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Alligators and crocodiles as indicators for restoration of Everglades ecosystems

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ABSTRACT

Alligators and crocodiles integrate biological impacts of hydrological operations, affecting them at all life stages through three key aspects of Everglades ecology: (1) food webs, (2) diversity and productivity, and (3) freshwater flow. Responses of crocodilians are directly related to suitability of environmental conditions and hydrologic change. Correlations between biological responses and environmental conditions contribute to an understanding of species' status and trends over time. Positive or negative trends of crocodilian populations relative to hydrologic changes permit assessment of positive or negative trends in restoration.

The crocodilian indicator uses monitoring parameters (performance measures) that have been shown to be both effective and efficient in tracking trends. The alligator component uses relative density (reported as an encounter rate), body condition, and occupancy rates of alligator holes; the crocodile component uses juvenile growth and hatchling survival. We hypothesize that these parameters are correlated with hydrologic conditions including depth, duration, timing, spatial extent and water quality. Salinity is a critical parameter in estuarine habitats. Assessments of parameters defined for crocodilian performance measures support these hypotheses.

Alligators and crocodiles are the charismatic megafauna of the Everglades. They are both keystone and flagship species to which the public can relate. In addition, the parameters used to track trends are easy to understand. They provide answers to the following questions: How has the number of alligators or crocodiles changed? Are the animals fatter or thinner than they should be? Are the animals in the places (in terms of habitat and geography) where they should be?

As surely as there is no other Everglades, no other single species defines the Everglades as does the American alligator. The Everglades is the only place in the world where both alligators and crocodiles exist. Crocodilians clearly respond to changes in hydrologic parameters of management interest. These relationships are easy to communicate and

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mean something to managers, decision makers, and the public. Having crocodilians on the list of system-wide, general indicators provides us with one of the most powerful tools we have to communicate progress of ecosystem restoration in Greater Everglades ecosystems to diverse audiences.

1. Introduction and background

Ecological monitoring is a key part of adaptive management (Lovett et al., 2007; Williams et al., 2007) and successful restoration. Not everything within an ecosystem can be monitored so it is important to select indicators that are representative of the system, integrate system responses, show clear responses to system change, can be effectively and efficiently monitored, and are easily communicated (Schiller et al., 2001; Doren, 2006; Doren et al., 2009).

Crocodilians (alligators and crocodiles) are one of the indicators that meet these criteria within the Everglades ecosystems. Restoration of hydrology is a major part of the Comprehensive Everglades Restoration Plan (CERP; U.S. Army Corps of Engineers, 1999), and 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., 2009).

Alligators and crocodiles integrate biological impacts of hydrological operations, affecting them at all life stages (Mazzotti and Brandt, 1994; Mazzotti, 1999; Rice et al., 2005; Mazzotti et al., 2007) through three key aspects of Everglades ecology: (1) Food webs: Top predators such as crocodilians are dependent on prey density, especially aquatic and semi-aquatic organisms (Barr, 1997). Crocodilians are critical in the food web as top predators, influencing abundance and composition of prey (Mazzotti and Brandt, 1994). (2) Diversity and productivity: Drier (nests) and wetter (trails and holes) conditions created by ecosystem engineers like alligators provide habitat for plants and animals that otherwise would not be able to survive. This variation in hydrologic conditions created by alligators increases diversity and productivity of Everglades marshes (Kushlan and Kushlan, 1980; Campbell and Mazzotti, 2004; Palmer and Mazzotti, 2004). (3) Freshwater flow: The distribution and abundance of crocodilians in estuaries is directly dependent on timing, amount, and location of freshwater flow (Dunson and Mazzotti, 1989; Mazzotti and Dunson, 1989). The American crocodile, a flagship federally threatened species, represents the importance of freshwater inflow to estuarine health and productivity (Mazzotti et al., 2007).

Responses of crocodilians are directly related to suitability of environmental conditions and hydrologic change (Mazzotti and Brandt, 1994; Rice et al., 2005; Mazzotti et al., 2007). Correlations between biological responses and environmental conditions contribute to an understanding of species' status and trends over time. Positive or negative trends of crocodilian populations relative to hydrologic changes permit assessment of positive or negative trends in restoration. Restoration success or failure can be evaluated by comparing recent and future trends and status of crocodilian populations with historical or reference population data and model predictions, as stated in the CERP hypotheses related to alligators and crocodiles (U.S. Army Corps of Engineers, 2004, Sections 3.1.2.5 and 3.1.2.6).

The crocodilian indicator uses monitoring parameters (performance measures) that have been shown to be both effective and efficient in tracking trends (Mazzotti and Cherkiss, 2003; Rice and Mazzotti, 2006). The alligator component uses relative density (reported as an encounter rate), body condition, and occupancy rates of alligator holes; the crocodile component uses juvenile growth and hatchling survival. We hypothesize that these parameters are correlated with hydrologic conditions including depth, duration, timing, spatial extent and water quality. Salinity is a critical parameter in estuarine habitats (Dunson and Mazzotti, 1989; Mazzotti and Dunson, 1989).

Alligators and crocodiles are the charismatic megafauna of the Everglades. They are both keystone and flagship species to which the public can relate. In addition, the parameters used to track trends are easy to understand. They provide answers to the following questions: How has the number of alligators or crocodiles changed? Are the animals fatter or thinner than they should be? Are the animals in the places (in terms of habitat and geography) where they should be?

1.1. *CERP hypotheses for crocodilians*

A system-wide monitoring and assessment plan (MAP) has been developed that describes the monitoring necessary to track ecological responses to Everglades restoration (U.S. Army Corps of Engineers, 2004). The plan includes descriptions of selected indicators, how those indicators are linked to key aspects of restoration (hypotheses), and performance measures.

The MAP poses three hypotheses for alligators: (1) Restoration of hydropatterns (depth, duration, distribution, and flow) in Southern Marl Prairies/Rocky Glades will expand the distribution and abundance of reproducing alligators and active alligator holes and restore the keystone role of alligator holes as refugia for aquatic fauna; (2) Restoration of estuarine salinity regimes will expand the distribution and abundance of reproducing alligators into oligohaline portions of estuaries; and (3) Restoration of hydropatterns in ridge and slough landscape will sustain current populations of reproducing alligators. The MAP hypothesis for crocodiles is that restoration of freshwater flows to estuaries and salinity regimes will increase growth and survival of crocodiles.

1.2. *Areas of the Everglades this indicator covers*

Crocodilians are present throughout virtually all Everglades freshwater wetlands and estuarine areas (Fig. 1). These

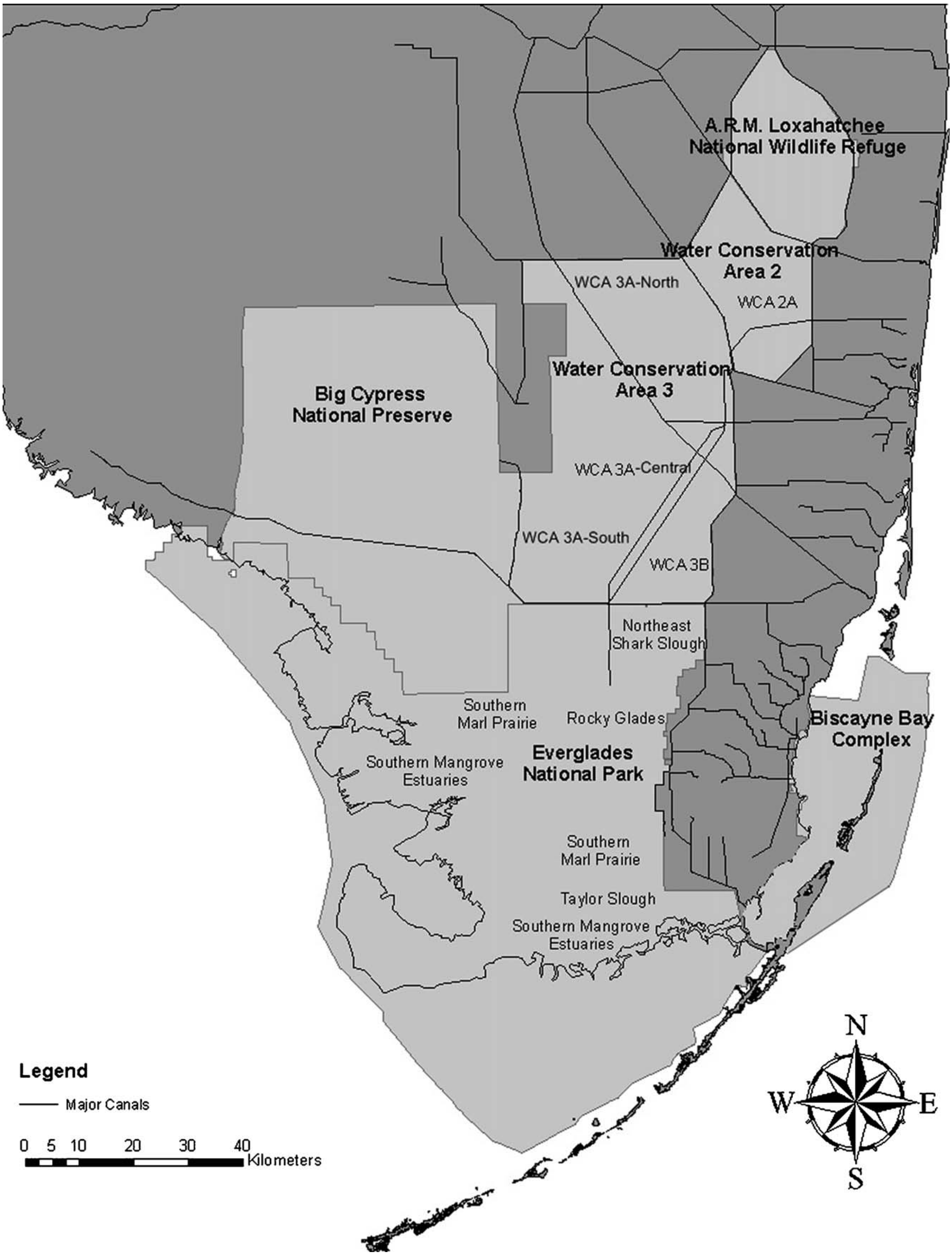

Fig. 1 – Areas important to monitoring and assessment of alligators and crocodiles in South Florida.

areas include the following Restoration Coordination Verification of Everglades Restoration (RECOVER) & Science Coordination Group (SCG) regional modules: Greater Everglades, Florida Bay and Southern Estuaries, Big Cypress, Lake Okeechobee, and the Kissimmee River Basin. Crocodilians are included as attributes in the following conceptual ecological models: Total System, Everglades Ridge and Slough, Southern Marl Prairies (Rocky Glades), Everglades Mangrove Estuaries, and Biscayne Bay. A system-wide monitoring and assessment plan has been developed for alligators and crocodiles that includes the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR) which includes Water Conservation Area 1, Water Conservation Areas 2 and 3 (WCA 2 and WCA 3), Everglades National Park (ENP), the Biscayne Bay complex, and Big Cypress National Preserve (Fig. 1). We sample for relative density and body condition of alligators in canals and marshes in LNWR, WCA 2A, WCA 3A and 3B; and canals, marshes and estuaries in ENP. Occupancy of alligator holes is sampled in Northeast Shark Slough, Rocky Glades, and Southern Marl Prairies (Fig. 1). Crocodiles are sampled throughout the southern mangrove estuaries (Fig. 1).

1.3. Indicator history

The significance of the crocodilian indicator relates to alligators' roles as top predator, keystone species and ecosystem engineer, and crocodiles' roles as top predator, flagship species and threatened species. Reproduction, growth, and survival of crocodilians are dependent on food availability—birds, mammals, fish, reptiles, amphibians, and macroinvertebrates—that in turn is dependent on hydrologic conditions. Loss of flow and relatively dry hydrologic conditions resulting from water management over the past several decades, and a loss of habitat (due partly to reduced areas of inundation, increased drydowns, and increased salinization) in the Everglades have adversely affected alligators and crocodiles (Mazzotti and Brandt, 1994; Rice et al., 2005; Mazzotti et al., 2007). Loss of habitat in Southern Marl Prairies and Rocky Glades and changes in hydropatterns (reduction in depth and period of inundation) of remaining areas have reduced abundance of alligators and alligator holes in these habitats (Craighead, 1968). Reduced prey availability throughout the system as a result of hydrologic alterations corresponds with lower growth, survival, and reproduction of alligators and crocodiles (Mazzotti and Brandt, 1994; Mazzotti et al., 2007).

Both alligators and crocodiles have been affected by loss of freshwater flow to estuaries. This loss of flow corresponds to a reduction in distribution and abundance of alligators (Craighead, 1968). Although there are more crocodiles in more places today than when they were declared endangered, virtually all of the increase is due to crocodiles occupying and nesting in man-made habitats such as the Turkey Point Power Plant site (Mazzotti and Cherkiss, 2003). The mangrove back-country of northeastern Florida Bay has always been considered as core habitat of the American crocodile in Florida (Kushlan and Mazzotti, 1989; Mazzotti, 1999). Today this physically unaltered area suffers from diversion of freshwater (McIvor et al., 1994). This area also has the lowest rates of growth and survival of crocodiles anywhere in Florida (Mazzotti et al., 2007).

Because of its unique geographic location and subtropical climate, South Florida is the only place in the world where both alligators and crocodiles occur. The most important regional factors affecting distribution and abundance of these crocodilians are loss of habitat (including extent of areas inundated for both species and nesting habitat for crocodiles), hydroperiod, water depth, and salinity (Mazzotti and Brandt, 1994; Mazzotti, 1999; Mazzotti and Cherkiss, 2003; Rice et al., 2005). Water management has changed the pattern of water levels in the southern Everglades, causing unnatural flooding events and failure of alligator nests (Kushlan and Jacobsen, 1990). Increasing drought frequency and depth of drying have reduced suitability of Southern Marl Prairie and Rocky Glades habitats and occupancy of alligator holes by alligators. Increasing drought frequency and depth of drying also increase the time required for fish and macroinvertebrate populations to recover to levels considered representative of the historical Everglades (Trexler et al., 2003; Trexler and Goss, in this issue). When drying events occur repeatedly at less than a three-to-eight-year interval, fish and macroinvertebrate populations are continually recovering from past droughts and may fail to reach densities sufficient to sustain large predators such as alligators (Loftus and Eklund, 1994; Turner et al., 1999; Trexler et al., 2005). This is correlated with lower growth and reproductive rates for alligators in the Everglades when compared to other parts of their range (Mazzotti and Brandt, 1994). Repeated drying events also may wipe out entire age classes, as alligators are forced to congregate in remaining water bodies where they may suffer predation and cannibalism.

Water salinity also affects populations of crocodilians (Dunson and Mazzotti, 1989; Mazzotti and Dunson, 1989). Although American crocodiles are more tolerant of salt water than alligators, both species prefer fresh to brackish water (Mazzotti, 1983). The distribution of alligators in estuaries has been affected by intrusion of salt water (Craighead, 1968; Mazzotti and Brandt, 1994). In northeastern Florida Bay, the occurrence of alligators corresponds with the presence of freshwater (Mazzotti, 1983). Regionally, lack of freshwater has been correlated with lower growth and survival of crocodiles (Moler, 1992; Mazzotti and Cherkiss, 2003; Mazzotti et al., 2007).

In a particularly encouraging finding, Mazzotti et al. (2007) reported that after Buttonwood and East Cape canals in Everglades National Park were plugged in the 1980s to reduce saltwater intrusion into interior areas of Whitewater Bay and Cape Sable, crocodiles responded positively by increasing nesting effort and success. This suggests that restoring salinity patterns in estuaries can have a positive effect on this indicator and that monitoring is effective at determining population responses. It also indicates that nesting effort and success should be added to growth and survival as monitoring parameters.

Models of different levels of complexity have been and are being developed using crocodilians as indicators for evaluation and assessment of hydrological alternatives. The Across Trophic Level Spatial Simulation (ATLSS) Spatially Explicit Suitability Index (SESI) alligator model simulates probability of alligator reproduction across the southern Everglades landscape based on hydrological drivers (http://www.atlss.org). A simple salinity suitability model was developed to evaluate

Table 1 – Decision rule questions for forming performance measure/suitability relationships for the crocodilian indicator communication tool

Alligator questions			
1. What is the current relative density for the American alligator (mean non-hatchling, >50 cm, animals per km during spring of reporting survey year) by management unit in South Florida?			
a.	0–1.47	Score: 0	Red
b.	1.48-2.70	Score: 0.50	Yellow
c.	>2.71	Score: 1.0	Green
2. What is the mean relative density for the American alligator (five-year running mean of non-hatchling, >0.50 cm, animals per km) by management unit in South Florida?			
a.	0–1.47	Score: 0	Red
b.	1.48–2.70	Score: 0.50	Yellow
c.	>2.71	Score: 1.0	Green
3. What is the most recent trend in relative density for the American alligator by management unit in South Florida?			
a.	−Slope	Score: 0	Red
b.	Stable	Score: 0.5	Yellow
c.	+Slope	Score: 1.0	Green
4. What is the current body condition for the American alligator (lowest spring or fall mean condition during reporting survey year) by management unit in South Florida?			
a.	0–9.31	Score: 0	Red
b.	9.32–11.27	Score: 0.50	Yellow
c.	>11.28	Score: 1.0	Green
5. What is the mean body condition for the American alligator (three-year running mean) by management unit in South Florida?			
a.	0–9.31	Score: 0	Red
b.	9.32–11.27	Score: 0.50	Yellow
c.	>11.28	Score: 1.0	Green
6. What is the most recent trend in body condition for the American alligator by management unit in South Florida?			
a.	−Slope	Score: 0	Red
b.	Stable	Score: 0.5	Yellow
c.	+Slope	Score: 1.0	Green
7. What is the current percentage of occupancy of alligator holes in Everglades National Park?			
a.	0–40	Score: 0	Red
b	>40–80	Score: 0.60	Yellow
c.	>80–100	Score: 1.0	Green
Crocodile questions			
8. What is the current growth of juvenile crocodiles (≤75 cm) in cm/day by management unit in South Florida during reporting year?			
a.	0–0.068	Score: 0	Red
b.	>0.068–0.15	Score: 0.50	Yellow
c.	>0.15	Score: 1.0	Green
9. What is the mean growth of juvenile crocodiles (≤75 cm) in cm/day by management unit in South Florida (three-year running mean)?			
a.	0–0.068	Score: 0	Red
b.	>0.068–0.15	Score: 0.50	Yellow
c.	>0.15	Score: 1.0	Green
10. What is the most recent trend in growth of juvenile crocodiles (≤75 cm) in cm/day by management unit in South Florida?			
a	−Slope	Score: 0	Red
b.	Stable	Score: 0.5	Yellow
c.	+Slope	Score: 1.0	Green
11. What is the current survival of hatchling crocodiles (mean monthly fall survival during reporting year) by management unit in South Florida during reporting year?			
a.	0–0.64	Score: 0	Red
b.	>0.64–0.85	Score: 0.50	Yellow
c.	>0.85	Score: 1.0	Green
12. What is the mean survival of hatchling crocodiles by management unit in South Florida (five-year running mean of monthly survival during fall of hatch year)?			
a.	0–0.64	Score: 0	Red
b.	>0.64–0.85	Score: 0.50	Yellow
c.	>0.85	Score: 1.0	Green
13. What is the most recent trend in survival of hatchling crocodiles by management unit in South Florida?			
a.	−Slope	Score: 0	Red
b.	Stable	Score: 0.5	Yellow
c.	+Slope	Score: 1.0	Green

A score of 1.0 for a performance measure is the restoration target.

water deliveries to Taylor Slough/C-111 (Mazzotti and Brandt, 1995). More sophisticated models are being developed for both species. An alligator production model has been developed that combines the alligator SESI model with functions for growth, dispersal, and survival to produce forecasts for nesting and relative density suitable for assessment of hydrological alternatives (Slone et al., 2003). Development of a similar crocodile model is underway.

1.4. Significance of the indicator to Everglades restoration

1.4.1. *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 or small portions of the ecosystem*

Alligators and crocodiles cover the entire spatial extent of Greater Everglades ecosystems and are characteristic of all Everglades freshwater and estuarine wetlands. They are top predators that affect prey populations of all sizes; productivity of populations and growth, survival, and body condition of individuals can be directly linked to hydrology (Dalrymple, 1996; Barr, 1997; Mazzotti et al., 2007). Alligators are a keystone species and ecosystem engineers. By constructing nests, trails and holes, they provide drier and wetter conditions for species of plants and animals that otherwise would not be able to survive (Craighead, 1968; Campbell and Mazzotti, 2004; Palmer and Mazzotti, 2004). Crocodiles are a flagship species for southern estuaries, representing the importance of restoring freshwater flow. Population measures for both species (relative density and body condition of alligators, occupancy of alligator holes, and growth and survival of crocodiles) are key outcomes (performance measures) in RECOVER Conceptual Ecological Models and in CERP Interim Goals. These performance measures vary at a local scale among Everglades management areas (Rice and Mazzotti, 2006). Hence, the crocodilian indicator can be used to compare responses of different management units as well as the entire system.

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

There are well-established methods for tracking the performance measures (Mazzotti and Cherkiss, 2003; Rice and Mazzotti, 2006) and there are both long- and short-term databases covering over 25 years for some parameters. These databases and expert opinion have been combined to create models to evaluate impacts of water management on this indicator (Mazzotti and Brandt, 1995; Slone et al., 2003). These databases and models are being improved through cooperative research, modeling, and monitoring projects with University of Florida, United States Geological Survey, United States Fish and Wildlife Service, United States National Park Service, United States Army Corps of Engineers, and Florida Fish and Wildlife Conservation Commission. This indicator is already included in the CERP RECOVER interim goals and Food Web Monitoring Component of the CERP MAP.

1.4.3. *The indicator is sensitive to system drivers (stressors) and integrative of system components*

Key hydrological drivers/stressors (e.g., rainfall, hydropattern, and salinity) are hypothesized to be correlated to species distribution, abundance, body condition, growth, and survival. Distribution and abundance of crocodilians in estuaries is limited by freshwater (Dunson and Mazzotti, 1989; Mazzotti and Dunson, 1989). Nesting of alligators and crocodiles has been statistically correlated with regional hydrological conditions (Kushlan and Jacobsen, 1990; Ugarte, 2006). As top predators in the Everglades, crocodilians integrate productivity throughout the trophic web; improvement in alligator populations will result in more aquatic refugia (alligator holes and trails) for all aquatic species in the system.

2. Communicating the crocodilian indicator

The crocodilian indicator consists of three performance measures for the alligator component and two performance measures for the crocodile component.

2.1. Indicator performance measures and metrics

The performance measures for the alligator component are relative density (reported as an encounter rate, number per kilometer), body condition (Fulton's K), and occupancy rates (percent occupied) of alligator holes in the Southern Marl Prairies/Rocky Glades in Everglades National Park. The performance measures for the crocodile indicator are juvenile growth (cm per day total length for crocodiles $\leq$75 cm) and survival (% monthly survival) of hatchling crocodiles in fall (August–December).

CERP RECOVER targets for crocodilian metrics are based on patterns that we consider natural for Everglades ecosystems, rather than a maximum or optimal value for a species. For example, alligators grow faster, get fatter (even obese), and have greater densities in nutrient-enriched open water systems than oligotrophic Everglades marsh and swamp ecosystems. Our targets take into consideration that Everglades alligators should grow more slowly, be more slender, and have lower relative densities than alligators in other areas such as central Florida. Maximizing or optimizing targets for single species is likely to be detrimental to maintaining species assemblages characteristic of the Greater Everglades.

2.2. The stoplight restoration report card system applied to crocodilians

This communication tool 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. A set of questions (decision rules; Table 1) has been developed for each performance measure. Answers are translated as suitability indices and colors (Table 2). Two questions are addressed using suitability indices: (1) have we reached the restoration target, or if not, (2) are we making progress toward targets? Finally, results are translated into a stoplight display.

Because performance measures and knowledge of performance measures vary among indicators, methods for producing suitability curves will vary among performance measures. For example, a five-year running average was used for mean relative density, where expected power to detect

Table 2 – Translation table for converting suitability or trend index for a performance measure or indicator into an index score and stoplight color

Index range	Index score	Stoplight color
0.0–0.4	0	Red
>0.4–0.8	0.5	Yellow
>0.8–1.0	1.0	Green

changes should enable trends to be detected in three to five years. A three-year running average was used for mean body condition where expected power should enable trends to be detected in one to three years. For most crocodilian performance measures, we used empirical data from reference sites as explained below (Rice and Mazzotti, 2006). The exception was occupancy rate of alligator holes, in which case the upper limit of the parameter was based on historical information (Craighead, 1968). Both targets and shapes of curves can be modified as more is learned about an indicator.

The trend for each performance measure is determined by plotting the mean score for the past five years. If the trend (slope) is negative the index score is 0, if the performance measure has remained the same the index score is 0.5, and if the trend is positive the score is 1.0.

2.3. *Metrics for the crocodilian stoplight restoration report card*

2.3.1. *Alligator relative density*

Values for relative density were developed by plotting frequency of relative density (mean non-hatchling, >50 cm total length (TL), alligators per km) across all survey routes (Fig. 2A; individual replicates of 10 areas over four to eight years) developed through the Alligator MAP night surveys, 1999–2006 (Rice and Mazzotti, 2006). We examined the data through use of quartiles and known relative densities of alligators in the Everglades and in central Florida (A.R. Woodward, unpublished data) for comparison.

Stoplights were developed by division along quartiles based on surveys conducted in the Everglades system only. Based on these divisions, for annual assessments, we evaluated the current relative density (mean of the two spring replicates within the reporting year), mean relative density (five-year running average of all replicates), and the most recent trend in relative density as in Table 1. Assessments were performed by individual management unit throughout the Everglades system (LNWR, WCA 2A, WCA 3A North, WCA 3A Central, WCA 3A South, WCA 3B, ENP—Northeast Shark Slough, ENP—Shark Slough, and ENP—Estuarine).

2.3.2. *Alligator body condition*

We used the distribution of body condition (Fulton's K) (Zweig, 2003) of all alligators captured and assessed during Alligator MAP monitoring, 1999–2006 (Rice and Mazzotti, 2006) to establish stoplight criteria for alligator body condition ($n = 1755$; Fig. 2B). We examined the data through use of quartiles and known body condition of alligators in the Everglades, and compared it to alligators in South Carolina (P.M. Wilkinson, unpublished data) and central Florida (A.R. Woodward, unpublished data). Stoplights were developed by division along quartiles based on animals captured in the Everglades system only. Based on these divisions, for the annual assessments, we assigned scores to the current body condition (lowest mean of fall ($n = 15$) and spring ($n = 15$) captures within the reporting year; Fig. 2B), mean body condition (three-year running average of all captures), and the most recent trend as in Table 1. Assessments were performed by individual management unit as above.

2.3.3. *Alligator hole occupancy*

Alligator holes occur throughout the Everglades landscape. Natural peat ponds in central ridge and slough wetlands do not have an underlying depression in the limestone bedrock, are not fixed features in the landscape, and can be created when an alligators needs access to the water table (Campbell and Mazzotti, 2004). In contrast, alligator holes in the marl prairies and Rocky Glades of the southern Everglades occur in depressions in the bedrock, are fixed in the landscape, and are maintained, but not created, by alligators (Craighead, 1968; Kushlan and Hunt, 1979). For that reason the alligator hole occupancy metric is only applied to southern Everglades wetlands.

We used the mean proportion of alligator holes occupied by at least one alligator as an index to occupancy of alligator holes in 2005–2006 (Rice and Mazzotti, 2006). We were unable to use the quartile approach or any more elaborate methodology to develop stoplight criteria for this component due to lack of data. Under MAP, we only assessed alligator hole occupancy during 2005–2006 in ENP. We also have results from surveys of alligator holes in WCA 3 by Campbell and Mazzotti (2004) as well as some historical information from Craighead (1968). We used a frequency diagram of all measures of occupancy from ENP during 2005–2006 along with the historical information to make determinations of stoplight divisions by breaks in the distribution (Fig. 2C). Based on these divisions, for the annual assessments, we assigned a score to the current occupancy (mean occupancy across all surveys within the reporting year) as in Table 1 for ENP. This component is applicable to areas of Northeast Shark Slough, Rocky Glades, and Southern Marl Prairies.

2.4. *Crocodile juvenile growth*

We used the distribution of all crocodiles captured and measured during studies conducted from 1978–2006 ($n = 498$; Mazzotti et al., 2007) to establish stoplight criteria for crocodile juvenile growth. Juveniles were defined as animals $\leq$75 cm total length (TL). Growth was measured in cm per day over the longest period between captures for animals recaptured at least once between hatching and 75 cm TL (Fig. 3A). We examined the data through the use of quartiles. Stoplights were developed by division along quartiles based on all animals captured in Everglades National Park and the Biscayne Bay complex. For annual assessments, we assigned scores to current crocodile juvenile growth (animals captured within the reporting year), mean growth (five-year running average of all captures), and the most recent trend as in Table 1. Assessments were performed by individual management unit (ENP and Biscayne Bay complex).

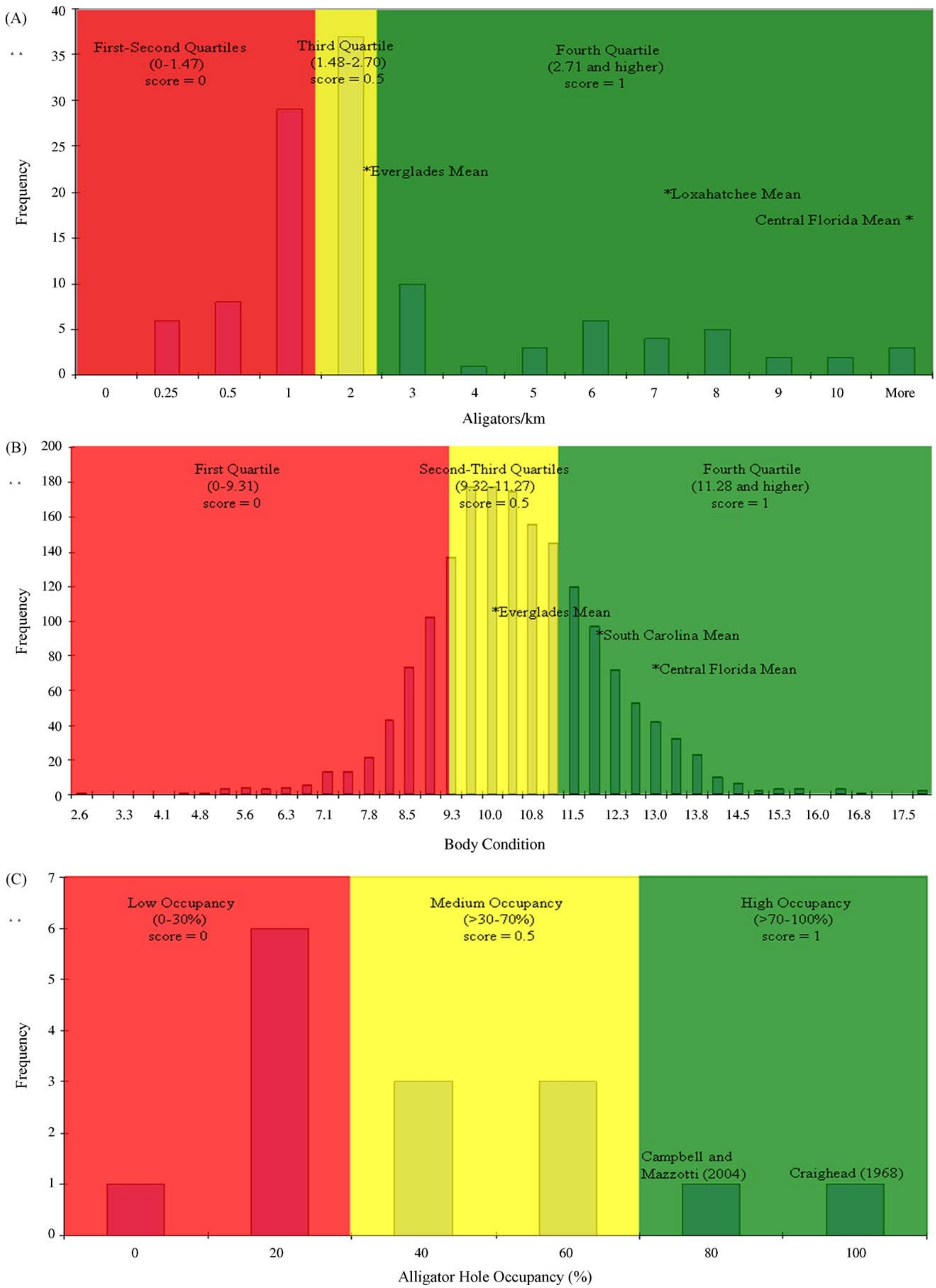

Fig. 2 – Alligator components used to determine stoplight thresholds for (A) distribution of night-light surveys of alligators in the Everglades of South Florida (1999–2006) used to determine relative density; (B) distribution of all alligators captured and

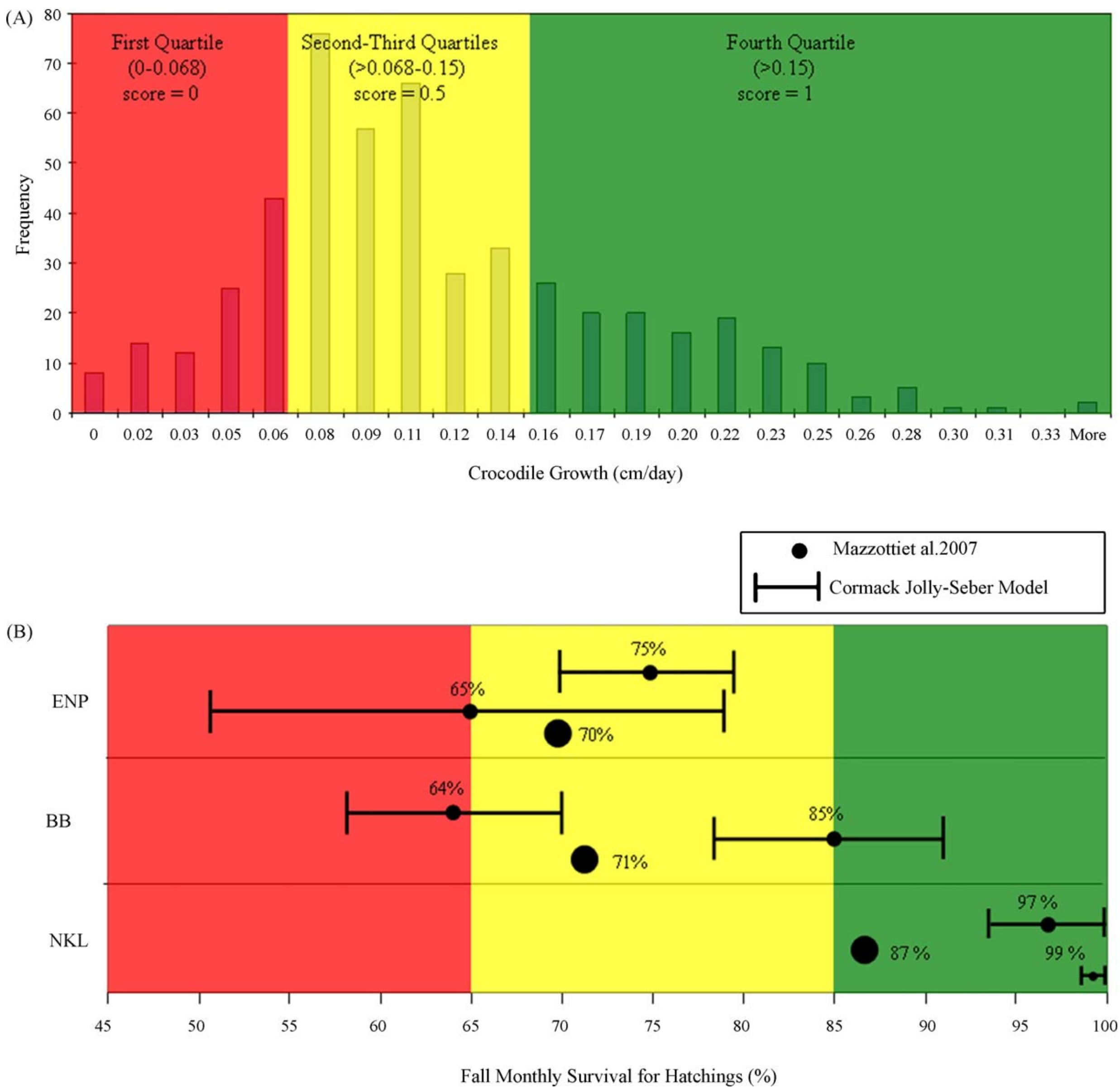

Fig. 3 – Crocodile components used to determine stoplight thresholds for (A) distribution of all growth rates of juvenile American crocodiles captured in South Florida, 1978–2006; and (B) monthly survival (%) of American crocodile hatchlings in Everglades National Park (ENP), Biscayne Bay complex (BB), and Northern Key Largo (NKL) from 1978–2006. Two separate analyses were used: Minimum Known Alive (Mazzotti et al., 2007) and multi-state (size class × management unit) capture-recapture survival analyses (Nichols and Kendall, 1995).

2.4.1. *Crocodile hatchling survival*

We established stoplight criteria for crocodile hatchling survival during the critical fall (August–December) post-hatching period (Mazzotti, 1983) by two methods. First, we used the Minimum Known Alive analysis of Mazzotti et al. (2007) to develop a range of possible survival probabilities (Fig. 3B). Second, we performed multi-state (size class × man- management unit) capture-recapture survival analyses (Nichols and Kendall, 1995) of all captures ($n = 3981$) from 1978–2004 using Program Mark (White and Burnham, 1999). The best model of fall hatchling survival included a management unit effect, a period effect (dry years vs. wet years), and a management unit × period interaction (Fig. 3B). This model had an Akaike weight of 0.96, indicating very strong support (Burnham and Anderson, 2002). Stoplights were developed by division along the mean estimates of survival from the above

assessed for body condition in the Everglades of South Florida, 1999–2006 ($n = 1755$); and (C) distribution of all surveys of alligator hole occupancy in the Everglades of South Florida (2005–2006) and historical evidence (Craighead, 1968; Campbell and Mazzotti, 2004).

analyses (Fig. 3B). Based on these divisions, for the annual assessments, we assigned scores to current crocodile hatchling survival (survival within the reporting year), mean hatchling survival (five-year running average of survival) and the most recent trend as in Table 1. Assessments were performed by individual management unit as above.

2.5. Scoring the crocodilian stoplight restoration report card

2.5.1. Alligator component score

The assigned component score was the mean of associated performance measures (e.g., current relative density, mean relative density, and trend in relative density).

2.5.2. Alligator management unit score

For each management unit, we assigned a score based on the mean of the component scores for relative density, body condition, and, where appropriate, hole occupancy.

2.5.3. System-wide alligator score

We defined the system-wide alligator score as the geometric mean of the management unit scores. We did this to emphasize any management unit that scored exactly 0 and would necessitate immediate management consideration.

2.5.4. Crocodile component score

The assigned component score was the mean of associated performance measures (e.g., current growth, mean growth, and trend in juvenile growth).

2.5.5. Crocodile management unit score

For each management unit, we assigned a score based on the mean of the component scores for juvenile growth and hatchling survival.

2.5.6. System-wide crocodile score

We defined the system-wide crocodile score as the geometric mean of the management unit scores. We did this to emphasize any management unit that scored exactly 0 and would require immediate management consideration.

2.5.7. Crocodilian index final score

We defined the overall crocodilian index score as the geometric mean of the system-wide alligator and crocodile scores. We did this to emphasize either species that scored exactly 0 and would require immediate management consideration.

2.5.8. 2006 Assessment

As an example, we provided an assessment of crocodilian populations in 2006. Detailed stoplight scoring and displays were examined and spatially referenced maps were prepared by component and management unit (Mazzotti et al., 2008).

2.6. Thresholds for crocodilian stoplight restoration report card

The system-wide indicator communication tool is based on RECOVER MAP ecological attributes and performance measures. The communication tool has been designed to distinguish between effects of restoration projects and natural phenomena. Targets for performance measures are established from historical data or reference sites. For crocodilians, we generally assigned the lower quartiles (below the median values) of possible distributions of parameters as the areas associated with caution and failure. By using spatially referenced suitability indices, the indicator communication tool can be linked directly to evaluation processes for restoration assessments. The communication tool instantly conveys the status of the indicator, whereas trend curves provide information on progress towards reaching a target. This indicator communication tool has the advantage that it can be applied regionally, by species, and collectively system-wide. Importantly, both targets and suitability curves can be adapted as science improves our understanding of crocodilians in the Greater Everglades ecosystems.

3. Discussion

3.1. Effectiveness of crocodilians as an indicator of ecological restoration

RECOVER Conceptual Ecological Models identify three major stressors to Everglades ecosystems that are hypothesized to affect populations of alligators and crocodiles: water management practices (affecting hydrology), agricultural and urban development (affecting habitat loss and hydrology), and decreased freshwater flow to estuaries (affecting salinity regimes) (U.S. Army Corps of Engineers, 2004). Our assessments of the metrics defined for performance measures for crocodilians support these hypotheses (Rice and Mazzotti, 2006; RECOVER, 2007). As Mazzotti and Brandt (1994) pointed out, alligators are not doing well in the Everglades.

The low relative density and poor body condition (Fig. 2B) of alligators in the Everglades is what we expect in hydrologically altered Everglades ecosystems. Restoration targets, set from reference populations in the Everglades, were confirmed by data from other alligator populations (P.M. Wilkinson, unpublished data; A.R. Woodward, unpublished data).

We hypothesize that alligators in areas that experience less extreme human-caused hydrological alterations—such as the central portion of LNWR—do better than in other areas of the Everglades where human-induced hydrology dominate. This hypothesis could be tested by sampling in drier (northern) and wetter (southern) portions of LNWR that are more influenced by water management.

Unlike American alligators, American crocodiles are doing well in South Florida in comparison to other portions of their range (Mazzotti et al., 2007). Even so, diminished rates of growth and survival have been related to regional hydrologic patterns (Moler, 1992; Rice and Mazzotti, 2006; Mazzotti et al., 2007) and are evident in the monitoring data displayed in Figs. 2 and 3. The ability to monitor growth and survival will improve, given that more than 50% of crocodiles captured annually are recaptures (Rice and Mazzotti, 2006). This high rate of recapture is without precedent in a crocodilian study.

The low relative density of alligators in estuaries supports our hypothesis for effects of diminished freshwater flow. The low relative densities observed today are in sharp contrast to earlier accounts, which consistently described the oligohaline–freshwater portion of estuaries as important alligator habitat (Craighead, 1968; Brown, 1993; Simmons and Ogden, 1998). This abundance of alligators in coastal wetlands is typical throughout the range of the American alligator (Potter, 1981; Joanen et al., 1984; Rice and Averitt, 1999), making the low abundance of alligators in Everglades estuaries even more significant. In an unplanned experiment in North Carolina, diversion of the location of freshwater discharge into an estuary was changed, resulting in a shift in distribution of alligators corresponding to the change in freshwater discharge (Birkhead and Bennett, 1981).

The performance measure metrics chosen for alligators and crocodiles reflect current ecosystem conditions. How effective are they at measuring changes? We have started to address this question by evaluating the power to detect trends in relative density and body condition of alligators. Our preliminary analyses show that we can detect a 5% change in relative density and a 10% change in body condition over a five-year period (Rice and Mazzotti, 2006). We conclude that alligator metrics not only reflect current ecosystem conditions but are also sensitive to changes in conditions. Power analyses of crocodile metrics are underway.

3.2. *Communicating the crocodilian indicator*

Alligators and crocodiles are the charismatic megafauna of the Everglades. No other species capture the imagination of the public, or symbolize the Everglades as do the ''Lords of the Everglades'' (National Geographic, 1997). More people go to the Everglades to see alligators than anything else. The first thing many visitors ask when they arrive in the Everglades is ''where can I see an alligator?'' Such charisma is important for a system-wide, general indicator. Crocodilians are species that have captured the hearts and minds of managers as well as the general public, and they are species that are strongly associated with the Everglades. It is to our advantage to capitalize on these conceptions by using crocodilians as a system-wide indicator of ecosystem restoration.

Making environmental decisions requires that information be communicated effectively to decision makers and that public perceptions of ecosystem values be considered (Schiller et al., 2001). As described above, crocodilians are good indicators because they have well-established relationships with environmental parameters under management control, and the metrics (body condition, relative density, growth, and survival) are remarkably easy to understand and communicate. The first MAP Annual Assessment Report for Alligators and Crocodiles summarizes the most recent advancements for both alligators and crocodiles (Rice and Mazzotti, 2006). The concepts of alligators in poor condition, crocodiles that survive more or grow less, and numbers of animals are all meaningful to managers. Tracking improvements or declines in these metrics because of restoration activities is easily communicated and understood.

As surely as there is no other Everglades, no other single species defines the Everglades as does the American alligator (Craighead, 1968). The Everglades is the only place in the world where both alligators and crocodiles exist. In a survey of visitors to natural areas in South Florida, respondents indicated that they want populations of the American crocodile to increase (Smithem and Mazzotti, 2008). Moreover, crocodilians clearly respond to changes in hydrologic parameters of management interest. These relationships are easy to communicate and mean something to managers, decision makers, and the public. Having crocodilians on the list of system-wide, general indicators provides us with one of the most powerful tools we have to communicate progress of ecosystem restoration in Greater Everglades ecosystems to diverse audiences.

3.3. *Longer-term science needs*

Basic biology of alligators and crocodiles in the Everglades and methods to monitor their responses to hydrologic management are relatively well understood. Continued work is needed to improve reliability of monitoring techniques in all habitats, to calibrate existing models and develop new ones, and to better understand implications of canals and levees for improved assessments of de-compartmentalization. Existing monitoring programs and projects need to continue to develop time-series information about these animals that can be used in impact assessment.

Current monitoring techniques for relative density of crocodilians use airboats in freshwater habitats and outboard motorboats in mangrove environments. While these techniques are excellent for much of the Everglades, there are limitations. In particular, neither technique can be used effectively in the Rocky Glades during the dry season, in cypress swamps, or in any wilderness area. Use of helicopters and other techniques for sampling in these landscapes need to be developed, especially for occupancy rates of alligator holes. Techniques to survey alligator nests in marshes of Everglades National Park have been established but may not be suitable for use in other parts of the Greater Everglades ecosystems. This is unfortunate because access to these areas is critical for research and monitoring of alligators and crocodiles, and is invaluable for assessment and evaluation.

Although the data presented here support the hypotheses for the effects of diminished freshwater flow on growth, survival, and abundance of crocodilians, they do not prove a direct relationship. Additional data are needed to evaluate growth, survival, movements, and habitat use of alligators and crocodiles in relation to salinity gradients and food supply. Recent advances in GPS/VHF telemetry and the ability to describe temporal and spatial changes in salinity may provide an opportunity to strengthen the linkage between crocodilians and salinity in the Everglades.

Although not included in conceptual models, exotic plant and animal species may impact populations of crocodilians. Exotic plants may affect alligators by altering native vegetation and hydrological characteristics of wetland areas. For example, melaleuca can replace open grassy wetlands with forest, and may raise soil levels, thus reducing the area of inundation and water flow. Exotic plants may affect crocodiles by limiting access to nesting substrate. Largely restricted to man-made bodies of water, the non-native caiman has not yet posed any threat to alligators or crocodiles. Prior to the establishment of exotic pythons, alligators were the only large, abundant, and widespread aquatic predators in Greater Everglades ecosystems. However, Burmese pythons are now breeding in Everglades National Park and adjacent areas and there have been five reported encounters between pythons and alligators. The results of these encounters have been mixed (Snow et al., 2006), and the long-term effect of interaction between these two top predators is unknown. Research is needed to determine what the long-term relationship will be.

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