VARIATION IN SIZE CLASS AND SEX RATIO OF MORELET'S CROCODILE IN WETLANDS OF CAMPECHE, MÉXICO

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Abstract.—Size class and sex ratio in crocodilians could potentially be affected by environmental conditions or by habitat use during different ontogenetic stages within a single population. In this study, we determined whether size class and sex ratio varied in relation to years and localities, and we considered the relationships between climate variables and sex ratio for a natural population of a Morelet's Crocodile (*Crocodylus moreletii*). We undertook surveys for crocodiles over 5 y (2007–2011) at three study sites within Los Petenes Biosphere Reserve, México. We estimated the age of captured crocodiles from snout-vent length using the von Bertalanffy model to estimate the year of hatching. Although the overall sex ratio reported in this study was significantly different from parity, we find no differences of sex ratio among size classes, survey localities, or survey-years. We found annual variation in sex ratio from estimated age data, but the relationship between sex ratio and climate conditions was unclear. Our results are a first step towards understanding size-class structure and sex ratios in the status and trends of populations of Morelet's Crocodile.

Key Words.-age class; Crocodylus moreletii; growth model; ontogenetic habitat shift; reptiles

INTRODUCTION

Sex ratio is an essential demographic parameter for population dynamics in crocodilians. Understanding the consequences of sex ratio variation on different life stages is required to implement effective conservation and management strategies. The population sex ratio in crocodilians is the result of interactions between intrinsic and extrinsic factors at each life stage. For instance, crocodilians exhibit temperature-dependent sex determination, wherein sex is determined by thermal conditions experienced in the thermo-sensitive period during gonadal development (Ferguson and Joanen 1982). As a result, sex ratios among crocodilian hatchlings can vary year-to-year depending on nesting sites and local climatic conditions (Campos 1993; Rhodes and Lang 1996; Lance et al. 2000; Simoncini et al. 2008; Simoncini 2011). Measuring sex ratio in earlier life stages may create strong sampling bias as sex-specific mortality during offspring development may alter ratios sex (Thorbjarnarson 1997). On the other hand,

measuring sex ratio among mature crocodiles in a population may bias results due to behavioral differences in habitat preferences of adult crocodilians (Rosenblatt and Heithaus 2011). Subalusky et al. (2009) observed that adult females tend to move between different habitats, while adult males tended to be sedentary. Therefore, to reduce sampling bias, studies of population sex ratio in crocodilians should be conducted in different habitats, over multiyear periods, and consider every life stage. Theoretical models concerning adaptive significance of temperature-dependent sex determination in crocodilians suggest a skewed female bias in natural populations (Phelps 1992; Woodward and Murray 1993), which agrees with the early observations on crocodilian populations (Ferguson and Joanen 1983; Hutton 1987). However, subsequent studies show unclear evidence of female biased sex ratios in crocodilians, suggesting there may be intraspecific differences, with both male and female biased sex ratios (Thorbjarnarson 1997; Lance et al. 2000).

Studies on Morelet's Crocodile Crocodylus

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Marta Suárez-Coya.—Size class sex ratio of Morelet's Crocodile.



FIGURE 1. Morelet's Crocodile (*Crocodylus moreletii*) during basking activity. (Photographed by Marco A. López Luna).

moreletii (Fig. 1) have determined many aspects of life history, such as population status (Platt and Thorbjarnarson 2000; Cedeño-Vázquez et al. 2006), reproductive and nesting ecology (Platt et al. 2008; Casas-Andreu et al. 2011; López-Luna et al. 2011), morphology (Platt et al. 2009; Barrios-Quiroz et al. 2012), feeding habits (Platt et al. 2002, 2006), and body condition (Cedeño-Vázquez et al. 2011; Mazzotti et al. 2012). However, few studies have evaluated population sex ratio of Morelet's Crocodile. In the present study, we determined variation in size class and sex ratio of Morelet's Crocodile at three survey areas in a coastal wetland of the Yucatan Peninsula, Mexico. We evaluated the role of local climatic variability and ontogenetic changes in habitat use on variation in population size class and sex ratios of Morelet's Crocodile, as a first step to understanding its population dynamics.

MATERIALS AND METHODS

We studied crocodiles in Los Petenes Biosphere Reserve in Campeche, México. This reserve is characterized by the presence of hillocks, known locally as "petenes" (CONANP 2006). Mean annual temperature varies from 26.4 °C to 27.8 °C and total annual precipitation varies from 725.5 to 1,049.7 mm. The dry season is from November to April, with a wet season from May to October (CONANP 2006). We undertook searches for crocodiles at three locations within the reserve: Isla Arena (20°33'N, 90°25'W), Hampolol (19°56'N, 90°22'W), and Petenes (20°12'N, 90°29'W). Isla Arena is characterized by the presence of petenes and mangrove swamp. Hampolol is a river surrounded by semi-deciduous forest, while Petenes is characterized by the presence of Survey localities were mangrove forest. separated by 32.0-82.6 km. We surveyed for

crocodiles from April to August in 2007 (24 surveys), July to October in 2008 (six surveys), April in 2009 (two surveys), June in 2010 (two surveys), and in March in 2011 (one survey in Isla Arena).

We searched for crocodiles at night between 2100 and 0500 using a spotlight (Bayliss 1987). We captured crocodiles either by hand or with a 2.5-m aluminum tube with steel loop at the end, depending on the size and proximity of the crocodile. After capture, we measured total length (TL) and snout-vent length (SVL) of each crocodile using a tape measure to 0.01 cm. With exception of recent hatchlings, we determined the sex of crocodiles by manual probing of the interior of the cloaca (Ziegler and Olbort 2007). Prior to release at the capture site, we permanently marked each crocodile by notching the dorsal edge of a unique series of caudal scutes (Mazzotti et al. 2012).

We used total length to allocate individuals to age-size classes according to the classifications of Platt and Thorbjarnarson (2000) for Morelet's Crocodile: hatchlings (TL < 30.0 cm), yearlings (TL = 30.1-50.0 cm), juveniles (TL = 50.1-100.0 cm), subadults (TL = 100.1-150.0 cm), and adults (TL > 150.0 cm). We tested the ratios of the number of males to females against a null hypothesis of a 1:1 sex ratio using Chi-square test. We also used Chi-square to test the differences in the frequency of males or females among size-classes, sites, and survey years.

The snout-vent length was used to estimate crocodile age using the von Bertalanffy model to determine the year when each captured crocodile was hatched. In contrast with invasive techniques that require sacrifice of the individual to determine the age-growth of the organism, the von Bertalanffy model is a non-invasive technique based on the life history of the organism. The von Bertalanffy model has been used successfully to estimate age in a number of studies of crocodilians (Webb et al. 1983; Rebêlo et al. 1997; Cupul-Magaña et al. 2004; Charruau 2011), and has been suggested as an accurate method to estimate age from capture-recapture data for wild populations (Eaton and Link 2011). In addition, we evaluated whether the number of males and females was correlated to climatic maximum variables of and minimum

temperature and total rainfall from 1993 to 2008 collected by the weather station maintained by the Comisión Nacional del Agua in Isla Arena town. For all statistical analysis, we considered $P \le 0.05$ to be significant.

RESULTS

We made 119 captures of 109 crocodiles, with 10 individuals re-captured at least once. Crocodile total length ranged from 27.3 to 212.5 cm. Of the 109 individuals we caught, 19 were hatchlings for which sex was not determined. Of the remaining 90 crocodiles, we captured more males (n = 56) than females (n = 34), which, was significantly different from 1:1 (χ^2 = 5.43, df = 1, *P* = 0.019). However, there was no significant association of sex ratio among size classes (χ^2 = 3.95, df = 3, *P* = 0.260) or with survey localities (χ^2 = 0.49, df = 2, *P* = 0.780). Sex ratios also did not differ from 1:1 among survey-years (χ^2 = 3.18, df = 4, *P* = 0.530; Table 1).

However, the frequency of crocodile size classes was significantly different among capture locality for both males ($\chi^2 = 66.69$, df = 6, P < 0.001) and females ($\chi^2 = 128.40$, df = 6, P < 0.001). Males presented a greater frequency of yearling and juvenile classes at the Isla Arena locality; whereas, for females there was a greater frequency of subadults and adults at Isla Arena than in the other localities (Fig. 2). In Hampolol, we observed an absence of subadult and adult females despite high percentage of yearlings;

TABLE 1. Sex ratios of Morelet's Crocodiles (*Crocodylus moreletii*) captured in Los Petenes Biosphere Reserve in Campeche, México from 2007 to 2011. The data omit 19 hatchling crocodiles for which we could not determine sex.

Year	Males (M)	Females (F)	Sex ratio (M:F)
2007	29	17	1.7:1
2008	13	11	1.2:1
2009	6	4	1.5:1
2010	4	0	-
2011	4	2	1.2:1
Total	56	34	1.6:1



FIGURE 2. Size-class percentage of (a) males and (b) females of Morelet's Crocodile (Crocodylus moreletii) in three survey-areas at Los Petenes Biosphere Reserve, Campeche, México (Hampolol = black; Petenes = white; Isla Arena = gray).

while in Petenes the percentage of females overall was similar between size-classes (Fig. 2).

According to the von Bertalanffy model, the crocodiles captured were between 1 and 16 y old. The largest crocodile, predicted to be 16 y old, was a male of 212 cm TL. The sex ratio, taken as the percentage of males, fluctuated greatly over the estimated hatch years. The number of males or females from each of the hatch years was not correlated with the climatic variables of maximum temperature (P > 0.05), minimum temperature (P > 0.05), or rainfall (P > 0.05).

DISCUSSION

The most striking result was the balanced sex ratio among size classes, survey localities, and survey-years, although we found a significant difference in the overall sex ratio (1.6:1 male:female) of Morelet's Crocodile in Los Petenes Biosphere Reserve. We expected to find a skewed sex ratio due to theoretical models for the interplay between sex ratio and survivorship in crocodilians that suggest that population sex ratios should be female biased, providing an advantage for population growth (Phelps 1992; Woodward and Murray 1993). In addition, Lovich and Gibbons (1990) suggested that species with sexual size dimorphism show a skewed sex ratio in favor of the sex that matures at an early age. Specifically for the Morelet's Crocodile, this species shows sexual size dimorphism (Platt et al. 2009; Barrios-Quiroz et al. 2012), and the females mature earlier than males (Casas-Andreu et al. 2011); thereby we also expected a female-bias in sex ratio of Morelet's Crocodile in Los Petenes. Despite the limited sample size of this study, our results on overall sex ratio could suggest some ecological implications. First, the theoretical assumptions might not be valid for all crocodilians (e.g., Thorbjarnarson 1997; Lance et al. 2000); therefore, demographic models for assessing the optimal sex ratio in Morelet's Crocodile are necessary to understand not only the evolutionary advantage of temperaturedependent sex determination, but also to know how variation of sex ratio can affect the longterm dynamics of crocodilian populations. Secondly, unlike the skewed sex ratio towards males in our study, some previous studies of Morelet's Crocodile among Yucatan Peninsula has found a balanced sex ratio (1:1.3) male:female; Cedeño-Vázquez et al. 2006; 1:1 male:female; Cedeño-Vázquez and Pérez-Rivera 2010; 0.8:1 male:female; Merediz-Alonso 1999), which suggests that the intrinsic and extrinsic factors at each life stage of Morelet's Crocodile could affect each population in the Yucatan Peninsula differently.

On the other hand, if mechanisms causing sex differences are not strong enough to modify hatchling sex ratio (e.g., Kallimanis 2010), then we expected that population sex ratios may be explained (partly) by local climatic variability. For instance, Rhodes and Lang (1996) observed that sex ratio of the American Alligator, *Alligator mississippiensis*, in natural conditions is associated with local climatic variability from year to year, in which wet conditions from high rainfall result in low incubation temperatures

producing a female biased sex ratio, and dry Nevertheless, this idea must be subjected to conditions produced a higher proportions of further research to better understand the males. Some species with temperaturedependent sex determination produce unisexual nests as a response to local climate variations (Shine 1999). Simoncini et al. (2008) observed in Broad-snouted Caiman, Caiman latirostris, that natural nests producing only females varied between 14% and 45% during four nesting seasons. However, we did not find a relationship between estimated-age data and climate conditions; therefore, environmental factors may act simultaneously such as weather conditions, nest location, insolation, nest material quantity and quality, outcome in different thermal conditions during incubation period and thereby different sex ratios.

The Morelet's Crocodile is considered as mound nesting species. The nest is composed of vegetation, soil, leaves, and woody debris, but in some cases is a mix of mollusk shells, rocks, and sand, or even trash in areas with high levels of human activity (Platt et al. 2008; Escobedo-Galván et al. 2009; López-Luna et al. 2011). The nesting season at Los Petenes Biosphere Reserve begins in early April (Escobedo-Galván et al. 2009), which is earlier than other nesting areas (Platt et al. 2008; López-Luna et al. 2011). Some species may alter the breeding and nesting season according to climate conditions to sustain balanced sex ratios (Schwanz and Janzen 2008). The Chinese Alligator, Alligator sinensis, showed changes in the breeding and nesting seasons in recent years in response to temperature variations (Zhang et al. 2009). Variations in nesting season not only affect offspring traits (sex ratio and performance) but also environmental conditions for hatchling development (Kushlan and Jacobsen 1990; Charruau et al. 2010). Recently, Mazzotti et al. (2012) showed that warm temperature and high water levels adversely affect health parameters in Morelet's Crocodiles; therefore, the survival rate at different life stages could be affected by body condition among sexes and size classes. Temperature-independent differential mortality between post-hatching males and females has been suggested as a bias in crocodilian sex ratio (Thorbjarnarson 1997), but empirical evidences are inconclusive (Parachú Marcó et al. 2010). class structures are known for Morelet's

relationship between climatic variability and sex ratios, while assessing the climate effect on differential survival rate between post-hatching male and female of Morelet's Crocodiles.

The frequency of captured crocodile size classes varied among localities. These results could suggest different niche requirements during ontogenetic development (Subalusky et al. 2009). Crocodilians exhibit different feeding habits during ontogenetic development (Erickson et al. 2003), which means that crocodiles of different size classes may move between habitats to find specific prey (Rosenblatt and Heithaus 2011). The greater abundance of male yearlings and juvenile crocodiles in Isla Arena could be associated with the low water level which reduces flow to a few streams and crocodiles are concentrated in ponds where water depth is < 1 m. In contrast, the homogeneous conditions of water level observed during spotlight surveys at Petenes may favor an encounter rate representative of all size classes. The higher percentage of yearlings and juveniles at Isla Arena and Hampolol suggests that both areas may be used as a nesting site and nursery area in spite of differences in habitat conditions such as salinity and vegetation (Padilla et al. 2010).

Our results are an additional step towards understanding size-class structure and sex ratios in the status and trends of populations of Morelet's Crocodile. Recently, the conservation status of Morelet's Crocodile was changed from Appendix I to Appendix II of CITES (CITES, Convention International on Trade Endangered Species of Wild Fauna and Flora. 2013. CITES Appendices I, II and III. Available from http://www.cites.org/ [Accessed 12 July 2013]), and it was also removed from the Federal List of Endangered and Threatened Wildlife by the U.S. Fish and Wildlife Service based on available survey data from Mexico and Belize (U.S. Fish and Wildlife Service. 2012. Federal Register. Available from https://federalregister.gov/a/2012-12263 [Accessed 20 July 2012]). However, only

limited available data such as sex ratios and size

Crocodile populations in México; therefore, the demographic and life-history information of Morelet's Crocodile is not only important as reference to assess the impact of human activities on population dynamics, but could provide a baseline to design a harvest program.

Acknowledgments.—This study was funded by the Dirección General de Asuntos del Personal Académico of the Universidad Nacional Autónoma de México (Project ID: IN221208), the Comisión Nacional de Áreas Naturales Protegidas (CONANP-RB Los Petenes), and Cleveland Metroparks Zoo-Cleveland Zoological Society. Sierra2Sea-ProCAT and IdeaWild provided partial support. We are grateful to Ernesto Perera, Mauricio González, Claudia Monzón, and Javier Gómez for field assistance. Armando Escobedo-Galván thanks Posgrado en Ciencias Biomédicas, Universidad Nacional Autónoma de México (UNAM) and the Consejo Nacional de Ciencia y Tecnología for support and scholarships during graduate studies. Sergio Padilla received a graduate scholarship from the Consejo Nacional de Ciencia y Tecnología. We thank Roxana Torres and Ruth Elsey for suggestions on this manuscript, and to Katherine Renton for English assistance and additional important suggestions.

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