.0599x - 0.5304$	0.88	0.01
Farfantepenaeus duorarum	FB	seine	occurrence	parabolic	$y = -0.0012x^2 + 0.088x - 1.1143$	0.95	0.003
Farfantepenaeus duorarum	FB	throw-trap	occurrence	parabolic	$y = -0.0011x^2+0.0733x-0.6021$	0.88	0.001
Farfantepenaeus duorarum	FB	throw-trap	concentration	exponential	$y = 195026e^{-0.0317x}$	0.82	0.005
Farfantepenaeus duorarum	FB	throw-trap	delta density	parabolic	$y = -103.14x^2 + 6055.7x - 37314$	0.67	0.06
Floridichthys carpio	BB	throw-trap	concentration	linear	$y = -800.64x + 38446$	0.85	0.009
Floridichthys carpio	BB	throw-trap	delta density	linear	$y = -76.224x + 3081.5$	0.87	0.006
Floridichthys carpio	FB	throw-trap	concentration	linear	$y = 4196.7x+14692$	0.84	0.0005
Gerres cinereus	BB	trawl	occurrence	linear	$y = -0.0329x + 1.4855$	0.98	0.01
Gerres cinereus	BB	trawl	concentration	linear	$y = -6.8878x + 288.32$	0.90	0.05
Gerres cinereus	BB	trawl	delta density	linear	$y = -6.2773x + 236.27$	0.88	0.06
Gerres cinereus	BB	visual census	concentration	linear	$y = -22.633x + 1790.4$	0.68	0.02
Gerres cinereus	BB	visual census	delta density	linear	$y = -10.434x + 641.74$	0.93	0.0004
Gobiosoma robustum	BB	throw-trap	occurrence	parabolic	$y = -0.0008x^2 + 0.0371x - 0.0518$	0.96	0.002
Gobiosoma robustum	BB	throw-trap	delta density	parabolic	$y = -23.494x^2 + 1065x - 2426.7$	0.98	0.0003
Gobiosoma robustum	FB	throw-trap	occurrence	parabolic	$y = -0.0007x^2 + 0.0629x - 0.66$	0.97	0.03
Gobiosoma robustum	FB	throw-trap	concentration	linear	$y = 868.27x+11459$	0.74	0.01
Gobiosoma robustum	FB	throw-trap	delta density	linear	$y = 1058.1x - 11736$	0.87	0.009
Lagodon rhomboides	BB	trawl	occurrence	parabolic	$y = -0.0009x^2 + 0.0287x + 0.5574$	0.79	0.10
Lagodon rhomboides	BB	trawl	delta density	parabolic	$y = -0.3686x^2 + 16.716x - 80.725$	0.94	0.02
Lagodon rhomboides	FB	trawl	occurrence	parabolic	$y = -0.001x^2 + 0.0826x - 1.1746$	0.95	0.005
Lagodon rhomboides	FB	trawl	concentration	parabolic	$y = -1.2449x^2 + 91.826x - 1271.3$	0.76	0.03
Lagodon rhomboides	FB	trawl	delta density	parabolic	$y = -0.7109x^2 + 53.457x - 779.32$	0.75	0.03
Lagodon rhomboides	FB	seine	occurrence	parabolic	$y = -0.0012x^2 + 0.0903x - 1.202$	0.86	0.05
Lagodon rhomboides	FB	seine	concentration	parabolic	$y = 8.239e^{0.1027x}$	0.90	0.03
Lagodon rhomboides	FB	seine	delta density	parabolic	$y = 0.1639e^{0.1839x}$	0.86	0.05
Lucania parva	FB	seine	occurrence	linear	$y = -0.0141x+0.9497$	0.87	0.0002
Lucania parva	BB	throw-trap	occurrence	linear	$y = -0.0068x + 0.6183$	0.56	0.07
Lucania parva	BB	throw-trap	concentration	linear	$y = -3465.7x + 207917$	0.63	0.03
Lucania parva	BB	throw-trap	delta density	linear	$y = -2565x + 119825$	0.79	0.01
Lucania parva	FB	throw-trap	occurrence	linear	$y = 0.0177x - 0.0608$	0.79	0.01
Lucania parva	FB	throw-trap	concentration	linear	$y = 4987.4x - 56519$	0.87	0.002
Lucania parva	FB	throw-trap	delta density	linear	$y = 4899.2x - 95119$	0.81	0.01
Lucania parva	FB	dropnet	concentration	linear	$y = -109.74x + 7265.1$	0.49	0.08
Lucania parva	FB	dropnet	delta density	linear	$y = -97.803x + 6881$	0.45	0.099
Lutjanus griseus	BB	trawl	occurrence	parabolic	$y=-0.0011x^2+0.0432x+0.0585$	0.97	0.01
Lutjanus griseus	BB	trawl	concentration	linear	$y = -0.4935x + 30.82$	0.72	0.03
Lutjanus griseus	BB	trawl	delta density	linear	$y = -0.3791x + 16.393$	0.95	0.001
Lutjanus griseus	FB	trawl	occurrence	parabolic	$y = -0.0007x^2 + 0.0525x - 0.8026$	0.80	0.08
Lutjanus griseus	FB	trawl	delta density	parabolic	$y = -0.0318x^2 + 2.3118x - 35.713$	0.82	0.08
Lutjanus griseus	BB	visual census	occurrence	linear	$y = 0.0044x + 0.131$	0.82	0.005
Opsanus beta	FB	trawl	occurrence	parabolic	$y = -0.0012x^2 + 0.0612x - 0.0851$	0.72	0.04
Opsanus beta	FB	trawl	concentration	linear	$y = 0.5546x + 31.494$	0.55	0.04
Opsanus beta	FB	trawl	delta density	parabolic	$y = -0.0651x^2 + 3.5999x - 15.81$	0.64	0.08
Opsanus beta	FB	throw-trap	occurrence	exponential	$y = 0.2158e^{0.0239x}$	0.83	0.001
Opsanus beta	FB	throw-trap	delta density	exponential	$y = 2999.4e^{0.047x}$	0.76	0.002
Sphyraena barracuda	BB	visual census	delta density	linear	$y = -1.3972x + 154.35$	0.42	0.08
Syngnathus scovelli	FB	trawl	occurrence	linear	$y = -0.0126x + 0.8021$	0.75	0.003
Syngnathus scovelli	FB	seine	concentration	exponential	$y = 79.873e^{0.0255x}$	0.78	0.001
Syngnathus scovelli	FB	seine	delta density	exponential	$y=54.605e^{0.0234x}$	0.60	0.009
Syngnathus scovelli	BB	throw-trap	delta density	parabolic	$y = -7.7216x^2 + 412.01x - 2484.5$	0.97	0.01

Table 7. Results of pair-wise comparisons of the community structure of each salinity bin (Biscayne Bay visual census). All cells contain p-values pertaining to each comparison; statistically significant (P<0.05) differences are indicated via underlined, bold font.

BIN	<5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40
<5	1.000	0.4550	0.2174	0.0940	**0.0388**	**0.0086**	**0.0106**	**0.0012**	**0.0328**
5-10		1.0000	0.8524	0.2772	**0.0384**	**0.0046**	**0.0014**	**0.0002**	**0.0096**
10-15			1.0000	0.7060	0.0864	0.1094	**0.0196**	**0.0034**	**0.0188**
15-20				1.0000	0.2710	0.0592	**0.0020**	**0.0002**	**0.0058**
20-25					1.0000	0.4736	0.2252	**0.0204**	0.0594
25-30						1.0000	0.4472	**0.0374**	0.0628
30-35							1.0000	0.1986	0.1184
35-40								1.0000	0.3700
>40									1.0000

Table 8. Regression probability-values associated with correlations between salinity range and fish abundance along Biscayne Bay mangroves during the wet season.

species	occurrence	concentration	delta density
Eucinostomus sp.	NS	0.03	0.097
Floridichthys carpio	NS	NS	NS
Gerres cinereus	NS	NS	NS
Haemulon sciurus	0.002	0.01	0.04
Lutjanus apodus	0.02	0.004	0.01
Lutjanus griseus	0.08	NS	0.09
Sphyraena barracuda	NS	NS	NS
Significant 90%	3	3	4
Significant 95%	2	3	2

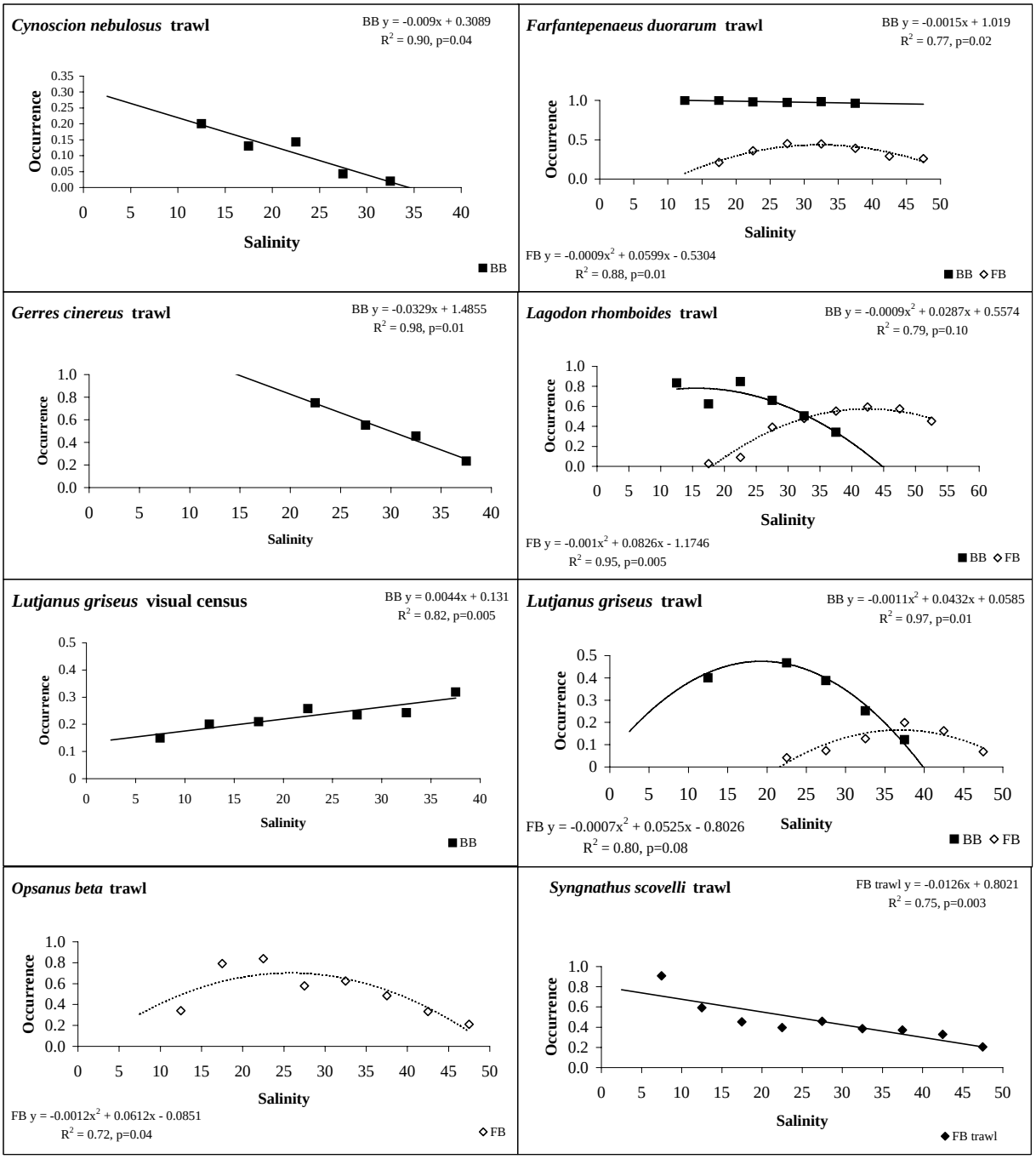


Figure 1. Summary of significant frequency of occurrence relationships with salinity found for Biscayne (BB, solid symbols, solid line and Florida Bays (FB, open symbols, dotted line) using visual census and trawl gears.

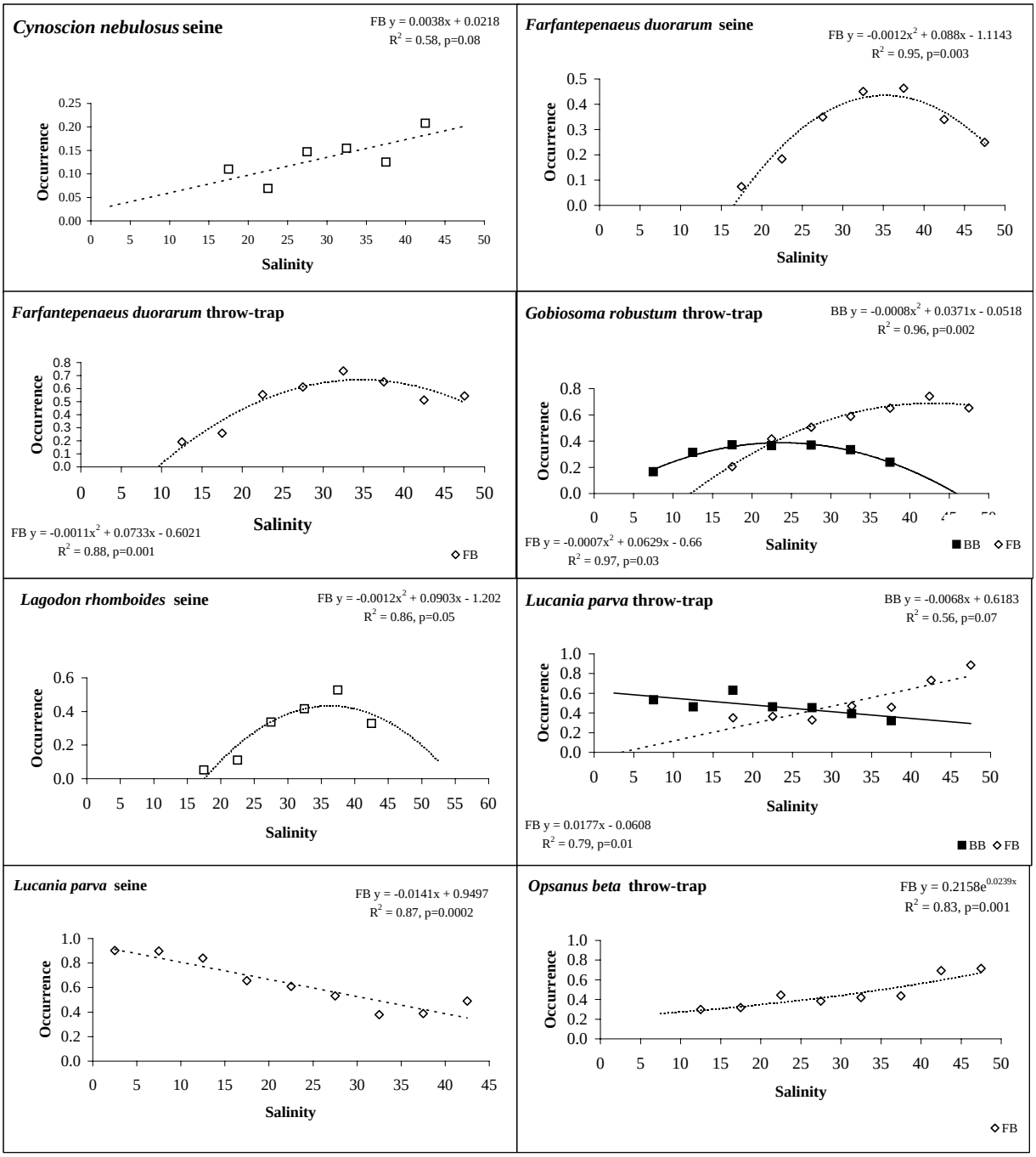


Figure 2. Summary of significant frequency of occurrence relationships with salinity found for Biscayne (BB, solid symbols, solid line and Florida Bays (FB, open symbols, dotted line) using seine, dropnet, and throw-trap gears.

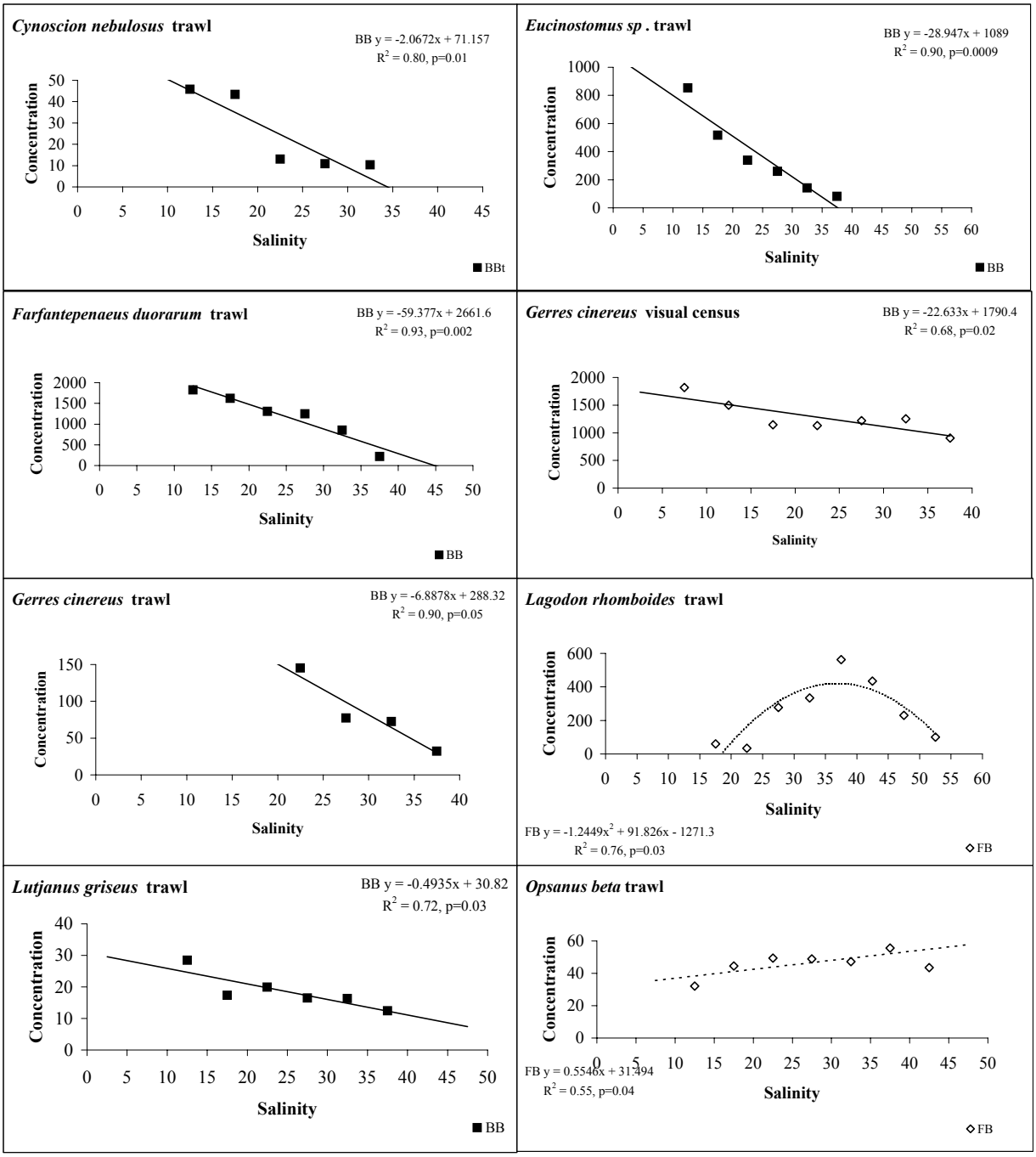


Figure 3. Summary of significant concentration (density of positive catches) relationships with salinity found for Biscayne (BB, solid line) and Florida Bays (FB, dotted line) using visual census and trawl gears (number/hectare).

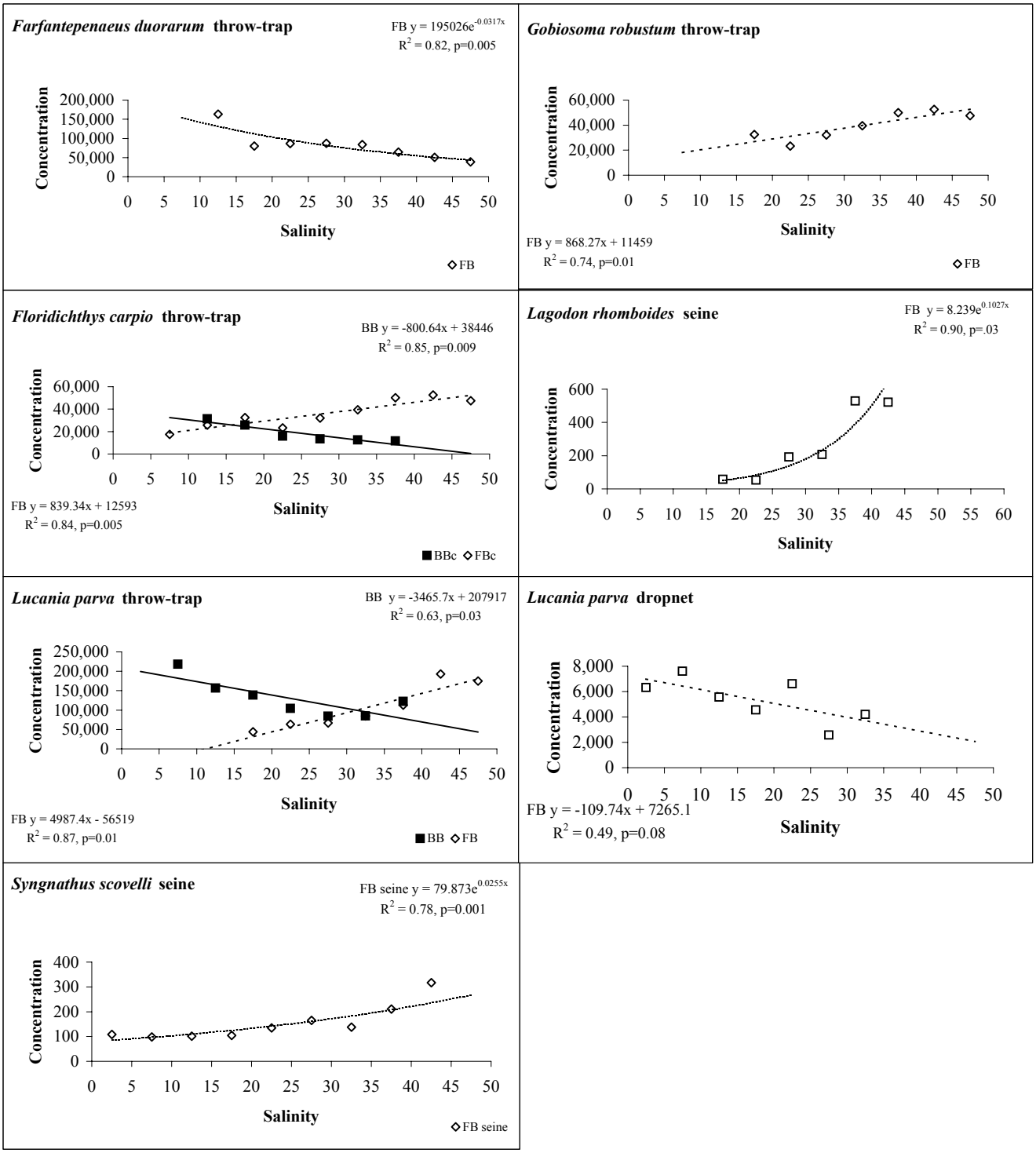


Figure 4. Summary of significant concentration (density of positive catches) relationships with salinity found for Biscayne (BB, solid line) and Florida Bays (FB, dotted line) using seine, dropnet, and throw-trap gears (number/hectare).

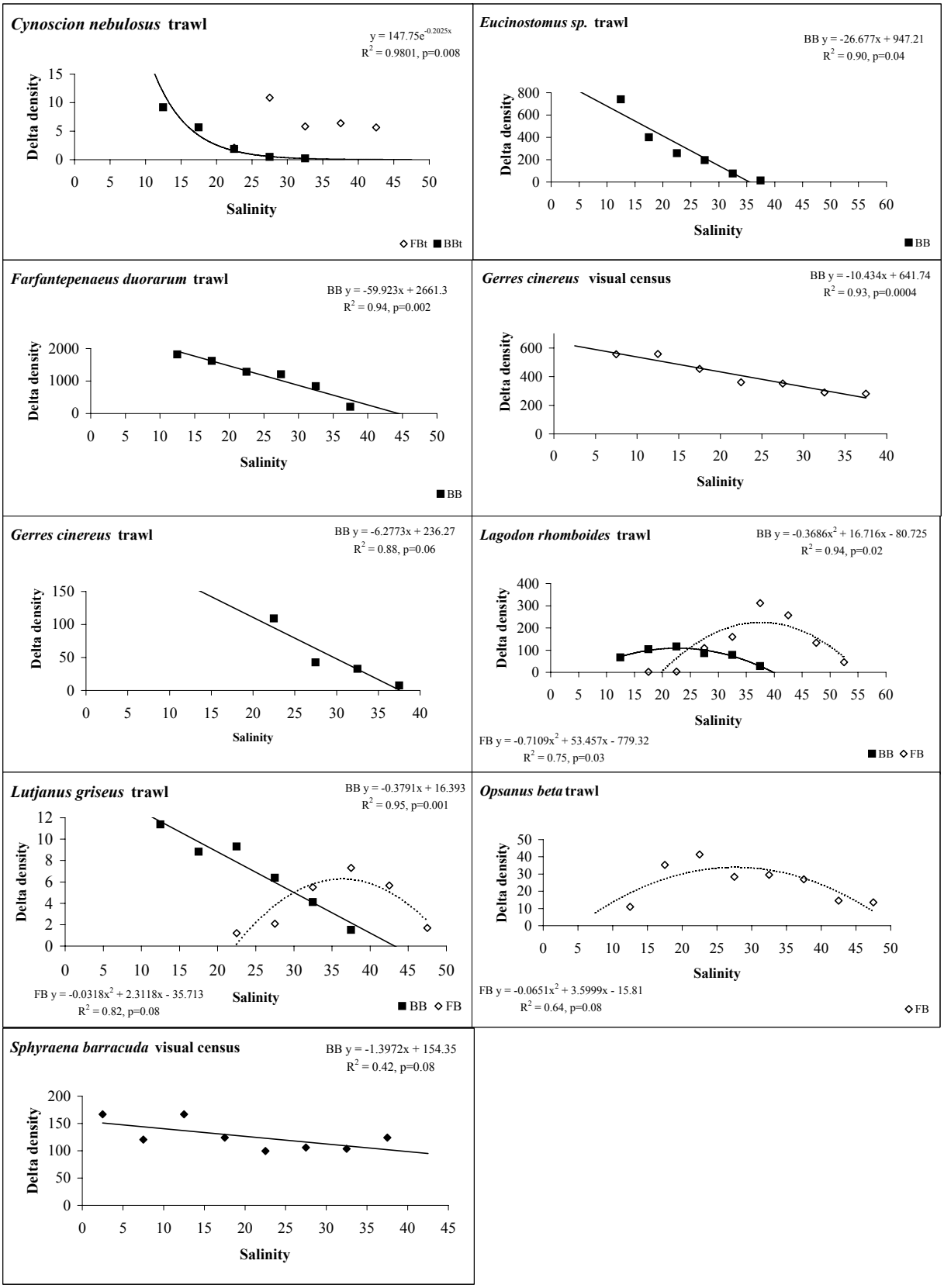


Figure 5. Summary of significant delta density relationships with salinity found for Biscayne (BB, solid line) and Florida Bays (FB, dotted line) using visual census and trawl gears (number/hectare).

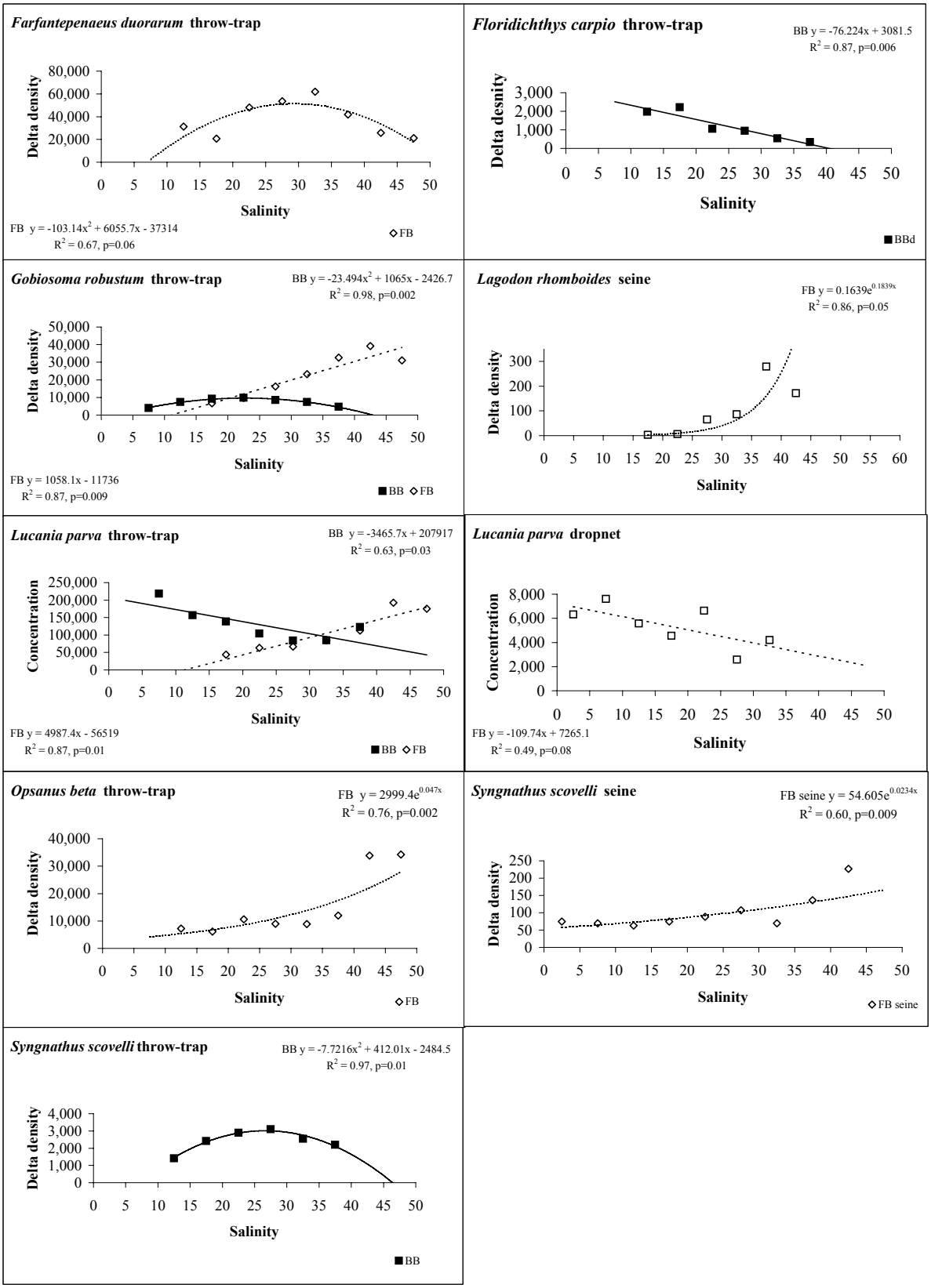
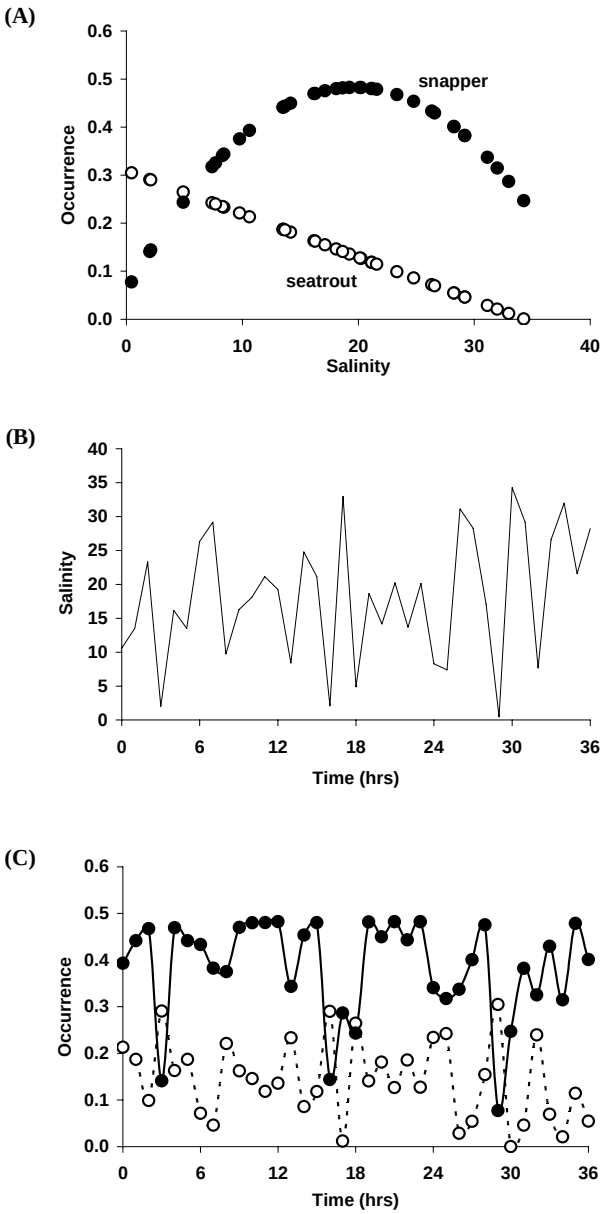


Figure 6. Summary of significant delta density relationships with salinity found for Biscayne (BB, solid line) and Florida Bays (FB, dotted line) using seine, dropnet, and throw-trap gears (number/hectare).

Figure 7. Hypothetical example of the utility of our HSI models. The table depicts a hypothetical salinity time series for a given location which is used to generate a time series of predicted occurrences (suitability indices) for young of the year spotted seatrout and gray snapper. Salinity-affinity relationships, salinity time series and fish time series are presented in panels (A), (B) and (C), respectively.

Hypothetical		Predicted	
Time (hrs)	Salinity	Seatrout	Snapper
0	10.62	0.21	0.39
1	13.52	0.19	0.44
2	23.34	0.10	0.47
3	2.02	0.29	0.14
4	16.18	0.16	0.47
5	13.52	0.19	0.44
6	26.34	0.07	0.43
7	29.17	0.05	0.38
8	9.76	0.22	0.38
9	16.27	0.16	0.47
10	18.09	0.15	0.48
11	21.14	0.12	0.48
12	19.23	0.14	0.48
13	8.40	0.23	0.34
14	24.78	0.09	0.45
15	21.16	0.12	0.48
16	2.09	0.29	0.14
17	32.98	0.01	0.29
18	4.90	0.26	0.24
19	18.65	0.14	0.48
20	14.17	0.18	0.45
21	20.24	0.13	0.48
22	13.68	0.19	0.44
23	20.15	0.13	0.48
24	8.28	0.23	0.34
25	7.39	0.24	0.32
26	31.13	0.03	0.34
27	28.27	0.05	0.40
28	17.12	0.15	0.48
29	0.45	0.30	0.08
30	34.28	0.00	0.25
31	29.19	0.05	0.38
32	7.68	0.24	0.33
33	26.58	0.07	0.43
34	31.99	0.02	0.31
35	21.58	0.11	0.48
36	28.24	0.05	0.40



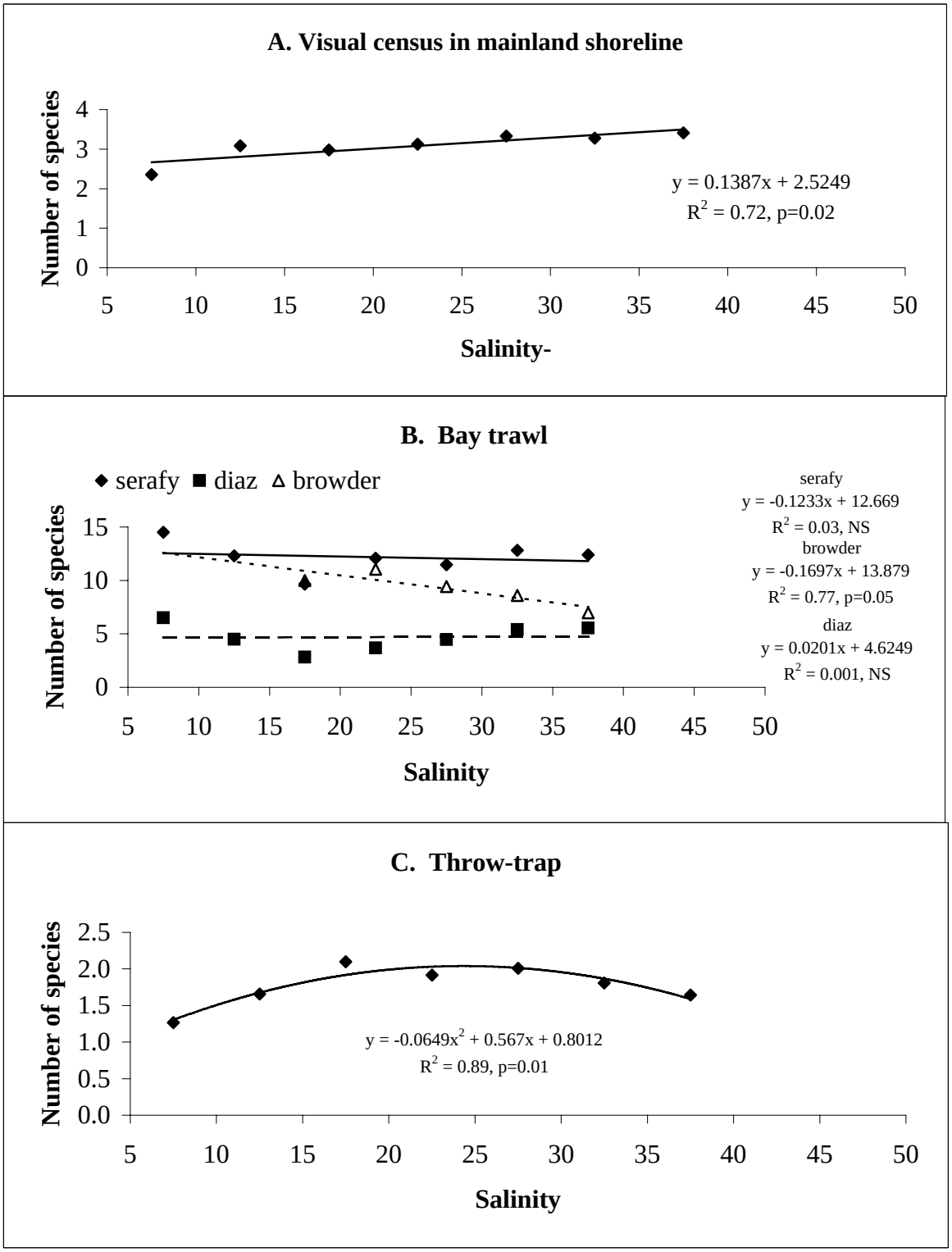


Figure 8. Average number of species collected in Biscayne Bay by salinity bin A. Visual census (Serafy 1998-2006) B. Trawl (Serafy 1993-1994, Diaz 1996-1997, Browder 2002-2004) C. Throw-trap (Browder 2005-2006)

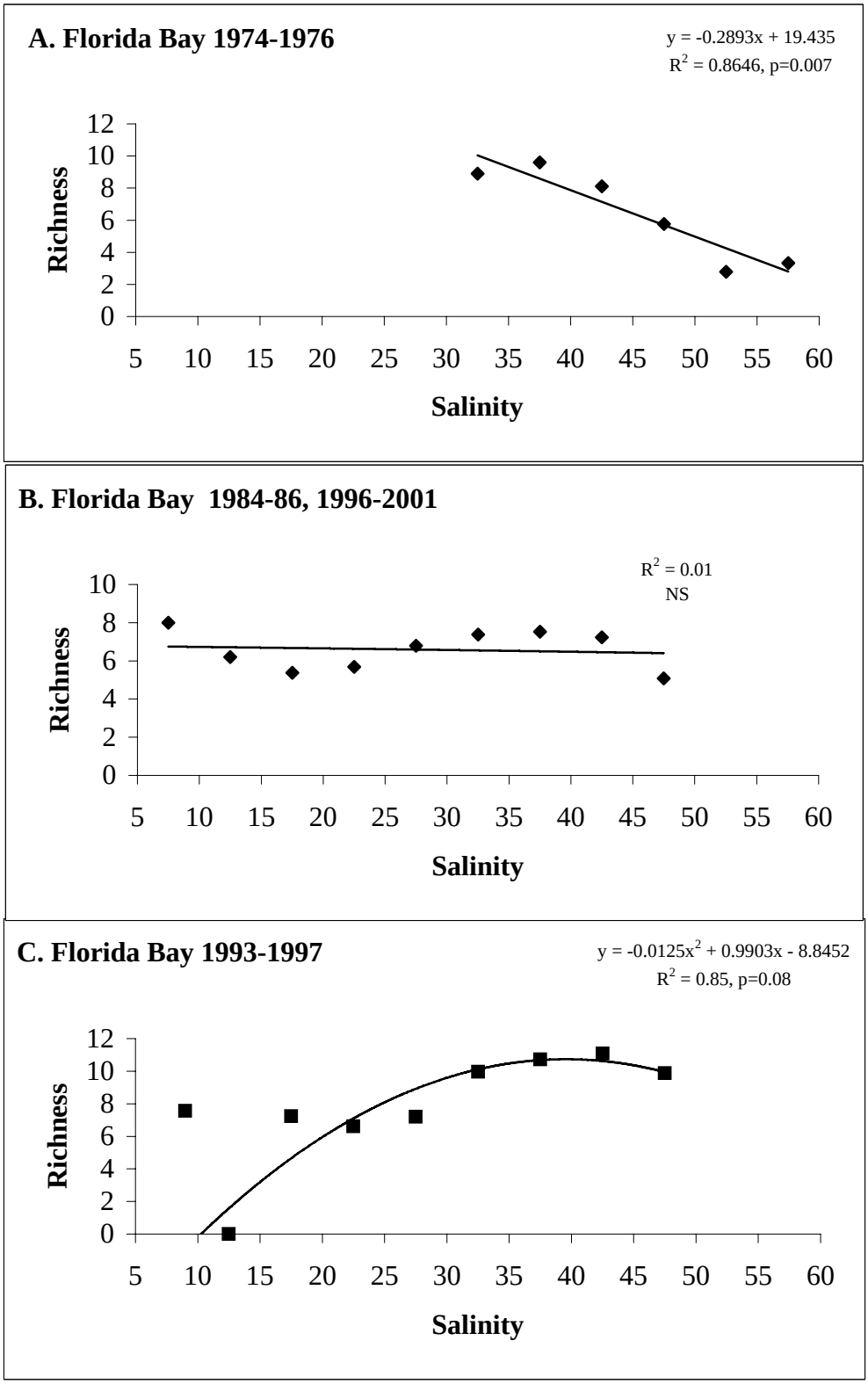


Figure 9. Florida Bay taxonomic richness by salinity for three trawl studies A. Schmidt 1974-1976, B. Powell 1984-1986, 1994-2001, and C. Colvocoresses 1993-1997.

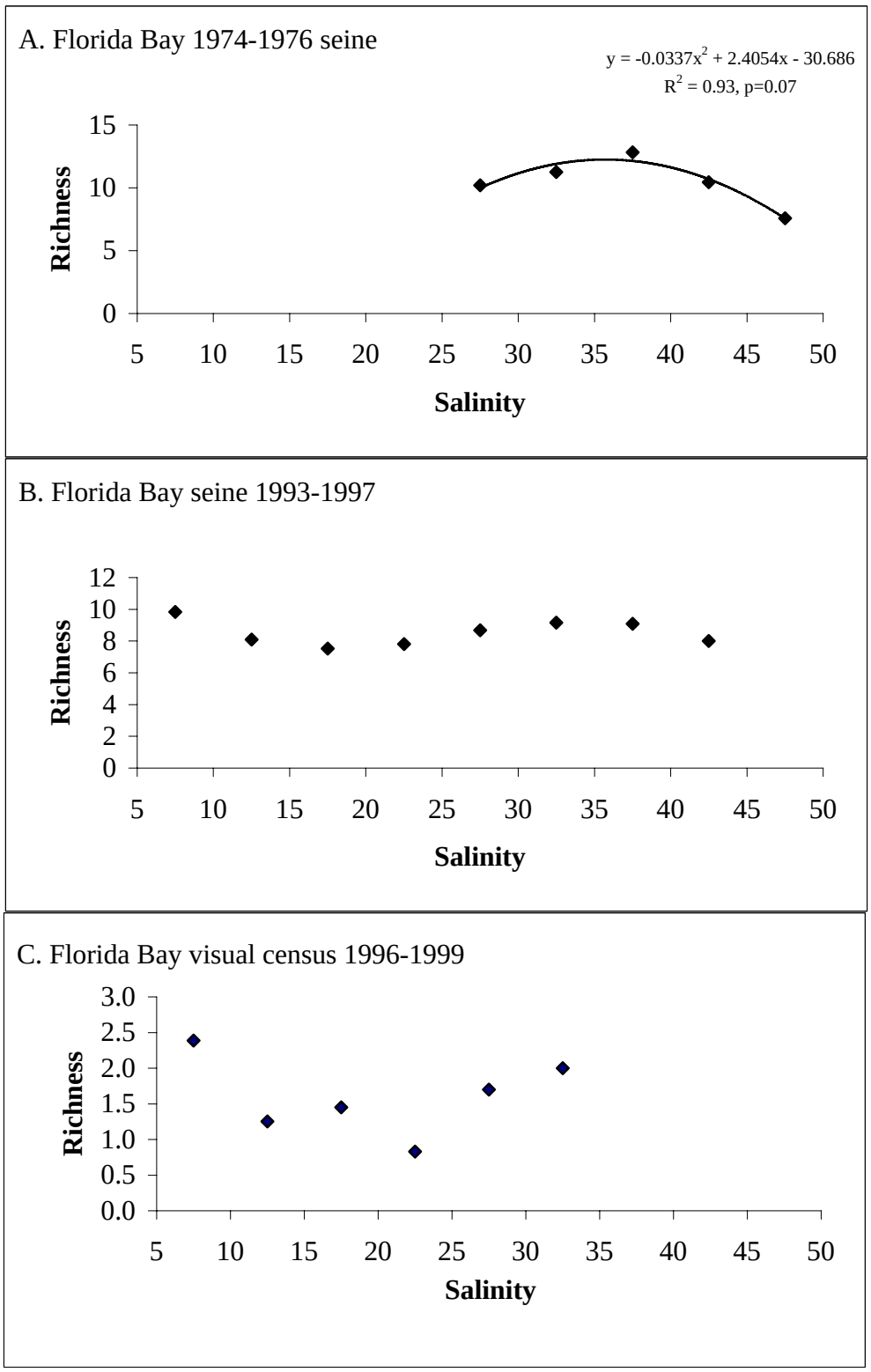


Figure10. Florida Bay taxonomic richness by salinity for two seine studies and one visual census study A. Schmidt (1974-1976) B. Colvocoresses (1993-1997) and C. Faunce (1996-1999).

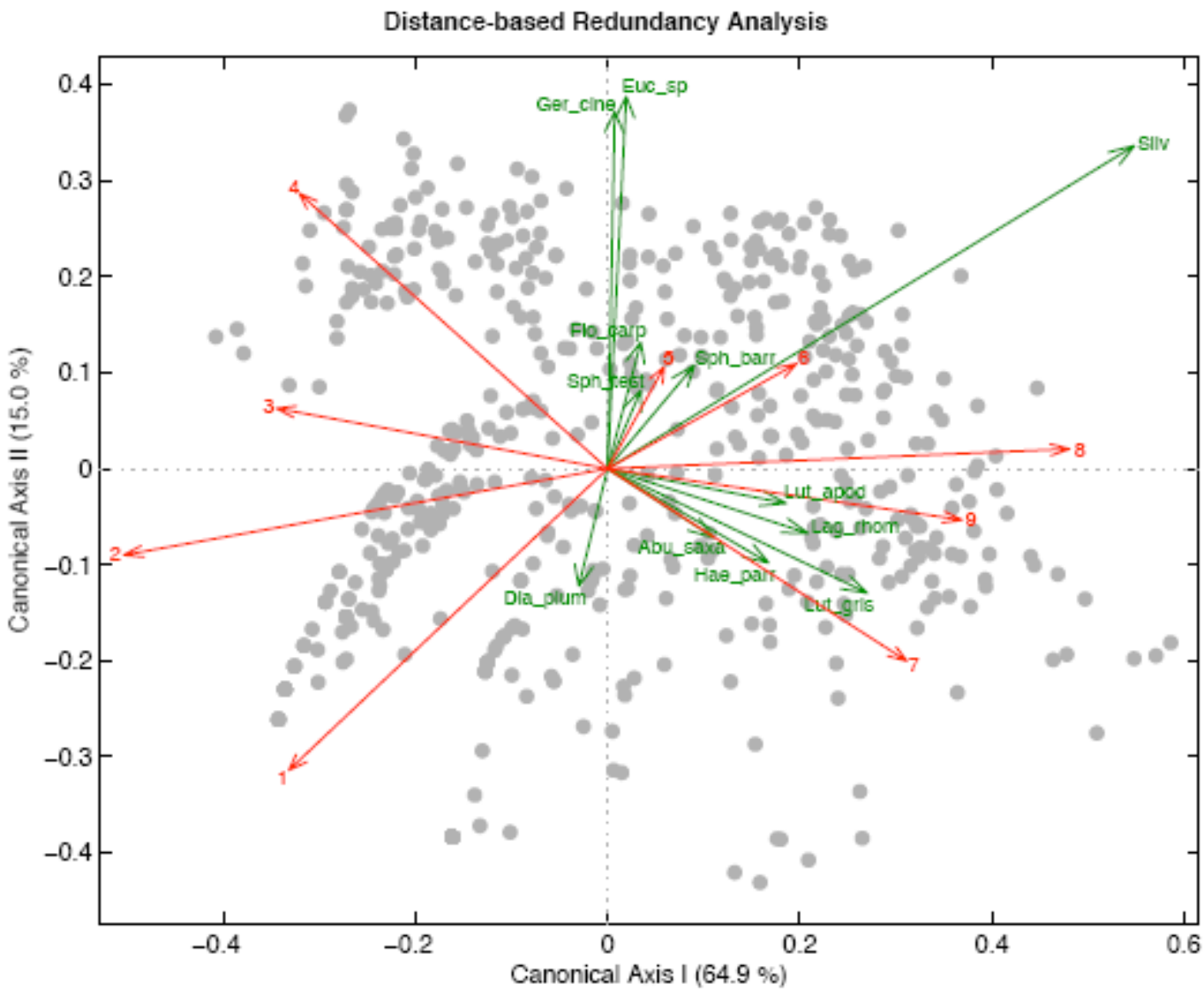


Figure 11. Distance-based redundancy ordination biplot (F=2.14, p=0.001) of wet season Biscayne Bay mainland shoreline species composition dissimilarity by salinity bins (1=0-5 psu, 2=6-10 psu, 3=11-15 psu, 4=16-20 psu, 5=21-25 psu, 6=26-30 psu, 7=31-35 psu, 8=36-40 psu, 9=41-45 psu) with most important species influencing species dissimilarity overlaid on plot. Species centroids (green text) represent abundance maxima for each taxa and are defined as follows: Abu_saxa = sergeant major, Dia_plum = striped mojarra, Euc_sp = *Eucinostomus* mojarras, Flo_carp = goldspotted killifish, Ger_cine = yellowfin mojarra, Hae_parr = Sailor's choice, Hae_sciu = bluestriped grunt, Lag_rhom = pinfish, Lut_apod = schoolmaster, Lut_gris = gray snapper, Sph_test = checkered puffer, and Sph_barr = great barracuda.

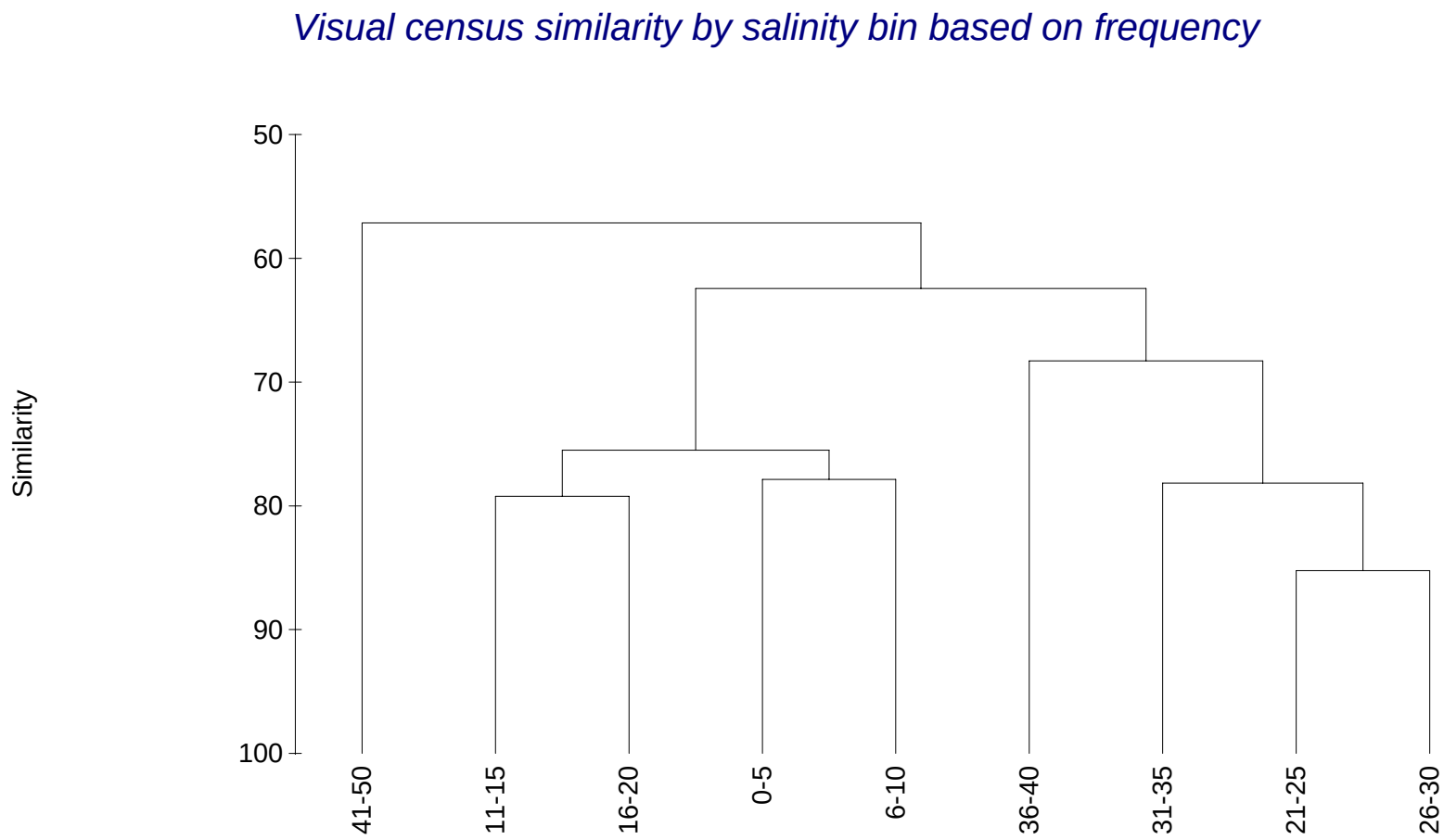


Figure 12. Cluster analysis of species composition (frequency of occurrence) by salinity bin for Biscayne Bay visual census data for the wet season mainland shoreline.

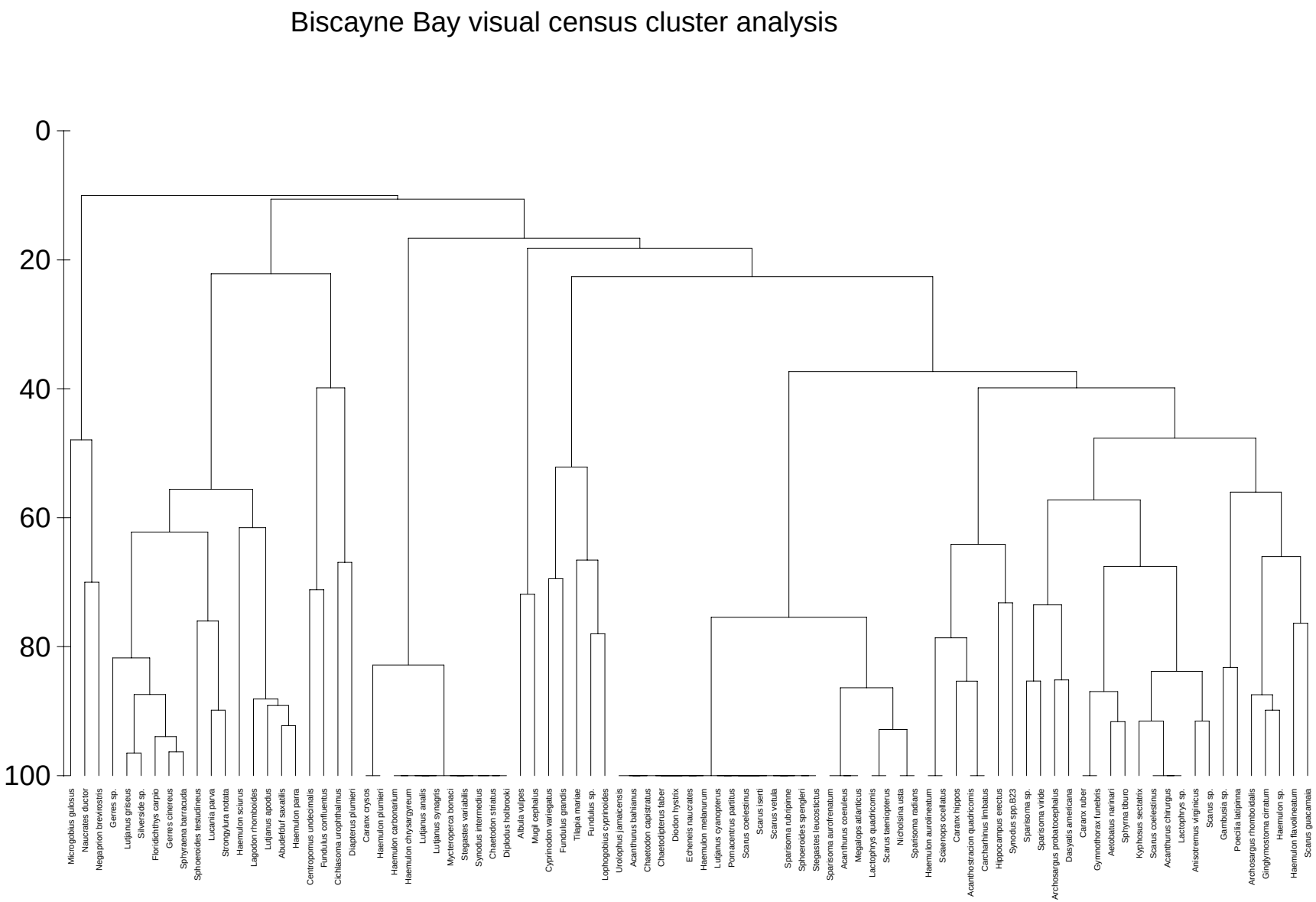


Figure 13. Cluster analysis by species for Biscayne Bay visual census wet season mainland shoreline.

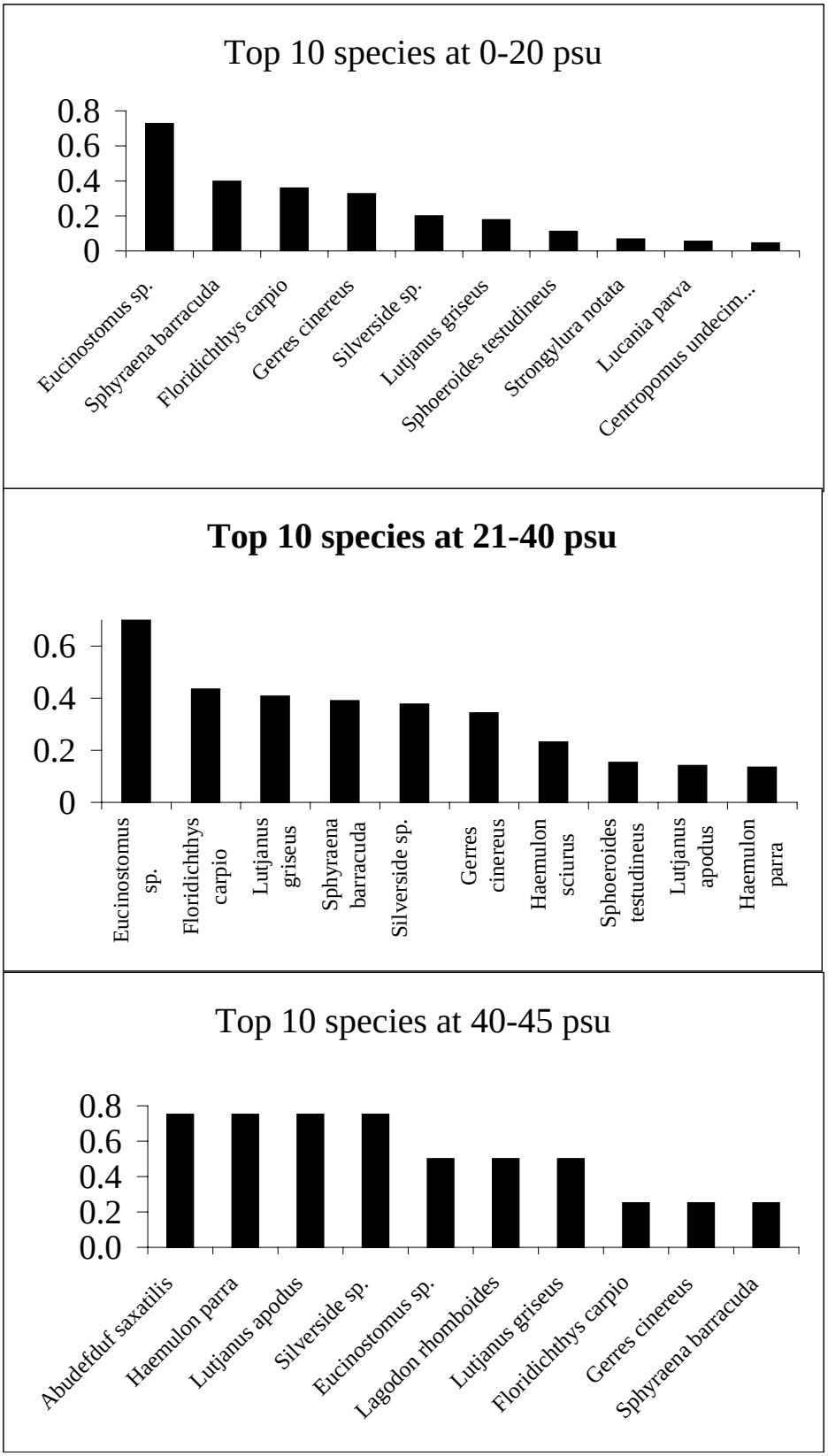


Figure 14. Most frequently occurring species by salinity groupings.

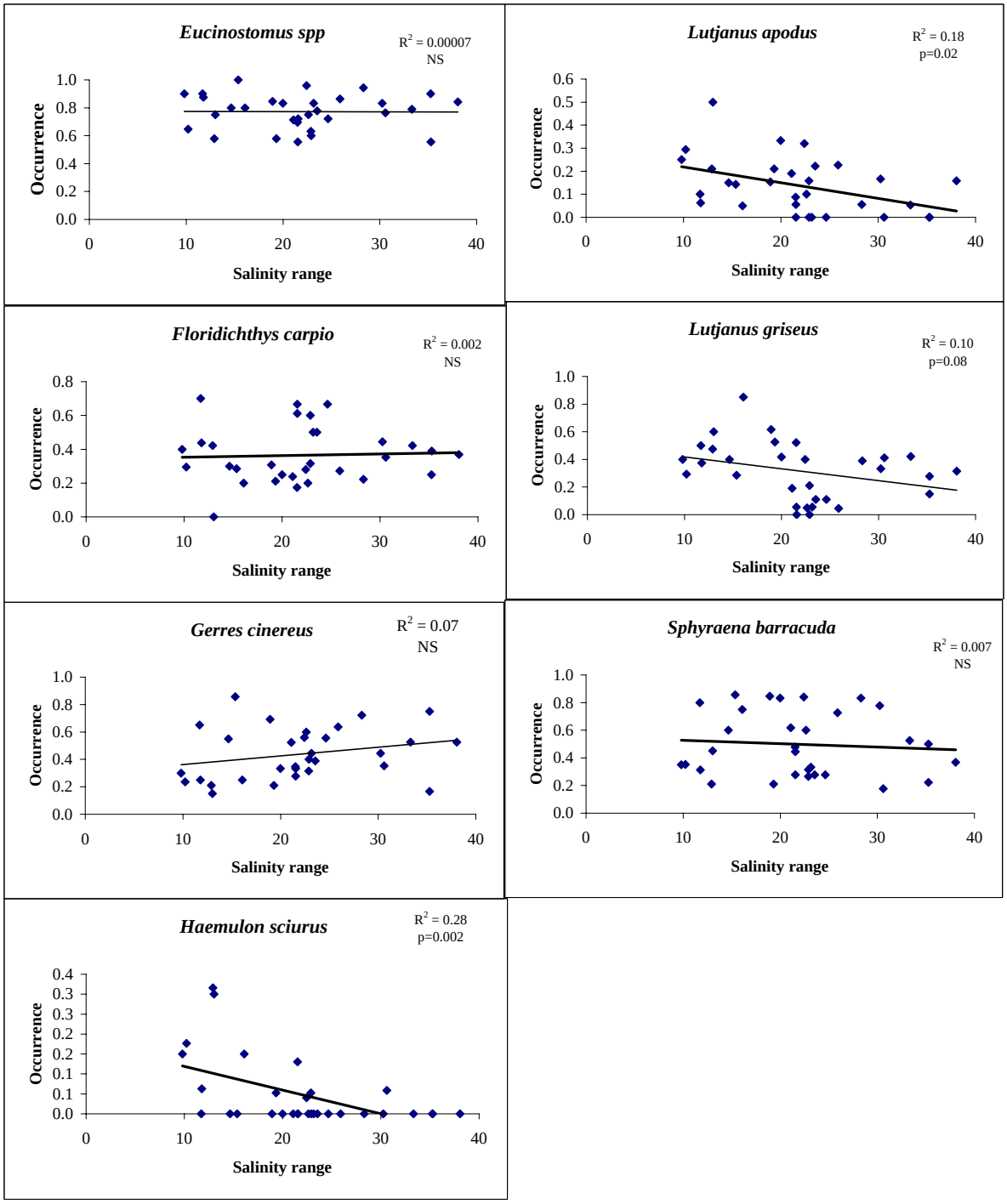


Figure 15. Frequency of occurrence by salinity range for species found in the wet season mangrove mainland shoreline (visual census) with r2 and p-value, NS= not significant.

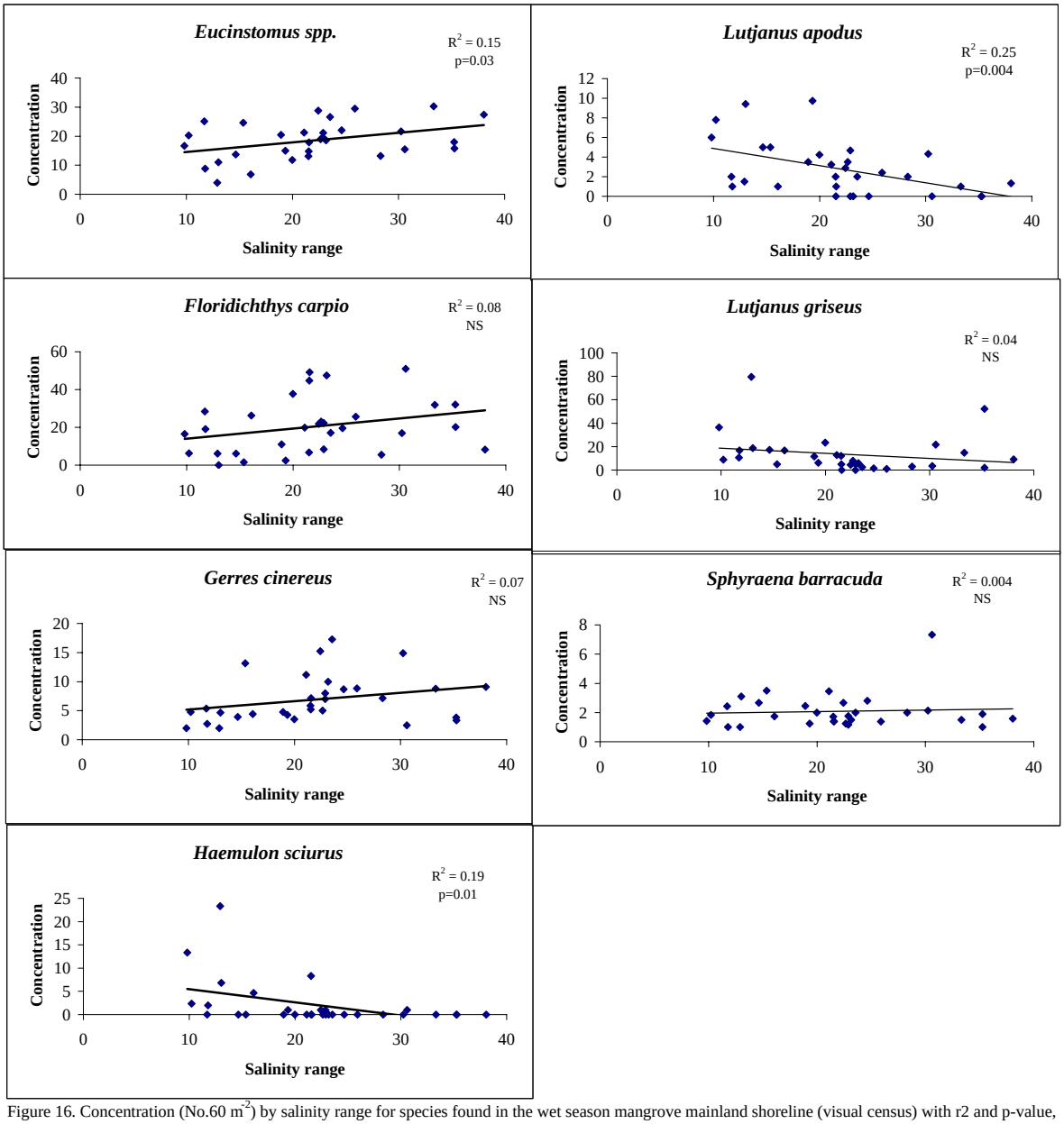


Figure 16. Concentration (No.60 m^{-2}) by salinity range for species found in the wet season mangrove mainland shoreline (visual census) with r2 and p-value, NS= not significant.

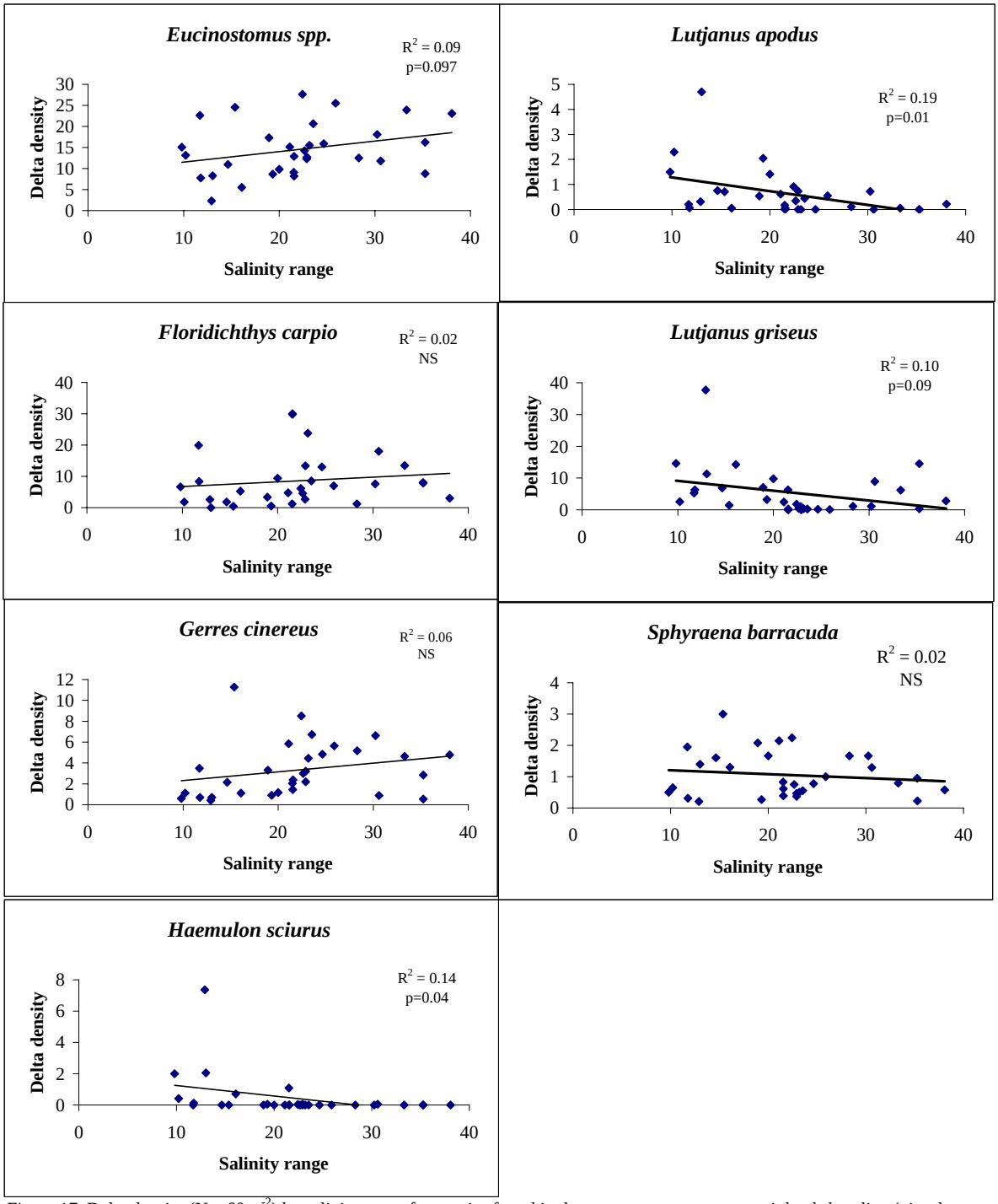
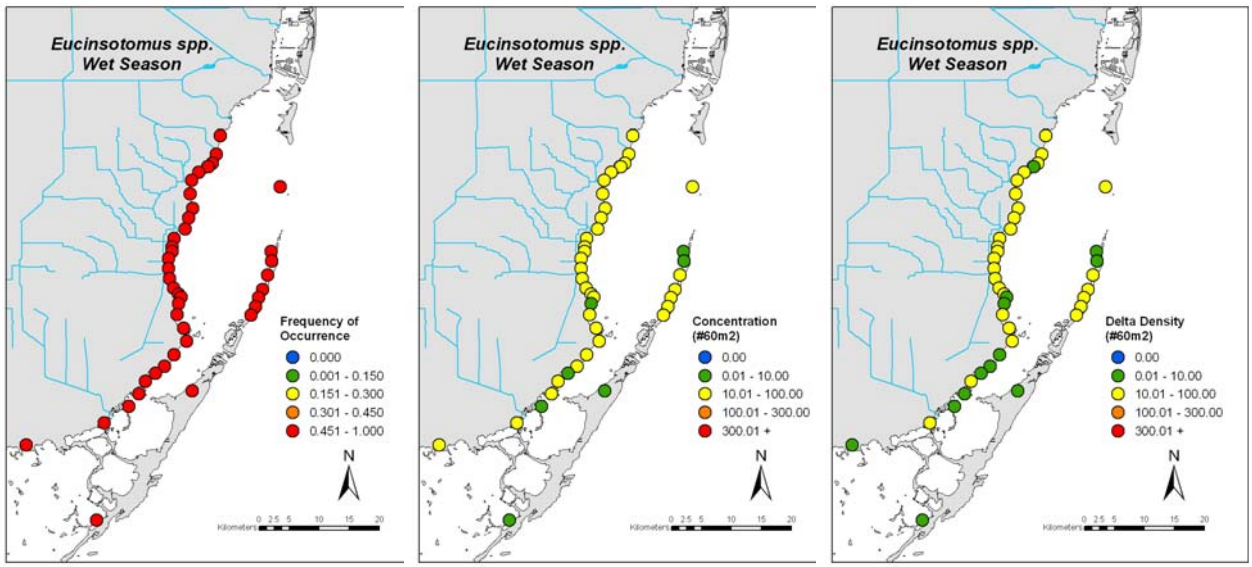


Figure 17. Delta density (No. 60 m^{-2}) by salinity range for species found in the wet season mangrove mainland shoreline (visual census) with r2 and p-value, NS= not significant.

Wet Season



Dry Season

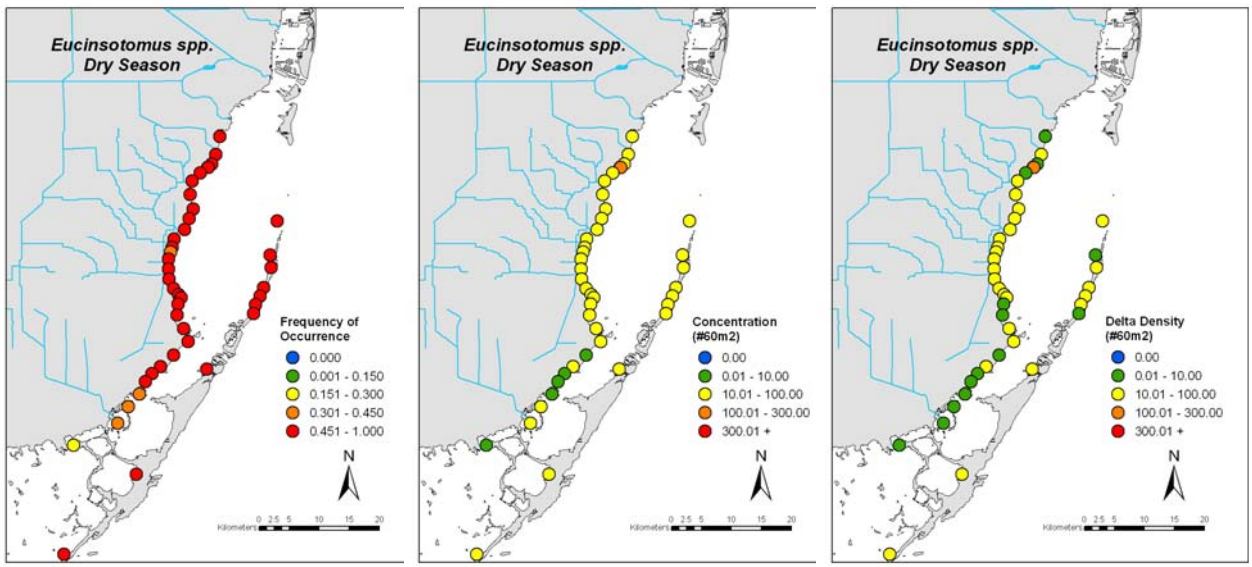
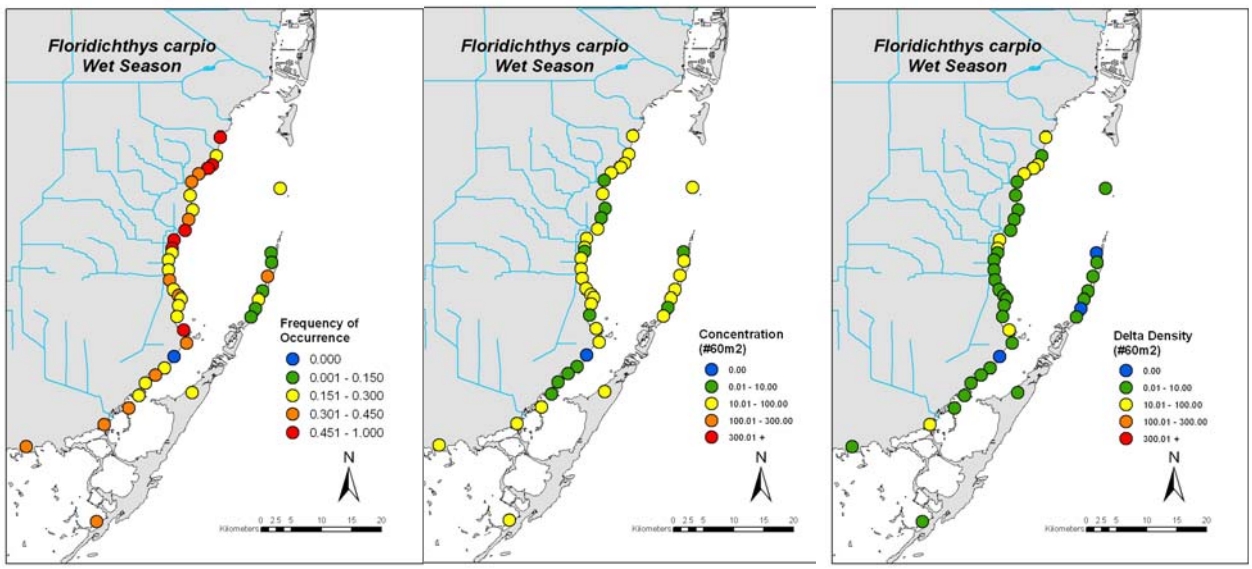


Figure 18. Wet and dry season frequency of occurrence, concentration (No. per 60 m^2) and delta density of small mojarras (*Eucinostomus spp.)* grouped by variability segments.

Wet Season



Dry Season

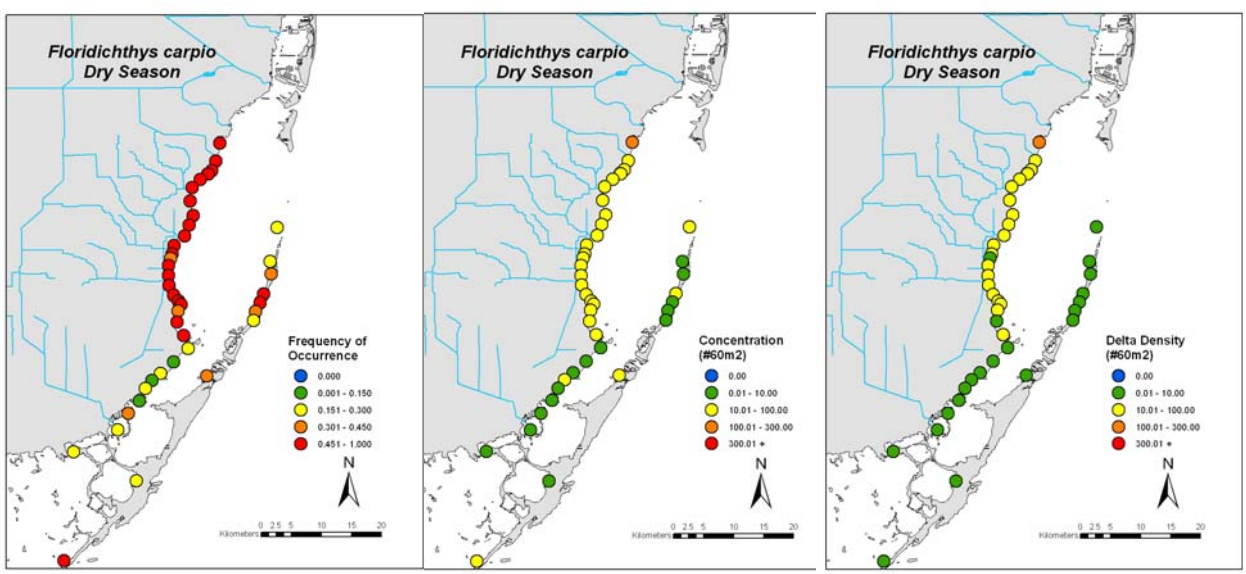
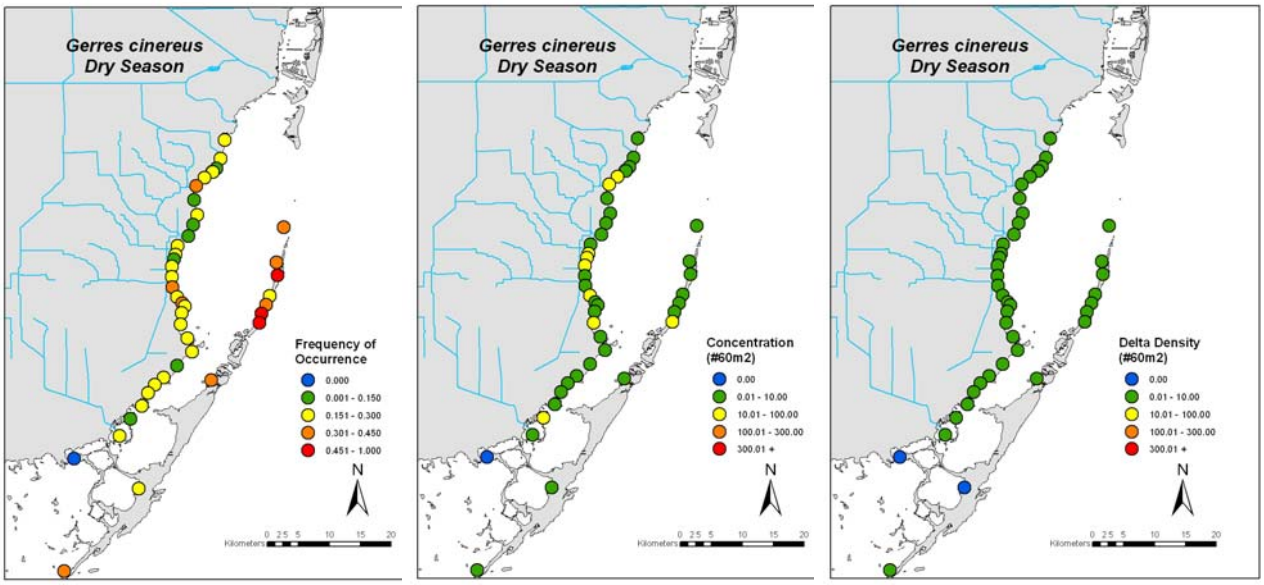


Figure 19. Wet and dry season frequency of occurrence, concentration (No. per 60 m^2) and delta density of gold-spotted killifish (*Floridichthys carpio)* grouped by variability segments.

Wet Season



Dry Season

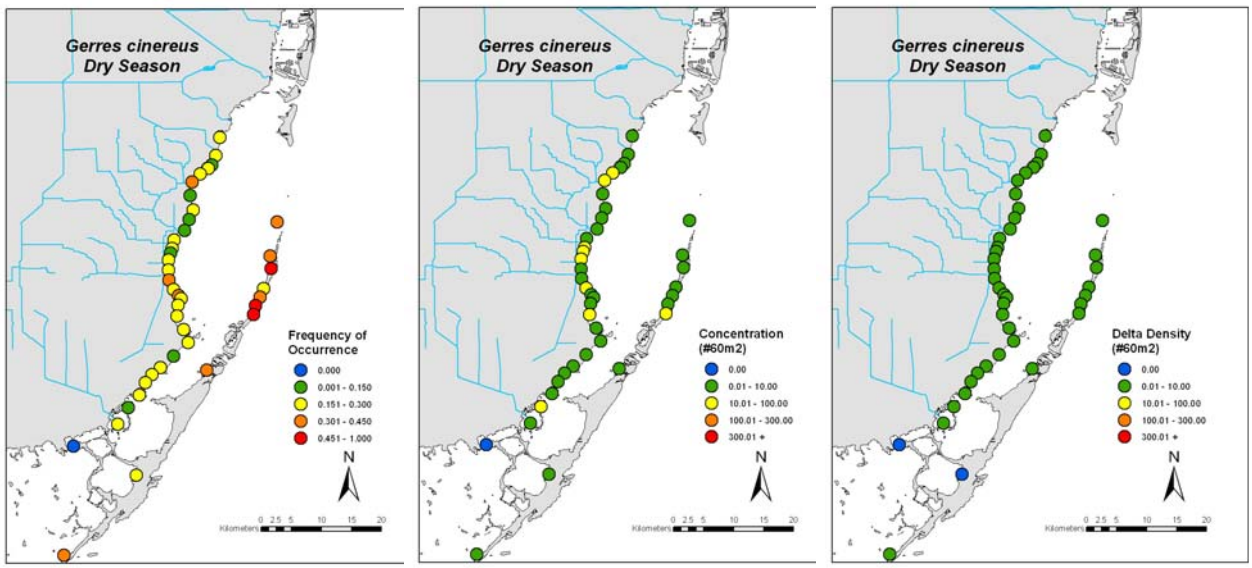
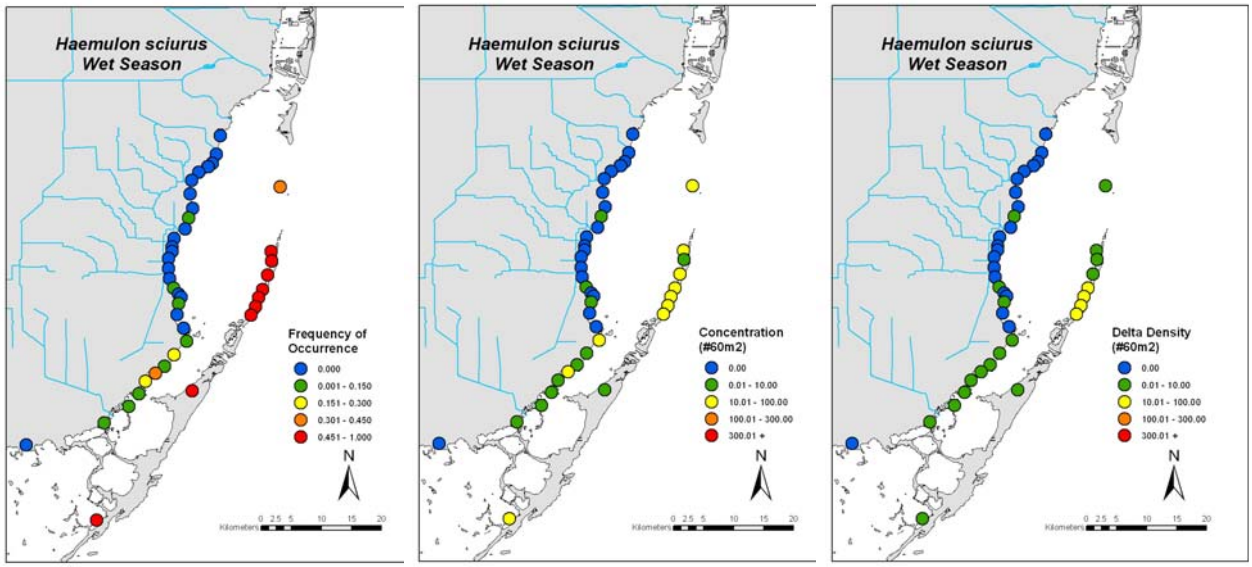


Figure 20. Wet and dry season frequency of occurrence, concentration (No. per 60 m^2) and delta density of yellowfin mojarra (*Gerres cinereus).* grouped by variability segments.

Wet Season



Dry Season

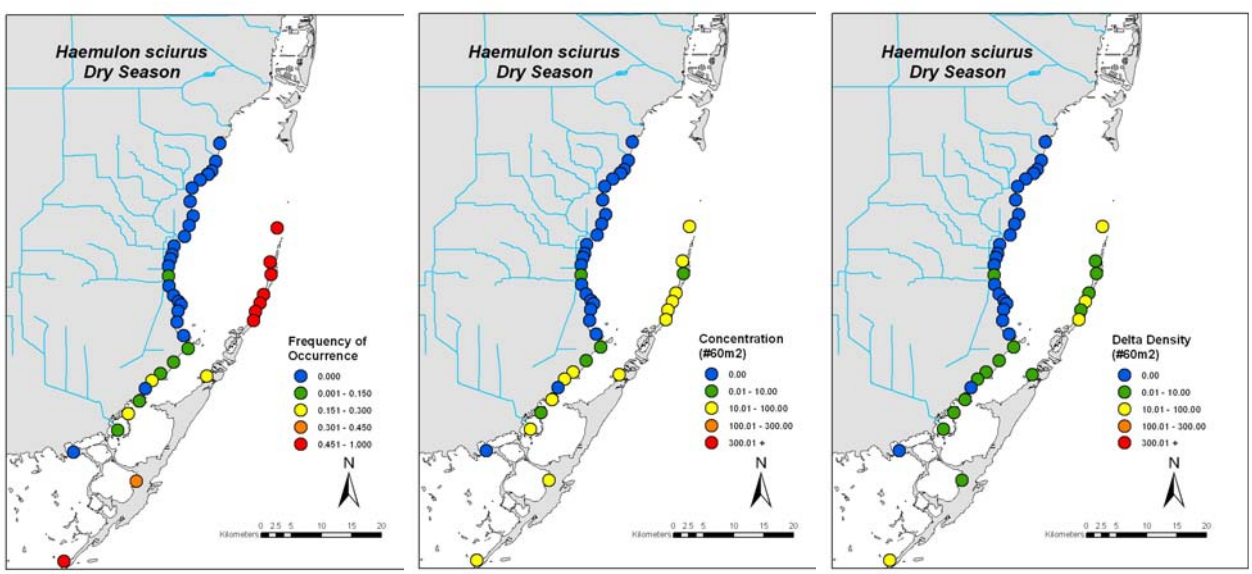
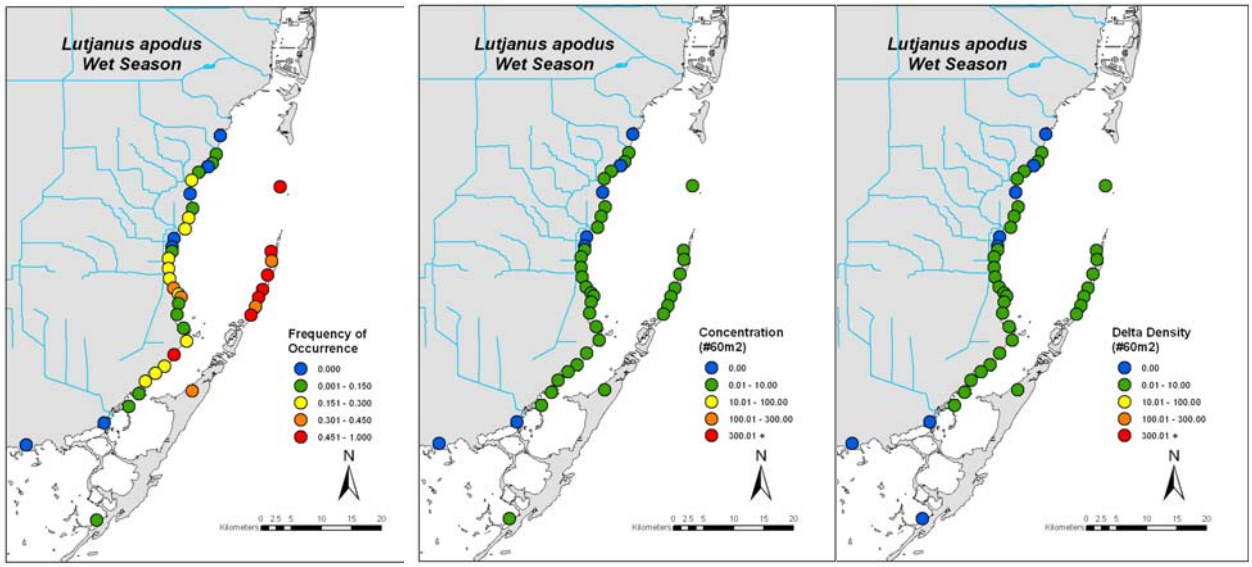


Figure 21. Wet and dry season frequency of occurrence, concentration (No. per 60 m^2) and delta density of blue striped grunt (*Haemulon sciurus).* grouped by variability segments.

Wet Season



Dry Season

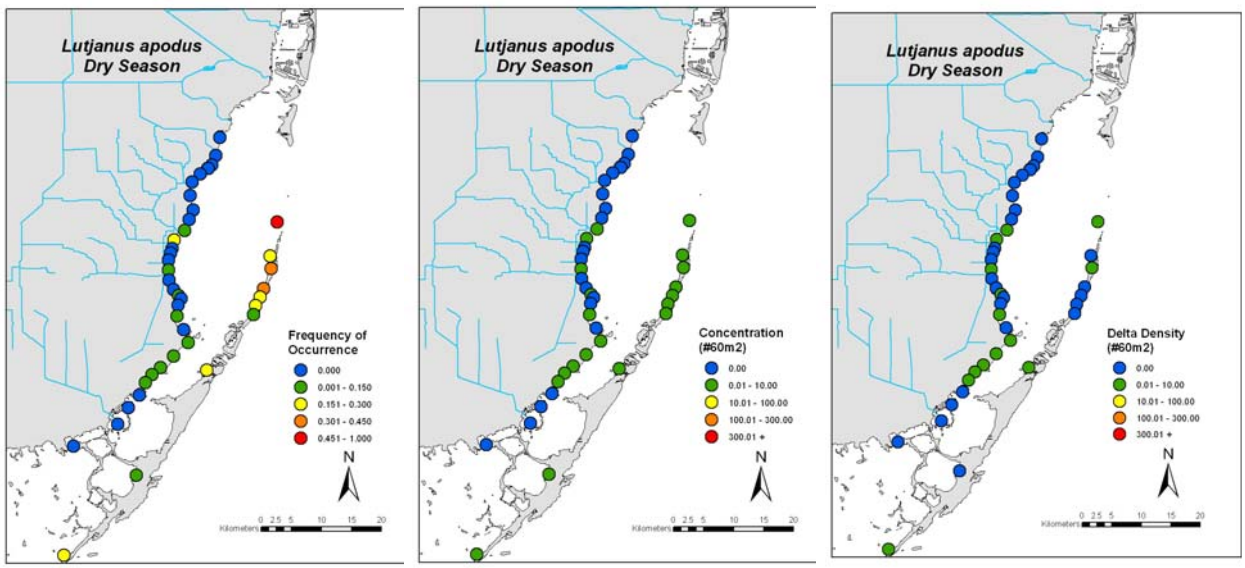
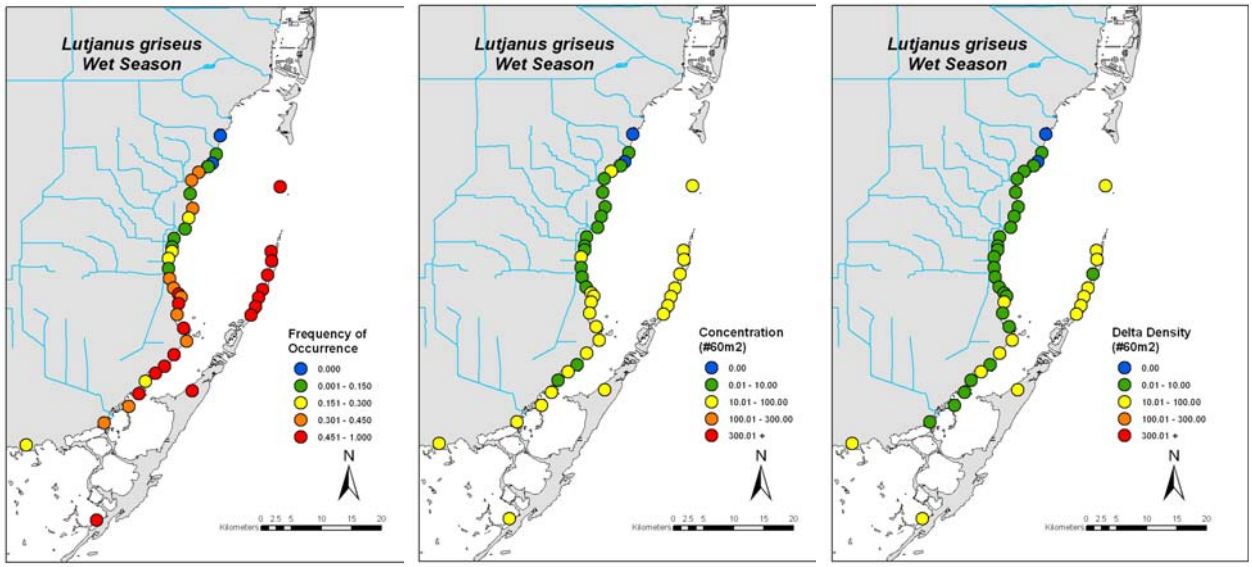


Figure 22. Wet and dry season frequency of occurrence, concentration (No. per 60 m^2) and delta density of schoolmaster (*Lutjanus apodus)* grouped by variability segments.

Wet Season



Dry Season

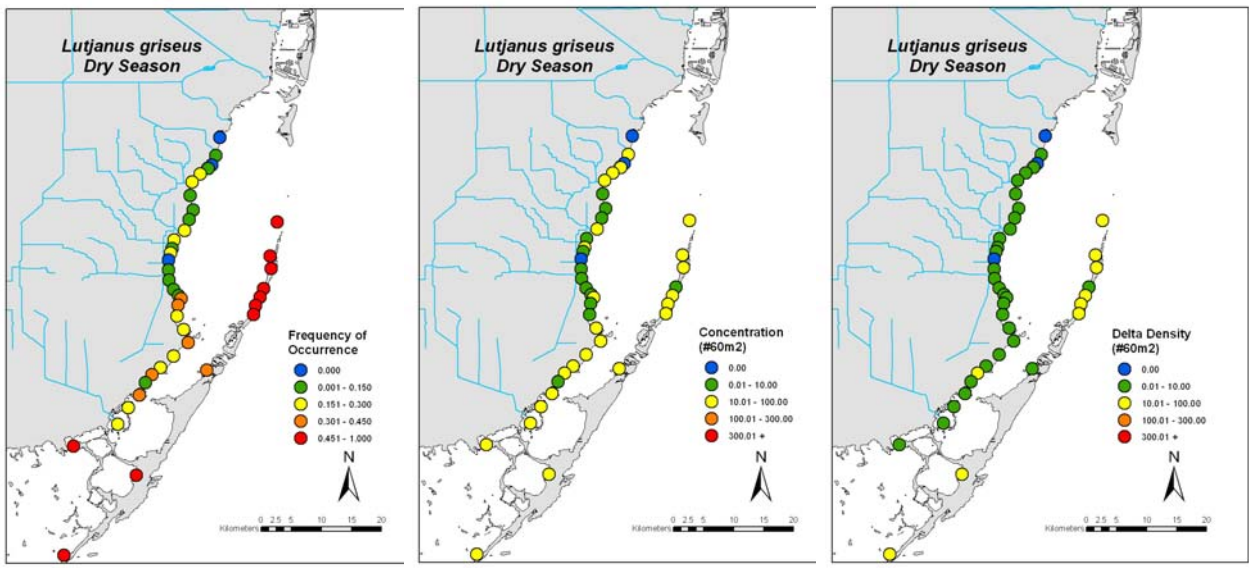
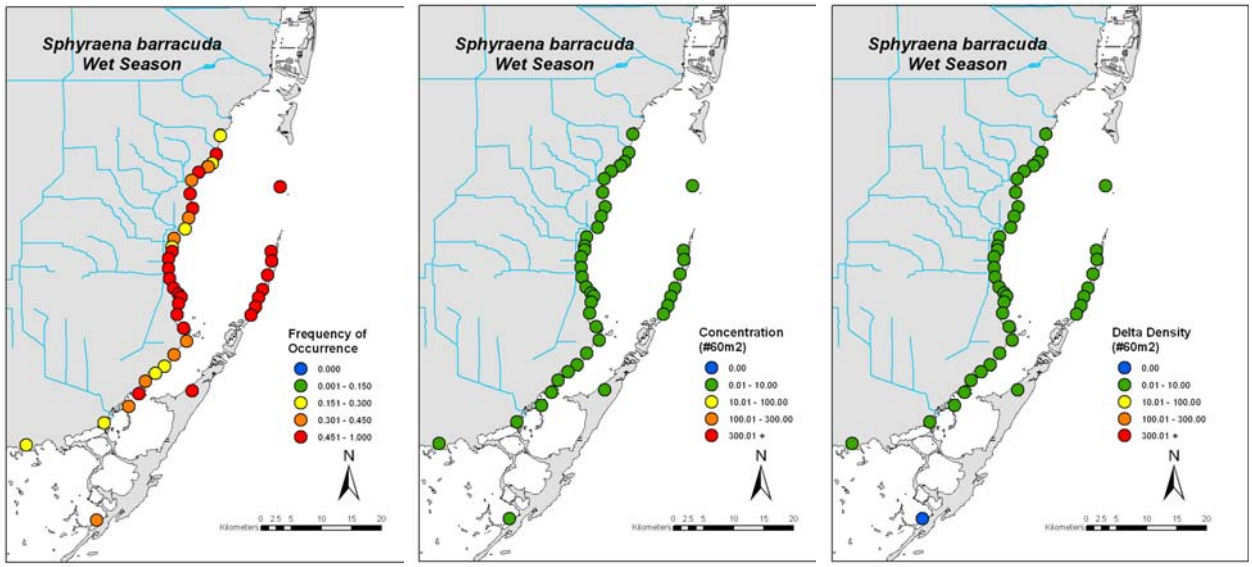


Figure 23. Wet and dry season frequency of occurrence, concentration (No. per 60 m^2) and delta density of gray snapper (*Lutjanus griseus)* grouped by variability segments.

Wet Season



Dry Season

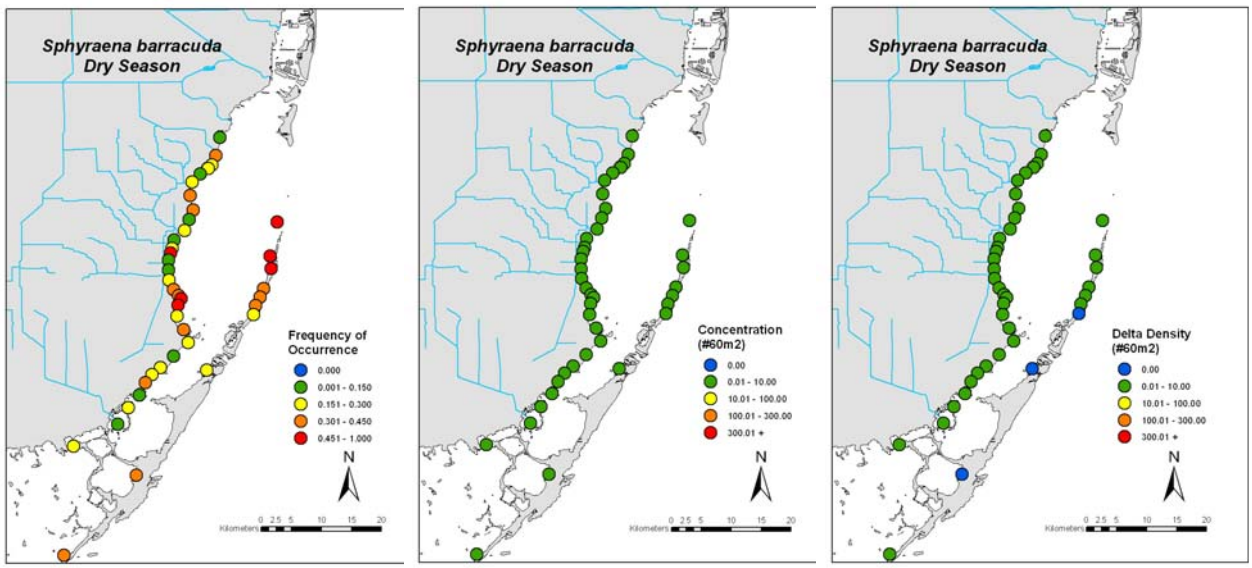
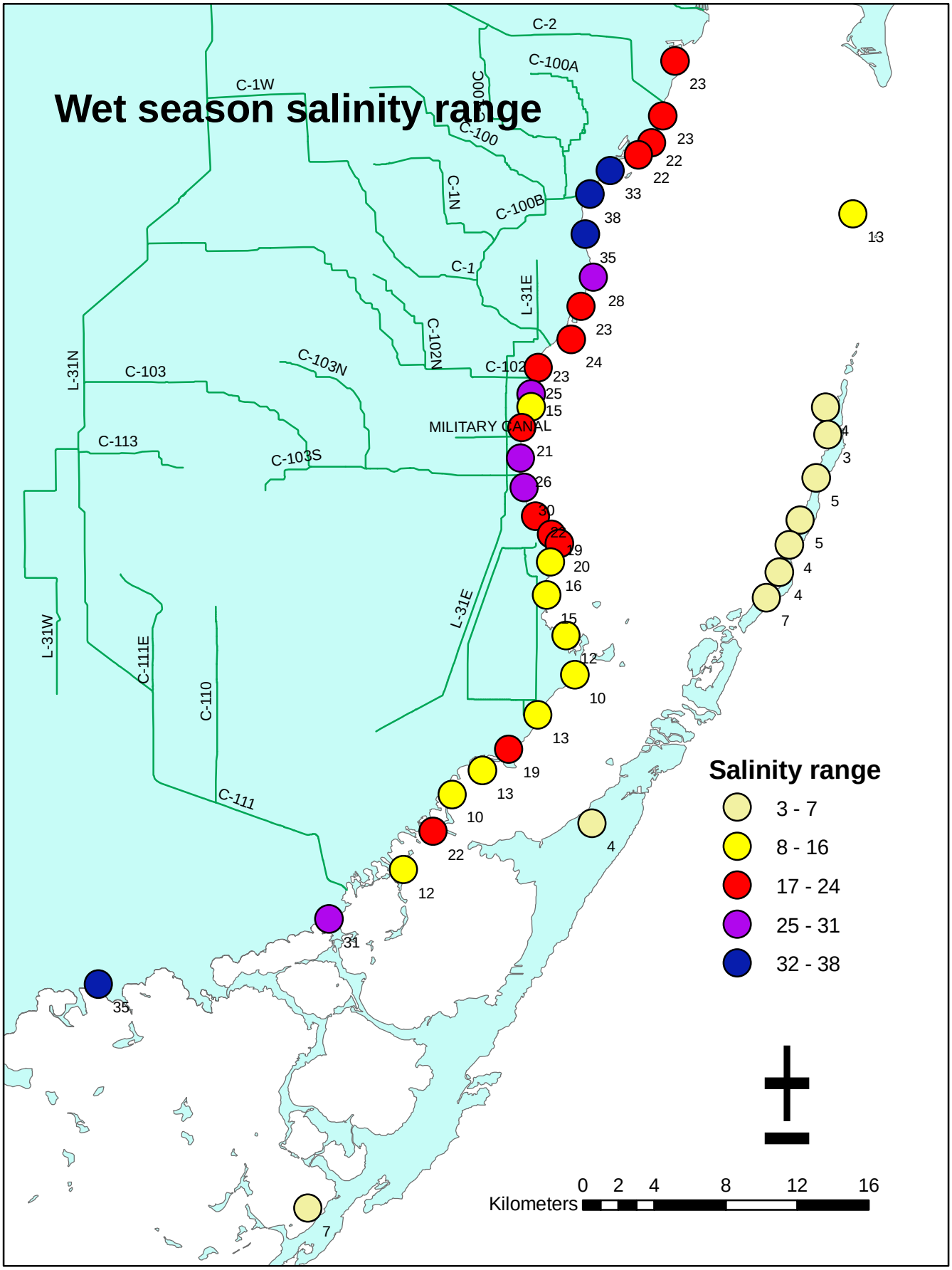
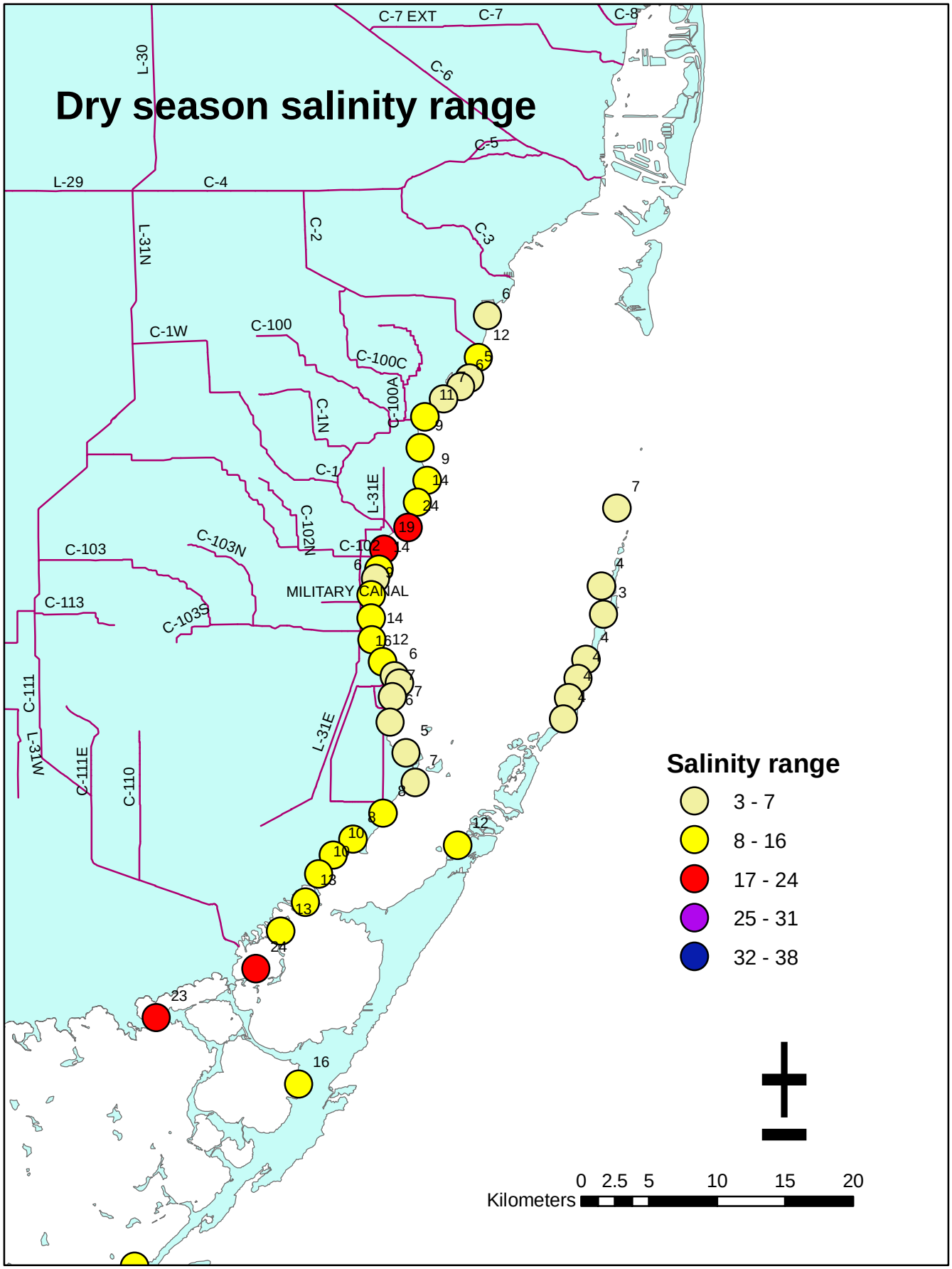
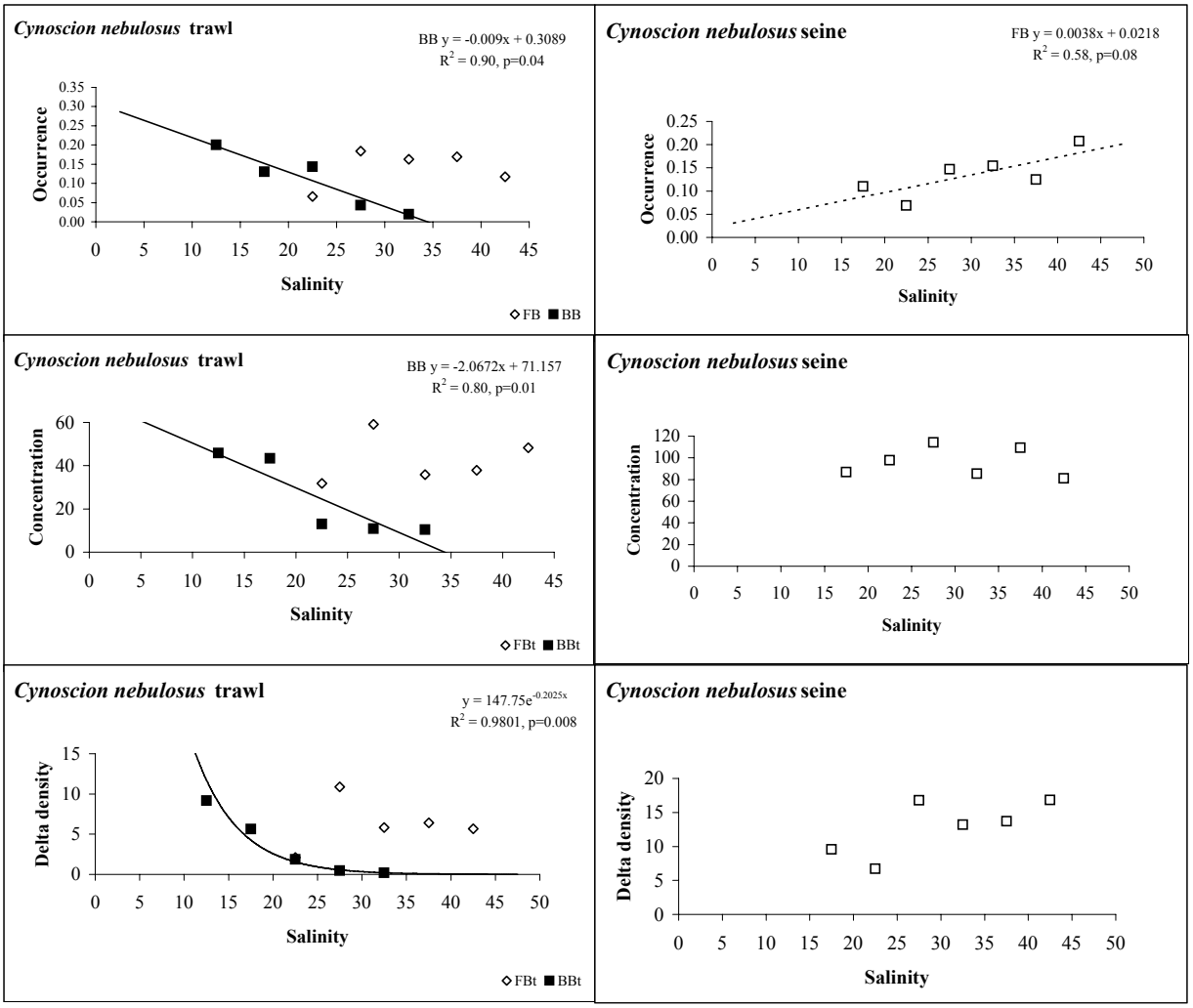


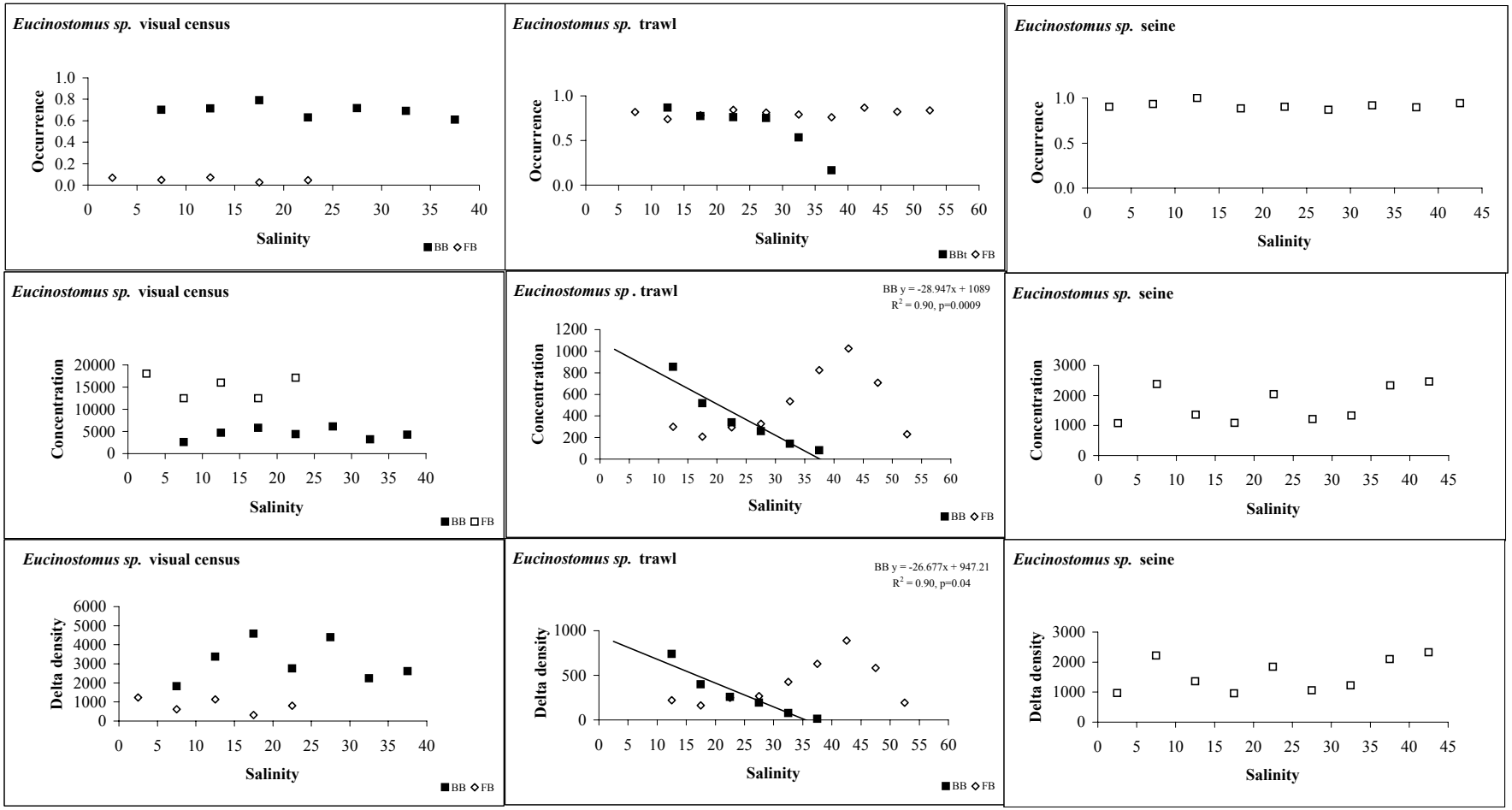
Figure 24. Wet and dry season frequency of occurrence, concentration (No. per 60 m^2) and delta density of great barracuda (*Sphyraena barracuda)* grouped by variability segments.


Wet season salinity range
C-2
C-100A
C-1W
C-100C
C-100
C-1N
C-100B
C-1
L-31E
C-102N
C-102
C-103N
C-103
L-31N
MILITARY CANAL
C-113
C-103S
L-31E
L-31W
C-111E
C-110
C-111
Salinity range
3 - 7
8 - 16
17 - 24
25 - 31
32 - 38
Kilometers
0 2 4 8 12 16

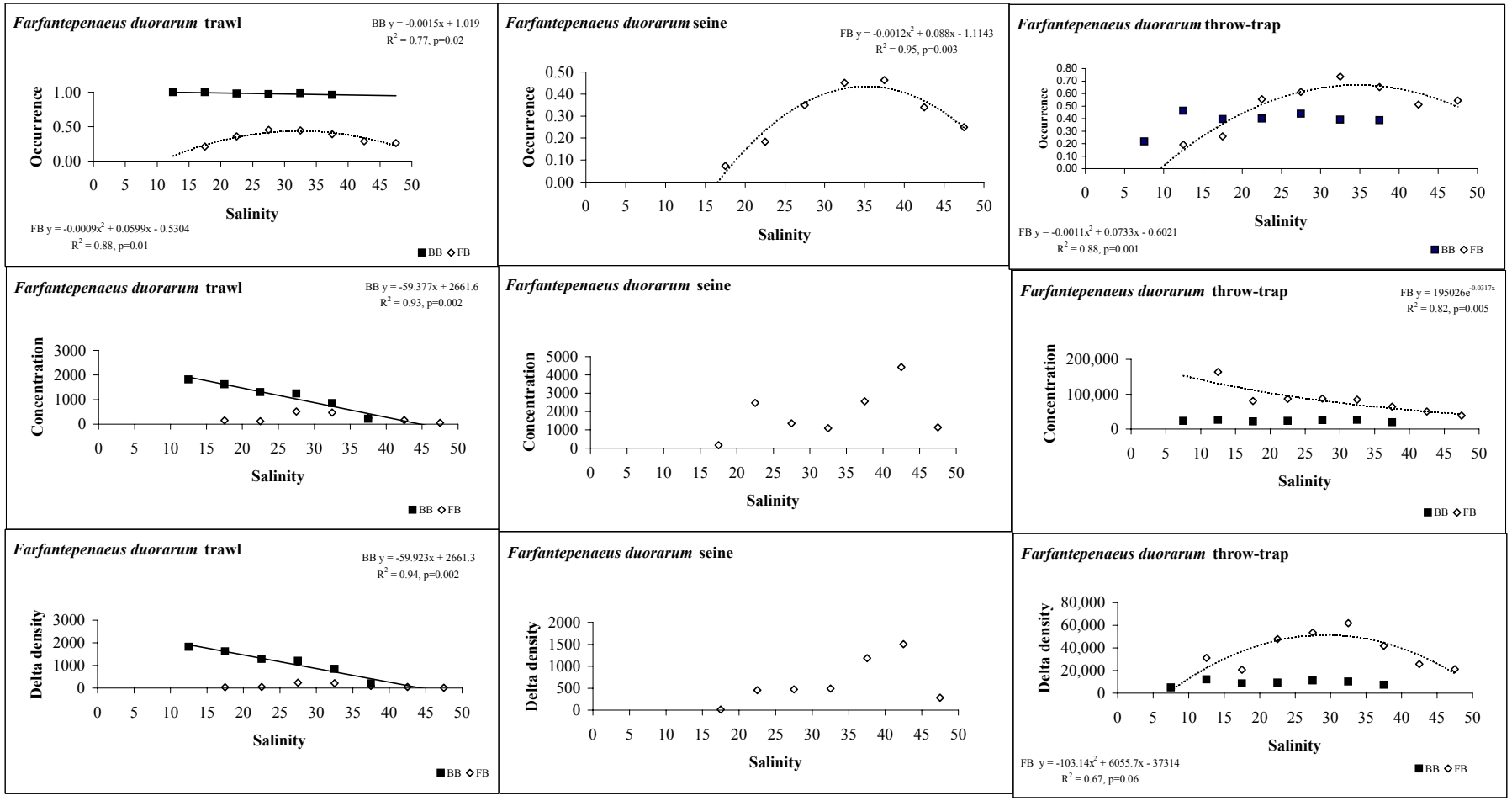

Dry season salinity range
C-7 EXT
C-7
C-8
L-30
C-6
C-5
L-29
C-4
L-31N
C-2
C-3
C-1W
C-100
C-100C
C-100A
C-1N
C-1
L-31E
C-102N
C-102
C-103
C-103N
MILITARY CANAL
C-113
C-103S
C-111
L-31W
C-111E
C-110
L-31E
Salinity range
3 - 7
8 - 16
17 - 24
25 - 31
32 - 38
0 2.5 5 10 15 20
Kilometers



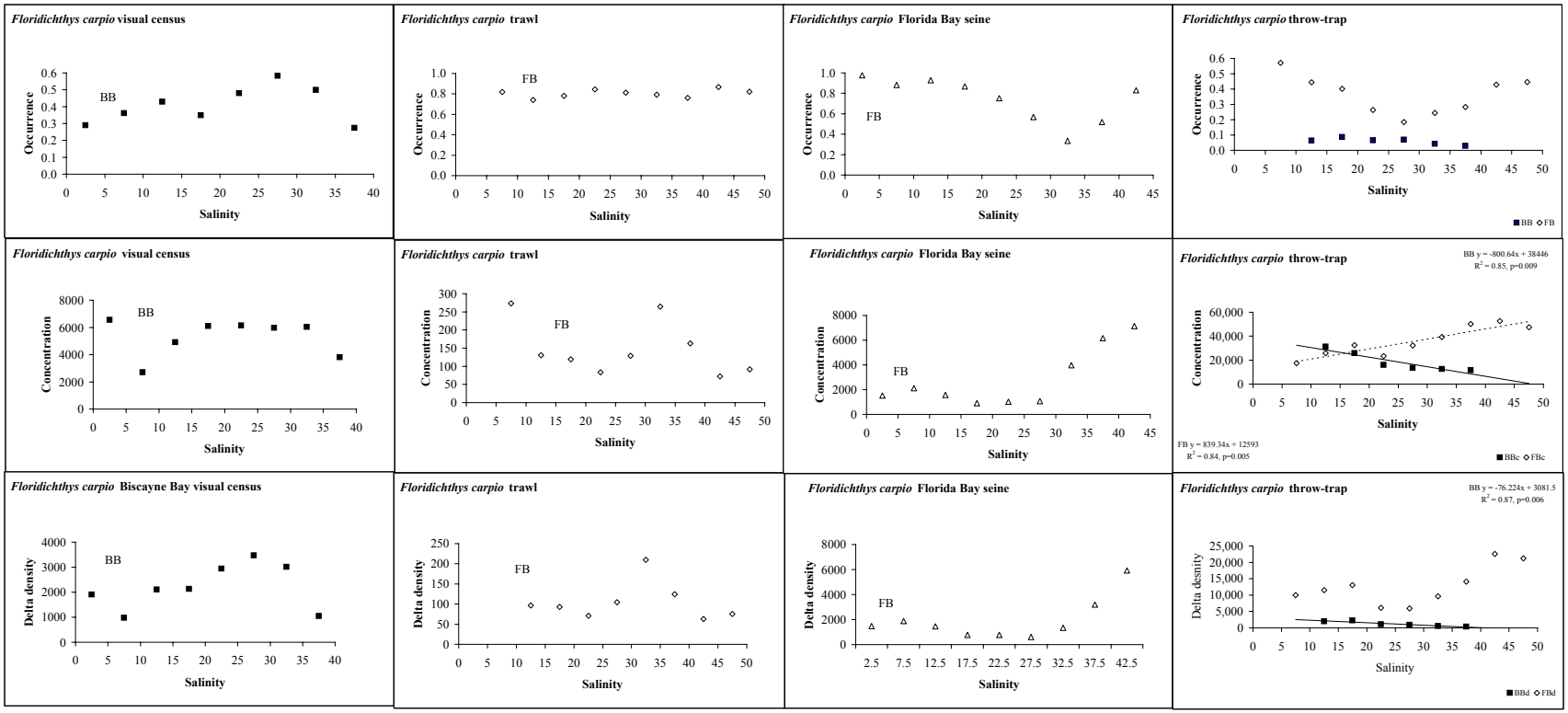
Appendix Figure 1. *Cynoscion nebulosus* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) trawl studies (Serafy only) and Florida Bay (FB) trawl and seine studies by salinity with plotted significant trend lines.



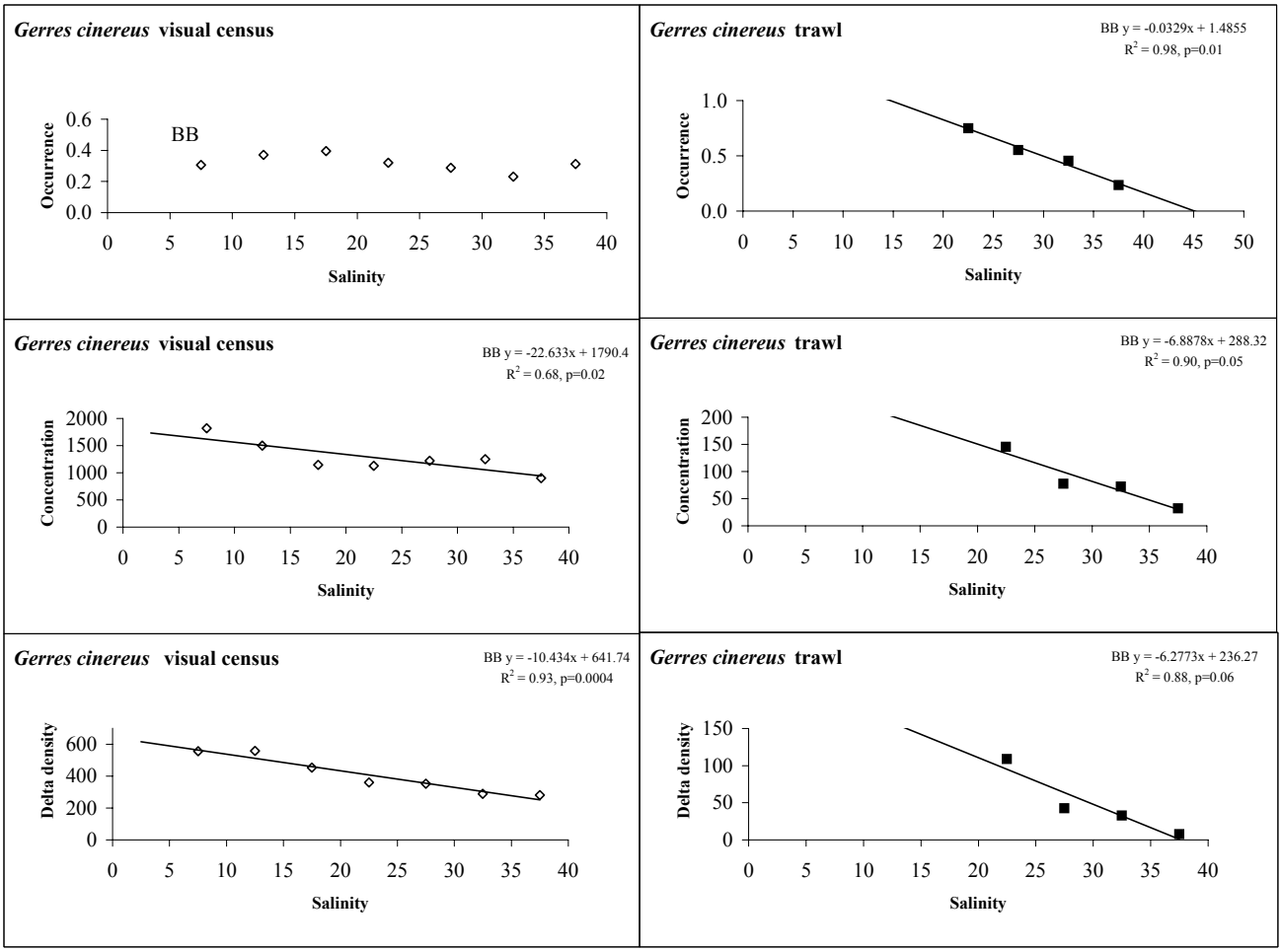
Appendix Figure 2. *Eucinostomus sp.* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) visual census and trawl studies and Florida Bay (FB) trawl, seine, and visual census studies by salinity with plotted significant trend lines.



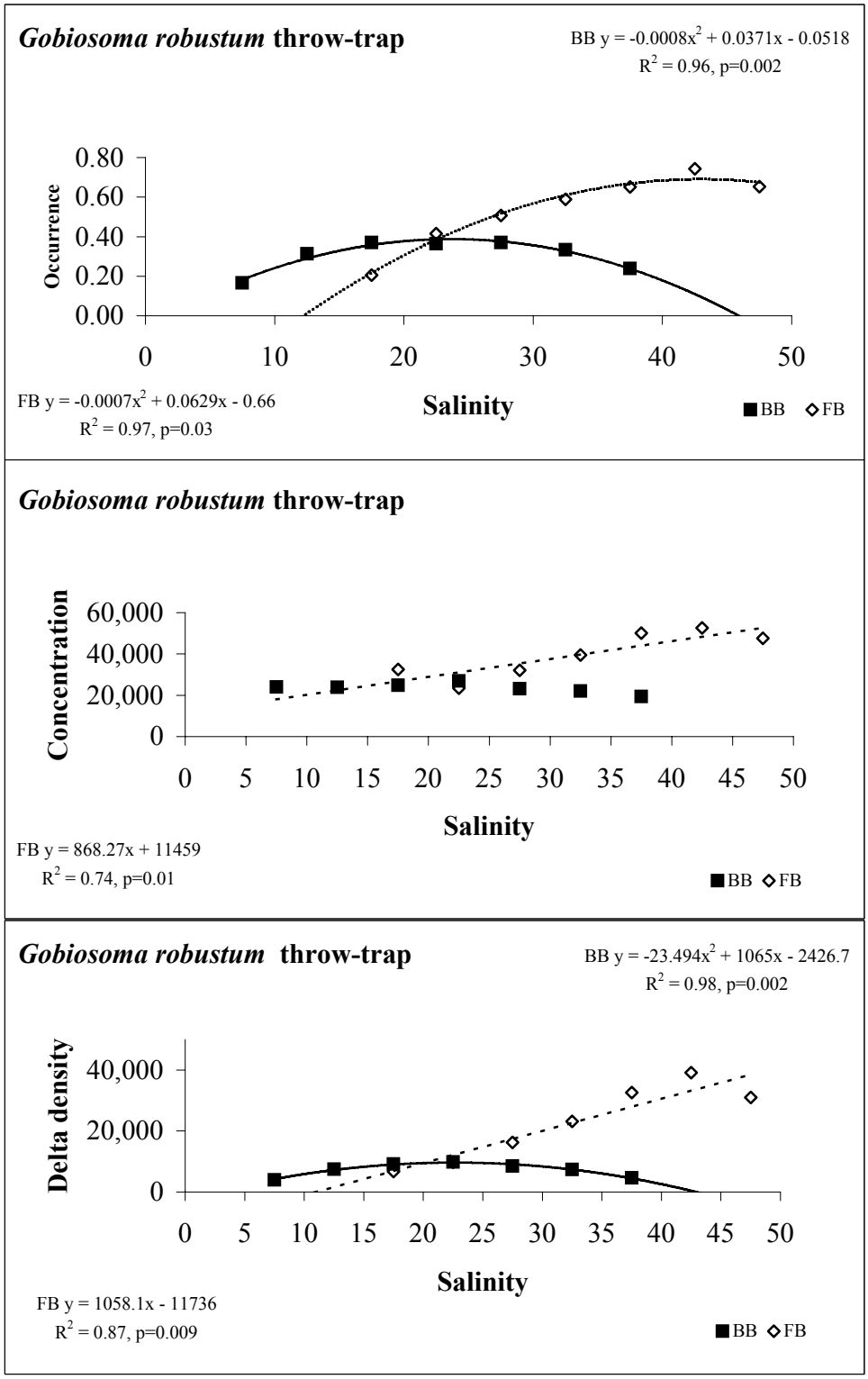
Appendix Figure 3. *Farfantepenaeus duorarum* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) and Florida Bay (FB) trawl, seine, and throw-trap studies by salinity with plotted significant trend lines.



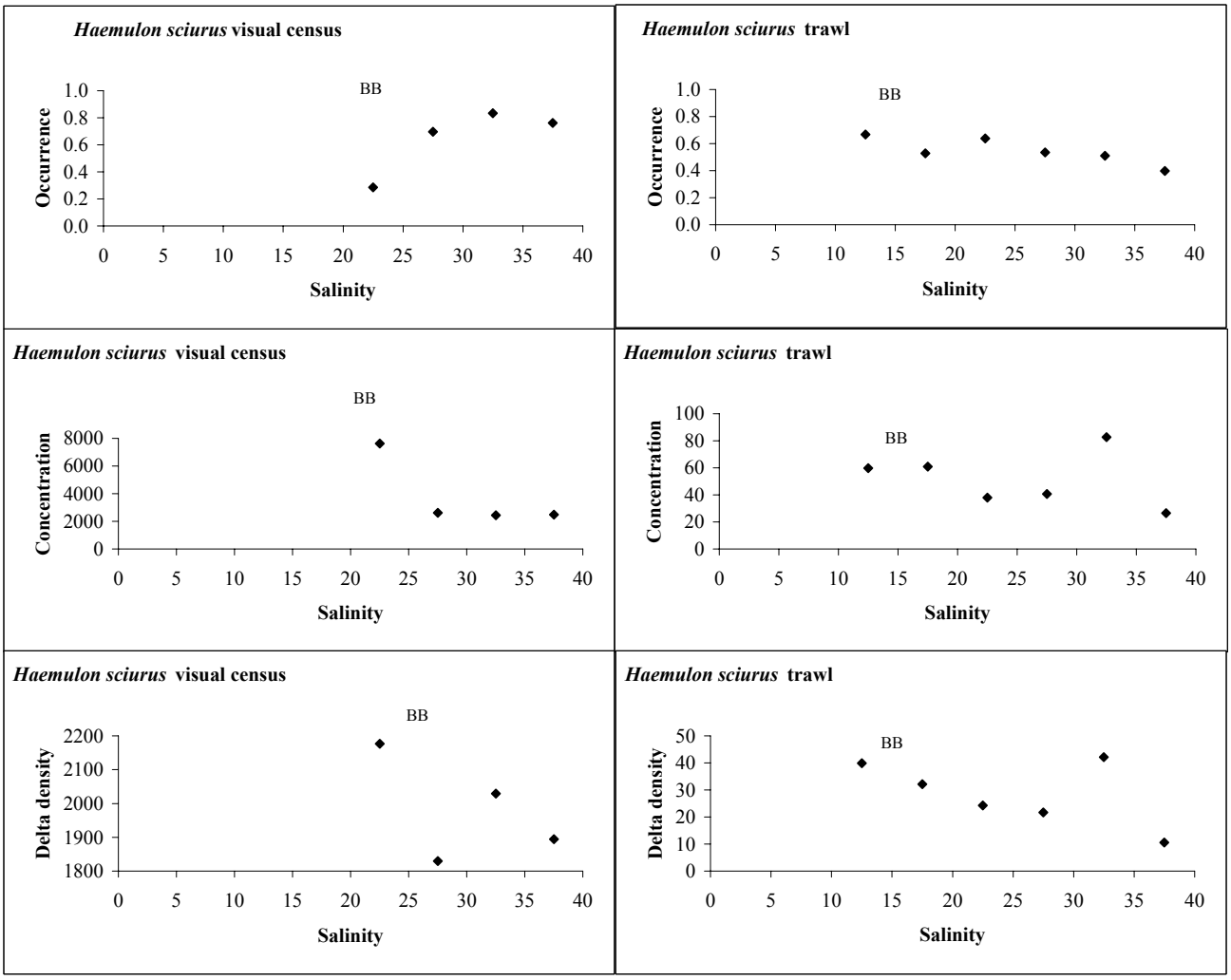
Appendix Figure 4. *Floridichthys carpio* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) and Florida Bay (FB) visual census, trawl, seine, and throw-trap studies by salinity with significant plotted trend lines.



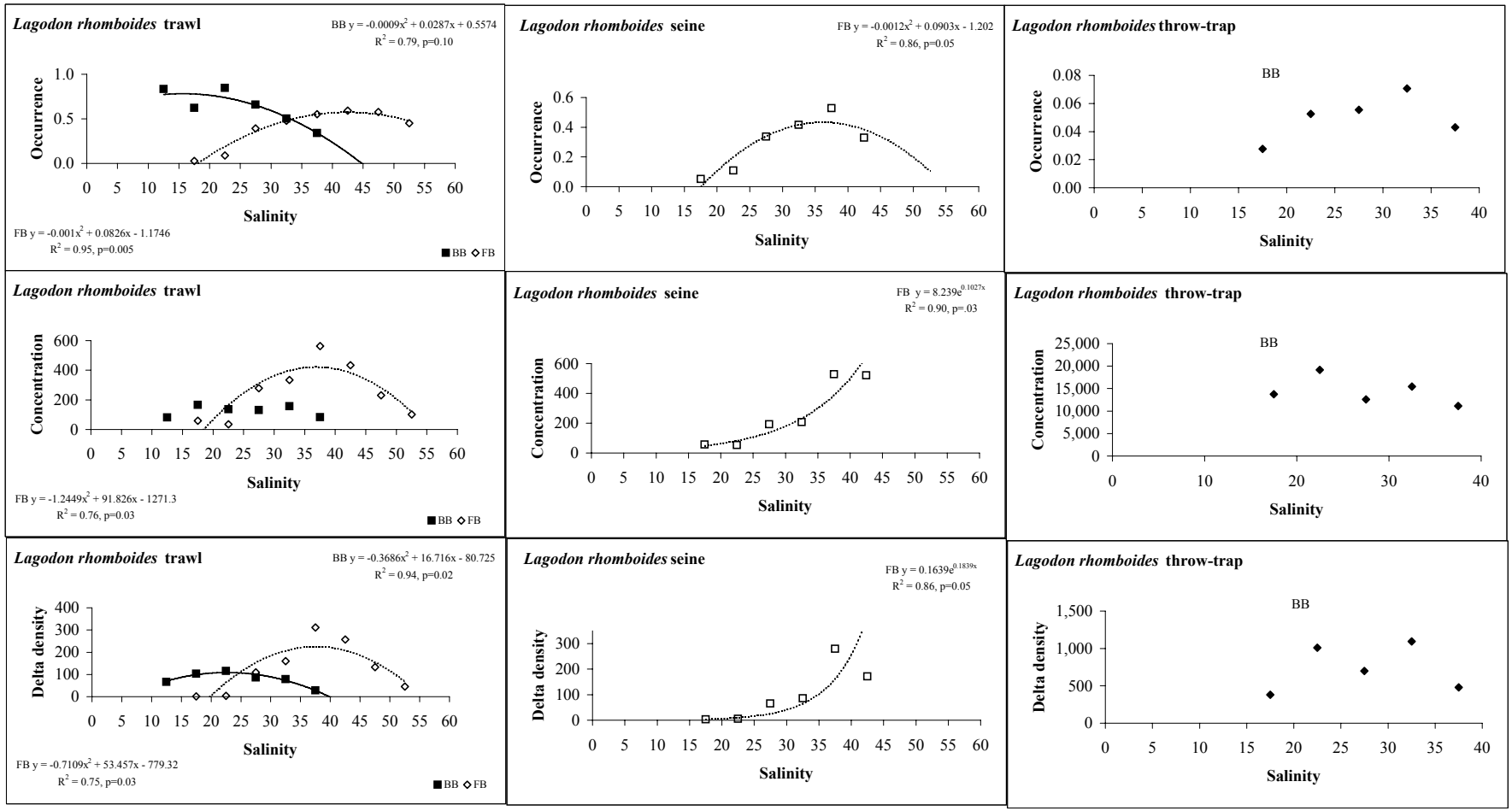
Appendix Figure 5. *Gerres cinereus* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) mangrove and bay studies by salinity with plotted significant trend lines. Florida Bay studies did not have enought data to plot.



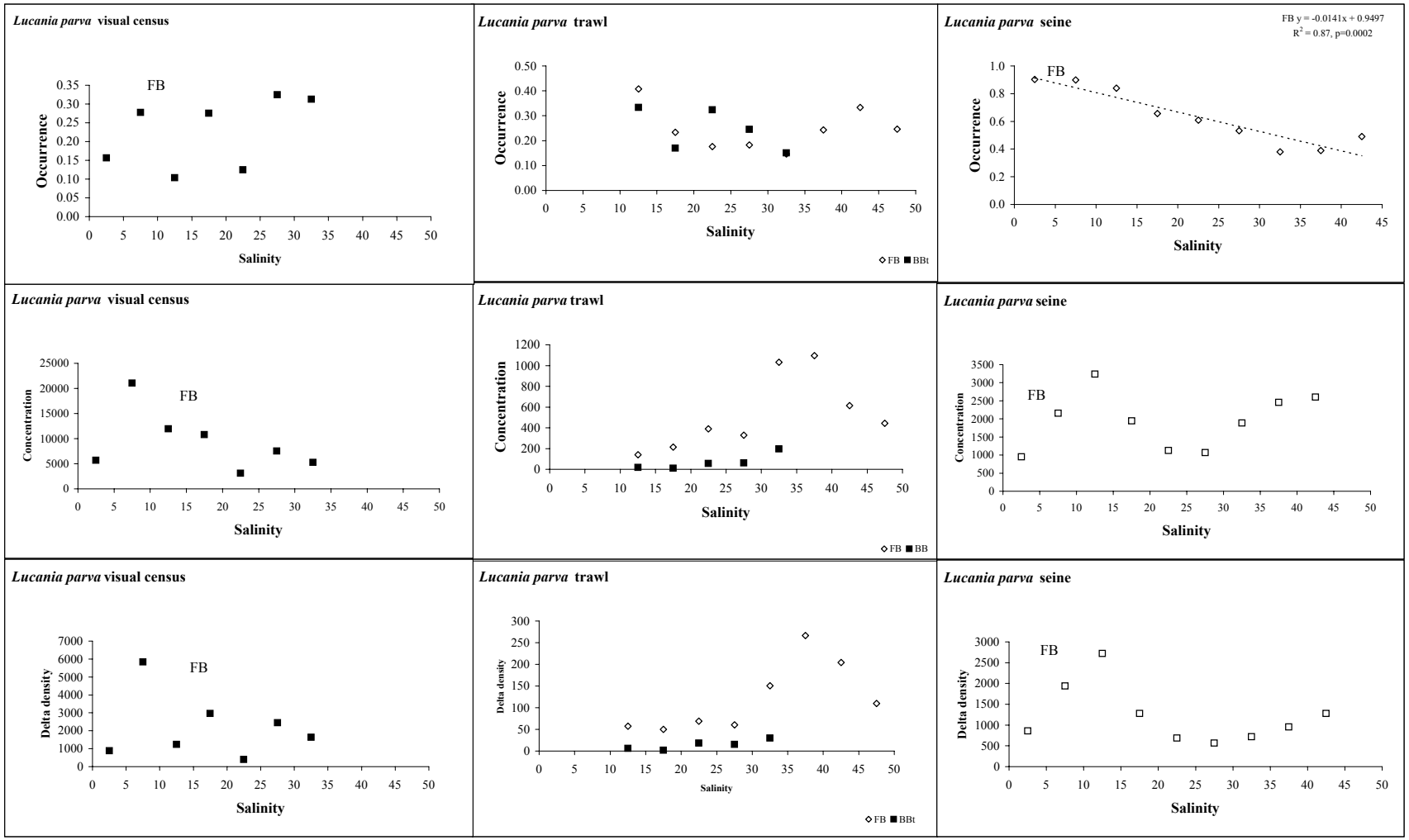
Appendix Figure 6. *Gobiosoma robustum* frequency of occurrence, concentration (No.hectare^{-1}), and delta density (No.hectare^{-1}) in Biscayne Bay (BB) and Florida Bay (FB) throw-trap studies by salinity with significant plotted trend lines.



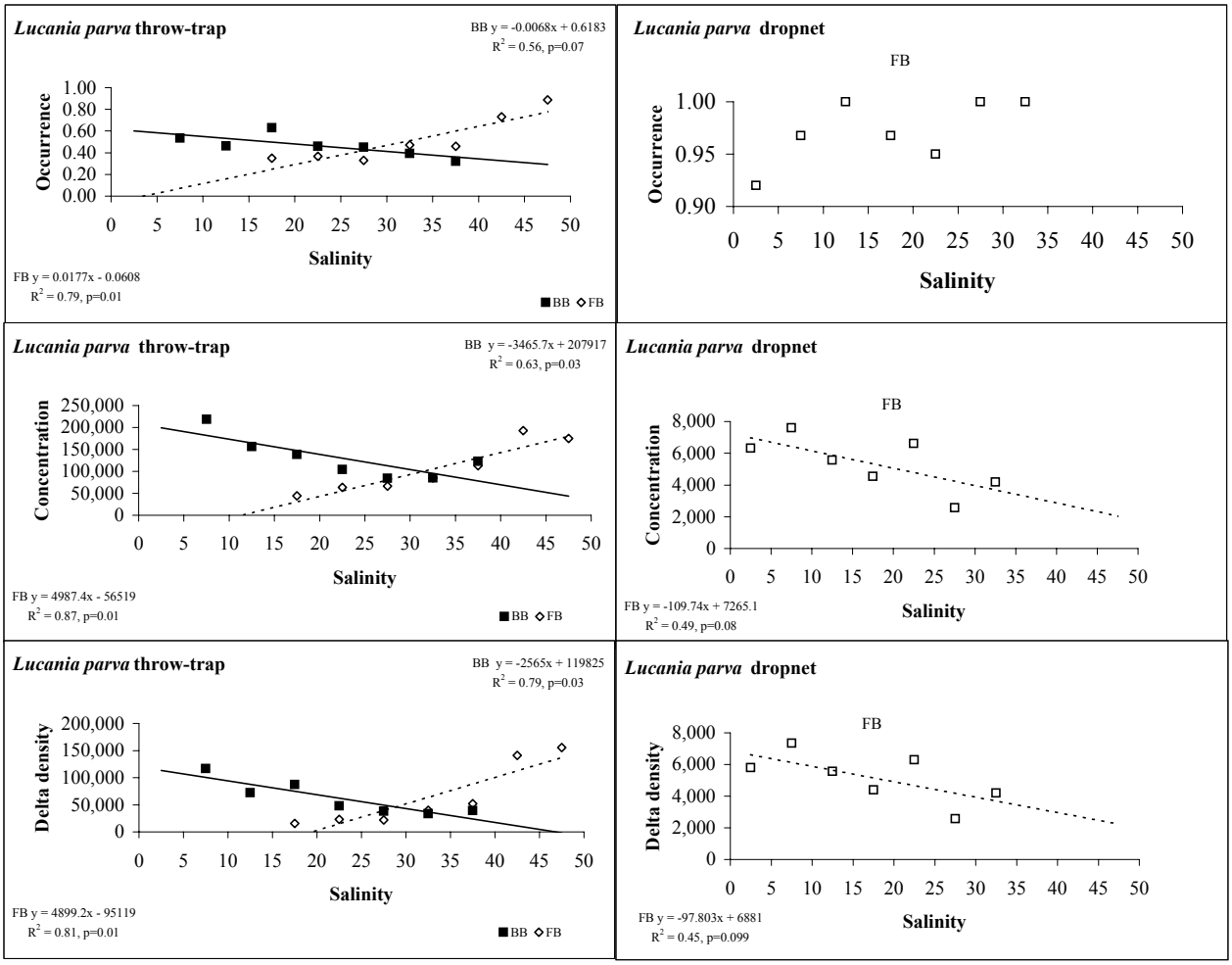
Appendix Figure 7. *Haemulon sciurus* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) visual census and trawl studies by salinity. None of the relationships were significant.



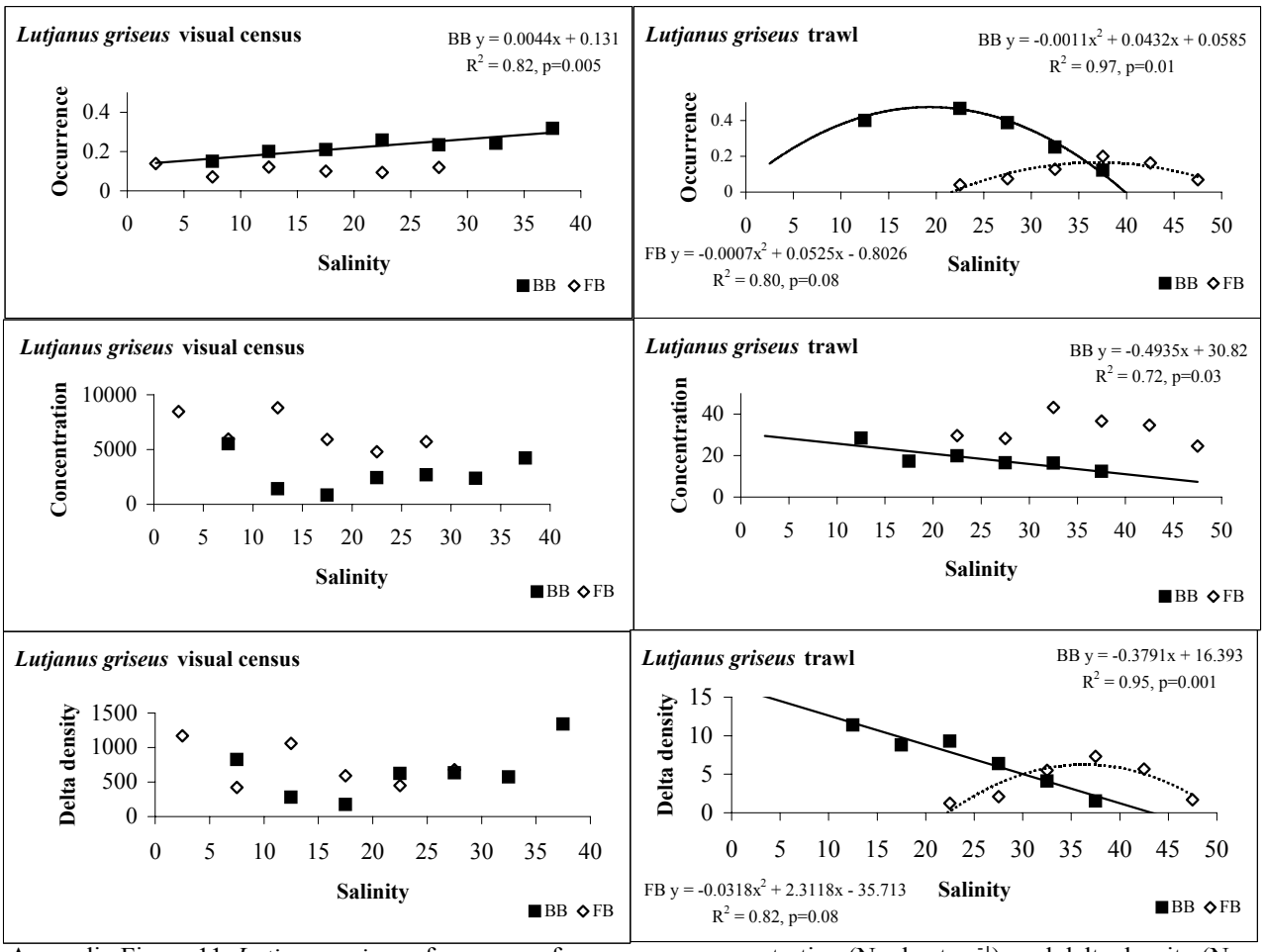
Appendix Figure 8. *Lagodon rhomboides* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) and Florida Bay (FB) trawl, seine, and throw-trap studies by salinity with significant plotted trend lines.



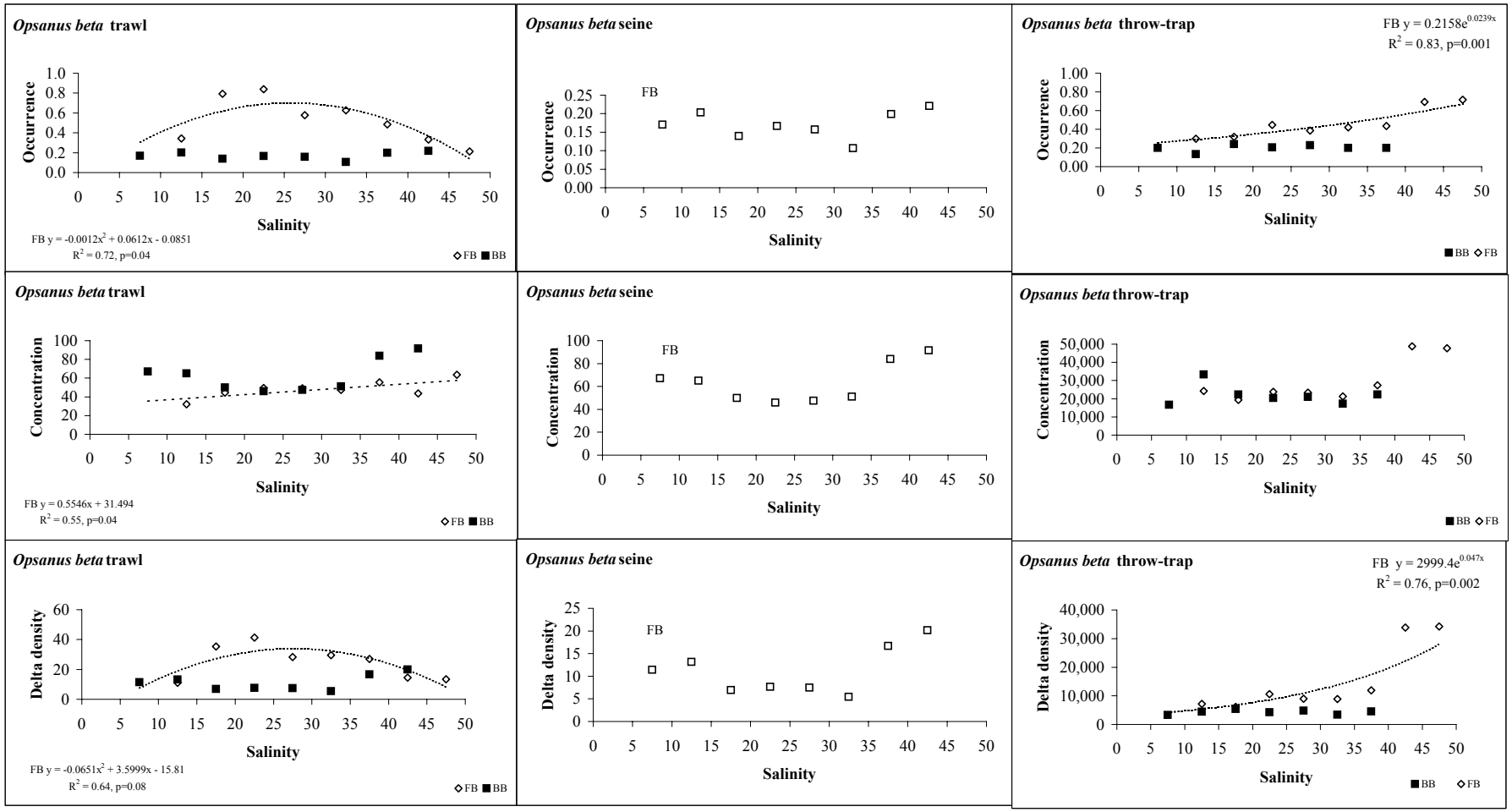
Appendix Figure 9. *Lucania parva* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) trawl studies and Florida Bay (FB) trawl and seine studies by salinity with significant plotted trend lines.



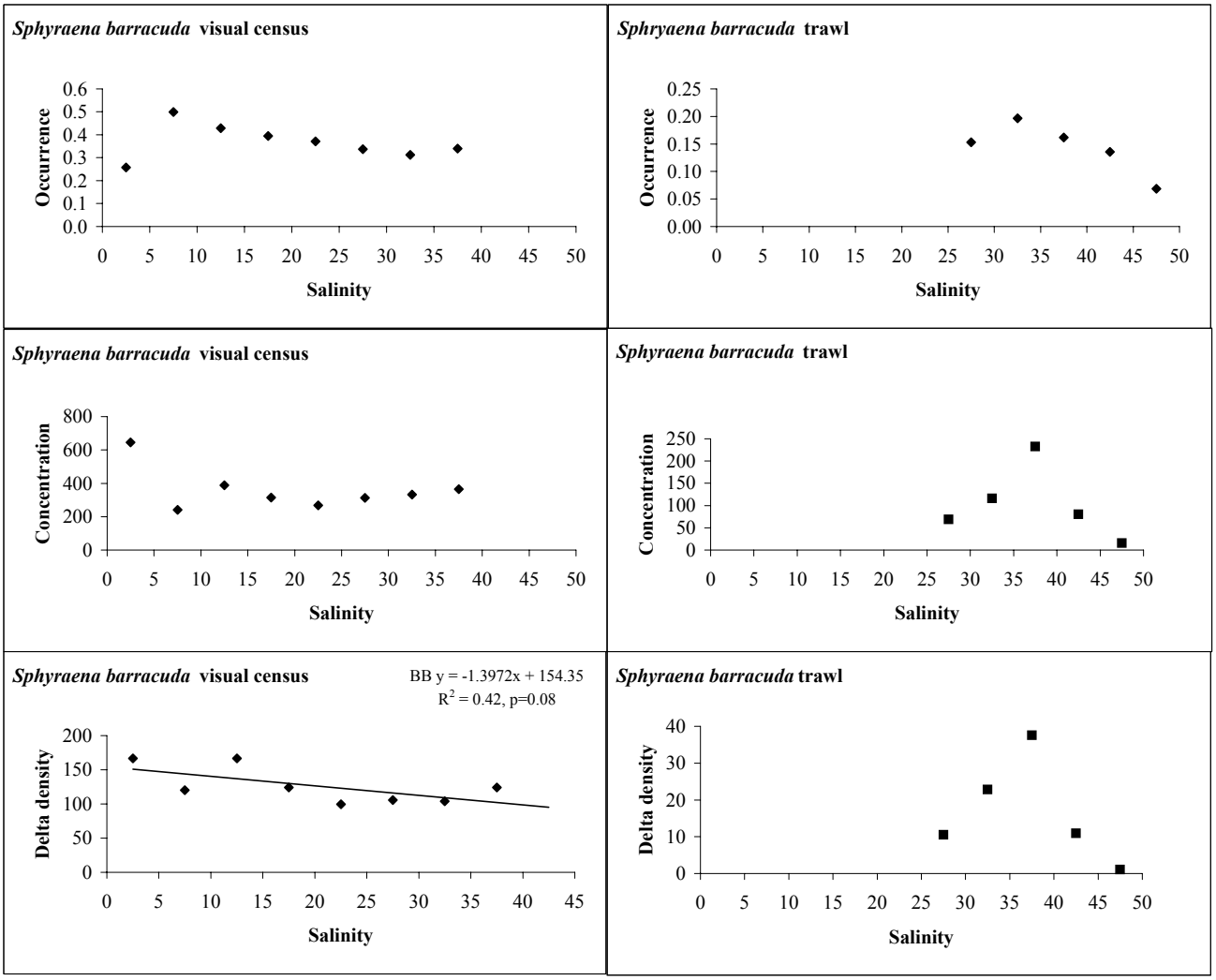
Appendix Figure 10. *Lucania parva* frequency of occurrence, concentration (No. hectare^{-1}) and delta density (No. hectare^{-1}) in Biscayne Bay (BB) and Florida Bay (FB) throw-trap and dropnet studies by salinity with significant plotted trend lines.



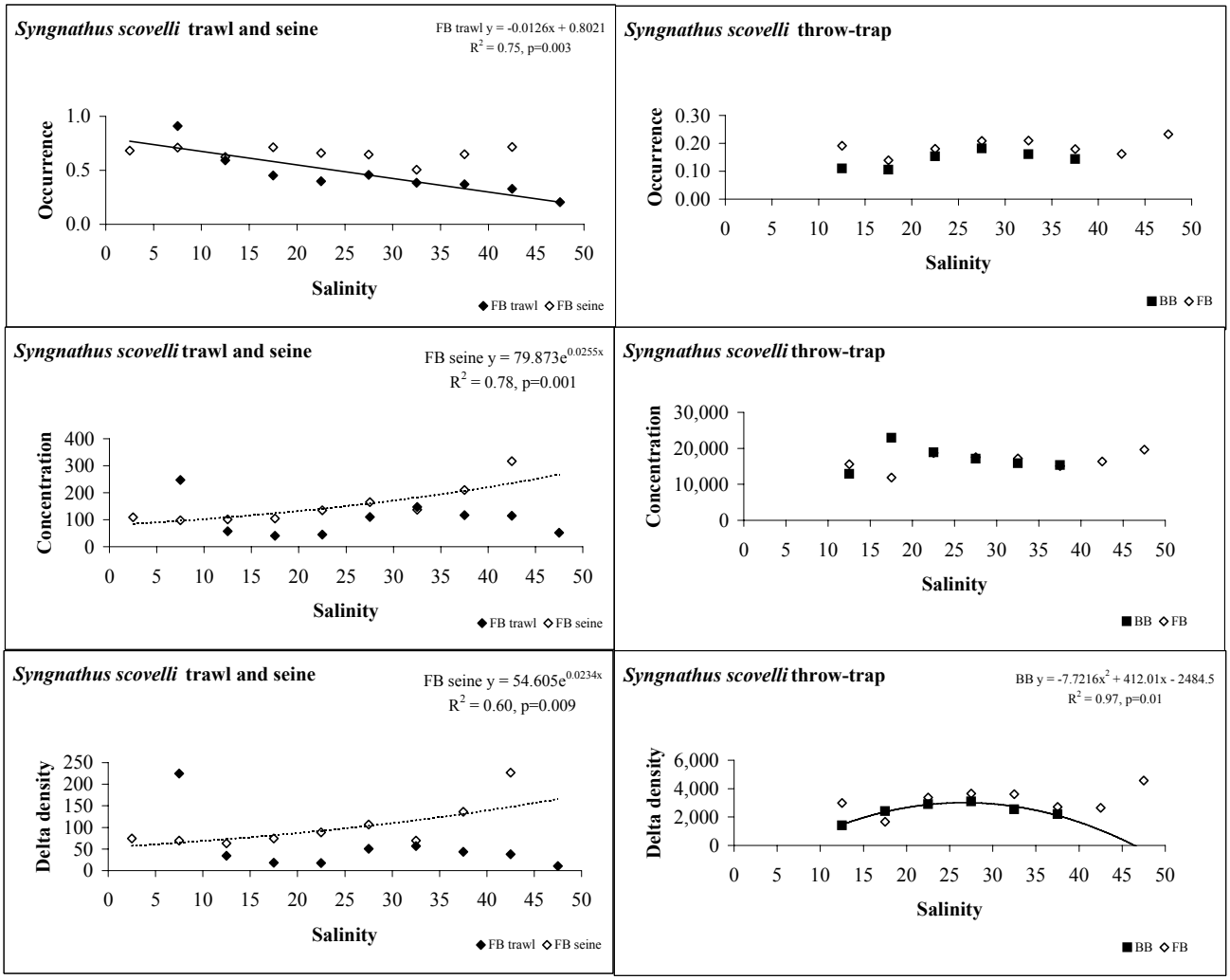
Appendix Figure 11. *Lutjanus griseus* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) and Florida Bay (FB) visual census and trawl studies by salinity with significant plotted trend lines.



Appendix Figure 12. *Opsanus beta* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) and Florida Bay (FB) trawl, seine, and throw trap studies by salinity with plotted significant trend lines.



Appendix Figure 13. *Sphyraena barracuda* frequency of occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) visual census and Florida Bay (FB) trawl studies by salinity with plotted significant trend lines.



Appendix Figure 14. *Syngnathus scovelli* occurrence, concentration (No. hectare^{-1}), and delta density (No. hectare^{-1}) in Biscayne Bay (BB) and Florida Bay (FB) trawl, seine, and throw-trap studies by salinity with plotted significant trend lines.