SRAS Final Report: Population status of the American crocodile (*Crocodylus acutus*) in the Dominican Republic

Student: Robert M. Greco Jr[1, 6]

Supervisors: Adam E. Rosenblatt[1], C. Marisa Tellez[3]

Collaborators: Jorge Brocca[2], R. Joel Espinal[4], Juana E. Peña[4], Ramon Peña Perez[2], Colmar Serra[5], Sophie Beckley[1]

[1] *University of North Florida, 1 UNF Dr., Jacksonville, FL 32224, USA*

[2] *SOH Conservación, Av. Gustavo Mejía Ricart 119B, Ensanche Julieta Apt. 401, Santo Domingo, SD 10130, Dominican Republic*

[3] *Crocodile Research Coalition, Maya Beach, Stann Creek, Belize*

[4] *Ministry of the Environment and Natural Resources, Santo Domingo, Dominican Republic*

[5] *Ecotopía, Parque Ecotopía, Playa Bonita, Las Terrenas, Dominican Republic, 32000*

[6] *Corresponding author. E-mail:* grecobobby@gmail.com

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ABSTRACT

Crocodilian populations declined globally during much of the 20th century because of overhunting and habitat loss. Some crocodilian populations recovered over the past 50 years through legal protections and habitat restoration, but the status of many crocodilian populations are data deficient. The status of the American crocodile (*Crocodylus acutus*) population in the Dominican Republic (DR) is currently unknown because the last country-wide surveys were done in the 1980s. We carried out population surveys in DR from May through July 2021 in areas where *C. acutus* has been observed historically and recently to provide an updated population status. Our surveys yielded no crocodile sightings in the northwestern part of DR, suggesting that crocodiles have been extirpated or nearly extirpated from this area. Our surveys of Lago Enriquillo in the southwestern part of DR produced 120 crocodile sightings over 72.6 km of shoreline, for an encounter rate of 1.7 crocodiles/km. Encounter rates were very high in the main nursery area of the lake (La Azufrada; 60.0 crocodiles/km) and low to moderate elsewhere. Our *C. acutus* sightings were composed of 18 (15%) hatchlings, 45 (37.5%) juveniles, 12 (10%) subadults, and 32 (26.7%) adults; we were unable to estimate size for 13 (10.8%) individuals. During 2021 nest surveys, we only located 42 nests in Lago Enriquillo. Our data suggest the DR population of *C. acutus* is critically endangered and is continuing to decline due to pressure from hunting, fishing, and habitat destruction caused by both anthropogenic factors and natural lake level fluctuations.

INTRODUCTION

During much of the 20th century crocodilians suffered global declines due to overhunting and habitat loss. Some species, like American alligators (*Alligator mississippiensis*) and the Indo-Pacific crocodile (*Crocodylus porosus*), have recovered strongly through legal protections, habitat restoration, and conservation management plans (Ross, 1998; Grigg and Kirshner, 2015). However, the status of many crocodilian populations are currently data deficient. Thorough evaluation of these populations is necessary to provide accurate data that can be used to make more informed and effective local and regional conservation management plans for species.

The American crocodile (*Crocodylus acutus*) is a large neotropical crocodile that occurs on the Atlantic and Pacific coasts of Mexico, Central America, and northern South America, as well as the Caribbean islands of Cuba, Jamaica, and Hispaniola, and the southern tip of Florida (Thorbjarnarson, 1989). Historically, individuals have been reported to reach lengths up to 7.0m (Schmidt, 1924; Medem, 1981) but today it is rare to find *C. acutus* longer than 4.0m (Thorbjarnarson, 1989; Rainwater et al., 2021). *C. acutus* is listed as "Vulnerable" by the International Union for the Conservation of Nature (IUCN; 25 February 2020) and listed on Appendix I of the Convention on Trade in Endangered Species of Fauna and Flora (CITES; Ponce-Campos et al., 2012; Rainwater et al., 2021). Though a few *C. acutus* populations have begun recovering since the implementation of IUCN and CITES, many populations throughout its range are still threatened with extirpation due to rapid habitat loss, pollution, and overhunting (Platt and Thorbjarnarson, 2000; Thorbjarnarson, 2010; Ponce-Campos et al., 2012; Tellez and Boucher 2018; Rainwater et al., 2021).

Crocodylus acutus is predominately a coastal species found in a variety of freshwater, brackish, and marine habitats, including estuarine sections of rivers, mangrove swamps, coastal lagoons, offshore islands, and atolls (Thorbjarnarson, 1989; Thorbjarnarson, 2010). They are very adaptable and can live in a variety of other habitats as well (Thorbjarnarson, 1989; Thorbjarnarson, 2010). Adult *C. acutus* are capable of living in habitats lacking freshwater, but habitats with a freshwater source are critical for hatchling survival (Thorbjarnarson, 1989; Thorbjarnarson, 2010). Habitat preference in *C. acutus* is largely size-class dependent. Younger size classes prefer areas with vegetation for hiding with adjacent open, shallow water habitats for foraging (Thorbjarnarson, 1989). Larger size classes prefer fringe habitat between shallow and deep water habitat with areas to bask and nest (Thorbjarnarson, 1989). Principle factors that contribute to habitat use in *C. acutus* are exposure to wave action, food availability, availability of nesting habitat, and presence of humans. Considered shy and timid, *C. acutus* often retreat to cover in the presence of humans and typically avoid areas frequented by humans (Thorbjarnarson, 1989; Thorbjarnarson, 2010).

One of the problems limiting conservation efforts is that the population status of *C. acutus* in some countries, such as the Dominican Republic (DR), is data deficient. The last attempt at a country-wide survey in DR was conducted in the 1980s, when a relatively large population was found in Lago Enriquillo in the southwest and a small population was found in the Monte Cristi region in the northwest (S. Incháustegui, pers. comm.; Thorbjarnarson, 1988). Thorbjarnarson started the survey in the 1980s but was unable to complete the investigation (S. Incháustegui, pers. comm.). Thorbjarnarson et al. (2006) estimated an island-wide population size of 100-500 with the only confirmed population in DR located in Lago Enriquillo based off of a workshop with leading experts. Schubert and Santana (1996) claimed that during the 1970s and 1980s there were an estimated 300-600 adult crocodiles in Lago Enriquillo with an estimated 100-150 nests per year around the lake. In 1992, it was estimated that there were 160 adults and subadults in the lake (Schubert and Santana, 1996). During three nesting seasons in 1990, 1991, and 1993, only 30, 10, and 36 nests were found, respectively (Schubert and Santana, 1996). A management plan centered around a head-start program was created in 1992 and implemented in 1993 (Schubert and Santana, 1996). The management plan was only short-term because the head-start program was seemingly successful and population size appeared to increase (Schubert and Santana, 1996). Lack of funding ultimately terminated the management plan and head-start program (S. Incháustegui, pers. comm.). More recent observations suggest the population in Lago Enriquillo is critically endangered due to habitat loss, illegal hunting, and climatic stressors affecting successful nesting and survival. Furthermore, an ongoing regional genetic study suggests that *C. acutus* is actually several species or distinct evolutionary lineages, thus the need to re-examine populations is a high priority to prevent extirpation of cryptic species or genetically unique populations (Milián-García et al., 2018; Milián-García et al., 2020).

Protecting *C. acutus* and its habitat in DR is necessary because the species may provide important ecological, economic, and cultural services (Somaweera et al., 2020). *C. acutus* is an apex predator that can be used as an indicator species for healthy ecosystems because *C. acutus* range widely across different aquatic and wetland habitat types and require healthy prey populations to thrive (Thorbjarnarson et al., 2006; Rainwater et al., 2021). Protecting important crocodile habitat also safeguards other species that share these habitats with them (Thorbjarnarson et al., 2006; Thorbjarnarson, 2010). *C. acutus* has also been economically beneficial in many parts of its range through ecotourism and sustainable farming for meat and

skins (Thorbjarnarson, 2010; Ponce-Campos et al., 2012; Rainwater et al., 2021). In addition, one god ("cemí") of the Taino people was represented by a crocodile (Oliver, 2009), and many people in the Caribbean today claim Taino ancestry. Therefore, crocodiles are culturally important to the Caribbean and the cultural ties can help increase people's interest and pride in the species as it has in other parts of its range (Tellez and Boucher, 2018).

Regular monitoring programs and ecological research have proven critical for crocodile population recovery (Mazzotti et al., 2007; Thorbjarnarson, 2010; Rainwater et al., 2021). Because the current conservation status of *C. acutus* in DR is unknown, and because local stakeholders have been concerned for years, we performed population surveys to gather critical data that can be used to develop an adequate conservation management plan. We focused on areas that were known to support crocodile populations previously, and we used a variety of techniques to collect relevant data, including nocturnal eyeshine surveys (NES), catch-and-release surveys, nesting surveys, and habitat assessments. These were used to determine abundance, obtain life history data, and assess habitat requirements.

MATERIALS AND METHODS

Study Sites. - Lago Enriquillo is a 375 km^2 hypersaline lake located in the Neiba Valley of southwestern DR (18.564392, -71.699384; WGS 84; Fig. 1). The lake is the remnant of an ancient marine channel that was separated from the sea by tectonic activity and sedimentation roughly 2500 years ago (Mann et al., 1984; Moknatian and Piasecki, 2019). The climate is arid to semi-arid with variable shoreline habitat types including sandy beach, coral fragment beach, rocky beach, mudflat, and marsh. The lake goes through drastic changes where water level, lake surface area, and salinity vary considerably from year to year (Schubert and Santana, 1996). Changes in lake conditions are caused by the arid climate that exhibits high variability in rainfall from year to year (prolonged droughts with little to no rainfall and hurricanes causing high rain fall) and high evaporation rates (Schubert and Santana, 1996). Most of the shore is dominated by submerged forests of trees that grew during periods of low lake levels, were submerged in water during periods of high water levels which killed them, and are now being exposed as water levels recede again. The south shore of the lake has a sparse submerged forest in comparison to the north shore. In recent years, surveys of the south shore have yielded few to no crocodiles (J.Brocca and R. Espinal, pers. obs.). Isla Cabritos, a 24 km^2 island in the middle of the lake, is a known nesting site and refuge of adult crocodiles (Schubert, 2002). The lake is surrounded by over 700 natural springs that serve as freshwater sources along with 18 tributaries (Mendez-Tejeda and Delanoy, 2017). In the past 20 years, Lago Enriquillo is thought to have the largest population of *C. acutus* in DR (Thorbjarnarson, 2010), and we concentrated most of our survey efforts there. Monte Cristi National Park, El Morro National Park, and Laguna Saladillo (19.70465, -71.73370; 19.86812, -71.65280; 19.66312, -71.71467; WGS 84) are located in the Monte Cristi region of northwest DR (Fig. 2). This system encompasses a large coastal area dominated by mangrove and emergent vegetation that historically supported a crocodile population; it was surveyed as well.

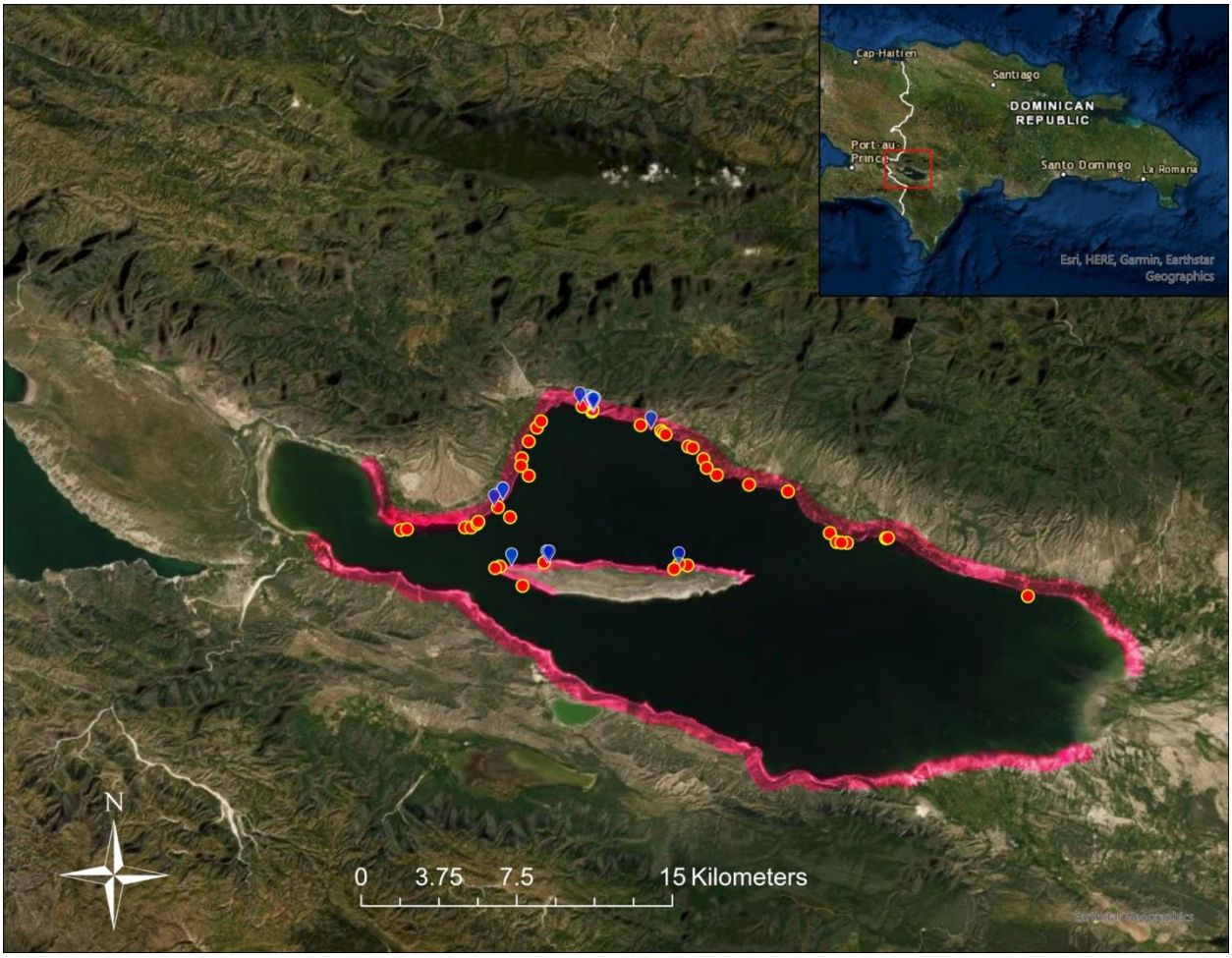


Fig. 1. Distribution of *C. acutus* in Lago Enriquillo, DR. Red dots are sighting locations of individual crocodiles, blue pins are nest locations, and areas highlighted in pink are the portions of the shoreline that we surveyed. Source: Esri, HERE, Garmin, Earthstar Geographics.

Nocturnal Eyeshine Survey. - We conducted NES on Lago Enriquillo over 17 nights between 13 May and 26 June 2021. We surveyed the north shore of the lake and the shore of Isla Cabritos on foot because of the density of the submerged forest. To confirm crocodiles do not use the south shore, we conducted a boat survey on 16 June 2021. We walked in line with 2 m between each other at a pace of 5-7 km/h. Keeping 2 m of distance kept us far enough from each other to have two to three people scan an area and close enough to call out crocodiles to prevent double-counting individuals. We surveyed the southern shore using a 7.5 m skiff with an outboard motor maintaining a speed between 10-12 km/h. We used a 4 m aluminum dinghy with an outboard motor and a 7.5 m skiff with an outboard motor maintaining a speed between 10-12 km/h for surveys in the Monte Cristi region. We conducted NES in Monte Cristi over three nights: Laguna Saladillo on June 18, El Moro National Park on June 19, and Monte Cristi National Park on June 20. Each survey started 30 minutes after sunset. At Lago Enriquillo, we covered as many km of shoreline as possible each night for walking surveys. Our longest walking survey was 6.3 km and our shortest was 0.9 km. We covered 21.2 km of shoreline

during our boat survey. During Monti Cristi boat surveys, we covered 5.9 km of shoreline at Laguna Saladillo, 8.4 km at El Morro National Park, and 10.9 km at Monti Cristi National Park. We marked the start and end points of each survey using a handheld GPS. We detected crocodile eyeshine using two or three 6000 lumen handheld spotlights. We recorded environmental factors (salinity, air temperature, water temperature) at the beginning and end of each survey, and at the point of every individual sighting to assess their influence on crocodile locations. We measured salinity using a refractometer and water temperature using a digital probe thermometer. Upon sighting a crocodile, we recorded the GPS coordinates, time, and approximate distance of sighting. We approached crocodiles as closely as possible and visually estimated their total length (TL) according to the following categories: hatchlings/yearlings < 30 cm, juveniles 31 – 90 cm, subadults 91 – 180 cm, and adults > 181 cm (Platt and Thorbjarnarson, 2000; Sánchez Herrera et al., 2011). We classified individuals for which TL could not be determined as "eyeshine only" (EO; Platt and Thorbjarnarson, 2000; Sánchez Herrera et al., 2011). The same observer (RMG) carried out the counts and size estimates on all surveys. With data collected from NES, we determined the encounter rate of crocodiles (crocodiles/km) as suggested by Platt and Thorbjarnarson (2000).

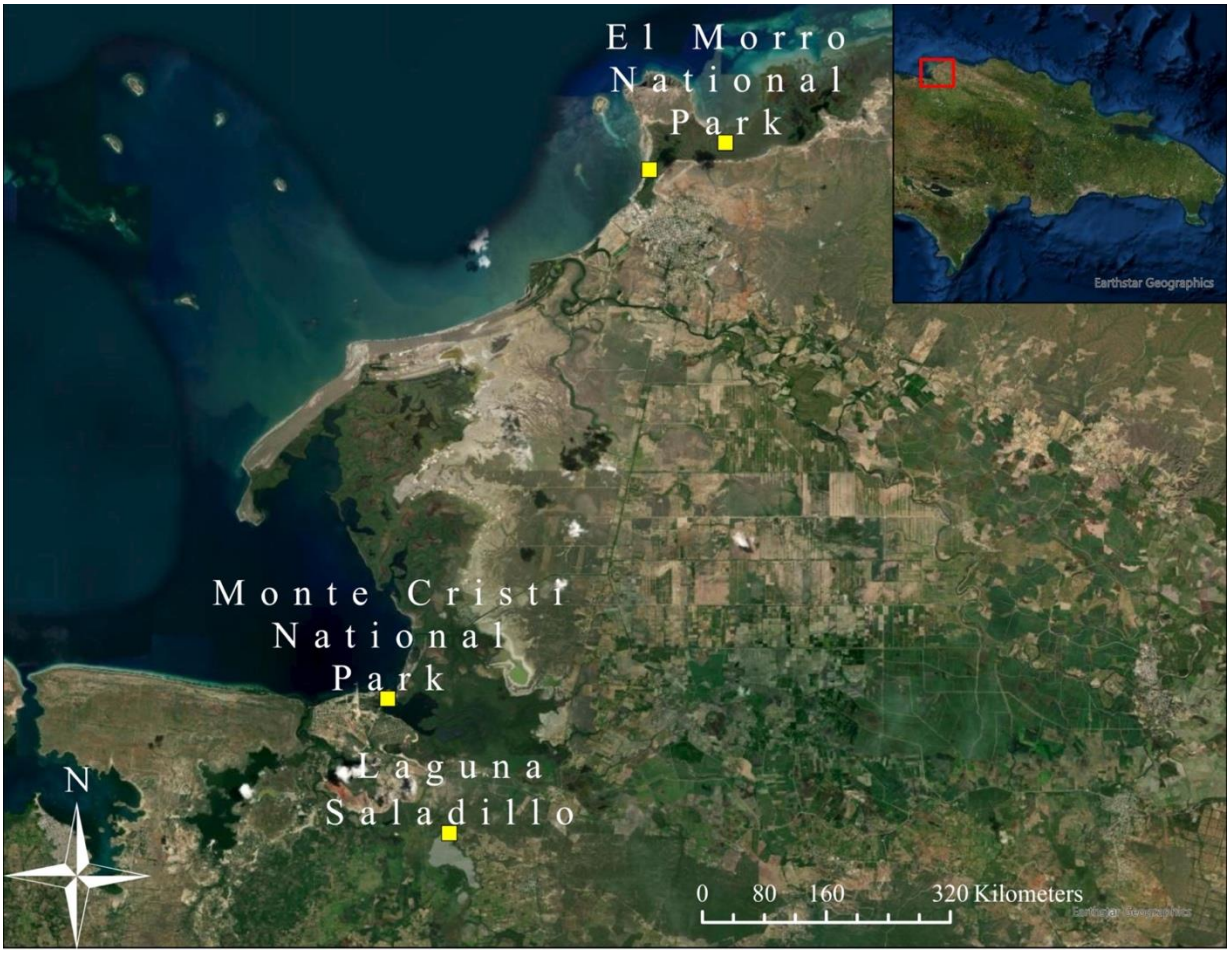


Fig. 2. Survey Locations for *C. acutus* in the Monte Cristi region. Yellow squares are site locations. Source: Earthstar Geographics.

Captures. - We conducted captures on Lago Enriquillo over 13 nights between 17 May and 28 June 2021. We conducted hatchling and yearling captures over 7 days during nest surveys between 19 May and 28 June 2021. We conducted captures on nights when we did not do NES and again recorded salinity, air temperature, and water temperature at the beginning and end of each survey. We captured crocodiles using hand capture or with catchpole snares and collected standard morphometric data: head length, snout length, cranial width, maxillary width, pre-maxillary width, TL, snout–vent length, tail girth, left hind foot length (all cm), sex, and body mass (Platt and Thorbjarnarson, 2000; Tellez et al., 2017). We weighed small individuals (<1 kg) using spring scales (PESOLA AG; Schindellegi, Switzerland) to the nearest gram, and all other individuals using a Moultrie 200 kg hanging scale (PRADCO; Birmingham, Alabama, USA) to the nearest kilogram. The gender of non-hatchling crocodiles was determined by examination of the cloaca for the presence of the penile structure in males (Brazaitis, 1968; Platt and Thorbjarnarson, 2000). We collected environmental data (salinity, air temperature, and water temperature) at every capture site and examined individuals for general health and the presence of external parasites as suggested by Tellez and Paquet-Durand (2011). We photographed each individual to document scalation and for future recapture reference. Before release, we marked crocodiles via dorsal caudal scute clipping with a unique numerical code for future identification (Platt and Thorbjarnarson, 2000; Tellez et al., 2016).

Absolute and Relative Population Model. - We estimated the minimum number of crocodiles in Lago Enriquillo by extrapolating our survey results to the shoreline of the entire lake and Isla Cabritos following methods used by Platt and Thorbjarnarson (2000). Survey results did not include crocodiles that were concealed in submerged forests or underwater, so our calculations represent a conservative estimate of the true number of crocodiles present. We excluded hatchlings from the analyses due to high mortality rates during the early years of life (Platt and Thorbjarnarson, 2000). Historically, crocodiles have not occurred in every area of the lake, so our first population size estimate is certainly an overestimation. To generate a more realistic estimate, we excluded those areas (the southern shore of Lago Enriquillo) for our second set of calculations. We used these results to compare with historical population trends and to use as a baseline coarse-scale population metric.

To produce a more fine-scale estimate, we calculated population density using encounter rates. Our first encounter rate calculations included every site surveyed, but were heavily biased by one site, La Azufrada (encounter rate = 50 non-hatchling crocodiles/km), due to it being a nursery and protected by the Dominican Ministry of the Environment and Natural Resources (MENR). We excluded it for a more representative encounter rate for the rest of the lake in our second set of encounter rate calculations.

Nesting Surveys. - Nesting surveys were led by MENR following the methods of Incháustegui et al. (1980), and SEA/DVS (1993). Surveys focused on historical nesting sites located by Schubert (2002). We located nests from March to May 2021 during the typical nesting season of this population (Schubert, 2002). We recorded location coordinates for nests. We revisited nest sites in June to collect hatchlings for morphometrics, and to transport them to a protected nursery.

Habitat Monitoring. - We evaluated the habitat occupied by *C. acutus* during the day and prior to NES before sunset. We noted habitat qualities such as vegetation cover and assessed potential current and future threats the crocodiles might face following methods used by Sánchez Herrera et al. (2011). We described the following major components: (1) types of water available on each

survey route; (2) types of habitat available; and (3) presence or absence of human activity. We also estimated vegetation state on a scale from 1 to 10 (10 = healthy and undisturbed), and noted visual signs of pollution in the water (i.e., presence of trash, visual signs of chemical drainage, etc.; Sánchez Herrera et al., 2011; Tellez et al., 2016).

Statistical Analysis. - To identify the relative density of *C. acutus* in DR, we calculated the encounter rate as described in Platt and Thorbjarnarson (2000). Using non-hatchling data from capture surveys, we tested against the null hypothesis of a 1:1 sex ratio in Lago Enriquillo with a chi-square test. We also tested the observed size distribution of crocodiles within Lago Enriquillo against the null hypothesis of an even distribution of size cohorts with a chi-square test using NES data. To provide a more rigorous assessment of body condition, we calculated Fulton's condition factor following methods used by Labarre et al. (2020) and the equation

$$K = M/SVL^3 \times 10^5$$

where K is body condition, M is whole body mass in g, and SVL is snout-vent length in cm. To determine habitat selection, we compared the average salinity of crocodile sightings between sites and between size cohorts to encounter rates at each site using linear regression. We excluded eyeshine only from the statistical examination of size class distribution among and within our field sites. We performed all statistical analyses using SPSS (IBM; Armonk, NY) and R (R Foundation for Statistical Computing; Vienna, Austria), and all analyses were considered significant at $P < 0.05$. We plotted GPS coordinates collected from crocodile sightings during NES and nest locations from nesting surveys in ArcGIS (ESRI; Redlands, CA, USA) to create updated distribution maps of *C. acutus* in Lago Enriquillo (Figs. 1, 3). To assess population distribution and dispersal trends we used the average nearest neighbor function in ArcGIS. This method calculates a nearest-neighbor index based on the average distance from each individual to its nearest neighboring individual and compares the average distance against a null distribution. If the average distance is less than the mean for a hypothetical random distribution, the distribution of the features being analyzed is considered clustered. If the average distance is greater than a hypothetical random distribution, the features are considered dispersed (Ebdon, 1991).

RESULTS

LAGO ENRIQUILLO

Nocturnal Eyeshine Surveys. - Our assessment of the south shore via boat yielded no crocodiles, so we focused our surveys on the north shore and Cabritos island. We encountered 120 crocodiles over 72.6 km of shoreline for an encounter rate of 1.7 crocodiles/km (Figs. 1, 4). Of those, 18 were hatchlings (15%), 45 were juveniles (37.5%), 12 were subadults (10%), 32 were adults (26.7%), and 13 were EO (10.8%; Figs. 3, 4). Size class distributions differed significantly from the null model ($\chi^2 = 18.63$, $P < 0.0001$); relative to an equal distribution across size classes, juveniles and adults were more abundant than expected and subadults were less abundant than expected. Of the crocodiles for which size could be determined, 15 were adults larger than 240 cm TL (14%), and the largest individual was larger than 350 cm TL.

Table 1: Data from nocturnal eye shine and capture surveys of *Crocodylus acutus* in Lago Enriquillo, Dominican Republic.

Site:	Number of Surveys	Number of Sightings	Average Size of Sighted Crocodiles (cm)	Survey Distance (km)	Encounter Rate (crocodiles /km)	Number of Captures	Average Salinity (ppt)	Average Water Temp (°C)	Average Air Temp (°C)	Habitat Assessment: Natural Vegetation Score (1-10)
Lago Enriquillo North Shore	13	46	102	36.2	5.72	10	28	27.1	28.8	7
Lago Enriquillo South Shore*	1	0	0	21.2	0	0	42.5	29.8	29.3	8
Isla Cabritos North Shore	3	13	237	11.7	5.58	42	44	28.2	29.3	9
Isla Cabritos South Shore	1	1	183	2.5	0.08	0	45	28.8	28.3	9
Azufrada	1	60	107	1	60.0	32	28	28.5	29.5	9

* Conducted via boat survey.

Capture Surveys. - We captured 84 crocodiles; 58 were hatchlings (69%), 24 were juveniles (29%), and 2 were subadults (2%; Fig. 4). We determined sex for 25 non-hatchling individuals, and 10 were female (40%) while 15 were male (60%). Sex distribution did not differ significantly from the null model of 1:1 (χ^2= 1, P = 0.32).

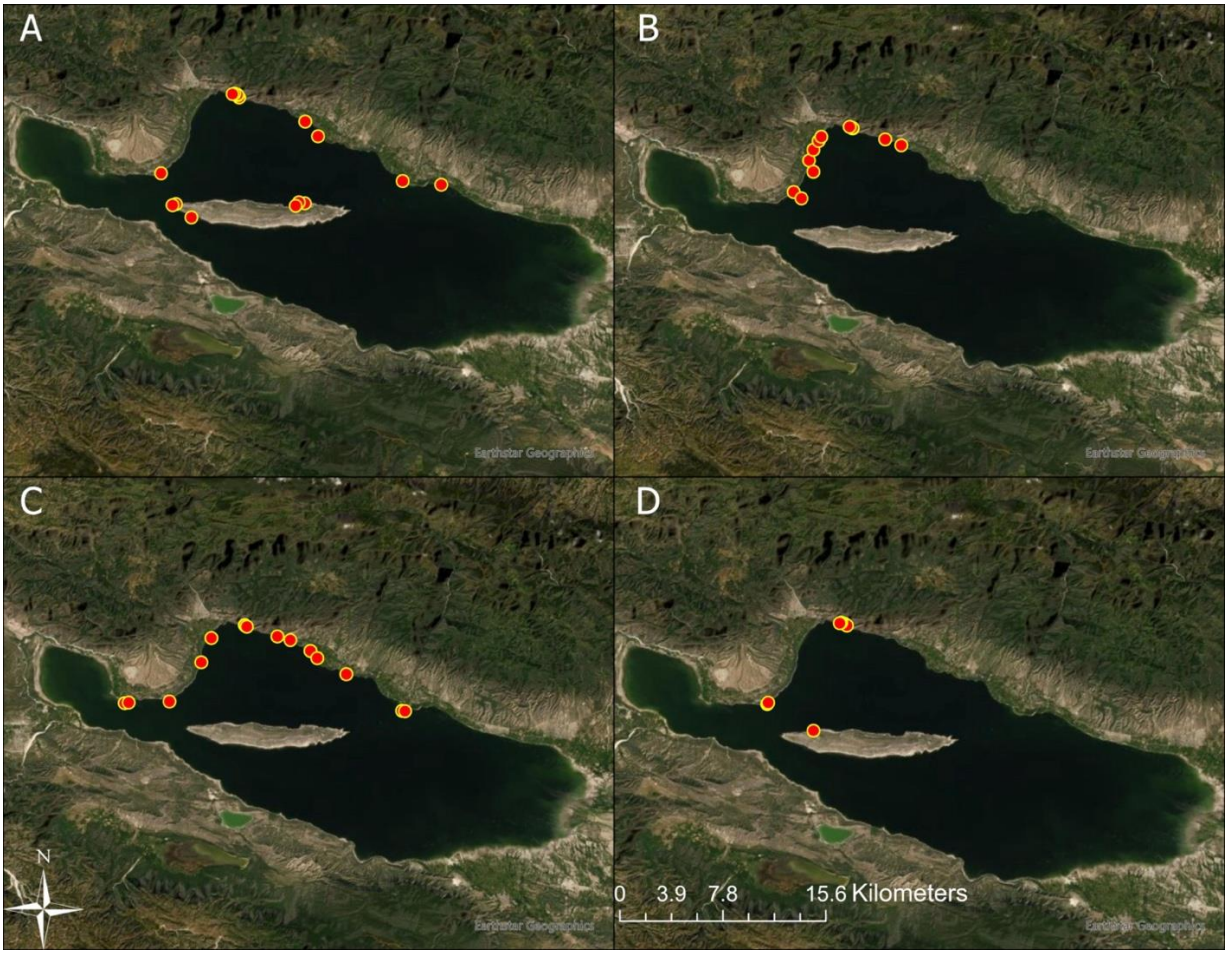


Fig. 3. Size class distribution of sighted *Crocodylus acutus* in Lago Enriquillo. A = red dots are adult sighting locations. B = red dots are subadult sighting locations. C = red dots are juvenile sighting locations. D = red dots are hatchling sighting locations. Source: Earthstar Geographics.

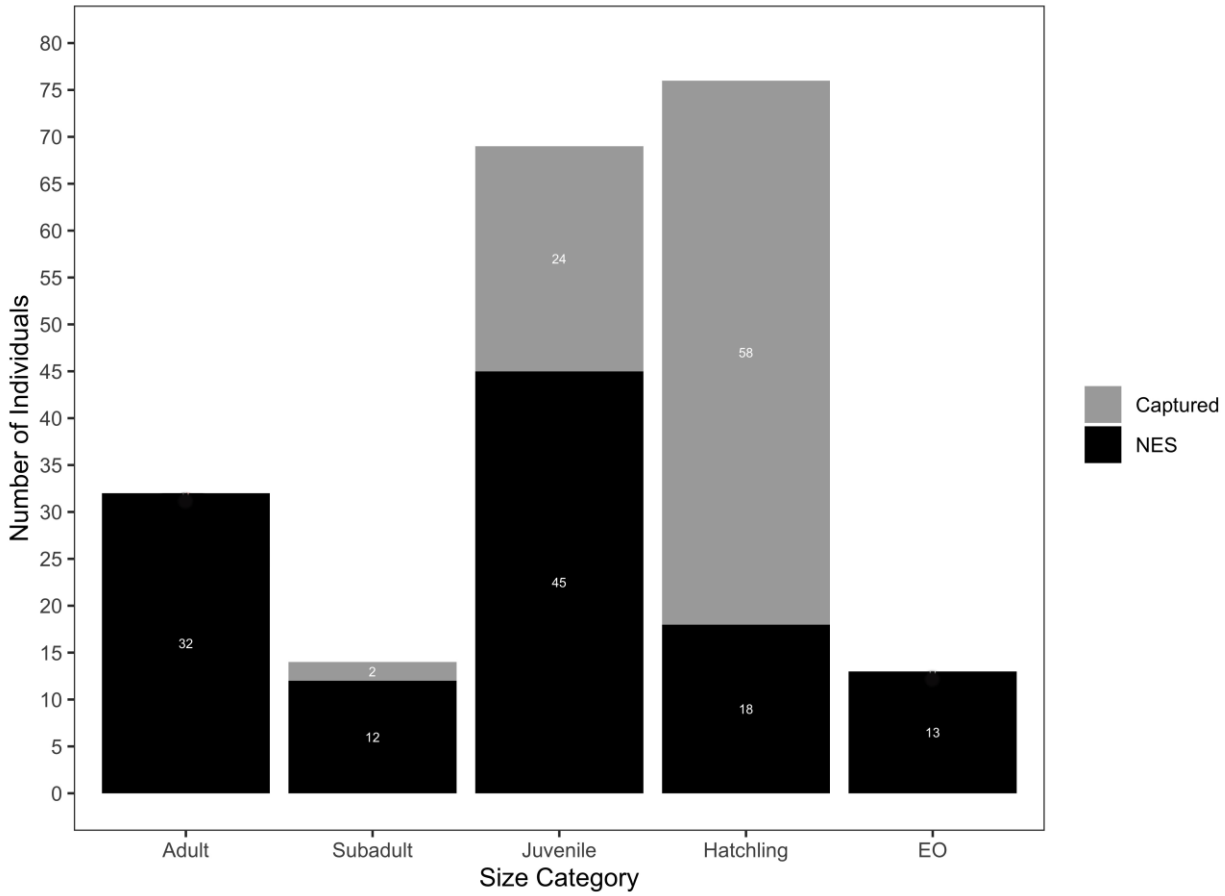


Fig. 4. Size class distribution of *Crocodylus acutus* in May and June of 2021. Gray bars indicate captured individuals of that size category.

Body Condition. - Physical examination (neck and tail girth, signs of injury, etc.) suggested that most individuals were healthy. Of the 84 crocodiles captured, we excluded one from our Fulton's condition factor calculations because we were unable to measure mass. Overall mean K (± SD) was 2.51 ± 0.44 (n = 83). We established the body condition categorical ranges as: poor, K < 2.07 (= 2.51 – 0.44); good, 2.07 – 2.95; and excellent, K > 2.95 (= 2.95 + 0.44) following the methods of Labarre et al. (2020). Numbers and percentages of captured crocodiles were summarized by body condition category and classified by size class (Table 2). Of the crocodiles in the data set 71 (85%) had a body condition value of good or excellent (Table 2).

Table 2: Number and proportions (as percentage) of *Crocodylus acutus* in each category of body condition by size class.

Body Condition	Hatchling	Juvenile	Subadult
Total	58	23	2
Poor	3(5.2)	9 (39.1)	0(0)
Good	48(82.7)	10(43.5)	1(50)
Excellent	7(12.1)	4(17.4)	1(50)

Habitat Assessment. - The predominant bodies of water were the lake itself, stream tributaries, and the spring-fed wetlands flowing into the lake. The shoreline habitat types of Lago Enriquillo along our survey routes were submerged forest (39%), sandy beach (16%), halophyte marsh (13%), mudflat (13%), rocky beach (10%), modified habitat (7%), and coral fragment beach (2%). The main human activities occurring in crocodile habitat were fishing and agriculture. We estimated the state of the overall shoreline habitat vegetation as 7 (out of 10) because most of the marsh and submerged forest appeared healthy and undisturbed, and we observed many species of avian and reptile wildlife. However, we commonly observed patches of cleared submerged forest for agriculture and litter in the form of fishing nets, old boats, and trash around the lake.

Habitat Selection. - When comparing crocodile encounter rate to average salinity between sites, we found that salinity significantly affected habitat selection by crocodiles ($P = 0.009$). We found that sites with lower salinity had higher crocodile encounter rates. La Azufrada was an outlier of our data set due to an extremely high encounter rate but was not excluded because it is ecologically critical to this population as a nursery. When comparing each size class's encounter rate to average salinity between sites, we found that salinity significantly affected habitat selection in hatchling crocodiles ($P = 0.008$), but not significantly for other size classes (Adult: $P = 0.4$; Subadult: $P = 0.5$; Juvenile: $P = 0.2$). The dispersion model for Lago Enriquillo was significantly clustered ($P < 0.05$).

Population Estimates. - From topographic maps we measured 119.6 km of shoreline habitat in Lago Enriquillo (including Isla Cabritos). Next, we multiplied that value by the average encounter rate of non-hatchlings (1.40 crocodiles/km) and found that the conservative population size was 167 non-hatchling crocodiles. Then, we multiplied the shoreline by the average adult encounter rate (0.44 crocodiles/km) and yielded a conservative estimate of 52 breeding adults. After excluding shoreline historically not used by crocodiles, we found that only 98.4 km of shoreline is likely relevant for population estimates. Next, we multiplied that value by the average encounter rate of non-hatchlings (1.40 crocodiles/km) and found that the conservative population size was 137 non-hatchling crocodiles. Then, we multiplied the shoreline by the average adult encounter rate (0.44 crocodiles/km) and yielded a conservative estimate of 43 breeding adults.

We calculated population density from the average encounter rate of every area surveyed. Our first calculation of non-hatchling crocodile encounter rate was 1.40 crocodiles/km. Our second calculation that excluded La Azufrada yielded 0.6 crocodiles/km.

Nesting Surveys. – We located 42 confirmed nests on the beaches of the northern shore of Lago Enriquillo and Isla Cabritos. Of the 42 confirmed nests, 24 were found on beaches with a sand substrate and 18 were found on beaches with a coral fragment substrate.

MONTE CRISTI

We surveyed 25.1 km of coastline across three nights. We did not encounter any crocodiles during these surveys.

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