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COMPARISON OF CONDITION INDICES IN MIGRATORY PASSERINES AT A STOPOVER SITE IN COASTAL LOUISIANA[1]

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Abstract. We evaluated the utility of four nondestructive condition indices—body mass, body mass scaled by wing chord length, fat scoring, and total body electrical conductivity method (TOBEC)—as predictors of lipid levels in migrating Wood Thrushes (*Hylocichla mustelina*), Swainson's Thrushes (*Catharus ustulatus*), and Summer Tanagers (*Piranga rubra*). The Red-winged Blackbird (*Agelaius phoeniceus*), a winter resident, was examined for comparative purposes. In addition, we examined differences among species in relationships of total body lipids and condition indices. Body mass was the best index of lipid levels, explaining 36%–82% of the variation in total body lipids in all four species. The relative contributions of the other indices to the prediction of lipid mass varied among species although TOBEC was selected for inclusion in each regression equation. For two species, equations including TOBEC measurements had lower errors in lipid prediction than equations only using the other nondestructive indices. Errors in lipid prediction were large for all the regression equations based on condition indices. In many cases it will be necessary to develop species-specific equations to predict lipid levels with condition indices.

Key words: Lipids; condition indices; energetics; passerines; total body electrical conductivity; TOBEC.

INTRODUCTION

Fat deposition is often used to determine the physiological condition of birds (Berthold 1975, Blem 1976, Moore and Kerlinger 1987). Ether extraction is considered to be an accurate measure of lipid levels (Blem 1990), but it is time-consuming and expensive, and it requires organisms to be sacrificed (Castro et al. 1990, Roby 1991). Because it directly measures lipid mass, ether extraction generally provides the standard against which condition indices are evaluated (Johnson et al. 1985).

Body mass is often considered an adequate measure of body condition (Johnson et al. 1985, Dunn and Gaston 1988); however, its usefulness as a predictor of lipid levels may vary among species (Johnson et al. 1985, Blem 1990). Often morphological measurements such as wing chord are used in association with body mass to account for anatomical differences among species or individuals that may affect the relationship between body and lipid mass (Bennett and Bolen 1978, Conway et al. 1994).

Fat scoring is a visual index of lipid levels developed by Helms and Drury (1960). This method uses subdermal fat deposits in the furcular and abdominal regions to assess physiological condition. Studies evaluating fat scoring indicate that it accounts for only about 50% of the variation in total body fat, and its accuracy varies widely among species (Rogers 1987, Krementz and Pendleton 1990).

Total body electrical conductivity (TOBEC) is a relatively new technique that provides an index of lipid levels based on differences in conductivity of lipid and lean mass (Walsberg 1988, Castro et al. 1990, Morton et al. 1991, Roby 1991). Although TOBEC estimates are highly correlated

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with lean mass when several species are used in the comparison (Walsberg 1988, Castro et al. 1990), the correlations are often lower in single-species comparisons (Scott et al. 1991). Regression equations differ significantly between species of shorebirds (Scott et al. 1991, Skagen et al. 1993), so species-specific calibration lines may be necessary to estimate lipid levels with TOBEC. Large errors were noted when TOBEC and body mass were used to estimate lipid mass in sandpipers (Skagen et al. 1993), and Conway et al. (1994) found that TOBEC was not a strong predictor of lipid mass in Wood Thrush (*Hylocichla mustelina*).

Body mass, wing chord, fat scoring, and TOBEC have the advantage of being measurements that can be taken under field conditions. More importantly, these indices do not require the sacrifice of organisms after the relationship between lipid mass and the index has been established. Although these are some of the most common methods used to determine physiological condition of birds, few studies (Conway et al. 1994) have directly compared the utility of these nondestructive indices for predicting lipid levels.

Migration may complicate the estimation of lipid mass with condition indices. The lipid mass of migrating passerines is of interest because individuals face high energy demands when crossing ecological barriers such as deserts or oceans (Moore and Kerlinger 1987). Exhausted migrants that are lipid depleted, dehydrated, or both are not unusual on the northern coast of the Gulf of Mexico during spring migration (Rogers and Odum 1964, Johnston 1968, Child 1969, Moore and Kerlinger 1987). Differences in the hydration state of migrants may adversely affect the prediction of lipid mass. Reductions in body mass may reflect loss of water rather than fat stores (Blem 1990). Walsberg (1988) and Roby (1991) found that TOBEC underestimated lean mass in dehydrated individuals. Roby (1991) suggested that TOBEC measurements from birds with questionable hydration states, such as those after a long flight, should be treated with caution. No investigations have compared predictions of lipid mass for migrating passerines based on commonly used condition indices.

Our objective was to determine which condition indices are the most useful for predicting lipid mass in migrating passerines under field conditions. We examined differences between species in the relationship of total body lipids and condition indices to determine whether predictive equations were consistent among species. If a single equation could predict lipid levels of passerines, fewer individuals would need to be sacrificed to obtain species-specific predictive equations from lipid extractions.

MATERIALS AND METHODS

Mist nets were used to capture 24 individuals of each of four species in Cameron Parish, Louisiana, during the spring 1993 migration. Three of the four species, the Wood Thrush, Swainson's Thrush (*Catharus ustulatus*), and Summer Tanager (*Piranga rubra*), had just crossed the Gulf of Mexico. A fourth species, the Red-winged Blackbird (*Agelaius phoeniceus*), was a winter resident in the area. Wing chord (unflattened) and mass were measured for all individuals. Individuals were also scored for fat using the fat index (Helms and Drury 1960). All birds were then restrained in a black nylon stocking and Velcro strap and placed in a SA-2 Small Animal Body Composition Analyzer (EM-SCAN, Inc., Springfield, Illinois [The use of trade names of commercial products does not constitute an endorsement by the U.S. Government.]). Five readings were taken and averaged for each organism. After this analysis, birds were sacrificed by thoracic compression (AOU 1988) and immediately frozen. Field measurements were taken by either of two individuals who were trained together to take consistent and repeatable data.

In the laboratory, we determined the masses of the total body, feathers, and ingesta. Carcasses were freeze dried at −50°C to constant mass and then homogenized with a grinder. We extracted fat from subsamples with petroleum ether by using either a Soxlet or Soxtech apparatus. Lipid mass was determined by subtracting lean body mass from total mass minus ingesta. An *F*-test for homogeneity of variances was used to evaluate differences in the variance of lipid mass among species.

We calculated Pearson product-moment correlation coefficients (r) to measure associations of lipid mass with body mass, wing chord, fat score, and EM-SCAN number. Because fat scores are not continuous, we also examined their correlation with lipid mass with Spearman's rank order coefficients. The same relationships between fat scores and lipid mass were statistically significant for both the parametric and nonparametric analyses; only the former are presented.

TABLE 1. Means ($\bar{x}$), standard deviations (SD), and ranges of lean mass, fat mass, and percentage body lipids for four species of passerines. Analyses were based on 24 individuals of each species captured in Cameron Parish, Louisiana during spring 1993.

Species	Lean mass			Lipid mass			Percent body lipid		
	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range
Red-winged Blackbird	16.6	1.1	14.9–18.4	2.5	0.6	1.6–3.9	5.0	1.0	3.2–7.4
Wood Thrush	12.4	0.1	10.9–14.6	6.4	3.3	1.1–13.2	13.6	6.2	3.1–24.7
Swainson's Thrush	7.7	0.4	6.7–8.8	3.6	2.3	0.7–8.5	12.4	7.0	3.2–26.4
Summer Tanager	8.2	0.5	7.2–9.0	5.2	2.9	0.8–8.7	16.1	6.5	3.5–25.1

We used multiple regression to examine the relationships between lipid mass and condition indices for each of the four species (PROC REG, SAS Institute 1985). To determine if regression lines differ between pairs of species, we developed equations including all of the indices and tested the hypothesis that the lines were coincident using indicator ("dummy") variables (Montgomery and Peck 1982). We calculated the partial correlations of each variable with lipid mass to determine its importance as a predictor of body lipid after accounting for the effects of the other condition indices.

Because measurement of TOBEC requires expensive equipment, we wanted to determine how much predictive power was lost by not including EM-SCAN number in regression models. We used forward selection procedures to determine which indices best predicted lipid mass when TOBEC was included or excluded from the regressions. Following Conway et al. (1994), we performed cross-validation procedures using the INFLUENCE option in SAS (PROC REG, SAS Institute 1985). By determining the error of estimates of lipid mass from the different regression models, we could compare the strength of predictions of the different indices. Differences between the regression models in absolute and percent error in predicted lipid mass were evaluated with paired t-tests and Wilcoxon signed rank tests, respectively. A 5% level of significance was used for all statistical comparisons.

RESULTS

Red-winged Blackbirds had the highest lean body mass, while Summer Tanagers and Swainson's Thrushes had the lowest (Table 1). The three migrating species had higher lipid masses than the resident blackbirds. The blackbirds also had the lowest percentage of body lipids (Table 1). The variance in total lipid mass of blackbirds was lower than that of the other species ($P <$ 0.001).

Body and lipid mass were significantly correlated in all species (Table 2). Wing chord and TOBEC were not correlated with lipid mass. Fat scores were significantly correlated with lipid mass in the migrating species but not in the blackbirds (Table 2).

The multiple regression equations incorporating all of the condition indices accounted for 66%–92% of the variation in lipid mass in the four species (Table 3). Regression equations were not coincident for any two species ($P \leq 0.05$). When the effects of the other nondestructive indices were controlled, both body mass and EM-SCAN number were significantly correlated with lipid mass for all four species (Table 4). The partial correlations of lipid mass with wing chord were significant for Red-winged Blackbirds and

TABLE 2. Correlation coefficients of lipid mass with condition indices for four species of passerines. Analyses were based on 24 individuals of each species captured in Cameron Parish, Louisiana during spring 1993. Asterisks indicate correlation coefficients that are significantly different than zero.

Species	Body mass	Wing chord	Fat score	EM-SCAN number
Red-winged Blackbird	0.60**	−0.08	0.18	0.06
Wood Thrush	0.74***	0.17	0.60**	0.05
Swainson's Thrush	0.90***	0.21	0.84***	0.18
Summer Tanager	0.91***	0.08	0.45*	−0.07

* = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$.

TABLE 3. Coefficients of determination (R^2) and average prediction errors of multiple regression models using condition indices[a] to predict total lipid mass (LM) for four passerines. Regression models include all of the condition indices (A), indices selected by forward selection (B), and indices selected by forward selection from a subset of variables excluding EM-SCAN number (C). Regressions were based on 24 individuals of each species captured in Cameron Parish, Louisiana, during spring 1993.

Equation	R^2	R^2 [b]	Absolute error ($\bar{x} \pm$ 95% CI)[b]	Percent error ($\bar{x} \pm$ 95% CI)[b]
Red-winged Blackbird				
A -LM = 7.367 + 0.191BM − 0.065WC + 0.156FS − 1.891EM	0.66	0.43	0.26 ± 0.08	10.7 ± 4.1
B -LM = 7.369 + 0.193BM − 0.066WC − 1.901EM	0.65	0.50	0.25 ± 0.09	10.3 ± 4.4
C -LM = 4.096 + 0.141BM − 0.082WC	0.51	0.40	0.29 ± 0.12	11.7 ± 4.9
Wood Thrush				
A -LM = 18.959 + 0.637BM + 0.047WC + 0.516FS − 12.746EM	0.82	0.70	1.21 ± 0.29	26.6 ± 13.5
B -LM = 23.384 + 0.722BM + 13.422EM	0.81	0.74	1.22 ± 0.32	28.1 ± 13.6
C -LM = −15.392 + 0.478BM	0.55	0.47	1.80 ± 0.53	37.5 ± 14.5
Swainson's Thrush				
A -LM = −0.181 + 0.820BM − 0.106WC + 0.580FS − 3.225EM	0.91	0.88	0.25 ± 0.09	19.9 ± 9.2
B -LM = −9.017 + 0.742BM − 3.015EM + 0.631FS	0.89	0.86	0.59 ± 0.19	25.4 ± 10.3
C -LM = −15.184 + 0.636BM + 0.679FS	0.85	0.81	0.74 ± 0.19	27.3 ± 8.7
Summer Tanager				
A -LM = 3.369 + 0.737BM − 0.096WC + 0.296FS − 4.891EM	0.92	0.85	0.25 ± 0.09	18.7 ± 4.3
B -LM = 5.243 + 0.764BM − 4.781EM − 0.106WC	0.91	0.86	0.58 ± 0.14	18.9 ± 9.2
C -LM = −15.550 + 0.647BM + 0.661FS	0.85	0.82	0.65 ± 0.24	18.2 ± 12.2

[a] BM = body mass, WC = wing chord, FS = fat score, EM = EM-SCAN number.
[b] Coefficient of determination and errors in prediction of lipid mass from cross-validation tests.

TABLE 4. Partial correlation coefficients of condition indices with lipid mass obtained from multiple regression models for four species of passerines. Analyses were based on 24 individuals of each species captured in Cameron Parish, Louisiana during spring 1993. Asterisks indicate partial correlation coefficients that are significantly different than zero.

Species	Body mass	Wing chord	Fat score	EM-SCAN number
Red-winged Blackbird	0.65***	−0.47*	0.17	−0.54**
Wood Thrush	0.79***	0.09	0.26	−0.74***
Swainson's Thrush	0.84***	−0.41	0.49*	−0.58**
Summer Tanager	0.95***	−0.44*	0.25	−0.61**

* = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$.

Summer Tanagers, as was the partial correlation of fat score and lipid mass in the Swainson's Thrush (Table 4).

Variables selected for the multiple regression equations that best predicted lipid mass often differed among the species (Table 3) and reflected patterns observed in the partial correlation analysis (Table 4). Body mass and EM-SCAN number were included in all the regression equations, while the inclusion of other indices was species-dependent. When regressions were based on all of the nondestructive indices except for EM-SCAN number, fat scores were selected for inclusion in the regressions for the Swainson's Thrush and Summer Tanager, while wing chord was included in the regression for the Red-Winged Blackbird (Table 3).

Forward selection procedures selected variables for inclusion in regression equations on the criteria of maximizing the variance in lipid mass explained by the model (R^2). Inclusion of EM-SCAN number in the regressions indicates that this measurement, in combination with other indices, provides the highest R^2 for all species ($P < 0.05$). But large increases in R^2, over regressions that did not include EM-SCAN number, were observed for only the Red-winged Blackbird and Wood Thrush (Table 3). Including EM-SCAN numbers in regressions decreased prediction errors of lipid mass for the Wood Thrush ($P < 0.02$) and Swainson's Thrush ($P < 0.05$), but not for the other species.

DISCUSSION

The physiological condition of migrating passerines is so variable in terms of lipid mass (Johnston 1968, Moore and Kerlinger 1987, Lindstrom and Piersma 1993) and water content (Johnston 1968, Child 1969, Carmi et al. 1992) that lipid indices may be severely affected. In our study, condition indices were equally or more highly correlated with lipid mass in migrating species than in the resident blackbirds, although prediction errors were higher for the migrants. Differences between the migrating and resident species in the amount of variance in lipid mass explained by the regressions may be due to differences in the variance in lipid mass among species. Low variance in lipid mass may help explain the low correlations of lipid mass with the condition indices of blackbirds.

Body mass is a simple, inexpensive measurement that explained more of the variance in lipid mass than any other nondestructive condition index in all of the examined passerines. Although fat scoring is one of the most commonly used condition indices (Connell et al. 1960, Helms and Drury 1960, Blem 1980, Cherry 1982, Nolan and Ketterson 1983, Rogers 1987, Moore and Kerlinger 1987), it provided less information about lipid mass than did body mass, and was not correlated with lipid mass in the Red-winged Blackbirds. Because wing chord and EM-SCAN number are indices of size and lean mass, their low correlations with lipid mass were not unexpected.

Body mass, wing chord, and fat scores are easier and less expensive to obtain than EM-SCAN number. If TOBEC is not measured, the combination of indices that best predicts lipid mass varies greatly among species. Once body mass was included in the regressions, fat scores helped predict lipid mass in two of the species but contributed little to lipid estimation in Wood Thrushes and Red-winged Blackbirds. Wing chord contributed to the prediction of lipid mass in only the blackbirds.

When selection procedures were used to maximize the variance in lipid mass explained by the regression models, body mass and EM-SCAN number were included in the equations for all species. Although TOBEC increased the amount of variation explained by the regression equations, it did not always improve their predictive power. Errors in lipid mass prediction were significantly reduced by inclusion of EM-SCAN numbers in the regression equations for only the Wood and Swainson's Thrushes.

Regression lines were significantly different among species, indicating that species-specific equations are needed for estimates of lipid mass, an observation also made by Skagen et al. (1993). It is also likely that temporal changes in physiological status will require development of separate equations for different seasons. Conway et al. (1994) found that fat scores followed by body mass provided the best predictions of lipid mass for Wood Thrush during the nesting period. For migrating Wood Thrush, body mass, followed by TOBEC, best predicts lipid mass. The equation Conway et al. (1994) provide for estimating lipid mass from fat scores and body mass overestimates body lipids for the Wood Thrush we examined by an average of 4.4 g (69%). Differences in energetic and reproductive status of birds between our study and that of Conway et al. (1994) probably produced these different results. The mean percentage lipid content (4.8%) and range (3.9–11.2%) for the Wood Thrush reported by Conway et al. (1994) are substantially smaller than for the individuals we examined (Table 1).

All of the regressions had average percent errors in the prediction of lipid mass of over 10% and half had average errors of over 25%. These large errors may be an artifact of basing regressions on relatively small samples of 24 birds of each species. Alternately, the indices may simply be relatively weak predictors of lipid mass. We cannot evaluate the merits of these two hypotheses with available data. The only other studies of prediction errors associated with condition indices found high errors in lipid mass prediction but also examined only 22–24 birds (Skagen et al. 1993, Conway et al. 1994). Lipid mass needs to be measured in a large number of individuals ($n > 100$) to determine to what extent prediction errors are a function of the number of individuals sacrificed and not of a weak relationship between lipid mass and condition indices.

In summary, short of measurement of lipids from ether extraction, body mass is the best predictor of total body lipids in the passerines we studied. The importance of body mass as an easy, inexpensive, nondestructive index of lipid levels in passerines is clear. The best combination of nondestructive indices for estimating lipid mass was species-dependent. In two of the migrating species, TOBEC reduced errors in the prediction of lipid mass, while in the other species little was gained by the inclusion of this variable in predictive equations based on other nondestructive indices. Variation in relationships of condition indices and lipid mass among species and seasons suggests that most investigators will find it necessary to quantify the predictive power of the condition indices to determine which combination of measurements will provide the precision required to achieve the objectives of their study.

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