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Use of Body Mass, Footpad Length, and Wing Chord to Determine Sex in Swainson's Hawks

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Many studies of avian ecology require an expedient means to determine sex, and the use of molecular techniques has provided an effective and accurate means to determine sex of raptors in the field (Sarasola and Negro 2004, Donohue and Dufty 2006). Sometimes investigators need to rely on morphometric measurements to determine sex of monochromatic species such as Swainson's Hawks (*Buteo swainsoni*) because they lack funds or facilities to use molecular techniques or they are analyzing extant data. Discriminant analyses conducted on morphometric measurements have been effective for sexing many raptor species (e.g., Edwards and Kochert 1986, Bavoux et al. 2006, Donohue and Dufty 2006). Sarasola and Negro (2004) recently reported on the effectiveness of seven morphometric measurements as means to identify sex of Swainson's Hawks on the hawk's austral summer areas in Argentina. They proposed a combination of the length of forearm, wing chord, and tail as an effective means to determine sex, with an overall accuracy of 93%. However, Sarasola and Negro (2004) did not assess the effectiveness of using footpad length (sometimes called toe-pad) to classify sex of these hawks. Footpad length and mass were quite effective in sexing Golden Eagles (*Aquila chrysaetos*), a species with a degree of dimorphism similar to that of Swainson's Hawks (Snyder and Wiley 1976), with an overall accuracy of 98% (Edwards and Kochert 1986). We here report the utility of using footpad length and mass, as well as wing chord length, as a means of sexing Swainson's Hawks on the nesting grounds.

Methods

During 1995–2006, JOM trapped and measured 169 adult and Basic I (hawks in 1- to 2-yr-old plumage; England et al. 1997) Swainson's Hawks during the nesting season in southwest Idaho near the city of Boise (42°50′N, 115°50′W). Hawks were trapped between 13 April and 19 September as part of a larger investigation of Swainson's Hawk nesting ecology and population turnover. Birds were captured mostly in dho-gaza nets, using a Great Horned Owl (*Bubo virginianus*) as a lure (Bloom et al. 1992), and also in bal-chatri traps (Bloom et al. 2007) baited with live gerbils (*Gerbillus* spp.). We recorded mass ($N = 169$) to the nearest g with Pesola spring scales. We measured wing chord ($N = 165$) to the nearest mm with a ruler as in Pyle (1997). We measured footpad length ($N = 109$) in mm with calipers from the distal end of the pad on the hind toe (hallux) to the distal end of the pad on the middle (third) toe, with the toes maximally extended (Edwards and Kochert 1986).

Each bird received a colored leg band with a unique alphanumeric code. We assigned sex based on observations of 115 color-marked individuals during copulation; we categorized the bird in the mounting (top) position as the male. We also assigned sex to an additional 54 color-marked individuals that were mated with a color-marked Swainson's Hawk of a known sex. Although reverse copulation has been observed in rare cases in American Kestrels (*Falco sparverius*; Bowman and Curley 1986), we observed no case of reverse mounting during 175 copulations involving 115 color-marked Swainson's Hawks of known sex (61 males and 54 females).

We used SAS statistical software (SAS Institute 1999) and performed a MANOVA to assess differences in measurements among age and sex classes (Zar 1999). We conducted linear discriminant function analyses on mass, wing chord, and footpad length to test the accuracy of the variables as predictors of sex and used a cross-validation procedure to calculate the proportion of individuals misclassified. We also calculated a Cohen's kappa statistic and tested significance for each of the discriminant functions to estimate the correct classification adjusted by chance and the effect of unequal group sample sizes (Titus et al. 1984).

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Table 1. Morphometric characteristics of 158 adult and 11 Basic I Swainson's Hawks during the nesting season in southwest Idaho. Mass is measured in g; all other characteristics are mm.

	MALES				FEMALES			
VARIABLE	*N*	MEAN	SD	RANGE	*N*	MEAN	SD	RANGE
Mass	96	764.9	70.4	615–950	73	1005.0	81.3	835–1220
Wing chord length	96	384.2	8.0	368–403	69	412.8	8.3	400–440
Footpad length	62	73.7	1.9	70–77	47	80.5	2.3	75–85

RESULTS

Of 169 Swainson's Hawks we weighed and measured, 96 were determined to be males and 73 females, based on copulation behavior or mating status. Six females and five males were in Basic I plumage. Because mean mass, footpad length, and wing chord did not differ between adults and birds in Basic I plumage (MANOVA, $F_{3,102} = 0.80$, $P = 0.50$), we combined all age classes in our analyses. Females were significantly larger than males in all measurements (MANOVA, $F_{3,102} = 192.80$, $P < 0.001$). Mass, footpad length, and wing chord averaged 1005.0 ± 81.3 (SD) g, 80.5 ± 2.3 mm, and 412.8 ± 8.3 mm respectively for females and 764.9 ± 70.4 g, 73.7 ± 1.9 mm, and 384.2 ± 8.0 mm respectively for males (Table 1). All three measurements overlapped between sexes. Wing chord length overlapped the least (4%); footpad length was intermediate (13%); and mass overlapped the most (19%).

We developed seven significant functions using individual variables and a combination of variables from our sample (Table 2). We standardized all functions to 0 such that males and females had Z values of <0 and >0 respectively. The combination of mass, footpad length, and wing chord, with a linear function $Z = 0.023 * \text{mass} + 1.088 * \text{footpad} + 0.326 * \text{wing} - 234.000$, was the best predictor of sex (Table 2). The function correctly classified the highest percentage of all birds and had the highest kappa value. The low Wilks' lambda value suggests that the sexes were more separated with this linear combination than the other variables or combination of variables. We correctly classified 99.2% of the individuals (all females, and 98.4% of the males) based on the function derived from the three variables combined (Table 2). The only misclassified hawk was an exceptionally large male that weighed 156 g above the mean male mass and was within the range of mass, wing chord, and footpad lengths for females. We correctly classified 97–99% of the individuals and 97–100% of the males and females using the functions derived from different combinations of two variables (Table 2). The combination of these variables produced the following linear functions: (1) $Z = 0.036 * \text{mass} + 0.375\ \text{wing} - 181.000$; (2) $Z = 0.028 * \text{mass} + 1.274 * \text{footpad} - 123.256$; and (3) $Z = 0.370 * \text{wing} + 1.295 * \text{footpad} - 247.000$. The combination of wing chord length and mass was the best combination of two variables. It was nearly as accurate as the combination of all three variables based on the percentage of individuals correctly classified and the kappa statistic value. The function derived from wing chord length and mass correctly sexed 99.0% of all individuals and 98% of the males and all the females.

Because some banders do not measure multiple variables or extant data contain only one measurement, we generated functions to classify sex based on mass, wing chord, or footpad solely. The function for wing chord, $Z = 0.431 * \text{wing} - 172.000$, correctly classified 97.4% of all birds (all the females and 93.9% of the males) and the function $Z = 1.594 * \text{footpad} - 122.866$ for footpad alone accurately classified 96% (all the males and 91.5% of the females). Mass was the least accurate variable, and the

Table 2. Accuracy of sexing Adult and Basic I Swainson's Hawks trapped in southwestern Idaho from discriminant analyses using single or combined measurements and assessed by the cross-validation procedure and Cohen's kappa statistic.

	PERCENT CORRECTLY CLASSIFIED						
VARIABLE	*N*	WILKS' LAMBDA	FEMALES	MALES	ALL BIRDS	COHEN'S KAPPA	*P*
Mass + Wing + Foot	107	0.150	100.0	98.4	99.2	0.98	<0.001
Mass + Wing	165	0.172	100.0	97.9	99.0	0.98	<0.001
Mass + Foot	109	0.204	95.7	100.0	97.9	0.96	<0.001
Foot + Wing	106	0.169	97.7	96.8	97.2	0.94	<0.001
Wing	165	0.248	100.0	94.8	97.4	0.92	<0.001
Foot	109	0.268	91.5	100.0	95.7	0.92	<0.001
Mass	169	0.283	91.8	93.8	92.8	0.86	<0.001

function for mass alone, $Z = 0.042 * \text{mass} - 35.562$, correctly classified only 93% of all the birds (92% of the females and 94% of the males).

DISCUSSION

We found that female Swainson's Hawks had greater mass and longer footpad and wing chord lengths than males. Sarasola and Negro (2004) also reported that females were larger in five other morphometric measurements of adult and immature (Basic I and first-year birds combined) Swainson's Hawks trapped on the austral summer grounds in Argentina. In contrast to widely dimorphic species, such as the Prairie Falcon (*Falco mexicanus*; Steenhof and McKinley 2006), we found overlapping distributions between sexes in all three measurements, with wing chord length overlapping the least and mass the most. Sarasola and Negro (2004) also found considerable overlap between sexes in other morphometric measurements of adult and immature Swainson's Hawks in Argentina.

The combination of mass, footpad, and wing chord was the best predictor of sex of Swainson's Hawks in Idaho. The function from the combination of these variables correctly classified a higher proportion of all birds than did the function from the combination of forearm, tail, and wing chord lengths (99% vs. 93%), which was the best predictor of sex for adult and immature Swainson's Hawks in Argentina (Sarasola and Negro 2004). We also correctly sexed a higher proportion of all birds (97%) using the function from wing chord length alone than reported by Sarasola and Negro (2004; 88%). Wing chord measurements of hawks in Idaho had considerably less variability and overlap (4%) between sexes than hawks trapped in Argentina (38%; Sarasola and Negro 2004). Satellite telemetry data indicate that the areas where Sarasola and Negro (2004) sampled contained an amalgamation of Swainson's Hawks from many widely separated geographical areas of the breeding range (U.S.G.S. Snake River Field Station unpubl. data), which may explain the greater variation in their sample. Also, Swainson's Hawks tend to molt more inner primaries on the nesting grounds and molt more outer primaries on the austral summer areas in Argentina (Schmutz 1992, Bechard and Weidensaul 2005). Wing chord measurements can be biased on birds with worn feathers, in molt, or with incomplete feather growth (Ferrer and de le Court 1992). Perhaps wear of old outer primaries or molt of these primaries contributed to the greater variability in wing chord length on the austral summer grounds. In our study, only one researcher (JOM) measured wing chords of all the Idaho hawks, which may partially account for the low variability in measurements.

Mass, footpad, and wing chord provide a reliable means of sexing adult and Basic I Swainson's Hawks; however, these variables should be used with some caution. Measurements of mass and footpad are subjected to inherent imprecision or biological factors that affect their reliability (Edwards and Kochert 1986). Mass, the least accurate predictor of sex in our study, varies depending on the time of year, condition of the bird, and whether the bird just fed (Newton et al. 1983, Edwards and Kochert 1986, Steenhof and McKinley 2006). Molt and feather wear can affect accuracy of wing chord measurements (Ferrer and de le Court 1992), and error occurs with wing chord and footpad measurements (Edwards and Kochert 1986, Steenhof and McKinley 2006). Measurement error of footpad length for Golden Eagles, for example, was ±2 mm (Edwards and Kochert 1986). We did not assess error associated with measurement of footpad length for Swainson's Hawks. However, when we applied a ±2 mm error to footpad length of four female hawks that we originally misclassified as males (using footpad as the lone classification metric), three of them were correctly reclassified.

The functions we described allow *a posteriori* sexing of Swainson's Hawks from extant data sets, including those in which researchers measured only a single variable. However, we suggest that investigators avoid using single measurements, and we encourage them to use multiple measurements including those involving hard tissue with little inherent imprecision (see Bortolotti 1984, Ferrer and de le Court 1992, Sarasola and Negro 2004).

USO DE LA MASA CORPORAL, LA LONGITUD DE LAS ALMOHADILLAS DE LAS PATAS Y LA CUERDA ALAR PARA DETERMINAR EL SEXO EN *BUTEO SWAINSONI*

RESUMEN.—Utilizamos análisis lineales de funciones discriminantes sobre la masa corporal y medidas de las almohadillas de las patas y de la cuerda alar tomadas en 169 aves adultas (96 machos y 73 hembras) y en plumaje básico-I para evaluar la efectividad de estas variables para predecir el sexo de individuos reproductivos de la especie *Buteo swainsoni* en áreas del suroeste de Idaho. Desarrollamos siete funciones significativas usando las variables individualmente y combinaciones de éstas. La combinación de la masa corporal, la longitud de la almohadilla de las patas y la cuerda alar (con la función lineal $Z = 0.023 * \text{masa} + 1.088 * \text{almohadilla} + 0.326 * \text{ala} - 234.000$) fue la que mejor predijo el sexo. Esta función clasificó correctamente el 99.2% de los individuos (todas las hembras y el 98.4% de los machos). Las funciones derivadas de distintas combinaciones de dos variables clasificaron correctamente el 97–99% de los individuos y el 97–100% de los machos y hembras. Entre las variables únicas, las funciones basadas en medidas de la cuerda alar y las almohadillas de las patas clasificaron correctamente el 97% y 96% de los individuos, respectivamente, mientras que la masa corporal tuvo una exactitud menor, con el 93% de los individuos clasificados correctamente. Sugerimos que los investigadores eviten el uso de medidas únicas, y los animamos a tomar varias medidas.

[Traducción del equipo editorial]

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