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Roseate spoonbill reproduction as an indicator for restoration of the Everglades and the Everglades estuaries

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ABSTRACT

Ecological monitoring is key to successful ecosystem restoration. Because all components within an ecosystem cannot be monitored, it is important to select indicators that are representative of the system, integrate system responses, clearly respond to system change, can be effectively and efficiently monitored, and are easily communicated. The roseate spoonbill is one ecological indicator species that meets these criteria within the Everglades ecosystem. Monitoring of roseate spoonbills in Florida Bay over the past 70 years has shown that aspects of this species' reproduction respond to changes in hydrology and corresponding changes in prey abundance and availability. This indicator uses nesting location, nest numbers and nesting success in response to food abundance and availability. In turn, prey abundance is a function of hydrological conditions (especially water depth) and salinity. Metrics and targets for these performance measures were established based on previous findings. Values of each metric were translated into indices and identified as stoplight colors with green indicating that a given target has been met, yellow indicating that conditions are below the target, but within an acceptable range of it, and red indicating the measure is performing poorly in relation to the target.

1. Introduction and background

Adaptive management based on ecological monitoring is a key aspect of successful ecosystem restoration (Lovett et al., 2007; Williams et al., 2007). Because all components within an ecosystem cannot be monitored, it is important to select indicators that are representative of the system, integrate system responses, clearly respond to system change, can be effectively and efficiently monitored, and are easily communicated (Schiller et al., 2001; Doren, 2006; Doren et al., in this issue).

The Comprehensive Everglades Restoration Plan (CERP; U.S. Army Corps of Engineers, 1999) provides a framework to restore, protect and preserve the Greater Everglades ecosystem of southern Florida. One of the CERP's major emphases is restoration of hydrology; thus, in addition to the criteria mentioned above, indicators used for tracking progress of Everglades restoration should have clear relationships to hydrologic conditions (U.S. Army Corps of Engineers, 2004; Doren et al., in this issue).

The roseate spoonbill is an indicator that meets these criteria within the Everglades ecosystem. Monitoring of

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roseate spoonbills (*Platalea ajaia*) in Florida Bay over the past 70 years has shown that this species responds to changes in hydrology and corresponding changes in prey abundance and availability (Powell et al., 1989; Lorenz et al., 2002). We propose that spoonbill nesting location, nest numbers, and nest production in relation to prey fish abundance and availability may serve as powerful ecosystem indicators. Prey fish species composition, abundance, and availability are functions of hydrologic conditions (especially depth) and salinity (Lorenz and Serafy, 2006). Spoonbill nesting effort and success correlate with prey abundance and availability, and are therefore equally dependent on suitable environmental conditions. These relationships have been well documented such that spoonbill reproductive response can be directly related to changes in hydrology and salinity (Lorenz, 2000).

Correlations between spoonbills' biological responses and environmental conditions contribute to an understanding of the species' status and trends over time (Lorenz, 2000; Lorenz and Serafy, 2006). Positive or negative trends in spoonbill populations relative to hydrological changes permit an assessment of the effectiveness of restoration efforts (Lorenz, 2000; Lorenz et al., 2002; Bartell et al., 2004). Restoration success or failure can be evaluated by comparing past and predicted trends and status of spoonbills with historical population data and model predictions, as stated in the CERP hypotheses related to the food web (CERP Monitoring and Assessment Plan Section 3.1.2.4; U.S. Army Corps of Engineers, 2004).

The roseate spoonbill is representative of the Everglades system and its importance as an indicator of restoration is easily communicated. Spoonbills are one of several charismatic fauna found in the Everglades. They are both umbrella and flagship species (Hobbie et al., 1999; Bowman et al., 2003) of high interest and visibility to the public. In addition, parameters used to track trends are easy to understand: how has the number of spoonbill nests changed through time? Are they as productive as they were historically? Are the animals in optimal places? Is their prey as abundant as under natural conditions?

1.1. *Indicator history*

There is a 70-year intermittent database of roseate spoonbill nesting activity in Florida Bay (Fig. 1; Powell et al., 1989; Lorenz et al., 2002). Lorenz et al. (2002) demonstrated that nesting patterns are highly dependent on hydrologic conditions on the foraging ground nearest to the nesting colonies (Fig. 2). Spoonbills primarily feed on wetland fishes (Dumas, 2000) and time their nesting with low water levels, which results in prey base fishes becoming highly concentrated in remaining wetted areas (Loftus and Kushlan, 1987; DeAngelis et al., 1997; Lorenz, 2000; Bartell et al., 2004). Studies suggest that tactile feeding wading birds, such as the roseate spoonbill, are particularly dependent on high prey density to successfully forage, more so than visually oriented avian predators (Kahl, 1964; Frederick and Spalding, 1994; Gawlik, 2002). Tactile feeders are more efficient when prey density is very high, and visual predators are more efficient at lower prey densities (Kahl, 1964). Gawlik (2002) experimentally demonstrated that two species of tactile feeders (wood stork and white ibis) abandoned foraging sites while prey was still abundant enough to attract visually oriented wading birds in high numbers. Although no spoonbills visited their study site, Gawlik's (2002) experimental approach supports the idea that tactile feeders are more sensitive to prey availability. Because tactile foraging birds in general, and roseate spoonbills in particular, are more dependent on high prey concentration than other wading bird species (Kahl, 1964; Gawlik, 2002), they are more sensitive to changes in environmental conditions that determine fish concentrations, specifically water levels (Gawlik, 2002). The requirement for highly concentrated prey is exacerbated during nesting cycles, when the high-energy demands of their offspring require a consistently available high density of prey items (Kahl, 1964; Dumas, 2000; Lorenz, 2000).

Beginning with completion of a series of canals and water-control structures known as the South Dade Conveyance System (SDCS) in the early-1980s, water deliveries to Taylor Slough and northeastern Florida Bay (Fig. 2) changed

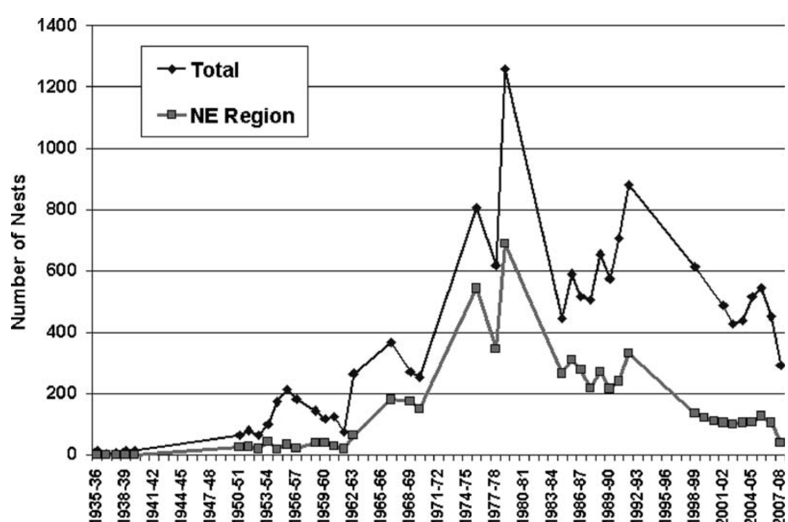

Fig. 1 – Annual number of roseate spoonbill nests for all of Florida Bay (Total) and for just the northeastern region of the bay from 1935 to 2008.

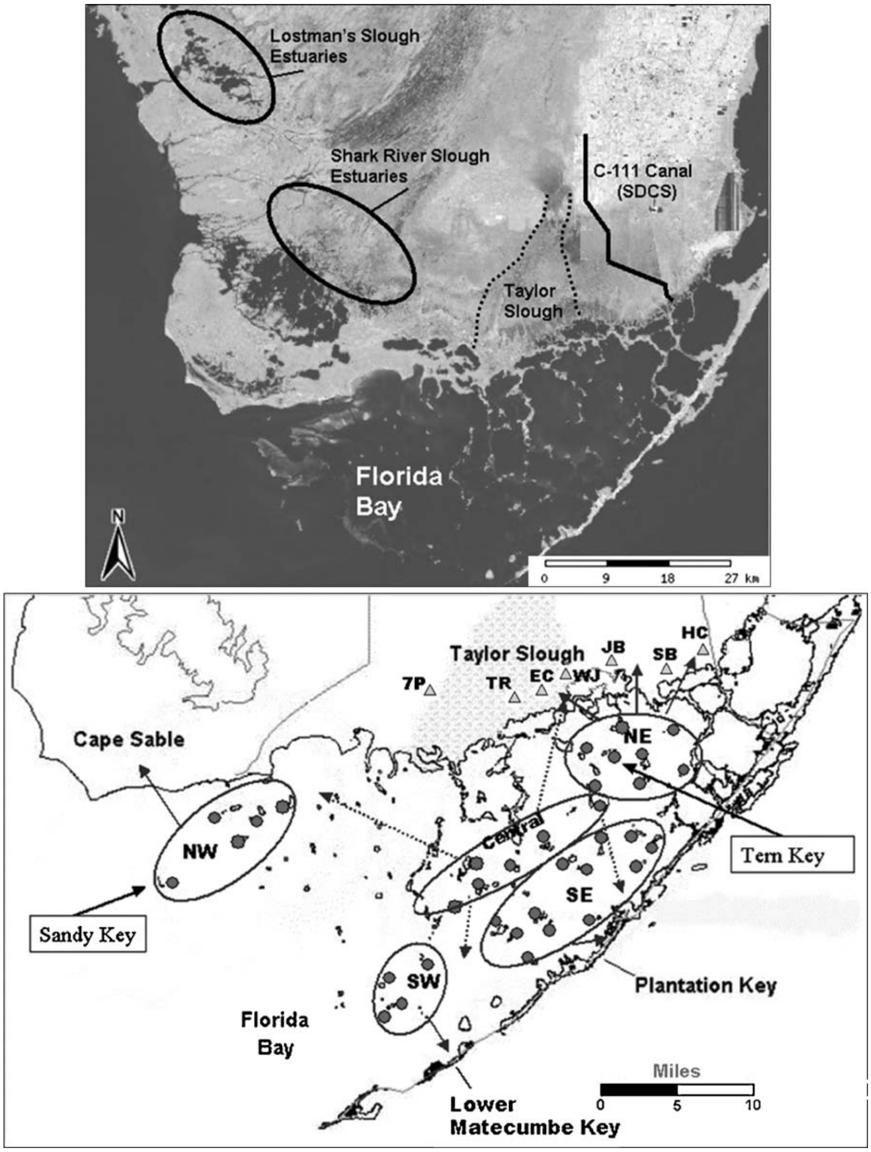

Fig. 2 – (Top) Map of southern Florida indicating the major features discussed. (Bottom) Map of Florida Bay indicating all the nesting locations for spoonbills since 1935 (circles), the primary foraging areas for five regions of Florida Bay (ovals) and the fish sampling sites used to evaluate the spoonbill's forage base (triangles). 7P = Seven Palms Lake, TR = Taylor River, EC = East Creek, WJ = Western Joe Bay, JB = Eastern Joe Bay, SB = Sunday Bay, and HC = Highway Creek.

dramatically (Light and Dineen, 1994; McIvor et al., 1994; Lorenz, 2000). This canal system is immediately adjacent to Taylor Slough and just upstream from where the majority of spoonbills nested in Florida Bay at the time (Fig. 2; Powell et al., 1989). The SDCS heavily impacted coastal wetlands that were the primary feeding grounds for the spoonbill nesting population (Bjork and Powell, 1994). In 1979, 1258 roseate spoonbill nests were located in Florida Bay, with more than half the nests located in the northeastern bay (Fig. 1; Powell et al., 1989; Lorenz et al., 2002). Today, the number of nests is less than one-third of 1979 numbers and their distribution has shifted from northeastern Florida Bay to the northwestern region (Fig. 2; Lorenz et al., 2002). The shift is attributed to the decline of nest production following the completion of the SDCS: Lorenz et al. (2002) calculated that spoonbills in northeastern Florida Bay produced an average of 1.38 chicks per nest prior to the SDCS but only 0.67 chicks per nest after its construction. Lorenz and colleagues demonstrated that this decline was the result of changes in hydrology and salinity caused by the SDCS, which affected production and availability of the spoonbill's prey base (Lorenz, 1999, 2000; Lorenz et al., 2002; Lorenz and Serafy, 2006).

In addition to a large nesting population in Florida Bay, spoonbills historically nested in the thousands along the southwest coast of Everglades National Park south of Cape Romano (Scott, 1889). During the late-1800s, spoonbills were largely extirpated in this region due to the plume hunting industry (Allen, 1942). Before spoonbills could recolonize this region, the estuaries were heavily impacted by Everglades ''reclamation'' projects from the late-1800s through today

(Light and Dineen, 1994) and although there has been some documentation of spoonbill nesting in this area, the numbers have been negligible. Restoration of hydrological conditions should promote greater prey abundance and availability in the southwestern Everglades estuaries, leading to an increase in spoonbill nesting success (measured in terms of the survival of offspring to the fledging stage). In this way, roseate spoonbill reproduction may serve as an effective indicator to evaluate the degree to which CERP is restoring estuarine conditions (Lorenz et al., 2002).

1.2. CERP hypotheses for roseate spoonbills

A CERP system-wide Monitoring and Assessment Plan (MAP) was developed to describe monitoring necessary to track ecological responses to Everglades restoration (U.S. Army Corps of Engineers, 2004). Included in this plan are descriptions of selected indicators, hypotheses regarding indicators' relationships to key aspects of restoration, and performance measures (monitoring parameters) to assess indicators' status and trends over time. The MAP hypotheses for roseate spoonbills state that restoration of freshwater flows from interior wetlands to southern estuaries will result in the following positive changes:

- An increase in nest numbers to pre-SDCS levels with at least half in the northeastern region (as defined by Lorenz et al., 2002) of Florida Bay.
- A return of significant nesting activity along the southwestern coast of Florida in the estuarine areas of Shark River and Lostman's sloughs (Fig. 2).
- Improvements in nest production (chicks/nest) and nest success (defined as average annual fledging of >1 chick/nest).
- Prey community structure that is dominated by freshwater species (as defined by Lorenz and Serafy, 2006).

These hypotheses are translated into performance measures, metrics, and targets below (Section 2).

1.3. Areas of the Everglades this indicator covers

Roseate spoonbills are found throughout the Everglades landscape; however, the species predominantly occurs in the Florida Bay estuary (Fig. 2) and covers the Greater Everglades and Southern Estuaries regions. Spoonbills are included as attributes in the Total System, Everglades Mangrove Estuaries, and Florida Bay conceptual ecological models (Davis et al., 2005; Ogden et al., 2005; Rudnick et al., 2005). The reason for inclusion in all three of these models is that spoonbills are dependent on the correct quantity, distribution and timing of freshwater flows to the Everglades estuaries, and thereby incorporate components of upstream water management practices. A monitoring and assessment plan has been developed for spoonbills nesting in Florida Bay. To examine spoonbills as a system-wide indicator, we perform a complete nest count of the entire bay, monitor nesting success for focal colonies in five regions of Florida Bay (Fig. 2) and perform quantitative assessments of the mangrove fish community, which makes up the bulk of the spoonbill's diet while nesting in Florida Bay.

1.4. Significance of the indicator to Everglades restoration

1.4.1. The spoonbill indicator is feasible to implement and scientifically defensible

Research on roseate spoonbills has been conducted for over 70 years, providing a remarkably long-term database (Lorenz et al., 2002). Currently, cooperative research and monitoring programs are funded and underway with U.S. Fish and Wildlife Service, Everglades National Park, U.S. Geological Service-Biological Resources Division, U.S. Army Corps of Engineers, and the South Florida Water Management District. This research has produced reliable models to determine the impacts of water management on nesting patterns (Bartell et al., 2004), and a landscape suitability model is currently being developed as part of a joint ecosystem modeling effort. In addition, the research has resulted in numerous peer reviewed journal articles (Lorenz et al., 1997, 2002; Lorenz, 1999; Faunce and Lorenz, 2000; Trexler et al., 2000; Faunce et al., 2004; Serafy et al., 2003; Davis et al., 2005; Green et al., 2006; Lorenz and Serafy, 2006). The scientific value of the spoonbill indicator is further confirmed by its inclusion in the CERP interim goals and trophic monitoring component of the Monitoring and Assessment Plan (U.S. Army Corps of Engineers, 2004).

1.4.2. The spoonbill indicator is sensitive to system drivers (stressors)

Key environmental drivers, such as water depth, hydroperiod and salinity, are significantly correlated with spoonbill nesting success and nest numbers (Lorenz, 2000; Lorenz et al., 2002; Lorenz and Frezza, 2007). A causal relationship exists among hydropatterns, prey abundance and availability, and nesting success (Lorenz, 2000; Lorenz and Serafy, 2006). Nesting failure has been linked to number and location of nests in a given region, such that persistent failure results in a decline in nesting effort and a concurrent increase in other regions. That spoonbills are able to move about the landscape to find the most suitable conditions supports our hypothesis that improving hydrologic conditions will attract increasing numbers of spoonbills.

1.4.3. The indicator is integrative

Spoonbill nesting success is linked to fish production (Lorenz, 2000), fish production is linked to periphyton and SAV production (Frezza and Lorenz, 2003), and all are linked to water depth, hydroperiod and salinity (Lorenz, 1999, 2000; Lorenz et al., 2002; Frezza and Lorenz, 2003; Lorenz and Serafy, 2006). Furthermore, spoonbills integrate coastal and interior wetlands through natural patterns (timing, locations, and amounts) of water flow. Numerous other species are also dependent on the same biological and physical resources as the spoonbill (Lorenz, 2000). Ospreys (Bowman et al., 1989), bald eagles (Sonny Bass, Everglades National Park, pers. commun.), reddish egrets (Powell et al., 1989), great white herons (Powell and Powell, 1986; Powell et al., 1989) and brown pelicans (Kushlan and Frohring, 1985) are some examples of bird species that are dependent on the same conditions that benefit spoonbills and that have also been in decline since water management practices affected the Everglades estuaries. Other species such as crocodiles (Mazzotti, 1999), manatees (Odell, 1979), and assorted game and commercial fisheries species (e.g., snook, seatrout, redfish, pink shrimp, and spiny lobster; Zieman et al., 1989; Gulick, 1995) are also dependent on the proper quantity, timing and distribution of flows to the Everglades estuaries. With the notable exception of crocodiles, these species are not as well studied and, therefore, the resources needed to use these species to evaluate restoration are not available. However, since all of these species are dependent upon the same physical and/or biological conditions, spoonbills represent an umbrella indicator for the Everglades estuaries. Positive spoonbill nesting responses are representative of hydrological improvements (i.e., water management) that will also benefit ecosystem function of the Everglades estuaries. Since the only way to realize this positive response is to correct all upstream disturbances of flow to the estuaries, the spoonbill represents a species that is indicative of the entire Everglades restoration effort.

2. The spoonbill indicator performance measures

2.1. *Performance measures*

The spoonbill indicator consists of four performance measures:

- Number of nests in Florida Bay.
- Location of nests (number of nests in northeastern Florida Bay, northwestern Florida Bay, and southwestern Everglades National Park estuaries).
- Nesting production and success (average number of chicks fledged per nesting attempt and number of years out of the last ten in which production exceeded 1.0 chicks per nest fledged).
- Prey community structure (percent of total community that are considered freshwater species per Lorenz and Serafy, 2006).

2.2. *The stoplight restoration report card system applied to spoonbills*

The stoplight restoration report card is a communication tool that is based on MAP performance measures (either by module or system-wide) and is expected to be able to distinguish between responses to restoration and natural patterns. Metrics and targets were developed for each performance measure (Table 1). Values of each metric were translated into indices and identified as stoplight colors with green indicating that a given target has been met; yellow indicating that conditions are below, but close to, the target; red indicating that the measure is performing poorly in relation to the target. The stoplight restoration report card addresses two questions: (1) have we reached the restoration targets? and (2) if not, are we making progress toward targets?

2.3. *Calculation of metrics and thresholds for the spoonbill stoplight restoration report card*

2.3.1. *Number of spoonbill nests in Florida Bay*

Since 1935, spoonbills have been recorded nesting on 38 keys throughout Florida Bay (Fig. 2; Powell et al., 1989; Lorenz et al.,

Table 1 – Metrics and targets to calculate stoplight colors for the roseate spoonbill indicator stoplight restoration report card.

1. Florida Bay Nest Number: 5-year mean of the percentage of pre-SDCS peak nest numbers found throughout Florida Bay. Target is 1258 nests based on the peak number of nests found in 1978 (Powell et al., 1989).	
a. <33% of Target	Red
b. 33–67% of Target	Yellow
c. >67% of target	Green
2. Nesting Location: the lowest score among all of the regions will be used as the metric.	
A. Northeastern Region: 5-year mean of the percentage of pre-SDCS peak nest numbers found in northeastern Florida Bay. Target number is 688 based on the peak number of nests found in 1978 (Powell et al., 1989).	
a. <33% of Target	Red
b. 33-67% of Target	Yellow
c. >67% of target	Green
B. Northwestern Region: 5-year mean of the number of nests found in the northwestern region since the SDCS was completed.	
a. <130 Nests	Red
b. 130-210 Nests	Yellow
c. >210 nests	Green
C. Southwestern Everglades Estuaries: no stoplight metric can be established at this time.	
3. Nesting Production and Success: the lowest score in either region in either metric will be used as the stoplight indicator (i.e., if either metric is red for either region than the stoplight will be red).	
A. Nest Production: 5-year mean of nest productivity (chicks per nest) in northeastern and northwestern Florida Bay. Target is 1.38 chicks/nest based on the pre-SDCS average in the northeastern region (Lorenz et al., 2002).	
a. <1 Chicks/nest	Red
b. 1–1.38 Chicks/nest	Yellow
c. >1.38 Chicks/nest	Green
B. Nesting Success: number of successful nesting years (average of >1 chick fledged per nest attempt) out of the previous 10 years in northeastern and northwestern Florida Bay. Target is 7 out of 10 successful years based on the pre-SDCS average (Lorenz et al., 2002).	
a. 0–4 Years	Red
b. 5–6 Years	Yellow
c. 7–10 Years	Green
4. Prey Community Structure: annual percentage of prey base fish sample that are classified as freshwater species according to Lorenz and Serafy (2007). Target is 40% freshwater species of the total annual catch collected at six sampling sites within the foraging grounds of spoonbills nesting in northeastern Florida Bay (Fig. 2: 7P, TR, EC, WJ, JB, SB, and HC). Note that this metric is integrative of 3 years.	
a. <5% Freshwater Spp.	Red
b. 5–40% Freshwater Spp.	Yellow
c. >40% Freshwater Spp.	Green
5. Composite Spoonbill Stoplight Metric: the mean of the four stoplights where red is scored 1, yellow is scored 0.5 and red is zero.	
a. <0.33	Red
b. 0.33–0.67	Yellow
c. >67	Green

2002; Cook and Herring, 2007). Spoonbills typically establish nests in Florida Bay in November or December of each year; however, nest initiation has started as early as October and as late as March (Powell et al., 1989; Alvear-Rodriguez, 2001). All known nesting keys are visited every 21 days during the nesting season. Our data show that prior to the establishment of the SDCS, the peak number of nests was 1258 in 1978 (Fig. 1; Lorenz et al., 2002). For this performance measure, annual nest counts are divided by 1258 to generate the annual percentage of the peak number of nests (Fig. 3). Because there is a great deal of natural interannual variation in nest numbers, a 5-year mean of total nests was used as the stoplight metric (Fig. 3). By examining various time frames from previous data, we concluded that by using a 5-year running average, no single good or bad year could skew results into an inappropriate color classification. Each stoplight color was given equal weight across the 0–100% scale so that as the target of 1258 is approached, the metric changes to green prior to reaching the target (Table 1; Fig. 3).

2.3.2. *Spoonbill nesting location*

Lorenz et al. (2002) divided Florida Bay into five regions based on the primary foraging grounds for each colony within each region (Fig. 2). The northeastern and northwestern regions have a high degree of probability of being impacted by Everglades restoration efforts, so these regions were used in evaluating this performance measure. The location performance measure consists of three metrics: a return to pre-SDCS nest numbers in the northeastern region, continued consistent nesting effort in the northwestern region, and return of spoonbills to nesting colonies along the southwest coast of the Everglades in the Shark River Slough and Lostman's Slough estuaries.

Powell et al. (1989) reported that in the peak year of 1978 more than half of the 1258 nests were located in the northeast region (688 nests). Following completion of the SDCS, this number dropped to approximately 100 nests annually from 2000 to 2007 (Fig. 1). In 2008 there were a total of 47 nests in the region. For restoration to be considered successful, we should expect a return of nesting to pre-SDCS numbers. Thus, the first metric for this performance measure is the percentage of 688 nests that occur annually (Fig. 4). As for total nests in Florida Bay (Section 2.3.1), the interannual variation can bias individual years so a 5-year mean was used for this metric (Fig. 4). Each stoplight color was given equal weight across the 0–100% scale so that, as the target of 688 is approached, the metric changes to green prior to reaching the target (Table 1; Fig. 4).

The second metric for the location performance measure is continued consistent nesting effort in the northwestern region. Since completion of the SDCS, spoonbill nesting effort shifted from the northeastern to the northwestern region (Lorenz et al., 2002). Effort in the northwestern region has been consistent since the early-1980s and the population has remained stable. Restoration efforts may have a positive affect on the primary foraging ground by lowering salinity and reducing tidal influences, thereby stimulating higher production in wetlands of Cape Sable. At the very least, restoration activities should not diminish the productivity of these wetlands, so the population in this region should remain at or above current levels. Since 1984, the largest number of nests in the northwestern region was 325 (Powell et al., 1989) and the lowest was 130 (Lorenz et al., 2002) with an average of 210 nests. Because we expect annual effort to remain the same or increase, we set the threshold for a green score at the current mean nesting effort of 210 (Table 1; Fig. 4). Any effort below the smallest number of nests from 1984 to 2008 (130 nests) would signal that the wetlands had been adversely affected by restoration efforts and would be scored red. Again, high interannual variation required that the 5-year mean nesting effort be used as the stoplight metric.

The third metric for nesting location is the return of spoonbills to nesting colonies in the southwestern Everglades estuaries. In the late-19th century, spoonbills nested in large numbers along the southwest coast of the Everglades in the Shark River and Lostman's slough estuaries (Scott, 1889). Our hypothesis is that historic hydrological conditions promoted greater prey abundance and availability in this region, and that hydrological restoration will restore prey populations, leading to a return of spoonbill nesting in this region (Ogden, 1994). In recent years, Everglades National Park has performed aerial wading bird surveys of this area and has documented spoonbill nesting (Sonny Bass, pers. commun., Supervisory Wildlife Biologist, Everglades National Park); however, accurate surveys of spoonbill nest numbers cannot be performed

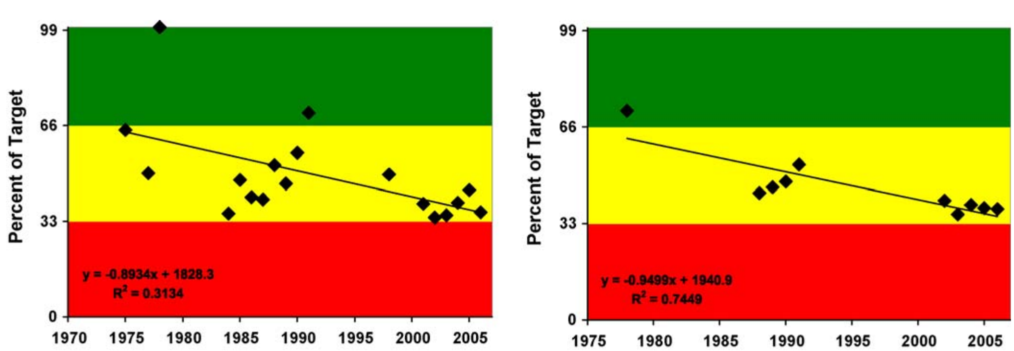

Fig. 3 – Nest number metric. (Left) Number of nests bay-wide as a percentage of a target of 1258 nests. The target was set based on the maximum number of nests in Florida Bay prior to the completion of the South Dade Conveyance System (SDCS) as reported by Powell et al. (1989). (Right) Five-year running mean of the data presented to the left. Note that due to data limitations the earliest data point was a mean of only 3 years; however, the 5-year mean will be used for the actual stoplight metric.

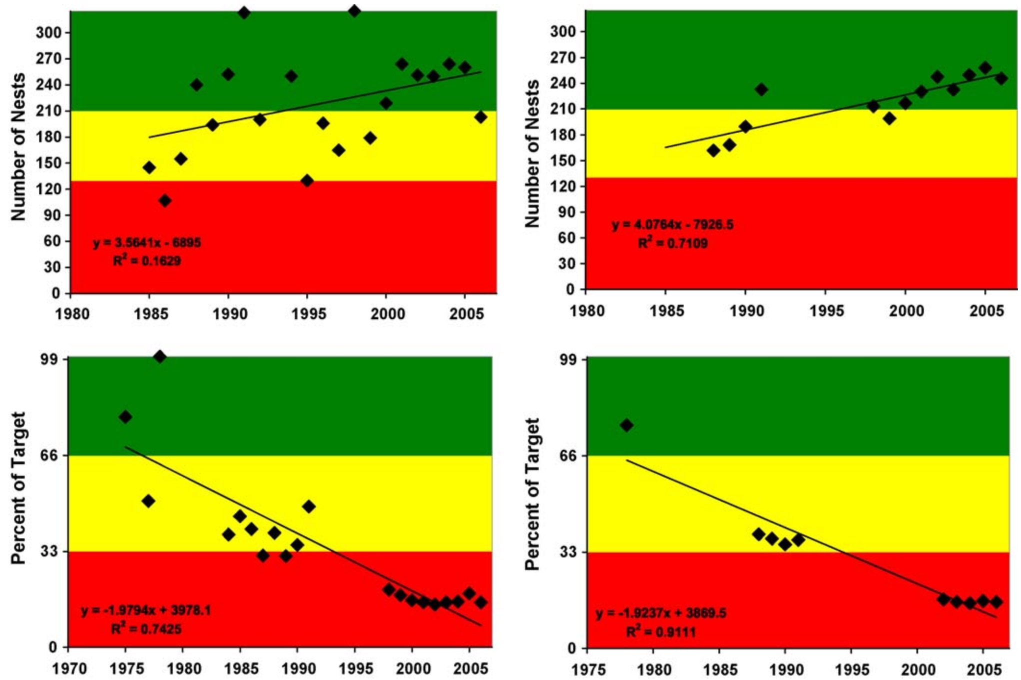

Fig. 4 – Nest location metric for northwestern and northeastern Florida Bay. (Top Left) Number of nests in northwestern Florida Bay since the completion of the SDCS. The target was set based on the average number of nests in northwestern Florida Bay since the completion of the SDCS as reported by Lorenz et al. (2002). (Top right) Five-year running mean of the data presented to the left. (Bottom Left) Number of nests in northeastern Florida Bay as a percentage of a target of 688 nests. The target was set based on the maximum number of nests in northeastern Florida Bay prior to the completion of the SDCS as reported by Powell et al. (1989). (Bottom Right) Five-year running mean of the data presented to the left. Note that due to data limitations the earliest data point was a mean of only 3 years; however, the 5-year mean will be used for the actual stoplight metric.

from aircraft because spoonbills tend to nest low in the canopy. Although it is imperative to get a baseline for pre-CERP nesting in this critical region, no surveys are underway. As a result, no stoplight metrics can be established at the time of this publication.

We reason that restoration activities should at least maintain, if not benefit, all three regions that are evaluated in this performance measure (northeastern and northwestern Florida Bay and the southwestern estuaries). If one of the regions does not perform well in relation to targets, then we may infer that restoration activities are not meeting the needs of roseate spoonbills in the Greater Everglades. In other words, success of restoration should be gauged by the metric (i.e., region) that performed the worst. We therefore use the lowest score from the two regions (or three regions if data for the southwestern estuaries becomes available in the future) as the overall stoplight metric for nest location.

2.3.3. *Spoonbill nesting production and success*

The method used to evaluate this performance measure is based on surveys of focal colonies (defined as the largest colonies within a region). These surveys entailed marking up to 50 nests shortly after clutches (2–4 eggs) had been laid and revisiting the nests on an approximate 7–10 day cycle to monitor chick development and survival. This performance measure uses two metrics, nest production and nest success, which measure nesting productivity at different (5-year and 10-year) time scales. Both metrics will be calculated for the northeastern and northwestern regions.

Nest production and success were based on number of chicks per nest that survived to 21 days. After 21 days, chicks become very active and move throughout a colony, precluding accurate accounting of individual nest production. Since 2003, chicks were leg-banded so that individual chicks could be identified. By resighting these individuals later in the nesting cycle, we confirmed our estimates of chick survival. Preliminary analysis of this mark-resighting technique generally validated that 21-day survival of chicks per nest was an accurate method to calculate annual nest production and success.

Lorenz et al. (2002) demonstrated that prior to the SDCS annual mean spoonbill production in the northeast region was 1.38 chicks per nest and that this dropped to 0.67 chicks per nest post-SDCS. Following the completion of the SDCS, spoonbills began to nest in the northwestern region in large numbers and have a production rate of 1.24 chicks per nest since. As the number of nests in the northwestern region has been slowly but steadily increasing (Fig. 4) over that period, we consider a production rate of 1.24 to be high enough to sustain a population of spoonbills. Data from the 1930s to the 1950s (prior to large-scale anthropogenic impacts) suggest that spoonbills historically produced two or more chicks per nest in Florida Bay; it is uncertain that future restoration efforts will be complete enough to return to this level of production

(Lorenz et al., 2002). Based on these data, we believe that a sustainable population should produce 1.24 chicks per nests while an increasing population (such as the northeastern population prior to the SDCS) should be higher than 1.38 chicks per nest. Wading bird studies suggest that a population that does not produce at least one chick per nest on average will decline. Based on these findings, we set the nest production metric thresholds for green at scores > 1.38, and for red at scores < 1.00. This scale places our estimate of 1.24 chicks per nest for a sustainable population squarely in the yellow score (Table 1). As with the previous metrics, the high degree of interannual variation in nest production required that a 5-year mean be used for this metric (Fig. 5).

As noted above, a nesting year is defined as successful when annual mean nest production is greater than 1 chick per nest. The metric for nesting success was calculated as the number of successful years out of the previous 10 years. Prior to the establishment of the SDCS, spoonbills nesting in the northeastern region averaged 71% successful years but have fallen to 36% since 1984 (Lorenz et al., 2002). During this same period, the northwestern region had an average success rate of 62%. Based on these data we set the threshold for a green score at ≥7 out of 10 years based on the production rate of a growing population (71% prior to the SDCS), and the threshold for a red score at ≤4 out 10 years based on the production rate of a declining population (36%) following completion of the SDCS. This again places the rate of the stable northwestern population (62%) in the yellow range (Table 1). Estimates for the nesting success metric for the period of record are presented in Fig. 6 for both northeastern and northwestern regions.

As previously noted, restoration activities should at least maintain, if not benefit, both of the northern regions of Florida Bay. If one of the regions does not perform well in relation to targets, then we may infer that restoration activities are not meeting the needs of spoonbills in Florida Bay. As for the nesting location performance measure (described above), we use the metric with the lowest score as the overall metric for productivity and success. Therefore, if any of the four metrics (nesting productivity or nesting success, northeastern region or northwestern region) used for this performance measure are red, then the overall stoplight score is red. For example, in 2006, the scores for both metrics were green or yellow in the northwest region but red in the northeastern region (Figs. 5 and 6). As a result, the overall score for the performance measure was red, thus indicating that further restoration efforts are needed to meet requirements for recovery of Florida Bay. Decision makers who wish to delve deeper would also find that the northwestern population is performing well but the northeastern population is performing poorly, so any restoration effort to improve conditions should be focused on northeastern Florida Bay.

2.3.4. *Prey community structure*

Spoonbills primarily feed on small demersal fishes found throughout the Everglades system (Allen, 1942; Dumas, 2000). Lorenz et al. (1997) developed a methodology for sampling fishes in the dwarf mangrove foraging grounds that are

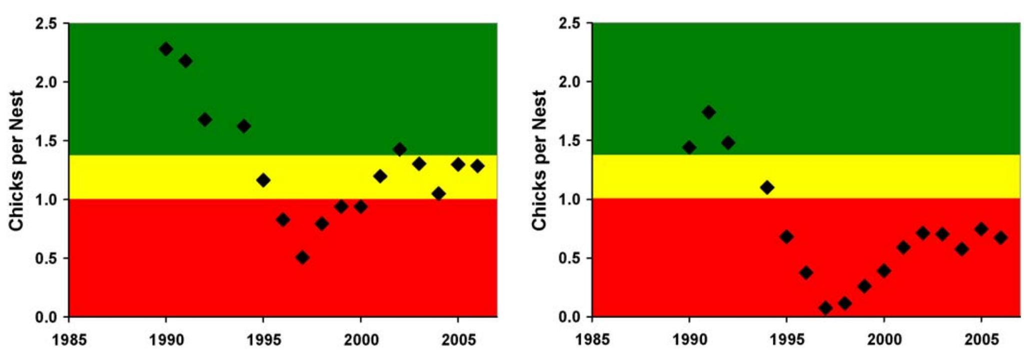

Fig. 5 – Florida Bay nest production metric. (Left) Five-year mean number of chicks per nest fledged in northwestern Florida Bay since the completion of the SDCS. (Right) Five-year mean number of chicks per nest fledged in northeastern Florida Bay since the completion of the SDCS. The target is based on pre-SDCS nest production data presented by Lorenz et al. (2002).

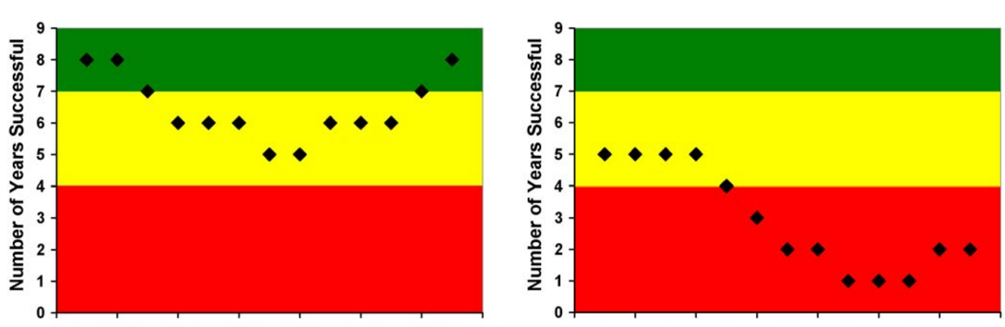

Fig. 6 – Florida Bay nesting success metric. (Left) Number of years nesting was successful in the last 10 years in northwestern Florida Bay. (Right) Number of years nesting was successful in the last 10 years in northeastern Florida Bay.

preferred feeding locations for spoonbills nesting in Florida Bay. The sampling design uses a 9-m^2 drop trap at fixed locations at known spoonbill feeding sites. Data collection began in 1990 at two sites; currently, there are seven sampling sites associated with northeastern Florida Bay's nesting spoonbill population (Fig. 2). Collections made at these seven sites were used to calculate this metric.

Lorenz (1999) documented that these fish respond markedly to changes in water level and salinity, and that these factors can be altered by water management practices. However, the complexities that the wet–dry season cycle have on fish abundance by concentrating fish into refuge wetted areas when water levels are low preclude the direct use of fish abundance as a metric for evaluating the impact of water management practices. Lorenz and Serafy (2006) performed a fish community analysis of 8 years of data from six sites; they found 3 consecutive years of unusually high rainfall and freshwater flows to the estuary which resulted in low salinity similar to what was believed to have occurred in the region prior to water management influences. The authors placed individual species in one of four salinity categories (freshwater, oligohaline, mesohaline or polyhaline) based on the Venice System of Estuarine Classification (Bulger et al., 1993). During periods of low salinity and high fish abundance, they found that more than 40% of the fish species were freshwater affiliates (Fig. 7). Furthermore, they demonstrated that these low salinity communities were much more productive based on both number and biomass of the standing stock (Fig. 7). Hence, we use the proportion of fish designated freshwater affiliates as the metric for prey community structure, and set the threshold for a green score at >40% (Table 1). We set the threshold for a red score at <5% based on the common statistical use of 5% as the threshold for being a significant (i.e., freshwater species make up a significant portion of the total catch when they reach 5% of the total catch). Lorenz and Serafy (2006) also demonstrated that it took two to 3 years of low salinity for freshwater populations to return to a site; therefore, although this metric will be reported

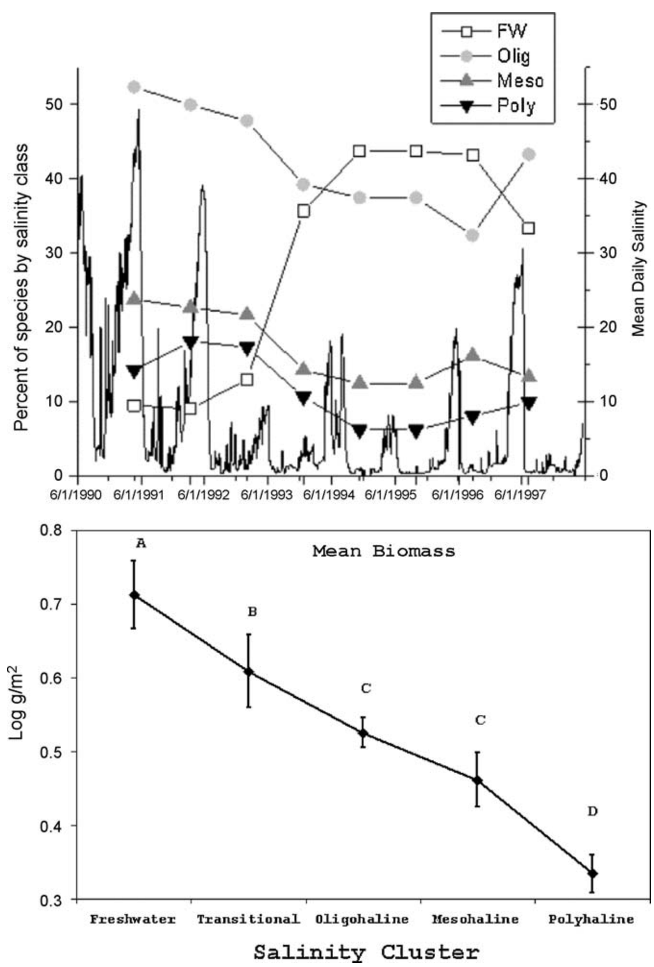

Fig. 7 – (Top: Left Axis) Percent of total species collected annually at the three estuarine fish sampling sites (Fig. 2: TR, JB, HC) by each salinity category as defined by Lorenz and Serafy (2006). (Right Axis) Mean daily salinity from the three sites for the period of record. Note that years following a high salinity dry season have lower representation of freshwater species and higher representation of mesohaline and polyhaline species. The figure also indicates that it takes 2–3 consecutive years of low salinity for the freshwater species to become the dominant fish category. (Bottom) Differences in fish biomass between salinity categories as defined by Lorenz and Serafy (2006) using Non-Metric Multidimensional Scaling from 8 years of fish collections at six sites. Their results show that samples dominated by lower salinity species have significantly higher biomass than those dominated by higher salinity species.

on an annual basis, it is integrative for the previous 2 years as well.

2.3.5. *Composite roseate spoonbill stoplight metric*

Each of the four performance measures (nest number, location, success and productivity, and prey base community structure) yields one stoplight score. To determine overall performance of the spoonbill indicator, an average of the four stoplight scores is used. For each performance measure, a green score is given the value of 1, a yellow score is 0.5, and a red score is 0. The mean of the four scores will therefore fall between 0 and 1. To determine the composite spoonbill stoplight, the average score range of 0–1 is simply divided into three equal sub-ranges (because all of the performance measures are equally important) and a stoplight color is assigned as follows: <0.33 is red, 0.33–0.67 is yellow, and >0.67 is green.

3. Discussion and conclusions

3.1. *Longer-term science needs*

Methods to monitor responses of spoonbills to hydrologic management are relatively well understood and techniques to survey spoonbills are relatively well established; however, there are components of their basic biology that are unknown. For example, life expectancy and age at maturity have not been documented. Furthermore, migratory patterns are not well understood and need to be assessed to determine if spoonbills nest in multiple locations annually or if the nesting population in Florida Bay is distinct from other nesting locations around Florida. Also, our knowledge of the dispersal of fledglings from nesting colonies is limited. In addition, a satellite tagging program would provide a great deal of information on international movements (e.g., to and from the Bahamas, Cuba, the Yucatan Peninsula). This would also allow definitive data on local foraging flights. We currently use inferences (such as flight line counts) to track where birds are feeding.Currently, there are no efforts to survey wading bird nesting colonies in the estuaries of the southwestern coast of the Everglades, even though this has been documented as an important nesting area prior to the plume hunting era. A return to nesting in this area has been identified as an important indicator for restoration of flows through Shark River and Lostman's sloughs, and surveys to this area should be initiated.

3.2. *Effectiveness of spoonbills as an indicator of ecological restoration*

In southern Florida, spoonbills show a distinct fidelity to estuarine habitats with approximately 90% of all nests found within Florida Bay, Tampa Bay and Indian River Lagoon (Cook and Herring, 2007; Audubon of Florida, unpublished data). In recent years spoonbills have begun nesting in inland freshwater habitats such as the Corkscrew Swamp, Water Conservations Areas and mainland Everglades National Park; however, the numbers are small (<10%) compared to the total spoonbill nests found in estuarine habitats (Cook and Herring, 2007). In contrast, other wading birds are much more plastic in their selection of breeding sites with a well-documented switch from coastal mangrove habitats to the water conservation areas in response to water management practices (Ogden, 1994). Spoonbill prey species and composition are dependent on flow of freshwater to estuarine areas. Given these characteristics, spoonbills are an indicator for Florida Bay, the southwest coastal estuaries, and hydrological connectivity within central Everglades wetlands.

Roseate spoonbills are well accepted by managers and policy makers as a species that is important to our understanding of estuarine systems. Spoonbills provide information to assess restoration of the Everglades that is unique from that provided by other wading bird indicators. Also, spoonbills require different methods of assessing their reproductive success because they nest cryptically within the canopy of mangroves and are not conspicuous from the air, thus requiring nesting surveys to be performed on the ground. As a result, different parameters have been used to monitor spoonbills from those used for other wading bird species. Since we must enter nesting colonies to monitor nesting effort, we are able to obtain more accurate counts and locations of nests. Success of individual nests is documented through mark and revisitation of the nests.

The RECOVER Conceptual Ecological Models for the Greater Everglades identify three major stressors to wetlands that affect spoonbill nesting activities in the Everglades estuaries: reduced freshwater flow volume and duration (affecting hydrology and salinity, fish abundance and availability); invasive exotic species (affecting primary producers and the prey base fish community); sea level rise (affecting habitat loss, wetland function and geomorphology, and preliminary and secondary production in the prey base) (U.S. Army Corps of Engineers, 2004; Davis et al., 2005). Only the first of these stressors will be ameliorated by CERP and, therefore, the spoonbill assessment tool focuses on water flow, volume, timing, and duration.

Spoonbill performance measures for nesting success, production, location and number assess these impacts of water management practices. Changes in timing and distribution of freshwater deliveries have resulted in pulsed increases in water levels on spoonbills' primary foraging grounds during the nesting season in northeastern Florida Bay (Lorenz, 2000). These out-of-season pulse releases resulting from upstream water management activities rapidly raise water levels above the concentration threshold and cause fish to disperse across the surface of the wetland. Thus, the abundant and easily captured food resources needed by nesting spoonbills are less available. Even brief reversal events (3–5 days) can result in total failure of spoonbill colonies. CERP and related projects should alleviate this situation, leading to higher nesting success and a return to higher nest numbers in northeastern Florida Bay. In this way spoonbills can serve as a quantifiable measure for restoration success.

In addition, spoonbills are an indicator of the impacts of changes in salinity patterns. Stresses caused by rapid and frequent fluctuations in salinity reduce primary production (Montague and Ley, 1993; Ross et al., 2000; Frezza and Lorenz, 2003), and alter the prey base fish community to a state of lower productivity (Lorenz, 1999; Lorenz and Serafy, 2006). As a result, the overall abundance of spoonbill prey items is reduced. The spoonbill assessment tool includes a parameter that examines fish community structure, which has been shown to have a direct link to prey fish productivity.

Performance measure metrics chosen for spoonbills reflect current and historical ecosystem conditions and are easy to communicate to managers. The metrics used to evaluate spoonbills have been well documented in the literature and are based on the best understanding of how the Everglades estuaries functioned historically, how they function currently, and how we expect them to function under restored conditions. The metrics provide both spatial and temporal criteria to assess the state of recovery efforts. We conclude that the spoonbill assessment tool will provide a powerful and integrative means to evaluate CERP activities.

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