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CHARACTERIZATION OF MORPHOLOGICAL TRAITS OF COMMERCIAL INTEREST IN THE MORELET'S CROCODILE (*Crocodylus moreletii*)

[CARACTERIZACIÓN DE RASGOS MORFOLÓGICOS DE INTERÉS COMERCIAL DEL COCODRILO DE PANTANO (*Crocodylus moreletii*)]

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SUMMARY

Crocodylus moreletii is a species of commercial interest based on its skin. In this study, five morphological traits of commercial interest were characterized in 125 captivity-raised specimens of *C. moreletii* from four populations (Puente Chilapa, Gutiérrez Zamora, Villa Juárez and Puerto Vallarta). A canonical discriminant analysis (CDA) was used to differentiate the populations according to their morphological traits, a cluster analysis (CA) was used to infer which populations had the largest total length (TL), and a covariance analysis (ANCOVA) was used to assess the allometry and detect which population was different in terms of TL. The CDA showed no significant effects, suggesting that the morphological traits were similar among populations; the CA grouped two populations which had the largest body size; the ANCOVA revealed a significant correlation between morphological traits and detected a TL effect significantly lower in males and females from Puente Chilapa, in comparison with the other three populations. In conclusion, the males from Gutiérrez Zamora and the females from Villa Juárez were morphologically outstanding in terms of TL, and they would be the right crocodiles to establish a breeding nucleus in order to obtain offspring with their phenotypic characteristics.

Key words: *Crocodylus moreletii*; Morelet's crocodile; Management Unit for Wildlife Conservation.

RESUMEN

Crocodylus moreletii es una especie de interés comercial por su piel. En este estudio se caracterizaron cinco rasgos morfológicos de interés comercial en 125 ejemplares de *C. moreletii* criados en cautiverio, provenientes de cuatro poblaciones (Puente Chilapa, Gutiérrez Zamora, Villa Juárez y Puerto Vallarta). Se aplicó análisis canónico discriminante (ACD) para diferenciar las poblaciones por sus rasgos morfológicos, análisis de agrupación (AG) para inferir las poblaciones con mayor longitud total (LT), y análisis de covarianza (ANCOVA) para evaluar la alometría y detectar qué población era diferente en función de la LT. El ACD no determinó efectos significativos, lo cual sugiere que los caracteres morfológicos fueron similares entre poblaciones; el AG agrupó dos poblaciones con mayores dimensiones corporales; el ANCOVA reveló correlación significativa entre los rasgos morfológicos y detectó un efecto de la LT significativamente menor en machos y hembras de Puente Chilapa con respecto a las otras tres poblaciones. En conclusión, los machos provenientes de Gutiérrez Zamora y las hembras de Villa Juárez sobresalieron morfológicamente en términos de LT, y serían los cocodrilos adecuados para establecer un núcleo reproductivo con el fin de obtener crías con sus características fenotípicas.

Palabras clave: *Crocodylus moreletii*; cocodrilo de pantano; Unidad de Manejo para la Conservación de la Vida Silvestre.

INTRODUCTION

Body development in crocodilians maintained under captivity conditions is usually affected by temperature (Pérez and Rodríguez, 2005), density (Poletta *et al*., 2008), feeding frequency and diet quality (Pérez *et al*., 2009). This causes differentiation in morphological traits and is the main factor that leads to economic losses in crocodilian captivity production systems (Hutton and Webb, 1992). For this reason, strategies for an efficient management have been used to reduce the period of time needed to commercialize their skin (Pérez and Escobedo-Galván, 2007); many of these strategies have focused on evaluating the specific captivity conditions contributing to a greater body development in crocodiles (Huchzermeyer, 2003; Hutton and Webb, 2007).

The evaluation of body development in crocodiles allows differentiation, and eventually prediction of biological interest traits, such as sex, age and size (Hall and Portier, 1994; Verdade, 2003). This type of studies helps detect specimens with outstanding phenotypic characteristics (mainly of commercial interest); those specimens might be selected as breeders to pass those characteristics to their offspring (Isberg *et al*., 2005). In addition, it is possible to identify crocodiles with the largest body dimensions, which might become more productive in terms of skin, meat, oil and other handicraft by-products (skull, teeth and vertebrae) commercialized at a lower scale (León, 2004).

The Morelet's crocodile, *Crocodylus moreletii*, is one of the three extant crocodilian species from Mexico (Lee, 2000). The skin is considered by the national market as having excellent quality (INE, 1999). The lack of laws regulating its sustainable exploitation under wild conditions, allowed in the past its indiscriminate hunting, leading to demographic unbalances and even the extinction of some populations (Ross, 1998).

Thus, some specimens were selected and used in an effort to recover wild populations; others were held in captivity for their commercial exploitation in breeding and raising systems called Management Units for Wildlife Conservation (UMA) (SEMARNAT, 2000). According to Domínguez-Laso (2006), the raising of *C. moreletii* at UMAs has had satisfactory results; however, one of the problems at the UMA Cacahuatal in Veracruz, Mexico, is the differentiation of certain morphological traits in the specimens used for commercialization, resulting in skins with distorted scale patterns, which reduces the leather trade price.

The objective of the study was to characterize morphologically four populations of *C. moreletii* found at the UMA Cacahuatal, La Antigua, Veracruz, Mexico, to select individuals with the largest body size, to form a breeding nucleus for offspring production with desirable morphological traits.

MATERIALS AND METHODS

This study was conducted at the UMA Cacahuatal (INE/CITES/DFYFS-CRIN-0069-SIN/99), located in the town José Ingenieros, municipality of La Antigua, Veracruz, Mexico. At this UMA, specimens of *C. moreletii* from four different geographical origins were studied: Puente Chilapa and Gutiérrez Zamora, in the state of Veracruz; Villa Juárez, in the state of Sinaloa; and Puerto Vallarta, in the state of Jalisco. Individuals from Veracruz were born in the wild, but were raised in captivity at the UMA Cacahuatal. Those from Villa Juárez and Puerto Vallarta were born in captivity and were later taken to the UMA Cacahuatal. Individuals with the same origin were coetaneous.

Population management

To minimize variability on body development caused by temperature, population density, feeding frequency, food quality and quantity in four populations of crocodiles, all individuals had a similar management on captivity. Crocodiles were raised during a five-year period (2003-2008) in 200 m^2 cages at 30 °C on average; during the first year, all crocodiles were fed daily, and the following years they were fed every second day. The diet was based on a mixture of cow liver (40 %), bone, fish, poultry and soy (10 % each), cow suet (5 %), salt, vitamins and minerals (5 % each). When crocodiles reached a total length greater than 100 cm (from snout to tail tips), they were relocated into 80 m^2 aqua-terrariums in the open with an average density of 0.8 crocodiles m^{-2} (Serna-Lagunes *et al*., 2010).

Specimen selection and study variables

One hundred and twenty five specimens were randomly selected, registered and identified with an inter-digital plate (number and origin), from the total population of crocodiles (N = 800). Number of individuals selected by origin was as follows: 30 (24 %) from Puente Chilapa (PC), 30 (24 %) from Gutiérrez Zamora (GZ), 30 (24 %) from Villa Juárez (VJ), and 35 (28 %) from Puerto Vallarta (PV). Crocodiles were measured on the back using a measuring stick with minimum graduation of 0.5 cm. The following morphological traits of commercial interest were recorded (cm): total length (TL), measured from the tip of the snout to the tip of the tail; femur length (FL), measured from the pelvic acetabulum to the femur distal end; head length (HL), measured from the tip of the snout to the dorsal supra-occipital border; and head width (HW), measured between the lateral surfaces of the jawbone condyles. In addition, the snout-vent length (SVL) was ventrally measured from the tip of the snout to the anus, excluding the tail (Serna-Lagunes *et al*., 2010). Finally, sex was identified by cloacal palpation (Chabreck, 1963). From the total number of crocodiles selected, 67 (53.6 %) were females and 58 (46.4 %) males, and they were classified as sub-adults (TL between 101 and 150 cm) and adults (TL > 151 cm) to minimize the effects of the development stage and age (Monteiro and Soares, 1997; Monteiro *et al*., 1997).

Statistical analysis

Measures of central tendency were determined for all morphological traits by population. A canonical discriminant analysis (CDA) was used to determine the differentiation among populations, considering the five morphological measures. Because the SVL had a significant effect on the other four morphological variables (see results), residuals of individual linear regressions among SVL and the variables TL, FL, HL and HW were calculated. A CDA was applied directly on these residuals. After that, a cluster analysis (CA) was used to group population(s) with the greatest body development determined by TL. Finally, an analysis of covariance (ANCOVA) was applied for each morphological trait, using SVL as covariate and TL, FL, HL and HW as explanatory factors to explore in which of them significant effects of the explanatory factors and the covariate were present (Johnson, 1998). This last analysis specifically determined the population in which body development was different in terms of TL. The statistical procedure was performed using the software STATISTICA v. 6.0.

RESULTS

Male crocodiles from Gutiérrez Zamora had the largest dimensions for the five morphological traits evaluated. On the other hand, females from Villa Juárez had the largest TL, but had less wide and long head, shorter femur and shorter SVL, in comparison with Gutiérrez Zamora population. In contrast, the two other populations had shorter body traits (Table 1).

The CDA indicated a similarity in the five morphological traits of all four *C. moreletii* populations. The first canonical discriminant root was not significant (χ^2_{12} = 8.67, P = 0.73), suggesting that it is not possible to differentiate among the four populations based on the morphological variables adjusted by SVL (residues). This pattern of morphological similarity is shown in Fig. 1, in which the values for each individual crocodile in the first and second canonical discriminant roots are presented, explaining both 88 % of the total variance.

The CA showed two population groups considering TL dimensions. One group included crocodiles from Villa Juárez and Gutiérrez Zamora (mean TL´s 133.4±13.5 and 130.9±15.7 cm, respectively), and the second group included individuals from Puerto Vallarta and Puente Chilapa (122.2±13.5 and 110.8±13.8 cm) (Fig. 2). Therefore, the population from Puente Chilapa was morphologically more distant (regarding TL) from the population of Villa Juárez and Gutiérrez Zamora, but had morphological traits similar to those crocodiles from Puerto Vallarta (Table 2).

Table 2. Clustering matrix through the Euclidean distances method, according to the total length dimensions of four *Crocodylus moreletii* captive populations from Mexico.

Population	PC	GZ	PV	VJ
PC	0	150	110	159
GZ	150	0	132	111
PV	110	132	0	129
VJ	159	111	129	0

PC = Puente Chilapa; GZ = Gutiérrez Zamora; PV = Puerto Vallarta; VJ = Villa Juárez.

The ANCOVA showed a significant effect based on SVL (P < 0.001 in all the cases; Table 3). The significant interaction of the effect on TL resulted from crocodiles of Puente Chilapa, which had significantly shorter length compared to crocodiles from other three populations ($F_{3,120}$ = 13.455, P = 0.00; Fig. 3). This is consistent with the overlap of the confidence intervals (α = 95 %; Fig. 3) observed in the Villa Juárez, Gutiérrez Zamora and Puerto Vallarta populations, which suggests that these populations had similar TL. The morphological measures for HW, HL and FL showed no significant differences due to the interaction between sex and population (P > 0.001 in all three cases).

Table 1. Morphological traits by sex (mean ± standard deviation in cm), of four *Crocodylus moreletii* captive populations from Mexico.

Trait	Puente Chilapa		Puerto Vallarta		Gutiérrez Zamora		Villa Juárez	
/ sex	Females	Males	Females	Males	Females	Males	Females	Males
SVL	54.6±8.0	55.9±4.7	60.2±6.6	60.1±4.8	64.0±7.4	68.5±9.9	63.9±8.97	68.8±6.26
TL	110.3±15.6	111.9±10.1	122.2±13.5	122.3±11.2	126.9±11.5	136.2±19.2	134.9±17.7	133.2±12.9
HW	6.6±1.2	6.8±0.7	7.7±1.2	7.7±1.8	7.9±1.6	9.0±2.2	7.7±1.16	8.9±1.34
HL	4.2±0.8	4.5±1.0	4.6±1.1	5.0±1.3	4.9±1.0	5.6±1.2	4.6±0.73	5.4±0.85
FL	7.4±1.4	7.8±1.5	8.3±1.2	7.6±1.5	7.8±0.8	8.9±1.5	7.6±1.14	8.6±0.95

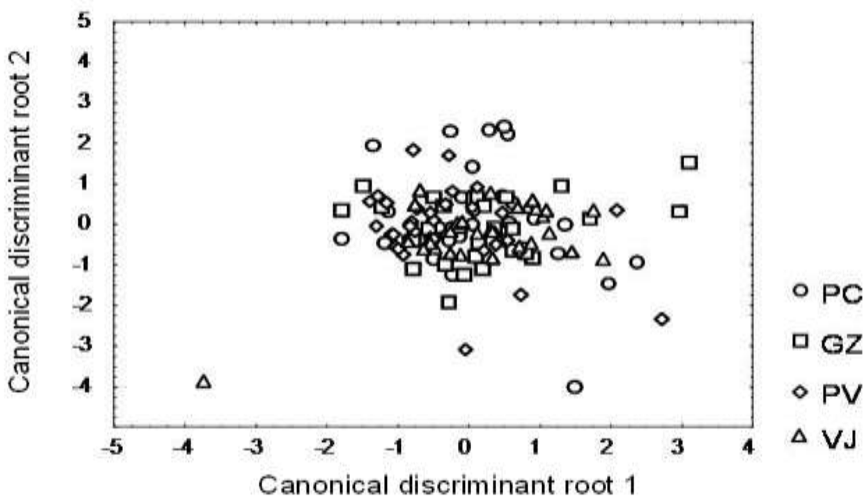

Figure 1. Values of the first two canonical discriminant roots (88 % of morphological variance explained) for all *Crocodylus moreletii* specimens studied. Symbols represent the following populations: PC = Puente Chilapa, GZ = Gutiérrez Zamora, PV = Puerto Vallarta, VJ = Villa Juárez.

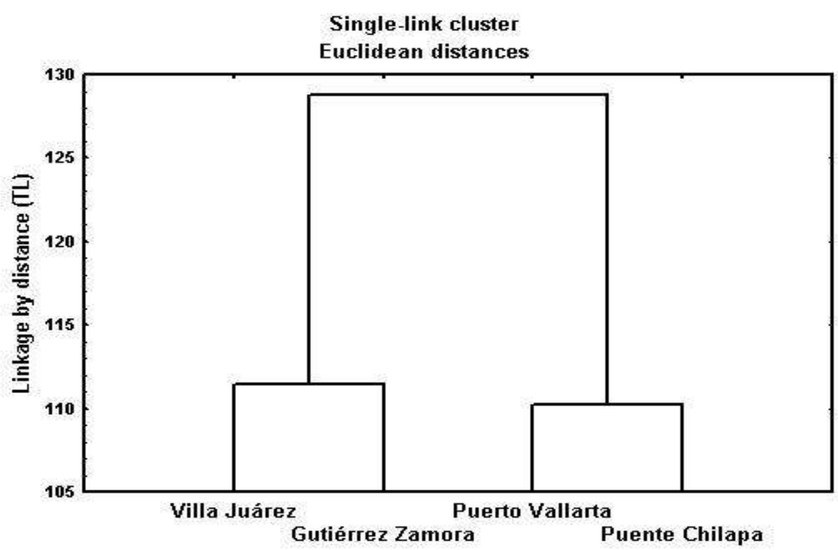

Figure 2. Clustering of crocodile populations according to body size. Individuals from Villa Juárez and Gutiérrez Zamora had greatest total length (TL).

Table 3. Significant effects of the interaction of the snout-vent length (SVL) with the morphological traits of commercial interest in *Crocodylus moreletii*, resulting from the ANCOVA.

Effect	SS	df	MS	F	P
Total length					
SVL *	18954.91	1	18954.91	539.95	< 0.001
Population × sex *	410.5	3	136.84	3.90	0.011
Error	4072.15	116	35.10		
Head width					
SVL *	159.89	1	159.89	214.52	< 0.001
Error	86.46	116	0.75		
Head length					
SVL *	46.12	1	46.12	78.01	< 0.001
Error	68.58	116	0.59		
Femur length					
SVL *	58.64	1	58.64	56.79	< 0.001
Error	119.78	116	1.03		

Sum of squares (SS), degrees of freedom (df), mean squares (MS), estimated value of F and its associated probability (P) that the null hypothesis is true, and significant effects (*).

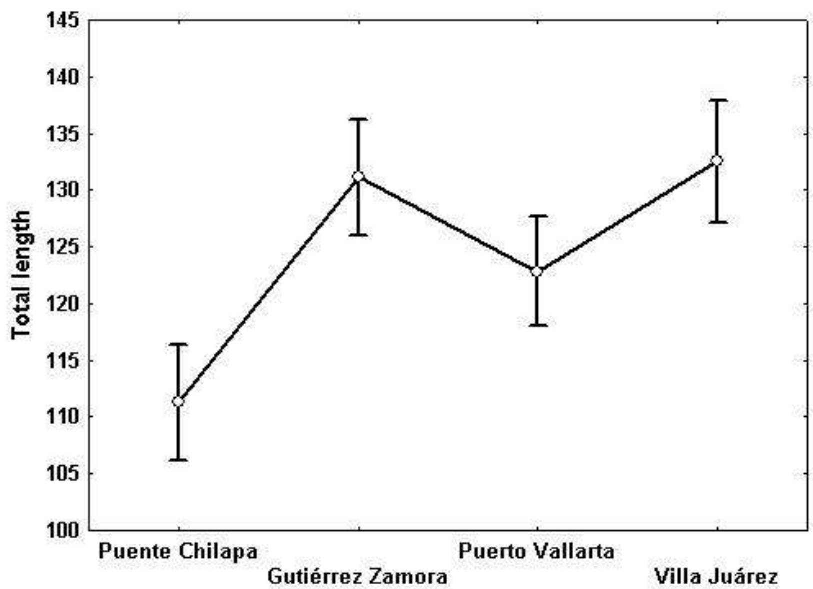

Figure 3. Effect of total length (TL) and population interaction. Crocodile population from Puente Chilapa had a significantly shorter TL compared to the other three populations. Bars indicate 95 % confidence intervals.

DISCUSSION

Crocodylus moreletii is a small-size crocodile species that usually reaches sexual maturity at 135 to 150 cm of length or 6 to 8 years of age (Navarro, 2004), with a maximum length of 416 cm (Pérez-Higareda *et al.*, 1991). Our length estimations were within these intervals; in fact, the studied crocodiles were sub-adults and adults, in the size category where they reach sexual maturity (Platt *et al.*, 2008), which occurred in a period of five years. This might indicate that captivity management features (temperature, feeding and density) at the UMA Cacahuatal were ideal for the development of *C. moreletii*, since they equalized the phenotypic traits that are expressed in wild populations; our results were even greater than those reported as characteristic for this species.

Crocodiles from Puente Chilapa had a shorter TL, in comparison with those from the other three populations. These differences could be attributed to the low body growth rates showed by these crocodiles in a previous study (Serna-Lagunes *et al*., 2010), which suggests that a longer period of time is needed for them to reach commercial size; this has been demonstrated and corroborated by several authors, who indicate that low body growth rates limit body development (Pérez and Escobedo-Galván, 2007; Meraz *et al*., 2008).

The CDA showed no evidence of a population being different on any of the five morphological traits evaluated, suggesting that all crocodiles had similar body conformation. This could be attributed to the fact that during sub-adult and adult stages, crocodiles show slow development, and thus it is difficult to detect any differentiation in these stages (Wu *et al*., 2006; Piña *et al*., 2007). On the other hand, two population groups were formed according to their similarity in TL. The first group included crocodiles from Villa Juárez and Gutiérrez Zamora, and the second group was formed by individuals from Puente Chilapa and Puerto Vallarta. Crocodiles from the first group would be the ideal specimens for establishing a breeding nucleus, since they had the largest body dimensions.

According to ANCOVA, SVL was the morphological trait that allometrically had a significant effect on the other morphological measures. Thus, larger individuals usually had larger TL, wider and longer head and longer femurs (Verdade, 2000). Therefore, raising crocodiles of larger size would represent a greater productivity in terms of skin, meat, oil and skulls, which would turn into greater income for the UMA Cacahuatal. Allometry for *C. moreletii* and *C. acutus*, both in captivity and in the wild, has been reported by Villegas (2005), who indicates that the cranial characteristics were significantly related with body size. The same is true in most crocodilians, where several morphological traits have significant effects among each other, particularly the cranial and body traits (Montague, 1984; Deeming and Ferguson, 1990; Hall and Portier, 1994; Wu *et al*., 2006).

The outstanding population group in terms of TL was formed by crocodiles from Villa Juárez and Gutiérrez Zamora, in comparison with the group of crocodiles from Puente Chilapa and Puerto Vallarta. Differences can be attributed to better conditions of incubation temperature during embryo developmental stage in the nest in the wild (Gutiérrez Zamora) or at the UMA where they were born (Villa Juárez), which contributed to a greater expression of the morphological traits (in this case TL) (Deeming and Ferguson, 1990; Milnes *et al*., 2001; Piña *et al*., 2005). It has been reported that inconstant incubation temperatures cause anomalies in the morphology and sexual development of crocodiles (Allsteadt and Lang, 1995). Larger body size could be an effect of: quality of ecological conditions in the area of origin (Montague, 1984), management variation in captivity (Huchzermeyer, 2003), comparison of wild populations with specimens born in captivity (Elsey *et al*., 1992), of factors unconnected to captivity such as increase in environmental temperature (Pérez and Escobedo-Galván, 2009), or during the raising stage at the UMA of origin due to differences in the quality of the diet or in the frequency of feeding (Cremieux *et al*., 2005).

Future studies should investigate the relationship among these variables and the morphology and body growth of crocodiles, with the aim to manage them appropriately and maximize their exploitation. This study shows information on the main characteristics of captivity management conditions that encourage the presentation of outstanding morphological traits in *C. moreletii*, suitable for its commercial utilization, that could be considered for the establishment of other UMAs and for the management of this species in the Mexican tropics.

CONCLUSION

The limited morphological differentiation in *C. moreletii* is the result of the homogeneous conditions that captivity offers, expressing all crocodiles the same phenotype. Population from Puente Chilapa showed a shorter TL, probably because it was in the process of adaptation to captivity conditions. The breeding nucleus of crocodiles should include females from Villa Juárez and males from Gutiérrez Zamora. Future studies should analyze the influence of incubation temperature on embryo development of *C. moreletii* with the aim to determine the optimum ranges that contribute to the expression of a larger body size. This will reflect into specimens with larger body dimensions, which will reduce the time needed for crocodile production and the expenses due to their maintenance up to commercial size during longer periods of time.

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