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Fluctuating water depths affect American alligator (*Alligator mississippiensis*) body condition in the Everglades, Florida, USA

Laura A. Brandt[a,*], Jeffrey S. Beauchamp[b], Brian M. Jeffery[b,1], Michael S. Cherkiss[c], Frank J. Mazzotti[b]

[a] U.S. Fish and Wildlife Service, 3205 College Avenue, Davie, FL 33314, USA
[b] University of Florida, Ft. Lauderdale Research and Education Center, Davie, FL, USA
[c] U.S. Geological Survey, Wetland and Aquatic Research Center, Davie, FL, USA

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ABSTRACT

Successful restoration of wetland ecosystems requires knowledge of wetland hydrologic patterns and an understanding of how those patterns affect wetland plant and animal populations. Within the Everglades, Florida, USA restoration, an applied science strategy including conceptual ecological models linking drivers to indicators is being used to organize current scientific understanding to support restoration efforts. A key driver of the ecosystem affecting the distribution and abundance of organisms is the timing, distribution, and volume of water flows that result in water depth patterns across the landscape. American alligators (*Alligator mississippiensis*) are one of the ecological indicators being used to assess Everglades restoration because they are a keystone species and integrate biological impacts of hydrological operations through all life stages. Alligator body condition (the relative fatness of an animal) is one of the metrics being used and targets have been set to allow us to track progress. We examined trends in alligator body condition using Fulton's *K* over a 15 year period (2000–2014) at seven different wetland areas within the Everglades ecosystem, assessed patterns and trends relative to restoration targets, and related those trends to hydrologic variables. We developed a series of 17 *a priori* hypotheses that we tested with an information theoretic approach to identify which hydrologic factors affect alligator body condition. Alligator body condition was highest throughout the Everglades during the early 2000s and is approximately 5–10% lower now (2014). Values have varied by year, area, and hydrology. Body condition was positively correlated with range in water depth and fall water depth. Our top model was the "Current" model and included variables that describe current year hydrology (spring depth, fall depth, hydroperiod, range, interaction of range and fall depth, interaction of range and hydroperiod). Across all models, interaction between range and fall water depth was the most important variable (relative weight of 1.0) followed by spring and fall water depths (0.99), range (0.96), hydroperiod (0.95) and interaction between range and hydroperiod (0.95). Our work provides additional evidence that restoring a greater range in annual water depths is important for improvement of alligator body condition and ecosystem function. This information can be incorporated into both planning and operations to assist in reaching Everglades restoration goals.

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1. Introduction

Successful restoration of wetland ecosystems requires knowledge of wetland hydrologic patterns and an understanding of how those patterns affect wetland plant and animal populations. These relationships can be articulated in conceptual ecological models that diagram linkages between drivers, stressors, ecological effects, and attributes that can then be used as indicators of ecosystem state, status, and trends (Gentile, 1996; Rosen et al., 1995). Development and application of conceptual ecological models also can help to guide restoration planning and implementation. Developing

* Corresponding author. Tel.: +1 9545776343.
E-mail addresses: Laura_brandt@fws.gov (L.A. Brandt), jbeach@ufl.edu (J.S. Beauchamp), bjeffe01@ufl.edu (B.M. Jeffery), mcherkiss@usgs.gov (M.S. Cherkiss), fjma@ufl.edu (F.J. Mazzotti).
[1] Present address: Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Box 110485, Gainesville, FL 32611-0485, USA.

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stronger and more explicit relationships between drivers and indicators will improve the likelihood of success of restoration efforts (Gentile, 1996; Karr, 2000).

Within Everglades restoration, an applied science strategy including conceptual ecological models (Ogden et al., 2005; Ogden and Davis, 1999) is being used to organize current scientific understanding to support restoration efforts. The applied science strategy includes performance measures and restoration targets, a system-wide monitoring program, and a performance assessment protocol. A key driver of the system is the timing, distribution, and volume of water flows that result in water depth patterns across the landscape. These patterns have been altered from what was experienced prior to 1881when the extensive water management network of canals and structures was initiated (Light and Dineen, 1994). A goal of the Comprehensive Everglades Restoration Plan (CERP) is to "get the water right" by restoring more natural patterns of timing, distribution, quantity and quality of water to the ecosystem to support native flora and fauna and ecosystem processes (U.S. Army Corps of Engineers, 1999). Defining what that means in terms of restoration plans and water management operations is one of the biggest ecological challenges of CERP. Because the distribution of organisms in wetlands is greatly impacted by seasonal and long term changes in wetland water depth (Bedford et al., 2012), following trends of, and understanding relationships between, hydrology and ecological indicators described within the Restoration Coordination and Verification (RECOVER) Monitoring and Assessment Plan (MAP; RECOVER, 2001, 2004) is one of the ways ecological information is being brought into restoration planning.

Alligators (*Alligator mississippiensis*) are an indicator for Everglades restoration because they are a keystone species within the ecosystem and integrate biological impacts of hydrological operations through all life stages (Mazzotti et al., 2009). They are important in food webs as predator, prey (Mazzotti and Brandt, 1994), and protector (Burtner, 2011). They act as ecological engineers by creating areas of high (nest) and low (alligator holes and trails) micro topography that contribute to wetland diversity and productivity (Palmer and Mazzotti, 2004). Patterns of water fluctuations are known to affect many aspects of alligator biology including breeding, nest success, growth, survival, and population size class structure (Mazzotti and Brandt, 1994; Rice et al., 2004; Shinde et al., 2014). Changes in patterns of water levels in the Everglades (including increases in frequency and intensity of droughts) have resulted in increased physiological stress for alligators (Jacobsen and Kushlan, 1989), habitat degradation, and reduction in prey base.

Alligator body condition is one metric being used to assess Everglades restoration efforts. Thresholds for desired Everglades restoration targets have been developed for alligator body condition (Mazzotti et al., 2009). Our expectation is that alligator body condition will increase as more natural hydrologic conditions are restored.

Body condition indices, defined by a mass to length relationship, have been used to describe an animal's health, quality, or vigor and could be an important determinant of fitness (Peig and Green, 2009). Body condition indices describe how well an animal is coping with environmental stressors (Murphy et al., 1990; Taylor, 1979) and reflect energy reserves that can be used for growth or reproduction. They are a non-destructive measure and data are relatively easy to collect. Previous studies have looked at alligator body condition in the Everglades in relation to season (Barr, 1997; Dalrymple, 1996) and water depths (Fujisaki et al., 2009). These studies evaluated one hydrologic factor (water depth) that could affect alligator body condition. Other hydrologic factors such as maximum fall water depth, water recession rate, and frequency and intensity of dry downs known to affect aquatic prey (Loftus and Eklund, 1994; Sargeant et al., 2011) have not been examined. Understanding how these multiple aspects of hydrology affect alligator body condition is an important step in developing and implementing restoration plans that restore ecosystem processes.

In this study we examined trends in alligator body condition over a 15 year period (2000–2014) in seven different wetland areas within the Everglades ecosystem, assessed patterns and trends relative to restoration targets, and related those trends to hydrologic variables. We developed a series of *a priori* hypotheses that we tested with an information theoretic approach to identify which factors affect alligator body condition and discuss our results in the context of overall Everglades restoration.

2. Methods

2.1. Study area

Our study area consisted of freshwater wetlands within the ridge and slough landscape (Ogden, 2005) of the Everglades ecosystem including the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LOX), Water Conservation Area (WCA) 2A, WCA3A, and Everglades National Park (ENP; Fig. 1). Vegetation is a mosaic of sloughs, wet prairie, sawgrass marsh, tree islands, and cattails and varies among areas (Gunderson, 1994; Loveless, 1959). Hydrology is influenced by rainfall and water management with 75% of rainfall (approximately 1320 mm/year; Richardson, 2010) occurring May–October (wet season) and 25% November–April (dry season). Water depths vary seasonally with lowest depths generally in mid-May and highest in mid-October. Surface hydrology is managed for flood protection, water supply, and wildlife conservation by the South Florida Water Management District (SFWMD) and U.S. Army Corps of Engineers (USCOE) under various water regulation schedules, operating plans, and input from Florida Fish and Wildlife Conservation Commission, U.S. Fish and Wildlife Service and National Park Service, Everglades National Park.

2.2. Hydrology

Average daily stage and ground surface elevation were obtained from seven USGS gauges that are within proximity of alligator capture locations and can act as a reference gauge for that area (Fig. 1). Water depth was calculated as stage height minus ground surface elevation. Water year (WY; May 1 of the previous year to April 30 of the reporting year) hydroperiod was calculated as number of days in each water year when the gauge reading was equal to or above 15 cm (6 in.) below which is the depth that makes it harder for alligators to move around the marsh to feed and mate (Rice et al., 2004; Shinde et al., 2014). Three measures of average depth were calculated: the entire water year, depth spanning our spring sampling (January–May), and depth spanning our fall sampling (August–December); however, the entire year average water depth was not used in analysis since it was highly correlated (Pearson's coefficient $\geq$0.7) with both average spring and fall water depths. Water year range was calculated by subtracting minimum depth from maximum depth. Average number of days since last dry down (DSD) was calculated for each water year as a way to characterize relative timing of dry events. Number of days in that dry event (DIND) also was calculated as a measure of intensity of dry down (Appendix 1).

2.3. Alligator captures

Alligators greater than or equal to 1.25 m total length (TL) were captured by hand or noose during spring (January–May) and fall (August–December) from WY 2000 to 2014 in seven areas within the four wetlands (Fig. 1, LOX, WCA2A, WCA3AHD, WCA3ATW, WCA3AN41, ENPFC, ENPSS). Number of captures varied among