CSG Report: Geometric Morphometric Analysis of Antillean Crocodiles

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Introduction

Geometric morphometrics commonly have been utilized to explore patterns of variation across a wide range of taxa. We present a geometric morphometric analysis of skull shape morphology for New World crocodilians of the genus *Crocodylus*, placing emphasis on studying variation within the Greater Antillean region of the Neotropics. It has been suggested that the major factor contributing to the modern diversity of Cuban (*C. rhombifer*) and American crocodiles (*C. acutus*) in the Greater Antilles is the result of ancient hybridization (Weaver et al. 2008). Genetic studies found that mitochondrial DNA haplotypes for *C. acutus* in the Greater Antilles are actually more closely related to *C. rhombifer* than other American crocodiles throughout the Neotropics (Weaver et al. 2008). The funds provided by the Crocodile Specialist Group (CSG) were used for air travel and lodging while sampling crocodile skulls at three museums.

Methods and Materials

A total of 30 *C. acutus*, 12 *C. rhombifer*, 2 *C. intermedius* (Orinoco crocodile), 2 *C. moreletii* (Morelet's crocodile), and 9 *C. niloticus* (Nile crocodile) were used in this study. Specimens were selected according to overall skull completeness and their proposed size class. Only sub-adult and adult specimens were included in analyses to reduce possible differences in allometric growth. Skulls were photographed in dorsal aspect along the horizontal plane with a scale bar included to record the size of each specimen. For the morphometric analyses, a set of specific landmarks were chosen and measured based on previous studies (Pierce et al. 2006; Pierce et al. 2008; Sadleir and Makovicky 2008; Pearcy and Wijtten 2010; Pearcy and Wijtten 2011). Landmarks were digitized using the program TpsDig 2.04 (Rohlf 2005) and were of either Type 1 or Type 2 (Bookstein 1991). The number of landmarks differed with respect to two different analyses: (1) Population level shape variation: 63 landmarks, with five located along the midline of the skull and 58 bilaterally symmetrical landmarks. (2) Individual level shape variation: 35 landmarks, with five located along the midline of the skull and 30 bilaterally symmetrical landmarks.

In order to assess the number of morphologically distinct groups within our data set, a cluster analysis was conducted on all sample locality consensus specimens for LM1 using Euclidean partial Procrustes distances in the program Past version 1.59 (Hammer et al. 2001). To establish whether returned groupings had statistical significance, we next subjected these groupings to a pair-wise significance test of their mean shapes in the program TwoGroup 6h (Sheets 2000). The cluster results were then compared to current and historic geographical occurrences as well as genetic phylogeny.

Results

The cluster analysis and associated pair-wise significance tests recovered three broad groups within morphospace, Group A, or sub-fossil *C. rhombifer*, consisting of extremely broad-snouted morphotypes; Group B, or present day *C. rhombifer*, Antillean *C. acutus* and *C.*

moreletii, consisting of broad-snouted morphotypes with varying degrees of length; and Group C, or mainland *C. acutus* and *C. intermedius*, consisting of more narrow-snouted morphotypes with varying degrees of length. Within Group B there are two main clusters, B-1 and B-2, which differ significantly from each other. Cluster B-1 is composed of *C. acutus* from the Greater Antilles (B-1.1) and *C. rhombifer*, whereas cluster B-2 is composed of *C. moreletii*. Within cluster B-1, cluster B-1.1 appears to be significantly different from present day *C. rhombifer* in Cuba, however statistical tests were not performed on this grouping since the *C. rhombifer* group was only represented by one locality. Within Group C there are two main clusters, C-1 and C-2, which are significantly different from each other. Cluster C-1 is composed of *C. intermedius* and cluster C-2 is composed of mainland *C. acutus*. Within C-2, cluster C-2.1 appears to be different from *C. acutus* originating from Nicaragua although like above for Group B, statistical tests were not performed on this grouping since it was only represented by one locality.

Conclusions

Crocodylus acutus from the Greater Antilles have significant morphological disparity when compared to other *C. acutus*, as well as the rest of the Neotropical crocodilians. Interestingly, sub-fossil *C. rhombifer* show significant morphological disparity compared to its modern day conspecific and is highly divergent from all other New World *Crocodylus* species. A further study of fossil specimens from extant taxa may provide an interesting example of crocodilian skull shape evolution and adaptation given a changing global climate. On the other hand, this skull shape difference may be attributed to suspected ancient hybridization events between *C. rhombifer* and *C. acutus* and therefore modern day Cuban and American crocodiles may possess a somewhat intermediate skull shape. Regardless of the cause of this morphological disparity, it is apparent that *C. acutus* from the Greater Antilles are divergent from the rest of the American crocodile complex.

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