Sexing adult Cory's Shearwater Calonectris diomedea by Discriminant Analysis of body measurements on Linosa Island (Sicilian Channel), Italy.

Article *in* Waterbirds · February 2001

Impact Factor: 0.64 · DOI: 10.2307/1522026

Mario Lo Valvo
Università degli Studi di Palermo

Sexing Adult Cory's Shearwater by Discriminant Analysis of Body Measurements on Linosa Island (Sicilian Channel), Italy

MARIO LO VALVO

Department of Animal Biology, University of Palermo, Via Archirafi 18, I-90123, Palermo, Italy
Internet: mlovalvo@dtpm.unipa.it

Abstract.—Males and females of many avian species may show no plumage dimorphism, but often can be sexed by differences in body measurements. Sex determination of many Cory's Shearwaters *Calonectris diomedea*, was possible by multiplying bill length by bill depth. In this study, discriminant analysis of six measurements (bill length, bill depth, wing, tail, tarsus and mass) was performed on Cory's Shearwaters breeding on Linosa Island (Sicilian Channel), Italy and the efficiency of sex determination was compared with the univariate method. Results show the advantages of the discriminant functions. Bill depth is the best parameter (up to 92% correct classification), followed by mass (84% correct classification); using mass is simple and causes less disturbance to the birds. *Received 10 August 2000, accepted 2 February 2001.*

Key words.—Cory's Shearwater, *Calonectris diomedea*, Discriminant Analysis, Sicily.

Waterbirds 24(2): 169-174, 2001

Cory's Shearwater *Calonectris diomedea* is a sexually monomorphic species, with monochromatic plumage. Sexes can be distinguished by cloacal inspection at egg-laying time (Serventy 1956). Ristow and Wink (1979, 1980) used the product bill length-bill depth (previously used by Dunnet and Anderson (1961) for Northern Fulmars *Fulmarus glacialis*), to determine the sex of about 95% of a sample made up of 38 pairs of Cory's Shearwaters breeding on Aegean Islands. Mougin *et al.* (1986), by applying the same method to 326 pairs belonging to the Atlantic subspecies *(C. d. borealis)*, recorded a 33% overlap between the two sexes. In recent years, the use of measurement to sex species of birds is becoming more frequent (Dunnet and Anderson 1961; Green 1982; Coulson *et al.* 1983; Scolaro *et al.* 1983; Wood 1987; Kavanagh 1988; Green and Teobald 1989; Desrochers 1990; van Franeker and ter Braak 1993; Phillips and Furness 1997). In particular, Granadeiro (1993) applies discriminant analysis to distinguish sex among samples belonging to one of the Atlantic populations of Cory's Shearwater. At the same time, he emphasized that the discriminant functions so obtained can be applied only to the colony studied and were probably not suitable for Mediterranean colonies of *C. d. diomedea*, which are morphometrically (Massa and Lo Valvo 1986; Lo Valvo and Massa 1988) and biochemically (Randi *et al.* 1989) different. Bretagnolle and Thibault (1995) have applied discriminant analysis, using four variables, to sex chicks in a colony of *C. d. diomedea* located on the Lavezzi Islet, between Corsica and Sardinia in the western Mediterranean.

To examine if discriminant analysis is a better method than bill length x bill depth to identify sex of Cory's Shearwaters, I applied it to specimens on Linosa island (Sicilian Channel), Italy (35°50'N, 12°50'E).

The aims of this paper are:

a) to find unstandardized discriminant functions suitable for Mediterranean colonies, and standardized discriminant functions useful even for Atlantic colonies;
b) to verify if sex determination by discriminant functions can be significantly simplified compared with the index proposed by Ristow and Wink (1980);
c) to limit the number of variables contributing to efficient sex determination, saving time and reducing disturbance of birds.

METHODS

At least one of the following variables was measured on 725 individuals in 1982-86: bill length (**Bl**) and depth (**Bd**) (Fig. 1), tarsus length (**Tsl**), tail length (**Tll**), wing length (**Wl**) and mass (**W**) (Ristow and Wink 1980; Iapichino *et al.* 1983; Massa and Lo Valvo 1986). Contrary to what has been observed on gulls (Coulson *et al.* 1981,

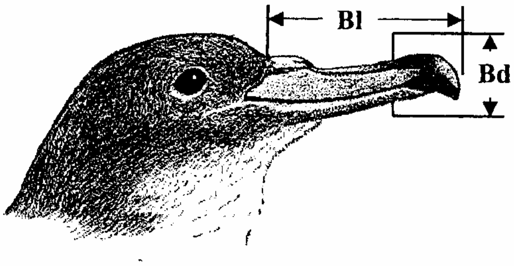

Figure 1. Illustration of bill measurements taken on Cory's Shearwater. Bl = bill length; Bd = bill depth.

1983), Granadeiro (1993) did not find bill depth differences among breeding individuals of Cory's Shearwater from one year to the next. He excluded **Wl** and **W** from his analysis because their variance was too high; for the first variable this was due to the abrasion of the flight-feathers; for the second it was due to seasonal changes in the nutritional status and variation in date. I have, however, considered these two variables because high variability does not exclude low or null overlapping between the two sexes.

A total of 630 birds (87%) were sexed by listening to the vocalization at the time of capture (hoarse for the female and sharp for the male) (cfr. Ristow and Wink 1980; Bretagnolle and Thibault 1995).

In particular, the measurements taken regarded:

- 6 variables (**Bl, Bd, W, Wl, Tsl, Tll**) on 98 individuals (49 males and 49 females)
- 3 variables (**Bl, Bd, W**) on 211 individuals (104 males and 107 females)
- 1 variable (**W**) on 618 individuals (317 males and 301 females after the egg laying period))

Data analysis was carried out by:

4) the index obtained by the product of the bill depth and bill length;

5) discriminant analysis (Legendre and Legendre 1979; Digby and Kempton 1987; Sokal and Rolf 1989), which produces a linear function (equation predictive), unstandardized and standardized, that combines the external morphometric characters taken from birds of known sex, maximizing the variance between groups.

Later, the discriminant function was used to assign sex to birds randomly caught and of unknown sex. Discriminant analysis also allowed the calculation of a probability coefficient, corresponding to the chance that the bird has been correctly sexed.

Compared with the unstandardized function, the standardized function the mean value of the sample is removed from to the value of each variable and the result divided for its standard deviation. The new samples will always have mean 0 and variance 1 and the standardized function could be applied to any colony of Cory's Shearwater is being studied.

RESULTS

Means of six morphometric variables are given in Table 1. T-test showed statistically significant differences between males and females ($P < 0.01$ for all six variables), as previously observed with a smaller sample by Massa and Lo Valvo (1986).

Bill Depth × Length

The total variation of the index ranges from 506 to 845; on average index of females scored 600, and that of males 719 (Table 1). The overlapping between the two sexes ranges from 602 to 700, and includes 31 males and 50 females, about 38% of the entire sam-

Table 1. Morphometric data (mean ± sd; N) and level of significance (P) between males and females of Linosa Island (central Mediterranean) colony of Cory's Shearwater.

	Females	Males	P
Tail length (mm)	143.0 ± 8.37 49	148.3 ± 8.91 49	<0.01
Tarsus length (mm)	52.8 ± 2.02 49	54.2 ± 2.67 49	<0.01
Wing length (mm)	345 ± 9.86 49	357 ± 9.21 49	<0.001
Mass (g)	561 ± 40.6 301	668 ± 58.4 317	<0.001
Bill length (mm)	49.6 ± 1.83 107	52.9 ± 1.84 104	<0.001
Bill depth (mm)	12.1 ± 0.49 107	13.6 ± 0.61 104	<0.001
Bill depth × length	601 ± 34.5 107	719 ± 44.6 104	

ple (N = 211). Figure 2 shows normal distributions (Sokal and Rolf 1989) obtained for both sexes from the equation:

$$y = \frac{N}{\sigma\sqrt{2\pi}} e^{-(x-m)^2/2\sigma^2}$$

Discriminant Function Analysis

Table 2 shows the results obtained by discriminant analysis on the single variables, and in a randomly drawn sub-sample. Table 3 shows the results on all paired combinations of variables. In order to compare the values obtained, avoiding error due to a different sample size (Mougin *et al.* 1986; Brennan *et al.* 1991), the same number of males and females was used when comparing different variables. By combining three or more variables, the probability of correct sexing increases to 97%, and the canonical correlation to 0.89 (P < 0.001) in the sample examined.

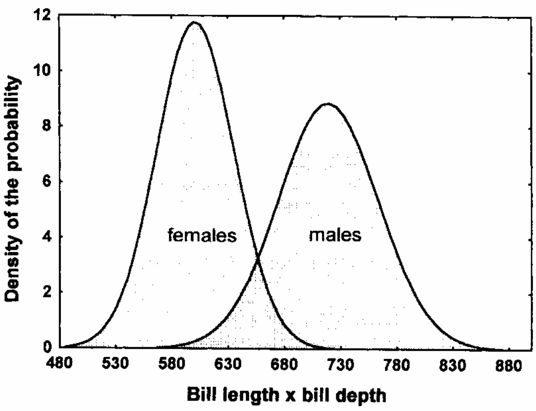

Figure 2. The normal distributions of the bill index (product of bill depth and bill length in mm) from Cory's Shearwater at Linosa Island (central Mediterranean).

DISCUSSION

The product bill length-bill depth, applied to a central Mediterranean population of Cory's Shearwater did not allow correct sexing of about one third (38%) of the specimens examined. A slightly lower value (33%) has been reported for the Atlantic population by Mougin *et al.* (1986), while an extremely low overlap (5%) for the East Mediterranean population is reported by Ristow and Wink (1980).

Moreover, the **Bd** character used by Ristow and Wink (1980) differed from that employed in the Atlantic and central Mediterranean colonies, since bill depth was measured at the bill base, thus including nostril height. To examine this problem, measurements of 76 Linosa specimens were made by both techniques, and on comparing the relative coefficients of variation (CV) (Sokal and Rolf 1989), no large differences in sexing were found (CV males: 4.2% with nostril height and 3.7% without; CV females: 5.7% with nostril height and 5.9% without). Therefore, the low overlapping obtained for the Aegean birds is not due to the different parameter used, but possibly to the low sample size (38 pairs) (Mougin *et al.* 1986) or that Ristow and Wink (1980) sexed *a priori* the individuals of pairs on the basis of body size. In fact, Mougin *et al.* (1986) showed that

Table 2. Percentage correct sex classification, canonical correlation coefficient (r), level of significance (Wilks' test) and discriminant function obtained with discriminant analysis, upon six morphometric characters treated one by one of Linosa Island (central Mediterranean) colony of Cory's Shearwater. D.S. = Discriminant Score (if D.S. > 0 the specimen is probably male, while if D.S. < 0 is probably female/V).

	Percentage of correct classification	r	Significance	Unstandardized function coeff.	Percentage of correct classification (subsample = 50)
Bill depth (N = 211)	92%	0.845	P < 0.001	D.S.V. = 1.86 **Bd** - 24.0	94%
Mass (N = 618)	84%	0.740	P < 0.001	D.S. = 0.02 **W** - 11.7	90%
Bill length (N = 211)	80%	0.672	P < 0.001	D.S. = 0.58 **Bl** - 30.6	70%
Wing length (N = 98)	75%	0.519	P < 0.001	D.S.V. = 0.11 **Wl** - 37.0	66%
Tarsus length (N = 98)	63%	0.291	P < 0.001	D.S. = 0.42 **Tsl** - 22.3	56%
Tail length (N = 98)	56%	0.289	P < 0.001	D.S. = 0.11 **Tll** - 16.7	52%

Table 3. Percentage correct sex classification and, in parentheses, canonical correlation coefficient, obtained by discriminant function analysis on six morphometric characters, treated in couples on Linosa Island (central Mediterranean) colony of Cory's Shearwater. All discriminant functions resulted in statistical significance (P < 0.001 Wilks' test).

	Bill length	Mass	Wing length	Tail length	Tarsus léngth
Bill depth	94.4% (0.87)	93.3% (0.85)	95.5% (0.86)	95.5% (0.85)	95.15% (0.87)
Bill length		91.0% (0.80)	84.3% (0.71)	86.5% (0.71)	80.9% (0.68)
Mass			87.6% (0.77)	83.2% (0.75)	89.8% (0.75)
Wing length				75.3% (0.55)	73.0% (0.54)
Tail length					70.8% (0.44)

in 35 pairs of *C. d. borealis* both partners had index values (bill depth-length product) that fell into the overlap area.

Sexing the specimens on the sole basis of body size, as done by Ristow and Wink (1980) might have produced errors. Considering the Linosa colony of Cory's Shearwater, the overlap area for body mass is greater than that obtained with the bill length-bill depth product. Moreover, sexing one partner of a pair by its body size can be misleading, since it is likely, though not certain, that the larger of a pair is the male. Sex determination based on body size would leave out "unusual" specimens (that is to say "small" males considered as females and/or "large" females taken for males) which are the individuals contributing to the overlap area.

Although the bill length × depth product has proven of some help in discrimination of sex, it is not as accurate a method as discriminant analysis, and in some cases the latter is reliable even when only one morphometric character is considered (e.g., bill depth, mass, bill length, wing) (Table 2).

In the sample examined the best discriminating variable was **Bd**, giving 92% correct classification, followed by (84%) **W**. Even though the value of this latter parameter varied throughout the year, and over the years (sometimes individual variations reached 100 g, i.e., 15% of the whole body weight in males and 18% in females: Lo Valvo and Massa 1986; Granadeiro 1993), the discriminant function based on mass alone correctly reclassified 84% of 98 specimens (Table 2) and 87% of 618 specimens examined. The discriminant functions applied to a sub-sample (N = 50) randomly drawn have produced good results for bill depth and mass. When the **Bd** variable is combined with a second variable, the chance of correct classification increases to values between 93% and 95%.

The two-variable discriminants (Table 4) allow us to graphically plot the probability contours and easily distinguish the sexes (Green 1982; Green and Teobald 1989). For instance, Figure 3 displays measurements of bill length-depth for the sample of specimens examined, together with probability

Table 4. Standardized and unstandardized discriminant functions obtained by bill depth treated in pairs with other morphometric characters from Linosa Island (central Mediterranean) colony of Cory's Shearwater. DS = discriminant score; Bl = bill length; Bd = bill depth; W = mass; Wl = wing length; Tsl = tarsus length; Tll = tail length. [Bd] = (Bd-$\overline{\text{Bd}}$)/s.d. (cfr. § Methods).

	Standardized	Unstandardized
DS =	(0.86*[**Bd**]) + 0.45*[**Bl**])	(1.60*[**Bd**]) + 0.26*[**Bl**]) - 34.2
DSV =	(1.03*[**Bd**]) + 0.47*[**Tsl**])	(1.91*[**Bd**]) + 0.20*[**Tsl**]) - 35.1
DSV =	(0.93*[**Bd**]) + 0.33*[**Wl**])	(1.73*[**Bd**]) + 0.03*[**Wl**]) - 34.7
DS =	(1.07*[**Bd**]) + 0.23*[**Tll**])	(1.98*[**Bd**]) + 0.03*[**Tll**]) - 21.7
DSV =	(0.82*[**Bd**]) + 0.32*[**W**])	(1.53*[**Bd**]) + 0.01*[**W**]) - 23.4

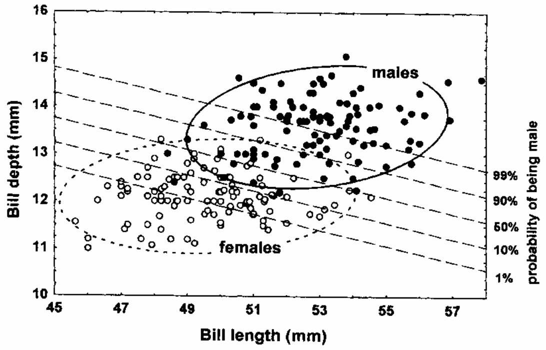

Figure 3. Segregation of male and female Cory's Shearwaters, with probability lines, corresponding to given probabilities of being male, calculated from the discriminant function. Each ellipse encloses the area within which 95% of the males or females will occur.

levels of belonging to either sex derived from discriminant functions, and equiprobability ellipses which include the area where 95% of sexed specimens should fall (Lagonegro and Feoli 1985).

I have tested the unstandardized discriminant functions using means and standard deviations in different colonies of Cory's Shearwaters, published by other authors (Zino 1971; Ristow and Wink 1980; Gaultier 1981; Witt *et al.* 1984; Granadeiro 1993), and the functions have separated sexes correctly, despite the different biometry.

By combining three or more variables, this correct percentage goes up to 97%, similar to values respectively obtained by Granadeiro (1993) on *C. d. borealis* (<95%) with three variables and Bretagnolle and Thibault (1995) on chicks of another population of *C. d. diomedea* (94.6%) with four variables, values which do not improve the results enough to justify measuring a greater number of parameters and, above all, the disturbance caused to the individuals captured.

ACKNOWLEDGMENTS

I thank all persons who helped me in the field, especially S. Bonadonna, S. Benvenuti and P. Ioalè. I am most grateful to Bruno Massa, for his collaboration in the field and for useful advices on the first draft of this paper. John C. Coulson, Leonard A. Brennan, and Ettore Randi provided many helpful suggestions on the original manuscript.

LITERATURE CITED

Araujo, J., J. Munoz Cobo and F. J. Purroy. 1977. Los rapaces y aves marinas del archipelago de Cabrera. Naturalia Hispanica 12: 1-94.

Brennan, L. A., J. B. Buchanan, C. T. Schick and S. G. Herman. 1991. Estimating sex ratios with discriminant function analysis: the influence of probability cutpoints and sample size. Journal of Field Ornithology 62: 357-366.

Bretagnolle, V. and J. C. Thibault. 1995. Method for sexing fledglings in Cory's shearwaters and comments on sex-ratio variation. Auk 112: 785-790.

Coulson, J. C., N. Duncan, C. S. Thomas and P. Monaghan. 1981. An age-related difference in the bill depth of Herring gulls *Larus argentatus*. Ibis 123: 499-502.

Coulson, J. C., C. S. Thomas, J. E. L. Butterfield, N. Duncan, P. Monaghan and C. Shedden. 1983. The use of head and bill length to sex live gulls Laridae. Ibis 125: 549-557.

Desrochers, A. 1990. Sex determination of Black-capped Chickadees with a Discriminant analysis. Journal of Field Ornithology 61: 79-84.

Digby, P. G. N. and R. A. Kempton. 1987. Multivariate analysis of ecological communities. Chapman and Hall, London.

Dunnet, G. M. and A. Anderson. 1961. A method of sexing live fulmars in the hand. Bird Study 8: 119-126.

Gaultier, T. 1981. Contribution à l'étude de la population de Puffinus cendrés (*Calonectris diomedea*) de l'île de Zembra (Tunisie). Ministère Enseignements Supérieurs et Recherche Scientifique, Institute Recherche Scientifique et Technique. 169 pp.

Granadeiro, J. P. 1993. Variations in the measurements of Cory's Shearwater between populations and sexing by discriminant analysis. Ringing and Migration 14: 103-112.

Green, P. T. 1982. Sexing Rooks *Corvus frugileus* by discriminant analysis. Ibis 124: 320-324.

Green, P. T. and C. M. Teobald. 1989. Sexing birds by discriminant analysis: further considerations. Ibis 131: 442-447.

Hemery, G. and E. d'Elbée. 1985. Discrimination morphologique des populations atlantique et mediterraneenne de Petrel tempete *Hydrobates pelagicus*. *In* Oiseaux marins nicheurs du midi et de la Corse. Annales du Centre de Recherches Ornitologiques de Provence 2: 63-67.

Kavanagh, B. 1988. Discriminating the sex of Magpies *Pica pica* from morphological data. Ringing and Migration 9: 83-90.

Iapichino, C., F. Lo Valvo and B. Massa. 1986. Biometria della Berta maggiore (*Calonectris diomedea*) dell'isola di Linosa (Pelagie). Rivista Italiana di Ornitologia 53: 145-152.

Lagonegro, M. and E. Feoli. 1985. The use of ellipses of equal concentration to analyse ordination vegetation patterns. Studia Geobotanica 5: 143-165.

Legendre, L. and P. Legendre. 1979. Ecologie numerique. 2 vols., Masson, Paris.

Lo Valvo, M. and B. Massa. 1988. Considerations on a specimen of Cory's Shearwater ringed at Selvagem Grande and Recovered in the central Mediterranean. Bocagiana 124: 1-5.

Massa, B. and M. Lo Valvo. 1986. Biometrical and biological considerations on the Cory's Shearwater *Calonectris diomedea*. Pages 293-313 *in* Mediterranean

Marine Avifauna (Medmaravis & Monbailliu, Eds.). Springer-Verlag, Berlin.

Mougin, J. L., B. Despin and F. Roux. 1986. La détermination du sexe par mensuration du bec chez le Puffin cendré *Calonectris diomedea borealis*. Comptes Rendue Academie des Sciences Paris 302: 91-96.

Phillips, R. A. and R. W. Furness. 1997. Predicting the sex of Parasitic Jaegers by Disciminant Analysis. Colonial Waterbirds 20: 14-23.

Randi, E., F. Spina and B. Massa. 1989. Genetic variability in Cory's Shearwater (*Calonectris diomedea*). Auk 106: 411-417.

Ristow, D. and M. Wink. 1979. Zur biometrie des sexualdimorphismus beim Gelbschnabelsturmtaucher (*Calonectris diomedea*). Die Vogelwarte 30: 217-219.

Ristow, D. and M. Wink. 1980. Sexual dimorphism of Cory's Shearwater. Il Merill 21: 9-12.

Serventy, D. L. 1956. A method of sexing Petrel in field observation. Emu 56: 213-215.

Scolaro, J. A., M. A. Hall and I. M. Ximénez. 1983. The Magellanic Penguin (*Spheniscus magellanicus*): sexing adults by discriminant analysis of morphometric characters. Auk 100: 221-224.

Sokal, R. R. and F. J. Rolf. 1989. Biometry. W.H. Freeman, New York.

van Franeker, J. A. and C. J. F. ter Braak. 1993. A generalized discriminant for sexing fulmarine petrels from external measurements. Auk 110: 492-502.

Witt, H. H., E. De Juana and J. M. Varela. 1984. Geschlechtsspezifische Grössenunterschiede in einer westmediterranean Population des Gelbschnabelsturmtauchers (*Calonectris diomedea*). Die Vogelwarte 32: 234-236.

Wood, A. G. 1987. Discriminating the sex of Sanderlings (*Calidris alba*): some results and their implications. Bird Study 34: 200-204.

Zino, P. A. 1971. The breeding of the Cory's Shearwater *Calonectris diomedea* on the Selvage Islands. Ibis 113: 212-217.