Water Year 2023 Monitoring Program: The American Crocodile in Everglades National Park

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Introduction

The American crocodile (*Crocodylus acutus*) is a coastal crocodylian that occurs across the Americas from southern Florida, USA, to northern South America and the insular Caribbean (Rainwater et al. 2022). This species has undergone severe declines in the past because of overexploitation and habitat loss across its range and it is currently categorized globally as Vulnerable (Rainwater et al. 2022) and locally in the United States as Threatened by the U.S. Fish & Wildlife Service (USFWS, 2007). Conservation measures developed in the last several decades in most regions across its range have facilitated the recovery of American crocodile populations in several countries. However, habitat loss because of agricultural and residential development and illegal hunting are ongoing threats (Rainwater et al. 2022).

In 2000, the Comprehensive Everglades Restoration Plan was authorized by Congress to implement restoration efforts to bring back more natural hydrological conditions to the ecosystem. It is expected that American crocodile populations across South Florida will be affected by Everglades restoration projects, as changes in sensitive environmental conditions (e.g., salinity) could shift populations attributes (e.g., natality and mortality rates, population density), making it more or less suitable for the species (Mazzotti et al. 2019, Briggs-Gonzalez et al. 2021). Thus, the status of the American crocodile has long been a matter of concern in Everglades National Park (ENP) and adjacent habitats due to their recognition as a flagship species and ecosystem indicator that is responsive to hydrological change (Ogden 1978; Mazzotti et al. 2007a, b).

As with other species in southern Florida (e.g., American alligators, wading birds), the survival and recovery of American crocodiles is linked with regional hydrological conditions, especially freshwater inputs to estuaries affecting water levels, salinities, and prey availability (Mazzotti et al. 2009, Briggs-Gonzalez et al. 2021). Crocodylian population parameters most susceptible to changing hydrologic conditions are nesting effort and success, growth, survival, distribution, abundance, and body condition (Mazzotti et al. 2007a). Monitoring these population parameters in southern Florida is key to understanding the effects of landscape modifications and has been ongoing in the area since 1978. Results of this long-term research have shaped species and land management decisions throughout southern Florida and provided the primary scientific evidence to support the 2007 classification of *C. acutus* from endangered to threatened (Mazzotti et al. 2007a, b).

The present water year (WY) 2023 annual report (Oct 1st, 2022, to Sep 30th, 2023) summarizes nesting effort and success (May–Sep) as well as population monitoring (abundance and body condition) during fall 2022 (Oct - Dec) and spring 2023 (Jan –March). We estimated growth and survival based on a comprehensive database over 3- and 5-year intervals covering WY 2012–2022 and compare patterns in American crocodile through time focused on understanding the species status in ENP.

Methods

Nest Monitoring

Surveys for crocodile nests effort were conducted by motorboat, jon boat, car, and foot across bays, coves, canals, berms, beaches, and roads within ENP during April and May, including both mainland and island areas looking for croc activity (tracks, tail drags, digging or scraping, mounds, holes) that could indicate crocodile nesting activity (Figure 1 top). The searched areas were Northeast Florida Bay (North Nest Key, Snipe Point, Deer Key, Dead Stork Beach, Cocoa Beach, Alligator Bay, Eagle Key, Little Madeira Beach, Club Key, Black Betsy Key, Lake Key), Flamingo/Main Park Road (Buttonwood Canal, Nine Mile Pond, Noble Hammock, Hells Bay, West Lake, Coot Bay Pond, Eco Pond, Bear Lake, Flamingo Boat Basin, Flamingo Marina, Flamingo Road Beach, and camp grounds), and Cape Sable (Clubhouse Beach, East Cape Creek -Western and Eastern shorelines, Cape Sable beaches from East Cape Creek up until just past the mouth of Lake Ingraham, East Cape Canal, and Homestead Canal). All potential nests were geolocated and crocodile activity described. All areas where we looked for nesting effort were revisited during the hatching period (June through August) to assess nest success based on the presence of an exposed chamber, evidence of digging, hatched eggshells, and/or hatchlings. Nest chambers were inspected for unhatched/infertile eggs as well as dead hatchlings. Hatchlings were captured by hand or tongs and uniquely marked by removing tail scutes (Mazzotti 1983). Morphometric data (snout-vent length -SVL, total length – TL, and weight), environmental data (air temperature, water temperature, and salinity), and geolocation were taken, and animals were released at point of capture. We defined failed nests when the nest passed hatching time (August) and no hatchlings emerged from it, depredated nests when we found any indication that at least one egg had been depredated, and successful nest when at least one hatchling has successfully emerged from the chamber (Mazzotti et al. 2022). Potential nests that did not hatch were dug up in September to confirm whether it was a true but failed nest, or a test nest where the female did not deposit eggs.

Population Monitoring - Relative Density

Spotlight surveys to count and capture American crocodiles were conducted along coastal and estuarine shorelines within ENP from Madeira Bay to the eastern boundary of ENP along U.S. Highway 1, including north Key Largo. We surveyed a total of 7 routes (from west to east - Madeira Bay, Little Madeira Bay/Taylor River, Deer Key/Davis Cove, Alligator Bay, Mud Bay, Joe Bay, and Long Sound; Figure 1 bottom) in both fall 2022 and spring 2023 surveys) always following the same direction and spending the least time possible when capturing animals to avoid affecting count data. We did both, counts and captures at the same time due to the scarcity of American crocodiles and the length of the routes, which reduce the likelihood of finding them again if counting was done first and then followed by captures. We attempted to separate counting and captures in four routes in fall 2022 (Deer Key/Davis Cove, Alligator Bay, Mud

Bay, and Joe Bay) to evaluate how feasible would be separate those but do it in the same night (counting in the way-in and capturing in the way-out routes). However, we saw that it has an effect in the number of crocodiles captured (less crocodiles were spotted to capture late at night) so we decided to continue using the former method. For spring 2023, we tried to double the effort conducting all 7 routes twice during the same season to evaluate whether the increased effort could help to increase the number of animals counted/captured per route, so more information can be obtained per route. In this specific case, we spread surveys out within the same route/season by at least 15 days apart to circumvent spatial autocorrelation on the data. Crocodiles were captured by hand, tongs, or by wire-noose, marked by clipping scutes along the single and double line on the tail, and measured them (SVL, TL, and weight). Additionally, Passive Integrated Transponder tags was applied to animals ≥ 0.9 m to provide a secondary method of identification. Habitat (canal, cove, pond, creek/river, and exposed shoreline) was noted for all crocodile observations.

During spotlight surveys, each crocodylian observation was recorded as "crocodile", "alligator", or "eyeshine" (used when species could not be discerned). When a crocodylian was observed but not captured, a size estimate was made whenever possible in quarter meter increments, with the estimate indicating the lower bound of the increment (e.g., a 0.5 m estimate indicates 0.5 m-0.74 m). All animals were assigned to one of several size classes defined as follows: hatchling = TL < 65 cm and observed during the hatching season (June–September), juvenile = TL < 65 cm and observed outside the hatching season or TL ≥ 65 cm and < 150 cm, subadult = TL ≥ 150 cm and < 225 cm, and adult = TL ≥ 225 cm. To estimate relative crocodile abundance, we calculated encounter rate as the number of non-hatchling crocodiles observed per kilometer of surveyed shoreline. In the case of spring 2023, we calculated encounter rate per survey as well as average encounter rate for the whole season.

Body Condition

We used Fulton's K [Fulton's $K = (\text{mass}/\text{SVL}^3)$; LeCren 1951] multiplied by 10^2 as the scale factor to calculate American crocodile body condition because of its suitability to make population comparisons on spatial and temporal scales (Zweig 2003, Mazzotti et al. 2012, Brandt et al. 2016). Body condition was calculated for non-hatchling crocodiles (> 65 cm TL), since hatchling variability in mass could bias Fulton's *K* values. Crocodiles with severe tail loss (missing beyond single scute eight) were not included in analyses to avoid bias. We compared body condition by size class, sex, habitat, and among routes. In addition, we compared body condition values to target categories developed for American crocodiles in Florida (Squires et al. 2018). Using the Squires et al. (2018) approach, body condition target categories are defined as follows: ideal (K > 2.4), acceptable (≥ 2.0, ≤ 2.4), and poor (K < 2.0).

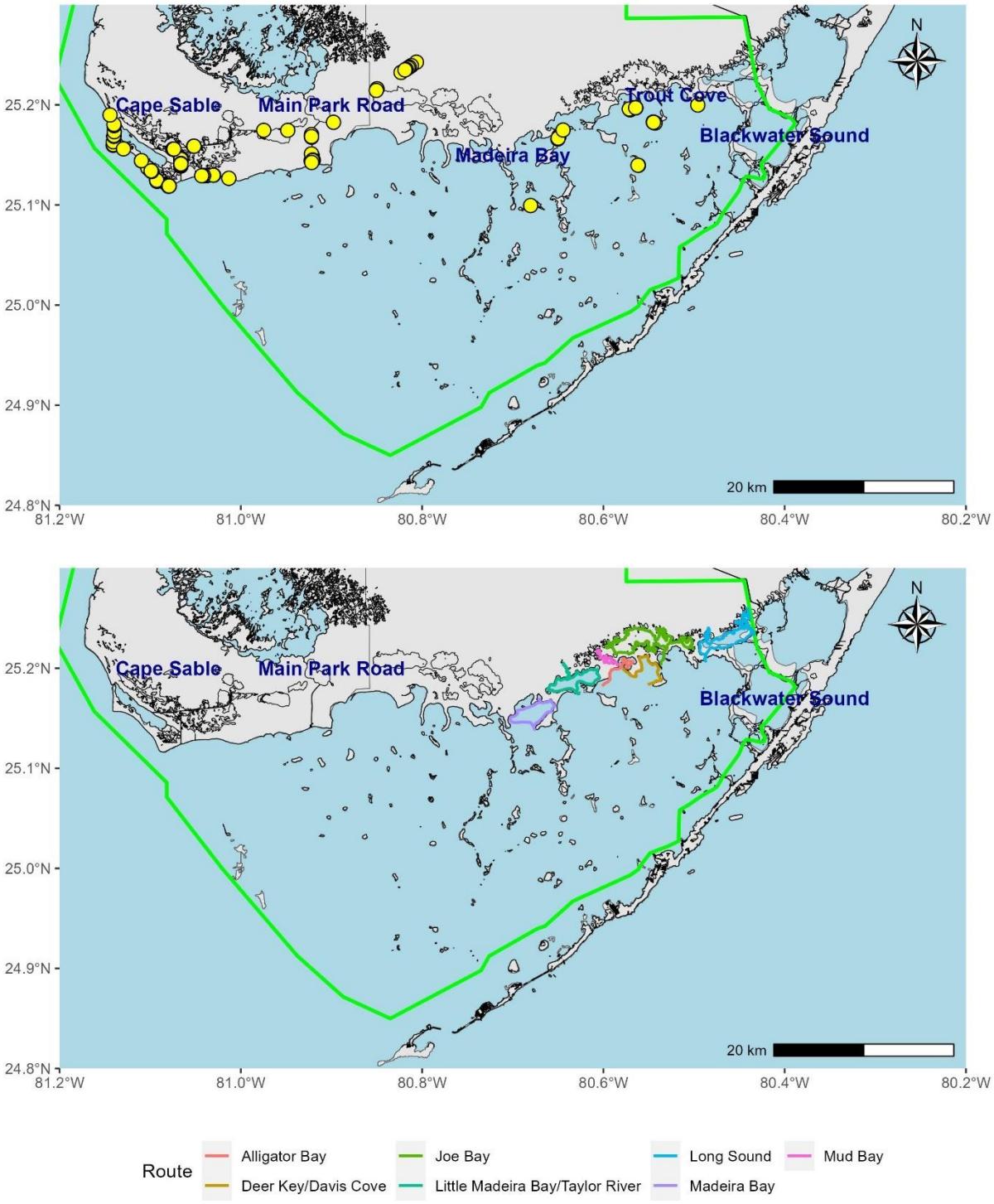

Figure 1. (top) American crocodile (*Crocodylus acutus*) nests (yellow dots) found in 2023 in Everglades National Park (ENP). (bottom) Survey routes followed to count and capture American crocodiles across Everglades National Park (ENP) from Madeira Bay to US1 road.

Growth and survival

We calculated system-wide crocodile stoplight indicator scores using a combination of crocodile juvenile growth and hatchling survival performance measures (see Mazzotti et al. 2009 for details) during WY 2012-2022. Performance measure scores were calculated on annual, 3-, and 5-year mean, and trend intervals. Interval scores range from 0.0 to 1.0 with a score of 1.0 being the restoration target. We calculated annual juvenile growth (cm per day) and hatchling survival values and used these values to assign performance measure interval scores as defined by Mazzotti et al. (2009). We then generated overall juvenile growth and hatchling survival performance measure component scores by calculating the mean of the current, 3-, and 5-year mean, and trend performance measure scores for both metrics (Mazzotti et al. 2009). We assigned a crocodile management unit score based on the geometric mean of the overall growth and survival scores by management unit (ENP and Biscayne Bay complex). Finally, we calculated the system-wide crocodile component score as the geometric mean of the crocodile management unit scores. The juvenile growth component scores, hatchling survival component scores, and final system-wide crocodile component scores range from 0.0 to 1.0, with a score of 0.0 requiring immediate management consideration and values less than 0.6 falling below the Everglades restoration target established for crocodiles. The system-wide scores are reported in stoplight categories defined as: 0.0-0.4 (red), >0.4-0.6 (yellow), >0.6-1.0 (green).

Results

Nest Monitoring

We located and confirmed a total of 156 nests during the 2023 nesting season within ENP of which 66.7 % (104) were found in Cape Sable (Clubhouse Beach, East Cape Creek -Western and Eastern shorelines, Cape Sable beaches from East Cape Creek up until just past the mouth of Lake Ingraham, East Cape Canal and Homestead Canal), 17.3 % (27) in Flamingo/Main Park Road (Buttonwood Canal, Noble Hammock, Hells Bay, West Lake, Coot Bay Pond, Flamingo Boat Basin, Flamingo Marina, Bear Lake), and 16 % (25) in Northeast Florida Bay (Snipe Point, Deer Key, Dead Stork Beach, Cocoa Beach, Little Madera Beach, Club Key, Lake Key; Figure 1 top). Of those, 8.3% of the nests (13) were either partially or fully depredated, and 14.7% of the nests failed (23). Most of the failed nests were found in Flamingo/Main Park Road (16) area followed by Cape Sable (6), and Northeast Florida Bay (1). A total of 94 nest were hole-type and 62 were mound-type. Most of the nests were found in sand (88) and marl (45) and a few of them were found in dirt (21). Most nests were found in shoreline beaches (87), followed by canals (55), roadsides (12), and creeks (2). Finally, most of the nests were found in mainland (145) and few of them were found in islands (11).

We marked a total of 725 hatchlings within ENP of which 415 were captured in Cape Sable, 200 were captured in Northeast Florida Bay, and 110 were captured in Flamingo/Main Park Road

area. Hatchlings were on average 26.6 ± 1.83 cm TL, 13.5 ± 0.92 cm SVL, and 51.2 ± 9.72 gr weight in Cape Sable, 27.3 ± 1.95 cm TL, 13.6 ± 1.13 cm SVL, and 59.1 ± 11.2 gr weight in Flamingo/Main Park Road, and 27.0 ± 1.21 cm TL, 13.5 ± 0.57 cm SVL, and 63.0 ± 8.57 gr weight in Northeast Florida Bay. Overall, hatchling's morphometrics in ENP were 26.83 ± 1.72 cm TL, 13.51 ± 0.88 cm SVL, and 55.68 ± 11.01 gr. Most hatchlings did not show any deformities (650). However, 56 out of 725 hatchlings had curled tail, 10 had fused single scutes, 6 had fused double scutes, and 3 had either crossbites, fused double scutes – curled tail, or kinked tail. Environmental conditions at the time hatchlings were worked up were on average 33.7 ± 1.96° C water temperature and 33.9 ± 6.70 psu salinity in Cape Sable, 32.4 ± 1.15° C and 17.9 ± 6.88 psu in Flamingo/Main Park Road, and 31.5 ± 1.90° C and 22.2 ± 2.75 psu in Northeast Florida Bay.

Population Monitoring - Relative Density

Table 1. American crocodiles observed at Northeast Florida Bay on surveys done in fall 2022 and spring 2023 (WY223). Eyeshine refers to animals that we could not get close enough to identify the species. MB = Madeira Bay, LMB/TR = Little Madeira Bay/Taylor River, DK/DC = Deer Key/Davis Cove, AB = Alligator Bay, MB = Mud Bay, JB = Joe Bay, LS = Long Sound.

		Fall		**Spring**			
				Survey 1		**Survey 2**	
	Route length (km)	**Crocodile**	**Eyeshine**	**Crocodile**	**Eyeshine**	**Crocodile**	**Eyeshine**
MB	17.27	1	0	0	0	0	0
LMB/TR	21.8	7	5	2	2	11	3
DK/DC	11.1	0	0	0	0	2	0
AB	8.4	0	1	0	0		
MB	13.9	0	3	1	3	0	1
JB	46.2	5	4	4	3	3	7
LS	34.7	1	1	6	4	2	7
Total	**153.37**	**14**	**14**	**13**	**12**	**18**	**18**
		28		**25**		**36**	

A total of 89 animals were observed in WY2023 across Northeast Florida Bay of which 45 were positively identified as American crocodiles (15 adults, 18 subadults, and 12 juveniles) and 44 were recorded as eyeshines only because of the inability to get close enough to clearly identify the species. It is highly possible that most of these eyeshines were American crocodiles but due to the occasional presence of American alligators in these areas, we did not assign these counts to a particular species. Most crocodile observations were done in the second survey completed in spring (36) followed by surveys done in fall (28), and the first survey done in spring (25). For

fall, Little Madeira/Taylor River had the largest number of crocodiles spotted (12) followed by Joe Bay (9; Table 1). In spring, Long Sound area had the largest number of crocodiles observed (10) in the first survey and Little Madeira/Taylor River the largest number in the second survey (14). Most animals were observed in coves (82), and a few were spotted within creeks/rivers (6).

We observed 0.18 non-hatchling crocodiles per km relative in fall 2022, 0.16 non-hatchling crocodiles per km in the first survey done in spring, and 0.23 non-hatchling crocodiles per km in the second survey (mean spring relative density 0.20 non-hatchling crocodiles per km). The overall relative density for WY2023 for Northeast Florida Bay (from Madeira Bay to US 1) was 0.19 non-hatchling crocodiles per km.

We captured a total of 15 American crocodiles (10 females and 5 males) out of the 89 animals observed across all routes of which 3 were captured in fall, 5 in spring survey 1 and 7 in spring survey 2. Most American crocodiles were captured in Little Madeira/Taylor River (6), followed by Joe Bay and Long Sound (3 each), Deer Key/Davis Cove (2), and Madeira Bay (1). 13 out of the 15 crocodiles captured were new and only 2 were recaptures. All crocodiles captured were in coves. Environmental conditions at the time animals were observed and captured were overall 21.7 ± 1.64° C air temperature, 23.1 ± 1.92° C water temperature, and 12.6 ± 6.81 psu salinity in fall and 20.5 ± 3.32° C air temperature, 23.3 ± 3.12° C water temperature, and 17.4 ± 7.26 psu, salinity in spring.

Body Condition

Table 2. Body measures and Fulton's *K* condition factor [(Mass/SVL^3) x 10^2] of American crocodiles (*Crocodylus acutus*) captured during Fall 2022 to Spring 2023 (Water Year 2023) in Everglades National Park from Madeira Bay to US 1. SD = Standard deviation

Morphological Character	**Size Class Mean ± SD**		
	Juvenile	Subadult	Adult
Total Length (cm)	104.0 ± 26.8	188 ± 25.9	254.0 ± 17.5
Snout-Vent Length (cm)	54.2 ± 14.9	101 ± 14.7	133.0 ± 12.7
Mass (g)	3850 ± 2995	23240 ± 9067	56500 ± 7778
Fulton's K	2.00 ± 0.13	2.16 ± 0.17	2.42 ± 0.36

Overall crocodile body condition ranged from 1.86 to 2.67 with a mean of 2.10 ± 0.21 for WY2023 (Table 2). On average, adults had the highest body condition (2.42 ± 0.36), followed by subadults (2.16 ± 0.17), and juveniles (2.00 ± 0.13). Males (2.19 ± 0.29) had better body condition than females (2.07 ± 0.18) and American crocodiles captured in Madeira Bay (2.28), Little Madeira/Taylor River (2.26 ± 0.22), and Deer Key/Devis Cove (2.14 ± 0.03) areas had better body condition than those capture elsewhere (Joe Bay and Long Sound = 1.91 ± 0.05 each). Using body condition targets developed for crocodiles in southern Florida, we found that

only one American crocodile captured in ENP between Madeira Bay and US 1 during WY2023 was in ideal body condition (K > 2.4), 8 individuals were in acceptable condition ($2.0 \geq K \leq 2.4$), and 6 individuals were in poor condition (K < 2.0).

Juvenile growth, hatchling survival, and system-wide crocodile scores

ENP juvenile growth scores ranged from 0.33 to 0.70 (red to green) during WY 2012-2022, with an average score of 0.48 (yellow; Table 3). ENP hatchling survival scores ranged from 0.16 to 0.50 (red to yellow) with an average score of 0.28 (red). The most recent scores for ENP growth and survival were red and are below the Everglades restoration targets established for crocodiles. However, ENP juvenile growth met the restoration target only twice during the 11-year period and ENP hatchling survival never met the restoration target in this period. Everglades system-wide crocodile scores ranged from 0.00 to 0.49 (red to yellow), with an average score of 0.23 (red). These scores are below the Everglades restoration targets established for crocodiles. Finally, the system-wide score met the threshold for immediate management consideration once during the 11-year period during WY 2016.

Table 3. American crocodile (*Crocodylus acutus*) juvenile growth and hatchling survival component scores from Everglades National Park (ENP) plus Everglades system-wide crocodile component scores during Water Years 2012-2022, calculated from juvenile growth and hatchling survival performance measures across the Everglades system. The scores are reported in stoplight categories defined as: 0.0-0.4 (red), >0.4-0.6 (yellow), >0.6-1.0 (green). Scores of 0.00 require immediate management consideration, and scores less than 0.6 fall below Everglades restoration target established for crocodiles.

Water Year	ENP juvenile growth score	ENP hatchling survival score	System-wide crocodile component score
2012	0.50	0.30	0.32
2013	0.50	0.50	0.29
2014	0.50	0.50	0.12
2015	0.50	0.50	0.38
2016	0.30	0.50	0.00
2017	0.50	0.30	0.20
2018	0.70	0.30	0.29
2019	0.70	0.50	0.29
2020	0.50	0.50	0.20
2021	0.33	0.16	0.25
2022	0.33	0.16	0.20

Discussion

The number of confirmed crocodile nests within ENP during the 2023 nesting season is the largest documented for ENP combining all areas (Northeast Florida Bay, Flamingo/Main Road Park, and Cape Sable) since nesting stated being recorded in 1970 (Mazzotti et al 2022). However, areas such as Cape Sable and Northeast Florida Bay have had larger numbers in past years (former: 110 in 2019 compared with 104 in 2023; latter: 30 in 2016 compared with 25 in 2023; Figure 2). Patterns in nesting among areas in 2023 were consistent with previous years with considerably more nests (~5X) located in the Cape Sable area when compared to Northeast Florida Bay (Figure 1). Areas such as Northeast Florida Bay are showing some recovery in the number of nests and Flamingo/Main Park Road are now sticking out as relevant areas for American crocodile nesting. These data confirm that Cape Sable is currently the most important nesting area for American crocodiles in ENP and across Florida (Mazzotti et al 2022).

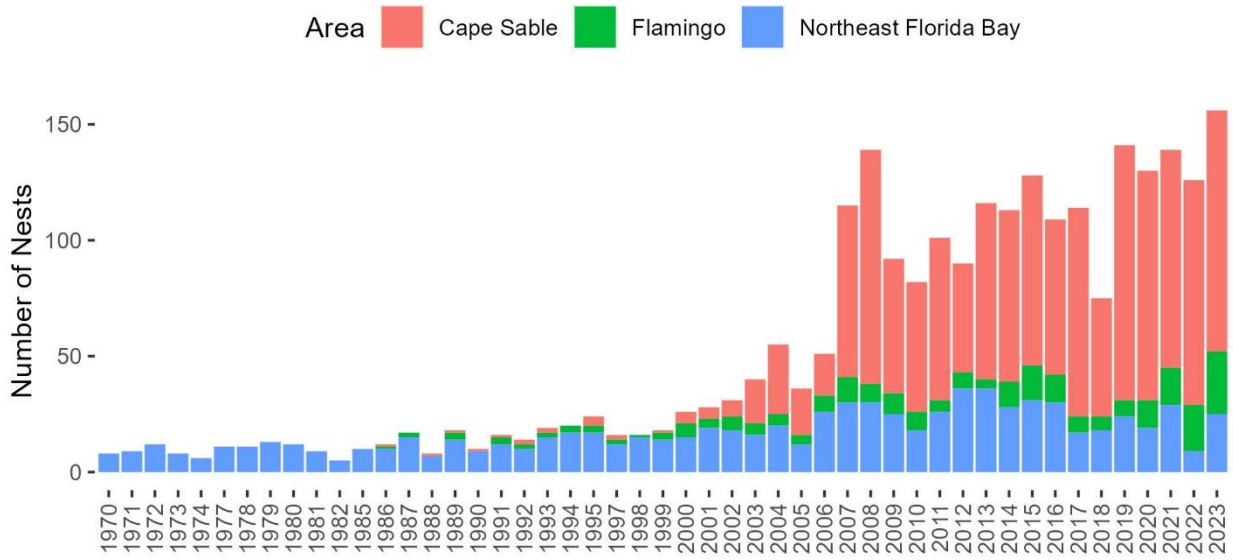

Figure 2. Historic and current American crocodile nests recorded in Everglades National Park since 1970 when the first efforts were to understand the nesting ecology of the species (Mazzotti 1983).

Relative density was overall low (0.19 non-hatchling crocodiles per km) across Northeast Florida Bay in 2023, compared with values reported in other areas such as Cape Sable and Flamingo areas (Mazzotti et al 2019). However, due to budget constraints we were unable to monitor these last two areas in WY2023, therefore comparisons for the year across all areas are not possible. We observed a slight increase in body condition for Northeast Florida Bay in WY2023 compared to WY2022 (1.95 ± 0.20) and a slightly decrease compared to WY2021 (2.23 ± 0.50). Northeast Florida Bay is still an area of concern and warrants continued monitoring efforts to detect when

crocodiles in this area will start to have positive responses to restoration efforts targeted at Florida Bay. Increasing survey effort in spring 2023 helped to increase the number of animals captured and improved our estimates of actual body condition for the population. However, due to the low numbers of crocodiles in Northeast Florida Bay, we did not see an overall increase in the number of animals observed compared with other spring seasons in the same area. Nonetheless, more survey effort is recommended in Northeast Florida Bay so that more data can be collected to clearly capture the variation in the metrics of interest and how they are affected by environmental target parameters such as salinity.

Long-term monitoring of American crocodiles in ENP has provided insights into factors affecting crocodile abundance, distribution, and population dynamics. Together our results are consistent with the hypothesis that restored freshwater flow and lower salinities will improve conditions for crocodiles and increase relative density, body condition, growth, survival, and nesting success (Mazzotti et al. 2019, Brigs-Gonzalez et al 2021). These crocodile population metrics are most clearly linked to salinity within an area such as Northeast Florida Bay. Our results indicate that increasing salinity results in fewer crocodiles that are in worse body condition, and exposure to hypersaline events decreases growth rates (Mazzotti et al. 2019, Brigs-Gonzalez et al 2021). Salinities at the time non-hatchling crocodiles were captured were overall below 20 psu in both fall and spring, which show an improvement of conditions for the Northeast Florida Area. However, by summer when hatchlings were captured, values above 20 psu were recorded which could affect (with continued increase) hatchling growth and survivorship. These results provide support for the ecosystem management recommendations for crocodiles in Northeast Florida Bay, which currently are to restore Taylor Slough as a main source of freshwater for this bay and, specifically, to restore early dry season flow (October to January) from Taylor Slough into Northeast Florida Bay. It is known that salinity is a major factor driving distribution and abundance of crocodiles in estuaries (Dunson and Mazzotti 1989). Measurable objectives of success for this area would be a fluctuating mangrove backcountry salinity that rarely exceeds 20 psu, to that we add that hypersaline events where salinity exceeds 40 psu should be minimized if not eliminated. Mazzotti (1983) found that in Northeast Florida Bay most sightings of crocodiles in higher salinities were females at nest sites. This has a strong effect on hatchlings and thereby diminishing population growth. As such, these conditions should be avoided – eliminated from the system to support a healthy population of American crocodiles.

Finally, relating occurrence of crocodiles to nutrient levels, and to distribution and relative density of prey items should improve our understanding of how crocodiles will respond to ecosystem changes. Restoration efforts aimed at increasing health of the Everglades ecosystem through improvement to habitat conditions, such as increased freshwater flow and restoring more natural salinity regimes, are expected to have positive effects on prey availability and distribution. As efforts to restore Greater Everglades ecosystems continue, indicators of ecological changes, such as the American crocodile can be used to track ecosystem responses

and provide a guide for how management efforts can benefit both threatened species and threatened ecosystems.

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