

SEXING RAZORBILLS *ALCA TORDA* BREEDING AT MACHIAS SEAL ISLAND, NEW BRUNSWICK, CANADA, USING DISCRIMINANT FUNCTION ANALYSIS

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Grecian V.D, Diamond A.W. & Chardine J.W. 2003. Sexing Razorbills *Alca torda* breeding at Machias Seal Island, New Brunswick, Canada, using discriminant function analysis. *Atlantic Seabirds* 5(2): 73-80. *In 2000 and 2001, we determined the sex of 80 adult Razorbills Alca torda caught on Machias Seal Island, New Brunswick, Canada, 71 birds in 2000 and 9 in 2001. Sex was determined for the 2000 birds using DNA from feathers, and for the 2001 captures using behavioural observations. Males averaged significantly larger than females in head+bill (3% larger), culmen (3%) and bill depth (4%). Discriminant Function Analysis (DFA) was used to classify birds that were not sexed. The function correctly classified 78% of birds using the linear measurements (head+bill, bill depth, wing chord, and tarsus) and 79% when a stepwise procedure was used. The highest classification success rate (80%) resulted from using only head+bill and bill depth. Bill size of Razorbills from Quebec and Labrador is very similar to those from Machias Seal Island, suggesting that the functions reported here may apply throughout the North American breeding population.*

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INTRODUCTION

Ornithological field observations are enhanced if the sex of the individual birds being studied is known. Without performing autopsies, laparotomies, or inferring the gender of an individual by behaviour, the sex of an individual bird is often difficult to determine. In monomorphic birds such as the Razorbill *Alca torda*, discriminating sexual characteristics are not observable. However, most otherwise sexually monomorphic species show some degree of size difference between the sexes, although this may be obscured by clinal differences across the geographic range of the species (Monaghan *et al.* 1983; Barrett *et al.* 1997). Bédard (1985) suggested that Razorbills from different locations should not be grouped for morphometric analysis because of such clinal variation.

Males and females of monomorphic species are commonly distinguished by Discriminant Function Analysis (DFA) using various morphometric

measures in a sample of known-sex birds (for example, larids: Fox *et al.* 1981; Coulson *et al.* 1983; Hanners & Patton 1985; Chardine & Morris 1989; Mawhinney & Diamond 1999; Devlin & Diamond, unpublished; and other seabirds: van Franeker & Ter Braak 1993; Weidinger & van Franeker 1998). Wagner (1999) presented extensive data on sexual dimorphism in Razorbills but did not explore the possibility of using the information to predict the sex of individual birds. In this study, we explore the potential of using Razorbill body measurements to predict the sex of birds using DFA.

METHODS

The study was carried out on a population of about 550 breeding pairs of Razorbills (Grecian & Diamond, unpublished) at Machias Seal Island (44° 30'N, 67° 06'W), which lies at the mouth of the Bay of Fundy, New Brunswick, Canada. In 2000, we determined the sex of 71 adults using the genetic technique developed by Fridolfsson and Ellegren (1999). A sample of DNA from each bird was extracted from the pulp of a few plucked breast feathers and processed to amplify different-sized introns from the gene CHD1 on each of the W and Z sex chromosomes. Individuals with a single band were scored as male, those with two bands as female. Twenty of the feather samples were processed twice to ensure correct identification; ten were retested because the DNA extraction cocktail was thought to be old and the other ten because there was insufficient DNA in the sample. The sex determination results of both tests were identical for all 20 birds. Nine birds in 2001 were sexed using mounting behaviour as described by Wagner (1992, 1999). Wagner found that while males would mount other males, either by mistake or while learning, females never mounted. Close observation of banded pairs (in which at least one individual was banded) during courtship and early egg laying allowed us to assign sex to 9 individuals.

For each bird, we measured natural wing-chord with a steel ruler to the nearest mm, head+bill length from the bill-tip to the extreme back of the head, exposed culmen from the bill-tip to the point at which the top of the bill and feathers meet, bill depth at gonys, and tarsus, all with vernier calipers to the nearest 0.1 mm. Body mass was measured with a Pesola balance to the nearest 5 g. Most of the birds were captured and measured by the same person (VDG), and a standardized measurement protocol was used to minimize variation between observers.

We performed DFA on the sample of 80 birds (71 sexed genetically, nine by behaviour), initially including wing chord, head+bill, bill depth, and tarsus, using *SPSS v. 10* (SPSS 1999). We also ran analyses using only the measurements selected by the default stepwise method provided in *SPSS*, and on

measurements whose means differed significantly between males and females in univariate comparisons and remained in the analysis. Birds for which any of the measurements were missing were automatically excluded from the analyses. Classification success rates were based on the jack-knife (leave-one-out) method. The method of determining the unstandardized discriminant functions, which could be used to classify birds of unknown sex in morphometrically similar populations, followed Phillips and Furness (1997) and Chardine (2002).

RESULTS

Mean measurements did not vary significantly between years (ANOVAs with effect of sex removed, $P > 0.05$) so data from 2000 and 2001 were pooled. Measurements for males ($n = 42$) and females ($n = 38$) are given in Table 1. Males were on average larger than females in all measurements except wing chord but differences were small and statistically significant only for head+bill (males 3% larger), culmen (3% larger), and bill depth (4% larger; t -tests, $P < 0.05$; Table 1). Results of the various discriminant function analyses are presented in Table 2. Culmen was not included in the discriminant function analyses in Table 2 because of the difficulty in measuring it consistently, but where it was included in a stepwise procedure it was always removed by the discriminant function. The function that included the linear measurements head+bill, bill depth, wing chord, and tarsus correctly classified 78% of birds (jack-knife classification). In the stepwise analysis of the same linear measurements, tarsus was dropped from the resulting discriminant function with a slight increase in the classification success rate to 79%.

The function giving the highest classification success rate, 80%, included head+bill and bill depth, which were the only two measurements used in the DFA that differed significantly between males and females. The discriminant function was:

$$D = 0.25(HB) + 0.73(DEP) - 40.84$$

where D is the discriminant score and HB and DEP are measurements in mm. Using this function, D was calculated for each bird, which in turn was used to determine the *a posteriori* probability (PP) of group membership based on Bayes' Rule (D and PP calculated by *SPSS*). Figure 1a shows the relationship between PP of being a male ($PP_{\text{female}} = 1 - PP_{\text{male}}$) and D for this discriminant function. The value of D associated with $PP = 0.5$ gives the cut-off discriminant score between males and females (D_{crit}). In this case, $D_{\text{crit}} = -0.04$; birds having a score greater than -0.04 were predicted to be males and those having a score less than -0.04 were predicted to be females.

Table 1. Measurements of known-sex adult Razorbills caught on Machias Seal Island in 2000 and 2001.

Tabel 1. Maten van adulte Alken van bekend geslacht, die in 2000 en 2001 gevangen zijn op Machias Seal Island.

| Measurement | Sample | n | Mean | SD | t^1 | P |
|-----------------|--------|----|------|-----|--------|---------|
| Head+bill | Male | 42 | 96.7 | 2.6 | 5.69 | < 0.001 |
| | Female | 38 | 93.6 | 2.2 | | |
| Culmen | Male | 37 | 35.5 | 1.7 | 2.67 | < 0.05 |
| | Female | 34 | 34.5 | 1.4 | | |
| Bill depth (mm) | Male | 42 | 23.5 | 0.7 | 5.53 | <0.001 |
| | Female | 38 | 22.5 | 0.9 | | |
| Wing chord (mm) | Male | 42 | 204 | 5 | - 0.53 | 0.60 |
| | Female | 38 | 205 | 5 | | |
| Tarsus (mm) | Male | 42 | 34.9 | 1.9 | 0.84 | 0.41 |
| | Female | 38 | 34.6 | 1.5 | | |
| Body mass (g) | Male | 42 | 700 | 46 | 0.61 | 0.55 |
| | Female | 35 | 693 | 55 | | |

¹ t -test for independent means; DF = male+female sample size; all variances were homogeneous (Levene's tests, $P > 0.05$).

Table 2. Results of stepwise discriminant function analyses classifying adult Razorbills caught on Machias Seal Island in 2000 and 2001 into male and female groups.

Tabel 2. Resultaten van een stapsgewijze discriminant-functie-analyse om adulte Alken in te delen in groepen mannen en vrouwen.

| Analysis | Discriminant function ¹ | Jack-knife classification success ² | | Statistical significance | D_{crit} ³ |
|-----------------------------|--|--|-------------------|--|-------------------------|
| | | Males n = 42 | Females n = 38 | | |
| All variables | $D = 0.28(HB) + 0.91(DEP) - 0.11(WCH) - 0.12(TAR) - 21.63$ | 76% | 79% | Wilks' Lambda = 0.55 $\chi^2_4 = 45.1, P < 0.001$ | -0.04 |
| Stepwise variable selection | $D = 0.27(HB) + 0.87(DEP) - 0.11(WCH) - 22.6$ | 81% | 76% | Wilks' Lambda = 0.56 $\chi^2_3 = 44.1, P < 0.001$ | -0.04 |
| HB and DEP | $D = 0.25(HB) + 0.73(DEP) - 40.84$ | 79% | 82% | Wilks' Lambda = 0.64 $\chi^2_2 = 34.6, P < 0.001$ | -0.04 |
| HB | $D = 0.41(HB) - 39.27$ | 71% | 76% | Wilks' Lambda = 0.71 $\chi^2_1 = 26.9, P < 0.001$ | -0.03 |
| DEP | $D = 1.27(DEP) - 29.25$ | 76% | 66% | Wilks' Lambda = 0.72 $\chi^2_1 = 25.6, P < 0.001$ | -0.03 |

Figure 1b depicts bill depth in relation to head+bill length, with the line dividing predicted males (upper right portion of graph) and females (lower left portion). This line was calculated from the discriminant function for head+bill

and bill depth given above, setting D to -0.04 and solving for bill depth as follows:

$$BD = (0.25(HB) - 40.84 + 0.04) / -0.73$$

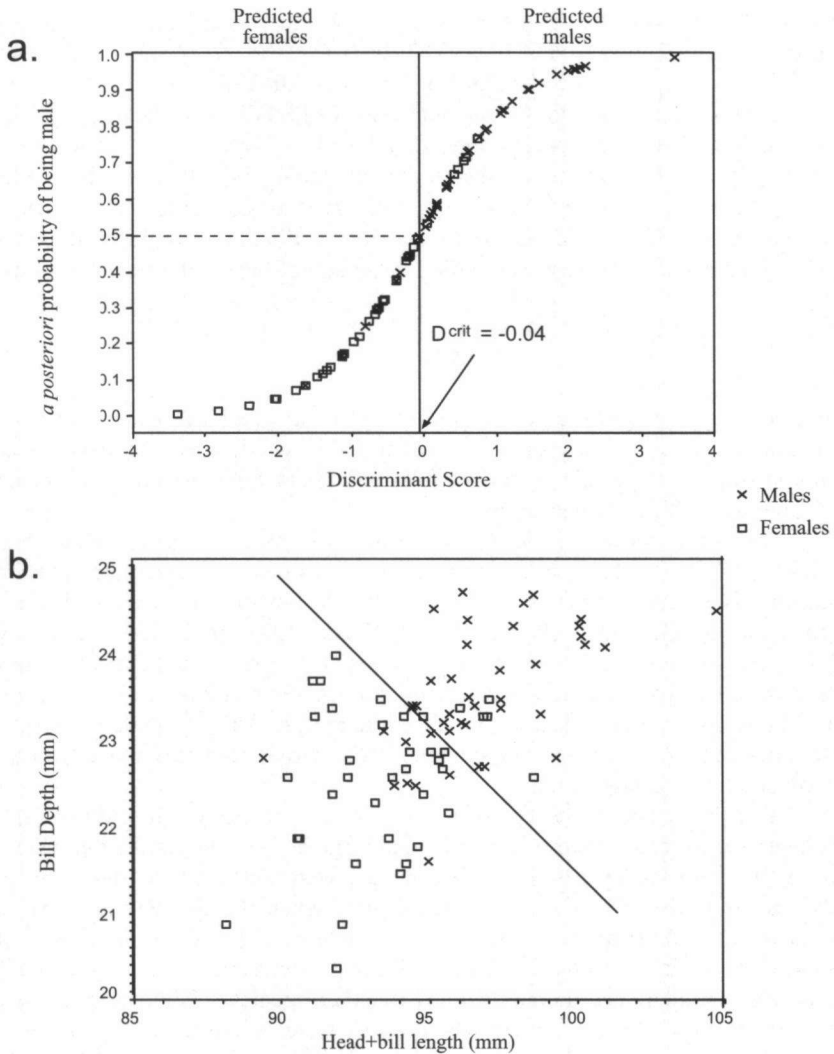
Discriminant functions that included head+bill or bill depth alone discriminated between males and females least well (74% and 72% respectively). All functions discriminated male and female Razorbills statistically better than by chance (χ^2 tests, $P < 0.05$; Table 2) and while determining sex through sexual behaviour observations may be difficult, all 9 birds from 2001 were correctly classified using any of the given discriminations.

DISCUSSION

We aimed to develop a method to sex Razorbills at Machias Seal Island from body measurements. Despite the relatively low degree of sexual size dimorphism, we were able to successfully sex about 80% of Razorbills using head+bill and bill depth measurements.

Our data show that male Razorbills on Machias Seal Island had significantly larger head+bill, culmen, and bill-depth measurements than females. The trend for males to have larger bill dimensions than females has been found in other alcids (Corkhill 1972; Nelson 1981; Jones 1993) and may be a standard feature across the family. Jones (1993) suggested that the larger bill of male Crested Auklets *Aethia cristatella* was the result of sexual selection for fighting ability amongst males for access to mates. As some male Razorbills obtain matings in a lek situation (Wagner 1992), larger bills may indeed confer a competitive advantage to males.

The differences between males and females in head+bill, culmen, and bill depth measurements were relatively small (males 3-4% larger than females), but (in the case of head+bill and bill depth) were sufficient to discriminate between the sexes with a success rate of 80% when the measurements were included in a discriminant function. Typically, auks show little sexual dimorphism in size (Gaston & Jones 1998), and discriminant function analysis might yield similar discrimination rates in other species. For example, only 65% of Atlantic Puffins *Fratercula arctica* were sexed correctly using a discriminant function that included culmen and bill depth (Corkhill 1972). In related species such as gulls, sexual size dimorphism is more pronounced and the classification success rates of discriminant functions using body measurements often exceed 90% (Fox *et al.* 1981; Coulson *et al.* 1983; Monaghan *et al.* 1983; Chardine & Morris 1989; Mawhinney & Diamond 1999).



The applicability of this function to other populations of Razorbills depends upon the variation in size among the populations. Culmen and bill depth measurements of Razorbills from Quebec and Labrador are very similar to those from Machias Seal Island (Hipfner & Chapdelaine 2002), suggesting that the function might apply throughout the North American breeding population.

Opposite page. Figure 1a. Logistic relationship between a posteriori probability (PP) of being a male, as calculated by SPSS using Bayes' Rule (SPSS 1999) and discriminant score (D) calculated for each bird using the discriminant function that included head+bill length and bill depth. The discriminant function was $D = 0.25(HB) + 0.73(DEP) - 40.84$. The value of D associated with PP = 0.5 gives the cut-off discriminant score between males and females ($D_{crit} = -0.04$).

Figure 1b. The relationship between bill depth and head+bill length for each bird in the sample. The line divides the cloud of points into predicted males (upper right) and predicted females (lower left) based on the above discriminant function and the observed value of D_{crit} . The actual sex of each bird as determined genetically is shown in both graphs.

Tegenoverliggende pagina. Figuur 1a. Logistische relatie tussen de a posteriori (achteraf bepaalde) kans (PP) een man te zijn, zoals berekend in SPSS (1999) met de regel van Bayes, en de discriminantscore (D) berekend voor iedere vogel met behulp van de discriminant-functie $D = 0.25(HB) + 0.73(DEP) - 40.84$, waarbij HB kop+snavelengte is en DEP de snavelhoogte. De waarde van D voor PP = 0.5 geeft de onderscheidende score tussen mannen en vrouwen ($D_{crit} = -0.04$).

Figuur 1b. De relatie tussen snavelhoogte en kop+snavelengte voor iedere vogel in de steekproef. De lijn verdeelt de puntenwolk in mannen (rechtsboven) en vrouwen (linksonder) zoals voorspeld met bovenstaande discriminantfunctie en de bijbehorende waarde van D_{crit} . In beide figuren is het werkelijke geslacht van iedere vogel weergegeven zoals vastgesteld aan de hand van DNA.

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GESLACHTSBEPALING VAN ALKEN *ALCA TORDA* BROEDEND OP MACHIAS SEAL ISLAND, NEW BRUNSWICK, CANADA, MET DISCRIMINANT-FUNCTIE-ANALYSE

In 2000 en 2001 bepaalden we het geslacht van 80 adulte Alken *Alca torda* die waren gevangen op Machias Seal Island, New Brunswick Canada (71 in 2000, 9 in 2001). Het geslacht van de vogels uit 2000 werd bepaald aan de hand van DNA afkomstig uit enkele veren, het geslacht van de vogels uit 2001 aan de hand van waargenomen gedrag. Maten van mannetjes waren gemiddeld groter dan vrouwtjes voor kop+snavel (3% groter), bovensnavel (3%) en snavelhoogte (4%) (tabel 1 & 2). Discriminant-functie-analyse (DFA) werd gebruikt om vogels met onbekend geslacht te kwalificeren. DFA kwalificeerde 78% van de vogels correct met behulp van lineaire maten (kop+snavel, snavelhoogte, vleugel en tarsus) en 79% met behulp van een stapsgewijze procedure (figuur 1). Het hoogste 'kwalificatiesucces' werd behaald door alleen kop+snavel en snavelhoogte te gebruiken.

Aangezien de grootte van de snavel van Alken in Quebec en Labrador vrijwel identiek is aan die van vogels van Machias Seal Island, zouden de beschreven DFA-functies gebruikt kunnen worden voor de gehele Noord-Amerikaanse broedpopulatie.

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