547 compared with 658, and on the Outer Ards, 1050 compared with 987. In 1985/86, our two midwinter counts, made at high water, produced totals of 2692 (December) and 2797 (February) for the whole study area. These results suggest a remarkable constancy in the numbers of Turnstone, both within and between winters, and is consistent with work elsewhere which has found that Turnstones are highly faithful to their wintering sites (Symonds *et al.* 1984, Metcalfe and Furness 1985).

As indicated above, low water counts of Turnstone have probably underestimated numbers by 50-60%. However, it is unclear if this discrepancy would be a general feature of all Turnstone counts or whether it is simply a result of the very variable nature of the habitats on this particular stretch of coastline. The current estimate of the Turnstone population of Northern Ireland is 3140 (M.E.Moser, pers. comm.) although the actual figure could be considerably higher, perhaps in the region of 4000-4500.

Wilson's Phalarope *Phalaropus tricolor*. One record of 3 on 16 September 1980.

CONCLUSION

Belfast Lough and the Outer Ards coast support considerable numbers of overwintering waders with some populations probably of 'national' or international importance. The estuarine areas of Belfast Lough have been counted for 7 years, for the BoEE and are of 'national' importance for Oystercatcher and Redshank (Weyl, in prep.). The Outer Ards and the shores of Outer Belfast Lough are clearly also of importance to waders, particularly Ringed Plover and Turnstone. The Winter Shorebird Count has shown Co. Down to be one of the best counties in the United Kingdom for waders, supporting an average linear density of 118 waders km^{-1} (M.E.Moser, pers. comm.). In both 1984/85 and 1985/86, the Outer Ards supported about 200 waders km^{-1} and must, therefore, rate as one of the best discrete sites for open shore waders in the UK.

ACKNOWLEDGEMENTS

We wish to thank P.J.T. Brain, P.M. Corbett, A.S. McMullin, R.S.Weyl and S.A. Wolfe-Murphy for their help with fieldwork in 1985/86; thanks also to R.S. Weyl and M.E. Moser for providing unpublished data and J.S. Furphy and M.E. Moser for their helpful criticism of early drafts of the manuscript.

REFERENCES

Hutchinson,C.D. 1979. *Ireland's Wetlands and their Birds*. Irish Wildbird Conservancy, Dublin.

Metcalfe,N.B. and Furness,R.W. 1985. Survival, Winter population stability and site fidelity in the Turnstone *Arenaria interpres*. *Bird Study* 32: 207-214.

Prater,A.J. 1981. *Estuary Birds of Britain and Ireland*. T and A.D. Poyser.

Salmon,D.G. and Moser,M.E. (eds.) 1985. Wildfowl and Wader Counts, 1984/5. Wildfowl Trust/British Trust for Ornithology.

Symonds,F.L., Langslow,D.R. and Pienkowski,M.W. 1984. Movements of wintering shorebirds within the Firth of Forth: Species differences in useage of an Intertidal Complex. *Biol. Conserv.* 28: 187-215.

Weyl,R.S. (in prep.) The Bird Populations of Inner Belfast Lough.

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A POTENTIAL BIAS IN LOG-TRANSFORMED ALLOMETRIC EQUATIONS

by A.G. Wood

INTRODUCTION

Many recent studies in avian ecology have used regressions with logarithmic transformations to estimate various biological parameters, particularly metabolic rate (Lasiewski and Dawson 1967, 1969, Zar 1968, Aschoff and Pohl 1970, Kendeigh *et al.* 1977). This paper examines a potential bias resulting from the use of such equations, and presents the appropriate methods for converting estimates from logarithmic equations back to untransformed units.

THE PROBLEM

In the general case, we have two variables X and Y which are related by the allometric equation:

$$Y = kX^b \qquad (1)$$

where k and b are constants. Although the relationship between X and Y is non-linear, the transformed variates logX and logY are connected by the straight line relationship:

$$\log Y = \log k + b\cdot\log X \qquad (2)$$

This equation implies a linear relation between the logarithms of X and Y based on three assumptions:

1. The expected value of Y, for a given X is $E(\log Y) = \log k + b\cdot\log X$
2. The variance V of logY, given logX, is constant.
3. For each value of logX, logY is normally distributed.

The parameters of transformed equation (2) can now be estimated using the biological data and standard least-squares regression techniques.

When a logarithmic transformation is used it is usually necessary to be able to express estimated values of Y in untransformed units. Such a back transformation is not direct, because if the distribution of logY at a given logX is normal, the distribution of Y cannot be normal, but will be skewed. In fact the solution of equation (2) for a given X, and determining the antilogarithm of logY, yields the median of the skewed distribution of Y rather than the mean (Baskerville 1971). The correction factor (CF) by which this median must be multiplied to obtain the mean of Y, has been derived by a number of authors (Baskerville 1971, Mountford and Bunce 1973, Sprugel 1983), and is calculated from:

$$CF = e^{(V/2)}$$

where V is the variance of logY, e is the base of natural logarithms 2.718.

In practice V is not known, but can be estimated from the square of the standard error of the estimate of the regression, giving equation (3).

$$CF = e^{(SEE^2/2)} \qquad (3)$$

where SEE is the standard error of estimate of the regression. The values for logk and b in equation (2) also have errors associated with them. However they can be considered insignificant if a large enough sample size for the regression is obtained.

The value of SEE depends on the base to which logarithms are taken when the values of Y are transformed (Sprugel 1983). To obtain the correct value for the correction factor (CF), SEE must be based on natural logarithms. Therefore, using a base 10 standard error does not give the correct value; this base 10 SEE should be converted to base e (multiply by $\log_e 10 = 2.303$) and this value used in equation (3).

In energetic studies, estimates are made of a species' metabolic rate from its weight using the following equation, derived from a number of other species in which the metabolic rate is known:

log(Metabolic rate) = logk + b.log(Body mass)

Given the body mass of a species, the antilog of the metabolic rate derived from this equation would give an estimate of the median metabolic rate for that particular mass. Only by multiplying this median by the previously defined correction factor would the mean metabolic rate for the particular body mass be obtained.

EXAMPLE

As an example of the difference between back transformation to the median and mean from published allometric equations, I will take the non-passerine estimators of basal metabolic rate (BMR) given by Lasiewski and Dawson (1967) and Kendeigh *et al.* (1977). The BMR estimates for Dunlin *Calidris alpina* and Grey Plover *Pluvialia squatarola* are presented in Table 1.

DISCUSSION

From the data in Table 1 it is clear that the inclusion of the correction factor produces a mean estimate of BMR which can be up to 2.3% above that which would normally be used (ie. the uncorrected median). A further complication in the application of such equations is the question of what body mass should be used? Tuite (1984) showed that the use of average lean mass rather than average total body mass greatly affects the metabolic rate estimate, and it is probably the average lean mass which best predicts the metabolic rate of a bird.

Table 1. Estimates of BMR (Kcal/bird/day) from allometric equations.

	Dunlin	Grey Plover
Average lean mass (g)	47.0	196.0
BMR from Lasiewski and Dawson (SEE = 0.068)		
Median	8.58	24.10
Mean	8.69	24.40
% difference	1.2	1.2
BMR from Kendeigh *et al.* (SEE = 0.093)		
Median	8.84	25.24
Mean	9.05	25.83
% difference	2.3	2.3

Basal metabolic rate is commonly used as a base for many energetics studies (Ashkenazie and Safriel 1979, Wood 1984). If there are large discrepancies as to which value of BMR to use, the multiplication of the error through a calculated energy budget will produce an even larger variation in the end result. The correction factor presented here does not appear to give a large change in the estimated BMR values. However, this is one source of error which is known about and can be corrected for; many others cannot yet be quantified.

ACKNOWLEDGEMENTS

I would like to thank Peter Rothery for the helpful discussion and advice he gave in the preparation of this paper. I am also grateful to Nick Davidson for his help, and to Peter Evans for his comments.

REFERENCES

Ashcoff,J. and Pohl,H. 1970. Rhythmic variations in energy metabolism. *Fed. Proc.* 29: 1541-1552.

Ashkenzie,S. and Safriel,U.N. 1979. Time - energy budget of the Semipalmated Sandpiper *Calidris pusilla* at Barrow, Alaska. *Ecology* 60: 783-799.

Baskerville,G.L. 1971. Use of logarithmic regression in the estimation of plant biomass. *Can. J. Forest Res.* 2: 49-53.

Kendeigh,S.C., Dol'nik,V.R. and Gavrilov,V.M. 1977. Avian energetics. *In* Pinowski,J. and Kendeigh,S.C. (eds.), *Granivorous birds in ecosystems*. Pp. 127-204. Cambridge Univ. Press, Cambridge.

Lasiewski,R.C. and Dawson,W.R. 1967. A re-examination of the relation between SMR and body weight in birds. *Condor* 69: 13-23.

Lasiewski,R.C. and Dawson,W.R. 1969. Calculation and miscalculation of the equations relating avian standard metabolism to body weight. *Condor* 71: 335-336.

Mountford,M.D. and Bunce,R.G.H. 1973. Regression sampling with allometrically related variables, with particular reference to production studies. *Forestry* 46: 203-212.

Sprugel,D.G. 1983. Correcting for bias in log-transformed allometric equations. *Ecology* 64: 209-210.