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Sexual Dimorphism and other Sources of Variation in a Sample of Dugong Skulls from North Queensland

A. V. Spain[AB], *G. E. Heinsohn*[A], *H. Marsh*[A] *and R. L. Correll*[AC]

[A] James Cook University of North Queensland, Townsville, Qld. 4811.
[B] Present address: 1107 Ross River Rd., Rasmussen, Qld. 4814.
[C] Present address: Division of Mathematics and Statistics, CSIRO, Private Mail Bag No. 2, Glen Osmond, S.A. 5064.

Abstract

A biometric analysis of 26 variables measured on 32 adult dugong skulls (16 males, 16 females) describes the nature of the sexual dimorphism present. Further sources of variation include the expected size variation and the continuance of attenuated allometric growth patterns into adulthood.

Introduction

Little appears to be known of variation in the cranium of *Dugong dugon* (Müller)· Previous work is limited to that of Krauss (1870), Pocock (1940), Mitchell (1973), and Spain and Heinsohn (1974). A major problem for most previous workers has been the inadequate number of skulls in good condition on which to base their studies. One exception to this is the work of Spain and Heinsohn (1974) on the size allometry of the dugong skull, which was based on a sample of 52 animals taken from the Townsville region.

It is of interest to examine the major sources of variation in a collection of adult skulls from one locality to establish their normal limits. This would presumably represent a sample from one breeding population and will thus provide a basis for the evaluation of differences between samples from other geographical locations. In particular, it was considered of particular interest to delineate the nature of any sexual dimorphism present.

For the purposes of this paper, adults are defined as those individuals with a body length greater than 240 cm or a condylo-premaxillary length of 34·1 cm (Heinsohn 1972; Spain and Heinsohn 1974).

Methods

Skulls for the present analyses were obtained principally from specimens caught in nets set fo· the capture of sharks in the region of Townsville (19°25′S., 146°15′E.) (Heinsohn 1972; Heinsohn and Spain 1974). They comprise an extension of the adult subsample of skulls analysed in Spain and Heinsohn (1974).

Thirty-two skulls were measured for the 26 variables listed below:

(1) Condylo-premaxillary length. Distance from posterior margin of occipital condyle to the anterior tip of the premaxillae.
(2) Zygomatic width. Width of skull at the anterior part of the zygomatic processes of the temporal bone.
(3) Mastoid width. Width of skull between the mastoid processes of the temporal bone.
(4) Postorbital width. Maximum width of skull between the postorbital processes.
(5) Width of external nares. Maximum width of nasal aperture between premaxillae.

(6) Length of external nares. Length of nasal aperture at midline.
(7) Posterior snout width. Width of both premaxillae at the anterior end of the external nares.
(8) Snout length. Length of distal part of premaxillae between anterior end of external nares and anterior tip of premaxillae along midline.
(9) Fronto-parietal width. Width of frontal bone at the junction between the frontal and parietal bones.
(10) Foramen magnum depth. Maximum distance across the foramen magnum opening between the supraoccipital and basilar portions of the occipital bone.
(11) Foramen magnum width. Maximum lateral distance across the foramen magnum between its right and left exoccipital portions.
(12) Frontal bone length. Length of frontal bone at midline.
(13) Hard palate length. Distance along midline from anterior end of the palatine process of the maxilla to anterior end of the internal nares.
(14) Posterior maxillary width. Width across maxillae and palatine bones at the anterior end of the internal nares.
(15) Pterygoid hamular width. Maximum width between the lateral surfaces of the pterygoid hamuli.
(16) Anterior snout width. Width of both premaxillae across the incisor sockets.
(17) Maxillary–premaxillary depth. Depth of the maxilla to the premaxilla at the anterior end of the orbit.
(18) Pterygoid–frontal depth. Depth of skull from the pterygoid hamuli to the posterior end of the frontal bone.
(19) Least mandibular depth. Depth of mandible posterior to the last molar.
(20) Greatest mandibular depth. Depth of the mandible from the dorsal tip of the coronoid process to the tip of the ventral angle.
(21) Anterior mandibular depth. Distance from the posterior end of the lower incisor socket row to the ventral anterior tip of the chin.
(22) Coronoid–condylar distance. Maximum distance from the anterior end of the coronoid process to the most posterior portion of the condyle.
(23) Maximum extra-mandibular width. Maximum distance between the most posterior projections of the mandible.
(24) Extra-mandibular coronoid width. Distance between the posterior ends of the right and left coronoid processes.
(25) Extra-mandibular chin width. Maximum width of chin.
(26) Mandibular length. Maximum length of mandible from the posterior end of the mandibular condyle to the most anterior point of the chin.

Where paired variables occur, mean values were used. All measurements were taken with vernier calipers.

Computation was carried out on the CSIRO Cyber 76 in Canberra using programs from the 'Genstat' system (Nelder 1975).

Results and Analysis

Means and standard deviations for all variables and both sexes are presented in Table 1.

All variables for both sexes were tested for significant skewness and kurtosis. Zygomatic width and greatest mandibular depth both showed significant ($P < 0\cdot05$) right skewedness and leptokurtosis in the male animals only.

Correlations were computed between the 26 variables for the 32 individuals of both sexes. Most were low to moderately positive, none exceeding 0·836 which is the correlation between snout length and condylo-premaxillary length. Fronto-parietal width showed negative correlation with some variables, notably the greatest mandibular depth, maxillary–premaxillary depth and posterior snout width. Other correlations with this variable were low positive or near zero.

Sexual Dimorphism

Univariate analysis of variance was used to test the significance of the differences between sexes for all 26 variables. The six variables showing differences significant at $P < 0{\cdot}05$ or less are listed below:

Variable No.	Variable Name	P
8	Snout length	$<0{\cdot}05$
16	Anterior snout width	$<0{\cdot}005$
18	Pterygoid–frontal depth	$<0{\cdot}001$
21	Anterior mandibular depth	$<0{\cdot}01$
25	Extra-mandibular chin width	$<0{\cdot}025$
26	Mandibular length	$<0{\cdot}05$

Canonical variate analysis was used to examine the differences between the sexes more closely. Table 2 presents the latent vector and constant term associated with the single root able to be extracted. Mahalanobis' distance was also calculated and found to be significantly different ($P < 0{\cdot}05$) from zero using a test from Rao (1952, p. 247).

Table 1. Means and standard deviations of 26 variables measured on 16 adult dugongs of each sex
All measurements are in centimetres

Variable No.	Males Mean	Males SD	Females Mean	Females SD	Variable No.	Males Mean	Males SD	Females Mean	Females SD
1	35·68	1·02	36·12	1·44	14	7·39	0·38	7·57	0·35
2	21·20	1·82	20·52	1·11	15	5·70	0·30	5·66	0·33
3	16·61	0·45	16·43	0·54	16	5·74	0·84	4·96	0·44
4	15·41	1·02	15·37	1·29	17	6·39	0·52	6·35	0·60
5	7·09	0·57	7·24	0·39	18	13·30	0·34	13·95	0·36
6	10·35	0·69	10·49	0·53	19	7·09	0·32	7·28	0·33
7	8·40	0·65	8·59	0·82	20	16·53	0·77	17·11	0·81
8	17·89	0·90	18·62	0·97	21	12·45	0·70	13·27	0·89
9	7·37	0·66	7·42	0·94	22	8·51	0·38	8·77	0·42
10	4·66	0·28	4·65	0·35	23	17·14	1·10	17·40	1·30
11	4·56	0·34	4·36	0·28	24	10·94	0·41	10·79	0·37
12	6·60	0·50	6·52	0·63	25	4·52	0·26	4·86	0·40
13	12·46	0·65	12·75	0·63	26	26·27	0·93	27·27	1·43

In general, the variables positively correlated with the canonical variate were associated with the jaws and those variates with negative associations related to other parts of the skull. The only exceptions were the anterior snout width (16), which had a strong negative correlation, and pterygoid hamular width (15) and extramandibular coronoid width (24), both of which are associated with the width of the posterior part of the lower jaw.

Subsets of variables were examined in the search for a simpler discriminator between the sexes. Two useful equations are:

$$\begin{aligned}\text{Sex indicating variable} = {} & -5{\cdot}201+(0{\cdot}187\times\text{snout length})\\ & -(0{\cdot}389\times\text{anterior snout width})\\ & +(0{\cdot}394\times\text{pterygoid–frontal depth});\end{aligned}\tag{1}$$

$$\begin{aligned}\text{Sex indicating variable} = {} & -1{\cdot}963+(0{\cdot}336\times\text{snout length})\\ & -(0{\cdot}499\times\text{anterior snout width}).\end{aligned}\tag{2}$$

There was no significant loss of discriminating power in using equation (1) compared to using all 26 variables. Equation (2) was best of all bivariate functions examined in the sense of minimizing the number of incorrect classifications—the only incorrect result was for a small male that was classified as a female. This compared favourably with equation (1), which classified wrongly a further two individuals.

Table 2. Canonical variate analysis of sexual dimorphism in the dugong skull
Loadings, correlations with each variable and constant term for each variable on the single root provide discrimination

Variable	Loadings	Correlation with cv	Variable	Loadings	Correlation with cv
1	1·8567	0·1776	14	−1·7895	0·2306
2	0·3227	−0·2257	15	1·8870	−0·0695
3	−0·9836	−0·1823	16	1·9505	−0·5120
4	−0·5372	−0·0201	17	1·4353	−0·0357
5	0·2198	0·1470	18	−5·9760	0·7000
6	1·7367	0·1146	19	−3·8744	0·2942
7	2·2456	0·1363	20	1·8556	0·3531
8	−1·3719	0·3719	21	−1·3313	0·4643
9	0·6568	0·0354	22	−4·1295	0·3161
10	−6·3959	−0·0195	23	−0·6137	0·1127
11	7·0234	−0·3143	24	1·0493	−0·1984
12	1·0271	−0·0752	25	−0·9894	0·4562
13	−3·4507	0·2239	26	0·5564	0·3890
			Constant term	−70·6433	

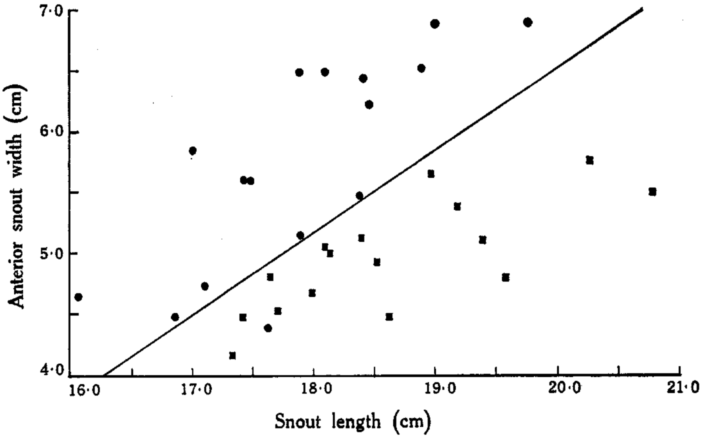

Fig. 1. Bivariate scatter plot of anterior snout width against snout length showing the line of separation computed from a discriminant function. ● Males. ■ Females.

The reliability of equation (2) as a discriminator was assessed by a method described by Hills (1966). Each skull was omitted from the determination of the coefficients and it was then allocated to its sex on the basis of the resultant function. In only two cases was there misallocation. The allocation procedure is very nearly a binomial process, thus the probability of a correct classification is approximately 0·938.

By substitution in equation (2), a line of separation between the two sexes is obtained (Fig. 1), with the relationship

$$\text{Snout length} = 10{\cdot}306+(1{\cdot}485\times\text{anterior snout width}).$$

Measurement of Skull Size

The definition of size of a skull must be arbitrary, as it is known that changes of shape occur during growth. Of the many possible definitions, condylo-premaxillary length (1) was chosen as it was the largest variable measured.

The simplicity of this method is attractive, and useful results have been obtained from it by Spain and Heinsohn (1974).

Table 3. Loadings of the first two principal components, allometry coefficients and their standard errors for the 26 variables

Variable No.	Components I	Components II	Allometry coefficient	Standard error
2	−0·093	−0·227	1·02	0·31
3	0·366	−0·181	0·49	0·14
4	0·000	−0·369	1·34	0·31
5	0·250	−0·139	0·58	0·35
6	0·028	−0·067	0·82	0·27
7	−0·180	−0·390	1·60	0·35
8	−0·254	−0·296	1·31	0·16
9	0·214	0·081	0·19	0·59
10	0·255	−0·145	0·30	0·36
11	0·360	−0·044	0·36	0·38
12	0·181	−0·052	1·35	0·38
13	−0·040	0·167	1·04	0·20
14	0·251	−0·135	0·41	0·25
15	0·215	−0·152	0·46	0·28
16	−0·288	−0·244	1·88	0·66
17	−0·186	−0·094	1·19	0·41
18	0·272	−0·127	0·54	0·16
19	0·092	−0·002	0·84	0·19
20	0·115	−0·210	0·95	0·19
21	−0·178	−0·407	1·51	0·24
22	0·088	−0·175	0·85	0·21
23	−0·080	−0·098	0·92	0·32
24	0·190	−0·070	0·23	0·19
25	0·130	−0·150	0·89	0·38
26	0·029	−0·231	0·96	0·19

Examination of Interskull Variation

Variations in the measurements taken would clearly be a function of skull size. This effect was eliminated by dividing all the measures by the skull size as defined above. Furthermore, sex was known to have a contribution. This effect was removed by adjusting the scores so that the males and females had the same mean vector. In practice, this was achieved by using the residuals from a one-way classification based on sex.

The remaining variation was examined using a Principal Components Analysis. The first four roots explain 18·3%, 13·0%, 10·5% and 8·7% of the variation respectively. It was noted that those variables with large positive loadings on the first two vectors were known to have large allometry coefficients, and conversely those with negative loadings small coefficients (Table 3). This was investigated further.

Allometry

Allometry coefficients (Sprent 1972) were calculated for variables 2–26 as described by Spain and Heinsohn (1974) and are shown in Table 3. The functional relationships of bones places constraints on their growth patterns, e.g. the growth of the upper jaw must be matched by that of the lower jaw to enable effective opposition, i.e. snout length (8) has to approximate anterior mandibular depth (21). The coefficients listed in Table 3 for the mature dugongs are closely comparable to those quoted by Spain and Heinsohn (1974).

Significant correlations ($P < 0 \cdot 01$) were found between the allometry coefficients and the first two vector loadings of the principal component analysis ($r = -0 \cdot 840$ and $-0 \cdot 532$), showing that a large component of the residual variation can be explained in terms of allometry.

As was found by Spain and Heinsohn (1974), those variables with small allometry coefficients were associated with the posterior parts of the skull. One exception was the extramandibular coronoid width (24), as this measure is limited by the corresponding articulating surfaces which are towards the posterior end of the skull.

Discussion and Conclusions

The sources of variation delineated provide a preliminary approach to the study of the species as a whole, in that the nature of sexual dimorphism and allometric variation are now known and may be separated from potential geographic variation.

Gohar (1963) has stated that the Red Sea population of the dugong is sufficiently different from the others to deserve subspecific status, although it is doubtful whether enough information was available to allow a firm decision. However, even if discrete breeding populations do not exist, it is probable that character clines will and, we hope, studies such as the present may permit identification of these in relation to the variation occurring in samples from one locality.

Skulls from mature dugongs may be relatively easily sexed on the basis of the development of the upper second incisors to skull size (Heinsohn and Spain, unpublished). However, we have noted one female dugong with fully erupted tusks, so this feature may not provide complete separation. Sexual dimorphism is most apparent in the development of the maxilla, premaxilla and the anterior part of the mandible, but other less obvious characters are involved such as the pterygoid–frontal depth.

After removing the effects of sexual dimorphism and size, principal components analysis allows a clearer appreciation of other variation present. Size variation is known, since dugong continue to grow for some time after puberty (Spain and Heinsohn 1975). In addition, allometric changes continue although these must be attenuated somewhat.

In conclusion, metric features of variation do not appear to be known at all for other extant Sirenia, and it would be of considerable interest to examine these in relation to those of the dugong.

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