

Factors influencing the occurrence of negative interactions between people and crocodilians in Mexico

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Abstract Negative interactions between people and crocodilians have increased worldwide, but in Mexico there have been few systematic reports and no rigorous evaluation of this problem. We compiled information on negative interactions between people and the spectacled caiman *Caiman crocodilus* and American crocodile *Crocodylus acutus* from the Worldwide Crocodilian Attack Database for 1993–2018, and we investigated interactions in greater depth, through interviews with people in La Encrucijada Biosphere Reserve. We examined the relationship between the occurrence of negative interactions between people and *C. acutus* and the species' nesting season and abundance, and presence records. In Mexico, the frequency of negative interactions increases when anthropogenic activities occur close to nesting sites (< 30 km) and during the nesting season (February–September). In La Encrucijada, following negative interactions with crocodiles, the local inhabitants killed 30 crocodiles measuring > 2.5 m long in 2011–2012. The frequency of negative human–crocodilian interactions was not correlated with the abundance of crocodilians but was correlated with the number of presence records of crocodiles. Strategies to minimize these interactions include warnings at nesting sites, increased monitoring of anthropogenic activities during the nesting season, and management of nests to prevent them being destroyed by people.

Keywords *Caiman crocodilus*, crocodile, *Crocodylus acutus*, human activities, human–crocodile conflict, Mexico, nesting, relative abundance

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Introduction

Of the 24 species of crocodilians (Uetz et al., 2016), one species of the family Alligatoridae, the spectacled caiman *Caiman crocodilus*, and two species of the family Crocodylidae, the American crocodile *Crocodylus acutus* and Morelet's crocodile *Crocodylus moreletii* occur in Mexico. On the IUCN Red List *C. crocodilus* and *C. moreletii* are categorized as Least Concern and *C. acutus* as Vulnerable (Cedeño-Vázquez et al., 2012; Ponce-Campos et al., 2012; Balaguera-Reina & Velasco, 2019), and in Mexico the three species are subject to Special Protection (SEMARNAT, 2010). Populations of *C. acutus* and *C. crocodilus* were severely affected by hunting for their skins until this was permanently banned in the 1970s. Since then the populations of the three species have increased, although in some regions of Mexico they are still exploited (INE-SEMARNAP, 1999; Aguilar-Galindo, 2005).

As a result of this recovery of crocodilian populations, and because of land-use change, flooding, human population growth and feeding of crocodiles by people, negative interactions between people and crocodiles have escalated (García-Grajales, 2013). Crocodile behaviour, such as territorial and self defence, and nest protection by females, exacerbate these negative interactions (Pooley et al., 1989; García-Grajales & Buenrostro-Silva, 2018). In the Americas, *C. acutus* and *C. moreletii* have been involved in a number of fatal incidents, with 2.9 and 0.5 cases/year, respectively (Sideleau, 2015). Such incidents are not, however, always recorded (Aust et al., 2009). Systematic compilation of data on interactions between people and crocodilians is required to identify the potential risks to people from crocodiles, and to avoid retaliatory killings (Caldicott et al., 2005).

In the state of Chiapas in Mexico negative interactions between crocodiles and people could be expected, as all three species occur there, but in the Worldwide Crocodilian Attack Database (CrocBITE, 2018) only four incidents have been recorded in this state, which is probably an underestimate. Here we examine the following questions: (1) Does the frequency of negative human–crocodilian interactions increase during the nesting season? (2) Does the frequency of incidents increase when there is human habitation within nesting areas? (3) Does the frequency of such interactions increase with crocodile abundance, both nationally in

TABLE 1 Records of the relative abundance index of *Crocodylus acutus* in Mexico during 1987–2012, from various sources, and in 2014.

Locality, State	Year	Relative abundance index ¹	Source
Amela lagoon, Colima	(not indicated)	45	Castillo (1996)
Chamela-Cuixmala Biosphere Reserve, Jalisco	1987–2003	20.57	García et al. (2010)
Chiricahueto lagoon, Sinaloa	1996	6.94	León-Ojeda et al. (1997)
La Encrucijada, Biosphere Reserve, Chiapas	1996	2.1 (11.5)	Martínez-Ibarra et al. (1997)
El Verde estuary, Sinaloa	1999–2000	7.7	Navarro-Serment (2001)
Boca Negra estuary, Jalisco	1999–2002	45.4 (0.7)	Huerta (2005)
La Manzanilla estuary, Jalisco	1999–2002	40.9 (2.3)	Huerta (2005)
La Ventanilla estuary, Oaxaca	2000–2001	47.3 (9.7)	Espinosa-Reyes & García-Grajales (2001)
Majahuas estuary, Jalisco	2000–2002	5.2 (4.6)	Huerta (2005)
Boca Negra estuary, Jalisco	2001	18.25 (0.8)	Cupul-Magaña et al. (2002)
Sumidero Canyon National Park, Chiapas	2001	2.8 (15)	Sigler (2010)
Banco Chinchorro Biosphere Reserve, Quintana Roo	2003	6.8	Charruau et al. (2005)
La Palmita lagoon, Oaxaca	2004–2005	6.38 (4.9)	Brandon-Pliego (2007)
San Blas estuary, Nayarit	2005–2007	1.94 (14.8)	Hernández-Hurtado et al. (2011)
El Cajon reservoir, Nayarit	2010–2011	0.67 (15.2)	González (2013)
Majahuas estuary, Jalisco	2010–2015	10.46	Tello (2016)
San Juan lagoon, Jalisco	2010–2015	8.75	Tello (2016)
Palmasola lagoon, Oaxaca	2012	70.1 (0.6)	García-Grajales & Buenroostro-Silva (2014)
La Encrucijada, Biosphere Reserve, Chiapas	2014	1.5 (28)	This study

¹Surveyed km, where known, are given in parentheses.

Mexico and locally in El Hueyate estuary in Chiapas? In addition, we examine the relationship of the number of negative incidents and presence records of *C. acutus* with socio-economic variables.

Methods

Negative interactions with *C. acutus* in Mexico

Monthly records of negative interactions with *C. acutus* in Mexico, with geographical coordinates, were compiled from CrocBITE (2018) for 15 August 1993–8 June 2018. From the coordinates we calculated the Euclidean distances to the nearest nesting site (Casas-Andreu, 2003; Cedillo-Leal et al., 2013; Cupul-Magaña et al., 2004; Valtierra-Azotla, 2007; Charruau et al., 2010; Sigler, 2010; Charruau et al., 2011; Hernández-Hurtado et al., 2011; González-Desales et al., 2016a; Charruau et al., 2017) and to the nearest site for which relative abundance data were available (Table 1), using ArcGis 10.2 (Esri, Redlands, USA). The distance of interactions to nesting sites and the distance of interactions to sites where abundance of *C. acutus* had been evaluated were classified in intervals, based on the Rule of Sturges (Sturges, 1926). Using simple linear regression, we examined the relationships between interaction frequency and proximity to nesting sites, relative abundance of crocodiles, and number of presence records of *C. acutus* up to 18 June 2018, (the latter from GBIF, 2017). A χ^2 test was used to identify any association between interactions and the nesting season of *C. acutus*. We describe six socio-economic characteristics

of Mexican municipalities (INEGI, 2019) with records of negative interactions and the presence of crocodiles: (1) principal economic activity (as primary: agriculture, livestock, forestry, hunting, fishing; secondary: mining, oil and gas extraction, manufacturing, electricity, water supply, construction; services: transport, government, other), (2) education level of males (mean years of study), (3) human population density (inhabitants/km²), (4) number of males in the population, (5) number of economically active males, and (6) municipality area (ha). We focused only on the characteristics of the male population, as negative interactions occur most frequently with them (García-Grajales & Buenroostro-Silva, 2019).

Human–crocodilian interactions in El Hueyate estuary

El Hueyate estuary in the La Encrucijada Biosphere Reserve on the Pacific coast of Chiapas state (Fig. 1) has two core areas (36,216 ha: El Palmarcito and La Encrucijada), and a 108,651 ha buffer zone (INE-SEMARNAP, 1999). Within the Reserve the caiman subspecies *C. crocodilus chiapasius* and *C. acutus* occur in both natural and anthropogenic ecosystems (dams, cattle ponds, fishery ponds and pampas; Sigler, 1996). There are 64 human settlements and 26,992 inhabitants in the Reserve, of which 28.5% do not receive school education of any level; the main economic activities are fishing, agriculture and livestock breeding (INE-SEMARNAP, 1999). Reports indicate there are more crocodilians in the core zone than elsewhere (Sigler & Martínez-Ibarra, 1998; Peña, 2011) and nesting of both

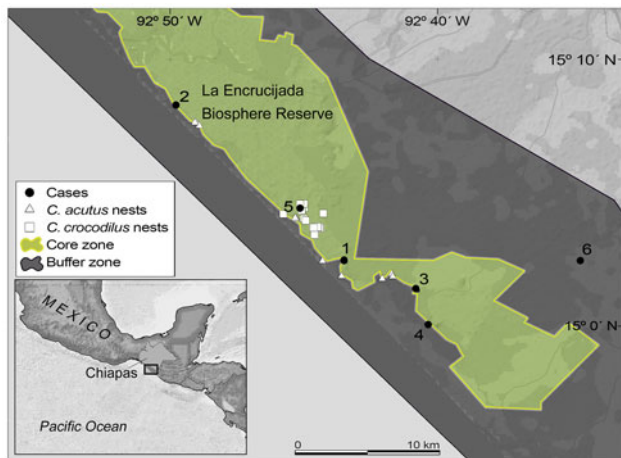


FIG. 1 La Encrucijada Biosphere Reserve, with the locations of the six negative interactions (cases) between people and crocodilians recorded during 2005–2018 (Table 2), five with American crocodiles *Crocodylus acutus* and one (Case 5) with a spectacled caiman *Caiman crocodilus chiapasius*, and nests recorded in 2014. For details of the six cases, see Table 2.

species has been recorded (Sigler & Martínez-Ibarra, 1998; González-Desales et al., 2016a,b), and therefore we examined human–crocodilian interactions and abundance of crocodilians only in the core zone.

During October 2013–September 2014 we conducted unstructured interviews in the principal settlements on the margin of the El Hueyate estuary (Aztlán, Brisas del Hueyate and La Ceiba) with 22 people (five women and 17 men; 22–51 years old), who were either involved in incidents, or relatives of those involved. As the total population in these settlements is 543, (CONABIO, 2014), we interviewed 4% of the total population. We focused on obtaining information about the date and location of any interactions, any actions taken against the crocodilians, activities that people were performing at the time of the incidents, and information from people that witnessed the events. From 2014 onwards we have made 2–3 visits per year to monitor reports of any additional negative interactions. We have knowledge of an incident that occurred in March 2017 but we have not yet been able to interview the family members of the affected person.

The abundance of *C. acutus* and *C. crocodilus chiapasius* was analysed using the Relative Abundance Index $R_{sp}/\text{travelled distance}$, where R_{sp} is the number of records of each species and $\text{travelled distance}$ is the total number of km travelled during monitoring (Sigler et al., 2011). We obtained relative abundance data of both crocodilians from literature (Martínez-Ibarra et al., 1997; Sigler & Martínez-Ibarra, 1998; Peña, 2011) and our fieldwork in 2014. In El Hueyate estuary we conducted 24 surveys during March–October 2014 during the nesting season of *C. acutus* and *C. crocodilus chiapasius*. The surveys were performed from a 6 m boat with a 15 HP outboard motor, using a 19

LED white light to search for the brightness of crocodilian eyes by projecting the light beam between the boat and the mangroves (Chabreck, 1966). When we located eye-shine we decreased speed and slowly headed towards the individual, to identify it (differentiation of the species was by the presence of bony crests and ossified inter-orbital bridge in the case of *C. crocodilus*, and the absence of these characteristics in *C. acutus*). The 28 km of the El Hueyate estuary monitored were the same stretch of the estuary surveyed in earlier studies (Martínez-Ibarra et al., 1997; Sigler & Martínez-Ibarra, 1998; Peña, 2011).

Results

Negative interactions with *C. acutus* in Mexico

CrocBITE (2018) contains 121 records of negative interactions between people and *C. acutus* in Mexico during 15 August 1993–8 June 2018, and no reports of interactions with *C. crocodilus chiapasius*. Of the 121 records only 117 included geographical location. There was a significant negative relationship between the frequency of interactions and distance to the nearest nesting site ($r = -0.76$; $P < 0.05$); i.e. there were more interactions closer to nesting sites. There was also a significant relationship between the number of negative interactions and presence records of *C. acutus* ($r = 0.92$; $P < 0.05$). There was no significant relationship between the frequency of negative interactions and the relative abundance of *C. acutus* ($r = -0.49$, $P > 0.05$). With respect to the date of incidents, there were significantly more negative interactions during the nesting season than at other times ($\chi^2 = 22.87$, $df = 1$, $P < 0.001$; Fig. 2). Regarding the socio-economic characteristics of the 70 municipalities where there were negative interactions or presence records, the economic activity ‘services’ was the most common in municipalities where interactions (24 municipalities) and sightings occurred (34 municipalities), human population density was lower in municipalities with negative interactions (mean $0.9 \pm \text{SD } 1.1$ inhabitants/km²), and in municipalities with negative interactions 57.1% of the adult male population (15–64 years old) had a mean of $7.4 \pm \text{SD } 1.2$ years of education.

Human–crocodilian interactions in El Hueyate estuary

We obtained data on the relative abundance of *C. acutus* in El Hueyate estuary for 1997, 1998, 2002 and 2008–2010, with 1.14–7.11 individuals per km, and for *C. crocodilus chiapasius* for 2002 and 2008–2010, with 0–2.42 individuals per km (Fig. 3a). The relative abundance index calculated for our fieldwork in 2014 was 1.5 *C. acutus* per km and 2.71 *C. crocodilus chiapasius* per km.

We obtained information on six negative interactions between people and crocodilians in El Hueyate estuary

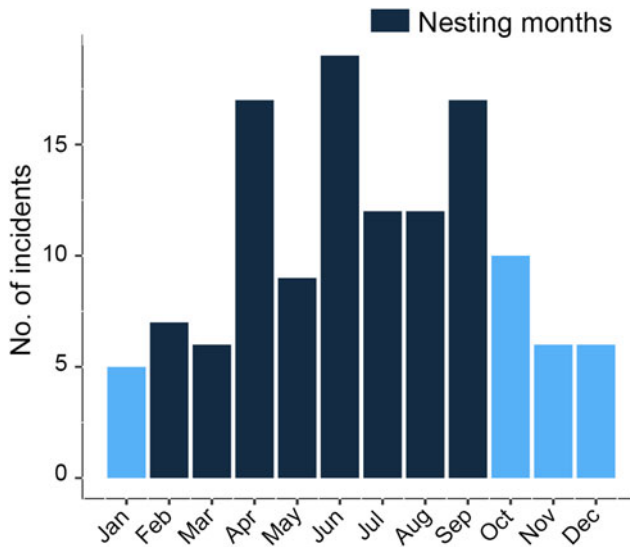


FIG. 2 Negative interactions by month involving *C. acutus* in Mexico, showing that the incidents are more frequent in nesting season.

during 2005–2014 (Fig. 3b). Two of the incidents were fatal, two resulted in major injury (limb loss or permanent motor impairment) and two resulted in minor injury. Five of the incidents involved *C. acutus* and one *C. crocodylus chiapasius* (Table 2).

According to the interviewees, incidents between crocodiles and domestic animals (mainly dogs) and livestock (cattle and pigs) are common in the area. Following negative interactions with crocodiles, 30 adult crocodiles were hunted by the inhabitants of the three settlements during 2011–2012. Five of the six negative interactions recorded occurred close to nesting sites (Table 2), where we observed 34 nests of *C. acutus* and 19 of *C. crocodylus chiapasius* in 2014 (Fig. 1; González-Desales et al., 2016a,b).

Discussion

As far as we are aware, this study is the first analysis of the potential causes of the negative interactions between people and *C. acutus* in Mexico, and the first standardized report of populations trends of *C. crocodylus chiapasius* and *C. acutus* in a coastal region of Chiapas. For *Crocodylus porosus*, in Australia and Sri Lanka, abundance and protection of the nest by females are the main factors that increase the probability of negative interactions with people (Caldicott et al., 2005; Amarasinghe et al., 2015). Our study suggests, however, that the abundance of *C. acutus* does not influence the frequency of incidents in Mexico.

The survey method used for the calculation of the relative abundance index is potentially subject to biases (García-Grajales et al., 2007) and therefore the lower relative abundance we detected in La Encrucijada in 2014 cannot necessarily be attributed to the illegal killing of crocodiles.

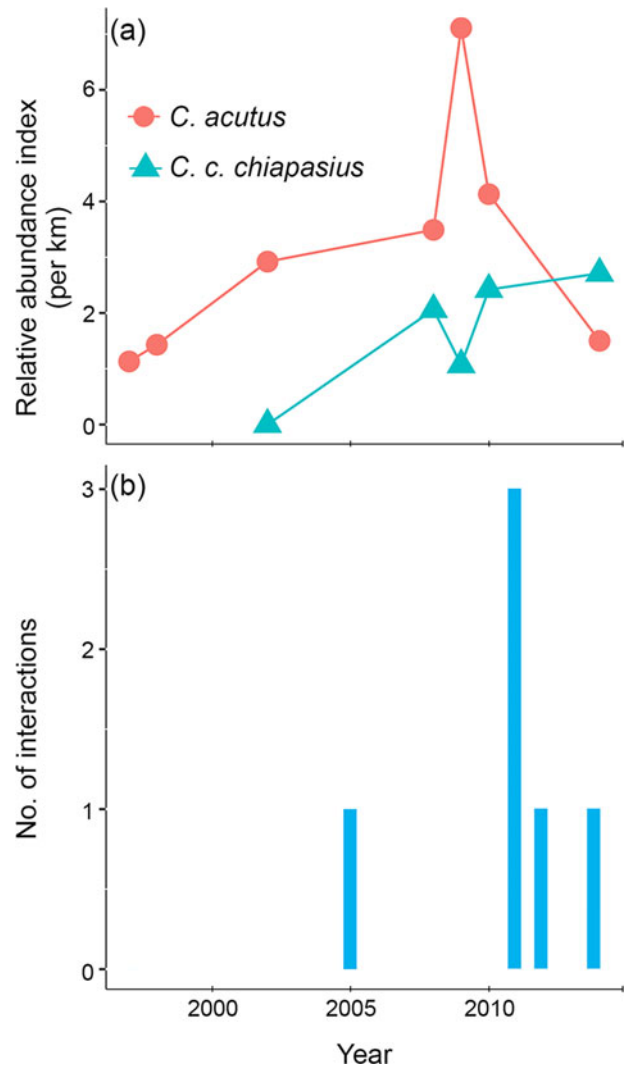


FIG. 3 (a) Relative abundance index (crocodilians observed per km, during 1997–2014) of *C. acutus* and *C. crocodylus chiapasius*, and (b) the number of negative human–crocodilian interactions per year (during 2005–2018), in El Hueyate estuary, La Encrucijada Biosphere Reserve, Mexico.

However, with illegal killings as high as 30 individual crocodiles per incident (according to the people we interviewed), such killings would be expected to affect abundance, especially if any of the crocodiles killed are reproductive females. A similar situation occurs in other regions of Mexico. Hernández-Hurtado et al. (2006) reported 11 negative incidents during 1993–2004 in the Western Pacific region, following which 155 crocodiles were hunted, injured or captured, of which 40 were hunted in Manzanilla, Jalisco. The illegal killing of crocodiles has been reported elsewhere after negative interactions, such as with *C. porosus* in Sri Lanka (Amarasinghe et al., 2015).

Following negative interactions between *C. acutus* and people in La Encrucijada, there was an apparent decrease in abundance of the species, to a level similar to that recorded when protection of the species began in this

TABLE 2 Incidents of negative interactions with crocodilians during 2005–2018 in El Hueyate estuary and nearby areas. Case five was with a spectacled caiman *Caiman crocodilus chiapasius* and the other cases were with American crocodiles *Crocodylus acutus*.

Case	Month & year	Age (years)	Occupation	Activity	Distance incident–nest (km)	Actions following incident	Consequences of incident for the affected person	Length of crocodilian (m)	Actions against crocodilians
1	2005	42	Fisher	Unknown	0.03	Search by local authorities & relatives located clothing & it was concluded he was killed by crocodiles	Fatal	Unknown	None
2	April 2011	21	Student, fisher	Swimming in the estuary	1.72	Medical & psychological attention	Non-fatal, loss of right arm	3.7	Killing crocodiles until missing arm located
3	February 2011	35	Fisher	Preparing a bird on the estuary bank	0.01	Medical attention	Non-fatal, scars on abdomen	2.5	None
4	2011	32	Fisher	Fishing at the estuary shore	1.93	Medical attention	Non-fatal, lesions on the foot & difficulty with walking	2.5	Killing crocodiles ≥ 2.5 m long
5	May 2012	44	Fisher	Cast netting in swampy areas	0.12	Medical attention	Non-fatal, scars on right foot & left hand	1.5	None
6	June 2014	46	Unknown	Swimming under the influence of alcohol	12.61	Human remains recovered by municipality & federal authorities	Fatal	Unknown	Killing of crocodiles by local people & crocodile translocation by local authorities

area. Management strategies are now required for this crocodile population, as employed in 1998 and 1999 when eggs were recovered from nesting areas within the estuary, with 123 offspring reared from 126 incubated eggs and then released in the Reserve (Sigler et al., 2000). In other regions of Mexico, habitat protection, nest and clutch care, and long-term monitoring have helped the recovery of *C. acutus* populations (García et al., 2010).

Since 2011, following the incidents with crocodiles, people living along El Hueyate estuary no longer engage in fish harpooning for fear of being attacked; they also destroy crocodile eggs (Sigler & Martínez-Ibarra, 1998; Sigler et al., 2000; González-Desales et al., 2016a) and no longer swim or bathe in the estuary. Negative human–crocodilian interactions affect both parties (Table 2; Pooley, 2015). People may suffer fatal incidents, temporary or permanent physical and/or psychological damages, economic expenses and loss of domestic animals. The decline of a crocodile population can affect the local economy directly, and negatively, as a result of an increase in species of mammals, birds and arthropods considered problematic for agriculture (Cott, 1961; Fittkau, 1973), and short-term ecological imbalance (Nifong, 2018).

It is therefore important to collect data systematically, to understand the dynamics of crocodile populations and to document their interactions with people and, subsequently, to recommend actions that facilitate coexistence (Pooley, 2015). Ecotourism and sustainable harvest of crocodilian populations are potential management strategies (Fukuda et al., 2014). To conserve crocodiles, it is vital to involve all stakeholders, including government agencies, non-governmental organizations, business and tourism sectors, the media, and the public, both rural and urban.

The majority (78.5%) of incidents occurred during February–September, the nesting season of *C. acutus*, which is similar to *Crocodylus palustris* in India, where 71.8% of incidents were reported during the breeding season (Vyas & Stevenson, 2017). The main local economic activity is fishing within the estuary, close to nesting sites (Hernández-Hurtado et al., 2006; Das & Jana, 2017). Although the inhabitants in the study area suggested that the increase of crocodiles in the estuary is the main cause of negative interactions, our findings suggest otherwise: negative interactions also occurred when crocodile abundance was low, such as in 2014 (Fig. 3). Another important aspect to consider is a crocodile's length (Fukuda et al., 2015): the average size of the crocodiles responsible for negative interactions in Mexico was 2.8 m (range 0.5–4.0 m), and in 36 cases the crocodiles were reported to be > 2 m in length (CrocBITE, 2018). The crocodiles involved in the negative interactions in El Hueyate estuary measured 1.5–3.7 m in length (Table 2), and the dates of the incidents recorded corresponded to the months of courtship, nesting or care of neonates. In other species of crocodilians it has

been documented that anthropogenic activities such as swimming, fishing, washing, walking near sources of water, sailing, catching crocodilians, falling into the water, bathing cattle, collecting water or crossing a body of water, are the main circumstances in which negative interactions occur between people and crocodiles (Caldicott et al., 2005; Langley, 2005; Jayson et al., 2006; Dunham et al., 2010; Brien et al., 2017).

Our findings indicate a relationship of negative human–crocodilian interactions with anthropogenic activities and the crocodile reproductive season (nesting and care of hatchlings), and potentially to some socio-economic characteristics of the municipalities where negative incidents occur. This is also the pattern on the Mexican Pacific coast. Abundance of crocodilians does not appear to determine the frequency of negative interactions, but the probability of negative interactions may increase in locations with more crocodile sightings. This should be considered in the safeguarding of tourists and the local population: monitoring of wild populations of *C. acutus* would help to establish whether there are more negative incidents at sites with greater numbers of crocodiles. Consideration of the socio-economic characterization of municipalities, and locating nesting zones, are the first steps required to identify risk sites and to implement prevention strategies: for example, signage at risk sites such as nesting areas and training of response groups for incidents with crocodiles.

Negative interactions between people and crocodiles are increasing in Mexico (García-Grajales & Buenrostro-Silva, 2019), and the study of this phenomenon is necessary to support public policies, possibly including the translocation or removal of troublesome individual crocodiles. Conservation strategies need to consider the ecological, socio-economic and cultural aspects of these interactions, to avoid the illegal killing of crocodiles (Carter et al., 2017). Public education about crocodiles needs to be improved, to inform people about high risk situations and how to avoid them, but it is also imperative to convey why crocodiles need to be conserved (Pooley, 2015; Cureg et al., 2016; Sideleau et al., 2017). Conveying this message to the diverse range of stakeholders could include various strategies such as the use of brochures, pamphlets, signage, media coverage, posters, public presentations and tourist guides (Amarasinghe et al., 2015).

Finally, we make the following recommendations: (1) monitoring recreational activities near the sites and during the nesting season (depending on the site, February–September) by tourism service providers and institutions responsible for crocodile monitoring and administration of natural areas, (2) dissemination of information on the possible risk of incidents, (3) protection of eggs in incubation pens, and (4) encouraging strategies to meet the social and economic needs of the local human population. We have implemented some of these strategies in El Hueyate estuary, and so far there have not been any reports of

further incidents. Signs are erected during the nesting season, and 58 nests were protected during 2013–2016 by local people (García-Grajales et al., 2019). We are continuing these activities.

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Author contributions Development of concept and methods: GAG-D, MMZ-G, OM-V; fieldwork: GAG-D, LS; writing: all authors; organization of crocodile monitoring and interviews: MMZ-G, OM-V; financial management: PC, MMZ-G, OM-V; data analysis: GAG-D, AB-S; translation: LS.

Conflicts of Interest None.

Ethical Standards The Universidad Autónoma del Estado de México approved this research under its code of ethics, no crocodilians were captured in the course of the fieldwork, people interviewed allowed us to make use of the information obtained, and the research otherwise abided by the *Oryx* guidelines on ethical standards.

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