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# Relative Abundance and Habitat Preference in Isolated Populations of Morelet's Crocodile (*Crocodylus moreletii*) Along the Coast of the Gulf of Mexico

*Alejandro Villegas*[1,2] *and Víctor H. Reynoso*[2]

[1]*Departamento de Etología, Fauna Silvestre y Animales de Laboratorio, Facultad de Medicina Veterinaria y Zootecnia, Universidad Nacional Autónoma de México, C.P. 04510, México, D.F., e-mail: alejandrovillegasmx@yahoo.com*
[2]*Departamento de Zoología, Instituto de Biología, Universidad Nacional Autónoma de México, C.P. 04510, México, D.F.*

***Abstract*.—Recently CITES removed the Morelet's Crocodile (*Crocodylus moreletii*) from Appendix I to II based on a range-wide population viability analysis. The Comisión Nacional para el Conocimiento y Uso de la Biodiversidad in Mexico is coordinating monitoring surveys to support that status change. However, more population studies on *C. moreletii* are needed to accurately assess its conservation status. We recorded the abundance and habitat preference of *C. moreletii* in Veracruz and Tamaulipas, Mexico. In Veracruz we obtained an encounter rate of 5.2 crocodiles/km along 8 km of waterway in 2008 and 5.5 crocodiles/km along 10 km of waterway in 2009. In Tamaulipas, we recorded a wide variation in crocodile encounter rates from 2010 to 2012, ranging from 0.4 crocodiles/km in Laguna Champayán to 27.5 crocodiles/km in Laguna del Carpintero. Through 2011 to 2012, we found differences in the population size-class structure in Tamaulipas lagoon complex only ($t = 2.86$, df = 4, $P < 0.05$). In Veracruz, juveniles had a higher preference for aquatic vegetation habitats ($\chi^2 = 61.3$, df = 4, $P < 0.05$), whereas in Tamaulipas juvenile crocodiles preferred wooded habitats ($\chi^2 = 72$, df = 4, $P < 0.05$). Only in Veracruz were crocodile sex ratios strongly male biased (1:3.5; $\chi^2 = 73.3$, df = 1, $P < 0.05$). Population isolation and habitat fragmentation are factors that impact the crocodile population size and size class structure in these two regions. Continuous monitoring will be needed to detect significant changes in Morelet's Crocodile populations in Veracruz and Tamaulipas over time.**

*Key Words.*—CONABIO; encounter rate; monitoring; population structure; sex ratios

## Introduction

Morelet's Crocodile, *Crocodylus moreletii*, is found in the Atlantic and Caribbean lowlands of Mexico, Guatemala, and Belize (Ross 1998). This species is mainly found in freshwater wetlands of the Yucatan Peninsula and the Gulf of Mexico plains (Lazcano-Barrero 1990). In 1970, the Secretaría de Industria y Comercio issued a decree to protect crocodiles from commercial hunting after they were almost exterminated in Mexico (Mendez de la Cruz and Casas-Andreu 1992). Currently, this species is listed in the NOM-059-ECOL-2010 as a special protection species (Diario Oficial 2010). However, a recent revision of the Convention on International Trade in Endangered Species of Flora and Fauna (CITES) removed it from Appendix I to Appendix II based on a range-wide population viability analysis (CONABIO 2010), and the US Fish and Wildlife Service (2012) eased restrictions on *C. morelettii* trade to the United States based on the same information. The IUCN Red List categories, based on a large survey data from Belize and more than 40 localities around the Gulf of Mexico, listed *C. moreletii* in the category of low risk of extinction, but conservation dependent (Ross 2000).

Studies on Mexican populations of *C. moreletii* have gradually increased, but more are needed to accurately assess its conservation status. Determining the distribution and abundance of a crocodile population is usually the first step towards establishing baseline information for conservation and management programs (Bayliss 1987). In Lago de Catemaco, Veracruz, up to 200 crocodiles were reported by Campbell (1972), and Pérez-Higareda (1979) mentioned areas with viable populations in Los Tuxtlas region. Additional data of *C. moreletii* nesting in Los Tuxtlas suggest this population is vulnerable (Villegas et al. in press) due to a high incidence of nest flooding and egg predation. Few published studies are available for southern Tamaulipas, but technical reports of Carrera (unpubl. reports) and Domínguez-Laso (2005) provide relative crocodile densities from surveys in several localities. The IUCN-Crocodile Specialist Group agreed that population surveys are a priority in all countries where *C. moreletii* occurs (Thorbjarnarson 1992; Ross 1998) and now the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) in Mexico is coordinating monitoring surveys to support the CITES status

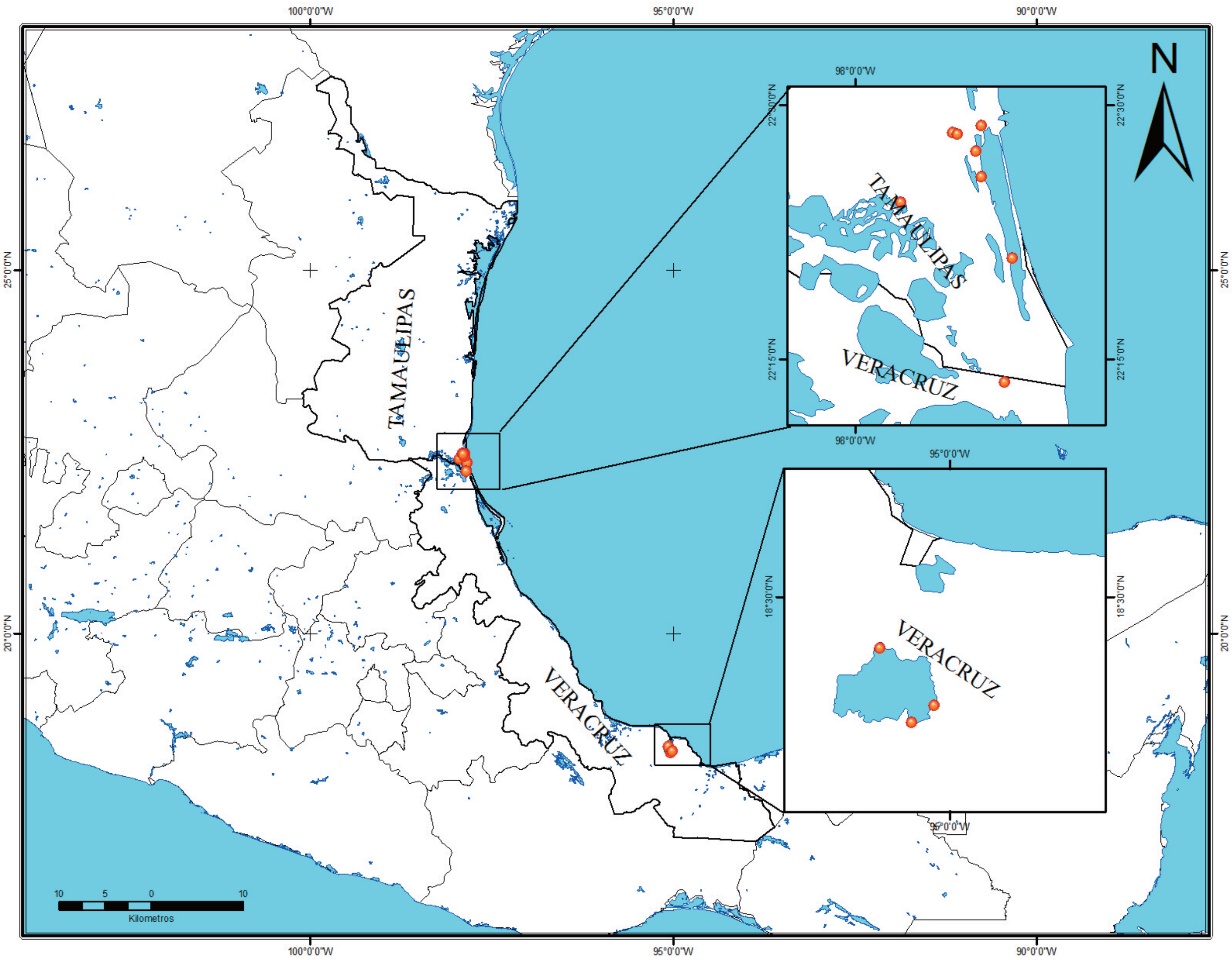


**Figure 1**. Areas in Tamaulipas and Veracruz, Mexico where Morelet's Crocodiles (*Crocodylus moreletii*) were surveyed 2008–2012.

change. In this study, we evaluated the size of two non-hybrid *C. moreletii* populations along the Gulf of Mexico (González-Trujillo et al. 2012) and assessed their habitat preferences.

## Materials and Methods

**Study areas**.—Lago de Catemaco (Fig. 1), comprising an area of 7,254 ha, is located within Los Tuxtlas Biosphere Reserve in Veracruz (18° 26′ 46″ N and 95° 04′ 06″ W; elevation 340 m). The average annual rainfall exceeds 2,000 mm/year and the annual average temperature is 24.1° C, with variations between 16.2 and 34.3° C. From October to April cold prevailing winds (called "Nortes") cause superficial water circulation (Diario Oficial 2007). The Tamesí wetland complex in southern Tamaulipas (Fig. 1) is part of the hydrological priority region Cenotes de Aldama listed by CONABIO (23° 22′ 48″–22° 16′ 48″ N; 98° 26′ 24″–97° 45′ 36″ W; elevation 0–30 m). There the average rainfall is 700 mm/year, most of which falls from June through August (Salinas et al. 2002), with an average annual temperature ranging from 22 to 26° C. Laguna del Carpintero (80 ha, 2,000 m long), located in Tampico City completely surrounded by urban development, connects to Río Pánuco through Canal de la Cortadura. We surveyed the following wetlands within Tamesí complex: Puente Nuevo Madero (22° 20′ 59.8″ N, 97° 50′ 45.3″ W); Contadero (22° 20′ 30.1″ N, 97° 50′ 16.2″ W); Laguna Petrochén (22° 28′ 24.2″ N, 97° 54′ 32.1″ W); Estero Garrapatas I (22° 28′ 48.8″ N, 97° 54′ 18.8″ W); Cañón de Perros (22° 25′ 46.1″ N, 97° 52′ 33.7″ W); Laguna del Carpintero (22° 13′ 41.6″ N, 97° 51′ 10.7″ W); El Cañón (22° 27′ 38.3″ N, 97° 52′

59.5” W); Estero Garrapatas II (22° 28′ 29.3″ N, 97° 53′ 51.7″ W) and Laguna Champayán (22° 24′ 11.4″ N, 98° 01′ 18.6″ W).

**Field methods**.—We conducted surveys from 2008 to 2012 during the same season (August - September) in all places, excepting those of Tamaulipas where not all routes could be assessed more than once due to restrictions concerning security. We used nocturnal spotlight surveys to census crocodile populations (Messel et al. 1981; Magnusson 1982; Bayliss 1987; O’Brien 1990; King et al. 1994). Surveys were conducted in an aluminum boat with an outboard motor. We traveled before sunset to assess the habitat, and we began nocturnal spotlighting 15 to 30 min after nightfall. We selected localities based on road and boat accessibility. We avoided conducting surveys during periods with calm weather and low water levels according to Woodward and Marion (1978).

We recorded habitat preference where each crocodile was first sighted (Platt and Thorbjarnarson 2000; Cedeño-Vázquez et al. 2006) as follow: (1) Aquatic vegetation: when the lake, creek, or river shoreline was covered with fresh-water emergent and submerged plants (including plant beds and marshes); (2) Rocky: when the lake, creek, or river shoreline was rocky without aquatic vegetation; (3) Wooded: when the lake, creek, or river shore had a high density of trees extending their branches over the water; (4) Human settlement: when the lake, creek, or river shore was associated with any kind of urbanization (e.g. constructions: wharfs, dams, houses, fences, roads, etc.); and (5) Open water: when the crocodile was far away from the wetland shoreline (> 3 m). During surveys, we approached crocodiles as closely as possible and classified them by age groups as follow: juveniles (Total Length, [TL] < 100 cm), subadults (TL = 100–150 cm), adults (TL > 150 cm). When we could not approach crocodiles closely enough to estimate TL, we recorded crocodiles as eyeshine-only (Platt and Thorbjarnarson 2000) and these were included in the census but not in our size class analysis. We used the same observer to collect census data and size estimation in all surveys. We use a wire snare attached to PVC pole to capture crocodiles: this is a common technique and works well when it is possible to approach the animal close enough to place a noose around the neck of the animal (Mazzotti 1983; McDaniel and Hord 1990). We marked animals by clipping tail scutes in a coded pattern (Platt and Thorbjarnarson 2000; Cedeño-Vázquez et al. 2006), and then we released them. To determine the sex of captured crocodiles, except hatchlings, we examined the cloaca (Brazaitis 1968). We established the geo-references of the starting and end points of each survey with a handheld Global Positioning System (GPS) Garmin GPSIII PLUS® (Garmin International Inc., Olathe, Kansas, USA). We estimated the survey route based on the midstream in linear habitats such as rivers, creeks, and shorelines (King et al. 1990).

**Analyses**.—We used encounter rates as an estimate of relative abundance. We calculated encounter rates as the number of crocodiles observed per kilometer. This encounter rate provided an index of relative density because not all crocodiles present in the area are observed during a survey; however, the relationship between the encounter rate and actual population size is assumed to remain constant over time, and any change in the encounter rate should reflect a proportionate change in the total population (Bayliss 1987). We calculated sighting fractions based on the method by Messel et al. (1981). This method assumes that the number of crocodiles observed represents a sighting fraction of a population because there are a number of crocodiles that will not be seen (Cherkiss et al. 2006). Because sighting fractions likely are different along different survey routes (suggesting the probability of sighting a crocodile differs because of some environmental factor), we compared encounter rates adjusted for similar habitats (instead of comparing unadjusted encounter rates from different routes). In other words, we calculated the number of additional crocodiles the sighting fraction suggests were missed and added these to the encounter rate, and then compared between sites. Relative indices are powerful when survey techniques are standardized (Bayliss 1987).

We used a chi-square goodness of fit test ($P < 0.05$) to compare size-class distributions within each habitat against a null model of equal distribution; it was assumed that all size classes were equally detectable (Messel et al. 1981; Thorbjarnarson 1988). We compared population size class structure among localities and years using a *t*-test, results were considered significant

**Table 1**. Location and year of survey, distance surveyed, and encounter rates of Morelet's Crocodile (*Crocodylus moreletii*) in Veracruz and Tamaulipas, Mexico, 2008–2012.

| Area | Location | Year | Distance surveyed (km) | Encounter rate (crocodiles/km) |
|---|---|---|---|---|
| Veracruz | Lago de Catemaco (north) | 2008 | 8 | 5.2 |
| | | 2009 | 10 | 5.5 |
| | Lago de Catemaco (south) | 2009 | 6 | 3.4 |
| Tamaulipas | Laguna Champayán[a,b] | 2010, 2012 | 13 | 0.4 |
| | Laguna del Carpintero | 2011 | 2 | 27.5 |
| | | 2012 | 2 | 8.8 |
| | Estero Garrapatas II[ab] | 2011, 2012 | 6 | 4.6 |
| | Puente Nuevo Madero[a] | 2010 | 2 | 2.5 |
| | Contadero[a] | 2010 | 5 | 2.8 |
| | Laguna Petrochén[b] | 2010 | 8 | 1.2 |
| | Estero Garrapatas I[c] | 2010 | 7 | 0.7 |
| | Cañón de Perros[c] | 2010 | 8 | 2.1 |
| | El Cañón[a] | 2011 | 1 | 3 |

[a]creeks, [b]shallow lake, [c]river

at $P < 0.05$. We also used a chi-square on sex ratios to test for a significant departure from the expected ratio of one male to one female ($P < 0.05$; Lance et al. 2000).

## Results

We recorded 201 crocodiles: the adjusted encounter rates in Veracruz ranged from 5.2 to 5.5 crocodiles/km in 2008 and 2009, respectively, in the northern portion of Lago de Catemaco. In the southern portion, we only carried out one set of surveys during 2009, and the adjusted encounter rate estimated was 3.4 crocodiles/km. In Tamaulipas, we surveyed several localities 2010–2012, and the adjusted encounter rates ranged from 0.4 crocodiles/km at Laguna Champayán to 27.5 crocodiles/km in Laguna del Carpintero (Table 1). Encounter rates for other localities were not adjusted because the surveys could not be replicated and the sighting fraction was not obtained (Table 1). However, data were different along the survey routes and in these routes we had low encounter rates of crocodiles.

Regarding population structure in Veracruz, during 2008, we found 16 crocodiles and captured 15, and we found many adults (64%) and few subadults (7%). In 2009 we found a high percentage of juveniles (47%) and only 21% were subadults (Fig. 2). In Tamaulipas, during three years, the percentage of juveniles from 17% to 37%, subadults from 23% to 44%, and adults from 31% to 39 (Fig. 2). There were no significant differences in population structure between the two years of surveys in Veracruz ($t$ = -0.98, df = 2, $P$ = 0.43). In Tamaulipas, there were no significant differences in population structure from 2010 to 2011 ($t$ = -0.66, df = 4, $P$ = 0.54), but population structure from 2011 to 2012 did differ significantly ($t$ = 2.86, df = 4, $P$ = 0.04).

We found differences in the habitat preference in some categories: juvenile and adult crocodiles of Lago de Catemaco prefer aquatic vegetation ($\chi^2$ = 61.3, df = 4, $P < 0.05$), while subadults were evenly distributed, which indicates this later size-class is equally distributed in all habitats surveyed (Table 2). In contrast, juvenile crocodiles of Tamaulipas preferred wooded habitats ($\chi^2$ = 72, df = 4, $P < 0.05$); although numerically aquatic vegetation seems to also be important in this area (Table 2). A general analysis of both areas including all size-categories showed the crocodile preference for aquatic vegetation and wooded habitats is similar (Table 3), with subadults and adults crocodiles preferring the open water habitat. Juveniles have

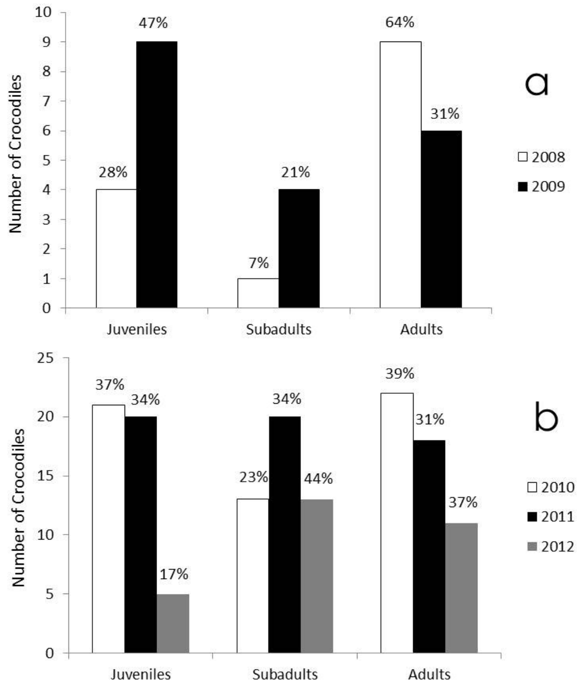


**FIGURE 2**. Population structure by year of Morelet's Crocodiles (*Crocodylus moreletii*) observed in Veracruz (a) and Tamaulipas (b), Mexico. Percentages above columns are rounded to whole numbers.

an evident preference for aquatic vegetation, whereas subadults prefer wooded habitats and adults prefer both aquatic vegetation and wooded habitats. We determined the sex of 50 of 51 crocodiles we captured. Only the Veracruz population departed from an even sex ratio and was male biased (Veracruz: 1:3.5; $\chi^2 = 73.3$, df = 1, $P < 0.05$; Tamaulipas: 1:1.8; $\chi^2 = 11.0$, df = 1, $P > 0.05$).

## DISCUSSION

Our data indicate a crocodile population reduction in the northern portion of Lago de Catemaco when they are compared to data reported by Campbell (1972) for the same area. Campell estimated that there were more than 200 crocodiles in the lake, between Arroyo Agrio and Río Quetzalapan, although his observations were limited. Even though the estimate of population size by Campbell is questionable, we think there has been a real reduction in size of the crocodile population in Lago de Catemaco because during our surveys in 2008 and 2009 we recorded < 50% of the number of crocodiles found earlier.

Pérez-Higareda (1979) mentioned that Río Quetzalapan also is an important refuge for crocodiles; however, during our study we did not observe any crocodiles in this area. The environment in the region largely has been converted into grazing land and no original vegetation remains on the riverbanks. Three kilometers south of Río Quetzalapan is another area with a large population of crocodiles. We found the lowest encounter rate at this site. The remaining native vegetation at this site seems to be important to the survival of crocodiles. The original vegetation still remains in both zones of the lake, at which we encountered many crocodiles. González-Trujillo et al. (2012) in a

**TABLE 2.** Frequency of Morelet's Crocodile (*Crocodylus moreletii*) associated with different habitats. Chi-square ($\chi^2$) values tested differences in frequency of habitat use by size classes from available use (*$P < 0.05$).

| | | Aquatic vegetation | Rocky | Wooded | Open water | Human settlement | $\chi^2$ |
|---|---|---|---|---|---|---|---|
| Veracruz | | | | | | | |
| | juveniles | 21 | 0 | 2 | 0 | 3 | 61.3* |
| | subadults | 1 | 1 | 1 | 1 | 1 | 0 |
| | adults | 8 | 3 | 1 | 1 | 2 | 11.3* |
| Tamaulipas | | | | | | | |
| | juveniles | 17 | 1 | 31 | 0 | 2 | 72.0* |
| | subadults | 12 | 1 | 23 | 4 | 2 | 40.6* |
| | adults | 17 | 0 | 19 | 12 | 3 | 27.7* |

**Table 3.** Overall frequency of Morelet's Crocodile (*Crocodylus moreletii*) in different habitats combining all years and all surveys. Chi-square ($\chi^2$) values tested differences in frequency of habitat use by size classes from available use (*$P < 0.05$).

| | Aquatic vegetation | Rocky | Wooded | Open water | Human settlement | $\chi^2$ |
|---|---|---|---|---|---|---|
| all classes | 76 | 6 | 77 | 19 | 13 | 130.2* |
| juveniles | 38 | 1 | 33 | 0 | 5 | 89.1* |
| subadults | 13 | 2 | 24 | 5 | 3 | 36.2* |
| adults | 25 | 3 | 20 | 14 | 5 | 26.6* |

detailed landscape analysis of crocodile lakes and surroundings concluded that wooded vegetation is extremely important as foraging and nesting habitat, and essential for maintaining a viable crocodile population. The lake shore and creeks in these two areas are inaccessible to humans and provide effective protection for crocodiles. However, we also found crocodile nests destroyed by people in both areas, and eggs were destroyed or taken. This activity no doubt has a negative effect on the crocodile population.

In Tamaulipas, encounter rates varied in all surveyed water bodies. Domínguez-Laso (2005) reported 17 crocodiles in a single survey in Laguna Champayán with data reported as the mean number of crocodile sightings. In Laguna del Carpintero, Manuel Carrera (unpubl. report) estimated an encounter rate of 57.4 crocodiles/km in 2003. This encounter rate is higher than our data for a one year survey, but Carrera included hatchlings in his estimate. The difference with our estimate may be due to the high density of mangrove and shallow water in the northern portion of the lagoon, making it difficult for us to access this habitat but good for crocodiles to take refuge during surveys. This has been demonstrated in many studies reporting crocodiles preferred wetlands where dense shoreline vegetation consisted of either aquatic and/or wooded habitat (Cedeño-Vázquez et al. 2006; Villegas and Schmitter-Soto 2008).

The population structure varied each year in both surveyed regions, but generally we found high numbers of juveniles and adults. These data differ from findings of others who have worked in Yucatan Peninsula: Cedeño-Vázquez et al. (2006) reported subadults as the most abundant size class, Leyte-Manrique and Ramírez-Bautista (2005) recorded hatchlings as the most abundant size class, and Cedeño-Vázquez and Pérez-Rivera (2010) found high numbers of adults and low numbers of hatchlings. At Lago de Catemaco, our data indicate a typical critical transition from hatchling to juvenile with low survival, even among robust populations of crocodilians, showing a Type III survivorship curve (Arribalzaga 2007), with high mortality of juveniles but low mortality for crocodiles making it to the adult size class (Congdon and Gibbons 1990). Other authors (Messel et al. 1981; Mazzotti 1983; Thorbjarnarson 1988; Sasa and Cháves 1992) suggest the low number of subadults in most crocodilian population studies are an effect of several factors: (1) their evasive behavior (Kushlan and Mazzotti 1986); (2) preference of marginal areas to avoid encounters with larger crocodiles (Lang 1987); (3) higher mortality rates during the juvenile-subadult transition (Thorbjarnarson1988; Sasa and Cháves 1992); and (4) the relatively short juvenile stage (Kushlan and Mazzotti 1986; Cedeño-Vázquez 1995). Villegas et al. (in press) indicate that nesting success in our area is low due to the severe flooding. If true, we can expect in subsequent surveys the proportion of juveniles and subadults will be lower compared with data reported in this study.

All crocodile size classes prefer aquatic vegetation and wooded habitats, but it seems to be that juveniles are more dependent on these habitats probably because of the foraging opportunities and escape cover afforded by this dense vegetation. We observed a great concentration of crocodiles in the northern and southern portion of Lago de Catemaco. In the northern zone of the lake, there is a tributary mineral water spring called Arroyo Agrio, while in the southern portion there is a small river that flows into the lake: both promote dense vegetation that provides refuge for crocodiles.

We found some nests in Arroyo Agrio, clearly suggesting that vegetated sites are important for crocodile population survival. Villegas et al. (in press) reported the importance of emerging vegetation and the shoreline in the Lago de Catemaco as nesting site for this species. Also, *C. moreletii* in Belize use areas with abundant vegetation (*Typha* and *Cladium*) for nests construction (Platt et al. 2008). Cherkiss et al. (2006) found that *C. acutus* juveniles are usually found in the shore vegetation and Cedeño-Vazquez and Pérez-Rivera (2010) suggested shoreline vegetation serves as nursery habitat offering greater protection to the most vulnerable life stages. Adult crocodiles are often found in aquatic and wooded vegetation areas, as well as cleared sites, demonstrating their ability to use habitats irrespective of vegetation cover.

At both sites we found crocodiles associated with human settlements. These areas lacked much vegetation cover and buildings were present. The availability of food (dogs, cats, and poultry) probably attracts crocodiles to these areas. López-Luna et al. (2010) found nests of *C. moreletti* in disturbed areas in Tabasco, southern México, suggesting that crocodiles are increasingly tolerant of human presence. The lack of suitable habitat in these areas has driven some crocodile individuals to establish near human settlements becoming more tolerant of human activity. In Tamaulipas lagoon complex, we suspect that habitat fragmentation is caused mainly by roads and crocodile populations become fragmented, which has a negative effect on adult migration between sites. Isolation and habitat fragmentation can impact crocodile populations by decreasing gene flow and promoting endogamy. We think it is necessary to continue long-term monitoring to detect significant changes in population patterns. On the other hand, our study shows a strong bias towards males, unlike previous studies of *C. moreletti* in Yucatan Peninsula (Domínguez-Laso 2002; Cedeño-Vázquez and Pérez-Rivera 2010) where a balanced ratio of sexes was reported, although other studies have recorded a male biased sex ratio in Quintana Roo (Cedeño-Vázquez et al. 2006) and Belize (Platt and Thorbjarnarson 2000; Platt et al. 2008). Biased sex ratios may be an effect of direct action of human predation or killing when females are more vulnerable during nesting season, when they become more aggressive and intolerant to nest invasions. Platt et al. (2008) argued the ultimate cause of the strongly male-biased sex ratio among *C. moreletii* in Belize has yet to be determined; it is much more likely the skewed sex ratios are the result of incubation conditions or rapid growth of males compared to females. Biased female sex ratios in crocodilians are associated with temperature dependent sex (TDS) determination and pivotal temperatures are quite narrow in some species (Hulin et al. 2009). However, warming may increase viability in sex-skewed populations when elevated temperatures approximate the thermal range that produces even sex proportion (Escobedo-Galván et al. 2011). Hence, male- or female-biased populations are often found, but sex ratio varies year-to-year depending on local climatic conditions across species' ranges (Lance et al. 2000, Wapstra et al. 2009).

In general, based on our study, we can say that populations of *C. moreletii* in both regions do not show a clear recovery trend as CONABIO (2010) has argued. In Veracruz, there is a severe problem of habitat loss; modification of the original vegetation is a key factor that affects the crocodile population. Campbell (1972) indicated that Lago de Catemaco should be considered as a sanctuary of crocodiles and therefore this area should be protected. Currently, it is necessary to protect both important nesting areas in the lake to ensure the local survival of this species. This population of *C. moreletii* is the last viable population of crocodiles in Los Tuxtlas region (Villegas et al. in press). Establishment of conservation strategies is necessary to obtain real data about trends of crocodile populations. Lago de Catemaco is currently included in the survey program of CONABIO to obtain information of encounter rates in areas of Mexico where they think this crocodile is abundant to support the change in the CITES Appendix. Lago de Catemaco is a "closed system" with an important concentration of crocodiles, where if the surveys routes are well defined, at the end of the monitoring program clear data should show the trends of this population. The surveys carried out in Tamaulipas are complicated. The complex lacustrine system is interconnected by rivers, floodplains, swamps, and creeks, with most of habitats inaccessible due to dense vegetation or because they are within a zone considered of high risk due to human conflicts in the area affecting Tamaulipas during the last years. We suggest, considering that only small portions of the Tamesí basin are surveyed by CONABIO, that estimations of encounter rates are not representatives of all crocodile populations of the region, and therefore, should not be extrapolated to the whole range of the species. We think this could mask the most vulnerable populations of *C. moreletti*.

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**Alejandro Villegas** is a Research Biologist; he is currently in a Postdoctoral Fellow in the Facultad de Medicina Veterinaria y Zootecnia at the Universidad Nacional Autónoma de México. He received his Ph.D. in Biological Sciences at the Universidad Autónoma Metropolitana in Mexico City (2011) and his M.Sc. in Management of Natural Resources (2006) from El Colegio de la Frontera Sur, Mexico. He is especially interested in ecology, conservation, and genetics of Crocodylia. (Photographed by Ingrid Ramírez).

**Víctor H. Reynoso** is a Titular Researcher at Instituto de Biología, Universidad Nacional Autónoma de México. He received his M.Sc. in Animal Biology at Facultad de Ciencias, Universidad Nacional Autónoma de México (1993) and his Ph.D. in Biology at McGill University, Canada in 1998. His research focuses on the evolution, systematics, ecology, and conservation of amphibians and reptiles. (Photographed by Alejandro Villegas).