Regression analysis between body and head measurements of Chinese alligators (*Alligator sinensis*) in the captive population

X. B. Wu, H. Xue, L. S. Wu, J. L. Zhu & R. P. Wang

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Abstract

*Regression analysis between body and head measurements of Chinese alligators (*Alligator sinensis*) in the captive population.*— Four body–size and fourteen head–size measurements were taken from each Chinese alligator (*Alligator sinensis*) according to the measurements adapted from Verdade. Regression equations between body–size and head–size variables were presented to predict body size from head dimension. The coefficients of determination of captive animals concerning body– and head–size variables can be considered extremely high, which means most of the head–size variables studied can be useful for predicting body length. The result of multivariate allometric analysis indicated that the head elongates as in most other species of crocodilians. The allometric coefficients of snout length (SL) and lower ramus (LM) were greater than those of other variables of head, which was considered to be possibly correlated to fights and prey. On the contrary, allometric coefficients for the variables of obita (OW, OL) and postorbital cranial roof (LCR), were lower than those of other variables.

Key words**:** Regression analysis, Allometry, Chinese alligator.

Resumen

*Análisis de regresión entre las mediciones del cuerpo y la cabeza del aligator chino (*Alligator sinensis*) en las poblaciones en cautividad.*— Se tomaron medidas de cuatro dimensiones del cuerpo y catorce de la cabeza de cada uno de los aligatores chinos *(Alligator sinensis)* según las mediciones de Verdade adaptadas. Se presentaron ecuaciones de regresión entre las variables del tamaño del cuerpo y de la cabeza, para predecir el tamaño corporal a partir de las dimensiones cefálicas. Puede considerarse que los coeficientes de determinación de los animales cautivos, concernientes a las variables del tamaño del cuerpo y la cabeza son muy altos, lo que significa que la mayoría de las variables del tamaño cefálico estudiadas pueden ser útiles para predecir la longitud del cuerpo. Los resultados del análisis alométrico multivariante indicaron que la cabeza se alarga como en la mayoría de especies de cocodrilos. Los coeficientes alométricos de la longitud del hocico (SL) y del ramus inferior (LM) fueron mayores que otras variables de la cabeza, estando correlacionados, posiblemente, con las luchas y la captura de presas; Por el contrario, los coeficientes alométricos para las variables de las óribitas (OW, OL) y del techo craneano postorbital (LCR) son relativamente menores que para otras variables.

Palabras clave: Análisis de regresión, Alometría, Aligator chino.

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Xiaobing Wu, Hui Xue & Lusheng Wu, College of Life Science, Anhui Normal Univ., 1 East Beijing Road, Wuhu, 241000 China.– Jialong Zhu & Renping Wang, Anhui Research Center for Chinese Alligator Reproduction, Xuancheng 242000, China.

Corresponding author: Wu Xiaobing. E–mail: wuxb@mail.ahnu.edu.cn

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Introduction

The skull is one of the most complicated organs in the body both morphologically and functionally (Pan & Oxnard, 2002). Total skull length was considered the independent variable reflecting overall size (Simpson, et al. 1960; Radinsky, 1981). Population monitoring of crocodilians usually involves night counts when frequently only the heads of animals are visible. Size–class distribution for the target population is therefore usually based on the relationship between length of head and total body length (Verdade, 1997). Allometric relations can be useful for estimating body size from isolated measures of parts of the body (Schmidt–Nielsen, 1984). As an example, Chabreck (1966) suggests that the distance between the eye and the tip of the snout in inches is similar to the total length of *Alligator mississippiensis* in feet. Choquenot & Webb (1987) proposed a photographic method to estimate total length of *Crocodylus porosus* from head dimensions. Ontogenetic changes in skull structure are of interest to biologists, and wildlife managers can use measurements of discarded skulls to estimate the sizes of hunted animals (Mourão et al., 1996). Relative or allometric growth has been studied in several kinds of crocodiles (Hall, 1994; Verdade, 1999), but as yet there is no comprehensive study on the Chinese alligator.

Allometric analysis can assess the covariation of characters (Cock, 1966) and provide a method to elucidate the relationship between processes of growth and evolution (Blackstone, 1987). Morphometric allometric relationships have been developed for bivariate allometric equations and for a multivariate generalization of the bivariate allometric equation. The formula of bivariate allometry (Huxley, 1932) assumes a power function of the form $y = bx^{a}$ where x and y are measurements and the constant a is often called the allometric coefficient. The special case when $a = 1$ is called isometry. Jolicoeur (1963) used the first eigenvector extracted from the covariance matrix of log–transformed data to reflect the multivariate allometic coefficients. When all loadings of the first eigenvector equal a value 1 divided by the square root of the number of the variable, the first eigenvector is called the isometry vector. The multivariate allometric coefficients can be easily translated to bivariate allometric coefficients by using the ratio of the coefficients in the first eigenvector for two variables corresponding to the variable in the bivariate allometric analysis (Shea, 1985).

The wild population of Chinese alligator may number < 130 (Thorbjarnarsona et al., 2002), so we studied relative and allometric growth in captive animals. Although the data taken in the paper is not based on wild specimens this is the most feasible way to explore the relationship between skull and body for this species.

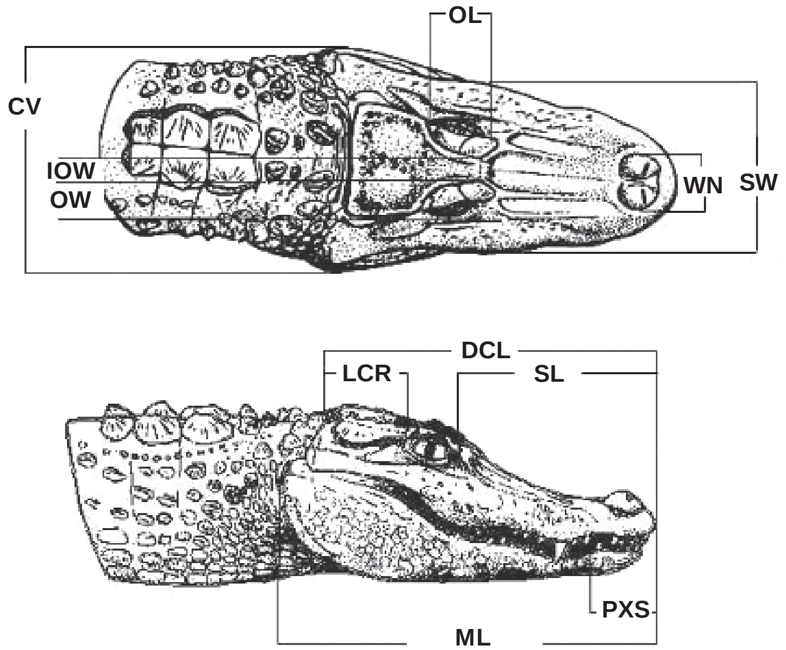

Fig.1. Measurements adapted from Verdade (1999). The picture shows the head–size variables of Chinese alligator (adapted from Wermuth, 1953). (For abbreviationssee material and methods.)

Fig. 1. Mediciones adaptadas de Verdade (1999). La ilustración muestra las variables del tamaño cefálico del aligator chino (adaptado de Wermuth, 1953). (Para las abreviaturas ver material and methods.)

Materials and methods

Samples

The samples were taken from the Anhui Research Center for Chinese Alligator Reproduction (ARCCAR). There were animals from five age groups at the centre: 18 individuals were eight months old, 20 individuals were one year old (about 15 months), 20 animals were two years old (about 27 months), 20 animals were three–year old (about 39 month) and 20 animals were four years old (about 51 month). The data from a total of 98 individuals were analyzed.

Measurements

Measurements were taken with a steel electronic digital caliper (0.01 mm precision, third decimal not considered) to take the head–size measurements, a tape (1mm precision) to measure the body–size, a balance (for animals < 1000 g, 0.2 g precision) and a hanging scale (for animals >1000 g, 5 g precision) to weigh the animals. The study began at the onset of the hibernation period.

Four body–size and fourteen head–size variables were taken from Chinese alligators: SVL. Snout–vent length, cm; TTL. Total length, cm; BW. Commercial belly width, mm; BM. Body mass, Kg/g; DCL. Dorsal cranial length: anterior tip of snout to posterior surface of occipital condyle, mm; CW. Cranial width: distance between the lateral surface of the mandibular condyles of the quadrates, mm; SL. Snout length: anterior tip of snout to anterior orbital border, mm; SW. Basal snout width: width across anterior orbital borders, mm; OL. Maximal orbital length, mm; OW. Maximal orbital width, mm; IOW. Minimal interorbital width, mm; LCR. Length of the postorbital cranial roof: orbital border to the posterolateral margin of the squamosal, mm; WN. Maximal width of external nares, mm; PXS. Length of palatal pre maxillary symphysis, mm; ML. Mandible length, mm; LMS. Length of the mandibular symphysis, mm; WSR. Surangular width, mm; LM. Length of lower ramus, mm. The measuremenst of these variables are shown in fig. 1 (Verdade, 1999; Chen, 1985; Cong & Hou, 1998). One of the measurements, PXS, the length of the premaxillary symphysis, is closely approximated by the distance from the snout tip to the anterior tip of the first tooth posterior to the prominent groove in the snout behind the nares because it is not seen in live animals (Verdade, 1999).

Statistical analysis

Bivariate polynomial regression analysis was performed with the snout–vent length (SVL, in cm) value as dependent variables and other variables as independent variables Verdade (1999). We used the first component obtained from a principal components analysis (PCA) as a generalization of simple allometry. In such an analysis, the ratio of coefficients on the first principal component (PC1) corresponds to (but does not necessarily equal) the coefficient that would be obtained if those same variables were regressed against one another in a typical bivariate allometry analysis (Huxley, 1932). The isometric vector has the standardized loadings $(1/p)^{1/2}$, where p is a number of traits. With fourteen traits of head in this study $(1/p)^{1/2}$ was 0.2673, so that the ratio of each trait's loading with 0.2673 is the bivariate allometry coefficient of that trait with overall body size (Badyaev, 2000).

Results

Regression analysis between body length and head length

There was a significant correlation between body– and head–size, and relative growth trajectory appears apparently (fig 2). The results were significant with extremely high coefficients of determination (r^2) (table 2); except for IOW (r^2 = 0.793) they were greater than 0.9 and all of the p–values were significant at 0.001.

Multivariate allometric analysis of head

Principal component analysis was applied to fourteen head variables, and the eigenvector of first principle component was calculated. Ten eigenvalues of head traits were greater than the isometric vector (0.2673), indicating these variables show positive allometric growth, and others have negative or no allometry. Among the variables, loadings of SL and LM were higher than all the others, while loadings of OL, OW and LCR were comparatively lower. Coefficients of length variables were all slightly greater than those of width variables (DCL > CW, SL > SW, ML > WSR, see table 3), but differences were slight. This indicates that the skull of Chinese alligator elongates during ontogeny.

Discussion

Although most of the researchers have used the model of Huxley (1932) to study allometry, we used polynomial regression rather than the power function to depict the relationship between head and body size, because the allometric function did not improve the regression equations with the exception of body mass in our study. The coefficients of determination of captive animals for body– and head–size variables can be considered extremely high. That is, most of the head–size variables studied can be useful for predicting body length. This can be particularly interesting in the study of museum collections and reconstruction of sizes of hunted animals from skulls left by hunters (e.g. Mourão et al., 1996).

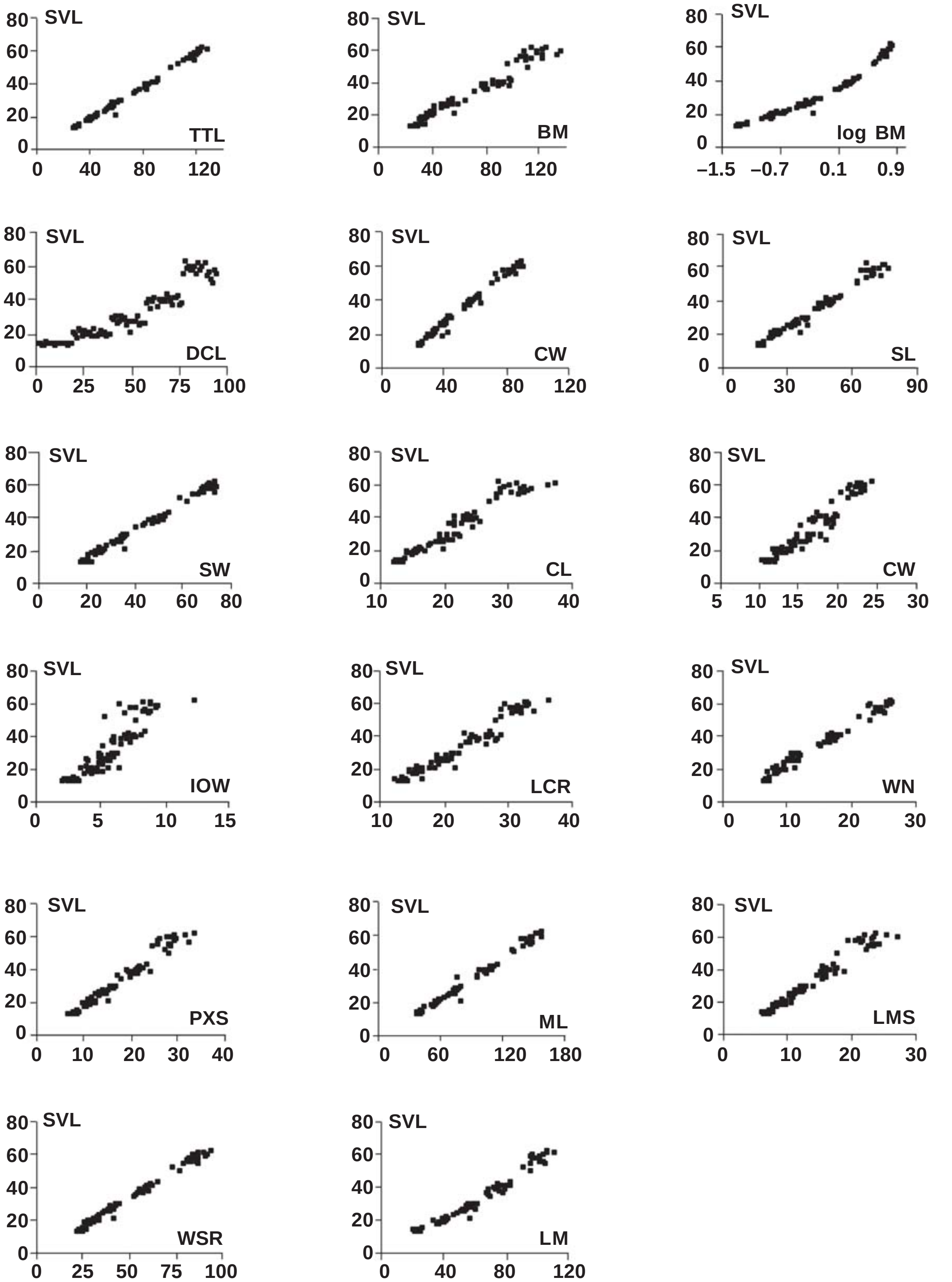

Fig. 2. Plot between body– and head–size variables for Chinese alligator. (Log BM: log–transformed BM, BM all in kg finally; SVL and TTL in cm, the others in mm). See table 2 for regression equations.

Fig. 2. Gráfico de la relación de las variables del tamaño corporal y cefálico del aligator chino. (Log BM: BM transformado logarítmicamente, BM finalmente en kg; SVL y TTL en cm, los demás en mm).

Table 2. Regression equations between body and head variables for Chinese alligator: Y = *a* + *b*X + *c*X^2 + *d*X^3; N. Sample size. (Log–transformation only was performed on BM to improve the coefficient of determination, r^2).

Tabla 2. Ecuación de regresión entre las variables corporales y cefálicas del aligator chino: Y = a + bX + cX² + dX³; N. Tamaño de la muestra. (La transformación logarítmica sólo se efectuó en el caso de BM, para mejorar el coeficiente de determinación, r²).

Y	X	*a*	*b*	*c*	*d*	r^2	*N*	*p*–value
SVL	TTL	–1.6566	0.5098			0.960	98	0.000
SVL	BW	13.2894	0.1526	0.0019		0.911	98	0.000
SVL	logBM	31.1874	–24.070	8.3614		0.956	98	0.000
SVL	DCL	–5.3251	0.4782			0.957	98	0.000
SVL	CW	–4.5712	0.7622			0.960	98	0.000
SVL	SL	–.8684	0.8427			0.952	98	0.000
SVL	SW	–2.3516	0.8722			0.966	98	0.000
SVL	OL	65.8007	–9.8093	0.5596	–0.0081	0.929	98	0.000
SVL	OW	–27.2680	3.6849			0.916	98	0.000
SVL	IOW	–6.0657	6.8427			0.793	98	0.000
SVL	LCR	–18.398	2.3385			0.915	98	0.000
SVL	WN	–0.9352	2.4374			0.944	98	0.000
SVL	PXS	–2.3766	2.0548			0.933	98	0.000
SVL	ML	–3.1303	0.4185			0.954	98	0.000
SVL	LMS	–11.682	3.8944	–0.0392		0.926	98	0.000
SVL	WSR	–2.0222	0.7125			0.967	98	0.000
SVL	LM	6.9786	0.2388	0.0026		0.947	98	0.000

Table 3. Multivariate allometry of morphological trait of Chinese alligator. The table shows the first eigenvectors and the proportion of total variance (%), accounted for by the first eigenvalue from the variance–covariance matrix of log–transformed values: PCI. The ratio of coefficients on the first principal component; P(+) / N(–). Positive (+) / Negative (–) allometric growth.

Tabla 3. Análisis de Componentes Principales de los rasgos morfológicos del aligator chino. La tabla muestra los primeros valores propios y la proporción de varianza total explicada (%), según el primer valor propio de la matriz de varianzas–covarianzas, a partir de los valores transformados logarítimicamente: PCI. Relación de los coeficientes de la primera componente principal; P(+) / N(–). Crecimiento alométrico Positivo (+) / Negativo (–).

	PC I				PC I		
Variables	Loadings	Var %	P(+)/N(–)	Variables	Loadings	Var %	P(+)/N(–)
DCL	0.2705	97.3	+	LCR	0.1911		–
CW	0.2696		+	WN	0.2940		+
SL	0.3134		+	PXS	0.2827		+
SW	0.2906		+	ML	0.2910		+
OL	0.1954		–	LMS	0.2689		+
OW	0.1581		–	WSR	0.2903		+
IOW	0.2436		–	LM	0.3237		+

Verdade (1997) found that determination coefficients of wild and captive broad–snouted Caiman (*Caiman latirostris*) were extremely high and drew the conclusion that animals lack morphological variation. The phenomenon also appears in Chinese alligator. The conclusion, which is similar to Verdade's, may be a little arbitrary, but it is an inevitable result that morphological variation would gradually disappear in the captive population due to current conditions, as the genetic variation disappears (Wu, 2002). Efforts should therefore be made to release captive Chinese alligators as soon as possible.

During ontogeny, the skulls of Chinese alligator elongate. The elongation is not particularly obvious as we found no significant differences between coefficients of length and width. Elongation of the skull also appears in *Caiman sclerops*, *Caiman yacare*, and *Melanosuchus niger*, but the skull of the broad–snouted Caiman becomes stout (Monteiro & Soares, 1997). Although the overall skull shape of the Chinese alligator is similar to that of the broad–snouted Caiman (short, broad snouts) the growth trajectory of the head is different. The allometric pattern observed in broad–snouted Caiman is unique among crocodilians (Monteiro & Soares, 1997).

Allometric analyses indicate that the snout and lower ramus grow most compared to other head features. This phenomenon may be associated with the functions of prey capture and fighting (Webb & Messel, 1978).

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