HAYWARD, C. L., M. L. KILLPACK AND G. L. RICHARDS. 1963. Birds of the Nevada test site. Brigham Young Univ. Sci. Bull., Biol. Ser. 3: 1–27.

LINSDALE, J. M. 1951. A list of the birds of Nevada. Condor 53:228–249.

PHILLIPS, A., J. MARSHALL, AND G. MONSON. 1964. The birds of Arizona. Univ. Ariz. Press, Tucson.

PRESNALL, C. C. 1935a. The birds of Zion National Park. Proc. Utah Acad. Sci., Arts and Letters 12:162–210.

PRESNALL, C. C. 1935b. Four new records from Zion National Park, Utah. Condor 37:82.

TANNER, V. M. 1927. Notes on birds collected in the Virgin River Valley of Utah. Condor 29: 196–200.

VAN ROSSEN, A. J. 1930. Critical notes on some Yellowthroats of the Pacific southwest. Condor 32:297–300.

WAUER, R. H. 1965a. Wintering Rufous-crowned Sparrows found in Utah. Condor 67:447.

WAUER, R. H. 1965b. Intraspecific relationship in Red-shafted Flickers. Wilson Bull. 77:404.

WAUER, R. H. 1966a. Flammulated Owl records following May storms in Zion Canyon, Utah. Condor 68:211.

WAUER, R. H. 1966b. Bird-banding at Zion National Park. Western Bird Bander 41:24–25.

WAUER, R. H. 1966c. Eastern Phoebe in Utah. Condor 68:519.

WAUER, R. H. 1967. New status for the Rufous-crowned Sparrow in Utah. Wilson Bull. 79: 348–349.

WAUER, R. H. 1968. Northern range extension of Wied's Crested Flycatcher. Condor 70:88.

WAUER, R. H., AND D. L. CARTER. 1965. The birds of Zion National Park and vicinity. Zion Nat. Hist. Assoc.

WAUER, R. H., AND R. C. RUSSELL. 1967. New and additional records of birds in the Virgin River Valley. Condor 69:420–423.

WOODBURY, A. M., C. COTTAM, AND J. W. SUGDEN. 1949. Annotated check-list of the birds of Utah. Bull. Univ. Utah 39:1–40.

Accepted for publication 14 August 1968.

CALCULATION AND MISCALCULATION OF THE EQUATIONS RELATING AVIAN STANDARD METABOLISM TO BODY WEIGHT

ROBERT C. LASIEWSKI

Department of Zoology
University of California
Los Angeles, California 90024

AND

WILLIAM R. DAWSON

Department of Zoology
University of Michigan
Ann Arbor, Michigan 48104

A variety of relationships of interest to biologists can be described by the general power function equation:

$$Y = aX^b. \quad (1)$$

This equation may be written in the more convenient logarithmic form:

$$\log Y = \log a + b \log X, \quad (2)$$

recognizable as a mathematical expression of a straight line. For a set of data conforming to this general relationship, the parameter estimates of a and b can be calculated by the least squares method. Although equations (1) and (2) are mathematically equivalent, their least squares solutions are not. The choice of the appropriate model for calculating estimates of a and b depends upon whether the data are homoscedastic (having constant variance) or heteroscedastic (lacking constancy of variance). Least squares regression theory assumes that the deviations between predicted and observed values of Y are normally distributed with a constant variance. If the original data exhibit heteroscedasticity, appropriate transformation of the data will stabilize the variance. Heteroscedastic data are often non-normally distributed and frequently "the transformation that gives a constant variance also simultaneously gives a distribution closer to normal" (K. A. Brownlee 1965. Statistical theory and methodology in science and engineering. Second ed. p. 146. John Wiley and Sons, New York).

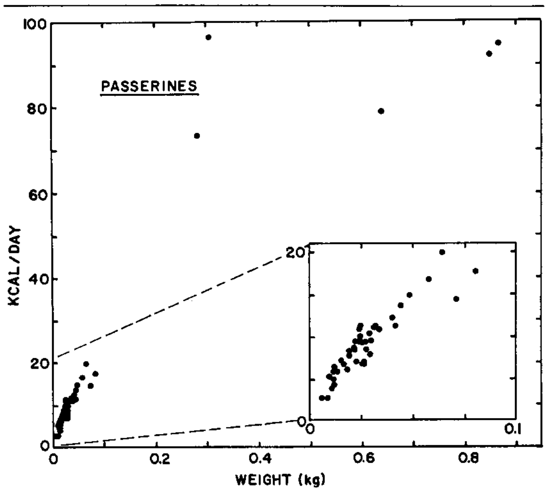

FIGURE 1. Arithmetic plot of data relating standard metabolic rate and body weight in passerine birds (from table 1 of Lasiewski and Dawson 1967).

The relationship between avian standard metabolism and body weight can be described by the generalized equations (1) and (2). Lasiewski and Dawson (Condor 69:13, 1967) presented data for standard metabolism and body weight of 48 passerine birds, which are plotted arithmetically in figure 1. The variance of the dependent variable (kcal/day) increases with increasing values of the independent variable (body weight), and these data are therefore heteroscedastic. Thus a least squares fit to the untransformed data is inappropriate.

Logarithmic transformation of the passerine data (fig. 2) stabilizes the variance, and more nearly approximates the normality assumptions of least

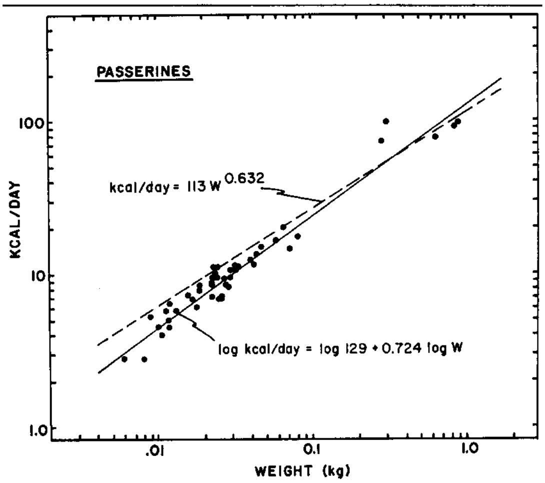

FIGURE 2. The relation between standard metabolic rate and body weight in passerine birds plotted on logarithmic coordinates. Solid line represents least squares solution fitted to logarithmically transformed data by Lasiewski and Dawson (1967). Dashed line represents Zar's (1968) least squares iterative fit to the untransformed data.

squares regression theory. The least squares regression line fitted to the transformed data is:

$$\log M = \log 129 + 0.724 \log W \pm 0.0806, \quad (3)$$

where M is kcal/day, W is body weight in kilograms, and the $\pm$ value represents the standard error or estimate of log M. This line is plotted in figure 2.

Choice of the incorrect model for calculating parameter estimates of a and b by least squares regression techniques may lead to spurious conclusions. For example, Zar (Bioscience 18:1118, 1968) has proposed that a least squares iterative fit to the untransformed data for avian standard metabolism and body weight is the "preferred" method for calculating estimates of a and b. His analysis of the data presented by Lasiewski and Dawson for all birds, passerine birds, and nonpasserine birds, gave three solutions which differ in varying degrees from the corresponding equations of these authors. Zar's equation for passerine birds, fitted by the least squares method to the untransformed data, is:

$$M = 113W^{0.632} \pm 7.87, \quad (4)$$

where the $\pm$ 7.87 represents the standard error of estimate of M. The dashed line in figure 2 shows Zar's solution. It demonstrates clearly, even by casual observation, that model (4) describes the available data poorly compared to model (3). The relatively poor fit of equation (4) is due primarily to the fact that the five metabolic values for ravens and crows (282 g and larger) exert a disproportionate influence upon the parameter estimates of the untransformed data, because of the large absolute values of the variance of these observations. Furthermore, Zar's model (4) inherently assumes that the regression passes through the origin (when $X = 0$, $Y = 0$). Clearly, a least squares fit to the untransformed data not only violates the assumption of the homoscedasticity of the data, but has led to a regression line which fits the data poorly.

The "goodness of fit" of a regression line to the untransformed data would probably be slightly improved by making no assumptions about the value of Y at $X = 0$, expanding model (1) to:

$$Y = a_0 + a_1X^b. \quad (5)$$

But why complicate an inappropriate model?

We thank Frederick E. Smith, Department of Wildlife and Fisheries, University of Michigan; William M. Rand, Division of Biostatistics, and Donald Landenberger, Department of Zoology, University of California, Los Angeles; and James T. Enright, Department of Oceanography, University of California, San Diego, for reading this manuscript and for their helpful discussions and suggestions.

Accepted for publication 4 April 1969.