ORNITOLOGIA NEOTROPICAL 20: 19–26, 2009

VARIATION IN THE CRANIAL MORPHOMETRY OF THE MAGELLANIC PENGUIN (*SPHENISCUS MAGELLANICUS*)

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Resumen. – Variación en la morfometría craneal del pingüino de Magallanes (*Spheniscus magellanicus*). – Se analizaron las variaciones morfométricas en cráneos de *Spheniscus magellanicus*. Se seleccionaron trece landmarks en la porción posterior del cráneo a fines de evaluar las variaciones morfológicas en las crestas nucales, la fosa temporal, la region interorbitaria y el surco para la glándula de la sal. Adicionalmente, se analizaron cinco landmarks en el rostro. La morfometría geométrica permitió establecer qué caracteres son más confiables en las identificaciones sistemáticas. Los resultados mostraron una variación mínima en el desarrollo del surco para la glándula de la sal, mientras que la extensión de la fosa temporal resultó ser el carácter más variable.

Abstract. – Skull morphometric variation was analyzed in Magellanic Penguin (*Spheniscus magellanicus*). Thirteen landmarks were selected in the posterior region of the skull in order to evaluate the morphology variation exhibited in the nuchal crests, the temporal fossa, the interorbital region, and the sulcus glandulae nasale. Additionally, five landmarks were analyzed in the rostrum. Morphometric geometry allowed to establish which characters are more reliable for systematic identification. The results show a minimum variation in the development of the groove of the salt gland among the analyzed specimens of *Spheniscus magellanicus*, while the extension of the temporal fossa is the most variable character. *Accepted 7 January 2009.*

Key words: Magellanic Penguin, *Spheniscus magellanicus*, geometric morphometry, skull anatomy.

INTRODUCTION

The Magellanic penguin *Spheniscus magellanicus* (Forster, 1781) is a seabird that breeds in large colonies along the coasts of Argentina and Chile (Fig. 1). The breeding colonies in which these birds live are generally monospecific, although in some areas of the Pacific Coast the species occurs sympatrically with the Humboldt penguin *Spheniscus humboldti* (Meyen, 1834). Both species can interbreed and produce fertile hybrids with an intermediate external morphology, which is not surprising considering that the four living species of this genus, including *S. demersus* (Linnaeus, 1758) and *S. mendiculus* (Sundevall, 1871), are very closely related (Giannini & Bertelli 2004, Bertelli & Giannini 2005, Acosta Hospitaleche *et al.* 2007).

The Magellanic penguin is a medium-sized species, reaching 70–76 cm in height (Martínez 1992). Previous osteological studies of geographic variations have concluded that there are no significant metric differences between populations from different localities (Cejuela 1995, Acosta Hospitaleche 2004; Acosta Hospitaleche & Gasparini 2006).

The recent discovery of several fossil skulls in South American sediments has sparked a new interest in the assessment of

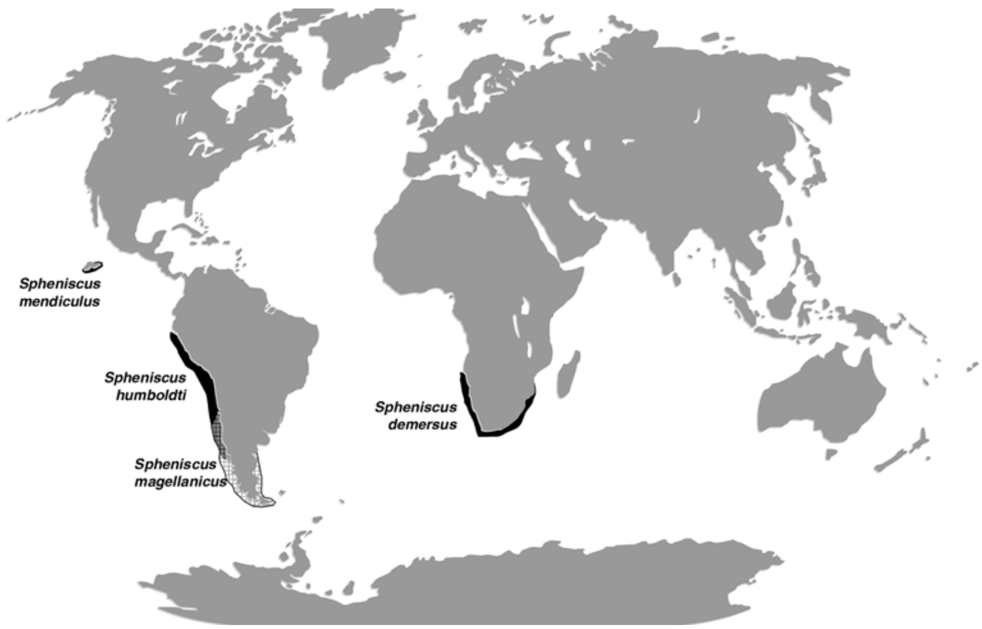

FIG. 1. Schematic map showing the breeding distribution of *Spheniscus magellanicus* and *S. humboldti*. On the Pacific coast of South America, *S. magellanicus* and *S. humboldti* occur in sympatry.

systematically relevant characters. This work is focused on the skull analysis, since this is the most frequently preserved area in fossil specimens. However, a separate analysis was performed in the rostrum, trying to locate the most variable areas. The goal of the present contribution is to evaluate the variation in the posterior region of the skull and the rostrum of *Spheniscus magellanicus*.

MATERIAL AND METHODS

Study material. Specimens examined are part of the collections of the Museo de La Plata (MLP), Argentina. All the material included in this analysis complies with the current laws of Argentina. Study skeletons were taken from individuals found already dead in breeding colonies of Peninsula Valdés (42º25'S, 64º31'W), Chubut Province, Argentina.

In order to eliminate variation related to age or preservation, only adult and complete skulls were considered in this analysis. Thirty-five skulls of *Spheniscus magellanicus* were photographed and included in the skull analysis: (MLP 1, MLP 2, MLP 35, MLP 473, MLP 597, MLP 614, MLP 643, MLP 717, MLP 718, MLP 722, MLP 723, MLP 727, MLP 772, MLP 789, MLP 791, MLP 842, MLP 846, MLP 847, MLP 848, MLP 849, MLP 850, MLP 851, MLP 852, MLP 853, MLP 854, MLP 855, MLP 856, MLP 857, MLP 858, MLP 859, MLP 860, MLP 861, MLP 862, MLP 863, MLP 873). Unfortunately, only 17 of them were complete and therefore could be included in the rostrum analysis (MLP 35, MLP 642, MLP 718, MLP 722, MLP 723 , MLP 727, MLP 756, MLP 772, MLP 789, MLP 791, MLP 846, MLP 847, MLP 848, MLP 849, MLP 855, MLP 864, MLP 873).

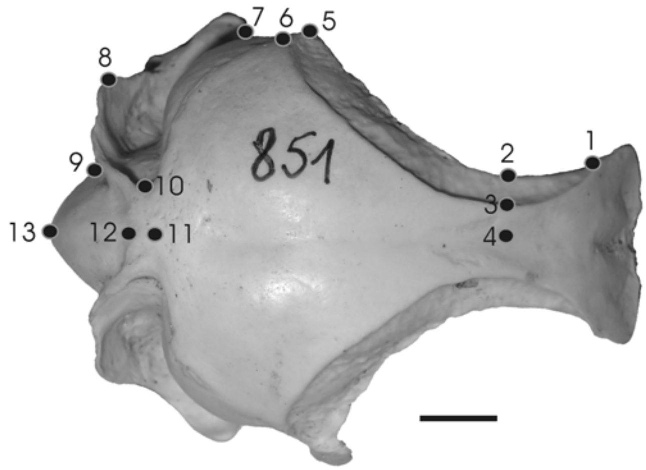

FIG. 2. Skull of *Spheniscus magellanicus* showing the landmarks analyzed. Scale bar: 10 mm.

Selection of characters to evaluate. The landmarks selected for this analysis were based on previous results of metric characters analysis (Cejuela 1995, Acosta Hospitaleche & Gasparini 2006)

For the skull analysis, 13 reference points were selected, comprising type I, II, and III landmarks (Rabello Monteiro & Furtado dos Reis 1999; Fig. 2). All landmarks are homologous points. Some of them (landmarks 1, 2, 5, 7, 8, and 13) were located at the end of structures; others (landmarks 3, 6, and 10) were placed at the contact between two structures. Over the sagittal line of the skull were placed Landmarks 4, 11, and 12. Finally, landmark 9 is positioned at the intersection between the most caudal extension of the temporal nuchal crest and the cerebellar prominence. Thus, the points indicating the regions of interest represent the right half of the skull.

In the present analysis, the groove of the salt gland is delineated by landmarks 1 (anterior end), 2, and 3 (width at the orbital level), and landmarks 5 and 6 (width at posterior end).

The temporal fossa is comprised by landmarks 7, 8 (fossa width or anteroposterior extension), and 10 (dorsal extension).

The sagittal crest is not ridge-like in all study specimens. However, it can be indicated by landmarks 10 and 11 (located at both of its ends).

Finally, landmark 13 indicates the extension of the cerebellar prominence.

The rostrum was analyzed through five landmarks (Fig. 3). Landmarks 1 and 2 indicate the exposed culmen, while landmark 3 measures the width at the base of the bill. Landmark 4 is at the most posterior end of the nasal foramen, and landmark 5 gives a reference point of the length respect to the skull.

Morphometric analysis. Variation in the shape of landmark configurations was established. Differences in size, orientation, and position were removed using procrustean reorientation. The latter was achieved by the use of procrustes superimposition (Rohlf & Slice 1990). This technique scales all configurations to have centroid size (square root of the summed squared distances from all landmarks to the configuration centroid) equal to 1, translates all configurations so that all centroids are located at the origin, and rotates all configura-

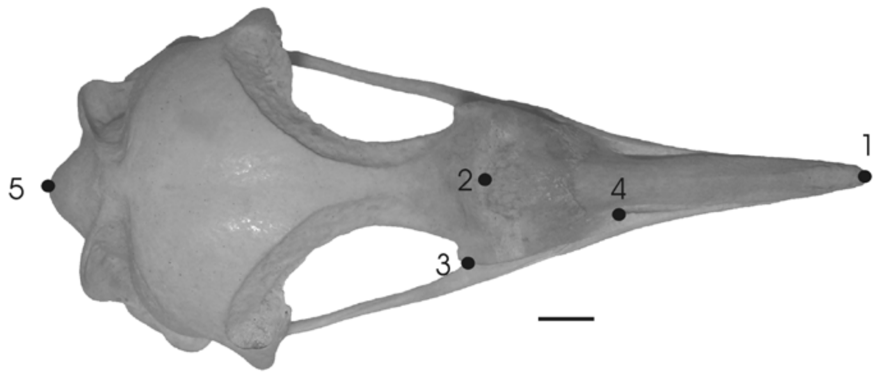

FIG. 3. Rostrum of *Spheniscus magellanicus* showing the landmarks analyzed. Scale bar: 10 mm.

tions by an optimum angle. These superimposition steps are used to minimize the sum of squared distances between corresponding landmarks. By means of generalized Procrustes superimposition (Rohlf & Slice 1990), the calculation of mean shapes from samples is possible

Thin plate splines, whose function is to minimize the energy required during the transformation, were used for graphic representations. This energy is a function not only of the amount of transformation in shape, but also of the degree of closeness among the configuration points. Once these values were obtained, a relative warp analysis, which is a modification of principal component analysis for shape coordinate data, was performed using the software tpsRelw (Rohlf 2005). To evaluate intraspecific variations of the posterior regions of the skull, the consensus configuration of *Spheniscus magellanicus* was calculated and compared to all specimens. After this, the other species of the genus were included, allowing visualization of variation in a main context.

Relative warps were computed with inclusion of the uniform component and no weighting by bending energy (Bookstein 1996). A relative warps analysis is reported by the joint distribution of weighted scores together with the diagrams of grid deformations corresponding to the eigenvectors that generated those scores.

RESULTS AND DISCUSSION

Among the analyzed specimens, the minimum variation is displayed by landmarks 1, 2, 3, 4, and 6 (Fig. 4). In anteroposterior and latero-medial direction, landmark 5 presents a slightly higher dispersion of dots with respect to the aforementioned landmarks.

The most important variable features found are related to landmarks 7 and 8. Dots disperse only in anteroposterior direction in landmark 7, while at landmark 8 they are equidistant from the mean value. This area is involved in predatory activities, as it belongs to the attachment point of jaw and neck muscles.

Other landmarks, e.g., landmarks 9 and 13, present very low variation, being equidistant from the consensus configuration. The dispersion at landmark 10 is enough to partially overlap landmarks 11 and 12. Nevertheless, landmarks 11 and 12 overlap each other,

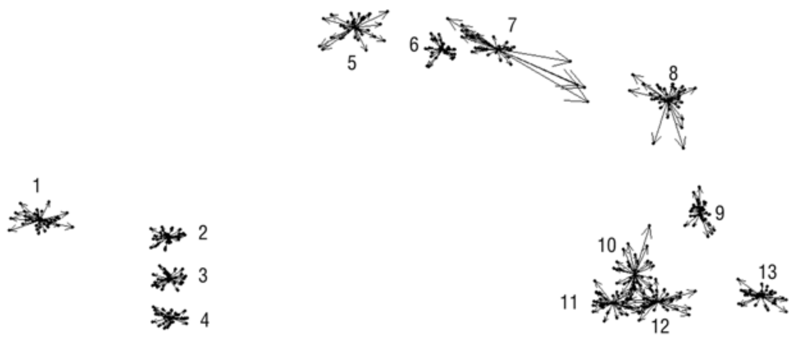

FIG. 4. Intraspecific variation in landmarks of the skull of *Spheniscus magellanicus*.

FIG. 5. Intraspecific variation in landmarks of the rostrum of *Spheniscus magellanicus*.

so they appear as a continuous dispersion of dots.

Regarding the rostrum analysis, it showed a very low the variation (Fig. 5). There is certainly a homogeneous spreading from the consensus and there is only a major dispersion at landmarks 3 and 4 which indicate the width at the base of the rostrum and varies in antero-posterior direction.

Some of the differences among the specimens of *S. magellanicus* (Figs. 6-7) could be explained by range, age-, or sex-related differences. However, geographic factors can be easily dismissed based on the results of Cejuela (1995), who analyzed two geographically separated populations of *S. magellanicus* and found no significant differences.

The age factor is not relevant here because this analysis included only adult specimens. Nevertheless it is worth mentioning that previous studies on *S. humboldti* and *S. demersus* revealed variation in the depth of the temporal fossa during ontogeny, which are widely separated from each other in juveniles (Ksepka *et al.* 2006).

Sex-related differences are more pertinent in terms of individual variation. In previous studies of this species, discrimination between sexes was based on external metric characters (Conway 1965, Boswall & MacIver 1974, Daciuk 1976), but only with limited success.

Anatomic differences between males and females could be quantified, since males have a relatively larger and more prominent head than females (Boswall & Maclver 1974, Daciuk 1976), as well as different dimensions of the bill and frontal region of the head from an early age (Scolaro *et al.* 1983, but see also Williams, 1995). These differences in the metric characters between females and males could respond to a disparity in the development of musculature rather than to deviations

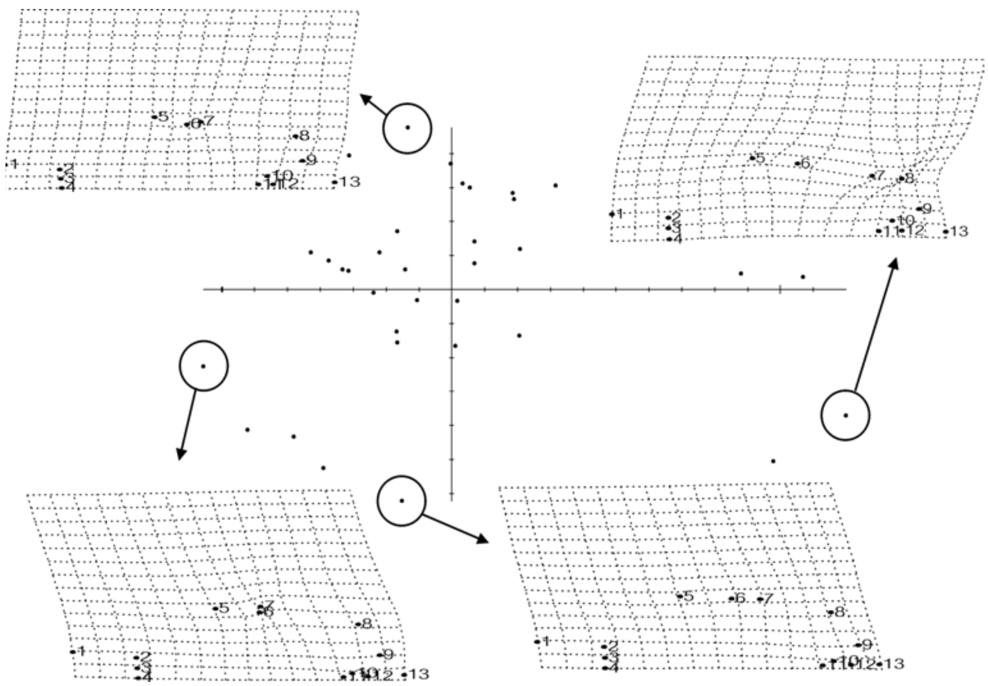

FIG. 6. Results of the relative warps analysis of the skulls in *Spheniscus magellanicus*. Deformation grids refer to the most extreme cases.

in osteologic characters, such as the ones evaluated in this study. However, the variation in the latter characters is uniform.

The living species of *Spheniscus* have been usually separated on the basis of plumage characters. However, since fossil records of penguins have been discovered, skeletal parameters have been added to evaluate species limits. In this context, osteological studies allow to establish several cranial and appendicular characters that are useful for species discrimination. As a fact, the morphology of the posterior skull, including the nuchal crests, the sulcus of the salt gland, and the temporal fossa, has been used for this purpose (see Stucchi *et al.* 2003, Acosta Hospitaleche & Canto 2005, Acosta Hospitaleche *et al.* 2006).

A characteristic expansion of the temporal nuchal crests in wing-like fashion has been assigned to *Spheniscus* (Acosta Hospitaleche *et al.* 2006) and by a consequent strong development of the temporal fossa, a character that the living species of *Spheniscus* share only with fossil congeners (Bertelli *et al.* 2006). Besides, each transversal crest is extended dorsally to the midsagittal line (Simpson 1946).

ACKNOWLEDGMENTS

Marcelo Stucchi and Herculano Alvarenga kindly provided some photographs. Lic. Cecilia Morgan and Sr. Nicolás Kass improved the English. PICT 499 for support. The reviewers and the editor helped to improve the manuscript.

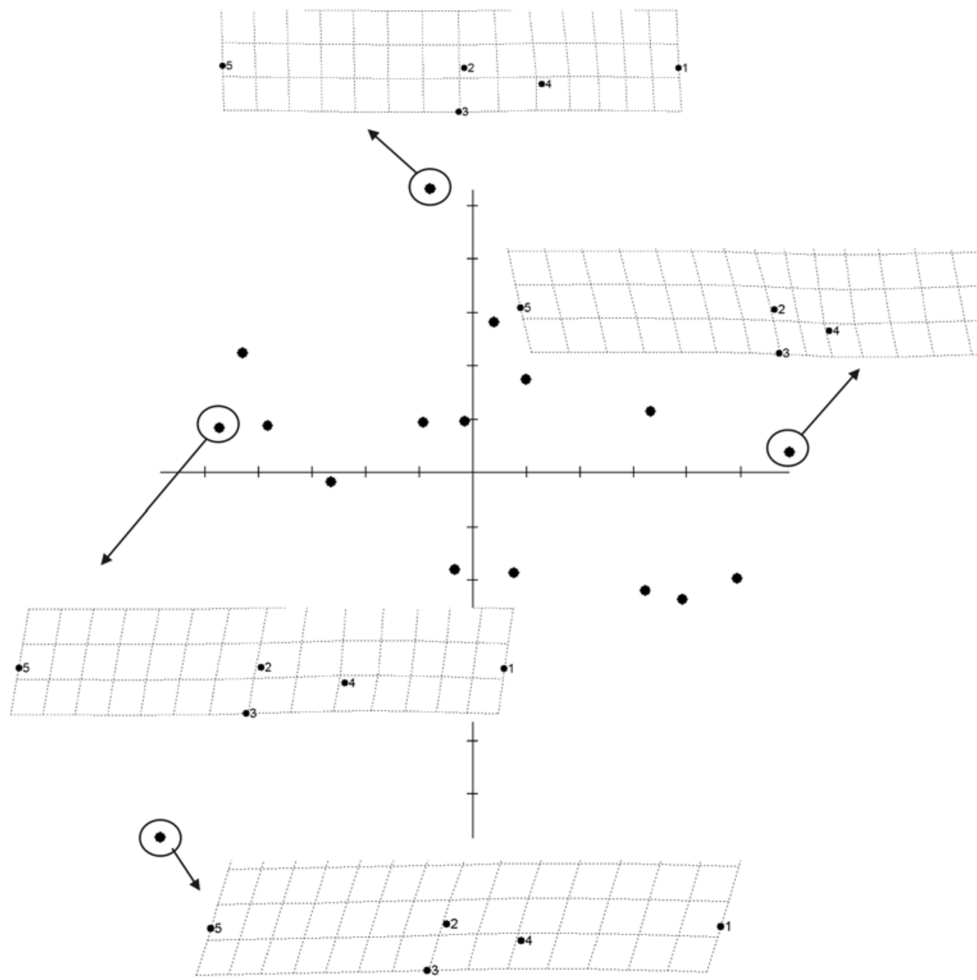

FIG. 7. Results of the relative warps analysis of the rostrum in *Spheniscus magellanicus*. Deformation grids refer to the most extreme cases.

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