

EXPONENTIAL RELATIONS OF STANDARD METABOLIC RATES OF BIRDS AND THE WEIGHTS OF EGGS

CHARLES A. LONG

APPARENTLY no one has investigated a relation in birds between calculated standard metabolic rate and empirically determined egg weight. To predict standard metabolism from egg weights depends on the one hand upon the well-documented relation between metabolism and bird weights (Lasiewski and Dawson, 1967; Scholander et al., 1950; Steen, 1958; Kendeigh, 1969, 1972; and others), but also upon a mathematical relation between species weight and egg weight. Heinroth (1922), Huxley (1927), Romanoff and Romanoff (1949), and Lack (1968) have discussed direct proportions between body and egg weights, and Amadon (1943) demonstrated a linear relation between egg and species weights for the Fringillidae. In any case, linear curves of the logarithms of numerous egg weights plotted against the logarithms of metabolic rates would reveal exponential relations (Huxley, 1927).

METHODS

Eggs available of the species for which standard metabolism has been calculated (see Lasiewski and Dawson, 1967) were weighed on a top pan balance after the eggs had been filled with water by means of a hypodermic needle (following the procedure of Romanoff and Romanoff, 1949). (Since the ostrich egg was too heavy for the balance, the value for its weight was taken from Romanoff and Romanoff.) The eggs are preserved in the August J. Schoenebeck collection of eggs in the University Museum at Stevens Point (see Alexia, 1970) and are listed in Table 1. Slight error might arise from air bubbles, etc., but as mentioned by Huxley (1927) the "regularity of the curves is in itself a presumption that the errors are not great." Logarithms of shell, egg, and body weights were plotted (Fig. 1) against log metabolic rate to determine from linearity if exponential relations exist. Twelve non-passerine birds and 15 passerine species were available. Slopes and y-intercepts were determined by the method of least squares for passerines and all available birds.

RESULTS

Bird weights, egg weights, and shell weights are shown in Table 1. The logarithms for these variables produced nearly linear scatter diagrams shown in Fig. 1. The passerines' line was above the line for non-passerine species as in graphs on body weights by Lasiewski and Dawson (1967) and Kendeigh (1972: 81, 84). Only one curve was calculated for the combined data on shell weights.

Equations relating standard metabolic rates to egg weights of passerines, and of all the available birds, and to egg shell are as follows:

TABLE 1
BODY WEIGHTS, STANDARD METABOLIC RATES, EGG WEIGHTS, AND SHELL WEIGHTS FOR
AVAILABLE PASSERINE AND NON-PASSERINE BIRDS.
Metabolic rates after Lasiewski and Dawson (1967), who also listed the body weights.

	Standard Metabolism (kcal/24 hr)	Egg Weights (g)	Shell Weights (g)
Passerines			
<i>Troglodytes aedon</i>	5.3	1.39	0.11
<i>Spizella arborea</i>	6.8	2.17	0.12
<i>Junco hyemalis</i>	6.1	2.50	0.14
<i>Melospiza melodia</i>	7.8	2.61	0.18
<i>Zonotrichia albicollis</i>	7.1	2.70	0.31
<i>Zonotrichia leucophrys</i>	8.0	2.90	0.19
<i>Loxia curvirostra</i>	10.5	2.10	0.22
<i>Passerella iliaca</i>	11.3	3.89	0.23
<i>Molothrus ater</i>	11.0	3.10	0.31
<i>Cardinalis cardinalis</i>	12.2	5.32	0.37
<i>Pipilo fuscus</i>	13.7	4.75	0.39
<i>Cyanocitta cristata</i>	17.6	6.4	0.42
<i>Corvus caurinus</i>	73.2	17.22	1.2
<i>Corvus cryptoleucus</i>	79.0	21.59	1.55
<i>Corvus corax</i>	92.0	26.4	1.91
Non-passerines			
<i>Archilochus colubris</i>	1.6	0.50	0.01
<i>Calypte anna</i>	2.2	0.49	0.01
<i>Scardafella inca</i>	5.2	2.74	0.18
<i>Chordeiles minor</i>	9.5	9.18	0.68
<i>Zenaida macroura</i>	13.4	6.1	0.38
<i>Colinus virginianus</i>	23.0	7.50	0.60
<i>Asio otus</i>	19.7	23.40	1.51
<i>Catharacta skua</i>	98	87.6	6.58
<i>Bubo virginianus</i>	108	62.70	4.82
<i>Ardea herodias</i>	128	77.0	7.18
<i>Aquila chrysaetos</i>	102	128.4	13.8
<i>Struthio camelus</i>	2,350	1,400	301

$$\log_{10}M(\text{passerines}) = 1.067 \log E + 0.51 \quad (1)$$

$$\log_{10}M(\text{all birds}) = 0.83 \log E + 0.57 \quad (2)$$

$$\log_{10}M(\text{all birds}) + 0.694 \log S + 1.487 \quad (3)$$

where M is the standard metabolism of resting birds at normal temperatures, E is the weight of the water-filled egg, and S of the dry shell. Standard errors of estimates are ± 0.1 for equation (1), ± 0.3 for (2), and ± 0.5 for (3).

The slopes of the curves agree with the range of constants (0.63–1.0)

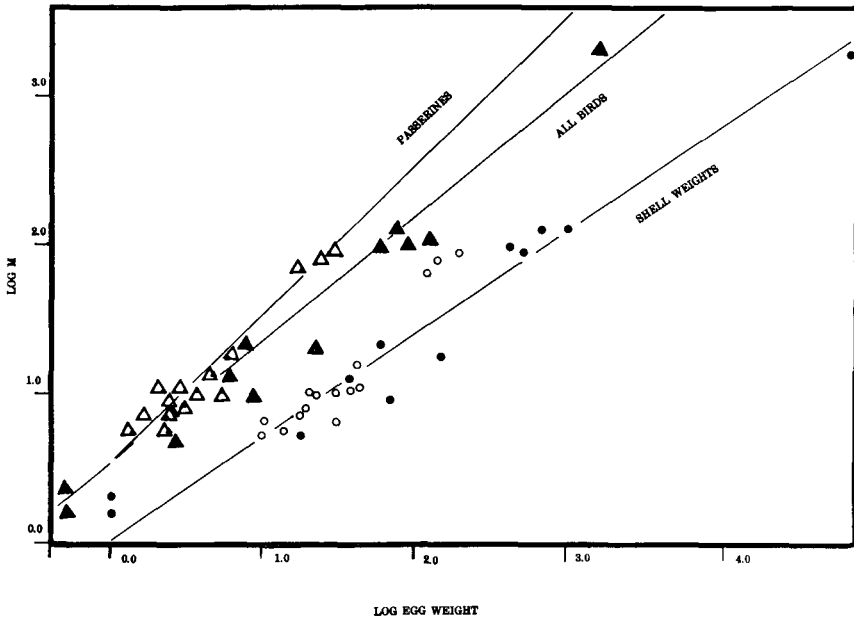


FIG. 1. Standard metabolic rates plotted against egg weights. The open triangles represent passerine eggs, the black triangles non-passerine eggs. The circles are passerine shell weights, the black circles non-passerine. The distribution of egg shell weights is displaced two units to the right (equivalent to increasing the characteristic by two, or multiplying the raw weights by 100), and the true Y-intercept is given in equation (3).

relating energy metabolism to body size in biological organisms (Zeuthen, 1953). The slope for the passerine species is at the upper limit.

The equations allow estimation of the standard rates of metabolism for several rare or extinct forms. The weight of the Ivory-billed Woodpecker's egg was 11.5 g, and of its shell 0.81 g. Equation (2) provides an estimate for standard metabolism of this rare or extinct bird as 28.1 kcal/24 hr, intermediate between the Bobwhite and the small crow *Corvus caurinus*. The predicted metabolic rate based on egg size is probably more accurate than a similar prediction based upon the few records of body weights recorded for this rare woodpecker. For future comparison with a closely related bird, the Pileated Woodpecker's similar weight of the egg (11.56 g, shell 0.80 g) permits estimation of a standard rate of 28.31 kcal/24 hr. The Passenger Pigeon's egg weighs 14.30 g, and its shell 1.36. The estimated standard rate is 33.81 kcal/24 hr.

Thickness of shell depends upon metabolism but also on the amount of yolk and precocial development of the embryo, which must develop sufficiently

to crack the shell (Lack, 1968). Most of the birds available for this study were altricial or nearly so. Heavier egg weights of precocial birds as a group would doubtless result in lower constants in the equations.

As the list of birds studied in regard to standard metabolism lengthens and additional egg weights are included, greater reliability can be placed on the values of *M*. When numerous species within families are studied the new constants obtained probably will permit quite valid predictions of metabolic rates, judging from the very close correspondence of egg size and body weight in the Fringillidae (Amadon, 1943).

SUMMARY

Equations were derived from empirical data relating egg weights for passerines and non-passerines and shell weights for both to published standard metabolic rates. Metabolic rates of two extinct or rare species were estimated.

ACKNOWLEDGMENT

I thank Dr. S. Charles Kendeigh, University of Illinois, for reading over the manuscript and providing information.

LITERATURE CITED

- ALEXIA, M. 1970. Catalog of North American bird eggs and nests in the August J. Schoenebeck Collection. Part 1, Report No. 2, Mus. Nat. Hist. Repts. Fauna and Flora of Wisconsin, p. 1-92.
- AMADON, D. 1943. Bird weights and egg weights. *Auk*, 60:221-234.
- HEINROTH, O. 1922. Die Beziehungen zwischen Vogelgewicht, Eigewicht, Gelegegewicht und Brutdauer. *J. Ornithol.*, 70:172-285.
- HUXLEY, J. S. 1927. On the relation between egg-weight and body-weight in birds. *J. Linnaean Soc., Zool., London*, 36:457-466.
- KENDEIGH, S. C. 1969. Tolerance of cold and Bergmann's Rule. *Auk*, 86:13-25.
- KENDEIGH, S. C. 1972. Energy control of size limits in birds. *Amer. Nat.*, 106:79-88.
- LACK, D. 1968. Ecological adaptations for breeding in birds. Methuen & Co., London.
- LASIEWSKI, R. C. AND W. R. DAWSON. 1967. A re-examination of the relation between standard metabolic rate and body weight in birds. *Condor*, 69:13-23.
- ROMANOFF, A. L. AND A. J. ROMANOFF. 1949. *The avian egg*. John Wiley and Sons, New York.
- SCHOLANDER, P. F., R. HOCK, V. WALTERS, AND L. IRVING. 1950. Adaptation to cold in arctic and tropical mammals and birds in relation to body temperature insulation, and basal metabolic rate. *Biol. Bull*, 99:259-271.
- STEEN, J. 1958. Climatic adaptation in some small northern birds. *Ecology*, 39:625-629.
- ZEUTHEN, E. 1953. Oxygen uptake as related to body size in organisms. *Quart. Rev. Biol.*, 28:1-12.

MUSEUM OF NATURAL HISTORY AND DEPARTMENT OF BIOLOGY, UNIVERSITY OF WISCONSIN, STEVENS POINT, WISCONSIN 54481, 31 MAY 1972.