

# PRACTICAL METHODS OF ESTIMATING VOLUME AND FRESH WEIGHT OF BIRD EGGS

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**ABSTRACT.**—Bird eggs begin to lose weight as soon as they are laid but their volume and linear dimensions do not change during incubation. The volume of an egg can be estimated within 2% from the relationship:  $\text{Volume} = 0.51 \cdot LB^2$ , where  $L$  is the length and  $B$  is the breadth (maximum diameter). The fresh weight of an egg can be estimated within 2% from the relationship:  $\text{Weight} = K_w \cdot LB^2$ , where  $K_w$  is a species-specific constant that can be determined empirically or calculated from published data. *Received 25 April 1978, accepted 28 October 1978.*

It is frequently useful to know the fresh weight of a bird's egg. One reason is that many aspects of the biology of bird eggs can be predicted from their weight and these predicted values can be used when empirical data are lacking. Alternatively, one way to detect adaptations to unusual situations is by comparing observed values with values predicted for an "average" egg. Some of the parameters that can be predicted from weight are metabolic rate (Rahn et al. 1974), incubation period (Rahn and Ar 1974), water vapor conductance (Ar et al. 1974), the daily rate of water loss (Drent 1970), surface area, density, and shell weight (Paganelli et al. 1974), and the relation of egg weight to adult body weight (Huxley 1923–24, Rahn et al. 1975). Additionally, accurate values of fresh egg weight are required for the calculation of fractional weight loss from the daily rate of water loss (Rahn and Ar 1974) and the estimation of incubation age (Westerkov 1950). However, fresh egg weight can only be determined at the time of laying because the egg immediately begins to lose weight by diffusion of water vapor. This daily loss is proportional to the 0.74 power of egg weight (Drent 1970) and totals about 16% of the initial weight by the end of incubation (Drent 1975). As a consequence, while a great deal of information is available on egg dimensions, there are few reliable reports of fresh egg weight. Fortunately, the linear dimensions of eggs do not change during incubation, and in the present paper I show that they can be used to predict egg volume and fresh egg weight.

Several authors have shown that the volume of a bird egg can be estimated from its linear dimensions (Bergtold 1929, Worth 1940, Westerkov 1950, Stonehouse 1963), and Preston (1974) suggested a more complex approach. In the present paper, I evaluate the accuracy with which volume ( $V$ ) can be predicted from linear dimensions ( $L$  = length,  $B$  = breadth or maximum diameter), using the equation:

$$V = K_v \cdot LB^2 \quad (1)$$

A similar relationship exists for initial weight ( $W$ ), and I evaluate the accuracy with which weight can be estimated from:

$$W = K_w \cdot LB^2 \quad (2)$$

These evaluations show that both volume and fresh weight can be estimated quite accurately from linear dimensions. Volume is most easily estimated with a common

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TABLE 1. Volume coefficients and weight coefficients for eggs of 26 bird species.<sup>a</sup>

Species	(1) N	(2) $K_V$	(3) COV	(4) $W$	(5) $K_W$	(6) COV	(7) $K_{WS}$	(8) %E
<i>Turdus m. migratorius</i>	12	.504	0.7	6.7	.534	0.9	.537	0.7
<i>Gygis alba rothschildi</i>	15	.520	1.4	21.2	.546	1.6	.551	1.0
<i>Anous tenuirostris</i>	11	.510	1.1	23.7	.531	1.3	.523	-1.5
<i>Fulica americana</i>	3	.499	1.6	26.7	.542	1.7	.547	1.0
<i>Chrysolophus amherstiae</i>	10	.507	1.0	29.5	.548	1.0	.547	-0.2
<i>Syrnaticus s. soemmerringii</i>	10	.503	1.5	31.5	.539	1.4	.544	0.9
<i>Chrysolophus pictus</i>	10	.500	0.9	32.2	.539	0.7	.543	0.8
<i>Phasianus colchicus mongolias</i>	10	.497	1.3	33.8	.546	1.1	.547	0.2
<i>Anous stolidus pileatus</i>	14	.505	1.3	37.5	.534	1.6	.530	-0.8
<i>Amazonetta brasiliensis</i>	7	.514	1.3	37.8	.552	1.3	.554	0.5
<i>Numida m. meleagris</i>	12	.502	1.5	39.0	.565	1.5	.568	0.6
<i>Aix sponsa</i>	3	.518	0.3	43.3	.562	0.5	.571	1.6
<i>Rissa tridactyla pollicaris</i>	9	.498	1.0	51.9	.527	1.0	.537	1.9
<i>Larus heermanni</i>	11	.496	1.1	53.4	.529	1.2	.535	1.1
<i>Sula leucogaster brewsteri</i>	4	.507	1.3	57.8	.540	1.8	.537	-0.5
<i>Lophophorus impejanus</i>	6	.506	1.7	63.7	.546	1.7	.544	-0.4
<i>Phaethon rubricauda</i>	2	.504	1.5	67.7	.544	1.3	.541	-0.5
<i>Anas platyrhynchos</i>	11	.515	1.2	72.4	.560	1.1	.560	0.0
<i>Buteo jamaicensis</i>	2	.510	0.5	74.8	.547	0.3	.551	0.8
<i>Larus occidentalis livens</i>	8	.497	1.5	96.6	.531	1.5	.533	0.4
<i>Pavo muticus</i>	8	.501	1.1	101.2	.552	0.7	.529	-4.2
<i>Pelecanus occidentalis californicus</i>	10	.507	0.8	110.5	.546	1.1	.558	2.1
<i>Anser fabalis</i>	3	.516	0.8	142.6	.567	1.3	.556	-1.8
<i>Dromaius novaehollandiae</i>	8	.507	0.6	631.6	.564	0.6	.566	0.4
<i>Pterocnemia pennata terapacensis</i>	6	.513	1.2	661.8	.566	1.0	.555	-2.0
<i>Struthio camelus</i>	5	.521	0.5	1692.3	.597	0.4	.595	-0.3

<sup>a</sup> N = sample size;  $W$  = weight (g);  $K_W$  = observed weight coefficients; COV = coefficient of variation ( $100 \times SD/\bar{x}$ );  $K_{WS}$  = weight coefficient calculated from Schönwetter; %E = percent error [ $100 \times (K_{WS} - K_W)/K_W$ ];  $K_V$  = volume coefficient.

volume coefficient ( $K_V$ ) that is applicable to eggs of all but a few species in which the eggs are very pointed. Weight must be estimated with a species-specific weight coefficient ( $K_W$ ) that can easily be determined empirically or derived from values of  $W$ ,  $L$ , and  $B$  reported by Schönwetter (1960-77).

#### METHODS

Initial weight ( $W$ ), volume ( $V$ ), length ( $L$ ), and breadth ( $B$ ) measurements were obtained on a total of 210 eggs from 26 species. Initial egg weight was estimated from the weight of the egg after filling the air cell with water. The assumptions in this method are that the weight loss of an egg is due exclusively to the loss of water and the volume of the air cell equals the volume of water lost (Drent 1970). More recent experiments have shown that after 18 days of incubation the weight of a chicken egg with its air cell filled with water is within 20 mg of the initial weight of the egg determined within 15 min of laying (Rahn et al. 1976). Egg volumes were determined from the difference between the weight of the egg in air and when suspended in water. Length and breadth were determined to the nearest 0.01 cm with a vernier caliper. The eggs were obtained on various field expeditions and from zoos and commercial sources.

Many of the eggs used to represent a single species were clutchmates and, therefore, do not represent independent samples from the population. As a result, the values of  $K_V$  and  $K_W$  are not the best possible estimates of the species means. Additionally, since eggs of a single clutch are likely to show less variability than those of the species as a whole, there is probably a tendency to underestimate intraspecific variability. However, we can compare  $K_V$  and  $K_W$  with respect to the relative amounts of intraspecific and interspecific variability since we are using exactly the same data for the calculation of both constants. Variability is evaluated by calculating the coefficient of variation (=  $100 \times$  standard deviation/mean).

#### RESULTS

Observed volume coefficients were calculated from the relationship  $K_V = V/LB^2$ . The values obtained for the 26 species in this study are presented in column 2 of

Table 1, the coefficients of variation in column 3. The average coefficient of variation is 1.10%. The mean value of  $K_V$  for all 26 species is  $0.507 \pm 0.007$  (= SD); the coefficient of variation is 1.44%. Thus, the interspecific variation in  $K_V$  is not much greater than the intraspecific variation.

Intuitively, it would seem that  $K_V$  should be a function of egg shape since an egg with two rounded ends should have a larger  $K_V$  than one with the same length and breadth but one pointed end. To test this, I examined the relationship between shape and  $K_V$  with the data of Hoyt (1976), which were based upon a series of eggs selected to represent the full diversity of shape exhibited by bird eggs. These data include the volume, length, breadth, and shape specifiers of 29 eggs. The two shape specifiers are asymmetry (*AS*) and bicone (*BI*), as defined by Preston (1968). Bicone quantifies the average roundness of the two ends of the egg, and asymmetry quantifies the difference in the roundness of the two ends of the eggs. A multiple regression of  $K_V$  on *AS* and *BI* yielded the following relationship:

$$K_V = 0.5228 - (0.1033 \cdot AS) + (0.0740 \cdot BI) \quad (3)$$

(N = 29;  $r^2 = 0.757$ )

Weight coefficients were calculated from the relationship  $K_W = W/LB^2$ . The species means are shown in column 5 of Table 1, the coefficient of variation in column 6. The mean value of the intraspecific coefficients of variation is 1.14, indicating that there is about as much intraspecific variation in  $K_W$  as in  $K_V$ . The mean value of  $K_W$  for the 26 species in this study is  $0.548 \pm 0.016$ ; the coefficient of variation is 2.83%. Thus, there is about twice as much interspecific variation in  $K_W$  as there is in  $K_V$ .

Predicted weight coefficients were calculated from the values of *W*, *L*, and *B* given by Schönwetter (1960–77) for the particular species or subspecies (column 7). The mean value of  $K_W$  is  $0.548 \pm 0.016$ , identical to that derived empirically. Of primary interest is the difference between the measured and predicted value for each species. This is expressed as a percent error and is shown in column 8. The mean absolute error equals  $1.0\% \pm 0.9$ . Thus, on average, the predicted  $K_W$  deviated from the observed species mean by about 1%. In only one case is the error greater than 2.1%.

In more than one-half of the species, the observed values of *W*, *L*, or *B* differ significantly ( $P < 0.05$ ) from the corresponding values published in Schönwetter (1960–77). In fact, more than half the species differ with respect to either two or all three of these parameters. (These differences are, presumably, simply due to sampling errors.) However, the error in predicted  $K_W$  is no greater for these samples than it is for those which do not differ with respect to any of the parameters. This is an important observation because it means that, although the absolute dimensions may differ, the relation between *W*, *L*, and *B* for an individual species remains the same.

#### DISCUSSION

The volume coefficient ( $K_V$ ) is a function of egg shape (equation 3). However, there seems to be about as much intraspecific variability in the volume coefficient as interspecific variability. This supports the suggestion of several authors that the volume of any avian egg can be estimated from its linear dimensions with reasonable accuracy, using a single value of  $K_V$ . Bergtold (1929) and Worth (1940) derived their

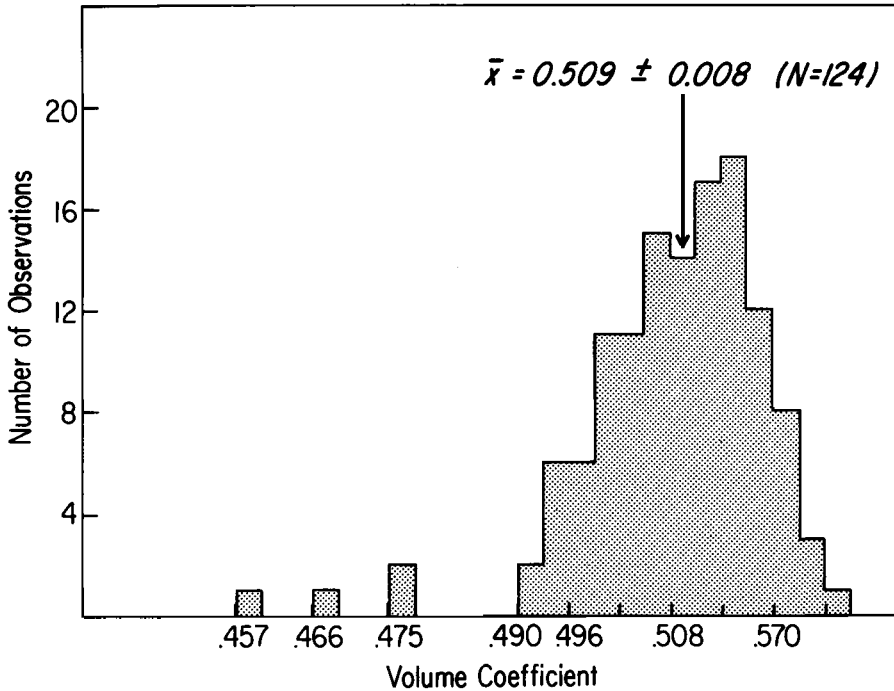


Fig. 1. Frequency histogram of 128 observations of  $K_V$ . The mean of  $K_V$  is  $0.509 \pm 0.008$  ( $N = 124$ ). The four low values that were not included in this mean are from very asymmetrical eggs laid by the following species ( $K_V$  in parentheses): *Uria aalge* (0.458), *Himantopus mexicanus* (0.467), *Calidris alpina* (0.476), and *Numenius americanus* (0.476). The data are based upon measurements taken from 818 eggs of 115 species. Twenty-six observations are from this study, 29 from Hoyt (1976), 10 from Lofton and Bowman (1978), and 63 (including 60 species and subspecies from the family Anatidae) are unpublished data.

values of  $K_V$  by assuming that the volume of an egg is equal to that of an ellipsoid of revolution with the same major and minor axes. In this case,  $K_V = 11/21$  ( $= 0.524$ ). Westerkov (1950) used  $K_V = 11/21.5$  ( $= 0.512$ ) for pheasant eggs (*Phasianus* sp.), but he did not explain the derivation of this value. Stonehouse (1963) reported a mean  $K_V$  of 0.512 for 150 eggs of 10 species of seabirds (no values were reported for individual species) and a mean  $K_V = 0.512$  for 50 Black Swan (*Cygnus atratus*) eggs (Stonehouse 1966). The mean of 124 determinations of  $K_V$  on eggs of 115 species of birds (Fig. 1) is  $0.509 \pm 0.008$ . Therefore, the volumes of most bird eggs can be determined within 2% from linear dimensions using  $K_V = 0.51$ . The major exceptions are very asymmetrical eggs. For these species, it would be best to determine  $K_V$  empirically or predict  $K_V$  with equation 3 from Preston's shape specifiers.

The weight coefficient ( $K_W$ ) is a function of both shape and density. The interspecific variability in  $K_W$ , therefore, reflects the interspecific variability in both of these parameters. As a consequence, the interspecific variability in  $K_W$  is larger than the interspecific variability in  $K_V$  and it is probably best to use a species-specific value of  $K_W$  for the prediction of fresh weight from linear dimensions. A species-specific value of  $K_W$  can be calculated from the data of Schönwetter (1960–77). These values are rarely in error by more than 2%.

The most accurate prediction of fresh egg weight is obtained by refilling the air

cell with water. However, this results in the death of the embryo. The second most accurate prediction is obtained by measuring volume (by immersion in water) and multiplying by density. Density can either be determined empirically on a sample of eggs from the population being studied or estimated (Rahn et al. in prep.) from the data of Schönwetter (1960–77). However, the determination of volume by immersion in water might be impractical under some conditions (e.g. field), or undesirable under others (e.g. with near-term embryos). The third most accurate prediction of fresh weight is obtained from  $K_w$  and linear dimensions. The weight coefficient ( $K_w$ ) can either be determined empirically on a sample of eggs from the population being studied, or estimated from the data of Schönwetter (1960–77). All of these methods yield reasonably accurate estimates of fresh egg weight.

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