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SEX IDENTIFICATION IN THE SPANISH IMPERIAL EAGLE

MIGUEL FERRER AND CLAUDINE DE LE COURT
Estación Biológica de Doñana, CSIC
Avenida María Luisa, Pabellón del Perú
41013 Sevilla, Spain

Abstract.—An external morphometric criterion for sex discrimination in the Spanish Imperial Eagle, *Aquila adalberti,* was investigated. Seven measurements were taken on 38 museum skins. Stepwise Discriminant Analysis selected forearm length, which classified correctly 94.7% of the birds. Tarsus length was also a useful criterion for sexing eagles. Repeatability, accuracy for sexing eagles in different conditions (alive, museum skins and skeleton), and age were tested using tarsus and forearm length. Forearm length was proposed as the best measurement for sexing Spanish Imperial Eagles and perhaps other dimorphic raptors.

IDENTIFICACÍON DEL SEXO EN *AGUILA ADALBERTI*

Sinopsis.—En este artículo se investigan criterios morfométricos externos para la discriminación del sexo en el Águila Imperial Ibérica *Aquila adalberti.* Para ello se tomaron siete medidas en 38 pieles de museo. El Análisis Discriminante por Pasos seleccionó una sola variable, la longitud del antebrazo (longitud del cubito-radio), la cual clasificó correctamente al 94.7% de los individuos. La longitud del tarso también resultó como un criterio válido para determinar el sexo en águilas. Se estudió la repetibilidad y la precisión de la longitud del tarso y del antebrazo para el sexado de águilas de diferentes condiciones (vivas, pieles de museo y esqueletos) y edades. La longitud del antebrazo es propuesta como la mejor medida para determinar el sexo en Águilas Imperiales Ibéricas y quizás otras rapaces dimórficas.

Studies of many aspects of the biology of a bird necessitate an easy, reliable method of sex determination. Ideally, a technique for sexing would be valid for individuals of all ages and under different conditions.

As sexual dimorphism in size is widespread in birds, morphometrics often provide a reliable method (Green 1989). Despite the potential value of morphometrics, reliable criteria for sex determination using external characteristics have been developed for only a few raptors (Bortolotti 1984a,b,c; Edwards and Kochert 1987; Gracelon et al. 1985). No criteria enabling reliable sexing from external characteristics have been described for the Spanish Imperial Eagle, *Aquila adalberti,* although the sexes reportedly differ in size (Cramp and Simmons 1979). With the development of captive breeding and reintroduction programs for this endangered species (Collar and Andrews 1988), accurate sexing is particularly important. The goal of our study was to find an accurate and versatile morphometric criterion for sex determination in Spanish Imperial Eagles valid for different states of preservation (alive, museum skins and skeletons) and for different age classes.

MATERIAL AND METHODS

We took seven measurements of each of the 38 skins of the Spanish Imperial Eagles from the collection of the Biological Station of Doñana.

These eagles died between 1960 and 1988, and all were found in Andalucia, south west Spain, mainly in Doñana National Park. Sex was determined by internal examination by the collectors. Individuals were classified by plumage as either immature (less than 5 yr old) or adult (Ferrer and Calderon 1990).

Using callipers, we took the following measurements (to the nearest 0.1 mm) on the left side of each skin: tarsus length (TARS), bill including cere length (BCER), length of exposed culmen without cere (BCUL), and length of hallux claw (HALC) (Bortolotti 1984a,c). Wing (WING) and tail length (TAIL) were measured with a metal ruler to the nearest mm (Bortolotti 1984b). We also measured the forearm length (FORE) which is the length from the front of the folded wrist to the proximal extremity of the ulna. FORE is measured by laying a ruler along the external side of the bone (Fig. 1). Mean, standard deviation, and range for all variables were calculated for each sex and each age class. All the variables were normally distributed. Length of hallux claw had a large number (18) of missing values and was excluded from the analysis. The 38 individuals in the analysis were 22 females (17 immatures and five adults), and 16 males (12 immatures and four adults).

Adults and immatures may differ in size (e.g., Bortolotti 1984b,c), so multivariate analysis of variance (MANOVA) and univariate analysis of variance (ANOVA) of differences between adults and immatures were performed. Next, in order to detect overall sexual differences, MANOVA was conducted, followed by an ANOVA for each of the six morphological characters. We estimated the power of ANOVA for each variable (Zar 1984). Sexes were discriminated with a Stepwise Discriminant Analysis using a jackknife procedure (Dixon et al. 1983) to calculate the percentage of misclassification.

The following steps were only performed on TARS and FORE, the two best predictors of sex. Three observers measured one study skin 10 times. Coefficients of variation for both variables were calculated for each person. A test among observer variances (Levene test) was performed for both measurements. To evaluate the adequacy of measurements for sexing in the nest, we compared TARS and FORE using the data from nine eagles measured and banded at the nest (52–72 d old) and later found dead after fledging (110–370 d old) and sexed internally (six females and three males). We also compared TARS and FORE on skeletal remains of 11 freshly dead eagles (after ligaments and tissues were removed) sexed internally (six females and five males).

RESULTS

MANOVA showed differences between immatures and adults (Hotelling $T^2 = 19.52$, df = 6, 31, $P = 0.0024$). ANOVA revealed that TAIL was greater in immatures than in adults ($F = 10.70$, df = 36, $P = 0.0024$). We therefore did not include TAIL in the multivariate analysis. MANOVA for the five measurements taken together showed highly significant differences between the sexes for all measurements (Hotelling $T^2 = 123.38$,

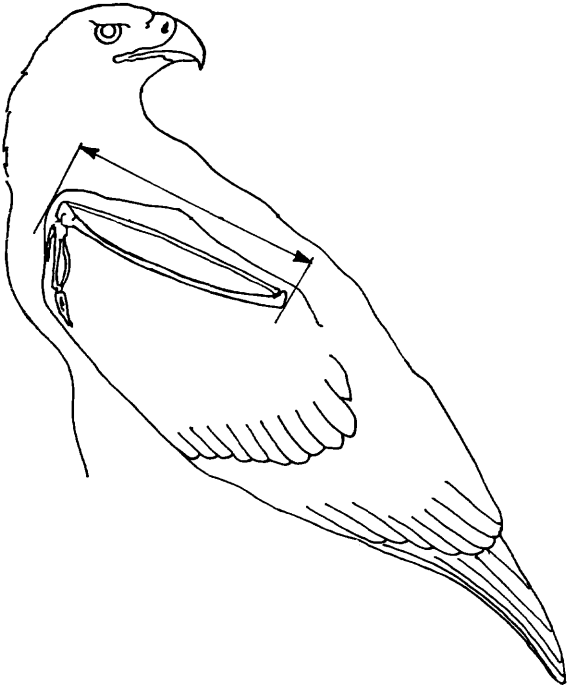

FIGURE 1. Measurement of forearm length (FORE) in Spanish Imperial Eagle.

df = 5, 32, $P = 0.0001$). ANOVA revealed that FORE, TARS and WING are the most dimorphic variables (Table 1). With only one predictor variable, FORE, in a discriminant function analysis, the correct sex was assigned to individuals 94.7% of the time, and this percentage was maintained using a jackknife procedure. One male and one female of the 38 birds were misclassified. The discriminant function was:

$$\text{female} = 6.96 + \text{FORE} - 843.37;$$
$$\text{male} = 6.41 + \text{FORE} - 716.91.$$

A FORE of 232.7 mm separates males, which are smaller, and females. The frequency distribution of males and females along the discriminant axis is represented in Figure 2. TARS alone in a Stepwise Discriminant Function analysis also correctly classified 94.7% of the birds.

Coefficients of variation for each of the three observers for 10 FORE measurements were 0.4%, 0.24% and 0.24%, respectively. For the observer with the least experience the variation was highest. For TARS, CV values were 3.5%, 1.0% and 3.3%. The CV for FORE was nearly an order of magnitude less than for tarsus. Significant differences between observers for tarsus ($P < 0.05$), but not for forearm measurements ($P > 0.05$) were shown by the Levene test for comparison of variances. The correlation

TABLE 1. Sex discrimination of Spanish Imperial Eagle: mean ($\bar{x}$), standard deviation (SD) and range of measurements and analysis of variance (ANOVA). Values of β are indicated for $\alpha = 0.05$.

	Female ($n = 22$)			Male ($n = 16$)			ANOVA		
	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range	F	P	β
FORE	242.2	5.53	232–255	223.3	6.37	213–235	95.19	0.0001	<0.01
TARS	102.1	3.15	98.9–110.0	93.8	3.14	87.8–99.3	63.03	0.0001	<0.01
WING	613.3	12.81	588–632	565.1	24.28	525–617	62.93	0.0001	<0.01
BCUL	60.6	1.99	56.2–65.0	56.1	4.98	41.0–64.8	15.35	0.001	0.04
BCER	46.0	2.86	39.8–49.4	43.1	3.47	35.6–49.6	7.55	0.01	0.60
	Immature ($n = 29$)			Adult ($n = 9$)			ANOVA		
	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range	F	P	β
TAIL	319.4	17.39	276–370	296.7	20.87	270–335	10.7	0.002	<0.01

between TARS measurements of nestlings and their study skins was significant ($r = 0.791$, $P = 0.009$, $n = 9$). The correlation was stronger with FORE measurements ($r = 0.993$, $P = 0.001$, $n = 9$). There was a strong correlation between the FORE measurements of 11 fresh dead birds and the corresponding bones after tissue removal ($r = 0.986$, $P = 0.001$, $n = 11$), the same was true for TARS measurements before and after tissue removal ($r = 0.888$, $P = 0.001$, $n = 11$). In all cases FORE and TARS from females were greater than for males.

DISCUSSION

Our results indicate significant size differences between the sexes, and only in TAIL between immature and adults. The three best measurements for discriminating the sexes of Spanish Imperial Eagles were FORE, TARS and WING. WING has obvious disadvantages, however, because it cannot be used on individuals with incomplete feather growth, in molt or with worn feathers, or for skeletal material. Using discriminant function based on either FORE or TARS, the sex classification of only two individuals disagreed with the sex determined from internal examinations. Use of FORE rather than TARS as a discriminating characteristic has important advantages, however. FORE is easier to measure and repeated measurements by the same and by different observers are less variable than repeated measurements of TARS. Tarsus is more difficult to measure because the points of measurement are not as clearly defined as FORE, and is more affected by the observer's experience. Relative to the most experienced observer, the CV of the least experienced observer was 1.6 times greater for FORE measurements and 3.5 times greater for TARS. FORE also varies less among nestling, museum skin, skeleton and observer than does TARS, so FORE was the best sexing criterion for different ages and under different circumstances. Forearm measurement

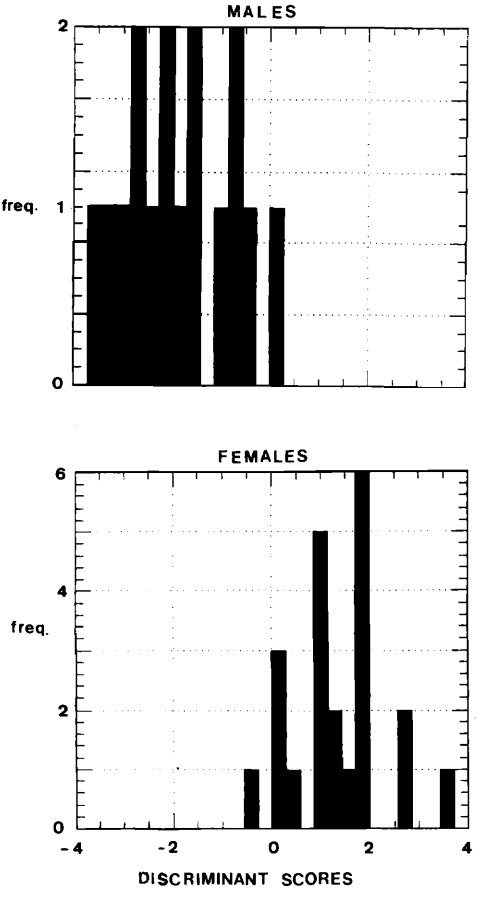

FIGURE 2. Distribution of museum specimens of male and female Spanish Imperial Eagles along the discriminant axis with forearm length as selected variable.

enables the sex of the Spanish Imperial Eagles to be easily and reliably determined from at least 52 d of age.

Other morphometric criteria for sexing large dimorphic raptors such as Golden Eagles (*Aquila chrysaetos*) and Bald Eagles (*Haliaetus leucocephalus*) that have been proposed are: bill depth, hallux claw, footpad length and body mass (Bortolotti 1984a,b,c; Gracelon et al. 1985; Edwards and Kochert 1987). All these methods have the important drawbacks that they are only applicable to well preserved skins or live individuals, and some of them differ according to the specimen's age and stage of growth (Bortolotti 1984a,c). The frequent loss of the lining of the beak and claw in corpses and their different degree of wear in captive individuals makes measurements of bill depth, hallux claw and culmen length of limited use in population studies. The other two measurements suggested in the

literature, footpad length and body weight can only be measured accurately on live specimens and with both there is a high variance for repeated measurements (Edwards and Kochert 1987). Other sexing techniques applied to dimorphic raptors have been karyotype determination and laparoscopy (Gracelon et al. 1985). Both of these techniques are exclusively applicable to live individuals, and have serious drawbacks. All of these factors make a reliable morphometric technique, such as forearm length, extremely useful for dimorphic birds.

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