Reproductive ecology of the American crocodile in northern Quintana Roo, Mexico

Ecología reproductiva del cocodrilo americano en el norte de Quintana Roo, México

Pierre Charruau[1*], Fidelina Hernández-Marcial[2] y Fausto R. Méndez de la Cruz[3]

[1] Centro del Cambio Global y la Sustentabilidad en el Sureste A.C.,
Calle Centenario del Instituto Juárez S/N, Col. Reforma, C.P. 86080 Villahermosa, Tabasco, Mexico.
[2] Instituto Tecnológico de Chetumal,
Av. Insurgentes No. 330, Esq. Andrés Quintana Roo, Col. David Gustavo Gutiérrez, A.P. 267, 77013 Chetumal, Quintana Roo, México.
[3] Laboratorio de Herpetología, Departamento de Zoología, Instituto de Biología,
Universidad Nacional Autónoma de México, 04510 Distrito Federal, México.
*Correo elctrónico: charruau_pierre@yahoo.com

ABSTRACT

The American crocodile (*Crocodylus acutus*) in coastal areas of Quintana Roo state (Mexico), is threatened by factors associated to the rapid development of this touristic region. As reproductive ecology the critical information to determine species conservation strategy, several studies on *C. acutus* reproduction have been carried out in Quintana Roo. However, these studies have been done in islands and no data for continental populations are available. Thus, the main goal of this study was to provide first knowledge on the reproductive ecology of *C. acutus* from Quintana Roo mainland. From 2012 to 2014 we searched for nesting sites in the Área de Protección de Flora y Fauna Yum Balam in northern Quintana Roo. We recorded nests characteristics and clutch attributes for each nest detected. Temperature loggers were placed at the center of the clutch of five nests and within the vegetation at shade to register temperature every 15 or 30 min. The nests were revisited from June to August to determine their fate and to recover the data loggers. The laying to hatching period seems to occur from late March to early July. Mean clutch size (42 ± 5.7 eggs) and mass (4196 ± 726 g) are among the highest reported for the species, which may indicate the presence of large females in the area or a higher fertility than the females from islands. Mean incubation temperatures (29.1 – 33.4 °C) suggest that nests produce both sexes. The high egg fertility rate (97.5%) and nests success (100%) suggest a good reproductive status of the population.

Keywords: Clutch parameters; *Crocodylus acutus*; incubation temperatures; nest characteristics; Yum Balam.

RESUMEN

El cocodrilo americano (*Crocodylus acutus*), presente en la costa del estado de Quintana Roo (México), está amenazado por factores asociados al rápido desarrollo turístico. Los parámetros de la ecología reproductiva son información crítica para determinar estrategias de conservación de una especie. Por lo tanto, se han realizados varios estudios sobre la reproducción de *C. acutus* en Quintana Roo. Sin embargo, esos estudios se hicieron en islas y no existe información del estado reproductivo de *C. acutus* en la parte continental del estado. El objetivo de este trabajo es proveer los primeros datos sobre reproducción de *C. acutus* en la parte continental de Quintana Roo. De 2012 a 2014 se buscaron sitios de anidación en al Área de Protección de Flora y Fauna Yum Balam. Se registraron las características de los nidos encontrados, los atributos de las nidadas y el éxito de anidación. La temperatura de incubación así como la temperatura ambiental se registraron en cinco nidos cada 15 o 30 min. El periodo de reproducción (ovoposición-eclosión) ocurre desde finales de marzo hasta principios de julio. El tamaño (42 ± 5.7 huevos) y el peso (4196 ± 726 g) promedio de las nidadas son entre los más altos registrados para la especie, lo que podría indicar la presencia de hembras muy grandes en el área o con fertilidad mayor a las de las islas. Las temperaturas de incubación (29.1 – 33.4 °C) sugieren la producción de ambos sexos. Los altos porcentajes de fertilidad de los huevos (97.5%) y éxito de anidación (100%) sugieren un buen estado reproductivo de la población.

Palabras clave: *Crocodylus acutus*; nidada; nidos; reproducción; temperaturas de incubación; Yum Balam.

INTRODUCTION

The American crocodile (*Crocodylus acutus*, Cuvier 1807) has the widest distribution range of crocodilians in America. It occurs from the State of Sinaloa in Mexico and the sub-tropical tip of the Florida Peninsula in USA to southern Venezuela and the limits of mangrove habitat in northern Peru, being present in both Atlantic and Pacific coasts of the continent and Caribbean islands (Thorbjarnarson et al., 2006). As occurred in other parts of its distribution, wild populations of *C. acutus* have been intensively exploited for skin trade during the early 20th century in the Yucatan Peninsula, Mexico (Casas-Andreu and Guzman-Arroyo, 1970). In 1939 a decree published in the Diario Oficial de la Federación (DOF) established a 5-year ban on crocodile capture in States of the Yucatan Peninsula (Campeche, Yucatan and Quintana Roo) (DOF, 1939). However, crocodile hunting continued until 1970 when a national and permanent ban of crocodile exploitation was established in Mexico (Casas-Andreu, 1995). In consequence, its populations critically decreased and remnant populations now only occur in the eastern coast of the Yucatan Peninsula, from Ría Lagartos Biosphere Reserve in northern Yucatan State to the Bahía of Chetumal in Quintana Roo State, including coastal islands and atolls (Charruau, Cedeño-

Vázquez, and Calmé, 2005; Cedeño-Vázquez, Ross, and Calmé, 2006; González-Cortés, 2007). These populations are still depleted and destruction and fragmentation of their habitat and hybridization with the sympatric Morelet´s crocodile (*Crocodylus moreletii*) difficult their recovery (Cedeño-Vazquez et al., 2006; Machkour M´rabet et al., 2009). Currently, *C. acutus* is considered Vulnerable by the International Union for Conservation of Nature (UICN), is listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and is considered as species subjected to special protection by the Mexican law NOM-059-SEMARNAT-2010 (DOF, 2010; Thorbjarnarson, 2010).

Reproductive status and ecology of animal species and their populations are critical information to determine any plan of recovery or conservation. The study of reproduction of *C. acutus* in the Yucatan Peninsula is recent and includes different aspects of the reproduction (Charruau, Thorbjarnarson, and Hénaut, 2010; Charruau, Méndez de la Cruz, and González-Cortés, 2011; Charruau, 2012; Charruau and Hénaut, 2012; Charruau, Hénaut, and Álvarez-Legorreta, 2013). However, these studies were done on island populations and no information exist on reproduction of *C. acutus* in the continental part, where populations are more threatened. Thus, the objective of this work was to provide the first data on nesting ecology and reproductive status of a continental population of *C. acutus* in Quintana Roo State, Yucatan Peninsula.

MATERIAL AND METHODS

Study site

The study was performed in the Protected Area of Flora and Fauna of Yum Balam (PAFFYB), located in the extreme north of Lázaro Cárdenas municipality, in northern Quintana Roo State, Mexico (Figure 1). The PAFFYB has an altitude from 0 to 15 m above sea level and an area of 154,052 ha (DOF, 1994). The majority of the reserve corresponds to marine ecosystems and wetlands, including lowland tropical forest, mangrove forest and coastal dunes. The climate of the region is warm sub-humid, with precipitations throughout the year and maximum in summer. Precipitation is very variable throughout the years and space distribution, mean annual precipitation can reach 1250 mm and decrease toward the north to 800 mm (Orellana et al., 1999). Mean annual temperature in the area varies from 24.6 °C

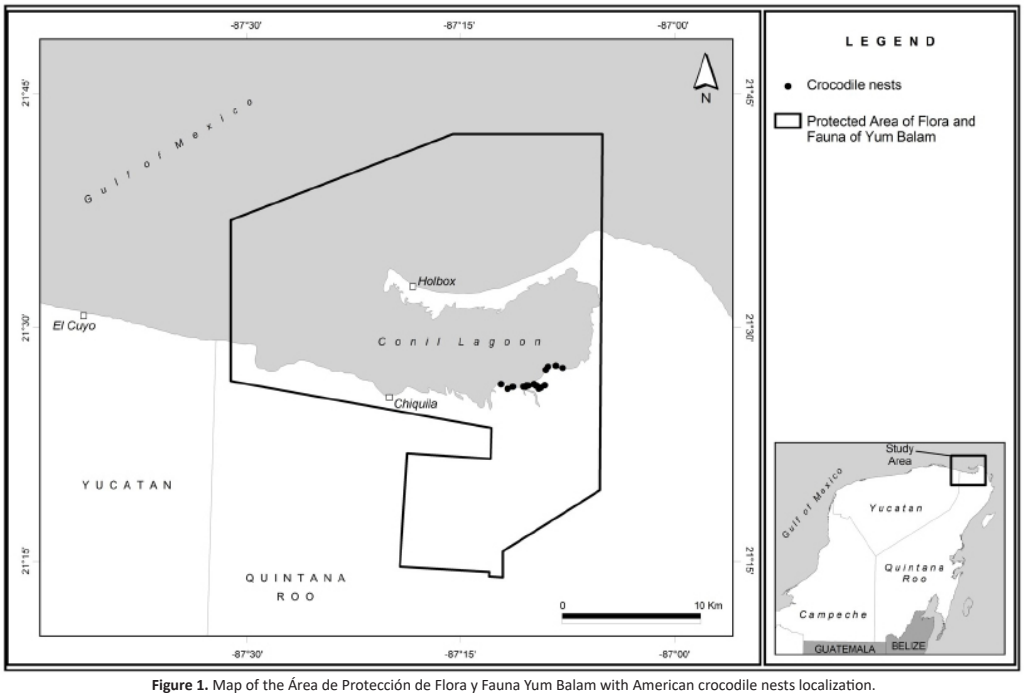

Figure 1. Map of the Área de Protección de Flora y Fauna Yum Balam with American crocodile nests localization.

to 27 °C with January and February as the coldest months and August as the warmest month. Both crocodile species, *C. acutus* and *C. moreletii*, are present in the area but very little information exist on their populations.

Nests search and data collection

Potential nesting areas of *C. acutus* were scanned by foot from March to May of 2012, 2013 and 2014 to detect nests. Each nest detected was georeferenced by a Global Positioning System (GPS) and the following information was taken: nest type (i.e. mound or hole nest), material used for the construction of the nest, type of surrounding vegetation, distance to the water edge and to the nearest tree or shrub and species of the nearest shrub/tree. These distances were measured from the center of the nest with a ruler tape (± 1 cm). The nests were carefully excavated and the distance to the uppermost egg was measured (± 1 cm) with a ruler tape. Eggs were then removed carefully from the nest and marked with pencil on their dorsal surface to keep their original position. Clutch size was recorded and length, width and mass of each egg were measured with an electronic caliper (± 0.1cm) and an electronic weighting scale (± 1 g). All eggs of clutches were measured in 2012 and only the first 15 eggs of each clutch were measured in following years. This was done because of the relatively high number of eggs (up to 53) and time needed to measure all of them, to avoid any effect of temperature changes on the development and mortality of embryos. The measures of fifteen eggs give us a well estimate of the eggs dimensions and we also can estimate clutch mass based on their mean weight. The fertility of each egg was also determined by the presence of the white band of embryonic development (Ferguson, 1985). The dimensions (width and length) of the egg chamber and distance from soil surface to the bottom of the egg chamber were also measured using a ruler tape (± 1 cm). The eggs were then carefully placed back in the egg chamber in their original position. Data loggers (HOBOS Pendant® Temperature/Alarm Data Logger 8K UA-001-08) were placed at the center of the clutch of five nests (one in 2012, three in 2013 and one in 2014), and in the vegetation at shade (one each year). These data loggers were programmed to register temperature every 15 or 30 min. The nests were revisited from June to August each year to determine their fate and to recover the data loggers. A nest was considered successful if at least one neonate emerge from it.

RESULTS AND DISCUSSION

A total of 28 nests were found during the three years: 15 in 2012, eight in 2013 and five in 2014. Oviposition occur from late March to late May with inter-annual variation similar to the laying period reported for *C. acutus* in the Yucatan region (Platt and Thorbjarnarson, 2000; Charruau et al., 2010, 2011). One nest (3.6%) was a mound nest; the other 27 (96.4%) were hole nests. Although the species mainly construct hole nests, it is known to also form mound nests in some areas of its range including the Yucatan Peninsula (Platt and Thorbjarnarson, 2000; Charruau et al., 2010). Nests were located on the sandy dune between the Conil Lagoon and wetlands on the southeastern shore of the lagoon (Figure 1). They were made of thick sand and pieces of shells (in 61.5 % of nests), grass (in 53.9% of nests), unidentifiable organic matter (in 46.2% of nests) and Salicornia sp. (in 46.2% of nests). Two nests were reused each year. Vegetation of nest sites was mainly composed of red mangrove (*Rhizophora mangle*), button mangrove (*Conocarpus erectus*) and black mangrove (*Avicennia germinans*), associated with coastal dune species: siricote (*Cordia dodecandra*), dwarf saltwort (*Salicornia bigelovii*), coconut tree (*Cocos nucifera*), Florida thatch palm (*Thrinax radiata*), beach spider lily (*Hymenocallis littoralis*) and a poaceae (grass). Nests were constructed at a mean distance of 3.5 m from the nearest tree (Table 1) which were *Conocarpus erectus* (n = 19), *Rhizophora mangle* (n = 4), *Avicennia germinans* (n = 4) and *Thrinax radiata* (n = 1). The nests were located at a mean distance of 6.3 m from nearest water edge (Table 1). Females nesting site selection in the PAFFYB does not differ from previous published information on *C. acutus* in islands of Quin-

Table 1. American crocodile nest characteristics and clutch attributes at Yum Balam protected area, Quintana Roo, Mexico. SD: Standard deviation.

Parameters	Mean	SD	N	Range
Nest characteristics				
Depth to uppermost egg (cm)	25.2	3.6	15	20.0-32.0
Depth to clutch bottom (cm)	42.6	8.4	15	21.0-52.0
Width of egg chamber (cm)	37.0	8.0	15	22.0-53.0
Length of egg chamber (cm)	40.9	8.3	8	29.8-54.0
Distance to water edge (m)	6.3	2.2	28	3.3-15.4
Distance to nearest tree (m)	3.5	1.8	28	1.0-7.3
Clutch attributes				
Clutch size	42	5.7	15	32-53
Egg length (mm)	72.0	3.3	170	65.0-76.0
Egg width (mm)	46.8	1.2	170	41.0-50.0
Egg ratio (length/width)	1.54	0.08	170	1.34-1.67
Egg mass (g)	98.3	11.8	170	79.0-115.0
Clutch mass (g)	4196	726.9	2	3682.0-4710.0
Clutch fertility (%)	100	0.0	2	-
Nest success (%)	100	0.0	28	-

tana Roo and other regions of the species range. They construct the nest in sandy substrate with little vegetation cover near water edge, decreasing the risk of flooding and allowing a good gas exchange and thermal conductivity which provide an adequate incubation environment (Charruau et al., 2010).

Other nests characteristics and the clutch attributes are presented in Table 1. In addition to the mass of two clutches, the mean clutch mass of 11 nests was estimated and we obtained a mean clutch mass for the area of 4353.9 ± 749.2 g (range: 3528-6042; n = 13). We also estimate the fertility of other six nests based on the data of 15 eggs of each nests and obtained a mean fertility rate of 97.5% (range: 80-100%). All the nests studied were successful but one was partially depredated by a raccoon (*Procyon lotor*). Clutch and nest parameters are within the range of data known for *C. acutus* and mean clutch size and mass are among the highest reported for the species (Charruau, 2010; Charruau et al., 2011). This could indicate the presence of large females in the area as clutch size and mass are positively correlated to female size in *C. acutus* (Thorbjarnarson, 1996) or a higher fertility rate than the females from islands. Furthermore, the high fertility rate and nests success suggest a healthy reproductive status of the American crocodile population in the study area.

The daily mean temperature of the clutch shows less variation than the daily mean environmental temperature (Figure 2). In figure 2 we can also observe that the clutch temperature follows, with a delayed response, the variation of environmental temperature. Furthermore, the abrupt decreases in environmental temperatures are certainly due to rainfall events and we can observe that clutch temperature does not decrease so low during these events (Figure 2) and stay at survival level for embryo (> 28 °C; Charruau, Martínez G. Cantón, and Méndez de la Cruz, 2017). These observations were expected and coincide with previous studies of American crocodile nest temperatures (Charruau, 2012, Charruau et al., 2010). The daily cycle of clutch and environmental tempera-

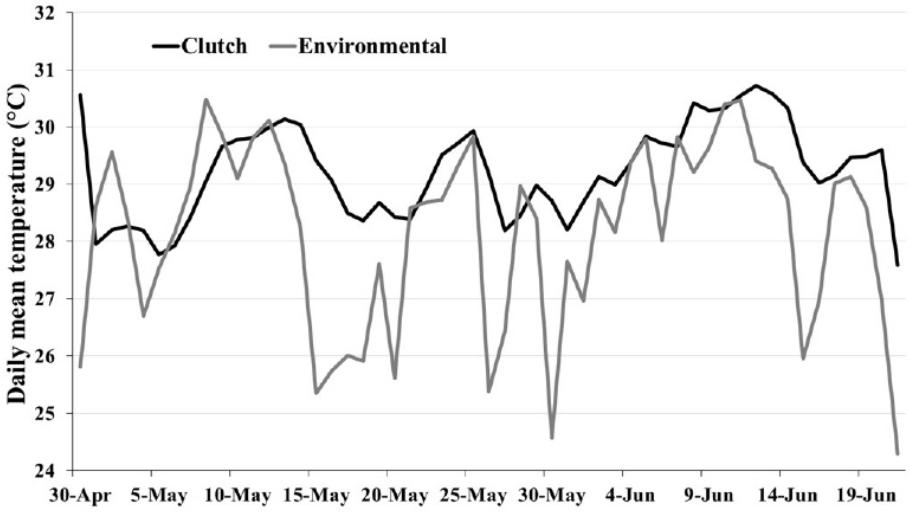

Figure 2. Variation of clutch and environmental daily mean temperature (°C) of the American crocodile nest of 2012 during the incubation period at Yum Balam protected area.

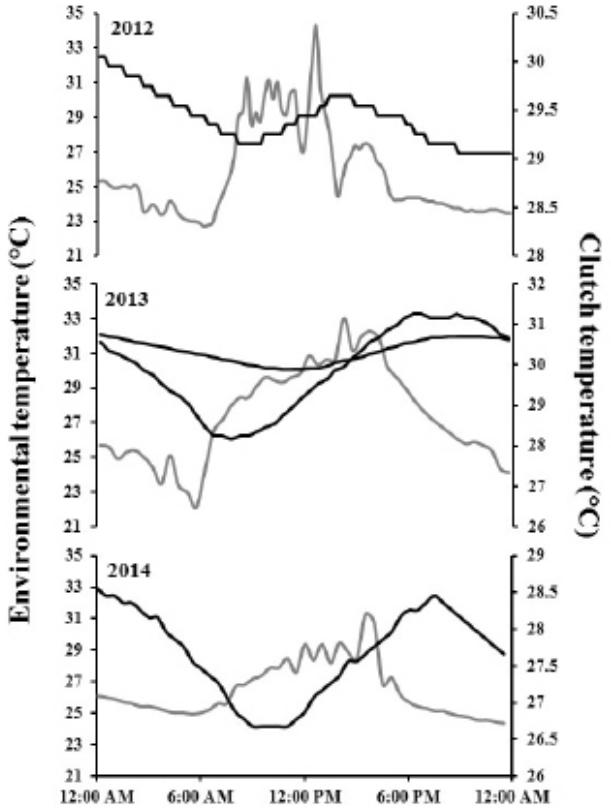

Figure 3. Daily cycle of clutch (black) and environmental (grey) temperatures in nests of American crocodile at Yum Balam on May 15 of each year.

tures (Figure 3) concur with previous studies done on nest temperatures of *C. acutus* (Charruau, 2012). Clutch temperature reaches its maximum during the night and its minimum during the day while environmental temperature reaches its maximum and minimum during the day and night, respectively. Environmental temperatures were lower than nests temperatures (Table 2). Mean incubation temperatures range from 29.1 °C to 33.4 °C with 24.7 °C and 36.9 °C as extreme temperatures (Table 2). These mean temperature data are within the range of temperature reported for nests of *C. acutus* in the region (Charruau, 2012) and within the survival range of temperature determined for *C. acutus* embryos (Charruau et al., 2017). On the other hand, incubation temperature seems to reach low and high potential lethal temperatures for *C. acutus* embryos (< 28.5 °C and > 34.5 °C; Charruau et al., 2017) at some moments of the incubation. However, all the nests were successful. This can be explained by the fact that embryos can survive extreme conditions during several hours (Ferguson, 1985) and in our case they experienced the extreme temperatures only during a short period and not constantly. Furthermore, the sex of *C. acutus* is determined by the incubation temperature and the range of temperature recorded in this study suggest the production of both sexes (Charruau et al., 2017).

Table 2. Clutch and environmental temperature (Temp., °C) of *Crocodylus acutus* at Yum Balam protected area, Quintana Roo, Mexico. SD: Standard deviation.

Nest	Clutch Temp.		Environmental Temp.	
	Mean ± SD	Range	Mean ± SD	Range
YB1_12	29.1 ± 1.1	24.5-36.7	28.1 ± 4.3	21.6-42.1
YB1_13	33.4 ± 1.8	29.1-36.9	28.0 ± 3.7	19.3-39.4
YB2_13	31.6 ± 2.1	24.7-36.6	-	-
YB5_13	29.6 ± 1.6	25.0-33.4	-	-

We determined the real hatching date of one nest in 2012 (21 June) and of three nests in 2013 (18 May, 28 June and 29 June). Two hatched in the morning between 6:30 and 7:30 and 11:06 and 11:20, and the other two at night between 00:30 and 1:00 and 22:30 and 23:00, indicating that hatching mainly occur at night and early in the morning, as reported by Charruau and Hénaut (2012) for this species. Hatching occur from mid-May to early-July, similar but slightly earlier to the hatching period reported for the species in the region (Platt and Thorbjarnarson, 2000; Charruau et al., 2010, 2011). Furthermore, observations of hatched nests allow to suggest that females help hatchlings to emerge from the nest as previously observed by Charruau and Hénaut (2012).

CONCLUSIONS

The nesting parameters of *Crocodylus acutus* found in this study suggest a good reproductive status of the species in the Protected Area of Flora and Fauna of Yum Balam. However, it is necessary to carry out more reproductive studies of the American crocodile along the coast of Quintana Roo. This would give us an idea of the general reproductive status of the species in the region and identify the priority sites that require conservation strategies.

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