SEPARATING BLACK-BROWED ALBATROSS *THALASSARCHE MELANOPHRIS* AND ATLANTIC YELLOW-NOSED ALBATROSS *T. CHLORORHYNCHOS* BY OSTEOLOGICAL MORPHOMETRIC ANALYSIS

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ABSTRACT

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Identifying albatross species in the wild involves recognizing plumage pattern and bill coloration. However, skeletal specimens in museums or deteriorated beached carcasses may lack the external characters needed for identification. Although it is possible to distinguish Black-browed Albatross *Thalassarche melanophris* from Atlantic Yellow-nosed Albatross *T. chlororhynchos* based on skull morphology, the specimen remains unidentified if the skull is not available. We measured 96 specimens of Black-browed and 55 Atlantic Yellow-nosed albatross, performing 64 measurements for the entire skeleton. Fifty-nine measurements were based on the literature and five new measurements were established specifically for this work. To search for morphometric differences, we first carried out *t*-tests and principal component analysis (PCA). Then, we performed discriminant function analysis on PCA results and on six selected postcranial measurements to generate a discriminant function. Sixty-one means (93.85 %) of Black-browed Albatross measurements were significantly larger than those of Atlantic Yellow-nosed Albatross. The discriminant function containing the six selected postcranial measurements correctly identified 97.35 % of the specimens through reclassification. This is the first work on osteological morphometric analysis of the entire skeleton for Black-browed and Atlantic Yellow-nosed albatross that is based on a large sample of specimens.

Key words: beach survey, discriminant analysis, mollymawk, osteology, *Thalassarche*

INTRODUCTION

Albatrosses are seabirds that are widely distributed across Southern Hemisphere oceans, with three species also breeding in the northern Pacific. They are currently divided into four genera: *Diomedea*, *Phoebastria*, *Phoebetria*, and *Thalassarche* (Nunn *et al.* 1996). Birds of the last genus are also called mollymawks, and they are the smallest species within those genera (Onley & Scofield 2007). The major threat for mollymawks is bycatch in longline fisheries (Bugoni *et al.* 2008a, Jiménez *et al.* 2009, Croxall *et al.* 2012). Two abundant species of mollymawks in the southern Atlantic Ocean are Black-browed Albatross *T. melanophris* and Atlantic Yellow-nosed Albatross *T. chlororhynchos* (Olmos 1997, Neves *et al.* 2006). The former breeds on sub-Antarctic islands in the Atlantic, Pacific, and Indian Oceans, whereas the latter is restricted to the Atlantic basin, breeding on the Malvinas/Falkland Islands, South Georgia, and the Tristan da Cunha group (Murphy 1936, Marchant & Higgins 1990, Onley & Scofield 2007). Both species can disperse far from their breeding sites during the non-breeding season (Huin 2002, Olmos 2002, Phillips *et al.* 2005, Neves *et al.* 2006), and south and southeastern Brazilian waters are important wintering grounds (Olmos 2002, Neves *et al.* 2006). Southern Brazil features the Brazil/Malvinas Confluence, which is one of the most productive regions of the world and which offers plentiful food resources for seabirds (Seeliger *et al.* 1997, Piola & Matano 2010). Albatrosses are commonly seen following fishing vessels in this region to feed on fishery discards.

In southern Brazil, albatrosses are frequently found beached (Olmos 1997, Bugoni *et al.* 2008b, Scherer *et al.* 2011). Beach surveys are a useful method for collecting information about pelagic birds, because carcasses can be used for studies on species occurrence patterns, health conditions, mortality, and potential threats (Hamel *et al.* 2009, Tavares *et al.* 2016, Uhart *et al.* 2017). In this sense, ensuring that specimens are correctly identified is essential. For albatrosses, plumage pattern and bill coloration are sufficient to identify species and maturity (Bugoni & Furness 2009, Flood 2014, Bugoni *et al.* 2015). On beach surveys, however, carcass deterioration impedes species identification. Frequently, skull features can be used to determine the species (Dénes & Silveira 2007, Dénes *et al.* 2007), but when the carcass is in an advanced decomposition state or the skull is missing, the species remains unidentified due to the lack of an alternative method of skeleton identification.

Previous studies have described morphometric differences between Black-browed and Atlantic Yellow-nosed albatross based on external biometry of live animals or skin specimens (e.g., from taxidermy specimens housed in museums) (Marchant & Higgins 1990, Waugh *et al.* 1999, Bugoni & Furness 2009). Forbes (1882) presented some osteological measurements of hindlimbs and forelimbs of Black-browed Albatross and other Procellariiformes. However, studies on the morphometrics of the entire skeleton for these two species are unknown. In fact, morphometric studies encompassing osteological material for any Procellariiformes are scarce. Our study aimed a) to present morphometric differences for the complete skeleton of Black-browed and Atlantic Yellow-nosed Albatross and b) to establish a reliable method to differentiate the two species through postcranial skeletal measurements. Thus, we present the first comprehensive osteological morphometric analysis of the entire skeleton for Black-browed and Atlantic Yellow-nosed albatross using a large sample size. In addition, we present a comparative analysis of the morphometry of both species.

METHODS

Specimens

We evaluated 151 specimens, of which there were 96 Black-browed Albatross and 55 Yellow-nosed Albatross, and visited three ornithological collections from Rio Grande do Sul State (southern Brazil): Fundação Zoobotânica do Rio Grande do Sul (FZBRS), Museu de Ciências Naturais (MUCIN) from Universidade Federal do Rio Grande do Sul (UFRGS), and Museu de Ciências e Tecnologia at Pontifícia Universidade Católica do Rio Grande do Sul (MCT-PUCRS) (Appendix 1, available on the website). The examined material was contained in 83 complete skeletons, 35 incomplete skeletons, 21 complete skulls, and 11 incomplete skulls (e.g., skulls lacking pterygoids or lachrymals but not influencing measurements). With each specimen, the museums provided a label that identified the species, and we confirmed these via cranial morphology (based on Dénes & Silveira (2007)) before proceeding with the analyses. Morphological nomenclature follows Baumel & Witmer (1993), but the measurement names proposed by the authors that established them were maintained.

Measurements

Fifty-nine measurements were based on Spring (1971), Livezey & Humphrey (1984), and Livezey (1989) (Table 1). We added five new measurements specifically for this work: internarial width, interorbital width, keel length, maximum sternal length, and nasal gland fossa width (Fig. 1). All measurements were taken by Alice Pereira with an electronic caliper (Starrett EC799A-12/300 model with 0–300 mm range and 0.01 mm accuracy), to avoid technical and inter-observer error and to maintain reliability.

Statistical analysis

We tested the normality of each measurement using the Shapiro-Wilk *W*-test and compared the data between Black-browed and Atlantic Yellow-nosed albatross using the two-tailed student's *t*-test. We defined a significance level of $P \leq 0.05$ for all statistical analyses. Some skeletons were incomplete; for these, we computed the missing data using single imputation by regression. This means that all available measurements of both incomplete and complete skeletons were used to predict the missing variables. The regression-imputation method predicts incomplete variables using regression equations that are calculated from the complete data set (Enders 2010). We undertook principal component analysis (PCA) to determine which group of measurements contributed the most to explain the data variance. PCA summarizes a large data set that is described by many variables into a smaller one that is described by a few variables but still contains most of the information in the larger data set. The variables in this smaller data set are a linear combination of the original variables and are thus classified as "principal components". For PCA, we excluded three measurements ($n = 61$) because they were sums of other measurements: wing total length (WTL), total leg length (TLL), and middle toe length (MTL).

To distinguish the albatross species, we carried out discriminant function analysis (DFA), which applies mathematical functions through combinations of predictors that can classify observed data within a population with known parameters. The analysis generates classification functions for each group that, when applied as an equation, can predict the group to which a variable belongs. The highest value resulted after calculating the equation for both groups, using their specific classification functions to acknowledge the predicted species. We ran the DFA for the measurements from the first principal component established in the PCA, because it was the strongest contributor to the data variance. Additionally, observations on carcasses during beach surveys led us to choose six specific measurements from the postcranium to apply in the DFA: total sternal length (TSL), maximum diagonal dimension of sternum (MDS), least sternal width (LSW), anterior sternal width (ASW), humerus length (HL), and ulna length (UL). To test the power of the DFA, we used a leave-one-out cross-validation technique for 10 000 rounds. This method consists of resampling the entire data set, removing one sample (i.e., a specimen) in each turn. The six-measurement discriminant analysis generated one constant for each species and six classification coefficients (one for each of the six measurements). To determine whether an evaluated specimen was Black-browed Albatross or Atlantic Yellow-nosed Albatross, we used these constants and coefficients, along with the original morphometric data, to calculate a classification score:

$$\text{Classification score} = \text{constant} + c_1(\text{TSL}) + c_2(\text{MDS}) + c_3(\text{LSW}) + c_4(\text{ASW}) + c_5(\text{HL}) + c_6(\text{UL}),$$

where c_1, c_2, etc. are the classification coefficients for each measurement. Each specimen was assigned to the species that retrieved the highest classification score. We reclassified the results by applying the derived discriminant functions for the entire data set to test its discriminatory power. We carried out normality tests and DFA in SPSS 18.0 (Carver & Nash 2011). For *t*-tests, we used R 3.4.0 (R Core Team 2017). All applied tests were part of software's basic version; it was not necessary to install exclusive packages for the applied tests in this paper.

RESULTS

Sixty-one means (93.85 %) of Black-browed Albatross measurements were significantly larger than Atlantic Yellow-nosed Albatross means (Appendix 2, available on the website). In only one mean, the interorbital width, Atlantic Yellow-nosed Albatross was significantly larger than Black-browed Albatross. Three means were not statistically significant: dorsal width of upper mandible's base, manubrium length, and sternal length posterior to keel.

PCA results showed that total variance is explained by seven principal components and that the first component can predict 58.88 % of the information in all 64 measurements (Table 2). The loadings of the first principal component (Table 3) classify ulna length as a good predictor to summarize morphometric differences in the data set.

The DFA that was derived from the first component of the PCA ($n = 22$ measurements) correctly identified 149 of 151 specimens (98.68 %). The two incorrectly identified specimens were two

TABLE 1
Measurements applied in the present study for morphometric analysis of Black-browed Albatross and Atlantic Yellow-nosed Albatross

	Measurement	Description	Reference
1	Total skull length (TSKL)	From the tip of premaxilla to proeminentia cerebelaris at occipital region.	Spring 1971
2	Cranial length (CL)	From the anterior end of nasal bone, at zona flexoria craniofacialis, to proeminentia cerebelaris at occipital region.	Spring 1971
3	Upper mandible length (UML)	Total skull length minus cranial length.	Spring 1971
4	Minimum width of the cranium (MWC)	Measured at parietal region, right after processus postorbitalis and anterior to os squamosale.	Spring 1971
5	Maximum width of cranium (MXWC)	Measured at processus postorbitalis.	Spring 1971
6	Cranial height (CH)	Maximum vertical distance in median sagittal plane, measured from basal tubercles at os basioccipitale to the top of cranial vault at the region of eminentia.	Spring 1971
7	Ventral width of upper mandible's base (VWUMB)	From the lateral mandible at the point of encounter of nasal process and posterior process of premaxilla to the opposite side in its maximum distance.	Spring 1971
8	Height of upper mandible's base (HUMB)	Vertical distance from the apex of upper mandible, at an eminentia where posterior end of the ramphoteca lies, to the point directly ventral.	Spring 1971
9	Dorsal width of upper mandible's base (DWUMB)	Maximum width of plate directly dorsal to external nares.	Spring 1971
10	Antorbital width (AW)	Maximum distance across the lacrimal bones' insertion region.	Livezey & Humphrey 1984
11	Postorbital width (PW)	Measured across the squamosal region at its maximum distance.	Livezey & Humphrey 1984
12	Frontonasal width (FMW)	Measured at zona flexoria craniofacialis region from the edge where lacrimals are articulated to the opposite side.	Livezey & Humphrey 1984
13	Interorbital width (IOW)	Measurement of the distance between the orbits on dorsal face of the skull at its midpoint.	This study
14	Nasal gland fossa width (NGFW)	Maximum width of salt gland concavity.	This study
15	Bill width (BW)	Measured along the plane of the eminentia where posterior end of the ramphotheca lies at the upper mandible, from the lateral part of the mandible and encompassing the jugal bar to the opposite side.	Livezey & Humphrey 1984
16	Bill height (BH)	With the lower mandible positioned, from eminentia where posterior end of the ramphotheca lies at the upper mandible to the ventral opposite site on lower mandible.	Livezey & Humphrey 1984
17	Internarial width (INW)	Maximum horizontal width of the inner portion of nasal aperture.	This study
18	Total sternal length (TSL)	From the anterior extremity of the manubrium to posterior medial extremity of the sternum.	Spring 1971
19	Maximum diagonal dimension of sternum (MDS)	Anterior extremity of the manubrium to posterior end of trabecula lateralis, measure taken diagonally.	This study
20	Sternal length less manubrium (SLLM)	From the horizontal plane of dorsal lip of coracoid sulcus in sternum medial point to posterior, medial extremity of the sternum.	Spring 1971
21	Manubrium length (ML)	Total sternal length minus sternal length less manubrium.	Spring 1971
22	Sternal length posterior to keel (SLPK)	From the posterior end of the keel where it fuses to sternum to the end of the posterior, medial extremity of the sternum (it does not necessarily consider curvature).	Spring 1971
23	Anterior sternal width (ASW)	From the external edge of processus lateralis to the opposite side at its maximum distance.	Spring 1971
24	Posterior sternal width (PSW)	From the external, medial point of trabecula lateralis to the opposite side at its maximum distance.	Spring 1971
25	Anterior sternal height (ASH)	At the medial plane, from the highest projection of keel to the ventral face of manubrium that is directly ventral.	Spring 1971
26	Least sternal width (LSW)	From the margin of incisura lateralis – recess located between the posterior end of margo costalis (at ribs insertion) and the anterior end of trabecula lateralis, to the opposite side.	Livezey & Humphrey 1984
27	Keel length (KL)	Anterior border of the keel where it is inserted in sternum to the posterior end where it disappears in sternum not considering curvature.	This study
28	Anterior height of keel (AHK)	Measured along line perpendicular to keel, from anterior dorsal edge of keel to intersection with ventral border of keel.	Spring 1971
29	Coracoid length (COL)	From the top of coracoid at processus acrocoracoideus to its base at facies articularis sternalis in a medial plane at its maximum distance.	Spring 1971
30	Width of coracoid base (WCOB)	From one side to the other along the facies articularis sternalis.	Spring 1971
31	Furcula height (FH)	From apophysis furculae to its posterior end at processus acromialis.	Spring 1971
32	Furcula width (FW)	From lateral extent of coracoidal facet on one side to the corresponding point on the other side.	Spring 1971

Table 1 continued on next page

Table 1 continued from previous page

	Measurement	Description	Reference
33	Scapula length (SL)	From acromion process to its caudal extremity, at its maximum distance.	Spring 1971
34	Humerus length (HL)	From humerus head to its distal extremity, at its maximum distance.	Spring 1971
35	Dorsoventral width of humerus (DVWH)	At its midpoint.	Livezey 1989
36	Anteroposterior width of humerus (APWH)	At its midpoint.	Livezey 1989
37	Radius length (RL)	From radius head to its distal extremity, at its maximum distance.	Spring 1971
38	Ulna length (UL)	From ulna head to its distal extremity, at its maximum distance.	Spring 1971
39	Carpometacarpus length (CML)	From trochlea carpalis to its distal extremity, at its maximum distance.	Spring 1971
40	Anteroposterior width of metacarpal II of carpometacarpus (APWC)	At its midpoint.	Livezey 1989
41	Dorsoventral width of metacarpal II of carpometacarpus (DVWC)	At its midpoint.	Livezey 1989
42	Pollex length (POL)	From proximal to distal end at its maximum distance.	Spring 1971
43	Proximal phalanx length of major digit (PPL)	From proximal to distal end at its maximum distance.	Spring 1971
44	Distal phalanx length of major digit (DPL)	From proximal to distal end at its maximum distance.	Spring 1971
45	Wing total length (WTL)	Sum of measurements of humerus length, ulna length, carpometacarpus length, proximal phalanx length of major digit, and distal phalanx length of major digit.	Spring 1971
46	Anterior pelvic width (APW)	Maximum distance between anterior iliac plates (ala preacetabularis illi).	Spring 1971
47	Medial pelvic width (MPW)	(=acetabular width) lateral extent of antitrochanter on one side to corresponding point on opposite side.	Spring 1971
48	Posterior pelvic width (PPW)	Maximum width from caudal extremity of posterior iliac plates (ala postacetabularis illi) to the opposite side.	Spring 1971
49	Synsacrum total length (STL)	From the rostral margin of ala preacetabularis illi to the caudal extremity of ala postacetabularis illi.	Livezey 1989
50	Anterior synsacrum length (ASYL)	From the rostral margin of ala preacetabularis illi to the anterior margin of foramen acetabuli.	Spring 1971
51	Posterior synsacrum length (PSL)	From the posterior margin of foramen acetabuli to the caudal extremity of ala postacetabularis illi.	Spring 1971
52	Femur length (FL)	From the top of crista trochanteris to its distal extremity, at its maximum distance.	Spring 1971
53	Femur anteroposterior width (APWF)	At its midpoint.	Livezey 1989
54	Femur lateromedial width (LMWF)	At its midpoint.	Livezey 1989
55	Tibiotarsus length plus cnemial crest (TLPC)	From the top of crista cnemialis to its distal extremity, at its maximum distance.	Spring 1971
56	Tibiotarsus length less cnemial crest (TLLC)	From proximal articular surface (facies articularis medialis) to its distal extremity, at its maximum distance.	Spring 1971
57	Tarsometatarsus length (TML)	From the top of eminentia intercotylaris to its distal extremity, at its maximum distance.	Spring 1971
58	Anteroposterior width of tarsometatarsus (APWT)	At its midpoint.	Livezey 1989
59	Lateromedial width of tarsometatarsus (LMWT)	At its midpoint.	Livezey 1989
60	Total leg length (TLL)	Sum of measurements of femur length, tibiotarsus length less cnemial crest, and tarsometatarsus length.	Spring 1971
61	Proximal phalanx length of middle toe (PPLM)	From proximal to distal end at its maximum distance.	Livezey 1989
62	Medial phalanx length of middle toe (MPLM)	From proximal to distal end at its maximum distance.	Livezey 1989
63	Distal phalanx length of middle toe (DPLM)	From proximal to distal end at its maximum distance.	Livezey 1989
64	Middle toe length (MTL)	Sum of measurements of middle toe phalanx lengths.	Livezey 1989

Atlantic Yellow-nosed Albatross (MUCIN 832 and MUCIN 833) that were assigned as Black-browed Albatross. These two specimens exhibited all the morphological characters attributed to Atlantic Yellow-nosed Albatross (Dénes & Silveira 2007) but were visibly large for the species. The DFA of the selected measurements (n = 6 measurements) exhibited the same results (98.68 %).

A cross-validation test using only the PCA measurements correctly identified 141 of 151 specimens (93.40 %) (Table 4). A DFA that accounted for our six additional measurements (Table 5) predicted 96.00 % of specimens correctly (145 of 151) after the cross-validation test. When we reclassified the data set using the classification-function coefficients that were calculated from the

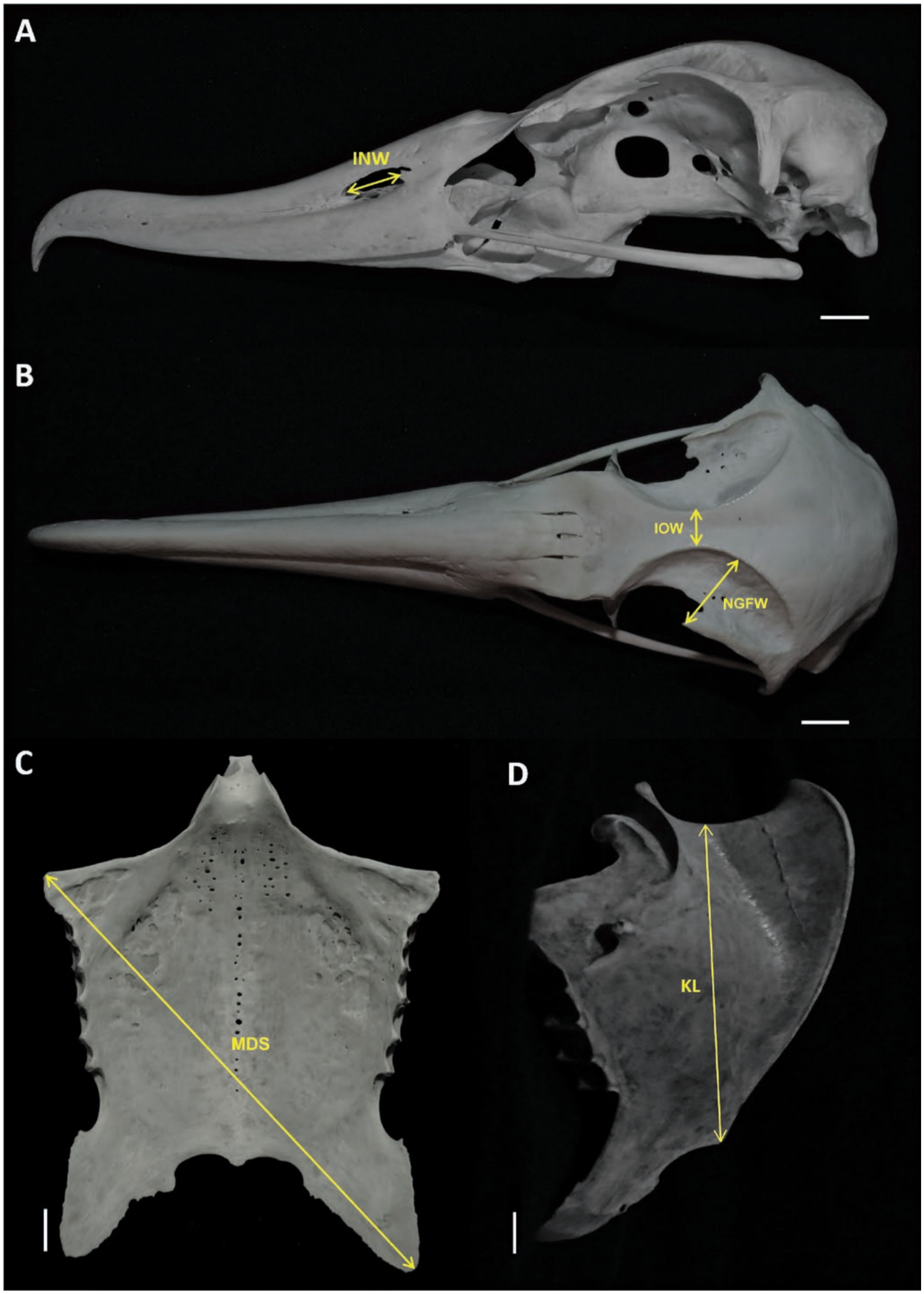

Fig. 1. Five measurements established for this work: (A) INW = internarial width; (B) IOW = Interorbital width, NGFW = nasal gland fossa width; (C) MDS = maximum diagonal dimension of sternum; (D) KL = keel length. White bar = 1 cm.

TABLE 2
Total variance explained by principal component analysis (PCA)

Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings				Initial Eigenvalues		
Total	% of Variance	% Cumulative	Total	% of Variance	% Cumulative	Component	Total	% of Variance	% Cumulative
35.919	58.884	58.884	14.280	23.410	23.410	1	35.919	58.884	58.884
3.535	5.795	64.679	10.968	17.981	41.390	2	3.535	5.795	64.679
2.258	3.702	68.381	8.348	13.685	55.075	3	2.258	3.702	68.381
1.929	3.161	71.543	7.713	12.644	67.719	4	1.929	3.161	71.543
1.343	2.201	73.744	2.588	4.243	71.962	5	1.343	2.201	73.744
1.239	2.030	75.774	2.118	3.472	75.434	6	1.239	2.030	75.774
1.091	1.788	77.563	1.299	2.129	77.563	7	1.091	1.788	77.563
						8	.954	1.564	79.127
						9	.852	1.397	80.523
						10	.796	1.304	81.828
						11	.688	1.128	82.956
						12	.673	1.104	84.060
						13	.646	1.060	85.119
						14	.616	1.010	86.129
						15	.575	.942	87.071
						16	.545	.894	87.966
						17	.504	.827	88.792
						18	.437	.716	89.509
						19	.433	.710	90.218
						20	.398	.652	90.871
						21	.373	.611	91.481
						22	.352	.577	92.058
						23	.346	.567	92.625
						24	.322	.528	93.153
						25	.315	.516	93.669
						26	.285	.467	94.135
						27	.282	.463	94.598
						28	.265	.434	95.033
						29	.227	.372	95.405
						30	.216	.354	95.759
						31	.205	.336	96.095
						32	.193	.317	96.411
						33	.186	.305	96.716
						34	.183	.300	97.016
						35	.173	.283	97.299
						36	.167	.273	97.572
						37	.153	.250	97.822
						38	.146	.239	98.061
						39	.127	.209	98.270
						40	.117	.192	98.463
						41	.111	.181	98.644
						42	.098	.161	98.805
						43	.092	.151	98.956
						44	.091	.149	99.105
						45	.075	.123	99.228
						46	.065	.107	99.335
						47	.057	.093	99.429

Table 2 continued on next page

Table 2 continued from previous page

Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings				Initial Eigenvalues		
Total	% of Variance	% Cumulative	Total	% of Variance	% Cumulative	Component	Total	% of Variance	% Cumulative
						48	.055	.090	99.519
						49	.047	.077	99.596
						50	.044	.072	99.668
						51	.040	.065	99.734
						52	.037	.061	99.795
						53	.035	.057	99.852
						54	.030	.049	99.901
						55	.024	.040	99.941
						56	.017	.028	99.968
						57	.009	.015	99.983
						58	.007	.012	99.995
						59	.003	.005	100.000
						60	.000	.000	100.000
						61	.000	.000	100.000

TABLE 3
Loadings of principal component 1 (PC1) extracted from the original rotated component-matrix[a]

Measurement	PC 1
UL	.826
RL	.825
HL	.775
TLLC	.775
CML	.774
TML	.774
TLPC	.758
POL	.745
PPLM	.730
PPL	.708
MPLM	.700
FL	.629
DPLM	.617
DPL	.601
STL	.558
SL	.545
PSL	.544
ASH	.539
COL	.533
SLLM	.526
KL	.516
ASYL	.514

[a] Rotation method: Varimax with Kayser normalization, rotation converged in 10 iterations.

TABLE 4
Classification results of the cross-validation test for the 22 measurements from the first component of PCA results applied in DFA analysis. Group labels: 1 = Black-browed Albatross, 2 = Atlantic Yellow-nosed Albatross

		Species	Predicted Group Membership 1	Predicted Group Membership 2	Total
Cross-validated[a]	*n*	1	90	6	96
		2	4	51	55
	%	1	93.8	6.3	100.0
		2	7.3	92.7	100.0

[a] 93.40 % of grouped cases with cross-validation classified correctly.

TABLE 5
Classification results of the cross-validation test for the DFA incorporating the six selected measurements. Group labels: 1 = Black-browed Albatross, 2 = Atlantic Yellow-nosed Albatross

		Species	Predicted Group Membership 1	Predicted Group Membership 2	Total
Cross-validated[a]	*n*	1	94	2	96
		2	4	51	55
	%	1	97.9	2.1	100.0
		2	7.3	92.7	100.0

[a] 96.00 % of grouped cases with cross-validation classified correctly.

six-measurement discriminant function (Table 6), the species was correctly identified in 97.35 % (147 of 151) of specimens (Table 7). However, when we reclassified the data set by applying the coefficients of PCA, 22 measurements correctly identified 78.81 % (119 of 151) specimens. As in PCA, ulna length was the most important measurement for the DFA.

DISCUSSION

Morphometric examination of live animals and/or skin specimens among Procellariiformes is the most common approach to assess differences between species (Waugh *et al.* 1999, Bugoni & Furness 2009, Judge *et al.* 2014), but studies on osteological morphometrics, especially concerning the postcranium, are uncommon (Forbes 1882, Porcasi 1999, Olson 2008, Mayr & Smith 2012). Osteological morphometry offers several potential advantageous applications, such as identifying museum skeletons and beached carcasses, sex differentiation, etc. Correctly identifying museum material is crucial for carrying out population studies through museum specimens (Burgman *et al.* 1995), studies on systematics (Olson 2003), and inventories (Cooper & Steinheimer 2003). Among other groups of birds, there are works that deal with skeletons for discussing phylogeny, adaptations, and the fossil record, but these studies are also few and do not focus on postcranial bones (Spring 1971, Livezey 1989, Holdaway & Worthy 1993). Conversely, for paleontological approaches, the postcranium is important for distinguishing among species or between sexes; sometimes it is the only part available (Dodson 1975, Dawnson 1994, Chinnery 2004). In this case, identification does not depend solely on skull features or morphometry that may not be available.

When the postcranium was the only part of the skeleton available, size was the most important parameter to differentiate one albatross species from the other. There are cranial features that distinguish Black-browed and Atlantic Yellow-nosed albatross (Dénes & Silveira 2007), but we could not find any difference in the shape of the postcranial bones. However, it is not simple for a person to observe these features for the first time or under field conditions. Therefore, in this case, the cranial morphometry is as important as the postcranial morphometry.

Alternative methods to identify albatrosses, such as those proposed in this study, help improve the accuracy of data presented on beach survey accounts. Brazil has a growing program of beach surveys (e.g., Projeto de Monitoramento de Praias da Bacia de Santos – PMP-BS). This project, which is funded by Petrobras, monitors approximately 1 041 km of coastline between Ubatuba, São Paulo State (23°S) and Laguna, Santa Catarina State (28°S). The 2016/17 PMP-BS annual report recorded 7 595 beached birds of 53 species. This number is almost 1 000 specimens more than the number of beached turtles and almost 6 000 more than the number of beached marine mammals (Petrobras 2018).

DFA was also used to identify living White-capped *T. cauta steadi* and Shy *T. cauta cauta* albatross (Double *et al.* 2003), as well as Wandering *Diomedea exulans* and Tristan *D. dabbenena* albatross (Cuthbert *et al.* 2003). The former study reported correct identification of species 89 % of the time, and the latter reported correct identification 98 % of the time. The present study showed 98.7 % precision for the six postcranial measurements and 97.35 % after reclassification. Morphometric skeletal analysis should be performed for White-capped, Shy, and Grey-headed *T. chrysostoma* albatross, as these three congeners occur in the same areas as Black-browed and Atlantic Yellow-nosed albatross. In fact, osteological morphometric analysis for all species of the genus *Thalassarche* is required, as all five species occur in southern Brazil, Uruguay, and Argentina (Costa *et al.* 2011, Seco Pon & Tamini 2013, Jiménez *et al.* 2015). However, the osteological material from albatrosses is scarce in scientific collections, especially for White-capped, Shy, and Grey-headed Albatross.

Sexual size dimorphism (SSD) is present in *Thalassarche* species; males are larger than females (Double *et al.* 2003, Phillips *et al.* 2004). SSD has important effects in discriminant analysis and can explain the variance in a data set (Dechaume-Moncharmont *et al.* 2011). It is reasonable that our results are influenced by SSD, and the overlapping region of our measurements means can be explained by similarities in size of Black-browed Albatross females and Atlantic Yellow-nosed males. Further studies involving specimens of known gender information are needed to confirm this.

This work presents the first osteological morphometric analysis of the complete skeleton for Black-browed and Atlantic Yellow-nosed albatross and the first such analysis for most species in the family Diomedeidae. The results presented here provide a way to identify Black-browed and Atlantic Yellow-nosed specimens from any osteological portion of the entire skeleton. To discriminate species, we suggest starting with measurements with high PCA loadings (Table 3), mainly ulna length. If any measurements are in the overlap region (Appendix 2), the next step is to apply the discriminant function (Table 6). However, if the skeleton does not have any of the bones involved in PCA loadings or in the discriminant function, a researcher can try measuring any of the other 64 measurements.

TABLE 6
Classification functions for species identification

Osteological Measures	Classification Coefficients: Black-browed Albatross	Classification Coefficients: Atlantic Yellow-nosed Albatross
TSL	1.928	0.634
MDS	0.685	0.806
LSW	−0.981	−1.182
ASW	0.883	1.089
HL	0.288	0.238
UL	4.586	4.693
(Constant)	−784.362	−702.322

TABLE 7
Reclassification of the data set (n = 151) applying the six-measurement discriminant function, where 97.35 % of specimens were classified correctly

Actual Group Membership	Predicted Group Membership: Black-browed Albatross	Predicted Group Membership: Atlantic Yellow-nosed Albatross
Black-browed Albatross	96	0
Atlantic Yellow-nosed Albatross	4	51

Even though there is an overlap in measurements between the two species, multiple measurement options and the discriminant function can offer some result out of the overlap region.

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