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Source: South American Journal of Herpetology, 16(1) : 10-15

Published By: Brazilian Society of Herpetology

URL: https://doi.org/10.2994/SAJH-D-18-00074.1

South American Journal of Herpetology, 16, 2020, 10–15

A Body Condition Score for Crocodilians

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Abstract. Body condition (BC) has been used extensively to evaluate fitness in animals. In traditional studies of crocodiles, the paradigm of evaluating BC with the Fulton index and interpreting the results with quartiles is predominant. However, the wide variety of indices available provides a diversity of tools with which BC can be interpreted in multiple ways. In this study, three indices based on the function of length and weight were evaluated: the Fulton index (K), relative condition index (Kn), and scaled mass index (SMI). The body condition score (BCS) index was also adapted. This was performed as a clinical evaluation of specific morpho-anatomical points. The Fulton index presented a strong relationship with corporal size that generates poor interpretation, scoring low BC in small individuals and high BC in large individuals. This problem does not occur in Kn, SMI nor BCS. SMI and Kn are difficult to interpret, but this is normally conducted by quartiles, generating ambiguous and potentially misleading explanations. The use of BCS avoids these complications because its direct and simple evaluation acts to convert the abstract numbers of the indices to a clinical reality.

Keywords. *Crocodylus acutus;* Health evaluation; Jalisco; La Manzanilla estuary.

INTRODUCTION

Body condition (BC) is understood as the physical status of the body of an animal (Stevenson and Woods, 2006) and is used to evaluate the fitness of animals in their environment (Taylor, 1979; Peig and Green, 2010). A great diversity of methods has been developed to conduct this evaluation (Stevenson and Woods, 2006). In general, crocodile studies are based on the paradigm that BC can be measured through the result of a mathematical function between weight and length, from which the amount of energy reserves of an individual can be deduced (Mazzotti et al., 2012; Zweig et al., 2014). This value allows us to relate several factors such as diet (Delany et al., 1999; Shirley et al., 2016), growth (Saalfeld et al., 2008), reproduction (Barão-Nóbrega et al., 2017), season (Hutton 1987; Barr, 1997), temperature (Brandt, 1991), and water level (Fujisaki et al., 2009; Brandt et al., 2016) to the health, quality, and vigor of individuals and populations (Stevenson and Woods, 2006; Peig and Green, 2009). BC has proven to be of such utility and importance that management programs have used it to evaluate the results of ecological restoration (Mazzotti et al., 2009).

The paradigms regularly applied for BC emerge from fishery sciences. The best known approach is the Fulton index (K), which is based on the assumption that all of the parts of an ideal theoretical fish grow in the same way (isometric growth), thus generating a constant that can be related to the length of the animal, dissociating body size and body condition, and obtaining an abstract measurement of energy reserves as a result (LeCren, 1951; Cone, 1989). However, this assumption is rarely true in reality (LeCren, 1951). Consequently, many methods have been created to calculate BC (LeCren, 1951; Cone, 1989; Stevenson and Woods, 2006; Peig and Green, 2009; Peig and Green, 2010), resulting in a large number of indices, all based on the same paradigm but with different assumptions and mathematical approaches.

This study compares this mathematical approach with another approach commonly implemented in veterinary sciences and cattle rearing. Through methodical, morphological, and subjective evaluation of the fat reserves and musculoskeletal situation of specific body regions, BC can be estimated without the isometric restriction. One method to achieve this is through the body condition score (BCS), which was originally designed for goats (Jefferies, 1961). This index classifies individuals into different categories from malnourished to obese (Edmonson et al., 1989) and has been widely used in the research of productive domestic species (Herd and Sprott, 1996; Fitzgerald et al., 2009; Sánchez et al., 2016) such as dairy cows (Edmonson et al., 1989; Agrawal et al., 2017; Keyserlingk et al., 2017), as well as in the clinical evaluation of domestic species (Jeusette et al., 2010; Aptekmann et al., 2014). However, it has also been modified and implemented for several wildlife species (Schiffmann et al., 2017; Singh et al., 2017).

How to cite this article: Ojeda-Adame R.A., Hernández-Hurtado H., Ramírez-Martinez M.M., Iñiguez-Davalos L.I. 2020. A body condition score for crocodilians. *South American Journal of Herpetology* 16: 10–15. http://doi.org/10.2994/SAJH-D-18-00074.1

Submitted: 29 October 2018
Accepted: 15 September 2019
Available Online: 07 August 2020

Handling Editor: Pablo Siroski
http://doi.org/10.2994/SAJH-D-18-00074.1

MATERIALS AND METHODS

We captured 20 specimens of *Crocodylus acutus* (Cuvier, 1807) in the estuary of La Manzanilla in Jalisco, Mexico (19°17′N, 104°47′W) in 2014, and another six captive adults were analyzed in 2016, for a total sample of 26 crocodiles. This sample was divided into five size classes (Thorbjarnarson, 1989). From each individual, we recorded total length (L) and weight (W). These data were used to calculate three indices: (1) Fulton index (K), calculated as:

$$K = \frac{W}{L^b} 10^n$$

where b is the scaling exponent (which is isometric and therefore equal to three); the result is multiplied by 10 raised to the power of n to achieve a unit; (2) the relative condition index (Kn), which has the same formula as K, but b is calculated through ordinary least squares regression of W against L (LeCren, 1951; Cone, 1989). Finally, with these data, we calculated (3) the scaled mass index (SMI):

$$\widehat{M}_i = Mi \left[\frac{L_0}{L_i}\right]^{b_{SMA}}$$

where Mi and Li are the body mass (W) and the linear body measurement of individual i (L), respectively; b is estimated by the standardized major axis regression (SMA) of W on L; L_0 is an arbitrary value of L (in this case, the arithmetic mean value for the study population); and $\widehat{M}_i$ is the predicted W of individual i when the linear body measurement is standardized to L_0 (Peig and Green, 2009). The results of these indices were interpreted using the quartile system (Mazzotti et al., 2009; Zweig et al., 2014).

The modification of BCS was based on observations and bibliography. We selected morphological zones of the neck and thorax (Huchzermeyer, 2003), as the accumulation of fat and skeletal muscle allows us to establish the following four evaluation points for BCS: 1) articular bone of the mandible, 2) cervical vertebrae, 3) scapular bones, and 4) cervical fossa, located in the lateral position of the neck (Huchzermeyer, 2003). According to the following characteristics of each point, individuals were classified into one of the five following BCS categories (Fig. 1):

BCS-1: The articular bones of the mandible, cervical vertebrae, and scapular bone are sharp on palpation. The cervical fossa is easily seen. This animal is considered to be malnourished.

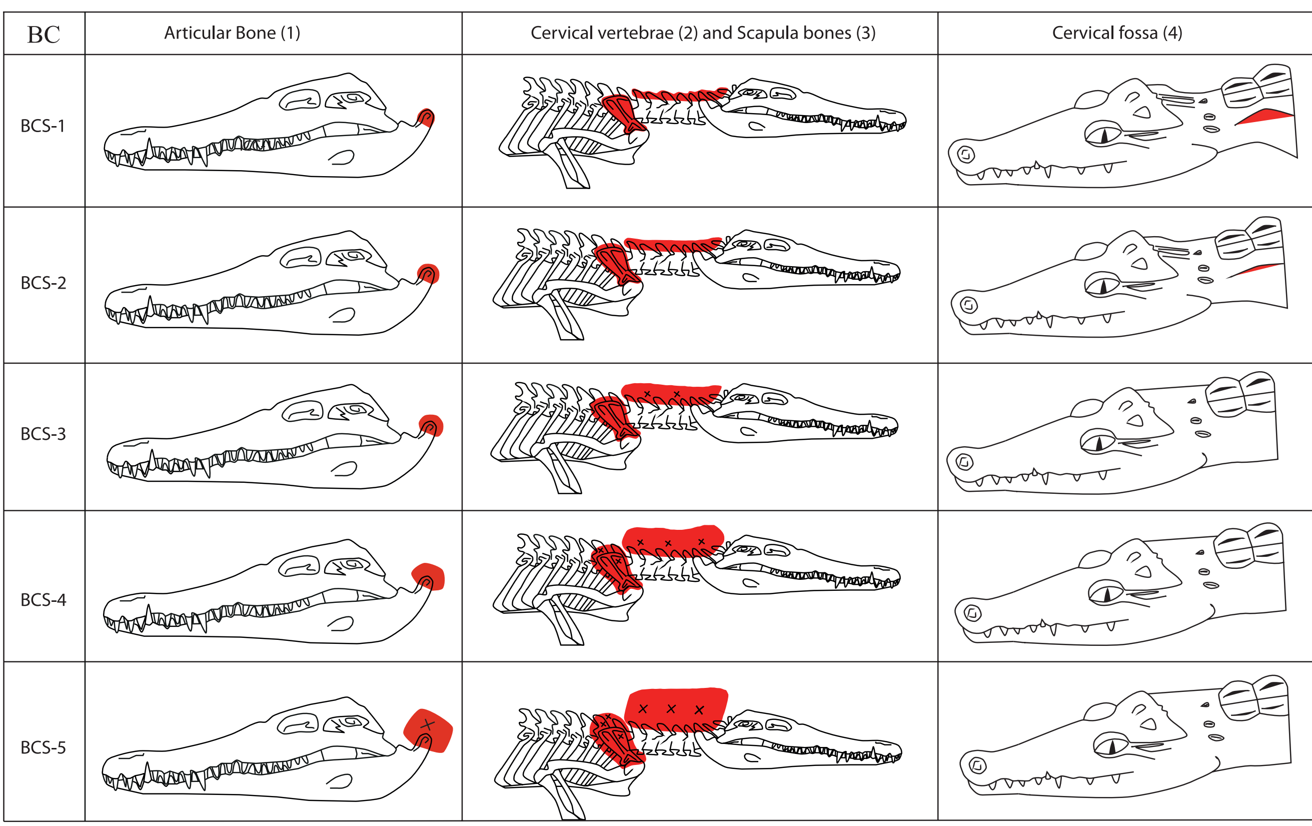

Figure 1. Explanation of the body condition score (BCS) design. In each category, the morphological situation and palpation of the bones are represented in red. When the colored area is small and close to the bone, the palpation is sharp, but as it increases, it becomes convex. The letters "X" indicate the points at which palpation is impossible. The cervical fossa is not palpable, so the color only shows its presence and form; in categories 3–5, it is absent.

BCS-2: The articular bones of the mandible, cervical vertebrae, and scapular bone are not visible, but are sharp on palpation. The cervical fossa is not very evident. This animal is considered thin.

BCS-3: The articular bone of the jaw is not visible and at palpation is convex. The cervical vertebrae and scapular bones are neither visible nor palpable. The cervical fossa is completely absent. This animal is considered normal.

BCS-4: Only the joint bone of the jaw is palpable, and this with some difficulty. The cervical vertebrae and scapular bones are neither visible nor palpable. The cervical fossa is absent and accumulation of fat is perceived. This animal is considered stout.

BCS-5: No bone points are palpable or visible. A large accumulation of fat is observed in the cervical region. This animal is considered obese.

The characteristics of each point are not shared among the different categories. To classify each individual, it is therefore required that each zone has all the characteristics. To avoid misinterpretation, those individuals with features belonging to two or more categories or with anatomical deformities should be excluded or assigned two BCS scores to incorporate the two possible scores that may accurately represent the sample; e.g., BCS4-5 (in our experience, this is a common practice in the field). The results of all the indices were related through a linear correlation (R^2) with length in order to determine their degree of independence from body size.

RESULTS

Figure 2 shows that SMI and Kn behave similarly. K show similar variability; however, the values increase with the size of the individuals ($R^2 = 0.81$). The other indices remained independent of body size ($R^2 = 0.01$ and $R^2 = 0.04$ for SMI and Kn, respectively). The results obtained by BCS (also independent of body size, $R^2 = 0.001$) show some differences from the other indices, which becomes clearer when the results are represented graphically (Fig. 3):

Class I: The four indices indicate a majority of individuals with normal BC. However, K classified several individuals with high BC and some with low BC. SMI and Kn classified individuals with high BC.

Class II: All indices except K indicate low BC. The four indices classified one individual of 106 cm as that with the lowest BC of the studied population.

Class III: Only one individual was analyzed. BCS and Kn classified it as presenting normal BC, K with high BC, and SMI with low BC.

Class IV: We did not capture class IV individuals.

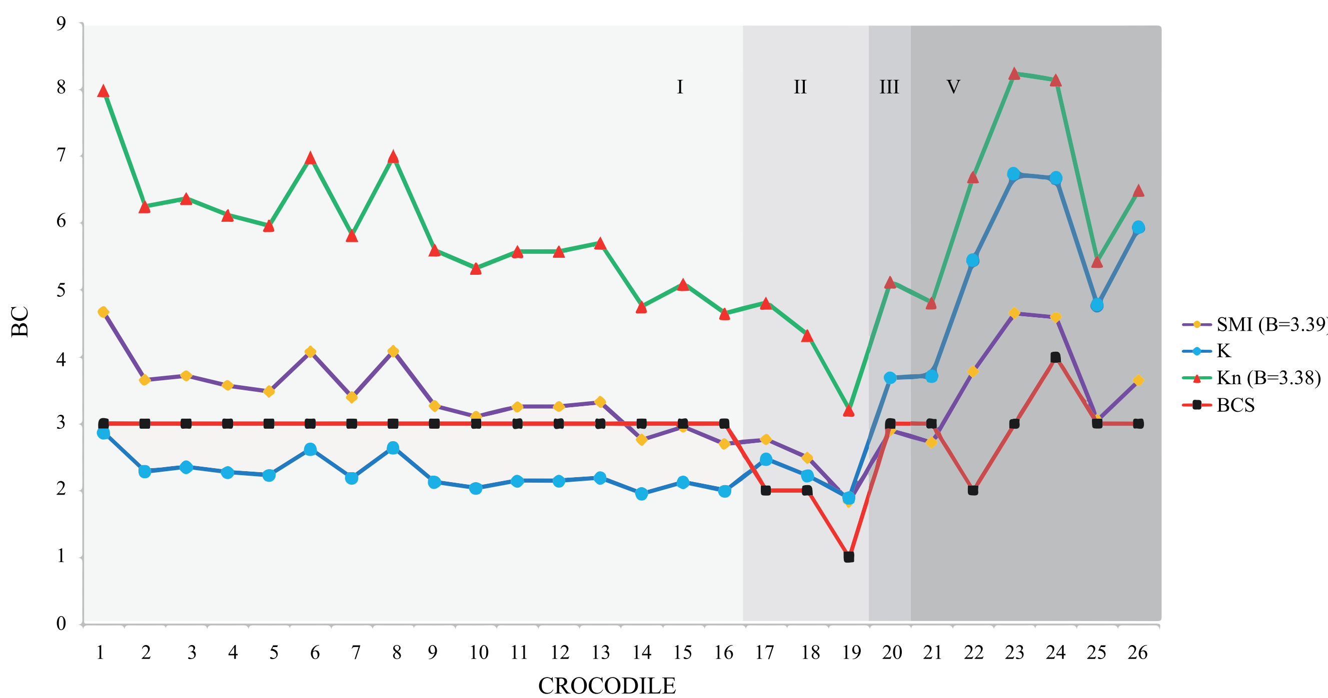

Figure 2. Results of the four indices evaluated for the individuals of this study, ordered from the smallest to the largest crocodile. Shades of gray symbolize the size classes, from class I with the lighter tone to class V with the darker tone; class IV was not captured and is therefore not presented. Abbreviations: B: isometric exponent; BC: body condition; BCS: body condition index; K: Fulton index; Kn: relative condition index; SMI: scaled mass index.

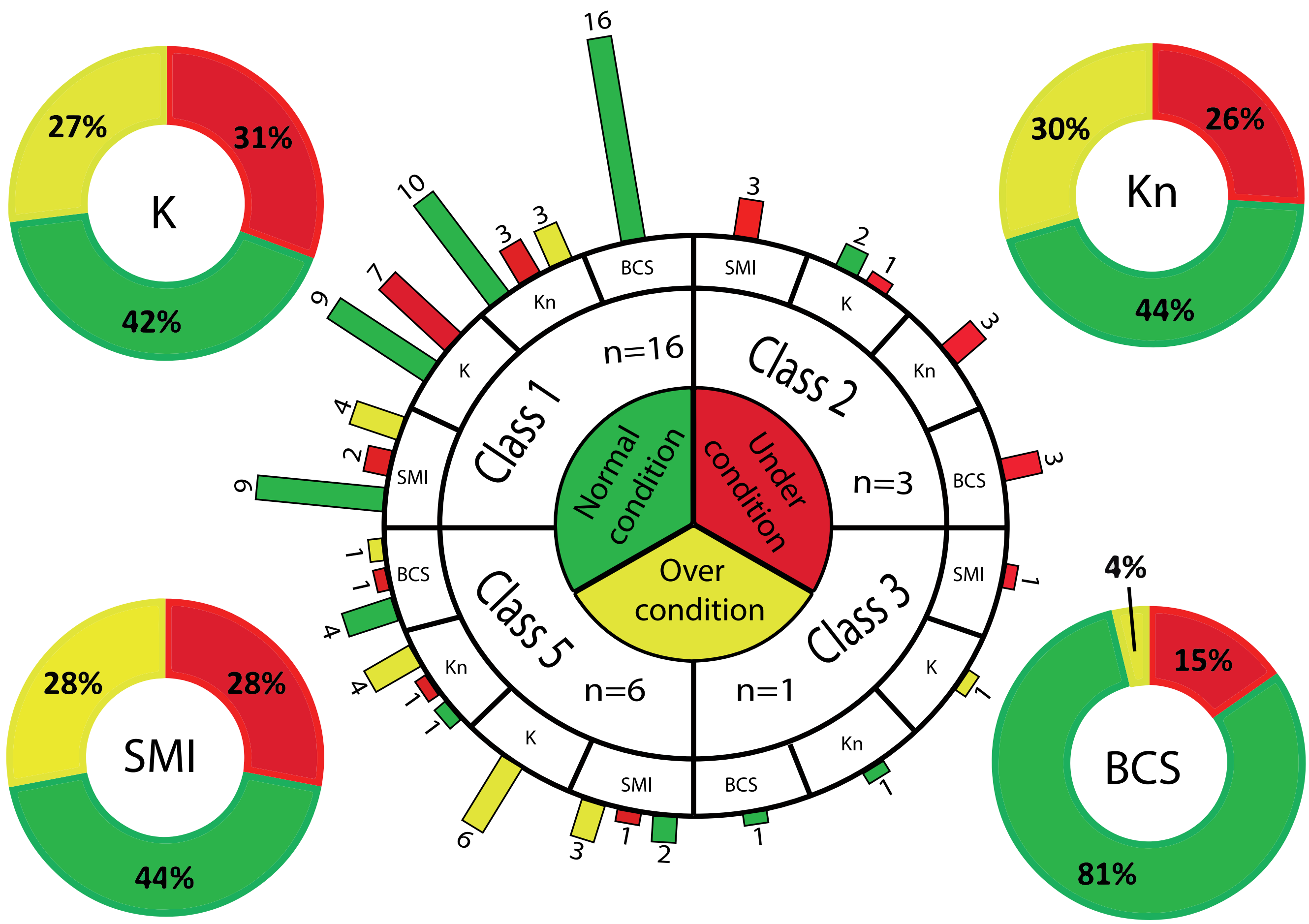

Figure 3. Distribution of the body condition (BC) data in this study. In the center of the larger circle, three colors are shown that represent the different interpretations of BC: Red indicates poor nourish condition, green indicates optimal BC, while yellow indicates fatty or even obese individuals. This circle is divided into four quarters representing each size class. Each quarter is subdivided into four sections that symbolize the different BC indices. On each of these subdivisions are bars indicating how many individuals present each type of the BC interpretation. Each small circle around the larger central circle represents the total population (*n* = 26), as interpreted with each of the four BC indices. Abbreviations: BCS: body condition index; K: Fulton index; Kn: relative condition index; SMI: scaled mass index.

Class V: All indices based on length and weight (isometric) showed this class mostly presented a high BC, although SMI and Kn also classified one crocodile with low BC. The BCS showed this class with normal BC, except for one individual with low BC (a different individual than that previously mentioned). All indices indicated one individual of 253 cm as that with the highest BC. We captured other two crocodiles but, due to their large size, the weights could not be obtained. We were therefore only able to calculate the BCS of the first (413 cm), with a BCS score of 3, and the second (441 cm), with a BCS score of 4.

DISCUSSION

K showed a strong relationship with body size, because of the assumption of isometric growth (LeCren, 1951). This produces the bias that smaller classes will present a poorer BC than larger classes. To prevent this, each size class must be analyzed independently (LeCren, 1951). However, this is unnecessary using any of the other indices analyzed; Kn and SMI do not take into account the type of growth, as they disregard the relationship with body size (LeCren, 1951; Cone, 1989; Peig and Green, 2009). On the other hand, BCS is based on morphological characteristics, which are independent of size, eliminating even the need to obtain the corporal measurements. BCS also lets us directly compare our results with those of other studies while, for the other indices, it is necessary to calculate the exponent "b", which requires both L and W data and it is not always possible to obtain.

This is an advantage of BCS that becomes evident when large crocodiles are captured, as recording the W data can be complicated or may require specialized equipment, with the result that the data of those individuals are not incorporated into calculations. With BCS, only technical experience is required and, while the validation is subjective, experience is not an important factor in BC categorization (Edmonson et al., 1989). However, the possible effects of sexual dimorphism have been not extensively researched and, therefore, require special attention (Platt et al., 2011; Barrios-Quiroz et al., 2012; Warner et al., 2016), although it has been observed that males have a larger head and body than females in some size classes (Barrios-Quiroz et al., 2012). Despite this, no differences in shape *per se* have been found between males and females, so we assume that this attribute should not affect the BCS assessment. Nevertheless, future research on BCS should explore sexual dimorphism.

The quartile system used to interpret the indexes based on L and W will always produce a quarter of the sample with low BC, one half with normal BC, and the other quarter with high BC. This is redundant if these data are not reinterpreted with a historical context (Mazzotti et al., 2009) or are compared with a direct method (Stevenson and Woods, 2006), which is usually destructive or very complicated to perform (Peig and Green, 2009). BCS is useful for making this comparison because the evaluation is based on regions that are affected by the nutritional situation, giving us a more direct approach. Making this comparison using BCS, we observe that most of the population presents a normal BC, with few individuals with low BC and only one individual with high BC. The results of BCS in class V seem to fit better with the hierarchical relationships of animals in captivity (J. Martínez, pers. comm.): animals with greater BC are dominant, while those of lower BC show submissive behavior. In class II, all of the indices except K present a low BC. In such cases, there should be no doubt regarding the accuracy of classification of the low BC. However, for our class I data, BCS must be used with caution because the results obtained are constant compared to those of the other indices (Fig. 2). This might be due to the variability of W and L in class I or the fact that energy reserves in this class could be found mostly in other body components, such as the body fat or the yolk sac in the newborn (Allsteadt and Lang, 1995). As a result of this and other studies about observations and criticism of the indices based on L and W, we agree with Stevenson and Woods (2006) and suggest that the use of different indices based on more than one paradigm to evaluate BC in the same population will provide results that more closely reflect reality.

ACKNOWLEDGMENTS

We thank the Mexican Science and Technology Council (CONACYT, by its Spanish acronym) for the scholarship grant 299939 to support RAOA in the program of M.Sc. in Natural Resources Management at the University of Guadalajara. Field and analytical work was funded by a University of Guadalajara grant to LIID. We also thank the ejido La Manzanilla for their participation, particularly José Martínez and Primitivo González, as their dedicated work on crocodile conservation and management made this project possible.

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