

SEX DETERMINATION OF DUNLINS IN WINTER PLUMAGE

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In species of birds that exhibit no plumage dimorphism and only slight size dimorphism between the sexes, discriminant function analysis (DFA) allows researchers to predict the sex of individual birds using specific body measurements. This is the case with most sandpipers (Scolopacidae) and to date only Clark (1981) and Skeel (1982) have demonstrated that DFA can be used to predict the sex of monomorphic sandpipers. Clark (1981) mentioned the use of DFA to sex the nominate Dunlin subspecies (*Calidris alpina alpina*) in England during winter, but did not discuss how effective this technique was. In this paper we present a statistical model based on DFA that can be used to predict the sex of Dunlins (*C. a. pacifica*) in winter plumage. In addition we discuss the effectiveness and limitations of this technique for sexing Dunlins that winter on the Pacific coast of North America.

METHODS

Between November 1980 and March 1981, 200 Dunlins (123 males and 77 females) were collected from 4 estuaries in western Washington state for an organochlorine contamination study. All collections were made between the fall and spring migrations, therefore we are confident no migrants were included in the analysis. All birds were sexed by gonadal inspection. Prior to dissection, Dunlins were weighed to .1 g on a triple beam balance. Natural (unflattened) wing chord was measured to the mm with a steel rule. Bill length (chord of the exposed culmen) was measured to .1 mm with dial calipers according to Baldwin et al. (1931). Age class was determined by primary feather wear and color of the distal edge of the innermost tertial feathers (Prater et al. 1977). We detected no significant difference ($P > .1$) between immature and adult weights, wing lengths, or bill lengths, therefore, both age groups were pooled for the analysis. To minimize variability 93% of the samples were measured by one observer (J.B.B.).

We used the "jackknife method" of DFA (BMDP-7M, Dixon and Brown 1979). Each Dunlin was singly removed from the analysis and classified with a separate discriminant function derived from the remainder of the data. Thus, each Dunlin was classified according to sex without influencing the function that determined its classification. Since our collections suggested the sex ratio of Dunlins in western Washington may be slightly skewed in favor of males (Buchanan, unpubl. data) the prior probability of correct classification was based on the relative size of each group.

TABLE 1. Morphometric data from Dunlins collected in western Washington state. Bill and wing lengths are in millimeters, weight in grams.

Variable	Males (n = 123)		Females (n = 77)		F-ratio ^a
	\bar{x}	SD	\bar{x}	SD	
Bill length	36.3	1.4	40.0	1.7	252.3
Weight	51.0	3.9	55.5	3.7	64.8
Wing length	119.2	2.5	122.0	2.6	40.6

^a One-way ANOVA. All *F*-ratios significant at $P < .01$, $df = 1, 198$.

RESULTS AND DISCUSSION

The predictive model.—Descriptive statistics of male and female Dunlin body measurements are given in Table 1. All intervariable product-moment correlation coefficients were $\leq .47$. The resulting discriminant function derived from the measures of 200 Dunlins of known sex correctly classified 183 (91.5%) of the birds (Fig. 1). Of the 17 Dunlins that were misclassified, 11 were males and 6 were females. Using discriminant analysis one can construct a statistical model with data from Dunlins of known sex and use this model to predict the sex of unknown Dunlins. The following equation can be used to predict the sex of an individual Dunlin on the basis of 3 morphometric variables:

$$DS = (-.5381 \times BL) + (-.06527 \times WT) + (-.0893 \times WL) + 34.5052,$$

where: DS = the discriminant score, BL = bill length, WT = weight, and WL = wing length. The 3 coefficients associated with the variables are the unstandardized discriminant function coefficients and the last term in the equation is a constant. A discriminant score $< -.3$ classifies a Dunlin as a female; if $DS \geq -.3$, the Dunlin would be classified a male (Fig. 1).

The posterior probability of correct classification associated with each discriminant score is the probability of correctly predicting the sex of a Dunlin given its body measurements. These probability values should be calculated by researchers who wish to make behavioral observations of color-banded individuals when their sex has been determined by DFA. The posterior probability of each Dunlin being assigned the correct sex is calculated by:

$$P(1|x) = \frac{1}{\left(1 + \frac{q_2}{q_1}\right) \exp\left(-x'k + \frac{t_1 + t_2}{2}\right)},$$

where: q_1 = the prior probability that the bird is from group 1, $q_2 = 1 - q_1$, x = a vector of mean corrected body measurements (in this case

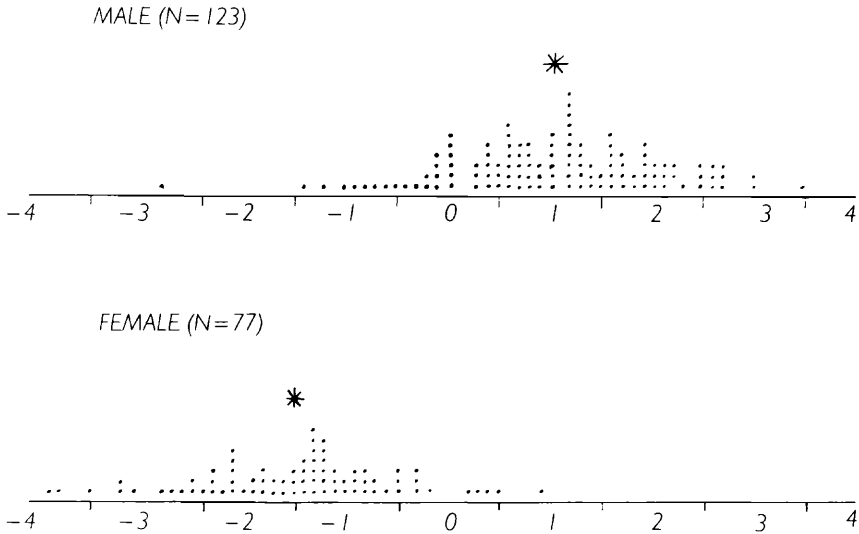


FIGURE 1. Discriminant scores of all male and female Dunlins of known sex collected for this study. These scores were determined by the discriminant function (linear combination of morphometric variables) which classified 91.5% of all Dunlins, to the appropriate sex. Asterisks denote the mean discriminant score for each group. Male discriminant scores greater than .9 and female discriminant scores less than -1.4 have at least .95 probability of being correctly classified.

bill, weight, and wing), k = a vector of unstandardized discriminant function coefficients, t_1 = the mean discriminant score for group 1 and t_2 = the mean discriminant score for group 2. The ratio of prior probabilities is based on the sample size of each group (Green 1978).

From the data in Table 1, it is clear female Dunlins have longer bills and wings and are heavier than males. When considered separately, each morphometric variable appears inadequate for predicting the sex of Dunlins with confidence. For example, bill length, the best single morphometric indicator of Dunlin sex, has a large range of overlap between the sexes (23% of the males and 48% of the females, Table 2). Our bill length data differ from those used by Page (1974) to predict

TABLE 2. Distribution of male and female Dunlins in the range of between sex bill length overlap.

	Overlap range (in mm)					Total
	37.4-37.9	38.0-38.4	38.5-38.9	39.0-39.4	39.5-39.9	
Males	15	6	3	3	1	28
Females	4	6	11	11	5	37

TABLE 3. Bill lengths (in mm) of Dunlins (*C. a. pacifica*) collected from western North America.

Source	Males			Females		
	n	\bar{x}	SD	n	\bar{x}	SD
Browning (1978)	45	37.1	1.5	46	40.0	2.2
MacLean and Holmes (1971)	112	37.2		111	40.5	
Page (1974)	87	36.9	1.7	82	40.5	1.6
This study	123	36.3	1.4	77	40.0	1.7

the sex of Dunlins based solely on bill length. Page observed an equal sex ratio of Dunlins (25% of the males and 28% of the females) within the same bill-length overlap range shown in Table 3. Since the sex ratios within this range of overlap vary, other methods of predicting the sex of Dunlins from morphometric data are needed. The linear combination of 3 body measurements (bill length, weight, and wing length) provides an alternative to the use of a single morphometric variable for Dunlin sex determination.

Comparison of our Dunlin morphometric data with similar data from other studies shows that caution must be used when extending our predictive model to other sites. Our data were obtained from a single subspecies (*C. a. pacifica*) collected during winter from one geographic area. Although the mean bill length of Dunlins from this study is only slightly shorter than the mean bill lengths of Dunlins measured by MacLean and Holmes (1971), Page (1974), and Browning (1978), (Table 3), MacLean and Holmes (1971) have shown there is considerable bill-length variation at the subspecies level. Also, the mean wing length of Dunlins from our study appears to be shorter than those of a different *C. a. pacifica* population from southern Alaska (Prater et al. 1977) (Table 4). Thus, we advise researchers to test our predictive model with morphometric data collected from other Dunlin populations or subspecies outside of western Washington, and if necessary, produce area-specific sex determination models.

Sexual size dimorphism of Dunlin bill lengths.—Compared to weight (.254), and wing length (.234), bill length has the highest within-groups correlation to the discriminant function (.847). Therefore, bill length has the most “influence” in the derivation of the discriminant function used to predict the sex of Dunlins. The strong discriminating power of bill length in avian sex determination models has been noted by others (Green 1982, Reese and Kadlec 1982, Scolaro et al. 1982, Skeel 1982).

In Dunlins collected for this study, the difference between male and female bill lengths is slight (3.7 mm or 9.2%), yet statistically significant ($P < .01$, Table 1). A longer bill may allow females to probe feeding substrates more deeply than males and thus enable them to obtain prey that would be unavailable to males. Alternatively, Jehl and Murray (1984)

TABLE 4. Wing lengths (in mm) of Dunlins collected from southern Alaska (Prater et al. 1977), and western Washington state.

Source	Males		Females	
	Range	\bar{x}	Range	\bar{x}
Prater et al. (1977)	116-127	121.3	120-131.5	125.0
This study	112-126	119.2	113-130	122.0

hypothesized that reverse sexual dimorphism in shorebirds may be related to the acrobatic flight displays of males on the breeding grounds. Since male Dunlins have a highly developed and complex territorial display that incorporates acrobatic flights (Holmes 1966), their smaller size (which bill length is correlated with) may be an adaptation to their breeding ecology.

SUMMARY

Discriminant function analysis was used to create a statistical model that correctly predicted the sex of Dunlins in 91.5% of a sample of 200 birds. Bill length had the greatest discriminating power, followed by weight and wing length. Dunlins in this study were slightly smaller than those reported from other studies in western North America. We recommend researchers test this model with similar data from other Dunlin populations and, if necessary, produce area-specific sex determination models. Researchers wishing to assign sexes to Dunlins banded for behavioral studies should do so only if the posterior probability of correct classification exceeds a predetermined probability cutpoint. When discriminant analysis is used to infer the sex ratio of a Dunlin population, the entire sample should be used.

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