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PREDICTING THE SEX OF HERRING GULLS BY USING EXTERNAL MEASUREMENTS

BY GLEN A. FOX, CARL R. COOPER, AND JOHN P. RYDER

Many problems of interest to field biologists require that the sex of individuals in the study population be determined. In monomorphic plumaged families like the Laridae, this is difficult. Bill and other morphometric measurements have been used to predict the sex of Herring Gulls (*Larus argentatus*; Drost 1938, Harris and Hope Jones 1969, Shugart 1977), Great Black-backed Gulls (*L. marinus*; Harris 1964), Lesser Black-backed Gulls (*L. fuscus*; Harris and Hope Jones 1969), Red-billed Gulls (*L. novaehollandiae*; Mills 1971), Ring-billed Gulls (*L. delawarensis*; Shugart 1977, Ryder 1978), and Western Gulls (*L. occidentalis*; Hunt et al. 1980).

In this paper we derive discriminant functions for predicting the sex of Herring Gulls and illustrate the usefulness of using individuals of mated pairs for the derivation of such functions when a suitable sample of individuals of known sex is not available. We believe our methodology to be superior to other techniques since the discriminant functions use measurements which do not vary with body condition, feather wear, or molt. Further, they have been tested for both sampling error and search bias using a large number of individuals of known sex from Lakes Ontario, Erie, Huron, and Superior. We compare the results of the application of these functions to those derived with the similar but less rigorously tested functions of Shugart (1977).

STUDY POPULATION AND METHODS

During 1978, 1979, and 1980 studies of Herring Gulls nesting on Gull Island in Presqu'île Provincial Park near Brighton, Ontario, we trapped most individuals on their nests using the method of Mills and Ryder (1979). Birds trapped were weighed to the nearest 10 g with a hand-held 1500 g Pesola spring scale. The distance from the tip of the bill to the posterior ridge which forms the parietal-supraoccipital junction (hereinafter referred to as "head length"), and the minimal depth of the bill immediately posterior to the downward projection of the lower mandible (hereinafter referred to as "bill depth") were measured with a dial caliper to the nearest 0.1 mm. Wing chord was measured to the nearest mm. In 1980 we measured the distance from the "knee" of the flattened tarsometatarsus to the base of the nail on the middle toe of the flattened foot to the nearest mm with a ruler (hereinafter referred to as "foot length"). The samples from the Lake Ontario colony were not mutually exclusive as some individuals were measured in two or more years. All specimens collected (either under permit or found dead) during these and other field studies were measured in the same manner and their sex determined by gonadal inspection.

Sexes were assigned to trapped individuals when both members of the pair were trapped. The member which was distinctly larger in the majority of measurements was assumed to be the male, the smaller member the female. This has been shown to be true in this and other larids (Drost 1938, Harris 1964, Barth 1967, Harris and Hope Jones 1969, Hunt et al. 1980). Where only one member of the pair was measured or where both individuals were very similar in size, sex was not assumed.

We chose head length, bill depth, and foot length for linear discriminant analysis because of their significant differences between the sexes (Table 1), ease of measurement when dealing with a live, frequently struggling bird, and freedom from the effects of body condition, molt, and feather wear. These data were analyzed using the RAO-V analysis of the subprogram DISCRIMINANT (Klecka 1975) in the Statistical Package for the Social Sciences (SPSS).

Search and sample bias were minimized by use of the V_1 validation procedure of Frank et al. (1965) in which only a proportion (analysis sample) of the total sample is used to derive the discriminant function which is then tested on the remainder (validation sample). Sixty percent of the individuals in our samples were randomly assigned by the computer to the analysis sample, the remainder formed the validation sample. We used two distinct samples. One consisted of 208 individuals of assumed sex (AX) trapped on the Gull Island colony in 1978 and 1979. The other consisted of 151 dead individuals of confirmed sex (CX) measured over the three years from Lake Huron (80), Lake Erie (36), Lake Ontario (20), and Lake Superior (15). The sex of all individuals measured was statistically determined by the discriminant functions derived from our analysis samples and the discriminant functions reported by Shugart (1977) for comparison.

RESULTS

When the measurements of the assumed sex (AX) and confirmed sex (CX) samples are compared, they differ only in their ranges (Table 1). This difference results from the criteria used to create the assumed sex sample which will underrepresent individuals from the region of overlap, and the inclusion of emaciated individuals of abnormal weight in the confirmed sex sample. Although overlap existed for all parameters, the mean values for the two sexes were significantly different in all cases.

The discriminant functions and their respective descriptive statistics derived from the two samples are presented in Table 2. Two functions use head length and bill depth. That based on the assumed sex sample

TABLE 1. A comparison of measurements of individual Herring Gulls of assumed sex (1978) and confirmed sex (1978–1980).

	Sexes		T-test between sexes
	Male	Female	
Assumed sex sample (AX)			
Head length	126.8 ± 3.1 (56)[a] (120.0–138.0)	115.8 ± 3.1 (55) (110.4–123.2)	$t_{109} = 18.8, P < 0.001$
Bill depth	19.2 ± 0.8 (56) (18.0–22.3)	(17.0 ± 0.8 (55) (15.2–19.0)	$t_{109} = 14.4, P < 0.001$
Wing chord	445.6 ± 8.8 (56) (425–465)	421.0 ± 11.5 (55) (395–445)	$t_{109} = 12.6, P < 0.001$
Weight	1192.5 ± 74.8 (56) (1070–1360)	962 ± 64.1 (55) (870–1100)	$t_{109} = 17.4, P < 0.001$
Confirmed sex sample (CX)			
Head length	126.7 ± 4.2 (67) (116.0–136.5)	115.6 ± 3.2 (84) (107.3–124.3)	$t_{149} = 18.4, P < 0.001$
Bill depth	18.9 ± 0.8 (67) (17.2–21.0)	16.9 ± 0.8 (84) (15.3–19.0)	$t_{149} = 15.8, P < 0.001$
Foot length[b]	134.8 ± 5.5 (49) (123–150)	123.2 ± 4.3 (67) (113–135)	$t_{114} = 12.8, P < 0.001$
Wing chord	448.0 ± 11.2 (66) (420–475)	422.4 ± 12.8 (80) (385–450)	$t_{144} = 12.7, P < 0.001$
Weight	1166.1 ± 160.6 (67) (797–1650)	942.6 ± 102.2 (84) (600–1240)	$t_{149} = 10.4, P < 0.001$

[a] Mean ± 1 standard deviation (n) (range).
[b] Data from 1980 only.

(AX: HL × BD) was very accurate (99.3%) in predicting the assumed sex of the validation sample from the same colony, but less so (94.7%) in identifying the confirmed sex of individuals from four Great Lakes (Table 3). Nevertheless, it has considerable accuracy, further validating the use of such methodology where necessary. Figure 1 illustrates the relationship between head length and bill depth in the assumed sex (AX) sample. The line that best separates males and females was calculated by substituting measurements into the discriminant function. The function based on the confirmed sex sample (CX: HL × BD) was also accurate (95.5%) in predicting the assumed sex of members of mated pairs, but more accurate in predicting the sex of individuals of confirmed sex (98.5%) (Table 3). The relationship between head length and bill depth in the confirmed sex (CX) sample is also illustrated in Figure 1. The discriminant based on head length and foot length (CX: HL × FL) was somewhat less accurate (94.7%) in predicting the sex of individuals of confirmed sex (Table 3). This may reflect bias in the small validation sample. The relationship between head length and foot length is illustrated in Figure 2.

TABLE 2. Discriminant functions for sexing Herring Gulls* based on the assumed sex (AX) and confirmed sex (CX) analysis samples, their descriptive statistics and accuracy, and those of Shugart (1977).

Analysis sample parameters	Discriminant function	Wilk's[a] lambda	χ^2	Significance	Apparent accuracy
AX: HL × BD	(HL × 0.231) + (BD × 0.571) = 38.440[b]	0.2033	111.52	$P < 0.001$	98.6% (72/73)
CX: HL × BD	(HL × 0.198) + (BD × 0.514) = 32.993[b]	0.2621	117.84	$P < 0.001$	96.5% (82/85)
CX: HL × FL	(HL × 0.183) + (FL × 0.077) = 31.956[b]	0.3187	84.61	$P < 0.001$	94.9% (74/78)
Shugart	(HL × 13.866) + (WC × 3.664) − 1673.246 = M[c] (HL × 12.680) + (WC × 3.454) − 1441.105 = F[c]	0.1829	86.95	$P < 0.001$	98.1% (54/55)

* Using measurements of head length (HL), Bill depth (BD), foot length (FL), and wing chord (WC).

[a] Wilk's Lambda is an inverse measure of the discriminating power in the variables which has not been removed by the derived function; the larger the number, the less information remains.

[b] Any individual whose discriminant score exceeds this critical value is a male.

[c] Measurements are substituted into both male (M) and female (F) functions; that yielding the largest value indicates the sex.

The accuracy of our discriminant functions is greater than those of Shugart (1977) when applied to individuals in our study population (Table 3). Although there is good agreement on males, Shugart misidentifies considerably more females. The overall accuracy of Shugart's functions is 92.3% (263/285) in contrast to the 98.2% (54/55) he reported

TABLE 3. The accuracy of our discriminant functions in predicting the sex of individuals in our assumed sex and confirmed sex validation samples, as compared to those derived by Shugart (1977).

Validation sample	Sex	Discriminant function			
		AX: HL × BD	CX: HL × BD	CX: HL × FL	Shugart
Assumed sex	M	67/67	67/67	—	66/67
	F	67/68	62/68	—	56/68
	M + F	134/135 (99.3%)	129/135 (95.5%)	—	122/135 (90.4%)
Confirmed sex	M	61/67	32/32	15/16	65/66
	F	82/84	33/34	21/22	76/84
	M + F	143/151 (94.7%)	65/66 (98.5%)	36/38 (94.7%)	141/150 (94.0%)
Overall		277/286 (96.8%)	194/201 (96.5%)		263/285 (92.3%)

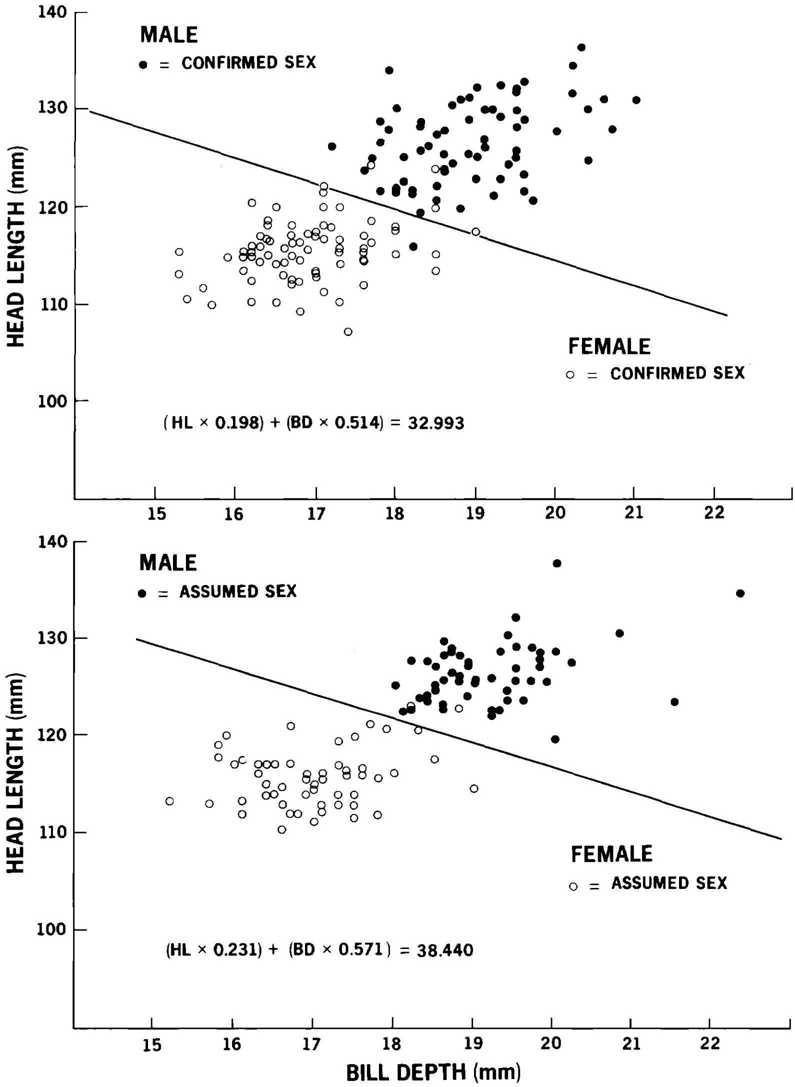

FIGURE 1. Relationship between head length and bill depth in Herring Gulls from the Great Lakes basin. (A) 111 individuals of assumed sex from the Gull Island colony, Lake Ontario, measured in 1978, (B) 151 individuals of confirmed sex collected in lakes Ontario, Erie, Huron, and Superior 1978–1980. The line representing the discriminant function which best separates males from females is given in each case.

based on his analysis sample. Based on Wilk's Lambda, our functions use considerably more of the discriminating power of the measurements than do Shugart's.

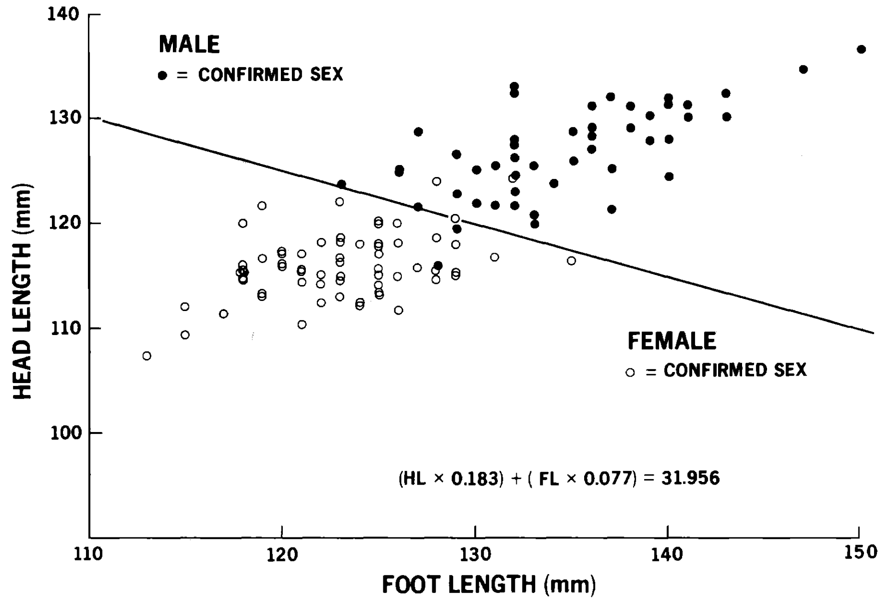

FIGURE 2. Relationship between head length and foot length in 116 Herring Gulls of confirmed sex from colonies in lakes Ontario, Erie, Huron, and Superior in 1980. The line represents the discriminant function (HL × 0.183) + (FL × 0.077) = 31.956 which best separates males from females.

DISCUSSION

One can successfully use individuals of mated pairs of gulls in which one sex is distinctly larger than the other for formation of assumed sex samples unless they are attending a supernormal clutch suggesting female-female pairing (Hunt and Hunt 1977, Ryder and Somppi 1979). Such methodology can be applied to rare and endangered species or in other situations where a large known-sex collection is not desirable.

Fewer exceptionally small males than exceptionally large females existed in our study population. This may reflect different selection pressures on the sexes or the effects of greater genetic variability in females due to their wider dispersal (Chabrzyk and Coulson 1976). Our discriminant functions error in favor of males, and most of these "errors" have discriminate scores of less than +0.50.

Discriminant function analyses have two inherent sources of bias (Frank et al. 1965). Sampling bias exists because the discriminant function maximizes separation within the sample without reference to the study population, resulting in an excessive estimate of the function's discriminating ability. Search bias results from the investigator choosing variables which best separate within the sample but which may not have the same separative capability when applied to the population. Neither

Mills (1971) nor Shugart (1977) tested their discriminant functions for these biases; hence it is impossible to assess the reliability of their methods. Our investigations have shown that those of Shugart are considerably less accurate than he reported.

Using our discriminant functions, the sex of an individual Herring Gull can be obtained quickly from measurements taken with a dial caliper, a rigid 150 mm rule, and a copy of Figure 2 or 3, or in "borderline" cases, a calculator. An individual with a head length of 127.5 mm and a bill depth of 19.8 mm, when substituted into function CX: HL × BD $(127.5 \times 0.198) + (19.8 \times 0.514) = 35.422$ is classified as a male since the discriminant score exceeds the critical score of 32.993. We prefer to use the form $(HL \times 0.198) + (BD \times 0.514) - 32.993 = DS$. If the score (DS) is a positive value, the individual is a male, if negative or 0, a female. This discriminant score is recorded as an indicator of the relative "maleness" or "femaleness" of the individual. In cases where both members of a pair are calculated to be males, a comparison of discriminant scores can be used to separate the true male from his exceptionally large mate. By subtracting the score of the smallest pair member from that of the largest, an index of sexual dimorphism for the two characters is obtained.

We have derived three discriminant functions. That based on the confirmed sex sample (CX: HL × BD) must be regarded as the most accurate (96.5%) at this time, although CX: HL × FL deserves further testing. The sex derived by the two functions is identical in 98% of cases ($n = 200$). Sexes derived from any discriminant function are only as accurate as the measurements upon which they are based. All measurements used in our methods are relatively easy to obtain, should be reproducible, and are likely equally subject to observer error. To date, we have not achieved complete reproducibility.

A comparison of measurements in 78 instances where an individual has been measured in two or more years, by a possible total of 9 researchers, indicates that head length (HL) differs by a mean of 1.65 mm whereas bill depth (BD) differs by a mean of 0.51 mm representing an error of 1.4% and 2.8%, respectively, for the "average" Herring Gull. In four of 74 cases (5.4%) the calculated sex of the individual changed between years. Two of these cases are thought to be the result of errors in the measurements, the others to errors in records. Reproducibility could be improved by holding the gull in a standardized fashion and by using a modified caliper with flat plates to measure head length. Since our discriminant function CX: HL × BD has been tested for sampling error and search bias on individuals from a wider geographic area within the Great Lakes basin and is more accurate and more convenient to use than that of Shugart (1977), it deserves consideration for use in field studies of Great Lakes Herring Gulls. However, its usefulness elsewhere should be confirmed with birds of known sex since interpopulation differences in body measurements exist (Barth 1967, Threlfall and Jewer 1978).

The sexes of six monomorphic species of *Larus* gulls have been successfully separated on the basis of bill and other measurements. These measurements have been used to derive discriminant functions for three of these species. Sex differences in morphometric parameters likely exist in other species. Our methods could be used to derive discriminant functions for these. Since weight, wing, and tail measurements vary with body condition, feather wear, and molt, these measurements should be avoided. We have found the measurements of head length, bill depth, and foot length, described herein, to be easily obtained in the field and feel they warrant consideration in studies of other larid species.

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Wildlife Toxicology Division, Canadian Wildlife Service, National Wildlife Research Centre, Ottawa, Ontario K1A 0E7, Canada (G.A.F.); Westworth and Associates, Environmental Consultants, Calgary, Alberta, Canada (C.R.C.); and Department of Biology, Lakehead University, Thunder Bay, Ontario P7B 5E1, Canada (J.P.R.). Received 16 Feb 1980; Accepted 28 Nov. 1980.