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The White Ibis and Wood Stork as indicators for restoration of the everglades ecosystem

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ABSTRACT

Large numbers of colonially nesting herons, egrets, ibises, storks and spoonbills were one of the defining natural phenomena of the historical Everglades. Reproduction of these species has been tracked over at least a century, and some clear responses to dramatic anthropogenic hydrological alterations have been established. These include a marked decline in nesting populations of several species, and a movement of colonies away from the over-drained estuarine region. Ponding in a large portion of the freshwater marsh has favored species that hunt by sight in deep water (egrets, cf. 25–45 cm), while tactile feeders (ibises and storks) that depend on concentrated prey in shallow water (5–25 cm) have become proportionately much less common. There has been a marked increase in the interval between exceptionally large breeding aggregations of White Ibises (*Eudocimus albus*). Loss of short hydroperiod wetlands on the margins of the Everglades have delayed nest initiations 1–2 months by Wood Storks (*Mycteria americana*) resulting in poor nesting success. These responses are consistent with mechanisms that involve foraging, and the availability and production of prey animals, and each of the relationships is highly dependent on hydrology. Here, we define a group of characteristics about wading bird dynamics (= indicators) that collectively track the specific ecological relationships that supported ibises and storks in the past. We suggest four metrics as indicators of restoration success: timing of nesting by storks, the ratio of nesting ibises + storks to Great Egrets, the proportion of all nests located in the estuarine/freshwater ecotone, and the interval between years with exceptionally large ibis nestings. Each of these metrics has historical (e.g., predrainage) data upon which to base expectations for restoration, and the metrics have little measurement error relative to the large annual variation in numbers of nests. In addition to the strong scientific basis for the use of these indicators, wading birds are also a powerful tool for public communication because they have strong aesthetic appeal, and their ecological relationships with water are intuitively understandable. In the interests of communicating with the public and decision-makers, we integrate these metrics into a single-page annual ‘‘traffic-light’’ report card for wading bird responses. Collectively, we believe these metrics offer an excellent chance of detecting restoration of the ecosystem functions that supported historical wading bird nesting patterns.

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1. Introduction

Large numbers of colonial wading birds (order Ciconiiformes; herons, egrets, ibises, storks and spoonbills) were once common in the Florida Everglades (Ogden, 1994) and were defining characteristic of the pre-drainage wetlands of south Florida (Ogden et al., 2005). In addition to their being characteristic, large wading bird populations are of interest for at least two other reasons. First, large populations of wading birds played important ecological roles, including massive redistribution of nutrients in an otherwise oligotrophic landscape (Frederick and Powell, 1994), creation of tree islands with high nutrient status and altered vegetation (Frederick and Spalding, 1994), and demographic effects on fish and invertebrate populations through predation (Kushlan, 1974, 1976, 1977; Gawlik, 2002a). Secondly, these large populations have particular aesthetic and spiritual appeal to humans. The decline of wading bird populations has been cited as a primary reason both for the creation of Everglades National Park, and for the need for a more recent comprehensive restoration program. This appeal to humans is of real interest, since it allows a communication venue with a largely nonscientific public about the progress of restoration (Gawlik, 2006).

1.1. *Relationships between food availability, reproduction and hydrology*

The key process driving wading bird nesting in south Florida is availability of food (Frederick and Ogden, 2001; Frederick, 2002; Gawlik, 2002a; Herring, 2008). Nesting is generally not limited by competition, predation, disease, human disturbance, or nesting substrate (Frederick and Spalding, 1994), and the behavior of Everglades nesting populations in relation to hydrology, foraging patterns, and physiological/reproductive information fits very well with the predictions of food-limited reproduction (Powell, 1983; Ogden, 1994; Frederick and Spalding, 1994; Crozier and Gawlik, 2003a). In addition, this interpretation is supported specifically by studies of fecundity, physiological stress, and availability of prey (Herring, 2008).

Successful reproduction by large populations of wading birds requires that prey availability be continuously high throughout a reproductive cycle or season (60–130 days), with particularly high energy demands when chicks are growing and fledging. This typically happens during the winter/spring dry season in south Florida when water levels recede most reliably. For much of the year outside this time, prey are present but largely unavailable because of uniformly deeper water and dispersed distribution of animals.

Since nesting is so strongly affected by caloric intake, it is critical to understand the ecological conditions affecting prey availability. Prey are more available to wading birds in shallow (5–10 cm) than deep water (20–30 cm, depending on species, Gawlik, 2002a), but both foraging success and choice of foraging habitat are strongly modified by vegetation density and type (Hoffman et al., 1994; Surdick, 1998; Bancroft et al., 2002) and in the coldest parts of the year, by temperature (Frederick and Loftus, 1993). In addition, prey standing stock is an important underlying constraint on prey availability (Gawlik, 2002a). Prey standing stocks are in turn strongly affected by antecedent water conditions, salinity, nutrient levels, and fish community dynamics (Loftus and Eklund, 1994; Turner et al., 1999; Trexler et al., 2005; Lorenz and Serafy, 2006; Rehage and Trexler, 2006; Green et al., 2006; Dorn and Trexler, 2007). Prey availability is therefore a highly variable landscape mosaic affected by vegetation, prior water conditions, water depth, salinity, and prey community structure.

All of these variables are driven by temporal and spatial aspects of hydrology, with thresholds that may be measured in water depth (cm), hydroperiod (days), topographic relief (mm), soil type, and days since reflooding. The birds are probably not tracking any one of these hydrological variables alone. Instead, avian reproduction seems to be tracking seasonal prey production and availability (Frederick and Spalding, 1994; Frederick, 2000; Herring, 2008).

This strong dependence on water depth for foraging, and the extreme seasonal and annual variability in rainfall of the region means that optimal foraging conditions will be quite transient, both temporally (daily, annually, and even decadally) and spatially (over tens or hundreds of km within a year or season). Short-term fluctuations in prey availability may be due to locally rising or falling water, rainfall events, and intensive predation. Longer-term fluctuations are related to lagged effects of hydrology on prey productivity, longer patterns of rainfall accumulation, changes in physiography due to fire or long term drying, or other patterns. In order to encounter and track areas of high prey availability, the birds must use large areas to forage and establish nesting colonies, and may integrate information from many different geographic regions as large as the Everglades or the even the southeastern U.S. (Frederick et al., 1996; Hylton, 2004). Even on a daily basis, individual wading birds may fly long distances (30–60 km) from roost or nest sites to find foraging areas, often crossing between freshwater and estuarine communities (Ogden, 2006). This extreme mobility is one of the key features that distinguishes the ecological responses of wading birds from those of most other Everglades faunal assemblages or indicators.

1.2. *Responses of storks and ibises to drainage and impoundment*

Alterations to the natural hydrological system in south Florida over the last hundred years have been extensive and have resulted in a number of key changes to wading bird habitats at a landscape scale. These effects have included compartmentalization of the central Everglades, and the reduction of freshwater flows into the formerly more productive estuaries (Ogden, 1994). Each of these stressors has affected bird populations through the dynamics of food availability, or declining area of suitable habitat.

Ibises and storks have responded to these stressors by largely abandoning former nesting and roosting sites in the southern Everglades and Big Cypress basins. In the case of storks, ‘‘replacement’’ colonies apparently formed outside of the Everglades in locations in central and northern Florida (Coulter et al., 1999). In the case of ibises, new colonies began showing up in the WCAs by the 1970s, and the geographic relocation of both species rather emphatically suggested that the coastal habitat had degraded (Ogden, 1994; Frederick and

Spalding, 1994). Declines in south Florida ibis colonies in the 1970s and 1980s also coincided with rapid increases in population in more northerly locations such as Louisiana and North Carolina (Frederick et al., 1996).

The absolute size of breeding populations of ibises, storks, and some of the other long legged wading birds also declined precipitously between the 1930s and 1970s (Ogden, 1994; Crozier and Gawlik, 2003a), with some evidence that much of the decline in storks took place shortly after water management drastically reduced flows to the southern estuaries in the 1960s. The number of ibises nesting in south Florida has declined from an estimated 100,000–200,000 pairs in the 1930s–1940s (peak years) to 5000–20,000 (also peak years) pairs up until the late 1990s. The number of nesting storks has declined from 14,000 to 20,000 pairs prior to 1960 to about 500–5,000 pairs since the late 1990s (Ogden, 1994; Gawlik, 1997, 2001, 2002b; Gawlik and Ogden, 1996a, 1996b; Crozier and Gawlik, 2003b; Crozier and Cook, 2004; Cook and Call, 2005, 2006).

Storks have also responded to changing hydrological conditions by delaying the initiation of nesting by several months (February–March vs. historical November–December initiations) also beginning in the 1960s. This is thought to be a result of the loss of early dry season foraging habitat typically found in the coastal region. The delay in stork nesting has often resulted in young birds still being in nests when summer rains begin (late May and June), and as the prey concentrations disperse with rapidly rising water, the chicks starve in large numbers. This effect alone is suggested to be large enough to drive the south Florida population to extinction within the foreseeable future (Borkhataria et al., 2008).

The size of annual breeding aggregations of wading birds have historically showed enormous interannual variation, with some years close to zero, followed closely in time by years with hundreds of thousands (Ogden, 1994; Crozier and Gawlik, 2003a). The numbers of nests in these exceptional years were dominated by White Ibises, and the variation presumably reflected very large variation in prey availability from year to year (Frederick and Ogden, 2001), probably driven by combinations of changing hydrology and prey community composition. There is some evidence that the degree of this interannual variability, or ‘‘pulsing’’ of wading bird populations has changed in the post-drainage period, and may have affected different species to varying degrees (see below under Indicator Performance Measures).

Finally, there has also been an apparent shift in the species composition of the wading bird community, from one dominated by tactile-foraging storks and ibises to one dominated by sight-foraging Great Egrets, Tricolored Herons (*Egretta tricolor*) and Great Blue Herons (*Ardea herodias*). This shift is thought to be due in part to the fact that tactile foraging requires much denser prey concentrations to be effective (Gawlik, 2002a). Thus a shift to sight-foraging species may indicate prey availability has in general decreased.

1.3. *Wading birds as indicators*

While wading birds seem to be good indicators of various aspects of the aquatic ecosystem (Temple and Wiens, 1989; Kushlan, 1993; Erwin and Custer, 2000; Stolen et al., 2005), there are important differences among species in foraging ecology, reproduction, and movements that markedly affect their responses to ecosystem conditions. We have chosen to concentrate on the White Ibis and Wood Stork as indicators. These are two abundant, ecologically important species for which there is a substantial understanding of the mechanistic relationships between nesting, foraging and hydrological and ecological dynamics. In several ways, these two species also represent very different aspects of foraging ecology and reproduction (Frederick and Ogden, 1997).

Wood Storks and White Ibises are both tactile feeders that require concentrated prey, that the birds follow across the Everglades landscape as waters recede (Kushlan, 1977; Gawlik, 2002a). These two species are good indicators of spatial variability in prey availability because the birds are quick to abandon feeding sites when prey availability begins declining and they relocate to new feeding areas along with other wading bird species. Despite these similarities, there are important differences between the species in foraging behavior and reproductive patterns. White Ibises forage for small fish and crustaceans in shallow water (5–20 cm), and tend to forage relatively close to nesting colonies (<20 km). For this reason, they must relocate their colony sites and change timing of nesting from year to year in response to shifting locations of high densities of prey (Kushlan and Bildstein, 1992; Bildstein, 1993; Frederick and Ogden, 1997). Ibises may even move breeding locations across the southeastern US by hundreds of km from year to year, depending on local conditions (Frederick et al., 1996). In south Florida, ibises historically initiated nesting in most years in mid- to late dry seasons (February–April; Kushlan, 1977; Ogden, 1994). In contrast, Wood Storks select larger sizes of marsh fishes than do ibises (Ogden et al., 1976). These larger fish depend on deeper pools that may not dry annually and are longer hydroperiod sites. Storks routinely travel large distances from colony sites (25–75 km one way) to foraging areas and therefore are able to reuse traditional colony sites for many years, despite the shifting locations of concentrated prey (Coulter et al., 1999). Storks initiated nesting considerably earlier in the dry season (November–January) than ibises (Ogden, 1994). Despite a comparatively short nesting cycle for ibises (60–80 days), and a much longer cycle for storks (90–110 days), both species historically fledged young in the late dry season before rains dispersed prey and created poor foraging conditions.

2. Predicted responses of wading birds to hydrological restoration

Since wading birds have reacted so obviously to altered hydrology by a decrease in numbers and shifts in timing and location of nesting, it seems likely that a restored hydrology will cause reversals of these trends. A number of specific predictions have been made formally as part of the Comprehensive Everglades Restoration Program (CERP, RECOVER, 2004, 2006a, 2006b).

- Foraging distribution of wading birds will shift in response to changes in prey community characteristics.
- Wading bird nesting colonies will be reestablished and numbers of nesting pairs and colony sizes will increase in

the southern Everglades in response to changes in prey community characteristics.
- Nesting success and annual survival rate of wading birds will increase in response to changes in prey community characteristics.
- Wading bird prey availability is directly related to the time since reflooding and the length of time the marsh was dry.
- Concentration of wading bird prey is controlled by the rate of water-level recession and habitat heterogeneity.

3. Areas of the Everglades this indicator covers

Storks, ibises, and many of the other long-legged wading birds can be found in virtually all south Florida wetlands depending on species, season, and water conditions. In some seasons and years, virtually the entire Everglades may be devoid of birds, particularly in exceptional droughts, or during deep-water periods. During these times, birds are likely to move out of the Everglades entirely and into other areas of Florida or the southeastern US. Within the Greater Everglades, large feeding and/or nesting aggregations have been reported from the Kissimmee River and associated floodplains, Lake Okeechobee, the Water Conservation Areas (WCAs), Holy Land and Rotenberger, Big Cypress National Preserve, interior wetlands of southwest Florida (Corkscrew Swamp and Okaloacootchee Slough), mainland Everglades National Park, Florida Bay, Biscayne Bay, southwest coast of Everglades National Park, Rookery Bay and Ten Thousand Islands area. A few species are most often found in estuarine or marine environments (Great White Herons *Ardea herodias occidentalis*, Roseate Spoonbills *Ajaia ajaja*, Reddish Egrets *Egretta rufescens*) or fresh water areas (Glossy Ibises *Plegadis falcinellus* and Little Blue Herons *Egretta caerulea*), but the majority can nest anywhere within the southern Florida peninsula. White Ibises and Wood Storks are generally found in estuarine or freshwater areas, though ibises can be found nesting in the marine parts of Florida Bay. The high seasonal and annual mobility of these birds means that the same birds can nest in the southern coastal Everglades 1 year and nest in the northern freshwater Everglades the next (Strong et al., 1997). For this reason, this group probably has the greatest potential of any animal indicator to integrate information on habitat conditions across the Everglades ecosystems, as well as to rapidly reflect the location of favorable conditions by choice of feeding or nesting location.

4. Significance of the indicator to Everglades restoration

To be of use in understanding ecological responses to restoration, biological indicators must be reflective of known relationships, be sensitive to parameters of interest, be reflective of appropriate spatial and temporal scales, and be feasible to implement. In this section, we justify the wading bird indicators on those grounds, and in later sections examine specific strengths and weaknesses of each indicator.

4.1. *The indicator is relevant to the Everglades ecosystem and responds to variability at a scale that makes it applicable to the entire ecosystem or large portions of the ecosystem*

- The White Ibis, Wood Stork, and other species of colonial-nesting wading birds are well adapted to a predrainage Everglades-type ecosystem.
- These species and formerly large populations of these species are characteristic of the predrainage freshwater and estuarine greater Everglades system.
- Ibises and storks are top predators in Everglades aquatic food webs and therefore reflective of many species of aquatic prey animals.
- The distribution and abundance of ibises, storks and other wading birds is strongly determined by temporal and spatial scales of production and availability of aquatic prey.
- Ibises, storks, and other species of wading birds move about over large spatial scales in response to variable seasonal and annual patterns in the quality of foraging habitat and their choices of foraging and nesting locations are therefore good indicators of within-region variation in ecological processes.
- The quality of foraging habitat is directly linked to regional and system-wide hydrological patterns, which are themselves targets of restoration.

4.2. *The indicator is feasible to implement and is scientifically defensible*

- Survey protocols for foraging and nesting patterns for ibises and storks and other species of colonial-nesting wading birds are well developed in south Florida.
- Major portions of the Everglades are currently being surveyed for nesting patterns.
- Size and interannual variation in nesting populations of storks and ibises have been monitored during extensive periods during the 1930s, 1940s and 1960s and 1970s; systematic surveys of nesting colonies and foraging patterns have been conducted throughout much of the system since 1986. This provides a strong record of past distribution, timing and size of foraging and nesting patterns during both pre- and post-drainage periods.
- There is a strong body of published information about wading birds and their prey in the Everglades system, providing an understanding of the linkages between hydrological patterns, prey dynamics and the reproductive ecology and biology of wading birds.
- Wading birds have been established as indicators for CERP success, and are included in the RECOVER Monitoring and Assessment Plan, and as a recommended CERP Interim Goal.

4.3. *The indicator is sensitive to system drivers (stressors)*

- Wading birds are sensitive to anthropogenically altered hydropatterns in the Everglades, to which they respond by changing the location, timing and magnitude of nesting and foraging at system-wide scales.
- There is published research demonstrating the mechanisms that link changing hydrology, foraging ecology, physiological condition, and reproductive responses of wading birds.

- A strong set of working hypotheses have been developed to explain how and why wading birds have been adversely affected by drainage and management practices in the Everglades system, as a basis for predicting wading bird responses to restoration programs.

4.4. The indicator is integrative

- The nesting and foraging patterns of ibises and storks and other species of wading birds are strongly influenced by patterns of availability of aquatic prey at the scale of the ecosystem.
- Because of known differences and similarities in foraging and reproductive strategies, the collective responses of these two species, and other species of wading birds, reveal broad system-wide conditions of aquatic production and availability.
- The demonstrated mobility of wading birds within and outside the Everglades system allows them to sample very large areas in their search for food, and to integrate the information about foraging and nesting conditions over large temporal and spatial scales.

4.5. Goals and performance measures are established for wading birds (RECOVER, 2004, 2006a, 2006b) and the following metrics are recommended for monitoring

- Locations of nesting colonies
- Timing of stork nesting
- Species composition of nesting colonies
- Frequency of occurrence of exceptionally large nesting events.

Performance Measures are, "...indicators of conditions in the natural and human systems that have been determined to be characteristic of a healthy, restored ecosystem," (www.evergladesplan.org/pm/recover/eval_team_perf_measures.aspx). These "indicators" that we have chosen are metrics related to a subset of the performance measures.

RECOVER CERP Performance Measures Related to Wading Birds are:

1. Increase and maintain the total number of pairs of nesting birds in mainland colonies to a minimum of 4000 pairs of Great Egrets, 10,000 to 20,000 combined pairs of Snowy Egrets and Tricolored herons, 10,000 to 25,000 pairs of White Ibises, and 1500–3000 pairs of Wood Storks.
2. Shift in timing of nesting in mainland colonies to more closely match pre-drainage conditions. Specific recovery objectives would be for storks to initiate nesting no later than January in most years and for ibises, egrets and herons to initiate nesting in February–March in most years.
3. Return of major Wood Stork, Great Egret and ibis/small egrets and heron nesting colonies from the Everglades to the coastal areas and the freshwater ecotone of the mangrove estuary of Florida Bay and the Gulf of Mexico.
4. Reestablishment of historical distribution of Wood Stork nesting colonies in the Big Cypress Basin and in the region of mainland mangrove forests downstream from the Shark Slough and Taylor Slough basins. Increase the proportion of birds that nest in the southern ridge and slough marsh-mangrove ecotone to greater than 50% of the total for the entire Everglades basin.
5. For Wood Storks, restore productivity for all colonies combined to greater than 1.5 chicks per nest.
6. The last performance measure was not formally codified as a CERP parameter of interest, but we suggest it here: Restore the relatively short intervals between exceptional White Ibis nesting events that were typical of the 1930s and 1940s.

5. Indicator performance measures, targets and thresholds

We chose four indicator metrics to measure the recovery of wading birds and the ecological functions upon which they depend in the Everglades ecosystem. These indicators were chosen because there is evidence that they are supported through important ecological relationships that were typical of the predrainage Everglades (e.g., size, abundance and community composition of fishes and macroinvertebrates, Turner et al., 1999). Positive change in these indicators will therefore be strong evidence that the mainland wetlands in south Florida are moving closer to ecological characteristics of a predrainage Everglades ecosystem (Ogden, 2006).

5.1. Ratio of the combination of Wood Stork and White Ibis nests to Great Egret nests

This indicator is related to performance measure one, "Increase and maintain the total number of pairs of nesting birds in mainland colonies to a minimum of 4000 pairs of Great Egrets,... 10,000 to 25,000 pairs of White Ibis, and 1,500 to 3,000 pairs of Wood Storks." One of the intents of this performance measure is to produce a community composition of wading birds that was representative of predrainage relationships.

Sight-foraging birds typically forage by stalking slowly, and this strategy is effective at considerably lower prey densities than are necessary to attract tactilely-foraging White Ibises or Wood Storks (Gawlik, 2002a). The shift towards dominance by Great Egrets therefore suggests that deeper, ponding from the altered system of the altered system is greatly favoring the Great Egrets at the expense of storks and ibises. A return to larger numbers of storks and ibises would suggest that prey availability has increased in important parts of the system.

5.2. Month of initiation of Wood Stork nesting

This metric tracks performance measure two, "Shift in timing of nesting in mainland colonies to more closely match pre-project conditions. Specific recovery objectives would be for storks to initiate nesting no later than January in most years."

One of the most obvious and measurable responses of storks to altered hydrology has been the delay in nesting by several months compared with historical patterns (Ogden, 2006). Historically, Wood Storks began nesting in November to December, whereas currently they begin to nest from January to March (Ogden, 1994). Loss of early-dry-season foraging habitats is probably responsible for the change in the onset of nesting, which also results in markedly lower reproductive success (Ogden, 2006). This indicator measures an important ecological function (early dry season availability of prey) and is also directly related to the demographic viability of stork populations (Borkhataria et al., 2008).

5.3. *Proportion of all wading bird nests that occur in the estuarine/freshwater ecotone of Everglades National Park*

This metric is directly related to performance measure three, ''Return of major Wood Stork, Great Egret. ibis/small egrets and heron nesting colonies from the central Everglades to the coastal areas and the headwaters ecotone of the mangrove estuary of Florida Bay and the Gulf of Mexico.''

Historically, very large colonies in the Everglades ecosystem were found in the ecotone where freshwater meets saltwater in the mainland mangrove region (Ogden, 1994; Ogden et al., 1996; Alligator and Rodgers River bays, East River and Lane River, Alligator Lake, Cuthbert and Maderia rookeries, Broad and Shark River headwaters). An example was a huge rookery recorded in 1934 along the extreme headwaters of Shark River, estimated to have been a mile long and several hundred feet wide and so dense with nests and young birds that it was difficult to walk through the colony without disturbing nests (Ogden, 2006). Although no surveys were performed in the freshwater interior during the predrainage period, several anecdotal bits of evidence suggest that coastal nesting typically included the vast majority of birds nesting in the Everglades. Nesting in the coastal ecotone with occasional nestings in the interior is common in other large wetland systems with similar coastal/inland characteristics such as the Usamacinta/Grijalva rivers delta in the Yucatan (Ogden et al., 1988). Second, in the early part of the 20th century at a time when wading bird plumes were worth more than their weight in gold, there were no reports of major interior colonies, and little evidence of plumes being traded from the interior. Lastly, the widely accepted hindcast modeling of water levels in what is now the freshwater interior suggests that the majority of this area was probably too deep for foraging by wading birds much of the time. It therefore seems reasonable to assume that the majority of nesting in most years of the predrainage era was taking place in the coastal ecotone.

Several factors may have supported the high proportion of nesting occurring in this area. The relatively low salinity regimes of the historical estuarine region probably provided higher densities of prey than in the drained, salinized condition (Lorenz, 2000). In addition, the large range of topographic relief of estuarine vs. freshwater areas probably accentuated the concentration of prey into depressions. A second result of the large range of ground elevations was that residents of coastal colonies also had immediate access to areas where prey would be available in both early and late breeding season. Finally, coastal colonies may have been more stable because they were reliably inundated by tidal water, as opposed to freshwater colonies that often dry out (Ogden, 2006). During the late 1960s, the number and proportion of all wading bird species nesting in the ecotone began dwindling, and, in the vast majority of years since the proportion has remained at less than 0.2 (=20%) of the Everglades basin total (Ogden, 1994). Since 1990, the average has been about 0.12.

Movement of the majority of breeding birds back to the coastal ecotone would be strong evidence that the freshwater interface is able to support wading bird reproduction, implying that the processes making prey abundant and available in that region have been restored.

5.4. *Interval between years of exceptional White Ibis nesting*

This indicator addresses our suggested last performance measure, ''Restore the relatively short intervals between exceptional White Ibis nesting events that were typical of the 1930s and 1940s''.

White Ibis nesting was historically highly variable between years (Frederick and Ogden, 2001, 2003), and exceptionally large nesting years nearly always occurred in the 1 or 2 years immediately following a severe drought. The mechanism behind this patter is unknown, but could involve a short-term pulse in populations of small fishes cued somehow by drought conditions. The interval between exceptional ibis nesting years was chosen as an indicator because these large nesting events were an obvious characteristic of the Everglades, and because the underlying ecological mechanisms (concentration of small fishes and crustaceans) are thought to be important for other parts of the community ecology and nutrient cycling of the Everglades. Moreover, by focusing on the temporal pattern of occurrence of an event rather than on the magnitude of the event, this metric emphasizes the notion of dynamic and pulsed functions that are a defining characteristic of wetland ecosystems. Occurrence of years with exceptionally large numbers of nesting White Ibis at predrainage frequencies will be a strongly apparent biological phenomena demonstrating that the carrying capacity of the Everglades has changed and that restoration is achieving success. Because of the aesthetic appeal of wading birds in general, and the importance of extreme biological abundance to the lay person, this indicator has the added value of being a powerful and visual way to communicate restoration success to the public (Gawlik, 2006).

5.4.1. *Indicators not selected*

We did not choose an indicator to track the absolute abundance of all species of wading birds since an increase in total wading bird nesting numbers alone would not necessarily reflect a change in hydrology to pre-drainage conditions. For example, wading birds might increase in numbers in the WCAs, while decreasing in areas of historic nesting. This would obviously not reflect restoration of coastal processes in the Everglades. In addition, increases in numbers may favor generalists, such as some of the herons, at the expense of specialized feeders such as the White Ibis and Wood Stork. Therefore, we chose measures that were clearly linked to known ecological mechanisms involving specific species for which we had historical information.

For performance measure two, only Wood Stork nest initiation was chosen as an indicator. Wood Storks are more specialized in their foraging habits than most herons and egrets and their nest initiation dates are more likely to reflect system-wide changes in hydrology and prey availability. In addition, information on nest initiation dates is only sporadically available from historical records of species other than storks.

No indicator was chosen for performance measure four because our indicator about the proportion of nests that occur in the Everglades coastal/headwaters ecotone, reports essentially the same dynamic. Both performance measures (3 & 4) track changes in geographic distribution of wading bird nests as a result in the reestablishment of pre-drainage water flows. In addition, data to track performance measure three were more readily available than data for performance measure four.

An indicator was likewise not chosen for performance measure five because data on number of chicks per Wood Stork nest are not collected either on a regular basis or on a broad geographic scale across the Everglades.

6. The stoplight restoration report card system applied to wading birds

6.1. *Wading bird data*

This section addresses where data for forming the wading bird thresholds for restoration were obtained. In addition, this section discusses some of the concerns with data compatibility, and therefore its comparability, between the various sources. Chronicling the data sources used to construct the thresholds s is also important because it will assist those working with the indicators in the future with a recipe for consistent data gathering and analysis. In all cases, the ‘‘South Florida Wading Bird Reports’’ refer to Gawlik (1997, 1998, 1999, 2000, 2001, 2002a, 2002b), Gawlik and Ogden (1996a, 1996b), Crozier and Gawlik (2003b), Crozier and Cook (2004), Cook and Call (2005, 2006) and Cook and Herring (2007).

One overarching concern with all the data included in this section is the differences in how and where historical and more recent data have been collected. The data from the 1930s and 1940s is based largely on a review of field notes of Audubon wardens and biologists (Ogden, 1994; Crozier and Gawlik, 2003a). The collection and interpretation of these data appear to be somewhat subjective, especially in comparison with the more systematic methods of more modern wading bird estimates (Frohring et al., 1988). In addition, the areas actually searched or surveyed are not always clear from the reports, and the degree of effort and even methods used are not always or even usually stated in the historical accounts. Therefore, while data from the historic period may be useful in determining some quantitative bounds of predrainage conditions, their usefulness in trend analysis and setting recovery targets may be questionable depending upon the precision desired in the comparison. While these problems do not preclude use of the historical information, it is clear that interpretation and comparison must therefore be undertaken on a case by case basis.

6.1.1. *Ratio of the combination of Wood Stork + White Ibis nests to Great Egret nests*

Data sources: For the years 1931 through 2001, data were obtained from Crozier and Gawlik (2003a). Data from 2002 to 2007 are from the South Florida Wading Bird Reports.

Data concerns: The assumption inherent in this indicator is that the numbers of nesting birds of each species are largely controlled by different foraging opportunities. There is some uncertainty about this assumption, since we also know that Great Egret populations were particularly targeted by plume hunters in the early part of the 20th century. Specifically, it is not clear whether Great Egrets had rebounded to carrying capacity of the marsh by the time of the 1930s, a benchmark era for this indicator. However, between the 1930s and the 1960s, Great Egret populations did not appear to change much, and if anything appeared to decrease. This suggests that carrying capacity had been reached by the 1930s. However, the survey data during the 1930s and 1960s is fragmentary and probably not good enough to be absolutely conclusive on this point. Therefore there is some uncertainty in using the 1930s ratios. We feel that this source of uncertainty is largely overcome by the argument above.

In addition, this indicator could give misleading values since it is a ratio. For example, even if ibis and stork absolute numbers were to recover to predrainage levels, this ratio could remain low as a result of similar increases in Great Egrets. In this case, misinterpretation would be easily countered by simply looking at the absolute numbers. Such a result, however, would also trigger a reexamination of the underlying assumptions of this hypothesis, since it assumes that the conditions that favor ibis/storks do not favor egrets. As long as the potential pitfalls of this indicator are understood, misinterpretation from a very literal view therefore seems unlikely.

6.1.2. *Month of initiation of Wood Stork Nesting*

Data sources: We used earliest month reported as our metric. For years 1931–1946 and 1974–1989, data were obtained from Ogden (1994), Table 22.6. Data are reported as averages; they were not broken down by individual year. It was also assumed that Ogden (1994’s) ‘‘Timing of colony formation’’ in Figure 22.3 was equivalent to month of Wood Stork nest initiation. In an effort to break down nest initiation into finer details, data from Ogden (1994), Figure 22.3, were used for years 1953 to 1989. Years 1962 and 1978 are missing from this data set. For years 1996 through 2006, the earliest date of Wood Stork nest initiation mentioned in the ‘‘Status of Wading Bird Recovery’’ section of the South Florida Wading Bird reports was used. No Wood Stork nest initiation data was recorded for 2003 and 2004 in these reports.

Data concerns: The only obvious concern with this metric is that stork nesting numbers may be influenced by conditions outside the Everglades. For example, storks may come into body condition for nesting by feeding in wetlands in southwest Florida. While annual rainfall patterns may be quite similar there, water behavior and management may be unrelated to the Everglades, and so stork initiation dates could be misleading as an indicator of Everglades wetland function. The only way to understand the magnitude of this problem will be to monitor movements of individual birds across the landscape in years with different hydrological characteristics. Based on observations in the 1960’s, storks in the southern estuary colonies appeared to aggregate and feed in that region during the prebreeding period (Ogden, 1994).

6.1.3. Proportion of all wading bird nests in the Everglades that occur in the estuarine/freshwater ecotone (Everglades National Park)

Data sources: Data for 1931 through 2001 was obtained from Crozier and Gawlik (2003a). We use nesting within Everglades National Park as measure of nesting on the coastal ecotone because trends for the Park mirror those in the ecotone, and the aggregated data have been published and are widely available. Relatively few birds nest in mainland Everglades National Park outside of the ecotone. Nesting within the Water Conservation Areas is considered the Everglades' interior. Data from 2002 to 2006 were from the South Florida Wading Bird Reports.

Data concerns: Data from years prior to systematic surveys in 1970s are difficult to interpret because sometimes only presence/absence is reported. This issue has been resolved by relying on the protocols for acceptance of estimates in Crozier and Gawlik (2003a). When a range of nest numbers was provided we used the midpoint.

An important assumption is that the majority of wading birds were nesting in the coastal zone during the predrainage period. While there is reasonable comparative information from other wetland systems to back this up, it is important to remember that there were no surveys of the interior until the 1970s.

With this in mind, the interpretation of this indicator must be done carefully since the proportion nesting in the Park is strongly affected by numbers nesting in the interior. Thus a high proportion in the Park could be achieved by having relatively few birds nest in the Park and virtually none in the interior. Conversely even very large numbers in the Park might be offset in a proportional sense by equal or greater numbers in the interior. The intended use of the indicator is that the Park should be proportionally at least as attractive to wading birds as the interior is. In addition, this indicator is not going to be used in isolation, and a look at the absolute numbers of birds should help steer biologists away from strict interpretations of this indicator. We selected 70% as an indicator of restoration based on the weight of evidence of estimates in the predrainage period, and from information from the ecologically similar Usamacinta/Grijalva system in the Yucatan (Ogden et al., 1988).

6.1.4. Interval between exceptional ibis nesting events.

Data sources: Nesting data from 1931 to 1944 and 1970 to 2001 come from Crozier and Gawlik (2003a). Data from 2002 to 2006 come from South Florida Wading Bird Reports. Data from 1945 to 1970 are spotty and may have missed some exception nesting events.

Data concerns: Estimates of very large numbers of wading birds are prone to a number of biases (Frederick et al., 2003). In this case, however, we are relying on the ability of biologists to categorize breeding population sizes as greater or less than over 13,000 nesting pairs. We feel that this categorization is relatively robust to the magnitude of error typical of most observers, and therefore believe that the indicator is relatively buffered from measurement error. We established the threshold for exceptional nesting as a predetermined 70th percentile of all estimates of annual ibis nestings, 1931–2006.

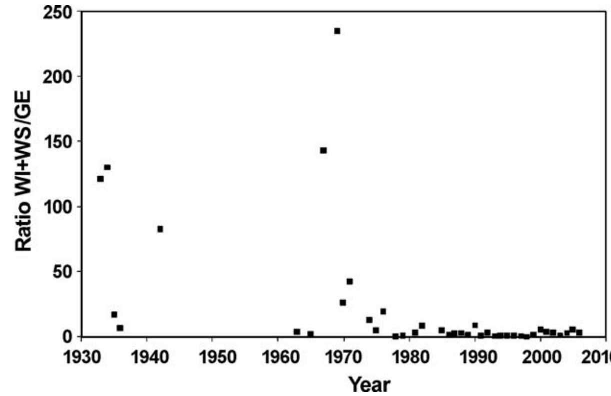

Fig. 1 – Ratio of Wood Stork (WS) plus White Ibis (WI) nests to Great Egret (GE) nests 1931–2006.

6.2. Supporting information for development of indicators

6.2.1. Ratio of the combination of Wood Stork and White Ibis nests to Great Egret nests

Fig. 1 shows the ratio of the sum of Wood Stork and White Ibis nests to Great Egret nests from the historic period (1930s and 1940s) until the modern era. During the historic era, the ratio of the combination of Wood Stork and White Ibis nests to Great Egret nests was about 120–1. This trend has fallen off rapidly by the 1970s and in the present era averages approximately 3–1 for most years (Fig. 2). However, numbers of White Ibis and stork nests were increasing faster than Great Egret nests during 2000–2006. The indicator therefore seems to be moving in the desired direction. Based on uncertainty in the number of Great Egrets, we have chosen a relatively conservative figure of 30:1 as the minimum threshold for restoration for this indicator.

6.2.2. Month of initiation of Wood Stork nesting

Records from 1931 to 1946 indicate that Wood Storks usually initiated nesting at the latest in December (Ogden, 1994). Fig. 3

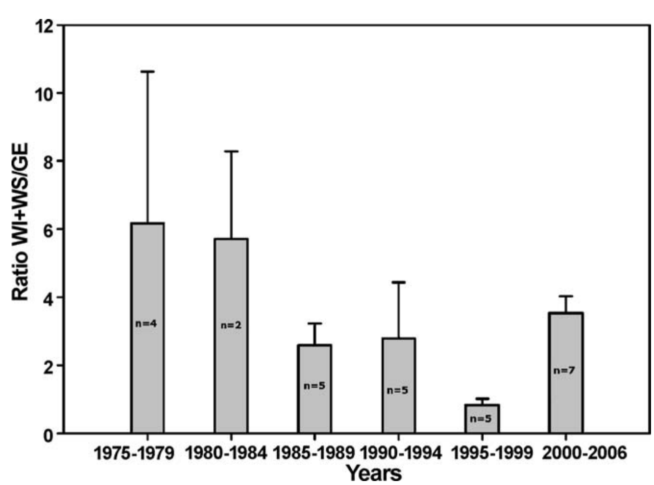

Fig. 2 – Ratio of Wood Stork (WS) plus White Ibis (WI) nests to Great Egret (GE) nests since 1975. Error bars represent interannual variability, and n is the number of years for which there are data within each interval.

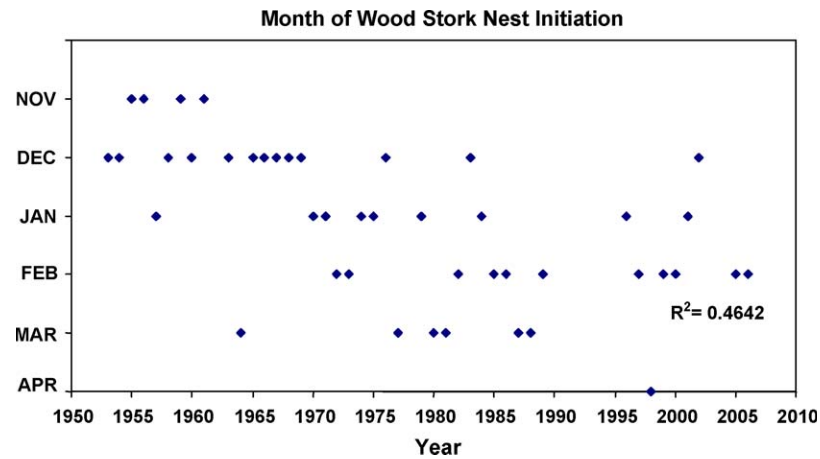

Fig. 3 – Month of nest initiation by Wood Storks in the Everglades 1953–2006. Data for the following years are not available: 1962, 1978, 1990–1995, and 2003–2004.

illustrates month of Wood Stork nest initiation from 1953 until present, although 10 years are missing from the data sequence (1962, 1978, 1990–1995, 2003–2004). The date of nest initiation may have become slightly earlier over the past decade, though this difference does not appear to be significant. A running annual 5-year average seems to damp the variation in the historical data to the point that a pattern can be discerned. Based on past nesting in the predrainage period and as late as the early 1960s, we suggest a running 5-year average of nesting dates corresponding to no later than December 30th as a threshold for restored conditions.

6.2.3. *Proportion of all wading bird nests that occur in the southern Everglades*

The proportion of all wading birds nesting in Everglades National Park is illustrated in Fig. 4, averaged over 5-year periods where data were available. The comparable proportion in the predrainage period was assumed to be at least 50%, and likely as high as 90% in many years. Based on the weight of evidence from the predrainage Everglades and from the Usamacinta system in the Yucatan, we believe that a threshold of 70% of all Everglades nesting being in the coastal zone is a conservative minimum for restored conditions.

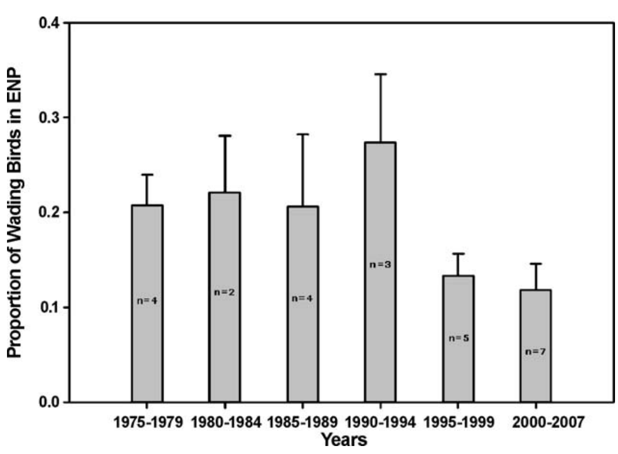

Fig. 4 – Mean proportion of Wood Stork, White Ibis, and Great Egret nests in the estuarine/freshwater ecotone (Everglades National Park) relative to the total in the Park and in Water Conservation Areas 1, 2, and 3. Error bars represent interannual variation, and n is the number of years for which there are data within each interval. Prior to 1975 surveys did not reliably cover the Water Conservation Areas, but we assume based on anectdotal evidence that the proportion in the 1930 s was greater than 0.70.

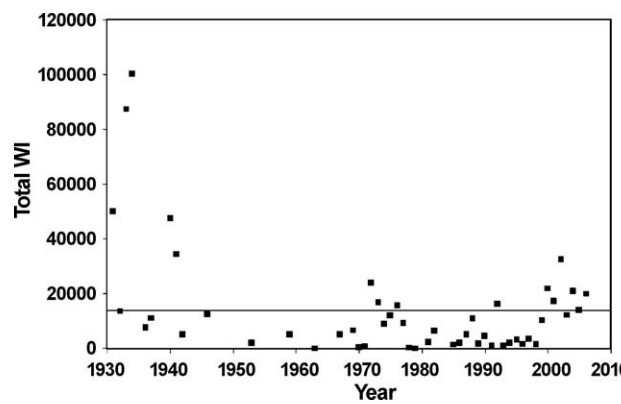

Fig. 5 – Numbers of White Ibis nests in the Everglades, 1931–2006, with horizontal line representing 70th percentile of nesting events in the entire period. This threshold (13,811 nests annually) is used as to identify exceptional nesting years. Note that the data from the period 1942–1972 are spotty and more unreliable for detecting exceptional nesting events than are years outside that time period.

6.2.4. *Interval between years with of exceptionally large White Ibis nesting*

Years with exceptionally large ibis nesting totals (= 70th percentile in the period of record, Fig. 5) occurred about every 2 years in the 1930s and 1940s in the Everglades (Table 1, Fig. 6). That interval increased to between 5 and 12 years between exceptional nesting events from 1970 to 2000. During the past 10 years, the interval has dropped back to historic levels.

Table 1 – Mean of intervals (in years) between exceptional ibis nesting events in the Everglades expressed for different periods of the record. Exceptional years are defined as 70th percentile of the period of record, or 13,811 nests.

Period	Mean	Standard deviation
1931–1941	1.45	1.81
1973–2006	4.47	4.63
1986–1999	7.36	5.09
2000–2006	0.14	0.38

6.3. *The traffic light key*

The following chart explains the traffic light graphics as they relate to the indicator.

- **Red** – Substantial deviations from restoration targets creating severe negative condition that merits action
- **Yellow** – Current situation does not meet restoration targets and merits attention, or may indicate improvement in trend.
- **Green** – Situation is good and restoration goals or trends have been reached. Continuation of management and monitoring effort is essential to maintain and be able to assess "green" status.

Example Wading Bird Indicator Traffic Light Report for 2006.

	Current status	1–2 year prognosis
Wading bird indicator	Three out of the four Wading Bird Indicators are Red based on the most current data available. Overall, wading bird populations and demographics are well below the recovery goals	Despite most indicators being well-below the recovery goals, there are positive trends for all four indicators, suggesting they will move closer to recovery goals in the near future
Ratio of combination of Wood Stork and White Ibis nests to Great Egret nests	The current ratio of 4 Wood Stork + White Ibis nests to every one Great Egret nest is well below the recovery goal of a 30–1 ratio	The ratio appears to have stabilized over the past two decades
Month of initiation of Wood Stork nesting	In 2006 Wood Storks initiated nesting in February, well below the recovery goal of November or December	Over the past decade there have been some years in which nesting has started as early as December and January
Proportion of all Wading Bird nests that occur in the Everglades Coastal/ Headwaters ecotone	The proportion of all wading bird nests occurring in the Park was 0.28 in 2006, far below yellow or green thresholds	Trends over the past two decades are stable or slightly decreasing
Interval between exceptional ibis nesting events	The mean interval for the last 6 years is now at the interval for the benchmark 1930s/1940s	While the trend is excellent, there is uncertainty in our ability to predict exceptional nesting events; none of these events have occurred to date in the mangrove ecotone

6.4. *Thresholds for Wading Bird Stoplight Restoration Report Card*

The green condition for the ratio of White Ibis + Wood Stork nests to Great Egret nests is any number greater than 30. Yellow conditions include ratios of between 10 and 20 AND an improving trend. The red condition is indicated by a ratio of less than 10.

For the month of Wood Stork nest initiation, the green condition includes running 5 year means corresponding to dates of earliest nesting earlier than December 30th, the yellow condition corresponds to means between December 31 and January 30th AND improving condition, and red conditions correspond to mean earliest nesting dates later than January 30th.

The green condition for the proportion of nesting population in coastal ecotone areas of Everglades National Park corresponds to greater than 70% of the total population (ENP + WCAs) nesting in the coastal ecotone. The Yellow condition is between 50 and 70% AND improving condition, and the red condition corresponds to less than 70% nesting in the coastal ecotone. The Green condition for exceptional ibis nesting events is indicated by a running 5-year mean interval of less than 3.2 (1930s mean plus one standard deviation). Yellow conditions prevail if the mean is 3.3–5 years AND decreasing intervals. Red conditions are indicated if mean intervals are greater than 5 years.

7. Discussion

7.1. *Effectiveness of Wading birds as an indicator of ecological restoration*

We believe that nesting wading birds are highly effective indicators of ecological restoration for a number of reasons. First, the birds have shown perhaps the most dramatic responses of any vertebrate to the drainage and hydrological alteration of the Everglades. Second, the responses to date are consistent with what we now know about the links between foraging ecology, physiological condition, nesting ecology, and

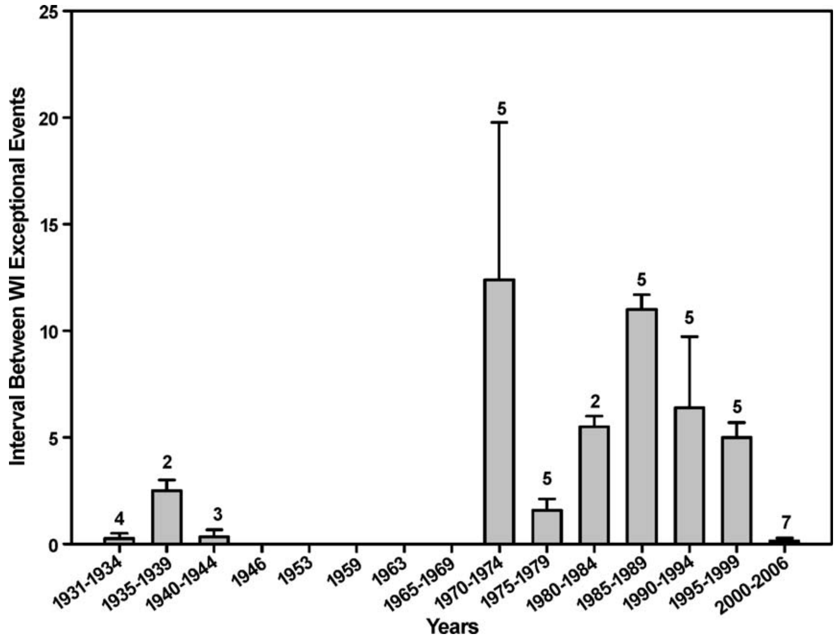

Fig. 6 – Mean interval (in years) between exceptional White Ibis nesting events in the Everglades expressed for 5-year periods in 1931–1945 and 1975–2006. Exceptional years are defined as the 70th percentile for the period of record, or 13,811 nests. Note that the data from the period 1942 to 1972 are spotty and more unreliable than years outside that time period.

hydrology. Third, through their movements, wading birds are able to react to ecosystem change over a variety of time scales, some of which are quite short (e.g., daily foraging movements), and others that may take decades (e.g., shift to coastal locations), allowing assessment of a number of restoration goals that may manifest themselves at different reaction times. These movements are manifested in the location of nesting, and the proportions of different species nesting. While foraging locations have not been suggested as an indicator, this parameter might be used, especially as we understand more about wading bird foraging/prey community relationships. Successful recovery of historical White Ibis and Wood Stork nesting patterns will be especially indicative of restoration success because these two species represent quite different habitat needs and ecological relationships. Wading birds also offer the chance to use a number of different species that may reflect different things about wetland relationships (e.g., storks vs. egrets). Finally, wading birds are an easy indicator for the public to identify with and understand on an aesthetic and ecological level. It seems likely that there may be further potential of wading birds as an indicator, especially as new patterns and relationships are discovered through more detailed and systematic monitoring. For example, wading birds are currently used as a primary indicator of mercury contamination in the system (Frederick, 2000).

7.2. *Longer-term science needs*

The process of formally identifying indicator species and indicator metrics has highlighted a number of limitations, mostly involving missing information or missing understanding. One example of missing understanding is the relationship between ibises and crayfish, an important prey item. While it seems likely that high availability of crayfish may have been important to supporting the large historical populations of ibises, the conditions necessary for producing high abundances of crayfish both currently and historically are unclear. The broader ecological roles of crayfish populations and their habitat needs are crucial pieces of the wading bird ecological puzzle.

There is also considerable uncertainty in understanding the interplay of high water and drought that are hypothesized to have organized pulses of production in an otherwise oligotrophic system, and which may have supported the periodic formation of exceptionally large colonies. Key questions have to do with the role of hydroperiod in nutrient and prey production dynamics in the greater Everglades, as well as other disturbance processes that may lead to pulses of productivity and availability (hurricanes, freezes, etc).

While there is relatively high confidence that wading bird populations will respond to restored hydrology with changes in timing, location and size of nesting, there is much uncertainty about the lag time necessary for these changes. This uncertainty about lag times might be addressed by further research into responses in similar systems elsewhere, or possibly through modeling studies. There is also concern that unforeseen relationships could override or alter the results of hydrological restoration and its relationship with nesting within the Everglades. These might include effects occurring outside the Everglades (attraction of birds to other sites, decreases in regional populations, changing regional weather patterns), as well as unforeseen effects within the Everglades like contamination, rising sea level, invasive species, changes in fish community dynamics, hurricane frequency, an increasing area of created eutrophic treatment wetlands, etc. While some of these potential effects simply cannot be foreseen, research and modeling of some of them (rising sea level, contaminants) could be very revealing. In addition, the ability to statistically correct apparent responses for changes in population size that are largely due to effects outside of the Everglades (attraction or repulsion elsewhere) would be of immense value in accurately assessing wading birds as indicators. To this end, any effort to foment cooperative survey efforts throughout the range of the birds could be extremely useful.

8. Conclusions

In this paper, we have identified a number of biological indicators, all of which are characteristics of wading bird populations in the Everglades, which we believe are metrics of the progress of ecological restoration. We believe that these metrics each are linked to aspects of the Everglades ecosystem that are indicative of conditions that were characteristic of a predrainage system. One of the most interesting things about using wading birds metrics is that the birds are integrative over large spatial scales, suggesting that they can sample the entire system in an efficient fashion. At the same time these highly mobile birds have relatively little site fidelity, and as a result their choices of feeding and breeding locations can be used directly to infer habitat quality. It is also clear that these metrics are compelling only because they have been measured over a very long period of change. Within the Everglades, there are no other animals whose population dynamics have been measured during the pre-drainage period and whose responses to hydrological manipulations have been so obvious. While this makes a very compelling argument for long-term monitoring in most ecosystems, it is important to remember that the characteristics of wading birds that make them such compelling indicators in this ecosystem (mobility, scale of movements, lack of fidelity, habitat relationships) may not be easily reproduced by any single species or guild in other ecosystems. Finally, it is rare that a species group so well suited to reflecting ecological functions in an ecosystem is also so charismatic and able to also serve as an effective communication tool with the public.

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