An Investigation of the Morphometric Characteristics of Eggs of the Chinese Alligator (*Alligator sinensis*)

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Abstract.- In this study we analyzed morphometric intraspacific differences in the eggs of the Chinese alligator, *Alligator sinensis*, (egg mass, egg width and egg length). Data were collected for 1460 eggs from 40 clutches at the Anhui Research Center for Chinese Alligator Reproduction (ARCCAR). Our results found that the mean clutch size was 36.5 eggs, mean egg mass per clutch was 41.9 g, and clutch mass was 1519.7 g. We generated three regression equations relating to relationships among egg width, length and mass. The average of clutch size in 2004 was much higher than it was in 1985 as indicated by a two-sample t-test.

Keywords.- Egg shape index, egg length, egg width, egg mass, clutch size.

Introduction

Studies of the reproductive ecology of *Alligator sinensis* are important for our understanding of its conservation biology and status. Several studies about the reproductive ecology of *Alligator sinensis* are available and include information on egg incubation in captivity (Gu and Zheng, 1983; Liang and Pan, 1990), nest excavation (Huang and Watanabe, 1986), the relationships between egg hatching and environmental factors (Wang et al., 2000) and captive breeding (Cheng and Wang, 1984; Wang and Zhang, 2000; Xu et al., 1989). Egg characteristics are important when examining reproductive ecology, as has been illustrated in previous studies (Cariello et al., 2004; Du, 2003; Huang et al., 2003; Reese, 2000), but little of this research has been devoted to *Alligator sinensis*. We herein record data on egg characteristics of the Chinese alligator in the ARCCAR, and analyze these characteristics to investigate intraspecific differences, providing fundamental information for further study of the influence of egg shape on hatching rate and quality of young alligators.

Materials and methods

***Measurements of eggs*.-** A total 1460 eggs from 40 clutches were collected between 5 and 16 July 2004 at the artificial breeding area of the ARCCAR. Eggs were collected within 12 hours of laying and taken to a hatching room where their length and width were measured with digital calipers (precision 0.01 mm). Egg mass was taken using a scale (precision 0.1 g).

Statistical analysis.- We analyzed the morphological characteristics of the eggs using the statistical software SPSS (Version 10.0). Data on the distribution of egg characteristics (including egg length, width, mass, egg shape index [length/width], clutch size, clutch mass and clutch mean egg mass) were analyzed using descriptive statistics. The coefficient of variation (SD/Mean) was used to study variation in egg characteristics. Regression analyses were used to examine the correlation among egg width, length and mass. Hoyt (1979) put forward an empirical formula:

$$W = K_W X Y^2$$

where K_W is the coefficient of mass, W is egg mass, X is egg length, and Y is egg width.

Results

Descriptive statistics of the morphological characteristics of the eggs of the Chinese alligator.- Table 1 provides descriptive statistics for the morphological characteristics of the eggs examined. From the frequency distributions of these morphological characteristics (Fig. 1), it is apparent that in most cases, egg length ranges from 51.42 mm to 60.00 mm, egg width from 32.49 mm to 37.51 mm, egg mass from 33.34 mm to 48.33 mm, clutch mass from 1200 g to 1800 g, clutch size from 30 to 45, and clutch mean egg mass from 35.0 g to 47.5 g.

The egg of the Chinese alligator usually has the form of an elongate ellipse, although some eggs deviated from this shape. From the frequency distribution of egg

Table 1. Descriptive statistics of the morphological characteristics of the eggs of *Alligator sinensis*.

	Maximum	Minimum	Mean	SD	N
Egg length (mm)	87.15	32.86	56.58	3.73	1460
Egg width (mm)	57.3	29.01	35.24	1.9	1460
Egg shape index	2.42	0.59	1.61	0.11	1460
Egg mass (g)	83.7	27	41.9	5.1	1460
Clutch size	46	15	36.5	6.2	40
Clutch mass (g)	1978.4	630.9	1519.7	266.7	40
Clutch mean egg mass (g)	51.1	32.7	41.8	3.9	40

shape index, it was evident that in most cases, egg shape falls between 1.50 and 1.72.

Intraspecific difference of egg morphological characteristics.- Since there were a high proportion of malformed eggs in four of the 40 clutches, only the 36 remaining clutches were analyzed. Figure 2 shows the CV (coefficient of variation) of egg morphological characteristics, indicating morphological variation among eggs of the same clutch.

There were differences in variation among the morphological characteristics of the eggs laid by different females. The CV of egg morphological characteristics were calculated from Table 1, revealing that variation in egg mass (CV = 0.18) and clutch size (CV = 0.17) were the greatest.

The correlations among the CV of egg morphological characteristics were analyzed using a Pearson correlation analysis (Table 2). Table 2 indicates that the CV of the egg shape index had a significant positive correlation with the CV of egg width. The CV of egg mass had a significant positive correlation with the CV of egg length.

Correlations of egg length, egg width and egg mass.- Data (including egg length, width and mass) collected from 1445 eggs (malformed and broken eggs not included) were used to generate scatter plots. These plots indicated that both egg width and length had a positive correlation with mass, while length was negatively correlated with width. In order to obtain the exact correlation between the two parameters, the influence of other parameters was eliminated by using a partial correlation analysis. The results showed that egg length had a significant positive linear relationship with egg mass ($r = 0.875$, $p < 0.001$); egg width had a significant positive linear relationship with egg mass ($r = 0.856$, $p < 0.001$); and egg width had a significant negative linear relationship with egg length ($r = -0.638$, $p < 0.001$).

Table 2. Pearson Correlations of CV of four egg morphological characteristics.

	Egg shape index	Egg length	Egg width	Egg mass
Egg shape index	1.000	0.424**	0.900**	0.287
Egg length	0.424**	1.000	0.242	0.774**
Egg width	0.900**	0.242	1.000	0.314
Egg mass	0.287	0.774**	0.314	1.000

** Correlation is significant at $p < 0.01$ (2-tailed).

Linear regression analysis was used to analyze the relationships between egg width (Fig. 4), length, and mass (Fig. 3). Two regression equations were generated

(1) $W = -29.855 + 1.265\, X_L$
$R^2 = 0.681$, $p < 0.001$; $df = 1443$

(2) $W = -53.078 + 2.699\, X_W$
$R^2 = 0.637$, $p < 0.001$; $df = 1443$.

Where W is egg mass (g), X_L is egg length (mm), X_W is egg width (mm).

We were able to approximate the original egg mass from data about egg width and length using the two equations.

In order to estimate egg mass (W) more exactly, we used the empirical formula given by Hoyt (1979) to derive another regression equation. From the scatter plots of egg mass and the volume (V) of the cube approximately the volume of the egg (egg width x egg width x egg length), it is evident that egg mass had a significant positively correlation with the volume of this cube. Linear regression analysis (Fig. 5) yielded the following equation expressing the relationship between egg mass and volume:

(3) $W = 1.656 + 0.00057V$
$R^2 = 0.928$, $p < 0.001$; $df = 1443$,

where $V = X_L X_W^2$, so the final equation is:

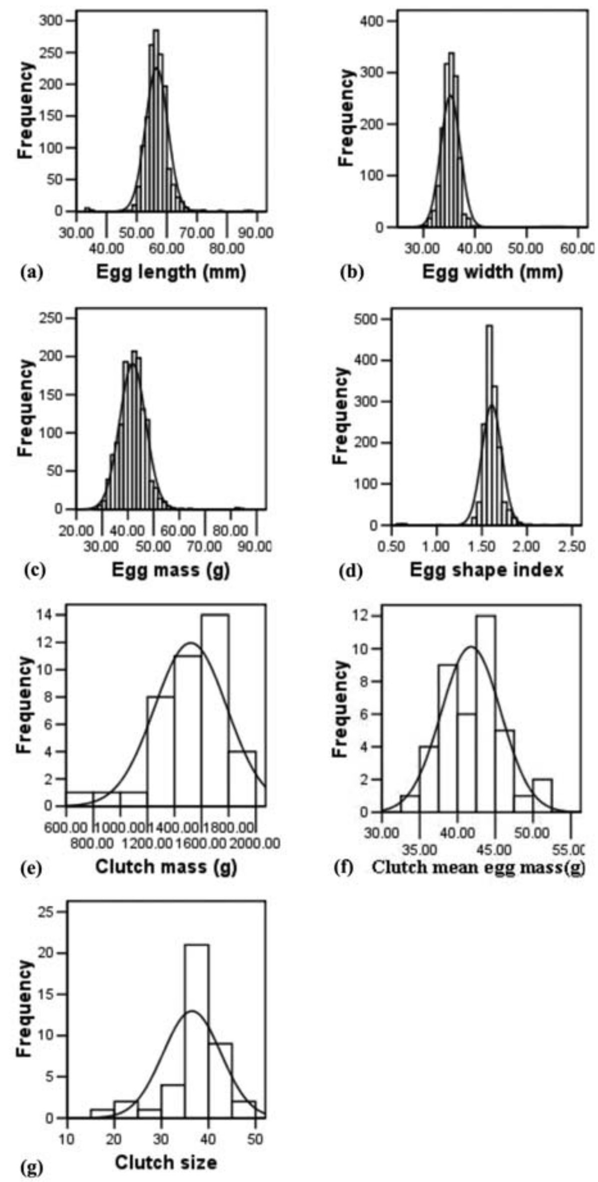

Figure 1. Frequency distributions of egg morphological characters of *Alligator sinensis*.

$$(4) \quad W = 1.656 + 0.00057X_L X_W^2,$$

where W is egg mass (g), X_L is egg length (mm) and X_W is egg width (mm).

Discussion

In 1985 it was recorded that the clutch size of Chinese Alligators at the ARCCAR, based on 29 clutches, was 26.2 (SD = 3.9; n = 29) (Xu et al., 1989). Means of clutch sizes in 1985 and 2004 were compared by a two-sample t-test, revealing that the average clutch size in 2004 was much higher than it was in 1985 ($t = 7.77$, $p < 0.05$). The data collected in 1985 were from the original parent generation captured from the wild, which is no longer breeding, leaving the F1 generation to constitute the dominant portion of the breeding population (Wu et al., 1999, 2005). Many reproductive characteristics of squamate reptiles are fictile, clutch size being one of them. In the wild, adult alligators must face pressures relating to natural selection potentially reducing their full reproductive potential, but in the ARCCAR, the nutrition of the alligators is regulated by artificial diets, maximizing their reproductive potential. One way to quantify this potential is to examine egg morphological characteristics, which are directly influenced by nutrition.

Egg width and length data can be collected easily, but data on egg mass are more difficult to obtain because some eggs might break while the female alligator protects her clutch, or if it is usurped by other females. Furthermore, there is variation in egg mass during incubation (Wang and Zhang, 2000). In bird species examined in the wild, investigators have correlated egg weight, width and length (Hoyt, 1979; Zhao and Ma, 1997; Zhou, 1994) in order to calculate egg mass. The regression equations (1), (2), and (4) established in this study have been found to accurately estimate the original egg mass from data on egg width and length, providing an efficient means of measurement that can also be applied to the mass of recently-hatched young alligators if only the eggshell is available. This information subsequently be used to estimate the constitution of the young alligators, gain basic information on wild populations, and develop a sound basis for investigation of wild populations. We conducted an analysis of variance test (ANOVA) to determine whether the egg masses predicted by the three equations differed from actual observations. The results showed no significant differences ($F = 0.891$, $p > p_{0.05}$), illustrating that all three equations can be used to calculate egg mass, although the accuracy of equation (3) ($R^2 = 0.928$) is higher than that of the other two [(1) ($R^2 = 0.681$); (2) ($R^2 = 0.637$)].

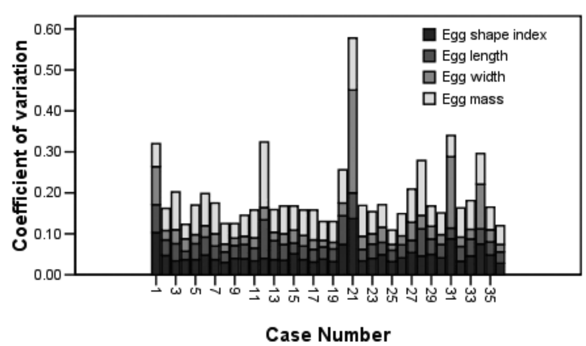

Figure 2. Coefficient of variation of egg morphological characteristics.

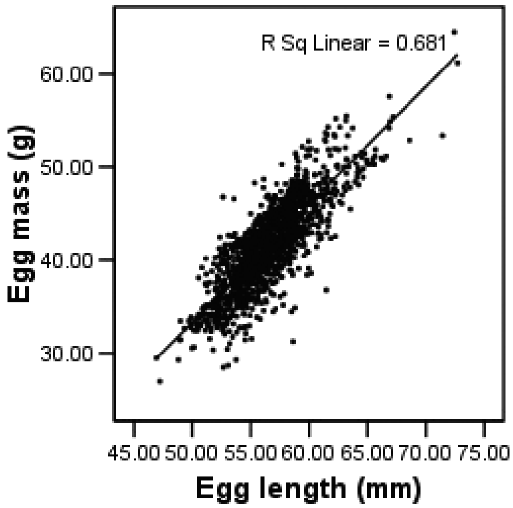

Figure 3. The relationship between egg mass and length.

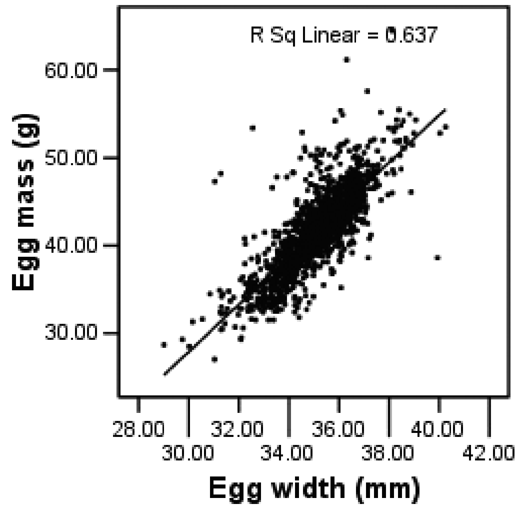

Figure 4. The relationship between egg mass and width.

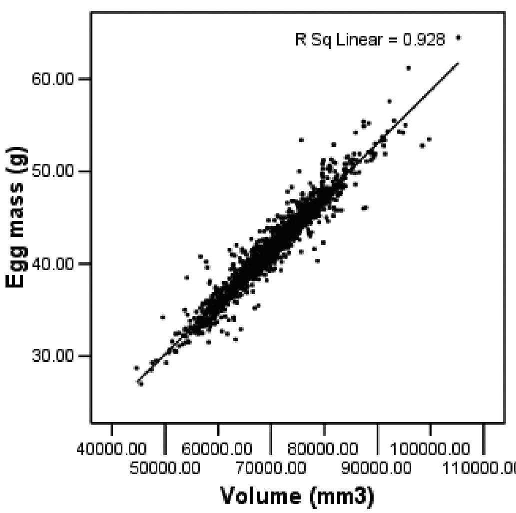

Figure 3. The relationship between egg mass and length.

Though selection females produce progeny of a certain size that are able to escape natural enemies and obtain food efficiently. Compared to progeny size, the number of progeny should show larger variation within a single brood (Lin and Ji, 2004). The results of this study suggest that the CV of egg mass (0.12) is smaller than the CV of clutch size (0.17), meaning that clutch size in the Chinese alligator exhibits greater variation than does egg mass.

Egg shape index can be used to describe the shape of eggs. From Table 2 we conclude that the CV of egg shape index has a significant positive correlation with the CV of egg width. This suggests that, compared to egg length, egg width has a greater influence on egg shape. According to studies on the hatching rate of some birds and reptiles (Fang et al., 2004; Fang et al., 2001; Zhu, 2002), egg shape had been found to be an important variable in hatching rate, however, little research on the relationship between egg shape and hatching rate has been made, and is in need of further investigation.

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