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MEASUREMENTS OF WINTERING DOUBLE-CRESTED CORMORANTS AND DISCRIMINANT MODELS OF SEX

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Abstract.—Body mass, maximum wing length, culmen length, culmen depth, tarsal length and sex were recorded from 200 Double-crested Cormorants (*Phalacrocorax auritus auritus*) collected from January through April 1991 at roost sites in the delta region of Mississippi. Body mass and tarsal length appeared to distinguish this population as excluding the *P. a. floridanus* subspecies, which is also reported to be geographically restricted to the Gulf Coast, or at least 250 km south of our study area. Wing length, culmen depth and culmen length, in order of importance, were the most useful variables for identifying sex in a discriminant function model that predicted sex with 96.5% accuracy.

MEDIDAS DE *PHALACROCORAX AURITUS AURITUS* INVERNALES Y MODELOS PARA DISCRIMINAR ENTRE LOS SEXOS

Sinopsis.—Entre enero y abril de 1991 se registró la masa corpórea, el largo máximo del ala, el largo y la profundidad del culmen, el largo del tarso y el sexo de 200 *Phalacrocorax auritus auritus* tomados en dormideros de la región del delta de Mississippi. La masa corpórea y el largo del tarso permitieron distinguir esta población como excluyendo la subspecie *P. a. floridanus,* la cual también se reporta como geográficamente restricta a la costa del golfo, o al menos a 250 km sur del área de nuestro estudio. El largo del ala, el largo y la profundidad del culmen fueron las variables más imporantes en ese mismo orden para identificar el sexo en un modelo de funciones discriminantes que predijo el sexo con 96.5% de certeza.

The ability to identify the sex of individual birds under study in sexually monochromatic species, such as the Double-crested Cormorant (*Phalacrocorax auritus*), is often of interest to field biologists. Although *P. a. auritus* are known to be sexually dimorphic with respect to size (Kury 1968, Palmer 1962), variation in size of this subspecies over its breeding range and overlap with the smaller subspecies *P. a. floridanus* over its wintering range (Palmer 1962) complicate the use of external measurements for sex determination. Lack of separation of these two subspecies wintering in Florida may be responsible for the divergence in size reported for *P. auritus* from Florida (Dunning 1993) and elsewhere (Kury 1968, Palmer 1962).

Discriminant analysis of external measurements has been used to distinguish the sex of King Cormorants (*Phalacrocorax albiventer*) (Malacalaza and Hall 1988) and many other monochromatic species (Brennan et al. 1984, Clark et al. 1991, Fox et al. 1981, Hanners and Patton 1985, Haywood and Haywood 1991, Maron and Myers 1984). These authors

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usually have used a stepwise discriminant analysis to reduce the number of measurements needed to develop an equation to predict sex from a sample of individuals of known sex. Most often these equations are validated by applying them to another sample of measurements of known sex.

In this paper we describe measurements from a wintering population of *P. a. auritus* that help to define further the morphometry of this subspecies, and from selected measurements we describe classification functions useful for discriminating sex.

METHODS

From January through April 1991, we obtained a complete set of external measurements from 200 cormorants collected at 10 winter roost sites distributed throughout the delta region of Mississippi (Glahn et al. 1995). We selected four linear measurements, in addition to body mass, that we believed were repeatable and obtainable from either live or dead birds in the field. Measurements were taken on all birds of the maximum (flattened) wing length (wrist joint to tip of longest primary), the exposed culmen length (most distal point of the bill to the notch at the base), bill depth (bill thickness of upper and lower mandible measured vertically from the anterior point of the nares) and the tarsal length (metatarsus measured from proximal to distal joint). We obtained measurements to the nearest millimeter using a stopped metric ruler for wing length and a divider with metric ruler or vernier caliper for other measurements. Body mass was measured to the nearest 50 g with a 5-kg Pesola spring balance and sex was identified by dissection and gonadal inspection.

Methods of analysis were similar to those of Hanners and Patton (1985). We separated the sample measurements taken in January and February from those taken in March and April to contrast groups of wintering individuals with those we believed to be primarily migrants that wintered elsewhere. Unlike wintering birds in January and February, birds in March and April often included individuals in breeding plumage and would be more similar to birds that would soon be arriving at their breeding areas. Measurements from January and February were subjected to stepwise discriminant analysis (Kshirsagar 1972) using PROC STEPDISC of the SAS computer software package (SAS Institute Inc. 1987) to select a small combination of measurements that best discriminated between the sexes. We then calculated the canonical coefficients of these selected measurements with PROC CANDISC and derived discriminant scores for each individual. The classification function was then standardized, so that it was centered on zero, by calculating a midpoint constant based on averaging the mean discriminant scores between individuals of each sex. We then tested the accuracy of the classification function by applying it to the January and February analysis sample and the test sample collected in March and April and determining the percentage of individuals correctly identified in each sample. We then examined the predictive accu-

TABLE 1. Measurements (mm) and body mass (g) of male and female Double-crested Cormorants (*Phalacrocorax auritus auritus*) collected in the delta region of Mississippi, January–April 1991.

	Males (n = 160) x̄ ± SE (Range)	Females (n = 41)[1] x̄ ± SE (Range)
Body mass	2498.1 ± 16.0 (2000–3000)	2162.2 ± 29.8 (1650–2600)
Wing length	336.2 ± 0.6 (317–335)	317.4 ± 0.9 (304–331)
Culmen length	55.6 ± 0.1 (50–61)	51.7 ± 0.3 (49–56)
Culmen depth	17.6 ± 0.1 (15.5–20)	15.8 ± 0.2 (14–18)
Tarsal length	68.8 ± 0.1 (65–73)	67.2 ± 0.3 (64–74)

[1] Culmen depth was recorded for 40 females only.

racy of the classification function between samples and pooled samples to calculate a new function with increased sample size.

RESULTS

Males on average were slightly larger than females for each measurement, but the sexes overlapped for all measurements to some degree (Table 1). Despite this overlap, means of male and female body mass, maximum wing length, culmen length, culmen depth and tarsal length differed significantly ($P < 0.001$).

Stepwise discriminant analysis indicated that wing length (F = 108.0, df = 1, 78, $P < 0.0001$) and culmen depth (F = 15.27, df = 1, 77, P = 0.0002) were the only significant variables, but the addition of culmen length to the model decreased Wilks' Lambda from 0.350 to 0.334 and was the best predictive model of all three-variable combinations. On the basis of Wilks' Lambda values, the inclusion of a fourth variable was not warranted. The classification function based on wing length (WL), culmen length (CL) and culmen depth (CD) from the January and February sample was:

$$CF = (0.1009 \times WL) + (0.1532 \times CL) + (0.3805 \times CD) - 47.548.$$

On the basis of this function, a Double-crested Cormorant is classified as a male if CF $\geq$ 0; otherwise, the cormorant is a female. Applying this function with the analysis sample, 64 of 67 males (95.5%) and 12 of 13 females (92.3%) were correctly classified. Using the test sample from March and April, 85 of 93 males (91.4%) and all 27 females (100%) were correctly classified for a classification accuracy of 95.7%.

The classification accuracy with the analysis sample (n = 80, 93.9%) and of our test sample (n = 120, 95.7%) were similar, suggesting minimal sampling bias. Therefore, we combined these samples and derived the following classification function based on the larger sample size:

$$CF = (0.09535 \times WL) + (0.2298 \times CL) + (0.3861 \times CD) - 49.932.$$

This function correctly classified 39 of 40 (97.5%) females and 153 of 160 (95.6%) males for an overall accuracy of 96.5%. The larger sample size used to derive this function and its slightly higher accuracy suggest it would be the most useful function.

A classification score was calculated for all individuals from the standardized classification function. This score for females in the total sample ranged from −3.764 to 1.447 with a mean of −1.683. In comparison the classification score for males from this sample ranged from −1.427 to 3.923 with a mean of 1.683. Thus, the area of overlap for male and female scores falls between −1.427 and 1.465.

One other combination of variables produced a discriminant function of similar predictive value. This alternative discriminant function model, having a similar high degree of accuracy (95.0%), was identified when culmen depth was removed from the stepwise analysis and was developed in an identical manner. In this model wing length and culmen length were significant ($P < 0.001$) and with tarsal length (TL) included had a Wilks' Lambda value of 0.350. The interim model:

$$CF = (0.1219 \times WL) + (0.2788 \times CL) - (0.1538 \times TL) - 44.421,$$

had a predictive accuracy of 93.1% and 94.1% for the analysis and test samples, respectively. The classification function derived from both samples was:

$$CF = (0.11298 \times WL) + (0.3387 \times CL) - (0.1155 \times TL) - 47.235.$$

The standardized classification scores for this model ranged from −3.118 to 1.164 (Mean = −1.618) for females and from −1.544 to 3.991 (Mean = 1.618) for males, and had an area of overlap for males and females between −1.544 and 1.164.

DISCUSSION

As plumage characteristics are not accurate criteria for distinguishing age (Palmer 1962), the wintering population we studied after 1 January could only be considered after-hatching-year birds. Birds in breeding plumage collected in March and April, however, would be considered after-second-year birds. The plumage of wintering birds varied from heavily mottled to completely black, but the ratio of adult-appearing birds (completely black) appeared to increase in the March and April samples. Thus, the models we report to distinguish sex may be irrespective of age.

As indicated from migration studies (Dolbeer 1991), the wintering population studied consists of migrants from a wide breeding range extending from the St. Lawrence River and New England Coast west to Alberta, but primarily from the area between the eastern Great Lakes Region and Saskatchewan. Thus, this wintering population may be representative of cormorants breeding East of the Rocky Mountains, but may not adequately sample birds breeding along the Atlantic Coast or western Canada.

The study population did not appear to contain the smaller Florida subspecies (*P. auritus floridanus*), which is reported to winter only along the Gulf Coast (Palmer 1962), or approximately 250 km south of our study area. Although our measurements have a wider range and are slightly larger than those reported for *P. a. auritus* (Palmer 1962), measurements of tarsal length (range 64–74 mm) did not overlap those (range 53–60 mm) reported for *P. a. floridanus* (Palmer 1962). As suggested by Palmer (1962), tarsal length may be a good criterion for separating these two subspecies. Lack of separation of these two subspecies in Florida may have added confusion in the literature to the true size of the more widely distributed *P. a. auritus* subspecies. Although body mass of our birds are slightly heavier than that of the average male (2233 g) and the average female (1861 g) reported from Maine (Kury 1968), they are substantially larger than those reported from Florida (Brugger 1993, Dunning 1993, Hennemann 1983, Owre 1967). These Florida birds, averaging less than 1800 g for both sexes combined, are reported to be representative of the body mass for this species (Dunning 1993), presumably because the largest sample of cormorant measurements have been obtained in this area.

Although body mass has been used as a variable in a similar analysis of King Cormorants (Malacalaza and Hall 1988), it did not help to discriminate sex in our analysis. This result was probably due to the added variance caused by the build up of body mass before spring migration (Glahn and Brugger 1995) and with the amount of fish recently consumed (Glahn et al. 1995).

As in the analysis for the King Cormorant, we found culmen depth and culmen length to be important discriminating measurements. Unlike that study, however, we found wing length to be the most discriminating variable in our models. Examining this variable alone on a slightly enlarged sample of 205 birds measured, we found that 88.5% of males and 95.0% of females could be successfully classified by assigning as females all birds with wing length of ≤326 mm. Some authors (Fox et al. 1981) have suggested avoiding the use of tail and wing measurements in these analyses because of feather wear. Although we avoided tail measurements because of observed tail wear and molt, we found no similar problems with measuring wing length throughout the study period.

Although the measurements in both discriminant models have been shown to be repeatable with other species (Clark et al. 1991), measurements in the alternative model are more commonly used and this model may be useful to investigators who have taken these measurements previously.

As a result of the reported geographic variation in size of this subspecies (Palmer 1962), it is difficult to assume that our classification functions of sex would be valid across the subspecies' entire range. Although banding data suggest that the wintering population we sampled may be from most of the subspecies' breeding range (Dolbeer 1991), how well we sampled any specific geographic subpopulation is unknown. Until further data can be collected from other areas to verify these models, these classification functions should be used with caution, especially when the calculated value of the function approaches zero. For the most accuracy in classifying sex, individuals should not be classified if their classification score falls within the calculated area of overlap between sexes.

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