ESTIMATING INTERNAL EGG VOLUMES FROM LINEAR DIMENSIONS: ISOMORPHY IN EGGS BELONGING TO THE FAMILY ARDEIDAE

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Egg volume is a good approach to egg size and remains unchanged over the incubation period (RAHN & AR, 1974). Therefore it is, in contrast to mass, one of the more reliable parameters to be used as a reference variable in breeding biology studies. Egg volume is relatively easy to measure in the laboratory using suitable devices such as hydrostatic balances, but it poses problems of accuracy under field conditions (MCNICHOLL, 1973). Two approaches have been used to solve these problems, first, special devices have been designed to reduce the inaccuracies derived from field volumetry procedures (LOFTIN & BOWMAN, 1978; THOMAS & LUMSDEN, 1981; VAN NOORDWIJK et al., 1981; MORRIS & CHARDINE, 1986) and second, the use of geometric models to obtain reasonable estimates of egg-volume from linear dimensions (STONEHOUSE, 1963, 1966; PRESTON, 1974; HOYT, 1979). These are easier to obtain under field conditions, either using a vernier calliper or from pictures, the latter enabling the estimation of shape parameters (BESCH et al., 1968; BAERENDS & HOGAN-WARBURG, 1982; URIBE & ROBLES, 1985; MÄND et al., 1986).

In this paper, values of the constant (K_v) relating volume to linear dimensions (Length x Breadth^2) to estimate internal volumes (hereafter K_{vi}) of eggs from four species belonging to the family Ardeidae (Squacco Heron *Ardeola ralloides*, Cattle Egret *Bubulcus ibis*, Little Egret *Egretta garzetta* and Purple Heron *Ardea purpurea*), are presented to provide the field ornithologist with accurate equations to calculate the internal volume of eggs.

Several fresh eggs (i.e. less than 24h after laying) of Squacco Heron (n=18), Cattle Egret (n=23), Little Egret (n=20) and Purple Heron (n=20), were collected, under license, and irrespective of their position in the laying sequence, in the Ebro Delta during 1988-1990. Only one egg per nest was collected in order to avoid any clutch effect which could affect independency among cases (PRESTON, 1968).

Eggs were numbered with a felt-tip pen and preserved at 4°C until processed in the laboratory. Length and breadth were measured using a digital calliper and eggs were immediately voided through two small openings situated at the opposite ends of the major axis. Once voided, the interior of the egg was thoroughly washed in running water and dried at 60°C in an oven for 24h. One hole was sealed with wax and eggs were refilled using a graduated buret (0.1ml accuracy) with 70% alcohol, in order to obtain interior volumes. A regression analysis (least squares, through origin) of volumes (V_i) against length (L) and breadth (B) values was undertaken to obtain K_{vi} in the equation:

$$V_i = K_{vi} \times L \times B^2$$

Analysis of covariance was used to assess the homogeneity of slopes among species, allowing us to generate a single general equation across these species. Normality of distributions was assessed by means of

Table 1. Descriptive statistics of linear dimensions of eggs: n. Sample size; s.d. Standard deviation; min.- max. Minimum and maximum values observed.

Species	n	mean	s.d.	min.-max.	estimated mean 95% C.I.
Egg length					
Bubulcus ibis	23	45.46	1.77	42.39-48.40	44.70-46.23
Egretta garzetta	20	47.15	2.00	43.80-51.20	46.22-48.09
Ardea purpurea	20	54.75	1.97	51.94-57.85	53.82-55.67
Ardeola ralloides	18	39.24	1.50	36.43-41.39	38.50-39.99
Egg breadth					
Bubulcus ibis	23	33.66	0.74	31.87-35.57	33.34-33.98
Egretta garzetta	20	34.21	1.16	32.70-36.00	33.67-34.75
Ardea purpurea	20	40.48	1.32	36.98-43.03	39.86-41.10
Ardeola ralloides	18	28.74	0.78	26.54-29.68	28.35-29.13

Shapiro-Wilks tests and homogeneity of variances-covariances using Boxs M tests.

Descriptive statistics of length and breadth for eggs of different species are given in table 1. To ascertain that regression through origin was a correct assumption, values of the intercept were also estimated both in specific and general analyses. In all cases they were not significantly different from zero. The outcomes of regression analysis of internal volume on egg linear dimensions ($L \times B^2$) for each species are given in table 2. The different slope values do not differ significantly among species (ANCOVA $F=0.53$, $p>0.6$), reflecting the isometric variation in egg-size. Figure 1 shows the overall relationship in the four species analyzed and the narrow confidence interval (95%) of individual values distribution.

Preston (1974) demonstrates that $L \times B^2$ of an egg is related to egg volume through a volume constant (K_v) which is theoretically equal to $\pi/6$ (approx. 0.52). Deviations from this value are due to shape parameters which are not defined by length or breadth (Preston, 1968). Hoyt (1979) derived empirically a mean value for K_v of 0.509 ± 0.008 from 124 bird species. In the species studied in our analysis, the Kvi values are very similar, suggesting that shape parameters are the same in all cases. This

Table 2. Estimated values of: K_{vi}. Internal volume constant; se(K_{vi}). Standard error; r^2. Coefficient of determination.

Species	K_{vi}	se(K_{vi})	r^2
Bubulcus ibis	0.4965	0.0017	0.999
Egretta garzetta	0.4922	0.0026	0.999
Ardea purpurea	0.4941	0.0025	0.999
Ardeola ralloides	0.4980	0.0019	0.999
Global	0.4945	0.0011	0.999

reveals a high degree of isomorphy among eggs in spite of size differences, which are near five fold in body size and three fold in egg volume (see CRAMP & SIMMONS, 1977).

Further studies involving the extremes of variation of the family Ardeidae (genus *Ixobrychus* and *Ardea goliath*) are needed to assess whether this egg shape constancy is maintained and to ascertain the constraints imposed by egg-shape constancy on egg-size scaling within this family.

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ABSTRACT

Estimating internal egg volumes from linear dimensions: isomorphy in eggs belonging to the family Ardeidae.– Recently laid (less than 24h) eggs of *Ardeola ralloides, Bubulcus ibis, Egretta garzetta* and *Ardea purpurea* were collected in the Ebro Delta during the breeding seasons of 1988-1990. Once measured (length and breadth) and voided, they were refilled with 70% alcohol using a buret to determine internal volumes. Internal volumes were related to linear dimensions (L x B^2) through a regression analysis both for each species separately and for all species together. Internal volume constant (K_{vi}) for all species is 0.4945 and the eggs of all the species are isomorphous, i.e. their volume constants are very similar.

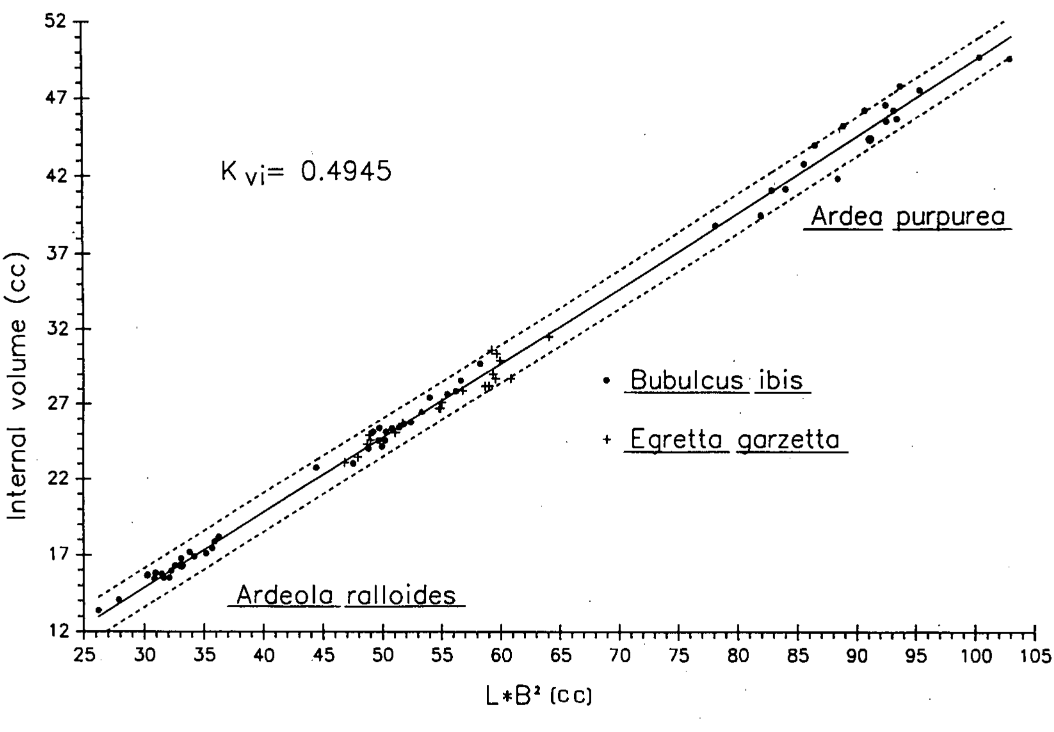

Fig. 1. Relationship between linear dimensions (L x B^2) and egg internal volume: ——— Fitted regresssion: -------- 95% confidence interval for the individual values.

Key words: Eggs, Length, Breadth, Volume, Herons, Ebro Delta.

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