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Pink shrimp as an indicator for restoration of everglades ecosystems

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ABSTRACT

The pink shrimp, *Farfantepenaeus duorarum*, familiar to most Floridians as either food or bait shrimp, is ubiquitous in South Florida coastal and offshore waters and is proposed as an indicator for assessing restoration of South Florida's southern estuaries: Florida Bay, Biscayne Bay, and the mangrove estuaries of the lower southwest coast. Relationships between pink shrimp and salinity have been determined in both field and laboratory studies. Salinity is directly relevant to restoration because the salinity regimes of South Florida estuaries, critical nursery habitat for the pink shrimp, will be altered by changes in the quantity, timing, and distribution of freshwater inflow planned as part of the Comprehensive Everglades Restoration Project (CERP). Here we suggest performance measures based on pink shrimp density (number per square meter) in the estuaries and propose a restoration assessment and scoring scheme using these performance measures that can readily be communicated to managers, policy makers, and the interested public. The pink shrimp is an appropriate restoration indicator because of its ecological as well as its economic importance and also because scientific interest in pink shrimp in South Florida has produced a wealth of information about the species and relatively long time series of data on both juveniles in estuarine nursery habitats and adults on the fishing grounds. We suggest research needs for improving the pink shrimp performance measure.

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1. Introduction and background

The pink shrimp, *Farfantepenaeus duorarum*, is proposed as a biological indicator of estuarine responses to the Comprehensive Everglades Restoration Project (CERP), which is undertaking alterations in the structure and operation of South Florida's water management system. With implementation of CERP, substantial changes are expected in the timing, quantity, quality, and distribution of freshwater to South Florida estuaries. Performance measures based on pink shrimp will help assess the effect of CERP on Florida's southernmost estuaries.

Shallow marine waters in South Florida are nursery habitat for the ecologically and economically important pink shrimp, a well studied and prominent member of the epibenthic community of small fish and invertebrates found most abundantly in vegetated habitats. Pink shrimp spawn on the southwest Florida shelf, migrate shoreward as larvae/postlarvae, and spend their juvenile stage in Biscayne Bay, Florida Bay, and the shallow open waters of southwest coast mangrove estuaries (Costello and Allen, 1966). They return to deeper offshore waters to spawn and support a major fishery operating near the Dry Tortugas, the Tortugas Grounds, and a smaller fishery north of Cape Romano, the Sanibel Grounds (Costello and Allen, 1966). Small commercial bait and food shrimp fisheries for pink shrimp also operate in Biscayne Bay, while commercial harvest is banned in Florida Bay and other coastal waters of Everglades National Park (Tilmant, 1989). Both offshore and in estuaries,

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the pink shrimp forms a critical intermediate link in the food webs of top consumers such as wading birds, crocodiles, and game fish (Palmer, 1962; Tabb et al., 1962; Odum and Heald, 1972; Rutherford et al., 1983; Schmidt, 1993; Mason and Zengel, 1996; Fry et al., 1999).

In South Florida the density of juvenile pink shrimp varies regionally, among monitoring locations within regions (Fig. 1), and seasonally, being most abundant in the fall (Robblee et al., 1991; Browder et al., 2005a). Variation in benthic vegetation, salinity regime, and accessibility to settlement-stage larvae may account for density differences among inshore areas, although this needs confirmation. Higher pink shrimp densities are found in western Florida Bay than in other regions of South Florida (Robblee and Browder, 2008), possibly because of a combination of suitable bottom habitat, suitable salinity range, and reliable seasonal influx of pink shrimp postlarvae from the offshore spawning grounds.

Statistical relationships between salinity and upstream groundwater stages (used as a proxy for freshwater inflow) have been defined in Florida Bay and the mangrove estuaries in a series of reports by Marshall (2003, 2005), Marshall and Smith (2007), and Marshall et al. (2003, 2004, undated). In addition, the hydrodynamic model of Wang et al. (2003) has related salinity to freshwater inflow in southern Biscayne Bay. Both the statistical models and the hydrodynamic models, applied to selected scenarios of water management, indicate that water management affects salinity patterns in these estuaries. Thus performance measures based on biological indicators that respond to changes in salinity can be successful metrics for assessing responses to CERP in South Florida's most southern estuaries.

Reported relationships of pink shrimp with salinity suggest that water management affects pink shrimp abundance on inshore nursery grounds. Laboratory trials with growth and survival of small juvenile pink shrimp from western Florida Bay were significantly related to salinity and demonstrated a temperature effect (Browder et al., 2002). Indices of pink shrimp abundance based on Tortugas fisheries data were significantly related to indices of freshwater flow from the Everglades (Browder, 1985; Sheridan, 1996). A meta-analysis of forage fish and macro-invertebrates in Florida Bay found that pink shrimp were more closely related to salinity and seagrass than as many as 19 other species examined (Johnson et al., 2002, 2005). Most recently, we have found that mean fall density (September and October) of juvenile pink shrimp in Johnson Key Basin, western Florida Bay, is significantly negatively correlated with salinity over the range 28.3–45.3 psu ($r^2 = 0.19$, $p = 0.0483$ and $n = 20$). The parabolic relationship of pink shrimp with salinity suggested in mean spring density was not significant (Fig. 2).

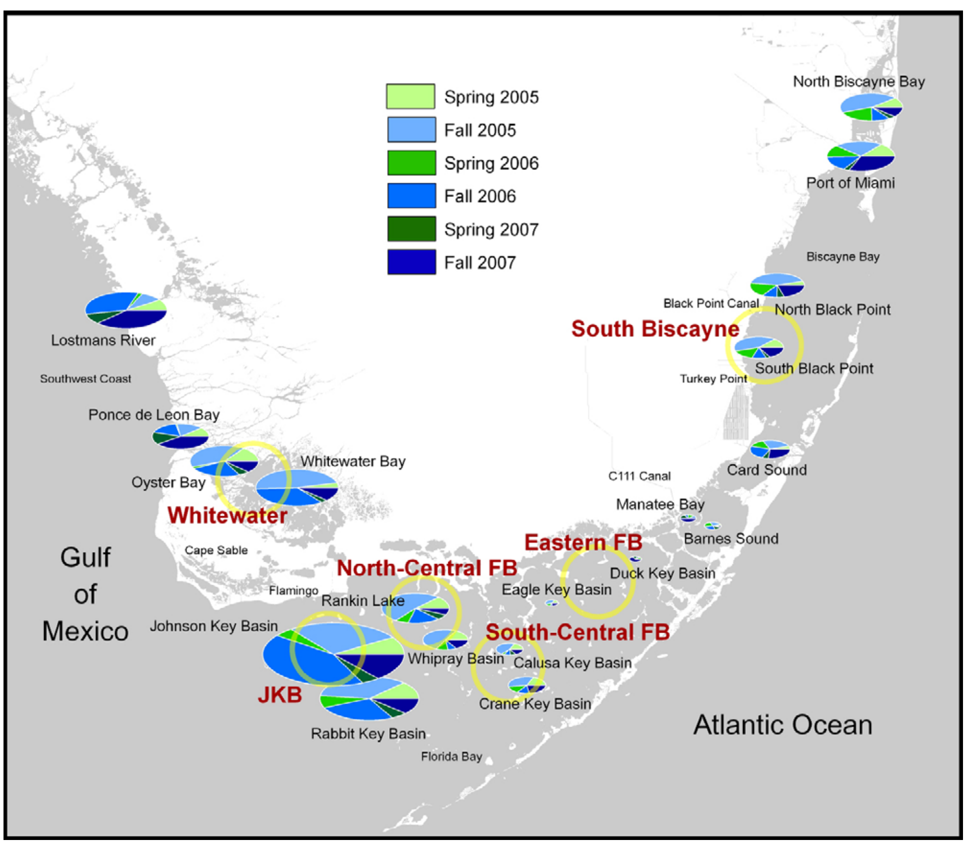

Fig. 1 – Map of South Florida estuaries showing locations of the 19 FIAN monitoring locations and the regional distribution of pink shrimp density (shrimp/m^2), from FIAN spring and fall collections, 2005–2007 (FB = Florida Bay). Yellow circles indicate the six pink shrimp assessment areas. Pie size at each monitoring location represents mean pink shrimp density summed for the six collections and scaled to the maximum, Σ = 50 shrimp/m^2 at Johnson Key Basin. Colored slices within each circle represent proportions of the sum of mean pink shrimp density at that location contributed by each collection. Read the pie counterclockwise starting with light green to go from first (spring 2005) to last (fall 2007) collection.

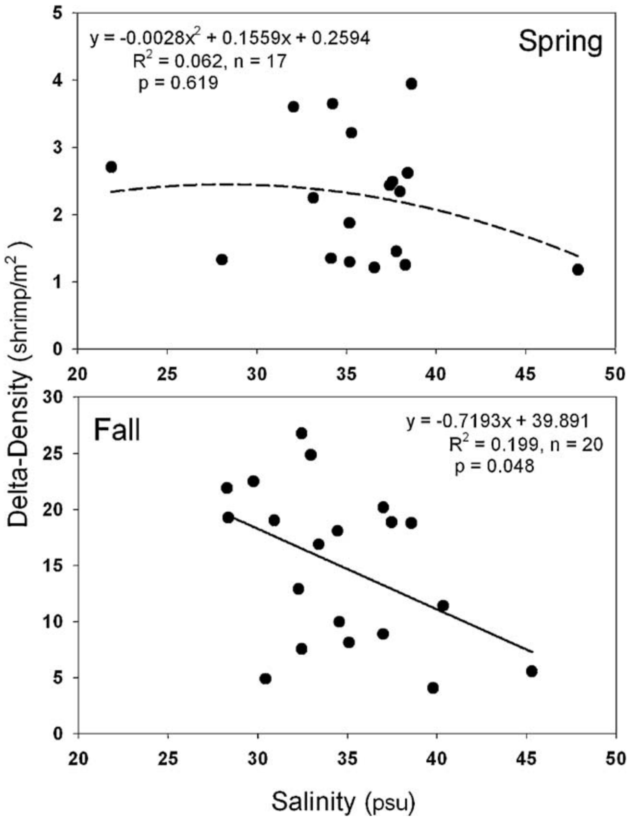

Fig. 2 – Relationship between mean pink shrimp delta-density (shrimp/m^2) and salinity (psu) in Johnson Key Basin, western Florida Bay, spring and fall. Density values are based on the 9 long-term stations in the historical (1984–2007) data set (Robblee et al., 1991). Delta-density = back-transform of log transformed [ln] concentration × occurrence; occurrence = proportion of samples with pink shrimp, concentration = mean density of pink shrimp in samples with pink shrimp.

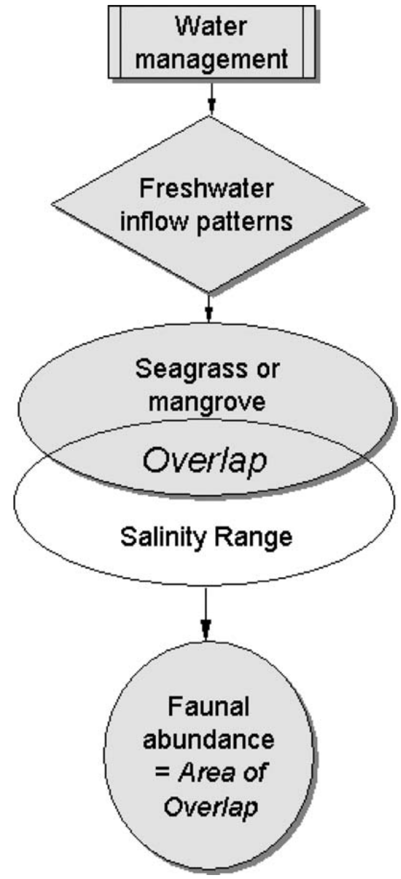

Fig. 3 – Conceptual ecological model for the Southern Estuaries relating changes in freshwater inflow and spatial patterns of salinity and habitat to the abundance of pink shrimp and other faunal species. Flows that maximize the area of overlap of favorable salinity and favorable bottom or shoreline habitat support the greatest faunal abundance.

1.1. *CERP hypotheses*

Pink shrimp form part of the fish and macroinvertebrate complex of the Monitoring and Assessment Plan (MAP) developed for CERP (RECOVER, 2004, 2007). The abundance of juvenile pink shrimp is used as an indication of expected benefits of CERP, expressed as hypotheses. Key CERP hypotheses related to pink shrimp and other fauna that were developed for the southern estuaries (RECOVER, 2008) and are embodied in Fig. 3 are as follows:

- *Hypothesis 1*: CERP will expand the gradient of salinities from near fresh to polyhaline to cover a larger nearshore zone and will reduce salinity fluctuation to a range and frequency characteristic of natural estuarine conditions, increasing the area of optimum salinity conditions for many species and, as a result, expanding local distribution, increasing abundance, and allowing a richer species assemblage.
- *Hypothesis 2*: CERP will reduce the intensity, duration, and area of coverage of hypersaline conditions, thereby increasing the area of optimum salinity conditions for nearshore fish and invertebrates.
- *Hypothesis 3*: CERP will increase the area covered by patchy or heterogeneous seagrass habitat, thereby increasing the area of optimum habitat for seagrass-associated fish and invertebrate species.
- *Hypothesis 4*: CERP will increase the length of shoreline receiving direct freshwater inflow and establish more persistent salinity gradients, thereby increasing the area of optimum habitat for fish species spending all or a part of their life cycle along the shoreline.
- *Hypothesis 5*: CERP will increase the area of overlap of favorable salinities with favorable bottom habitats and shoreline features, thereby increasing the distribution and abundance of a richer assemblage of species characteristic of estuaries.

1.2. *Areas of the everglades this indicator covers*

The pink shrimp indicator can be used to assess CERP's effects on South Florida's southernmost estuaries: Florida Bay, Biscayne Bay, and the mangrove estuaries of the lower southwest coast. These estuaries are at the downstream end of the South Florida water management system and are likely to be affected by water storage, upstream fresh water diversions, and shortages. At the same time, existing canal systems provide a means of delivering fresh water to these estuaries during periods when available water in the system is not wanted elsewhere. As the system is presently configured and operated, the estuaries often experience excessive wet season inflows and an artificially extended dry season compared to what would result from a natural hydrologic system.

1.3. Indicator history

A shrimp fishery developed in the Dry Tortugas area about 1950 when trawlable seabed with substantial quantities of pink shrimp was discovered (Idyll, 1950). The fishery grew quickly and in 1965 produced over 5000 metric tons of shrimp (Fig. 4B). Klima and Patella (1985) described the developed fishery. For many years the Tortugas pink shrimp fishery was South Florida's highest valued fishery in terms of ex-vessel value, although in recent years it has been overtaken by the spiny lobster and stone crab fisheries. NOAA Fisheries Service and the State of Florida have been collecting monthly catch and effort data by market size category (i.e., count per pound) on the Tortugas shrimp fishery since 1960, a 47-year time series (F. Patella, unpublished data, 2007). Early in the record (1965–1974), the catch per unit effort (CPUE), a rough estimate of abundance, averaged 273 kg/vessel-day annually; however the average annual CPUE decreased in each subsequent 10-year period to only 217 kg/vessel-day on average from 1995 through 2004 (Fig. 4A). The increase in catch and CPUE of small (≥68 count-per-pound) shrimp in the early 1980s (Fig. 4) may have resulted from a shift in effort toward small shrimp in response to favorable market conditions for them at that time. The increased CPUE of small shrimp was concurrent with a reduced CPUE of large shrimp and total landings. The decline in CPUE was substantial by 1985 and was, in part, attributed to a decline in the fall/early winter fishery (Sheridan, 1996; Ehrhardt and Legault, 1999), which had previously yielded the greater part of the annual catch of large shrimp. The decline roughly coincided with the die-off of seagrasses in western Florida Bay beginning in fall 1987, drought related hypersaline conditions between 1989 and 1991, and extensive algal blooms that persisted into the 1990s (Fourqurean and Robblee, 1999). The decrease in shrimp CPUE occurred before the seagrass die-off was reported, and Sheridan et al. (1997) concluded that the pink shrimp declines were not likely related to seagrass die-offs because they found no strong association between pink shrimp density and vegetated bottom. Average annual CPUE in the Tortugas pink shrimp fishery has been increasing since 1999 and was exceptionally high in 2005 and 2006 (Fig. 4), although total catches have declined due to decreased effort—probably resulting from competition from aquaculture products in the market and high fuel costs.

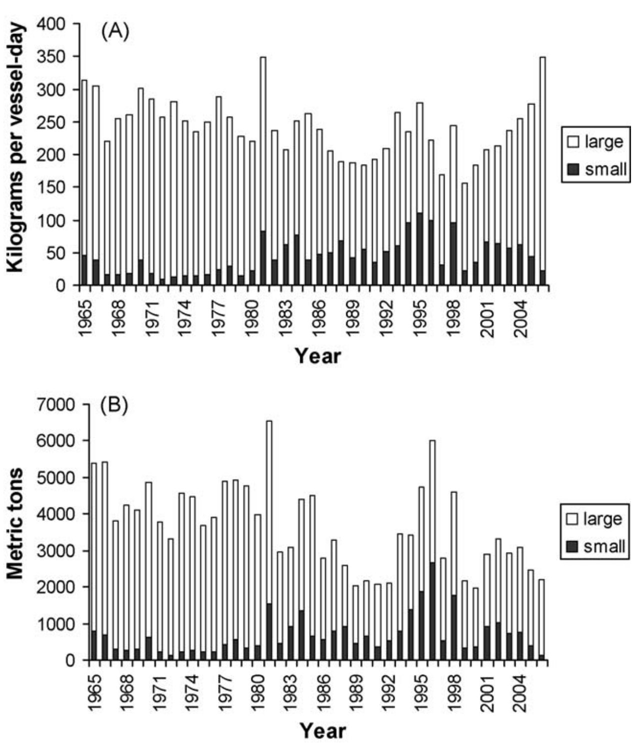

Fig. 4 – (A) Annual average catch per unit effort (CPUE) and (B) total annual catch of large (<68-count) and small (≥68-count) pink shrimp from Tortugas (statistical zones 1, 2, and 3, from Frank Patella, 2007, personal communication).

The ecology of the fishery during its early years was studied by the University of Miami, the U.S. Bureau of Commercial Fisheries (precursor to NOAA Fisheries Service), and others (Elred et al., 1961; Iverson and Jones, 1961; Iversen, 1962; Kutkuhn, 1966). In a tagging study of inshore pink shrimp, Costello and Allen (1966) linked Everglades estuaries to the Tortugas and Sanibel fisheries. A description of the distribution of early developmental stages of pink shrimp on the southwest Florida shelf supported this relationship (Jones et al., 1970). Criales et al. (2005, 2006, 2007) established that the principal pathway for larval pink shrimp entering Florida Bay is across the southwest Florida shelf into western Florida Bay, in contrast to the alternative pathway through the Florida Keys into south-central Florida Bay (Allen et al., 1980) and Biscayne Bay. The Criales et al. studies support the importance of larval vertical migration in response to tidal flow as a mechanism enabling postlarvae to reach Florida Bay from spawning areas northeast of the Tortugas. This phenomenon was studied earlier by Hughes (1969a,b) in the laboratory and by Tabb et al. (1962) in the Buttonwood Canal; this canal connected northern Florida Bay to Whitewater Bay through Coot Bay, beginning in 1957 (Tabb et al., 1962) but was closed by the Park in July 1982. Roessler and Rehrer (1971) developed a statistical relationship between the influx of postlarvae into Whitewater Bay through the Buttonwood Canal and Little Shark River that explained 61% of variation in the monthly catch in the Tortugas fishery. Yokel (1969) and Beardsley (1970) studied juvenile pink shrimp movements through the Buttonwood Canal out of the Whitewater Bay system near the water surface on the ebb tide, and Yokel et al. (1969) predicted fishery landings based on pink shrimp juveniles exiting the Whitewater Bay system through Little Shark River. More recently statistical relationships between Tortugas catches and indices of freshwater flow to Florida Bay and the southwest coast from the Everglades suggest that inshore environmental conditions affect shrimp abundance in the fishery (Browder, 1985; Sheridan, 1996).

Browder et al. (1999, 2002) developed a simulation model of juvenile pink shrimp growth and survival as functions of salinity and temperature. The model is based on experimental data on 2000 young pink shrimp from western Florida Bay and can be used to help estimate the impacts of water management on pink shrimp populations.

Juvenile pink shrimp have been monitored in Johnson Key Basin in western Florida Bay by the National Park Service and the USGS (Robblee et al., 1991, unpublished) since 1984. Although present throughout the year, juvenile pink shrimp are most abundant in late summer and fall. Annually, spring and fall peak shrimp densities summarized for nine stations in Johnson Key Basin (1984–2007) are quite variable (1.2–3.9 and 4.1–26.8/m^2, respectively), presumably at least partially in response to salinity (Fig. 2). The Johnson Key Basin time series has been augmented with spatial sampling projects in Florida Bay that show pink shrimp to be most abundant in western Florida Bay and least abundant in northeastern Florida Bay (M. Robblee, 2008, unpublished data), roughly coinciding with a west-to-east gradient of decreasing seagrass development (Zieman et al., 1989; Hall et al., 1999) and diminishing tidal currents (Smith, 1997). A second, shorter time series exists for the area between Black Creek Canal and Turkey Point in southern Biscayne Bay (Browder et al., 2005b). In an analysis of these data, a greater proportion of variability in pink shrimp abundance between October 2002 and November 2005 was explained by the abundance of seagrass and associated algae than by salinity.

FIAN, the Seagrass Fish and Invertebrate Assessment Network, began monitoring epibenthic fish, shrimp, and crab communities with the 1-m^2 throw-trap in nearshore waters of South Florida for MAP in April 2005. Dry and wet season collections are made in FIAN at 19 South Florida monitoring locations (Fig. 1), including Johnson Key Basin. The 1-m^2 throw-trap was first used to sample pink shrimp in Johnson Key Basin beginning in 1984 and now is the standard sampling gear used in FIAN. However, the FIAN sampling design differs from the sampling design used previously in Johnson Key Basin. Concurrent sampling using both sampling designs during a 3-year period of overlap (2005–2007) revealed that shrimp abundance estimates based on the two sampling designs were generally similar, especially when only data from stations in the original study that lay within the FIAN sampling grid were used (Fig. 5).

1.4. *Significance of the Indicator to Everglades Restoration*

The pink shrimp is an appropriate indicator for South Florida's estuaries because it is commercially and ecologically important. As a fishery species it has a recognized and significant economic value and a demonstrated dependence on nearshore South Florida waters as nursery habitat (Costello and Allen, 1966; Sheridan, 1996; Johnson et al., 2006a). Implementation of Everglades Restoration by altering freshwater flows into South Florida estuaries will impact pink shrimp by affecting salinity conditions and benthic vegetation. The pink shrimp is the most abundant penaeid shrimp throughout the year in South Florida estuaries and is a prominent member of an epibenthic community of small estuarine-dependent fishes and caridean shrimps characteristic of South Florida nearshore vegetated habitats (Holmquist et al., 1989; Sogard et al., 1989; Matheson et al., 1999). Within this community the pink shrimp is an important trophic link to top consumers such as game fish (Rutherford et al., 1983; Schmidt, 1993) and wading birds (Palmer, 1962) that prey on pink shrimp or its predators. By feeding on smaller herbivores and omnivores, the pink shrimp transfers energy captured in primary production of mangroves, seagrasses, and algae (Harrigan et al., 1989; Fry et al., 1999; Mason and Zengel, 1996; Odum and Heald, 1972) and passes it up the food chain.

In both laboratory and fishery- and field-based statistical studies, the pink shrimp has been linked to key environmental drivers expected to change with changes in water management brought about by CERP (Browder, 1985; Sheridan, 1996; Browder et al., 1999, 2002; Johnson et al., 2002, 2005, 2006b). Since pink shrimp density is related to the type and density of seagrass cover (Johnson et al., 2002, 2005), and seagrass type and density may be affected by future changes in salinity, there may be both primary and secondary effects of salinity change on pink shrimp. Seagrass changes can, themselves, be rapid (Thayer et al., 1994). Over 50 years of catch and effort data for the Tortugas fishery (F. Patella, 2007, unpublished data) contribute perspective on long-term cycles of region-wide pink shrimp abundance.

2. Communicating the pink shrimp indicator

2.1. *Indicator performance measures and metrics as applied to pink shrimp*

Pink shrimp abundance is difficult to assess because its distribution in South Florida estuaries can be sparse or patchy in time and space. Therefore, following the approach used in the southern estuaries component of the CERP Monitoring and Assessment Plan, shrimp abundance is viewed in three ways: as occurrence (proportion of positive samples), as concentration (mean density of positive samples), and as delta-density (back-transform of log transformed [ln] concentration × occurrence) (Pennington, 1983). Both delta-density and its constituents are shown in Fig. 5. The pink shrimp performance measure is based on delta-density and is made up of three metrics:

- *Density*: Mean number of pink shrimp per square meter in the spring (April/May) and fall (September/October) of the assessment year for each indicator area.
- *Running Mean Density*: Mean spring and fall density for the current year and the preceding 2 years.
- *Trend in Density*: 3-year trend in spring and fall mean number of pink shrimp per square meter for each indicator area.

Mean fall (September/October) density captures annual peak abundance of juvenile pink shrimp, which occurs near the end of the wet season in South Florida. Mean spring (April/May) pink shrimp density captures the abundance of pink shrimp near the end of the dry season. The fishery CPUE and previous studies (Munro et al., 1968; Yokel, 1969) suggest there may be a spring peak in abundance of postlarval and juvenile pink shrimp in South Florida in some years. Trend is followed

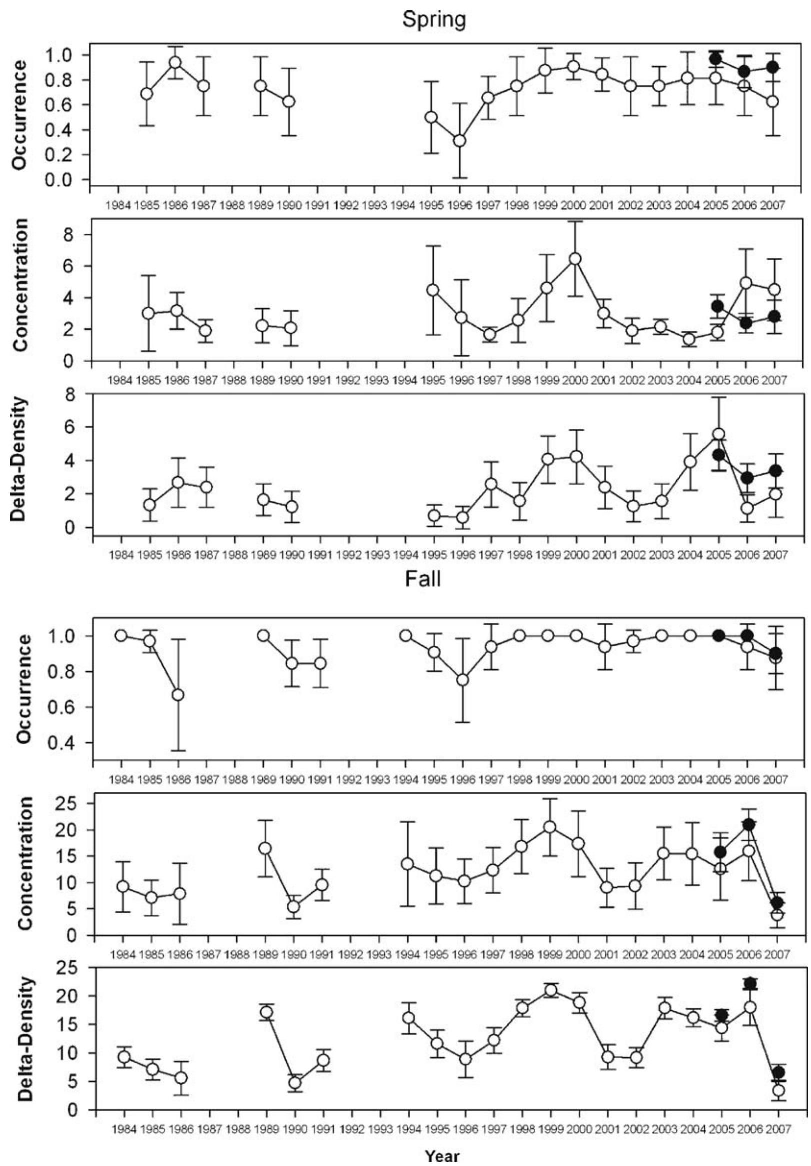

Fig. 5 – Pink shrimp abundance in Johnson Key Basin, spring (April/May) and fall (September/October), from period-of-record historical sampling (1984–2007), summarized from the four stations located within the FIAN sampling grid (stations 13, 18, 25, 27, Robblee et al., 1991) and from FIAN sampling (2005–2007). Abundance is shown in terms of occurrence (proportion of samples with pink shrimp), concentration (pink shrimp mean density of samples with pink shrimp), and delta-density (back-transform of log transformed [ln] concentration × occurrence). Open circles are historical occurrence and concentration and delta-density means with 95% confidence intervals (for 100% occurrence, the confidence intervals are zero, and thus there are no vertical bars). Solid black circles are mean shrimp delta-densities from FIAN collections.

to evaluate shrimp density over time and reflect the long-term status of the performance measure.

Annual assessment will consist of determining whether mean shrimp density exceeds a threshold based on the available pre-CERP data. Because shrimp density is expected to vary from year to year as a result of natural patterns of variability in salinity and other influencing factors, annual mean density (fall and spring separately) will also be viewed as a 3-year running average when sufficient data become available. This metric will reduce environmental noise so that CERP effects can more clearly be distinguished. The trend in delta-density will be followed once a FIAN time series of sufficient length is acquired; the FIAN data will be tested for trend through the various stages of CERP implementation, with changes in trend viewed in light of CERP progress.

Six assessment areas, each encompassing one or more FIAN monitoring location, provide the spatial context for evaluating change in mean pink shrimp density and trend (Fig. 1) in relation to CERP hypotheses: Whitewater (Oyster Bay & Whitewater Bay), Western Florida Bay (FB) (Johnson Key Basin), South-Central FB (Calusa Key Basin and Crane Key Basin), North-Central FB (Rankin Lake & Whipray Basin), Eastern FB (Duck Key Basin & Eagle Key Basin), and South Biscayne (South Black Point) (Fig. 1). Pink shrimp assessment areas represent regions among South Florida estuaries where an understanding of the ecology of juvenile pink shrimp exists and previous data are available to characterize pre-CERP population dynamics and interpret pink shrimp status.

Available long-term historical data from Johnson Key Basin will enhance the RECOVER effort by describing the pre-CERP baseline condition for pink shrimp in the Western FB assessment area. Throw-trap-based data are extensive for Johnson Key Basin in western Florida Bay where 15 and 17 years of data over a 24-year period, dry and wet season, respectively (Robblee et al., 1991), are available independent of more recent FIAN collections. Historical data available from the South Black Point monitoring location has the next longest pre-CERP time series, a 3-year (2002–2005) throw-trap-based data set; however a 3-year POR is not sufficient to provide a reliable estimate of baseline conditions in the assessment area. The other pink shrimp assessment areas identified in Fig. 1 have at best only 2 years of available pre-CERP throw-trap-based data. Other data sets from the regions represented by pink shrimp assessment areas but outside specific FIAN monitoring locations are available to contribute to the development and interpretation of baseline conditions, e.g., Tabb et al. (1962), Schmidt (1979), Holmquist et al. (1989), Matheson et al. (1999), Robblee et al. (1991), Schmidt (1993) and Sheridan et al. (1997).

2.2. *Thresholds and scoring for the stoplight restoration report card*

Fall and spring performance metrics will be scored separately. Each assessment area will be scored individually based on the distribution of pink shrimp density in the baseline dataset for that area. Scoring thresholds will be established based on quartiles of the distribution of mean shrimp density. Values less than the baseline 25th quartile are scored as zero, values between the 25th quartile and the 75th quartile receive a score of 0.5, and values equal to or greater than the 75th quartile receive a score of 1 (Table 1). Annual mean density targets for each season are to meet or exceed the 75th quartile from the long-term record for each assessment area. Thresholds for scoring the running means will be determined similarly. Thresholds for scoring trend are based on the slope of the line. A negative slope will be scored as zero, a slope not different from zero will receive a score of 0.5, and a positive slope will receive a score of 1. The annual targets for trend are positive slopes. Thresholds for each of the six pink shrimp assessment areas will be added or adjusted as FIAN data accumulates until CERP-implementation is initiated.

Johnson Key Basin in western Florida Bay is the only assessment area at present with a long enough record to provide reliable scoring thresholds (Fig. 6). Only data through 2004 are used so that density data from the three MAP years – 2005, 2006, and 2007 – can be assessed against it. The reference densities in Johnson Key Basin (delineated as the red/yellow and yellow/green boundaries in Fig. 6, spring and fall, respectively), are the 25th quartile (1.28 shrimp/m^2) and the 75th quartile (2.61 shrimp/m^2) of the distribution of spring mean pink shrimp (Fig. 6) and the 25th quartile (8.88 shrimp/m^2) and the 75th quartile (17.61 shrimp/m^2) of the distribution of fall mean pink shrimp density. For CERP assessment, mean shrimp densities in the yellow zone suggest a neutral season for pink shrimp while densities in the green zone suggest a positive season. Mean shrimp densities falling below the red/yellow boundary suggest a poor season for pink shrimp. South Biscayne Bay has a 3-year record, 2002–2005, and will be the next assessment area to be scored. Thresholds for the other assessment areas will be developed as soon as sufficient baseline data are collected by FIAN at the monitoring locations representing these areas.

Johnson Key Basin, representing western Florida Bay, is a key assessment area to watch because highest shrimp densities regionally occur in western Florida Bay (Fig. 1), the best developed seagrass beds historically characterize this region (Zieman et al., 1989; Hall et al., 1999), and the longest historical record of juvenile pink shrimp density is available from Johnson Key Basin (Robblee et al., 1991). Furthermore, this region is most directly connected to the offshore Tortugas fishing grounds (Costello and Allen, 1966; Criales et al., 2005, 2006, 2007), source of early-settlement-stage postlarvae. The salinity regime in western Florida Bay is influenced by changes in CERP affecting freshwater flow through both Shark River Slough (Kelble et al., 2007) and Taylor Slough.

3. Discussion

Juvenile pink shrimp, *Farfantepenaeus duorarum*, are ubiquitous in South Florida coastal waters where they are most abundant seasonally in late summer and fall. The pink shrimp is South Florida's most valuable commercial species dependent on estuaries as nursery habitat. Pink shrimp spawn offshore northwest of Key West in the vicinity of the Tortugas trawling

Table 1 – Spring and fall target and trend relationships, status, and scores for the performance measure metrics comprising the pink shrimp stoplight indicator communication tool. Johnson Key Basin (JKB).

Metric	Spring range *n* = 15	Fall range (*n* = 17)	Index score	Index color	Annual Status
Density in current year (no. m^{-2})	0–1.28	0–8.88	0	Red	Poor
	1.28–2.61	8.88–11.61	0.5	Yellow	Neutral
	>2.61	>11.61	1.0	Green	Good
3-Year running average density (no. m^{-2})	0–1.28	0–8.88	0	Red	Poor
	1.28–2.61	8.88–11.61	0.5	Yellow	Neutral
	>2.61	>11.61	1.0	Green	Good
3-Year trend	−Slope	−Slope	0	Red	Poor
	Stable	Stable	0.5	Yellow	Neutral
	+Slope	+Slope	1.0	Green	Good

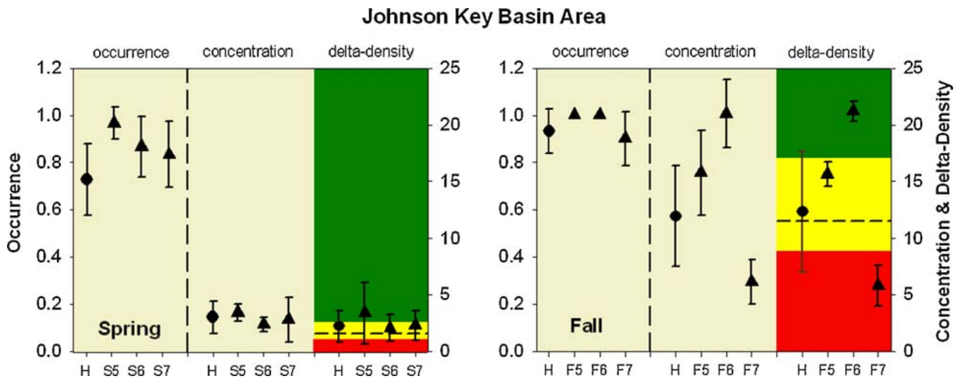

Fig. 6 – Mean occurrence, concentration, and delta-density of juvenile pink shrimp for the historical record (1984–2004) and three FIAN years (2005, 2006, and 2007), spring and fall. Solid black circles with 95% confidence intervals summarize the historical (H) period-of-record. Solid red triangles with 95% confidence intervals represent individual FIAN collections (S5–S7 and F5–F7, spring and fall for 2005–2007, respectively). Assessment thresholds for delta-density are based on the historical data: green > 3rd quartile, yellow > 1st and <3rd quartile, and red < 1st quartile (see Table 1 for numeric values). For MAP assessment based on delta-density, those data points that fall in the green zone indicate the status of juvenile pink shrimp in the area is good, those that fall in the yellow zone provide a neutral indication, and those that fall in the red zone indicate that pink shrimp status is poor.

grounds (Costello and Allen, 1966) and enter South Florida estuaries as postlarvae. After several months of growth through the juvenile stage, they return to offshore waters as young adults to spawn. Planned restoration activities in CERP will re-establish more natural patterns of freshwater flow from the Everglades into these coastal waters with expected positive benefits to the pink shrimp from changes in the salinity regime and seagrass habitat. However, fundamentally, CERP will be altering existing critical nursery habitat for juvenile pink shrimp. Therefore, a pink shrimp performance measure is essential for assessing the response of juvenile pink shrimp to restoration in order to ensure that expected benefits materialize and there is no unintended harm to nursery function and, ultimately, the Tortugas fishery.

The pink shrimp has many advantages as an indicator species. Its economic value as a fishery species is recognized. Both offshore and in estuaries, the pink shrimp has great ecological value, providing an important link in the food webs of top consumers such as wading birds, crocodiles, and game fish. The pink shrimp is a short-lived species with a lifespan of only 1–2 years, at most, which facilitates relating a specific cohort to the environmental conditions that produced it. An inshore life stage lasting for only a few months increases the likelihood that factors affecting growth, survival, and density on the nursery ground can be determined. Studies based on fishery, field, or laboratory data, have indicated that the pink shrimp is influenced by salinity, which is expected to be changed by CERP. The pink shrimp has been well studied in South Florida, and time series of data on pink shrimp extend back as far as the 1960s.

Concerns have been expressed, however, about the use of the pink shrimp as an indicator for assessing the success of CERP. The pink shrimp is one of many species present in estuaries mainly during its juvenile stage. A life cycle split between inshore and offshore stages presents challenges for its use as an indicator. During the offshore stage, pink shrimp are subjected to harvest in the fishery and regional oceanographic conditions that may affect both spawning and the transport of larvae to the nursery ground. Previous authors (Ehrhardt and Legault, 1999) have noted that the relationship between spawning stock and recruitment in this fishery is weak and overwhelmed by the influence of environmental variables, suggesting that fishing effort has little effect on recruitment. Nevertheless, both harvests and oceanographic factors may affect cohort strength and the density of young shrimp in inshore waters. The offshore variables make the pink shrimp indicator's inshore response to freshwater inflow and salinity more difficult to identify and interpret. However, in South Florida, the knowledge base defining the connection between inshore juvenile pink shrimp populations and the Tortugas fishery provides strong support for a pink shrimp performance measure. Costello and Allen (1966) recovered pink shrimp tagged in inshore waters of South Florida on the Tortugas Grounds. Statistical relationships have been developed for postlarval pink shrimp immigrating to, and juvenile pink shrimp emigrating from, coastal waters of Everglades National Park and catch in the Tortugas fishery (Roessler and Rehrer, 1971; Yokel, 1969). Statistical relationships between Tortugas catches and water levels and rainfall in the Everglades, proxy estimators of freshwater inflow and salinity in coastal estuaries, strongly suggest that inshore environmental conditions affect shrimp abundance and ultimately harvest in the Tortugas fishery (Browder, 1985; Sheridan, 1996).

The regions represented by the six assessment areas in the pink shrimp performance measure differ in relation to upstream restoration projects, benthic vegetation, accessibility to shrimp postlarvae, and salinity regime and therefore the impact of restoration-related freshwater modifications in each is expected to differ as well. Extended MAP datasets, when available, will allow an assessment of pink shrimp status concurrently in all six assessment areas relative to baseline conditions, which will be invaluable in helping to interpret pink shrimp responses to CERP regionally. At present Johnson Key Basin can be used as a reference site for possible fishery influences. Positive responses by the pink shrimp, including a positive trend, in Johnson Key Basin will be interpreted as resulting from improvements in freshwater inflow if salinities are in the lower part of the historical range during the collecting season, especially if positive responses are occurring in the other Florida Bay assessment areas and the Whitewater area (Fig. 1). Either lack of salinity changes or lack of changes in other Florida Bay areas would suggest that the changes were not brought about by CERP. On the other hand, negative responses in the other assessment areas will be interpreted as resulting from factors other than changes in freshwater inflow if salinities in that area have not changed appreciably, especially if Johnson Key Basin is also showing a negative response. Year to year changes in salinity are important to note because salinity is the main factor to be changed by CERP (through change in freshwater inflow) that would be expected to affect pink shrimp, either directly as suggested by the experiments (Browder et al., 2002), or indirectly through effects on seagrasses or some other as yet unknown factor influencing pink shrimp. Through MAP, the FIAN project is generating new data that can be used to evaluate the relationship of shrimp densities in Johnson Key Basin to those in the other assessment areas. To date, FIAN has generated 3 years of density data for all assessment areas for both seasons.

Using annual fall pink shrimp density in Johnson Key Basin as a reference against which to interpret shrimp densities in other assessment areas is not ideal. Linkage with the fishery either as an index or in a dynamic model would be better and is under development. Use of Johnson Key Basin as a reference site tacitly acknowledges the possible importance of the offshore pink shrimp fishery in influencing the density of juvenile pink shrimp in inshore areas. Johnson Key Basin is located toward the western margin of Florida Bay with the Gulf of Mexico (Fig. 1), relatively removed from the direct influence of restoration activities but where the influx of larvae from offshore spawning grounds would be expected to be strongest and less impeded by the shallow banks that honeycomb the bay. Among assessment areas, pink shrimp are most abundant in Johnson Key Basin, suggesting that, in addition to ease of larval access, habitat and salinity conditions also may be most favorable there (RECOVER, 2007). Seagrass meadows are well developed (Zieman et al., 1989; Hall et al., 1999). Salinity fluctuation in western Florida Bay is damped by proximity to the Gulf of Mexico. The influence of restoration-related hydrologic change on salinity in Johnson Key Basin would be through changes in freshwater outflow from the Everglades to the inner shelf of the Gulf of Mexico, where it is mixed with Gulf water before entering the western Bay (Kelble et al., 2007) or, possibly, from the gradual westward advection of large masses of water released to Taylor Slough. Our assessment approach emphasizes Johnson Key Basin, not only because of the abundance of shrimp there, but also because the availability of data supports development of statistical models with greater power to infer causes and effects that dynamically link spawning stock with inshore pink shrimp abundance. Two fishery independent time series of data from Johnson Key Basin and its vicinity, juvenile shrimp abundance in Johnson Key Basin and postlarval immigration via the channel at Middle Ground, will support model development (Robblee et al., 1991; Criales et al., 2006, M. Criales, 2008, unpublished).

The present targets for the performance measures are statistically based without any knowledge of the true baseline abundance of pink shrimp before the flow of fresh water through the Everglades and into coastal waters was forever changed. Pre-drainage pink shrimp densities may have been higher or lower than they are now. The targets we describe are based on recent past performance and include a wide neutral zone to provide for uncertainties associated with natural variation outside of the influence of CERP. Inter-annual variation in mean shrimp densities is substantial in Johnson Key Basin over the period-of-record, ranging from 1.2 to 3.9 and 4.1 to 26.8/m^2, spring and fall, respectively. Following the 3-year running mean density is another way of allowing for annual variation in natural factors. A quantitative method to standardize the sampled density and adjust the density target to take into account offshore spawning, larval transport and natural variation in salinity might allow broader perspective in assessing the effects of water management.

CERP, by altering freshwater inflow into South Florida coastal waters, seeks to modify existing salinity patterns to establish more natural (i.e., positive and extended) estuarine salinity gradients, reduce or eliminate the frequency and duration of hypersalinity, and extend the influence of base flow (usually moving as groundwater seepage) on salinities well into the dry season. Laboratory experiments have determined that optimum salinity conditions for juvenile pink shrimp from Florida Bay occur over the range of about 25–35 psu (Browder et al., 2002). Above or below these limits pink shrimp growth and survival are expected to decrease sharply. The inverse relationship of pink shrimp density with salinity in Johnson Key Basin provides field confirmation for this laboratory study on the high side of the salinity range (Fig. 2). Salinity conditions below 30 psu in western Florida Bay are rare and short-lived. These relationships suggest that pink shrimp should have a positive response to reduction of hypersalinity in Johnson Key Basin and other assessment areas in Florida Bay and Biscayne Bay. The response of pink shrimp to an expansion of the range and coverage of an estuarine salinity gradient might not necessarily be positive everywhere; in fact, the pink shrimp simulation model of Browder et al. (2002) predicts that pink shrimp will be less abundant at salinities $<$20 psu. Furthermore, other habitat variables might influence the effect on pink shrimp of a change in the salinity regime.

In contrast with western Florida Bay, relatively high pink shrimp abundance occurs in Whitewater Bay where salinities are routinely below 20–25 psu (Tabb et al., 1962, Fig. 1) and in the fall, when juvenile pink shrimp are most abundant have $<$12 psu (2005–2007). This pattern does not fit expectations based on the laboratory-derived survival and growth curves for pink shrimp in relation to salinity. No explanation is readily at hand. Interestingly, Gunter (1961) described pink shrimp as the only commercially important penaeid in the Gulf of Mexico that is ''clearly non-euryhaline'', and Tabb et al. (1962) remarked on Gunter's comment as contrary to what they found in Whitewater Bay. Several hypotheses need to be explored. One hypothesis is that the pink shrimp in Whitewater Bay are of a different phenotype with a greater tolerance for low salinities. Recent studies with decapods have found different behavioral phenotypes within what are likely the same populations (e.g., Lopez-Duarte and Tankersley, 2007); different physiological phenotypes within the same population seem equally plausible. Another explanatory hypothesis is that the hardness of the water flowing from the Everglades into Whitewater Bay buffers marine organisms from the effects of low salinity. Still another explanation might be that juvenile pink shrimp become adapted to the salinity regime prevailing at the location where they first settle as postlarvae. Another explanation is that different size-groups of pink shrimp found inshore have different salinity optima and tolerances. The salinity relationships of Whitewater Bay pink shrimp need to be explored.

The developing view of spatial patterns of pink shrimp abundance provided by MAP (Fig. 1) will be invaluable to interpreting responses to CERP implementation and also will strengthen the knowledge base supporting the pink shrimp indicator. The six assessment areas, South Biscayne, Whitewater, and the four Florida Bay areas, were chosen in relation to proposed restoration projects and represent regions of South Florida systems. FIAN monitors seven additional locations (19 locations in all) that will be available for assessment when time series of density data are acquired. Expectations of pink shrimp abundance metrics are not the same in all assessment areas or even throughout one area, reflecting differences in salinity regime, benthic vegetation, and access to postlarval shrimp. All depths encountered in nearshore South Florida estuaries can be sampled effectively with the 1-m^2 throw-trap, in use since 1984. The discrete nature of a throw-trap sample allows tight association with habitat. The FIAN sampling design allows comparisons with habitat and salinity within an area, among areas, and across years. The throw-trap is the standard method used in FIAN for MAP since 2005, and its use in other studies dating from 1984 greatly extends the baseline for the pink shrimp indicator.

4. Longer-term science needs

In summary, the pink shrimp makes a good indicator of the effect of CERP on the nursery function of South Florida estuaries, but priority science needs implied by the topics discussed above will make this indicator better. Longer time series of density data in all areas will allow development of performance measures for the other five identified areas, providing fuller coverage of the estuarine area potentially affected by CERP. More knowledge and models about the effect of offshore factors and inshore natural rainfall variability on pink shrimp density will improve the interpretation of year-to-year changes in juvenile density. Better understanding of the factors influencing spatial patterns of juvenile pink shrimp density will lead to targets that accurately reflect the spatial differences in potential density. The salinity relationships of pink shrimp juveniles and factors influencing these relationships in the mangrove estuaries of Florida's lower southwest coast need further examination.

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