

## SHORT COMMUNICATIONS

### Ratios in Avian Physiology

CHARLES R. BLEM

Virginia Commonwealth University, Department of Biology, Academic Division,  
Richmond, Virginia 23284 USA

Atchley et al. (1976), Anderson and Lydic (1977), Atchley and Anderson (1978), and Atchley (1978) convincingly demonstrated that bivariate ratios and proportions, common in much biological analysis, may not be used properly in many instances (but see Albrecht 1978, Dodson 1978, Hills 1978). Atchley and his colleagues specifically attack situations in which a variable is divided by body weight in order to remove the effects of size, but ornithologists apparently have given little attention to these warnings. Such calculations (or similar ones) are frequent in the quantification of avian metabolism, lipid reserve, or other variables; examples can be found in many recent ornithological journals.

Among the problems that may result from the computation of ratios are: (1) the effects of the denominator (in this case, body weight) are not eliminated and, in fact, often are enhanced; and (2) the distribution of ratios computed from normally distributed variables may be skewed and no longer normal (see Atchley et al. 1976). Consequently, seasonal, sexual, interspecific, and interlocality comparisons might be obscured by problem (1), and the presentation of untransformed data may result in unreliable means and confidence intervals because of problem (2). In many instances, the proper alternative to the use of ratios is covariance analysis of the variable in question, with body weight included as the covariant and other important factors (e.g. season, species, sex) considered as classification variables (see Zar 1974, Atchley et al. 1978). Alternatively, ratios might be subjected to normalizing transformation before computations are done. Computations may be performed on transformed data, with the results transformed back to ratio values, but this may yield biased estimates of means and will give asymmetrical (even if valid) confidence intervals.

In practice, what is the result of the injudicious manipulation of ratios? I performed empirical analyses of 12 avian data sets to compare results obtained from covariance analysis and/or transformation procedures with "conventional" manipulation of untransformed ratios. Ratios, including percentage lipid =  $100X/\text{body weight}$ , lipid index =  $X/\text{lean dry weight}$  and  $Y = Z/\text{body weight}$ , were computed where  $X = \text{g extractable lipid}$ ,  $Z = \text{metabolic rate (Cal/day)}$ , and body weight is in grams. Lipid ratios were also transformed by means of the arcsine transformation procedure (arcsine  $\sqrt{Y}$ ; see Zar 1974). Normality of data sets was tested by Shapiro-Wilk  $W$ -tests (Shapiro and Wilk 1965, SAS Institute 1982) when

$n \leq 50$ , or by a modified version of the Kolmogorov-Smirnov  $D$ -statistic when  $n > 50$  (Stephens 1974, SAS Institute 1982).  $F$ -values derived from covariance analysis with weight included as a covariant were compared with those derived from analysis of variance tests of weight-specific ratios.

Nine sets of lipid measurements (Table 1) were analyzed along with three sets of metabolic data. Species involved include the Japanese Quail (*Coturnix japonica*), Northern Bobwhite (*Colinus virginianus*), European Starling (*Sturnus vulgaris*), House Sparrow (*Passer domesticus*), House Finch (*Carpodacus mexicanus*) and White-throated Sparrow (*Zonotrichia albicollis*). Sample sizes vary among these from  $n = 36$  to  $n = 533$  (see Tables 1 and 2). In all of the data sets tested, when analysis of ratios indicated a significant effect, so did covariance analysis. Covariance analysis, however, detected one significant effect not revealed by analysis of transformed or untransformed ratios. If the distributions of body weights fit the normality and homogeneity of variance assumptions of the analysis of covariance, then the analysis of ratios resulted in the commission of a type II error (failure to reject the null hypothesis when it is false).

Analysis of metabolic data (Table 2) demonstrated that relationships between weight-specific metabolic rates and ambient temperature are not as precise as relationships between metabolism and temperature with body weight included as a covariant. The coefficient of determination ( $R^2$ ), which indicates the proportion of variation in metabolic rate (per bird or per gram) that is explained by a particular equation, was larger when weight was included as a covariant. With covariance analysis,  $F$ -values generated from tests of significance of regression were also larger. Coefficients associated with independent variables need to be interpreted with caution, because the statistical relationship between the dependent variable and any independent variable may affect the coefficients of all other independent variables in the model. One should view a coefficient as indicating the effect of the associated independent variable when other independent variables are being held constant. This occasionally produces results that seem contradictory or erroneous if the independent variables are highly correlated. More often, the analysis clarifies the relationship. For example, weight has only  $\frac{1}{3}$  the effect of ambient temperature in predicting metabolic rate for House Sparrows, while it is 3 times as influential for House Finches, even though the body sizes are similar (Table 2). This case has a biological

TABLE 1. Analysis of variance tests of the significance of effects on lipid content of birds. All *F*-values < 3.7 are not statistically significant at the 0.05 level. See text for description of analyses (\* = body weight included as a covariant, \*\* = % lipid arcsine transformed; sample size is in parentheses).

Species	Effect	<i>F</i> -values				
		g Lipid*	% Lipid	Lipid**	Lipid index	Lipid index**
House Sparrow (72)	Locality	35.5	22.1	21.1	17.9	20.6
House Sparrow (72)	Age	20.5	15.3	6.4	7.5	7.1
House Sparrow (121)	Sex	14.8	9.3	9.5	6.4	6.2
House Sparrow (100)	Capture month	0.8	0.4	0.5	0.6	0.7
White-throated Sparrow (99)	Sex	13.9	3.5	3.7	3.4	3.3
White-throated Sparrow (99)	Capture month	19.3	29.4	32.0	29.2	28.5
European Starling (168)	Sex	0.5	2.4	2.3	2.8	2.8
European Starling (111)	Locality	7.7	19.5	17.7	16.8	21.4
Northern Bobwhite (36)	Age	59.3	18.3	16.1	9.9	10.2
Japanese Quail (66)	Age	47.1	22.1	14.0	8.4	6.5

basis, as House Finches are less capable of attaining high metabolic rates and survive low ambient temperatures poorly (Sprenkle and Blem unpubl.). In general, larger  $R^2$  values associated with analyses of covariance and multivariate models give us greater confidence in: (1) the ability of the equation to predict dependent variables and (2) the significance of the independent variables in the equation.

In summary, I encourage investigators to employ covariance analysis when considering data that might be expressed as ratios. Not only are final conclusions more likely to be correct, but precision of expression, particularly equations, may be greatly improved. One should not discard previously published research based on ratios, however. It is likely that significant effects apparent in such studies are real, although other significant effects may have been overlooked. When ratios are used, it is advisable to transform them in order to produce data sets that do not deviate from normality, but one should be warned that blind use of transformation procedures still may not produce normally distributed values and further analysis may require nonparametric test procedures. Data sets with significant intersexual, seasonal, or other variation should be expected to fit binomial or more exotic

distributions, and this compounds the problem. Many physiological measurements are inherently ratios (energy utilization/unit time, lipid/gram) and are not likely to be normally distributed.

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TABLE 2. Comparison of tests of significance of metabolic relationships. ( $T_a$  = ambient temperature in °C,  $Wt$  = weight in g,  $ME$  = metabolized energy in kJ/day, age is in days,  $R^2$  = coefficient of determination,  $F$  = *F*-test of significance of regression; all regressions are significant at the 0.05 level).

Species	Equation	$R^2$	<i>F</i>	<i>n</i>
House Sparrow	$ME/bird = 4.904 - 0.050T_a - 0.033Wt$	0.71	639.6	533
	$ME/g = 0.172 - 0.004T_a$	0.28	203.8	533
House Finch	$ME/bird = 5.46 - 1.00T_a + 3.14Wt$	0.32	166.0	180
	$ME/g = 3.39 - 0.04T_a$	0.28	108.0	180
Northern Bobwhite	$ME/bird = 75.02 - 3.64Age + 4.02Wt$	0.83	410.6	78
	$ME/g = 2.527 - 0.021Age$	0.57	218.1	78

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### A Hybrid Red Crossbill-Pine Siskin (*Loxia curvirostra* × *Carduelis pinus*) and Speculations on the Evolution of *Loxia*

DAN A. TALLMAN<sup>1</sup> AND RICHARD L. ZUSI<sup>2</sup>

<sup>1</sup>Department of Mathematics, Natural Sciences and Health Professions, Northern State College, Aberdeen, South Dakota 57401 USA; and <sup>2</sup>National Museum of Natural History, Smithsonian Institution, Washington, D.C. 20560 USA

On the morning of 27 December 1981, a strange finch appeared at Tallman's feeder in a residential backyard in Aberdeen, Brown County, South Dakota. Alone and in the company of Pine Siskins, the bird consumed sunflower seeds. It fed on the ground and also cracked seeds while perched on a sunflower head hung from a clothesline. Tallman noted that this finch, when approached, did not fly with a small siskin flock but flew alone, silently, in a straight line from the feeder. The bird exhibited aggression toward siskins feeding near it. The finch was obviously not a regular North American species, being most like a siskin but larger, less boldly streaked, and with a proportionately larger bill and head. Immediately upon recognizing the bird as an oddity, Tallman opened Potter traps and mist nets and eventually caught it in a Potter trap. The bird was then prepared as a museum skin and sent to the National Museum of Natural History, Smithsonian Institution, where Zusi identified it as a hybrid between the Red Crossbill (*Loxia curvirostra*) and Pine Siskin (*Carduelis pinus*). Apparently no previous reports of a hybrid between *Loxia* and any other genus exist (Cockrum 1952, Gray 1958).

The absence of damage to the bill, feet, or plumage suggests that the bird had not been caged. We judged the bird—a female—to be at least a year old from the completely ossified skull and the shape of its rectrices. The latter are more rounded at the tip and have broader inner vanes than those of juvenile crossbills and siskins. We therefore compared it mainly with adult females taken in December and January.

The specimen (USNM 582513) may be described as follows (see Fig. 1). Underparts whitish, streaked with gray. Sides and flanks shading to grayish olive. Patchy yellowish wash on lower throat, breast, belly, and crissum. Streaks neither bold nor sharply defined, formed from longitudinal center stripes on feathers;

streaks weakest on lower throat and belly and darkest and best defined on flanks and crissum.

Upperparts dusky olive streaked or spotted with dark gray. Feathers of forehead and crown dark with whitish or yellowish edges, giving spotted effect. Longer feathers of nape, neck, and back dark gray bordered with dusky olive laterally, giving streaked effect. Rump contrasts with back in having feathers with paler olive centers and yellowish lateral edges. Upper tail coverts uniform grayish olive without pronounced center streaks, darker than rump but paler than back. Superciliary line whitish with dusky streaks. Auricular patch dusky grayish olive.

Wings sooty; median and greater wing coverts with pale, olive-whitish tips (and faint brownish cast) producing two narrow wing bars—the anterior one somewhat broken and the posterior one continuous. Narrow yellow edgings on all primaries, except outer, extending distally to point of emargination. Secondaries with short yellowish outer border toward tip (tips bilobed), becoming broader and whiter on inner, superficial secondaries. Inner vanes of primaries and secondaries with broad silvery yellowish inner border that narrows distally and ends proximal to tip (at point of emargination in primaries).

Tail strongly notched; sooty with yellow outer edges. Edges least pronounced on outer and most pronounced on inner feathers and broadest basally. Inner vanes edged narrowly with whitish.

Label data include the following: bill dark slate gray, iris dark brown, legs and feet dark brown, gape whitish, skull ossified, little to moderate fat, no molt, ovary tiny.

Measurements of wing, tail, tarsometatarsus, and bill are given in Table 1. They are compared with those of 10 specimens of *Carduelis pinus pinus* and 10 of *Loxia curvirostra sitkensis*—the smallest recognized North American race of the species. If wing length is taken as an index of body size, the hybrid is closer