Funding Report for the Crocodile Specialist Group Student Research Assistance Scheme for the project: Implications of Skull Shape for the Ecology and Conservation Biology of Crocodiles

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This project was part of a PhD study evaluating the use of skull morphometrics in conservation of crocodilians. Skull morphometrics in crocodiles has rejuvenated as a popular study over the last few years, however it routinely remains within morphological and evolutionary circles, rarely being presented as an applicable method for conservation and ecological studies especially with concern to sympatric crocodiles. This study is clarifying functional skull morphometrics and exploring conservation application using extensive, previously unexplored museum collections.

Methods

We visited five natural history museums throughout Europe (Senckenberg, Brussels, Paris, Amsterdam, and Leiden). We photographed their crocodile skull collections. Only subadult to adult specimens were used and deformed crania obviously from captive-raised individuals were excluded from the samples. Each of 23 crocodilian species were accounted for in a total of 159 skulls photographed.

We photographed the skulls in dorsal view. Methods for leveling skull, lighting and background are described in (Pearcy and Wijtten 2010). The photographs were used in a digital morphometrics analysis as described below, however we also took four measurements directly from the skull as reference points to verify our digital measurements. These measurements were total length, total width, Kälin 12-12 and the length from Kälin 12 to the tip of the snout. We found our digital measurements to be representative of our raw measurements and therefore representative of the actual skull.

Photographs were input into a digital photo analysis program (ImageJ) and landmarks were placed on the dorsal view in various locations representing a variety of skull measurement (Table 1, Figure 1). These landmarks were given x,y-coordinates. We calculated the Cartesian distances between landmarks and used these distances as measurements for further analysis. We use these measurements to define morphospace, or the shape of the skull in a defined space.

Table 1 Location of used landmarks within crocodilian skull

Landmark	Point Location
1	Tip of snout at anterior end of medial suture
2	Minimum width of notch immediately posterior to premaxilla, left side
3	Minimum width of notch immediately posterior to premaxilla, right side
4	Maximum preorbital width around 5th maxillary tooth, left side
5	Maximum preorbital width around 5th maxillary tooth, right side
6	Minimum preoribital width around 6th maxillary tooth, left side
7	Minimum preoribital width around 6th maxillary tooth, right side
8	Center of left orbit
9	Center of right orbit
10	Kälin 12 left side
11	Midline at Kälin 12
12	Kälin 12 right side
13	Maximum width quadratojugal bone, left side
14	Maximum width quadratojugal bone, right side
15	Posterior tip of supraoccipital (medial posterior margin of cranial table)

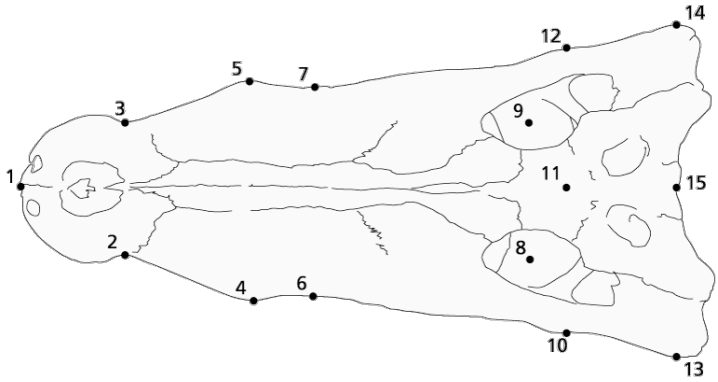
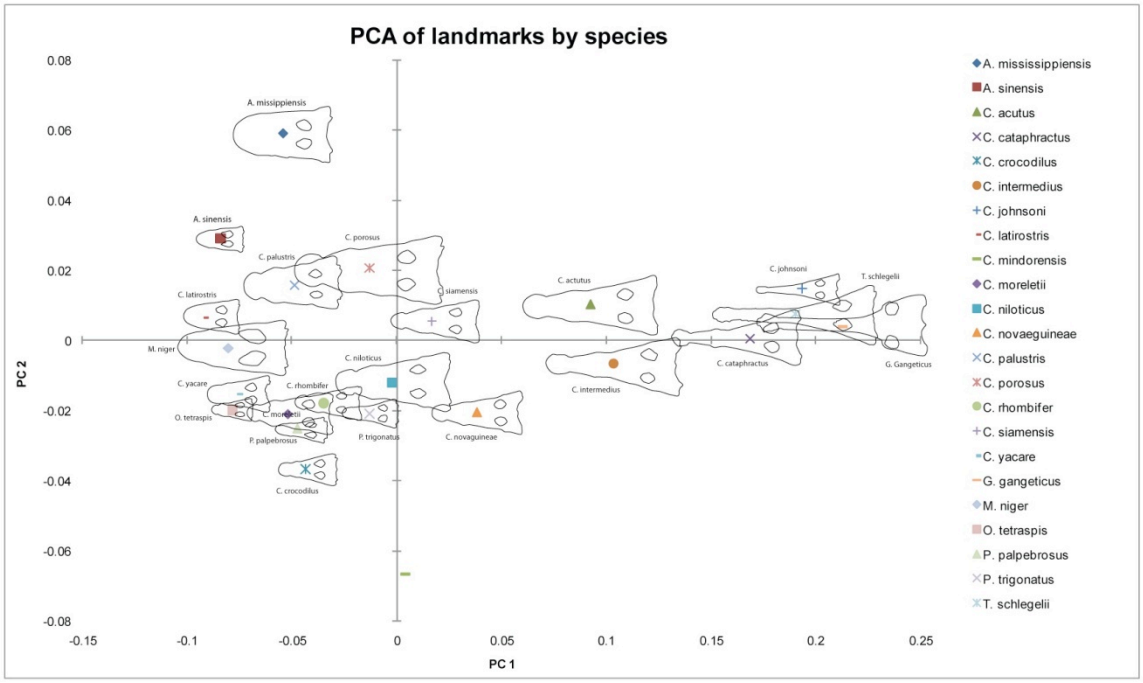


Figure 1 General position of landmarks on cranium corresponding to Table 1 (dorsal view)

Results

With the landmark study, we found the use of different measurements such as Kälin 12-12 compared to previous used ones of total length, total width and those suggested in other articles (Pierce et al. 2008) to be more accurate at separating species (Figure 2).



We also identified a measurement at Kälin 12-12 as being a slightly better indicator of size (in proportion to total body length) than head width. This is the width of the skull located at the anterior end of the postorbital bar suture. We also defined this measurement as a better location for determining size on Crocodylia (Pearcy 2010).

We found that through skull morphometrics we could identify relationships between sympatric species that were indicative of their realized niche. For example, when comparing the Australian species of crocodile, *Crocodylus porosus* and *C. johnsoni*, we found a small morphospace overlap of around 34%. This space was taken primarily by *C. porosus* (63%) with only 37% being associated with *C. johnsoni* (Figure 3). These species are highly correlated (0.932, p=0.01). If assumed

morphospace is equivalent to niche space, 34 of 100 crocodiles would overlap within a syntopic zone. Of these, 21.24 (=0.34 x 0.63) would be *C. porosus* and 12.58 (= 0.34 x 0.37) would be *C. johnsoni*. For every one *C. porosus,* 0.59 (=0.37/0.63) *C. johnsoni* would be successful at cohabitation.

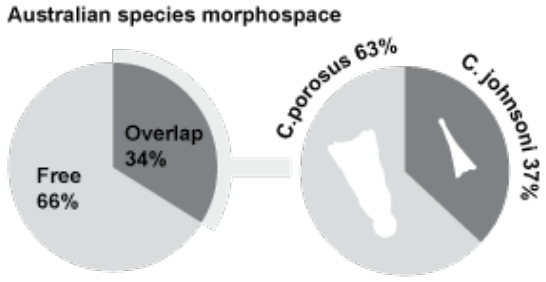


Figure 3 Pie charts showing the overlap in morphological characteristics and the division of overlap between Australian *Crocodylus* spp.

We could even use this to identify character displacement with an introduced species. The crocodiles of Cuba, originally *Crocodylus rhombifer* and *Crocodylus acutus*, had an overlap of 50% (Figure 4). When *Caiman crocodilus* was introduced, the overlap then increased to 74% (Figure 5), meaning 74% of available space is competed for. *C. rhombifer* and *C. acutus* are less similar (corr. =0.959, p=0.01) than *C. rhombifer* and *C. crocodilus* (corr.= 0.977, p=0.01). *C. crocodilus* is even less similar to *C. acutus* (corr.=0.946, p=0.01). Overlap between native species and introduced show higher overlap between *C. rhombifer* and *C. crocodilus* (38%) than *C. acutus* and *C. crocodilus* (33%). We can assume that the introduction of *C. crocodilus* negatively impacted the *C. rhombifer* population more than the *C. acutus* population and is a likely factor in the decline of *C. rhombifer* (already assumed in Ross 1998).

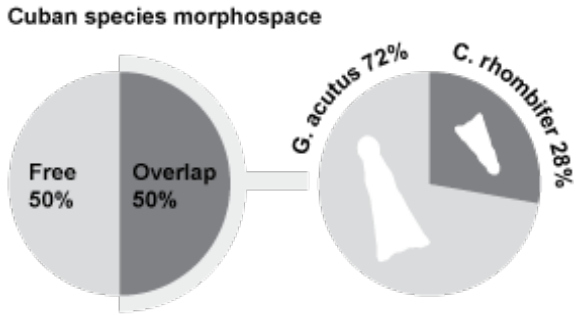


Figure 4 Pie charts showing the morphospace overlap of the two crocodile species native to Cuba

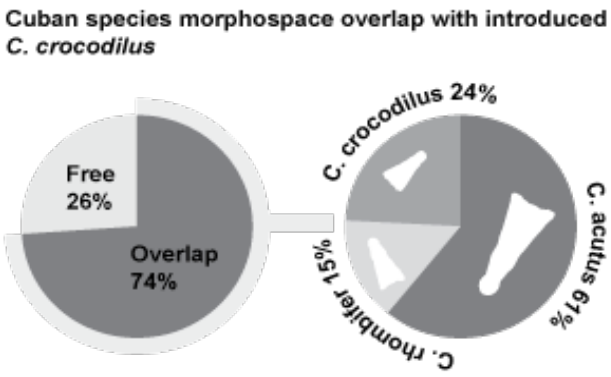


Figure 5 Pie charts showing morphospace overlap of crocodile species inhabiting Cuba after the introduction of *C. crocodilus*

We used the same methods to look at three other sympatric species sets in Africa (*C. niloticus*, *C. cataphractus*, and *Osteolaemus tetraspis*), South America (*Caiman crocodilus* and *Melanosuchus niger*) and India (*C. palustris* and *Gavialis gangeticus*). When we compared our studies, to studies done in the wild, we found similar population ratios as are suggested by our research.

We further verified our findings by comparing skull shape to other physical characteristics which have an ecological function. I used measurements taken from captive crocodiles in the Philippines. I tired to use captive crocodiles with little deformity and used measurements that would not be too affected by malnutrition and other consequences of captive rearing. We found that there is a strong correlation between skull measurements and physical characteristics, which was to be expected given the allometric relationship between the two (Greer 1974; Woodward *et al.* 1995). The Philippine crocodiles (*C. porosus and C. mindorensis)* are different enough ecologically but similar enough in head shape that they can be used to determine if the skull shape is indicative of realized niche. We found through its relationship to physical characteristics such as hind limb length (important in nesting and habitat preference) and tail length (habitat preference) that the skull was at least partially indicative of realized niche- along with the already known relationship to prey type (Busbey 1995).

Conclusion

What this study found was an extended use of skull morphometrics into ecology and conservation of sympatric crocodilians. We concluded that skull shape is indicative of realized niche and thus can be integrated into ecological conservation directives. We have suggested this new tool be integrated into conservation actions, issues regarding species differentiation, effects of hybridization, and evolutionary debate. A good follow-up study would be in a controlled environment with live specimens or a trial within wild specimens in populations already being harvested. Using these methods in the study hybrids would lend insights into the benefits (do they acquire more niche space?) or consequences (are they forced out?) of hybridization within sympatric populations. It could even be used to assess similar changes in the evolutionary past and possibly what head shapes have been driven to extinction by interspecific niche competition.

The project has already had success with a peer-reviewed journal, Herpetological Review. The description of used photographic methods and an article reviewing Kälin 12-12 as an indicator of size will be in the December issue. Other articles have been or will be submitted to the Journal of Herpetology (morphospace study), Zoomorphology (landmark study) and Herpetolgica (Philippine crocodile comparison). Parts of the project have been presented in two international conferences- the 20th Working Meeting of the Crocodile Specialist Group and the International Conference on Archaeozoology. I will apply to present the information at the Society of Experimental Biology conference under the Conservation Physiology session. I also participated in the Women in Science

Day in Frankfurt, running a session about my project for young girls. We will continue to pursue avenues of dissemination both in scientific and popular circles.

Literature Cited

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