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Use of Body Weight and Length of Footpad as Predictors of Sex in Golden Eagles.—Bortolotti (1984) recently proposed measurement of culmen length and hallux claw length as field characteristics suitable for identifying sex of Golden Eagles (*Aquila chrysaetos*). Unfortunately, these characteristics have not traditionally been collected on Golden Eagles, and extracting information on population or fledgling sex ratios from extant data sets is therefore difficult. Two characteristics commonly measured and reported in unpublished (e.g., Kochert 1972) and published (e.g., Ellis 1979) literature are body weight and/or footpad length. A technique using such measurements as a tool for *a posteriori* identification of eagle sex could prove useful, and our purpose here is to present a multivariate method by which measurement or knowledge of these variables can be used to sex individual Golden Eagles.

Data on weight and footpad length were collected by MNK on 49 Golden Eagles found dead in southern Idaho. Routine post-mortem examinations were performed on all birds, and all were internally sexed. Eagles whose ovaries or testes were not easily detected were excluded from analysis, thereby overcoming problems associated with the sex identification of immature birds with underdeveloped gonads (see Garcelon et al. 1985). Eagles were weighed (g) on a triple beam or Metler balance prior to being autopsied. Footpad length (mm), taken from the tip of the middle toe to the tip of the hallux, was measured with vernier calipers.

Weight and footpad length from the autopsied eagles were subjected to discriminant function analysis to test the accuracy of the variables as predictors of sex. The analysis generates a linear function of the independent variables, weight and footpad length, that discriminates between sexes in a manner that minimizes misclassification errors. To measure the overall accuracy of the function, classification from the discriminant function is compared to the known classifications, and misclassification probabilities are calculated. This percentage measure represents the ability of the function to correctly classify individuals at the population level and should be fairly high if the function is to have general application.

Posterior probabilities estimating the accuracy of classification for each individual, P_i, can be obtained from the equation:

$$P_i = 1/[1 + \exp^{(-z)}], \quad (1)$$

where z is the value of the discriminant function for that individual (Affifi and Clark 1984). Note that P_i values do not represent statistical probabilities; rather, they estimate the probability of belonging to a particular classification (here sex) and provide a subjective measure by which investigators can accept or reject the classification. As used here, P_i is the probability the classified bird is female while $1.0 - P_i$ is the probability of being male. Investigators should be cautious of sex classifications where P_i for either sex is close to 0.5. If a particular value of P_i (e.g., >0.9) is to be used as the basis for accepting or rejecting a sex classification, this value should be set prior to the analysis.

We also developed functions for those instances when only a weight or footpad measurement is available. Although not "true" discriminant functions since only a single variable was measured, the functions nonetheless estimate a dividing point within the range of weight or footpad that can be used to identify sex.

We assumed no significant variability in weight and footpad length over the range of Golden Eagles in North America. All analyses were performed using procedures found in the Statistical Analysis Systems Guides (SAS Institutes Inc., SAS Circle, P.O. Box 8000, Cary, North Carolina 27511). We tested and met all necessary assumptions for discriminant function analysis.

A total of 31 males and 18 females were identified from the autopsied specimens. Mean weights (±SE) were 3477.08 ± 100.95 g for males and 4913 ± 163.87 g for females. Mean footpad length was 131.64 ± 0.61 mm and 145.44 ± 0.94 mm for males and females, respectively. Three significant functions, one using both weight and footpad length (approximate $F = 164.51$, $P < 0.0001$), and one each for footpad length ($t = 12.82$, $P < 0.0001$) and weight ($t = 7.88$, $P < 0.0001$), were developed from the study specimens. All three functions are standardized to 0 such that birds with z values <0 and >0 are classified as male and female, respectively.

The first function, using weight and footpad:

$$z = 0.002 \times \text{weight} + 0.931 \times \text{footpad} - 137.447, \quad (2)$$

accurately sexed all males and was 94% (17 of 18) correct for females. The misclassified female had a weight approximately 1500 g below the mean female weight and was well within the range of male weights. Accuracy using the function for footpad alone:

$$z = 1.047 \times \text{footpad} - 145.035, \quad (3)$$

was 100% for both males and females. The dividing point between the sexes for footpad length, obtained by solving for 0, is 138.5 mm, with values < and > representing males and females, respectively.

The use of weight alone:

$$z = 0.004 \times \text{weight} - 16.781, \quad (4)$$

produced a less accurate function, resulting in 89% (16 of 18) accuracy for females and 94% (29 of 31) accuracy for males. All four misclassified eagles had weights within the range of the other sex, suggesting a greater degree of overlap in male and female weights than is found in footpad length. The dividing point between the sexes is 4195.5 g, with values < and > representing males and females, respectively. With the exception of the misclassified birds, P_i values for all eagles were in excess of 0.9 for each of the three functions.

To use the functions, simply insert weight and/or footpad measurements into the appropriate equation. For example, consider a bird of unknown sex with a 145 mm footpad and weight of 4600 g. Inserting both measurements into equation (2) gives a z-score of 6.748, a value greater than 0 and one indicating the sex is female. The posterior probability that the classification is correct is estimated from (1), where $z = 6.748$. The value, 0.998, is almost 1.0 and suggests a high degree of confidence in the classification as female. If only footpad length or weight is known, these values would be inserted into equations (3) and (4), respectively. Posterior probabilities would be estimated in a manner similar to that described above, using the appropriate z-score.

Together, these three functions provide a means by which individual Golden Eagles can be sexed and estimates of population or fledgling sex ratios obtained from extant data sets. As field characteristics, however, these variables should be used with caution. In contrast to the two anatomically "hard" characteristics suggested by Bortolotti (1984), both weight and footpad length are anatomically "soft" and hence are subject to greater potential variability in measurement. Such variability could introduce bias into measurements and lead to incorrect sex classification.

First, partial or full crops could confound weight measurements and lead to incorrect sex classification. Furthermore, weight data from extant data sets often fail to indicate whether or not crops were partial or full, or whether such information was even collected. To test the effect of partial or full crops on the accuracy of the functions, the body weight of each bird was adjusted by adding the maximum possible weight associated with a full crop (after Collopy 1984). Each bird was then reclassified. Although P_i values decreased for males and increased for females, in no instance was sex classification changed. Similar results, but in opposite directions for each sex, were found when the maximum possible weight of a full crop was subtracted from each bird. This suggests that the effect of partial or full crops on the accuracy of sex classification is negligible and that the weight + footpad and weight alone functions are robust.

A second potential problem involves measurement of footpad length. As a field characteristic, foodpad length measurements can be imprecise and highly variable due to the bird clenching and unclenching its foot during measurement. While much of this variability can be minimized with consistency in technique, we urge individuals considering use of footpad length as an indicator of sex to make repeated measurements until satisfied with the accuracy of the estimate. Repeated measurements by MNK on footpads of three birds revealed investigator variability of ± 2 mm and, as before, we examined the effect of measurement error on the accuracy of sex classification by the functions. No changes in sex classification occurred with the weight + footpad function, although P_i values changed in a manner similar to that described above.

The effect of a ± 2 mm error on the function using footpad alone, however, was more pronounced. Four birds, two males and two females, having footpad lengths within ± 2 mm of the dividing point were incorrectly reclassified. All others experienced a drop in P_i values. While the effect of measurement error in footpad length can be eliminated by excluding from consideration birds with P_i values <0.9, we suggest investigators refrain from using footpad length alone as a predictor of eagle sex. The value of the functions described here is their ability to allow for *a posteriori* sexing of eagles from extant data sets. Investigators looking for characteristics to aid in sex classification in future studies may be better served using the anatomically "hard" characteristics described by Bortolotti (1984).

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