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SHORT NOTE

Comparison of the skull of Brown Skua (*Catharacta antarctica lonnbergi*) and South Polar Skua (*Catharacta maccormicki*): differentiation source identification and discriminant analysis

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Abstract

Many contributions try to emphasize the similarities and differences between the Brown Skua *Catharacta antarctica lonnbergi*¸ and the South Polar Skua *Catharacta maccormicki*. Most of the morphological information of these species is based on field observation and referred to their external appearance. Few studies deal with their morphometry, mostly using characters measured in live birds, but the information about skeletal features is scarce. In the present study, skull differences between the Brown Skua and the South Polar Skua are quantified through independent quantitative analyses. Shape differences were evaluated in a geometric morphometrics test, while linear metric parameters were used to analyze the differences between species in a principal component analysis, and finally, in a discriminant test. Geometric morphometrics analysis cannot separate groups, whereas linear morphometrics divide well two different groups, showing significant differences. Notwithstanding, the most significant result was obtained using the discriminant analysis, which differentiates the species using simple equations which contain combined measures that can be easily obtained.

Keywords *Catharacta antarctica* · *Catharacta maccormicki* · Antarctica · Geometric morphometry · Discriminant analysis

Introduction

The Brown Skua *Catharacta antarctica lonnbergi* and the South Polar Skua *Catharacta maccormicki* breed sympatrically in the South Shetland Islands and Antarctic Peninsula (Ritz et al. 2008). Many contributions focus on the controversy about the slight morphological differences between them (e.g. Devillers 1978; Furness 1987; Reinhardt et al. 1997; Montalti 2005; Hahn et al. 2007; Montalti et al. 2009; Graña Grilli et al. 2011; Graña Grilli and Montalti 2012).

Most morphological information about these species refers to qualitative features taken during field observation. Few studies deal with skeletal morphometric characters. Although thorough osteological descriptions of both taxa and preliminary statistical analyses were carried out by Acosta Hospitaleche et al. (2009), the qualitative information provided by these is different from that which linear morphometrics provide. Therefore, this contribution is focused on comparing linear morphometrics analyses using the skull and mandible. Besides searching for morphometric differences between both species, the purpose of this paper is to propose the key factor in the differentiation through an equation. The sample used by Acosta Hospitaleche et al.

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(2009) has been updated in the present contribution, mainly due to additional information obtained about the weight of the specimens, selecting full-grown reproductive adults from both sexes. Regarding this, the sample has been reduced in size, but improved in terms of quality and fidelity of the information. In addition, new characters were selected for the geometric morphometrics analyses.

Materials and methods

Sample of 26 skulls (*C. antarctica lonnbergi* $n = 14$ and *C. maccormicki* $n = 12$) is in the osteological section (Ornithology) of the Instituto Antártico Argentino (IAA) (Online Resource 1). Materials come from Potter Peninsula (62° 15′ 0″ S, 58° 40′ 0″ W), King George Island, South Shetland Islands and Hope Bay (63° 23′ 60″ S, 57° 0′ 0″ W). The sample number is limited to complete and full-grown adults and identified specimens. We did not analyze sexual dimorphism variation, because the sample size was so small.

Skull differences between both species were quantified through different independent analyses. The first analysis (geometric morphometrics; GMA) focused on shape (Mitteroecker and Gunz 2009). In addition, a principal component analysis (PCA) based on linear measurements was performed (Rohlf 1996). Cranial differences between the species were also tested univariately with t-tests (Zar 1974). Finally, a discriminant analysis was performed (Sokal and Rohlf 1995) choosing variables with the best discriminant power and easier to measure. Wilks Lambda, P, and F values were added in ESM 8, and osteological terminology follows Baumel and Witmer (1993).

Geometric morphometrics analysis (GMA)

Each skull was photographed in dorsal and ventral (palatal) view keeping the same focal distance to prevent measurement errors. Mandibles were also photographed with the same method. Landmarks for the skull and mandible are based on previous works (Acosta Hospitaleche et al. 2009) and we added twelve additional landmarks: two in dorsal view (total: 12 landmarks, Online Resource 2), three in palatal view (total: 10 landmarks, Online Resource 3), and seven in mandibles (Online Resource 4). These landmarks were selected to provide information about form and location of cranial and mandibular structures. TpsDig (Rohlf 2005) software was used for the landmark digitalization and Procrustean reorientation, and tpsRelw for relative warp analysis (Rohlf 2005) including the uniform component (Bookstein 1996). Results of GMA are given in Online Resource 2 (analysis made on dorsal view of the skull), Online Resource 3 (palatal view), and Online Resource 4 (mandible). Axes of each graph are the two first principal components. The consensus configuration, the dispersal of dots, and the corresponding vectors are given together with each biplot.

Principal component analysis (PCA)

We measured twelve continuous variables on skulls and mandibles (Fig. 1) with a digital caliper of 0.01 increments, and are expressed in millimeters: total length of the skull (TL), total width of the skull (TW), bill length (BL), bill length from the nasal bones to the tip (BK), bill width at the *sulcus nasale olfactorius* (BW), length of the *fossa glandulae nasalis* (FL), width of the *fossa glandulae nasalis* (FW), length of the *lamina parasfenoidalis* (PL), width of the *lamina para sphenoidalis* (PW), width at the base of the skull (SB), total length of the mandible (ML), and the width of the articular end of the *ramus mandibulae* (MW). PCA was conducted on standardized data. The corresponding eigenvalues and eigenvectors were calculated. The obtained Jolliffe cut-off value (Jolliffe 1986) and complementarily the broken stick model were used for the recognition of the significant principal components.

Discriminant analysis

Based on the same continuous variables, two datasets corresponding to both species were constructed. The variance homogeneity was analyzed by Cochran, Hartley, Bartlett, and Levene tests. Additional Kolmogorov–Smirnov and

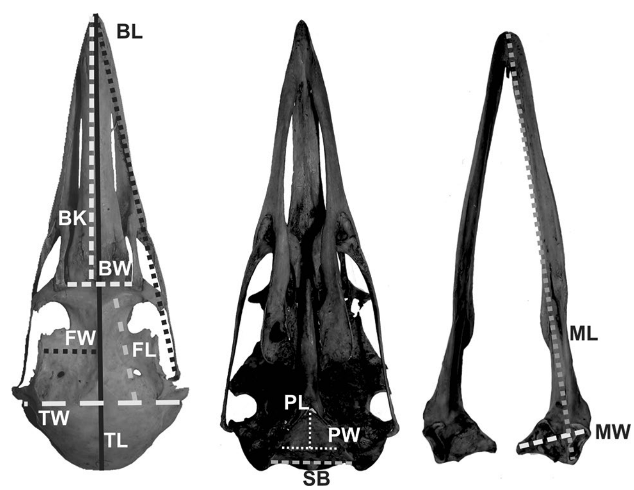

Fig. 1 Continuous variables measured used in the linear morphometrics analysis: total length of the skull (TL), total width of the skull (TW), bill length (BL), bill length from the nasal bones to the bbtip (BK), bill width at the *sulcus nasale olfactorius* (BW), length of the *fossa glandulae nasalis* (FL), width of the *gossa glandulae nasalis* (FW), length of the *lamina parasfenoidalis* (PL), width of the *lamina parasfenoidalis* (PW), width at the base of the skull (SB), total length of the mandible (ML), and the width of the articular end of the *ramus mandibulae* (MW)

Lilliefors tests were also performed. Data showed the necessary uniformity by fulfilling the conditioning assumptions.

Differences between species

Based on discriminant analysis, the two most powerful characters were selected to calculate the discriminant equation for each case. Two equations were calculated: one for the skull, using BK—BW and one for the mandible, using ML—MW.

Results

Geometric morphometrics (GMA)

In dorsal view of the skull, the separation between species is almost complete along the first axis, which explains 24.9% of the variance, although the second axis is needed for a more effective ordination of the two groups. That way, the 45.6% of the accumulative variance is explained.

Deformation grids are given in the two extremes of each axis, in order to have a more accurate idea of the variation (Online Resource 2). Specimens belonging to *C. maccormicki* are located in the top left quadrant, except for IAA1544 and IAA1491 (Online Resource 2). According to the morphospace where the specimens are located, *C. maccormicki* can be described through the landmark configurations corresponding to the upper and the left ends (Online Resource 2). Compared to the consensus configuration, landmarks C and E are caudally displaced, landmark B is asunder from E. Besides, landmark J is a bit displaced from the sagittal line of the skull, which resembles a wider skull. In addition, landmark I is more caudally displaced, which means the skull is longer that the consensus configuration.

The other taxon, *C. a. lonnbergi* is represented by the black stars, gathered in the right and lower quadrants of the biplot (Online Resource 2). These quadrants show that landmarks B and D are closer each other respect to the consensus configuration. Landmarks G and H are more separated from the midline of the skull and from landmark I.

In palatal view the ordination is not completely effective (Online Resource 3) due to specimens belonging to both species overlapping near the center of the graph. Most specimens of *C. maccormicki* lie along the first component which explains 36.1% of the variance, occupying the negative values of second axis with the single exception of specimen 1288 (Online Resource 3). Besides, few skulls belonging to *C. a. lonnbergi* are located among the specimens of *C. maccormicki*. Nevertheless, most specimens of *C. a. lonnbergi* are on the highest value of the second component, which accumulates 56.2% of the

Table 1 Cranial measures taken in skulls of South Polar *Catharacta maccormicki* (SP) and of Brown skuas *Catharacta antarctica lonnbergi* (BS)

Species	TL	TW	BL	BK	BW	FL	FW	PL	PW	SB	ML	MW
SP												
Mean	101.75	37.49	87.40	56.91	13.35	22.09	11.24	13.88	16.03	18.14	85.24	15.03
S.D.	2.42	3.56	3.96	3.17	0.71	0.93	2.32	1.30	1.24	0.75	1.98	1.13
N	8	10	11	11	11	10	11	10	10	10	10	10
Min	98.70	28.25	83.95	50.25	12.40	20.00	9.60	10.43	13.50	17.25	82.40	12.75
Max	105.00	41.00	97.40	60.70	14.70	23.35	16.40	15.00	18.40	19.20	87.55	16.35
BS												
Mean	114.26	42.64	97.3	65.56	16.60	25.21	11.64	16.58	18.14	20.73	96.44	18.04
S.D.	2.945	6.806	2.304	2.94	2.62	1.28	1.04	1.13	0.88	1.14	1.81	2.67
N	10	13	12	12	13	12	13	13	13	13	13	14
Min	110	21.10	92.55	61.60	14.40	23.45	9.80	14.45	16.50	17.80	93.70	16.45
Max	119.05	51.10	100.50	73.00	24.15	27.65	13.45	19.30	19.55	22.65	99.80	27.10
p	3.27×10^{-8}	3.0×10^{-2}	2.19×10^{-6}	1.29×10^{-6}	7.5×10^{-4}	2.30×10^{-6}	6.08×10^{-1}	$5.99\ 10^{-5}$	4.0×10^{-4}	2.14×10^{-6}	3.20×10^{-11}	1.4×10^{-3}

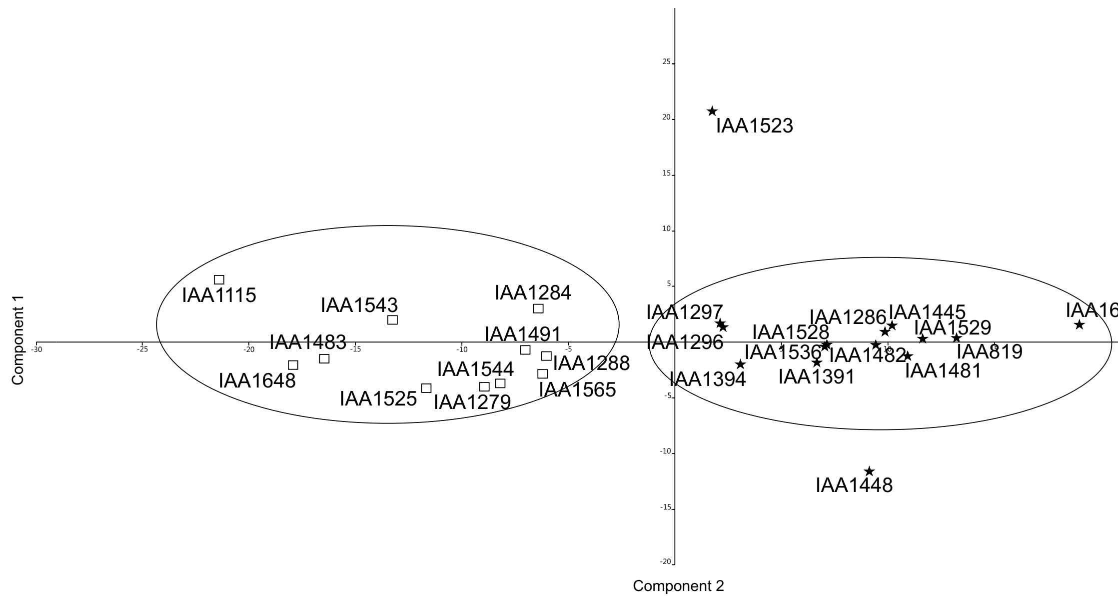

Fig. 2 Biplot with the results of the Principal Component Analysis given along the first two axes. Specimens belonging to *Catharacta maccormicki* are represented by white squares, whereas *Catharacta antarctica lonnbergi* are the black stars

explained variance. Characterization of this species can be made through the deformations grids located along the abovementioned axis.

Comparing *C. maccormicki* to the consensus configuration, the following pairs of landmarks are more separated from each other: A—B, E—I, and B—H. On the contrary, landmarks D and E are closer than on they are on the consensus configuration and the configuration for *C. a. lonnbergi*).

The configuration corresponding to *C. a. lonnbergi* shows landmarks D and E a little more separated, as well as landmarks G and H. Besides, landmarks H and J are more distant than those in the consensus configuration.

Configuration of the mandible does not permit the distinction of groups (Online Resource 4). Specimens from *C. maccormicki* and *C. a. lonnbergi* are dispersed and ungrouped.

Principal component analysis (PCA)

Significant differences were found in every measurement, except in the total width of the skull and width of the *sulcus glandulae nasalis* (Table 1). The results of a multivariate analysis based on a variance–covariance matrix show two clearly distinguished groups (Fig. 2). All the specimens of *C. maccormicki* are congregated into the negative values of the first component.

This axis, assisted mainly by the characters TL, BL, BK, and ML, explains almost the 70% of the variance. In the other half of the graphic, a second group constituted by *C. a. lonnbergi* occupies the positive values of the first component. The second axis explains more than 15% of the variance assisted by the variation of TW. Although axes 1 and 2 explain almost 83%, the second component seems not to play an important role in the separation of these two groups.

Discriminant analysis

The first set of measures includes BK and BW. The equation obtained was: $([BL \times (-0.31041)] + [BW \times (-0.28721)] + 23.29165)$ whose value was higher than 0.4431835 for *C. macormicki* and lower than − 0.53985 for *C. a. lonnbergi;* 100% of the cases were correctly identified.

The second set was constituted by ML and MW. The obtained equation was: $([(ML) \times (-0.52246)] + [(MW) \times (-0.11404)] + 49.7812)$. When the value is higher than 2.319679, the mandible should be assigned to *C. a. lonnbergi*, and when this value is lower than − 1.089174, it would belong to *C. a. lonnbergi*. The identification was correct in the 100% of the cases. Online Resource 5 shows the values of Wilks lambda (W), F y P for the obtained discriminant equations.

Discussion and conclusion

Skeletons are scarce in most of ornithological collections, consequently analysis of osteological structures are few even when they are fundamental for biomechanical and ecomorphological studies. Based on the results of Acosta

Hospitaleche et al. (2009), in which many skeletal elements were described and an exploratory morphometric analysis was performed, new specimens, elements, and landmarks were here analyzed. No significant differences were found in the shape of the mandible of both skuas, supporting previous results in skulls (Acosta Hospitaleche et al. 2009).

On the other hand, results of the PCA show significant differences between the skulls of both species. The measures that most contribute to this differentiation and explain the variation in these components are BL, ML, BK, TL, and TW. On the contrary, the characters which less contribute were MW, FL, FB, BW, PL, PW, and SW. These results are consistent with previous analysis in live birds and study skins (Peter et al. 1990; Montalti 2005).

Therefore, discriminant analysis resulted in equations with a high discriminant power. It means that all measures used in these equations differ significantly between *C. maccormicki* and *C. a. lonnbergi.* Particularly, BK and BW are the most useful measurements in this matter.

Skuas show sexual dimorphism, providing more intraspecific difference in size, overlapping ranges between small males of *C. a. lonnbergi* and large females of *C. maccormicki;* presence of hybrids is also highly probable although they were not included in this sample. Surprisingly males and females could not be clearly separated, maybe due to the low number of specimens.

Even when the analyzed sample is relatively small, results here discussed are relevant. The provided data are useful for the differentiation of the cranium and mandible of the South Polar Skua and the Brown Skua.

The present contribution brings new data explaining that differences are exclusively due to size. Although GMA showed homogeneity in shape between both species, analysis of linear metrical measurements indicated that Brown Skua is significantly larger than the South Polar Skua, even when form and proportions are invariable. As most of the variation is explained by the first two axes in the PCA, size should be considered as the most important character for the distinction of these taxa. A remarkable conclusion found in this study derived from the comparison of the results obtained from different statistical techniques; analysis of linear variables resulted more reliably in the differentiation of antarctic skuas than did GMA.

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