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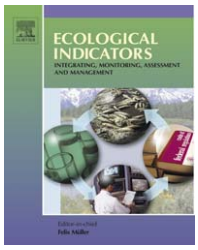

Alligators and crocodiles as indicators for restoration of Everglades ecosystems

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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).

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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