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VALIDITY OF PREDICTIVE EQUATIONS FOR TOTAL BODY FAT IN SANDERLINGS FROM DIFFERENT NONBREEDING AREAS[1]

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Abstract. We studied the validity of predictive equations for total body fat in shorebirds based on external morphology and body mass with data from Sanderlings (*Calidris alba*) collected in New Jersey, Texas, Panamá, and Perú. Equations derived at any one of these locations are not valid when applied to the other locations because changes in body mass involve both changes in fat and lean mass and because structural differences exist between these populations. We recommend that equations to predict total body fat in shorebirds derived at one location should not be applied to a different geographic area.

Key words: Fat; shorebirds; Calidris alba; *body composition; allometric equations.*

INTRODUCTION

Total body fat is significant in many aspects of bird ecology and evolution (reviews by King 1972, Blem 1976, Lindstrom 1986). An accurate and widely used method for determining total body fat requires collecting specimens and analyzing the carcasses using solvent extraction (Bligh and Dyer 1959, Dobush et al. 1985, Sibbald and Wolynetz 1986). Because large collections are undesirable under many circumstances (i.e., long-term studies, threatened species), researchers working with shorebirds have developed indirect means to estimate total body fat. The simplest approach is to use a subsample of individuals to derive a predictive formula for total body fat using easily measured external characteristics.

The predictive equations estimate lean body mass correcting for structural size (sensu Wishart 1979, and see Piersma 1988 for further discussion) and assume that the difference between total body mass and lean body mass is total body fat. Wing length is commonly used as the correcting factor for structural size in shorebirds (Page and Middleton 1972, McNeil and Cadieux 1972, Mascher and Marcstrom 1976, Pienkowski et al. 1979) but multiple regressions using wing length and other body measurements (Davidson 1983; Piersma and van Brederode, in press), and morphological and environmental characteristics (Blem and Shelor 1986 for passerines) have also been used. The equations can then be applied to a larger sample, without the need of further collecting (Davidson 1984).

Some authors have questioned the applicability of predictive equations to geographic areas or seasons other than those from which they were derived (Mascher and Marcstrom 1976, Pienkowski et al. 1979, Davidson 1983). Dunn et al. (1988) tested the applicability of the Page and Middleton (1972) equation for Semipalmated Sandpipers (*Calidris pusilla*) derived in Ontario to their study in Maine and concluded that the Ontario equation was not appropriate in Maine. To date, however, no other specific attempt to estimate the validity of predictive equations at different geographic locations has been made.

We used Sanderlings (*Calidris alba*) to test the applicability of predictive equations for total body fat based on external characteristics. Our data were collected from different geographic areas during a previous study (Castro 1988). The ecological significance of the variability in fat stores has been discussed extensively elsewhere (Castro 1988; Castro et al., unpubl.), and will not be addressed here.

METHODS

We collected Sanderlings during December and January of 1986–1987 and 1987–1988 at four

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TABLE 1. Predictive equations to estimate total body fat of Sanderlings using external measurements.[1]

Location	Equation	P	R^2	SEE
New Jersey	$F = -6.22 + 0.204M$	0.008	0.291	1.463
Texas	$F = -6.35 + 0.191M$	0.017	0.279	0.953
Panamá	$F = 0.25 + 0.041M$	0.147	0.071	0.479
Perú	$F = 10.04 + 0.245M - 0.053\ S$	0.001	0.488	1.016

[1] Symbols used: F = Total body fat (g); M = Total body mass (g); S = Wing span (mm); HB = Head-bill (mm), Number of cases: New Jersey = 23; Texas = 20; Panamá = 31; Perú = 23.

locations: Island Beach State Park, New Jersey, (39°55′N), Crystal Beach, Texas (29°30′N), Punta Chame, Panamá (8°44′N), and Puerto Viejo, Perú (12°33′S).

Birds were collected with shotguns and immediately weighed to the nearest 0.1 g with a Ohaus port-o-gram electronic balance. Carcasses were oven-dried at 65°C to constant mass. Each sample was homogenized in a coffee grinder, and a subsample was extracted for 10 hr in a Soxhlet apparatus using petroleum ether as solvent. Petroleum ether removes only nonpolar lipids thus these results do not include structural lipids (Dobush et al. 1985, Remington and Braun 1988).

The following external characteristics were measured: head–bill length (from distal edge of the head to the tip of the bill), exposed culmen length, nares–tip distance (from distal edge of nares to the tip of the bill), wing length (maximum chord), wing span (maximum), and tarsus length. For each location, we calculated a multiple regression equation to estimate total body fat using external measurements and body mass. The predictors included in each model were chosen after a stepwise regression using the above measurements and body mass (alpha to enter and to remove = 0.05, body mass forced into the model). We then applied each of these calculated equations to predict total body fat at each of the four locations studied. All statistical analyses were performed using the statistical package Systat 3.0.

RESULTS AND DISCUSSION

The predictors chosen varied among locations (Table 1). In New Jersey, Texas, and Panamá, only body mass was included (not significantly in Panamá). Similarly, Dunn et al. (1988) showed that wing length did not improve the predictive power of a regression beyond body mass alone for Semipalmated Sandpipers. In Perú, morphological measurements were included in the model.

We plotted the predicted values of total body fat using each of the four equations against the actual fat values observed at all locations (Fig. 1). Not surprisingly, each equation predicts total body fat for the location from which it was derived fairly well. When applied to the other locations, however, the predictive power decreases tremendously (based on visual inspection, and see below).

The equation derived from New Jersey (New Jersey equation) overestimated body fat at all other locations. The Texas equation overestimated fat in Perú and Panamá but not in New Jersey. The Panamá equation strongly underestimated fat at other locations. The Perú equation underestimated fat in New Jersey and Texas, but not in Panamá.

We calculated a hemisphere-wide equation by lumping the data from the four geographic areas and using a similar procedure (symbols as in Table 1):

$$F = 6.89 + 0.303 \cdot M - 0.189 \cdot HB - 0.026 \cdot S$$

$$(R^2 = 0.75;\ P < 0.0001;\ SEE = 1.14;\ n = 97)$$

The predictive power of this equation is shown in Figure 1e. Since it apparently explains the data points better than any of the other equations, we tested its validity using an analysis of covariance with the same predictors and testing for the effect of location. No significant interactions were found between location and the predictors (P values: mass = 0.11; head–bill = 0.70; wing span = 0.36). Therefore, the analysis was performed. Location was included in the model ($P < 0.0001$), meaning that after removing the effects of the predictors on total body fat some significant location effects on total body fat remain. Therefore, not even this equation is statistically correct to estimate body fat in Sanderlings from different geographic areas (even though it might provide a fair estimation).

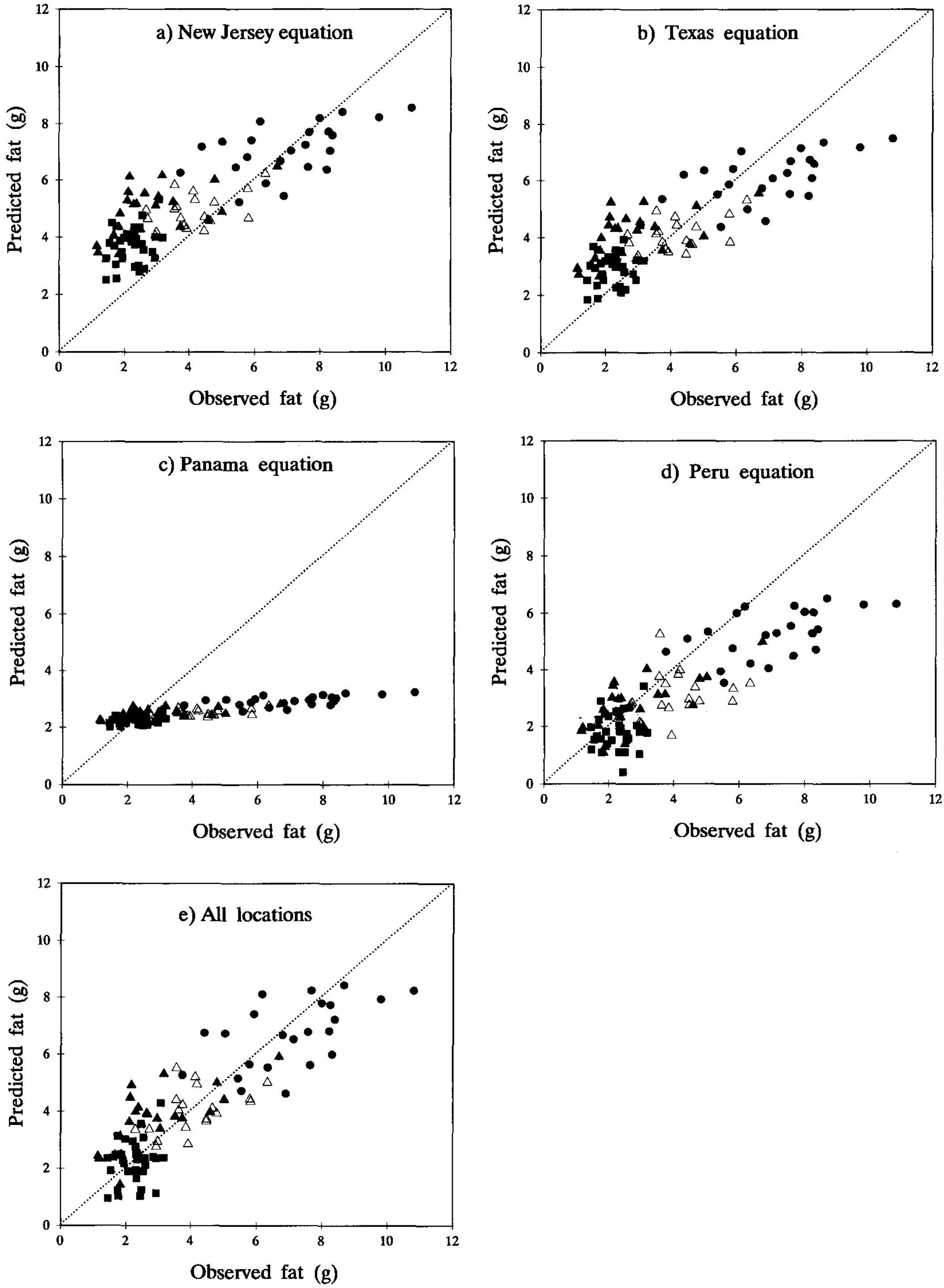

FIGURE 1. Predicted body fat (g) plotted against measured body fat (g) using equations for the four sites. The line represents a perfect agreement between predicted and observed values. Symbols are as follows: New Jersey (filled circle), Texas (open triangle), Panamá (filled square), Perú (filled triangle).

We offer two explanations for our findings. First, the assumption that all increases in body mass arise from increases in body fat is not necessarily true under some circumstances. In our case, for example, lean body mass was significantly correlated with total body mass (Castro 1988). An increase in lean mass with increases in total body mass has also been found in other studies (Summers et al. 1987; Piersma and van Brederode, in press; Piersma and Jukema, in press; Marsh 1984 and others). Consequently, the correction for structural size using external characteristics does not correct for increases in lean mass. Second, structural differences occur between the populations studied, based on multivariate analysis of external and internal measurements (Castro 1988; Sallaberry and Myers, unpubl.). Under these circumstances an equation derived from one population clearly cannot be applied to a different population.

We conclude that equations to estimate body fat derived at a given geographic location should not be extrapolated to different locations. This conclusion likely also applies to different times of the year, especially in migratory species, when separate populations or subpopulations can be involved. In cases where it is not possible to derive equations or collect specimens, alternative, nondestructive methods, such as total body electric conductivity should be used (Walsberg 1988).

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