Herpetological Conservation and Biology 7(1):16-26.
Submitted: 13 September 2011; Accepted: 30 November 2011; Published: 6 May 2012.

PREDICTING TOTAL LENGTHS OF SPECTACLED CAIMAN (*CAIMAN CROCODILUS*) FROM SKIN MEASUREMENTS: A TOOL FOR MANAGING THE SKIN TRADE

GRAHAME WEBB[1,2], MATTHEW BRIEN[1,2,4], CHARLIE MANOLIS[1], AND SERGIO MEDRANO-BITAR[3]

[1]Wildlife Management International Pty. Limited, P.O. Box 530, Karama, Northern Territory 0813, Australia,
[2]School of Environmental Research, Charles Darwin University, Northern Territory 0909, Australia,
[3]Cra 5 No. 6-60 Apto 202, Edificio Urpive, Cartagena, Bolivar, Colombia,
[4]Corresponding author, e-mail: mbrien@wmi.com.au

***Abstract.*—Colombia uses a closed-cycle captive breeding program for producing *Caiman crocodilus* (mostly *C. c. fuscus*) skins for export. Skin size limits are used as a regulatory measure to exclude illegal wild-caught adults entering legal trade. However, the size limits employed were not well defined by morphological endpoints, and the degree of shrinkage between raw and processed skins was not well grounded in science. Thus, trimming and cutting of skins to meet market demand makes compliance with the limits problematic. We examined the relationship between *C. crocodilus* total length (TL) in freshly culled animals and the size of whole skins and skin pieces at different stages of preservation and tanning (raw wet-salted, wet blue, crust, and finished leather) in 276 farm-raised *C. crocodilus* (423–2,210 mm TL). We present formulae for accurately predicting the TL of Caimans from which whole skins or skin pieces originated. To account for tail tip amputations, we used standardized total length (TL_{ST}). The results provide resource agencies in Colombia better tools for establishing meaningful size limits, and provide the Parties to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) with a better mechanism for assisting Colombia with compliance. This approach may have application to the regulation of other species of reptile in trade, where size limits are part of the regulatory procedures.**

Key Words.—*Caiman crocodilus*; Colombia; management; prediction; regression; skins; trade

INTRODUCTION

Skin size limits can be effective tools for regulating the sustainable use of crocodilian species, if they reflect the size of crocodilian from which the skin was taken, and this size has biological significance. For example, in Papua New Guinea upper skin-size limits direct harvesting away from larger adults (wild and captive), and minimum skin-size limits restrict the export of small juveniles, which is considered wasteful (Ross 1998). A similar upper skin size limit applies in Indonesia for the same reason (Ross 1998). In both cases, the skin measure used is belly width, which from a practical and economic viewpoint cannot be trimmed without reducing the commercial value of the skin. In both Venezuela and Louisiana (USA), management regulations restrict hunting of wild crocodilian populations to the larger adult male portion (Gorzula 1978; Joanen and McNease 1987; Velasco and Ayarzagüena 1995). Skin-size limits are not a regulatory requirement for trade, but they provide an independent index of whether the country's harvest strategies (with regard to size) are meeting their conservation goals (Gorzula 1978; Joanen and McNease 1987; Velasco and Ayarzagüena 1995).

The wild population of *Caiman crocodilus* (Fig. 1) in Colombia is legally protected, although various uses (legal and illegal) are known or suspected to occur (Jenkins et al. 1994; Larriera et al. 2004). Caiman skins are heavily ossified relative to classic skins, with only the flanks historically having commercial value (Fuchs 2006). The management program in Colombia restricts the commercial use of *C. crocodilus* to production by captive breeding and rearing, and an extensive and sophisticated farming industry has evolved over the last 30 years (Jenkins et al. 1994; Larriera et al. 2004). Until 2006, Colombia's skin trade industry imposed on itself an annual export quota of 0.6 million farm-raised skins, which constrained legal commercial production; it was lifted in 2006 (Jenkins et al. 1994; Larriera et al. 2004). The farmed caimans are mostly *C. c. fuscus*, but include some *C. c. crocodilus*, which are morphologically similar and for the purposes of trade under CITES, are treated as the one species (*C. crocodilus*; Jenkins et al. 1994; Larriera et al. 2004). Colombia uses skin size (total length [TL_{SKIN}] of skin) limits as the primary legal regulatory measure. The TL_{SKIN} size limits originally restricted exports to skins less than 1.20 m long (CITES 1993. Notification to Parties No. 742. Available from http://www.cites.org/ eng/notif/1993/742 [Accessed 20 February 2011]), which theoretically prevented adult male and female *C. crocodilus* from being harvested for

Copyright (c) 2012. Grahame Webb. All rights reserved.



FIGURE 1. A female *Caiman crocodilus fuscus* on a nest at Betlahem Caiman Farm, Atlantic Coast, Colombia. (Photographed by Matthew Brien)

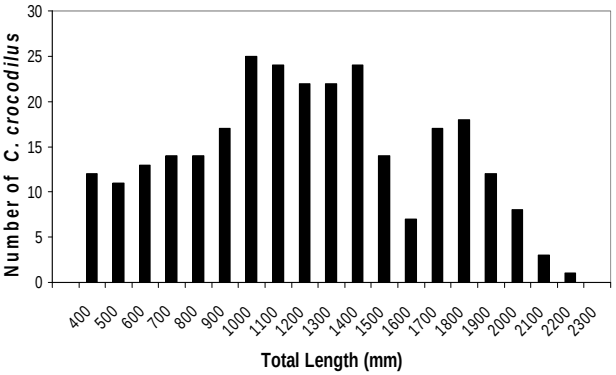


FIGURE 2. Size frequency distribution of 276 *Caiman crocodilus* examined in this study.

trade. This TL_{SKIN} size limit was also broadly consistent with the suspected commercial viability of raising *C. crocodilus* on farms at that time (Jenkins et al. 1994). Over time, the < 1.20 m TL_{SKIN} size limit has been adapted by Colombia (CITES 1997. Notification to Parties No. 978. Available from http://www.cites.org/eng/notif/1997/978.shtml [Accessed 20 February 2011]), and separate size limits (CITES 2002. Notification to Parties No. 031. Available from http://www.cites.org/eng/notif/2002/031.shtml [Accessed 20 February 2011]) now apply to a variety of different skin cuts in trade (flanks, throats, and tails). There have also been adjustments to allow the export of some larger *C. crocodilus* skins from breeding stock produced on farms, or legally obtained by farms from the wild as founder breeding stock (Jenkins et al. 1994).

However, the current TL_{SKIN} size limits are not defined by morphological endpoints on the skin, and the shrinkage-expansion factors referred to with processing are generalized and limited to only some skin pieces in trade. Trimming and cutting can therefore be used to make large skins comply with the size limits (Jenkins et al. 1994), which undermines Colombia's management goals and restricts the ability of the Parties to CITES to detect skins in trade that do not comply with the size limits prescribed in Colombia's national laws. Therefore, the aim of this study was to quantify the relationship between caiman total length (freshly culled - TL) and the size of whole skins and skin pieces in trade, so that TL_{SKIN} size limits, as a mechanism for regulating the size of Caiman taken, can be based on a sound scientific basis.

MATERIALS AND METHODS

Animals examined.—Farm-raised *C. crocodilus* (n = 276; mostly *C. c. fuscus*), ranging in TL from 423 mm to 2210 mm were provided by Caiman farmers in the Cartagena and Barranquilla areas, on the Atlantic coast of Colombia. We chose these animals to obtain similar sample sizes across the TL size range, with larger numbers in and around 1,200 mm TL (Fig.2). The sex ratio of animals was heavily biased towards males (219 males, seven females, 50 small animals of unknown sex), a consequence of temperature-dependent sex determination (TSD) in *C. crocodilus*, and the use of male-producing incubation temperatures on farms because males grow faster than females.

Measurements on freshly culled animals.—We took all measurements on freshly culled Caimans on 5–9 June 2009 and 27 September–10 October 2009. Body size indicators (all to ± 1 mm) were: head length (HL), the straight line distance between the tip of the snout (top jaw) to the posterior central margin of cranial platform along the dorsal surface; snout-vent length (SVL), the straight line distance between the tip of the snout (top jaw) and the anterior end of the cloaca measured along the ventral surface; and (TL), the straight line distance between the tip of the snout (top jaw) and the posterior tip of the tail (regardless of tail tip amputations), measured on a table with an embedded rule. In freshly culled animals, the muscles were relaxed relative to measurements taken on live, restrained animals.

Accounting for tail tip amputations.—TL_{SKIN} as a legally enforceable size limit can be confounded by naturally occurring tail tip amputations, tail trimming during the skinning process, and the deliberate trimming of the least valuable part of the skin (tails) for the purpose of meeting size limits (CITES, www.cites.org/eng/notif/1993.shtml; Jenkins et al. 1994). To account for these problems, we tried to ensure that animals selected for the study had more or less complete tails. This was not always possible due to the high occurrence of tail tip amputations in this species in the wild and in captivity (Fig. 3). It was also not always obvious whether there was a distinct amputation versus the loss of a few of the last, small, feathered scutes on

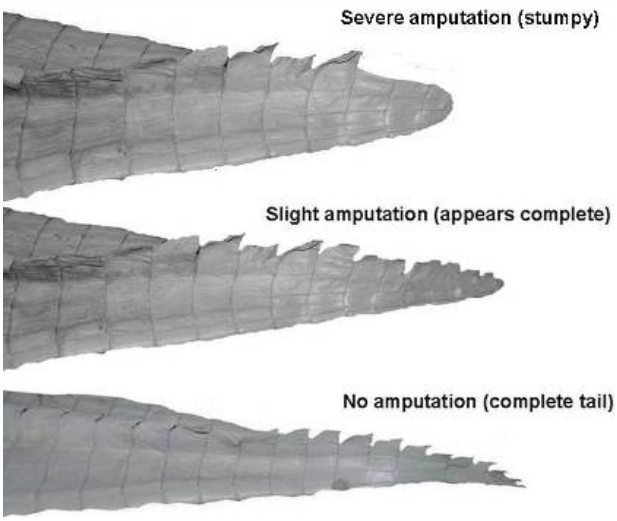


FIGURE 3. Extent of tail tip amputation on *Caiman crocodilus*. Only in smaller specimens is the feathered end of the tail completely intact.

the tail by erosion. As an independent measure of tail length, we counted the number of single vertical scutes on the tail.

Tails noted as 'complete' (Fig. 3) had a mean of 21.0 ± 1.61 (SD) single rows of vertical scutes (n = 178; range = 16–26 rows). We probably did not detect amputations of the relatively few animals with low counts. Those we noted as being obviously 'incomplete' and in which TL would be compromised, had a mean count of 15.9 ± 2.47 (SD) single rows (n = 98; range = 9–19 rows). We considered complete tails to be the "normal" situation, with the loss of a few single caudals due to abrasion and minor amputation. Virtually no large animals had the full complement of single raised scutes. Therefore predicting what the total length would have been, if they had the maximum number of single scutes, would have had no practical value. Our approach to correcting TL for amputations (the 'incomplete' part of the sample plus those rejected because of obvious amputations) was to accept that the animals with 'complete' tails (n = 178) were a realistic sample of animals without amputations. The relationship between SVL and TL in this sample was highly linear ($r^2 = 1.00$, $P < 0.0001$) and allowed us to predict TL from SVL of all 276 animals. Standardizing TL (TL_{ST}) in freshly culled Caimans with more or less complete tails was very important, as TL was the dependent variable in most relationships we describe in this paper.

Skinning.—Of the total sample of 276 animals, we prepared 146 as belly skins with a dorsal cut, in which the primary incision was down the middle of the dorsal armor or on either side of it (mean TL_{ST} = 1,337.4 ± 523.3 mm [SD]; n = 146; range = 415–2,258 mm; mean

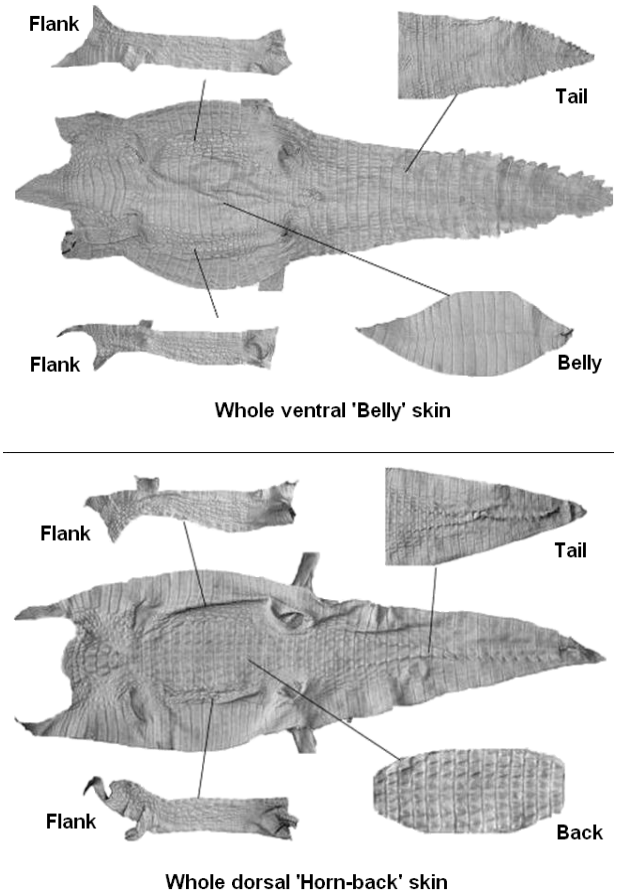


FIGURE 4. Whole ventral 'belly' skin and sectioned pieces (top), and whole dorsal 'hornback' skin and sectioned pieces (bottom) of a *Caiman crocodilus*.

SVL = 640.2 ± 245.7 mm). Of these, we retained 67 as whole belly skins (mean TL_{ST} = 1,287.7 ± 556.2 mm; range = 428–2240 mm), and we subdivided 79 (mean TL_{ST} = 1,379.5 ± 493.2 mm; range = 415–2,258 mm) into the standard pieces in trade (flank, tails, bellies, backs, throats; Fig. 4). We skinned the remaining animals (n = 130) with a ventral cut in which the primary incision was down the midline of the ventral surface. This produced a hornback skin, containing the dorsal armor down the midline, with the throat, belly, and tail skin subdivided into left and right pieces (Fig. 4). Of these, we retained 65 as whole hornback skins (mean TL_{ST} = 1,185.9 ± 463.3 mm; range = 429–2,069 mm) and we cut 65 into sectioned hornback pieces (mean TL_{ST} = 1,297.5 ± 392.1 mm; range = 492–2,092 mm). We attached a numbered CITES skin tag and an additional uniquely numbered plastic tag to each skin or skin piece for tracking through preservation and tanning. We took digital photographs of each skin and skin piece at each stage of measurement so that we could use the scale pattern to confirm identification if tags were lost.

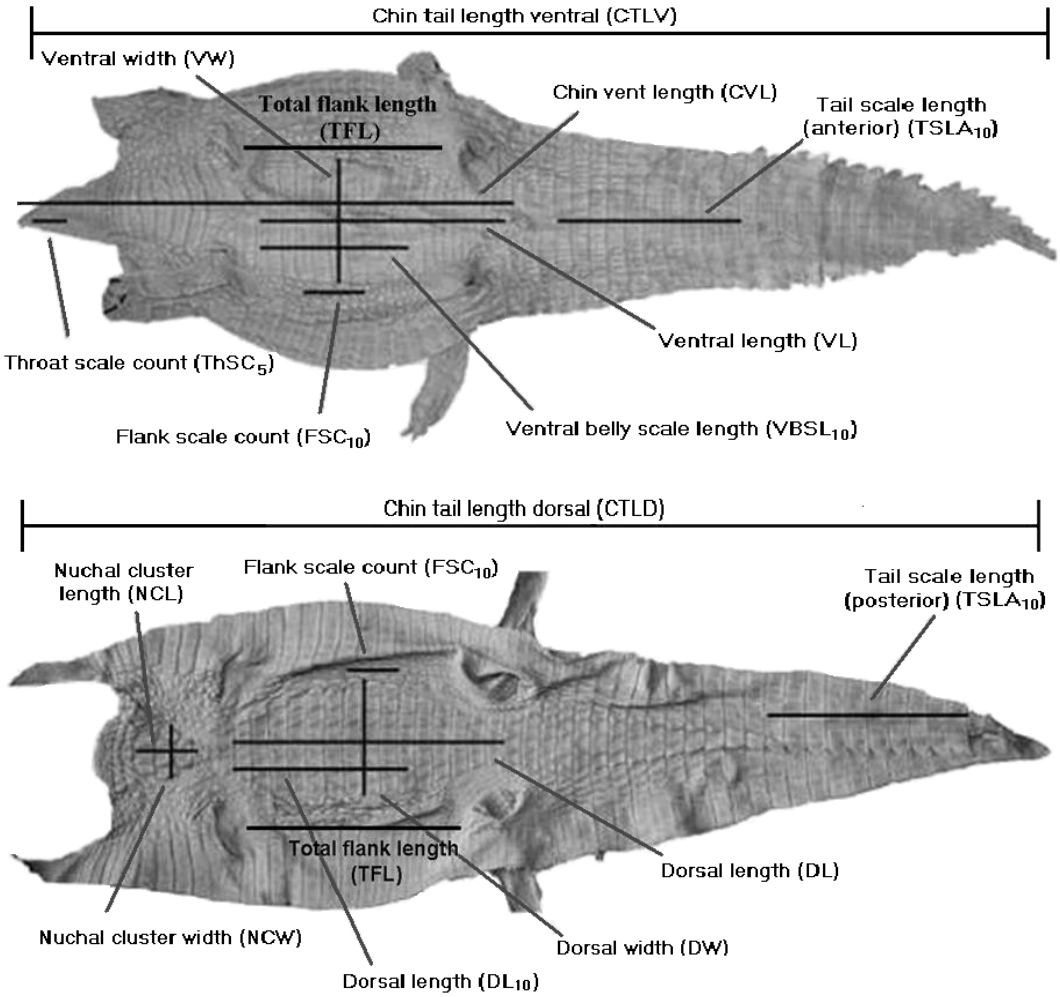


FIGURE 5. Location of measurements taken on whole belly (top) and whole hornback (bottom) skins of *Caiman crocodilus* used to predict TL_{ST}.

Skin measurements.—We recorded a number of new or novel skin measures, particularly ones from within the most valuable part of the skin and skin pieces; for example, between the leg skin on flanks, which we considered less likely to be altered by trimming (Appendix 1; Fig. 5). Flanks are a common skin product in trade and are one of the most common pieces of skin removed and traded from large Caimans (Jenkins et al. 1994). We considered other measures to have special utility for predicting TL_{ST} from products and scraps of skin left over from trimming if the scale pattern was distinctive enough to determine from where on the whole skin the piece originated (Appendix 1; Fig. 5). We recorded all measures with a steel tape measure or hard plastic ruler (± 1 mm).

Shrinkage and expansion of skins.—We recorded the same measurements on skins and skin pieces when raw wet-salted, tanned to wet-blue stage (skin is soft and hydrated), crust tanned (skin is stretched, dried and dehydrated), and finished (when the skin was dyed and finished into leather). We calculated correction factors for skins and pieces as they passed from raw wet-salted to wet-blue, to crust, and then to finished leather. However, these were often non-linear with increasing size, because a variety of different factors affect skin flexibility. Different parts of a skin are more heavily ossified than others, and the degree of ossification everywhere increases with increasing size, with the skins becoming thicker and less flexible. Skins are also fully hydrated in some stages of preservation and tanning but not in others.

Analyses.—The study involved a very large number of individual measures, increasing the probability of errors. We filtered the raw data by plotting measurements against each other and identifying obvious outliers (more than three SDs from the mean). We could easily rectify the problem in some cases, for example where SVL and TL had been transposed. In other cases, it was obvious

TABLE 1. Linear regression coefficients for predicting total length of live animals (TL), snout-vent length (SVL), head length (HL) from each other by linear regression (Y = a + bX). For HL and SVL, we used all *Caiman crocodilus* (n = 276) but for TL we used only animals with complete tails (n = 178).

Predict	From	a	b	SEE	%SEE	r^2	n
TL	SVL	12.84	2.00	25.28	2.36	1.00	178
TL	HL	-1.82	7.95	45.20	4.21	0.99	178
SVL	HL	-12.41	4.03	23.60	3.71	0.99	276
SVL	TL	-4.25	0.50	12.64	2.40	1.00	178
HL	TL	2.02	0.12	5.65	4.18	0.99	178
HL	SVL	4.63	0.25	5.83	3.63	0.99	276

that one measure in a series was grossly in error, for an unknown reason. If so, we deleted the measure from the analyses. We could not detect errors within three SDs . We assumed theses errors were randomly distributed, and we ignored them. We expected this would cause minimal effect on mean predicted values of TL_{ST} from other skin measures, but may have increased prediction errors slightly.

The majority of the analyses undertaken involved deriving formulae through which we could predict a dependent variable (mostly TL_{ST}) from skin measures (independent variables) for the complete size range of animals included in the study. As the aim was an accurate prediction across the complete size range, rather than describing the biological significance of a relationship, we examined the distribution of residuals closely to ensure the formulae were indeed accurate across the whole size range. We used simple linear regression models to predict TL_{ST} from each measurement. If the regression did not predict accurately in some parts of the size range, where the residuals were not normally distributed, we made the following adjustments: where there was a disjunct relationship (a point at which residuals were all positive or all negative), predictive accuracy for TL_{ST} was sometimes improved by subdividing the dataset and describing it by two regressions, of which each gave a normal distribution of residuals (despite the r^2 for each formula perhaps being less than for the combined data). The goal was a practical one of predicting TL_{ST} accurately from a skin measure. Some relationships between TL_{ST} and skin measures (especially skin measures that involved skin width) were curvilinear, in which case we used polynomial regressions ($Y = A + b_1X + b_2X^2$) to ensure a normal distribution of residuals across the complete data set.

Confidence levels around predictions from linear regression are curvilinear (Zar 1974), but in this case, with such highly auto-correlated data, there was no basis for assuming prediction errors should increase at either extreme. We assumed the Standard Error of Estimate (SEE) of Zar (1974), which is the mean square root of all residuals squared (to account for positive and negative residuals), was a good approximation of the SD at the mean TL_{ST} value, with variation generally decreasing in animals below the mean TL_{ST} and increasing in animals above the mean TL_{ST}. To account simply for the changing prediction error with size, we expressed the SEE as a percentage of mean TL_{ST} (% SEE), which allowed approximate scaling of the error across the complete size range. We used a significance level of $\alpha = 0.05$ for all statistical tests.

RESULTS

Measurements on freshly culled animals.—The relationships between TL, SVL and HL in freshly culled animals were linear (Table 1) and so each could be predicted accurately from each other by linear regression. Where TL was used to predict HL or SVL, or be predicted from them, we used only the values from animals noted as having complete tails (n = 178). The formula used to predict TL from SVL (Table 1) was thus the one we used to predict TL_{ST} from SVL for all individuals, creating the dependent variable in most other analyses.

Predicting TL_{ST} from skins and skin pieces.—Simple linear regression models ($TL_{ST} = a + bX$; where X = the relevant skin measure) described a high proportion of the general variation between TL_{ST} and a skin measure across the complete size range ($r^2 > 0.95$). When tested with four relationships, the results for %SEE matched the expected distribution from a conventional SD reasonably well: ± 1% SEE contained 73.3 ± 3.71% (SE; n = 4) of readings; ± 2% SEE contained 92.7 ± 3.10% of readings; and ± 3%SEE contained 99.0 ± 0.60% of readings. The accuracy with which TL_{ST} could be predicted from the many other skin measures taken varied from measure to measure. Not surprisingly, more accurate and precise predictions of TL_{ST} were obtained from whole skin measures relative to measures taken on small pieces of skin.

Whole skins.—We could accurately predict TL_{ST} from whole skins, using the following measurements: CTLV, CVL, VL, and VW for belly skins and CTLD, DL, and DW for hornback skins (Table 2; Fig. 4). For both whole belly and hornback skins, the most accurate formulae for predicting TL_{ST} (lowest prediction errors) from skin measures were derived from multiple regressions (for whole belly skins using VL and VW, and for whole hornback skins using DL and DW; Table 2; Fig. 4). Regardless of what TL size limit may be prescribed in freshly culled *C. crocodilus*, the formulae

TABLE 2. Formulae for predicting TL_{ST} (in mm ± SEE) from measurements taken on skins or skin pieces throughout the stages of preservation and tanning.

		Formula for predicting TL_{ST} (in mm ± SEE)			
Dimensions	Type of skin	Raw Wet-Salted	Wet-Blue	Crust	Finished
VL and VW	Whole belly	78.40 + 2.61 VL + 2.09 VW ± 46.11	95.71 + 2.73 VL + 1.71 VW ± 35.99	65.02 + 2.88 VL + 1.69 VW ± 30.45	74.11 + 2.51 VL + 2.29 VW ± 34.01
DL and DW	Whole hornback	81.64 + 2.23 DL + 3.08 DW ± 35.08	122.46 + 2.42 DL + 2.94 DW ± 38.45	104.22 + 2.45 DL + 3.13 DW ± 44.98	97.02 + 2.49 DL + 3.05 DW ± 39.87
TFL	Flank piece	34.24 + 4.41 TFL ± 46.37	55.70 + 3.92 TFL ± 68.02	49.40 + 3.84 TFL ± 46.35	49.71 + 3.79 TFL ± 53.30
$\bar{X}$ FSL	Flank piece	62.33 + 103.11 $\bar{X}$ FSL ± 100.94	100.06 + 96.61 $\bar{X}$ FSL ± 90.80	142.00 + 94.18 $\bar{X}$ FSL ± 100.98	166.93 + 91.49 $\bar{X}$ FSL ± 73.67
$VBSL_{10S}$	Belly piece	12.24 + 6.75 $VBSL_{10S}$ ± 51.31	84.65 + 6.24 $VBSL_{10S}$ ± 51.62	87.90 + 6.08 $VBSL_{10S}$ ± 57.63	105.55 + 6.03 $VBSL_{10S}$ ± 53.58
$\bar{X}$ VBSL	Belly piece	< 20mm: 72.63 + 65.88 $\bar{X}$ VBSL ± 50.36; > 20mm: -232.25 + 77.42 $\bar{X}$ VBSL + 89.07	49.52 + 63.12 $\bar{X}$ VBSL ± 48.91	43.20 + 63.79 $\bar{X}$ VBSL ± 55.24	38.61 + 63.00 $\bar{X}$ VBSL ± 56.83
DL_{10S}	Hornback piece	21.30 + 5.89 DL_{10S} ± 57.19	131. 21 + 4.92 DL_{10S} ± 40.75	88.44 + 5.15 DL_{10S} ± 31.70	115.30 + 4.92 DL_{10S} ± 59.67
$\bar{X}$ TSLA	Tail belly piece	-46.00 + 65.60 $\bar{X}$ TSLA ± 36.83	55.35 + 60.01 $\bar{X}$ TSLA ± 50.72	22.14 + 59.74 $\bar{X}$ TSLA ± 46.50	31.60 + 59.84 $\bar{X}$ TSLA ± 35.45
$\bar{X}$ TSLP	Tail hornback piece	15.11 + 58.07 $\bar{X}$ TSLP ± 34.71	85.70 + 54.39 $\bar{X}$ TSLP ± 41.30	44.15 + 55.25 $\bar{X}$ TSLP ± 43.0	51.00 + 54.76 $\bar{X}$ TSLP ± 34.25
$\bar{X}$ ThSL	Throat piece	33.43 + 199.38 $\bar{X}$ ThSL ± 103.50	6.22 + 212.66 $\bar{X}$ ThSL ± 96.08	35.20 + 209.32 $\bar{X}$ ThSL ± 117.13	71.04 + 207.28 $\bar{X}$ ThSL ± 140.59
NCL and NCW	Nuchal cluster	6.86 + 9.49 NCL + 8.62 NCW ± 50.81	76.31 + 6.58 NCL + 10.48 NCW ± 46.71	23.83 + 8.46 NCL + 8.75 NCW ± 52.01	13.50 + 9.69 NCL + 7.12 NCW ± 42.99

provided in Table 2 allow the skin dimensions of that sized animal to be predicted with confidence (see Table 3 for a 1,200 mm TL_{ST}, example).

Flanks and flank pieces.—Although measures of flank length on whole skins varied between hornback and belly skins, with the flank still attached, this was not the case when the flanks were separated and measured as skin pieces. Thus, we combined measurements of Total Flank Length (TFL) and Mean Flank Scale Length ($\bar{X}$ FSL) on hornback and belly skins (increasing sample sizes) to derive formulae predicting TL_{ST} from flank skins, using TFL (if the end points are present), or $\bar{X}$ FSL (if the end points had been trimmed off; Table 2; Fig. 5).

Other skin pieces.—TL_{ST} could be predicted accurately from belly skin pieces using Ventral Belly Scale Length: 10 scales ($VBSL_{10S}$) if end points were present, otherwise Mean Ventral Belly Scale Length ($\bar{X}$ VBSL) could be used (Table 2; Fig. 5). TL_{ST} could be predicted accurately from hornback skin pieces using Dorsal Length: 10 scales (DL_{10S}; Table 2; Fig. 5). For separate tail pieces, TL_{ST} could be predicted accurately using either Mean Tail Scale Length: anterior ($\bar{X}$ TSLA) for belly skins or Mean Tail Scale Length: posterior ($\bar{X}$ TSLP) for hornback skins (Table 2; Fig. 5). Regardless of the cut (belly or hornback), TL_{ST} could be predicted from throat pieces using Mean Throat Scale Length ($\bar{X}$ ThSL; Table 2). TL_{ST} could also be predicted accurately using a multiple regression formula involving both Nuchal Cluster Length (NCL) and Nuchal Cluster Width (NCW; Table 2; Fig. 5).

TABLE 3. Predicted skin lengths (mm) of a *C. crocodilus* of 1,200 mm TL_{ST}, with the skin in raw wet-salted and finished leather states using formulae in Table 2.

Dimension	Raw Wet-Salted Length (mm)	Finished Leather Length (mm)
VL	292.3	294.0
VW	164.8	168.7
DL	338.7	296.5
DW	115.7	116.3
TFL	264.6	303.7
$\overline{X}$ FSL	11.2	11.3
$\overline{X}$ TSLA	19.0	19.5
$\overline{X}$ TSLP	20.4	21.2
$\overline{X}$ ThSL	5.9	5.5
$VBSL_{10S}$	176.1	181.5
$\overline{X}$ VBSL	17.3	18.4
DL_{10S}	200.5	220.6
NCL	74.9	78.9
NCW	55.9	59.2

Shrinkage and expansion of skins.—The extent of shrinkage or expansion of a particular part of the skin was sometimes constant over the whole size range, allowing a single correction factor to be applied, but in other cases the correction factors themselves changed with increasing TL_{ST} (Table 4; Fig. 6). To explain the dynamic nature of shrinkage and expansion rates during preservation and tanning, we examined TFL in more detail (Table 4; Fig. 6). TFL in the wet-blue (WB) stage averaged 10.3 (± 0.66% SE) longer than in the raw wet-salted (RWS) stage (Fig. 6a). Total Flank Length at the crust (CR) stage averaged 13.5 (± 0.50% SE) longer than in the RWS stage (Fig. 6b). The relationship between TFL in the finished (F) stage had a curvilinear relationship with TFL in the RWS stages, averaging about 15% longer in the mid-range of flank sizes (Fig. 6c). Crust flanks were generally longer than WB flanks (Fig. 6d), but the relationship with increasing TL_{ST} was again curvilinear. Finished flanks averaged between 3.5% and 5.2% longer than in the WB stage (Fig. 6e) and 0.9 ± 0.31% longer than in the CR stage (Fig. 6f).

DISCUSSION

Caiman crocodilus is on Appendix II of CITES, which allows for any country in which the species naturally occurs to engage in international trade in wild harvested or farmed caimans if the trade is carried out in accordance with Article IV of the CITES Convention (CITES 1979. Article IV. Regulation of Trade in Specimens of Species Included in Appendix II. Section 2. Available from http://www.cites.org/eng/disc/text .php#IV [Accessed 20 February 2011]). Two obligations of

TABLE 4. Total flank length (TFL), measured between the leg skin, from different sized Caimans with complete tails (TL_{ST}), in raw wet-salted (RWS), wet blue (WB), crust (CR) and finished (F) stages. The percentage change relative to the RWS stage is in brackets.

TL_{ST} mm	RWS	WB	CR	F
500	148	162.94 (+ 10.33%)	167.57 (+ 13.47%)	157.90 (+ 6.92%)
750	204	225.54 (+ 10.33%)	231.96 (+ 13.47%)	227.36 (+ 11.22%)
1000	261	288.14 (+ 10.33%)	296.34 (+ 13.47%)	298.40 (+ 14.26%)
1250	318	350.74 (+ 10.33%)	360.73 (+ 13.47%)	368.89 (+ 16.04%)
1500	375	413.35 (+ 10.33%)	425.11 (+ 13.47%)	436.66 (+ 16.55%)
1750	431	475.95 (+ 10.33%)	489.49 (+ 13.47%)	499.57 (+ 15.81%)
2000	488	538.55 (+ 10.33%)	553.88 (+ 13.47%)	555.48 (+ 13.80%)

Article IV (Paragraph two) establish practical preconditions for issuing a CITES export permit, a prerequisite for engaging in international trade. These obligations are, that a 'Scientific Authority of the State of export has advised that such export will not be detrimental to the survival of that species'; and that a 'Management Authority of the State of export is satisfied that the specimen was not obtained in contravention of the laws of that State for the protection of fauna and flora' (CITES 1979. Article IV. Regulation of Trade in Specimens of Species Included in Appendix II. Section 2. Available from http://www.cites.org/eng/disc/text.php#IV [Accessed 20 February 2011]).

The management program that Colombia developed to harvest *C. crocodilus* sustainably largely overcame the precondition requiring assurance from the Scientific Authority that no detriment would occur to the wild population by restricting trade to specimens bred and raised in captivity. Some founder breeding stock were originally taken from the wild with compensation back to the wild at a later stage if it was deemed necessary (Jenkins et al. 1994). After this, trade was designed to be independent of the wild, and thus pose no threat to the survival of wild populations. By avoiding a wild harvest program, Colombia also avoided the wild population monitoring obligations of a wild harvest program, which would have been a difficult commitment to make given long-standing civil unrest in some parts of the country (Jenkins et al. 1994; Larriera et al. 2004).

As a further safeguard, Colombia introduced a maximum skin size limit (< 1.20 m) for farm-produced skins (Jenkins et al. 1994; Larriera et al. 2004). This was commensurate with the commercial inability to raise *C. crocodilus* in captivity to a large size in an economically

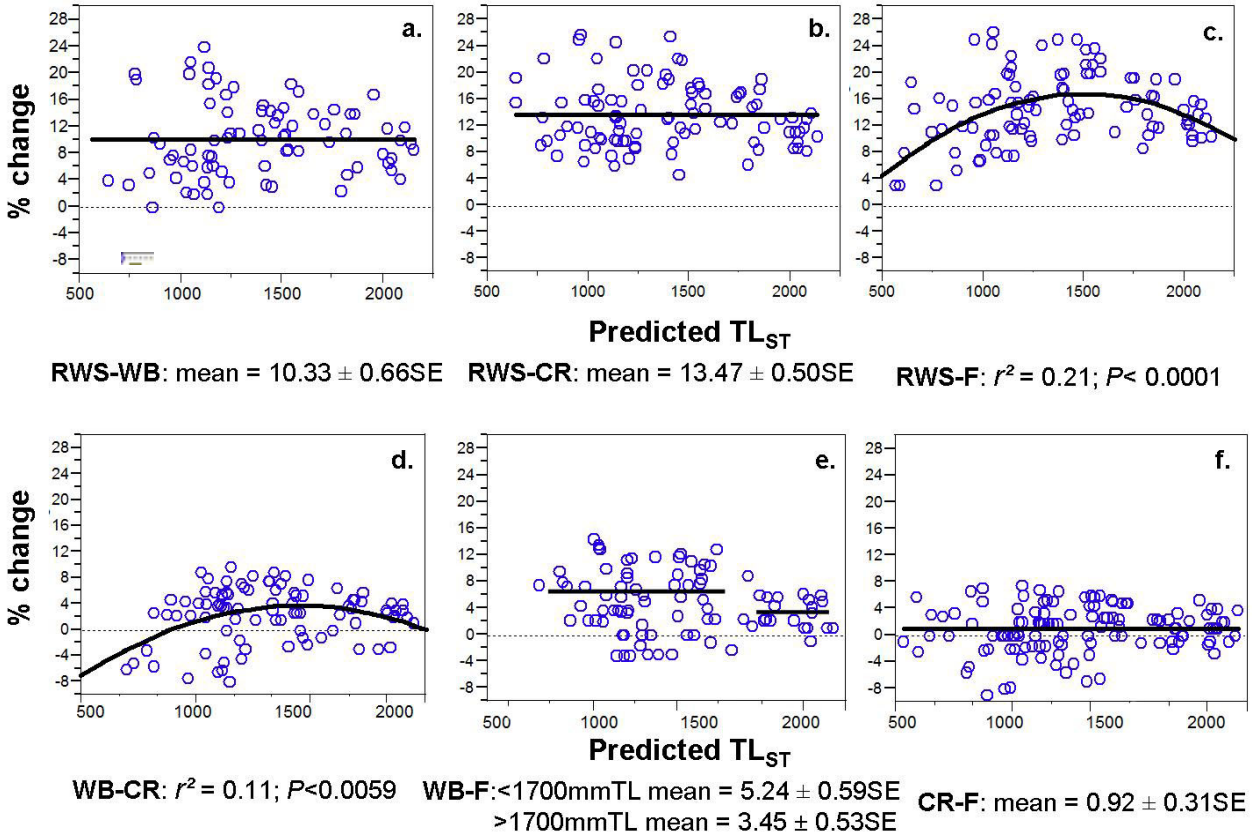


FIGURE 6. Percentage change (correction factors) in total flank length (TFL), measured between the skin of the front and back legs, during transition from raw wet-salted (RWS) to a) wet-blue (WB), b) crust (CR), and c) finished leather (F) stages; from wet-blue (WB) to d) crust (CR) and e) finished leather (F); and from crust (CR) to f) finished leather (F); as a function of increasing total length of *Caiman crocodilus* (TL_{ST}).

viable way, which was a production limitation at the time farming started (Jenkins et al. 1994; Larriera et al. 2004). It also created a further barrier to the illegal harvest for trade of larger, adult, wild-caught caimans, arguably the most valuable component of the wild population (Jenkins et al. 1994; Larriera et al. 2004). Nevertheless, adherence to the laws established by Colombia to protect the wild population, including the size limits on farm-produced skins, have been essential for overcoming the precondition that the specimen was not obtained in contravention of these laws.

Caiman farming activities in Colombia have been remarkably successful and production occurs on a larger scale than any other country (Larriera et al. 2004; Caldwell 2008). However, the current size limits (CITES 2002. Notification to Parties No. 031. Available from http://www.cites.org/eng/notif/2002/031.shtml [Accessed 20 February 2011]), although designed to be practical to implement and to complement the steadily evolving production technology on farms, are problematic from an enforcement viewpoint. A central issue for Colombia's trade is that Caimans larger than 1.2 m TL are legally breed and raised on some farms (Jenkins et al. 1994; Larriera et al. 2004). Caimans have highly variable individual growth rates, which mean that fast growing individuals can exceed 1.2 m TL while others in the same year class are below 1.2 m TL (Jenkins et al. 1994; Larriera et al. 2004). Delays in culling due to fluxes in market demand or other factors can result in Caimans on farms exceeding 1.2 m TL before skinning takes place (even though it may or may not be economically optimal). Mortality and the replacement of breeding stock is a further avenue through which skins > 1.2 m TL are legally produced on farms (Jenkins et al. 1994; Larriera et al. 2004).

Due to these constraints, Colombia introduced flexibility into the size limits to account for legally produced oversized skins (CITES 2002. Notification to Parties No. 031. Available from http://www.cites.org/eng/notif/2002/031.shtml [Accessed 20 February 2011]). This approach arguably eroded the utility of size limits as a barrier against larger, wild-caught adult skins entering trade (CSG 2008. Colombian Farm Management. Available from http://www.iucncsg.org/ph1/modules/Publications/newsletter/CSG_Newsletter_27_2.pdf [Accessed 20 February 2011]). The degree to which Caiman skins and

flanks can be trimmed to meet prescribed size limits and the changes that occur during the tanning process have added additional confusion and complexity.

Our study provides the tools needed for assessing the size of Caimans from which skins and skin products have been derived, regardless of the form in which the skins are exported. They also account for changes in the morphometric relationships between two body dimensions due to changes in shape and thickening of particular scutes that occur with increased size. Authorities in Columbia can use the tools prior to export and by the Parties to CITES at the point of import. They overcome anomalies caused by shortening skins to meet size limits, which has long been recognized as a problem (CITES 1993. Implementation of the Convention in Colombia. Available from http://www.cites.org/eng/com/sc/29/E29. [Accessed 20 February 2011]). Indeed, it prompted the original CITES review of Colombia's program (Jenkins et al. 1994). The results also provide a scientific basis for establishing biological significant size limits, in terms of the size of Caiman (rather than size of skin), that appears to be the original intent of Colombia's legislation. This study does not provide the morphological tools needed for discriminating between farm raised and wild skins *per se*, independent of size, although it seems likely that such tools could be developed and would be an obvious extension of this study.

At the present time, the size structure (in terms of Caiman TL_{ST}) associated with skins exported from Colombia has never been quantified, and so the relative role of oversized versus undersized skins in trade is unknown. This is perhaps the first step in deciding whether size limits should be definitive, as in Papua New Guinea (Ross 1998). There seems little doubt that a definitive size limit of caimans would greatly simplify regulation nationally and internationally, and would be a strong disincentive to laundering wild adult skins through farms. The approach taken in this study could easily be replicated not only with other species of crocodilian, but for other reptile species whose skins are in trade but subject to size limits.

Acknowledgments.—This study is a direct result of discussions held at the 19th Working Meeting of the IUCN-SSC Crocodile Specialist Group in Santa Cruz de la Sierra, Bolivia (2–6 June 2008), and we take this opportunity to thank all who participated in the discussions. Base funding for the study was provided to the CSG from Caiman farmers in Colombia, and Wildlife Management International Pty. Limited (WMI) provided additional support. Farms that contributed to the study financially and/or through the provision of Caimans for the study include: Garbe (Frank Garcia), Repticosta (Roberto Lafourie), Fauna Silvestre (John Calderon), Babilandia (Jose Malagon), Betlahem (Jorge Saieh), Zoofaucol (Alberto Pinilla),,Reptibol (Bernardo Maya), Zoocar (Jorge Lamprea), Fauna Exotics (Alfonso Barbosa), Reptiles del Caribe (Francisco Mogollon), C.I. Caicsa (Luis Felipe Martinez), and Reptiles World (Jorge Orozco). Jorge Saieh (C.I. Exotica Leather) and Francisco Mogollon (C.I. Curtiembre del Caribe) also provided the tanning facilities in which the skins were processed. We would particularly like to thank Jorge Saieh and Francisco Mogollon for their contributions, without which the study could not have been undertaken. Direct assistance with the measurements, recording, translation, and logistics of the study in Colombia came from Jorge Saieh, Francisco Mogollon, John Calderon, Antonio Gomez, and Giovanna Webb, and we are most grateful for their help. The support and encouragement of CSG Deputy Chairs, Alejandro Larriera and Dietrich Jelden, is gratefully acknowledged.

LITERATURE CITED

Caldwell, J. 2008. World Trade in Crocodilian skins 2005–2007. United Nations Environment Programme-World Conservation Monitoring Centre. Cambridge, UK.

Fuchs, K. (Ed.). 2006. The Crocodilian Skin: Important Characteristics in Identifying Crocodilian Species. Chimaira, Frankfurt and Main, Germany.

Gorzula, S. 1978. An ecological study of *Caiman crocodilus crocodilus* inhabiting savanna lagoons in the Venezuelan Guayana. Oecologia 35:21–34.

Jenkins, R.W.G., F.W. King, and J. Ayarzagüena. 1994. Management of captive breeding of wildlife in Colombia, with particular reference to *Caiman crocodilus fuscus.* 31st Meeting of the CITES Standing Committee Report, Strasbourg, France.

Joanen, T., and L. McNease. 1987. The management of Alligators in Louisiana, USA. Pp. 33–42 *In* Wildlife Management: Crocodiles and Alligators. Webb, G.J.W., S.C. Manolis, and P.J. Whitehead (Eds.). Surrey Beatty & Sons, Sydney, Australia.

Larriera, A., G. Webb, A. Velasco, M. Rodriguez, and B. Ortiz. 2004. Crocodile Specialist Group Mission to Colombia: Final Report. Crocodile Specialist Group, Darwin, Australia.

Ross, J.P. (Ed.). 1998. Status Survey and Conservation Action Plan: Revised Action Plan for Crocodiles. IUCN-World Conservation Union, Gland, Switzerland.

Velasco, A., and J. Ayarzagüena. 1995. Situacion actual de las poblaciones de baba (*Caiman crocodilus*) sometidas a aprovechamiento commercial en los llanos Venezolanos. Publicaciones de la Asociación Amigos de Donaña 5. 71 p.

Zar, J.H. (Ed.). 1974. Biostatistical Analysis. 1st Edition. Prentice-Hall, Inc., Englewood Cliffs, USA.



GRAHAME WEBB completed his Ph.D. in Zoology in 1973 and has been active in wildlife research, conservation, and management, nationally and internationally, since then. He has published some 150 scientific papers and prepared hundreds of consultancy reports and conference papers. He is Chairman of the IUCN-SSC Crocodile Specialist Group, Director of Wildlife Management International Pty. Limited, an Adjunct Professor at Charles Darwin University, and Chairman of the Northern Territory Environment Protection Agency. He is regarded as one of the world's leading authorities on crocodilian research and management, and on the concept of conserving wildlife through sustainable use. In 2001, he was awarded the Clunies Ross National Science and Technology Award, for his contribution to a new vision for wildlife conservation based on sustainable use. In 2003, he was awarded an Australian Centenary Medal, for his contribution to crocodile research and to the establishment of The Essington School in Darwin. (Photographed by Giovanna Webb)



MATTHEW BRIEN received his B.Sc. (Hons I) in Zoology from the University of Queensland, Australia (2004). Since then he has worked mainly on the conservation, management, and biology of crocodilians in various parts of the world, including Australia, USA, Colombia, Belize, and Costa Rica. He has also been involved in research efforts involving introduced Burmese pythons in the Florida Everglades. In 2011, he was awarded a national scholarship (Australian Post Graduate Award) and began a Ph.D. at Charles Darwin University studying behavior of hatchling Saltwater Crocodiles (*Crocodylus porosus*) and the factors important for growth and survival. (Photographed by Jemeema Brien)



CHARLIE MANOLIS received his B.Sc. in Zoology/Biochemistry from the University of New South Wales, Australia. Since graduating in 1979, he has worked mainly on the conservation, management, and biology of crocodilians in various parts of the world. He is an active member of the IUCN-SSC Crocodile Specialist Group, with responsibility for the Australia and Oceania region. Current research topics include satellite tracking of Saltwater Crocodiles (*Crocodylus porosus*), nutrition of farmed crocodiles, and captive breeding of Hawksbill Sea Turtles (*Eretmochelys imbricata*). (Photographed by Wendy Manolis)



SERGIO MEDRANO-BITAR received his B.Sc. from the Universidad Nacional de Colombia in 1989. He has since been working on the conservation of reptiles in Central and South America, including crocodiles, sea turtles, tortoises, as well as with boas and iguanas. He is an active member of the IUCN-SSC, Crocodile Specialist Group with responsibility for Colombia. He is currently involved in the conservation of crocodiles in the Caribbean region of Colombia and is undertaking a Master's degree in Wildlife Management. (Photographed by John Calderon)

APPENDIX 1. Measurements taken on *Caiman crocodilus* skins and skin pieces (see Fig. 5) at different stages of preservation and tanning. Flank measures were taken separately on ventral and dorsal cut skins, and skin pieces, but were combined as appropriate for analyses.

Measurement	Abbreviation	Measurement type	Definition
Ventral or belly skin			
Chin-vent Length	CVL	Length (mm)	Anterior tip of untrimmed throat skin to the anterior end of the vent.
Chin-tail Length Ventral	CTLV	Length (mm)	Anterior tip of the untrimmed throat skin to the posterior tip of tail or point of tail tip amputation.
Ventral Length	VL	Length (mm)	Anterior edge of the first scale row posterior to the collar, in the midline, to the anterior end of the vent.
Ventral Width	VW	Length (mm)	Widest row of rectangular ventral scales on the belly, measured from the outer margin of the scales, demarcated by the flanks.
Total Flank Length	TFL	Length (mm)	Posterior edge of the front leg to the anterior edge of the back leg in the midline of the flank. Measured only on flanks separated from the whole skin (for BELLY and HORNBACK skins).
Ventral Belly Scale Length (10 scales)	$VBSL_{10S}$	Length (mm)	Midline distance from the anterior edge of first uniform scale row posterior to the collar, and the trailing edge of the 10th scale row posteriorly.
Mean Ventral Belly Scale Length	$\overline{X}$ VBSL	Average scale length (mm)	$VBSL_{10S}$ divided by 10.
Tail Scale Length (anterior) 10 scales	$TSLA_{10S}$	Length (mm)	Midline distance from the anterior edge of first uniform scale row posterior to the vent, and the trailing edge of the 10^{th} scale row posteriorly.
Mean Tail Scale Length (anterior)	$\overline{X}$ TSLA	Average scale length (mm)	$TSLA_{10S}$ divided by 10.
Throat Scale Count (5 cm)	$ThSC_5$	Scale count (0.1 scale)	Number of midline scales in a 5 cm length of gular skin extending posteriorly from the chin tip where untrimmed.
Mean Throat Scale Length	$\overline{X}$ ThSL	Average scale length (mm)	$ThSC_5$ divided by 50.
Flank Scale Count (10 cm)	FSC_{10}	Scale count (0.1 scale)	Number of scales in a 10-cm length centrally situated within the flank (for BELLY and HORNBACK skins).
Mean Flank Scale Length	$\overline{X}$ FSL	Average scale length (mm)	FSC_{10} divided by 100 (for BELLY and HORNBACK skins).
Dorsal or hornback skin			
Dorsal Length	DL	Length (mm)	Length of the dorsal armor from the anterior edge of the first row of four complete dorsal osteoderms to the anterior of the first row of osteoderms immediately posterior to where the back legs attach.
Dorsal Width	DW	Length (mm)	Widest row of keeled dorsal osteoderms on the dorsal armor measured between the outer margin of the scales.
Chin-tail Length Dorsal	CTLD	Length (mm)	Distance between a line joining the anterior tips (left and right) of untrimmed throat skin, on a hornback skin, to the posterior tip of tail or point of tail tip amputation.
Nuchal Cluster Length	NCL	Length (mm)	Anterior to the posterior midline margins of the cluster of heavily ossified scales on the neck.
Nuchal Cluster Width	NCW	Length (mm)	Maximum width of the cluster of heavily ossified scales on the neck.
Dorsal Length (10 scales)	DL_{10S}	Length (mm)	Midline distance between the anterior edge of the first uniform row of osteoderms on the dorsal armor, and the posterior edge of 10th row posteriorly.
Mean Dorsal Armor Scale Length	$\overline{X}$ DASL	Average scale length (mm)	DL_{10S} divided by 10.
Tail Scale Length (posterior) 10 scales	$TSLP_{10S}$	Length (mm)	Length of 10 scales on the tail measured dorsally or on the side, immediately posterior of the caudal join where the two rows of single raised scutes become one row.
Mean Tail Scale Length (posterior)	$\overline{X}$ TSLP	Average scale length (mm)	$TSLP_{10S}$ divided by 10