J. Mar. Biol. Ass. U.K. (2002), **82**, 269–278
Printed in the United Kingdom

Morphometry of the northern Patagonian sympatric populations of *Loligo sanpaulensis* and *Loligo gahi*

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Loligo gahi and *Loligo sanpaulensis* (Mollusca: Cephalopoda), two squid species presently under exploitation in the south-west Atlantic, are sympatric in coastal waters of northern Patagonia. In the present study, the morphometry of both species' northern Patagonian populations was analysed and compared. Relationships between the morphometric variables and mantle length, the standard measure of size for squids, are allometric in most cases. Weight and fin length show different rates of growth relative to mantle length in males and females of both species. Fin length, fin width and mantle length are the best morphometric variables to discriminate the mantle/fin complexes. Free rachis length, gladius length and gladius width are the most useful to separate both species' pens. The best discrimination of the tentacles is provided by the diameter of the central and marginal suckers and the number of teeth on the three largest sucker rings. Discriminant functions are provided to allow the classification of individuals from both species and the identification of pens and tentacle clubs found in predators digestive contents.

INTRODUCTION

In squid, several morphometric (continuous) and meristic (discrete) measurements have been employed to characterize taxonomic groups (Haefner, 1964; Wittacker, 1978; Vigliano, 1985) and to identify differences between species or subspecies (Augustyn & Grant, 1989; Sánchez et al., 1996), between populations or stocks of a single species (Cohen, 1976; Kashiwada & Recksiek, 1978; Nigmatullin, 1986; Carvalho & Pitcher, 1989), and between identical taxonomic units subjected to different fixation and preservation techniques (Cohen, 1976; Andriguetto & Haimovici, 1988). Also, morphometric measurements are an important source of information for the identification of species in digestive contents of numerous predators (Clarke, 1986; Wolff, 1984; Pineda et al., 1996, 1998; Aguiar dos Santos & Haimovici, 1998).

Two species of the genus *Loligo* are currently recognized for the Atlantic waters of Patagonia: *Loligo gahi* D'Orbigny, 1835, and *Loligo sanpaulensis* Brakoniecki, 1984, (Castellanos & Cazzaniga, 1979; Brakoniecki, 1984). The former species has supported the largest world catches for a loliginid during the last decade (FAO, 1999). The latter is an important resource for artisanal fisheries throughout its range of distribution off the Atlantic coast of South America (Vigliano, 1985; Andriguetto & Haimovici, 1991). Both species are present in waters off the coast of northern Patagonia (Barón, 2001), and are frequently found together in fishing samples (Barón & Ré, in press). Like other loliginids (Hanlon, 1988; Roper & Hotchberg, 1988), *L. gahi* and *L. sanpaulensis* can be identified on the basis of their patterns of colour and abundance of chromatophores (Castellanos & Cazzaniga, 1979). Still, the morphometric characterization of some of their hard and soft parts is necessary to identify individuals with skin damage, and parts of the body that could be found in the digestive tract of their predators. Even though previous studies have described some of the morphometric relationships of the soft parts (Castellanos & Cazzaniga, 1979; Brakoniecki, 1984; Vigliano, 1985; Andriguetto & Haimovici, 1988; Carvalho & Pitcher, 1989; Hatfield, 1992; Cardoso et al., 1998), beaks and statoliths (Pineda et al., 1996, 1998) of these species, many other relationships have not been studied yet. Also, the lack of recognition of allometric growth in some of these studies (Castellanos & Cazzaniga, 1979; Vigliano, 1985; Carvalho & Pitcher, 1989) limits the accuracy of the relationships reported.

The comparison of shape between groups of organisms can be done by regressions, indices and multivariate analysis (Humphries et al., 1981). The use of regressions is practical only when analysing few variables (Sokal & Rohlf, 1979). The indices have been extensively used to characterize the morphometry of loliginids (Haefner, 1964; Castellanos & Cazzaniga, 1979; Vigliano, 1985; Andriguetto & Haimovici, 1988; Pineda et al., 1996, 1998; Sánchez et al., 1996). Unfortunately, there is evidence indicating that indices present several methodological problems (Humphries et al., 1981; Andriguetto & Haimovici, 1988; Voight, 1991, 1994). The discriminant analysis is the most appropiate multivariate technique when the dependent variable is not metric (e.g. species or sex) and the objects of the analysis are assigned to different groups by the interaction of a set of independent variables (Hair et al., 1999).

Taking into account the state of knowledge on the morphometry of *L. gahi* and *L. sanpaulensis*, the objectives of the present study are to describe the morphometry of *L. gahi* and *L. sanpaulensis*, applying appropriate statistical methods and extending the size range and number of variables employed in previous studies, and to determine the relative efficiency of different combinations of morphometric variables to discriminate the body structures of both species.

MATERIALS AND METHODS

A total of 346 *Loligo gahi* (31–227 mm +291 mm of mantle length [ML]) and 1501 *Loligo sanpaulensis* (10–200 mm ML) specimens were caught in coastal waters of northern Patagonia, between 42° and 44°S, from 1996 to 1999. The number of individuals employed in each of the different morphometric analysis is indicated in the results. The squid were identified to species level by the presence of a dense band of brown chromatophores on the dorsal mantle of *L. gahi*, absent in *L. sanpaulensis* (Figure 1), and their sex was established by the observation of the reproductive organs. One meristic and 18 morphometric characters were recorded (Figure 2; Table 1). All measurements were done with a digital calliper to the nearest 0.01 mm on fresh-caught individuals. Only the measurement of the tentacles' suckers, and the counting of teeth on the sucker rings, were completed with an eyepiece under the light microscope. Several indices of frequent use (Voss, 1956; Haefner, 1964) were calculated (Table 1). All the morphometric variables registered were transformed into their natural logarithms (ln) to line up the data. Regressions of the ln-transformed variables on ln ML were calculated after testing normality (Kolmogorov–Smirnov test) and homogeneity of variances (Bartlett's test) (Sokal & Rohlf, 1979). For each regression, the null hypothesis of isometry (Ho) was tested using the methodology described by Voight (1991). Covariance tests (Sokal & Rohlf, 1979) were used to establish lack of parallelism between the regression lines corresponding to (i) both species; (ii) both sexes of one species; and (iii) the same sex of the two species. Given that most indices displayed non-linear relationships with ML, all of them were ln-transformed and their correlation with ln ML was tested. For those that showed significant correlations, subsamples with similar ML distributions, verified with Kolmogorov–Smirnov two sample tests (Statsoft Inc., 1996), were obtained. Also, it was taken into account that both sexes were equally well-represented in both subsamples. Indices were then compared using Mann–Whitney *U*-tests. The potential of different combinations of morphometric variables to discriminate the body structures of the two species was determined with Fisher's linear discriminant analysis (Hair et al., 1999; Statsoft Inc., 1996). As carried out with indices, sub-samples of both species with similar size distributions were included in the analysis. All variables were ln-transformed and equality of variance–covariance matrixes was tested with Box's M-tests (Hair et al., 1999). The discriminant potential of the functions obtained by this method was tested with additional samples.

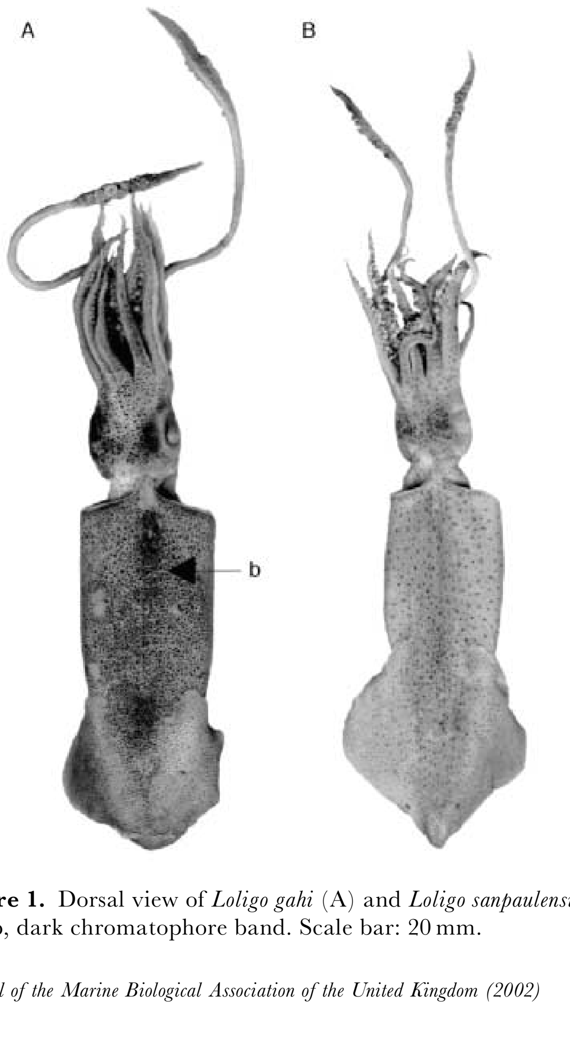

Figure 1. Dorsal view of *Loligo gahi* (A) and *Loligo sanpaulensis* (B). b, dark chromatophore band. Scale bar: 20 mm.

RESULTS

Regressions

The regressions of the ln-transformed morphometric variables on ln ML were all significant and showed high determination coefficients (Table 2). The slopes of the regression lines will be expressed hereafter as growth rates of the non-transformed morphometric variables relative to ML. The growth rate of W (weight) relative to ML is greater in *Loligo sanpaulensis* than in *Loligo gahi*, and in the females of both species compared to the males (Table 2). Nevertheless, the scatter-plot of ln W on ln ML shows that this relationship does not allow a clear separation of both species for squid smaller than 110 mm ML (Figure 3). The growth of FL (fin length) relative to ML is positively allometric and shows identical rates for both species (Table 2). Significant differences were found between the intercepts of the regressions of ln FL on ln ML indicating that the fins of *L. sanpaulensis* are relatively longer than those of *L. gahi* (Table 2). The scatter-plot of ln FL on ln ML shows that the relationship allows the separation of both species over most of their size ranges (Figure 3). The growth rates of FL relative to ML are slightly higher in females than in males (Table 2). In both species, the growth of FW (fin width) relative to ML is slightly allometric (the possibility of isometry is not completely discarded). No significant differences were detected between the slopes and intercepts of the regression lines of ln FW on ln ML (Table 2). However, the confidence and prediction intervals (P=0.95) of the regression lines did not overlap over the size range from which data were available, *L. sanpaulensis* displaying proportionally wider fins than *L. gahi*. The scatter-plot of ln FW on ln ML suggests that this is an appropriate relationship to discriminate these species (Figure 3). The variables of the head, mantle and cartilaginous structures: HL (head length), HW (head width), FuL (funnel length), FuW (funnel width), FCL (funnel cartilage length) and

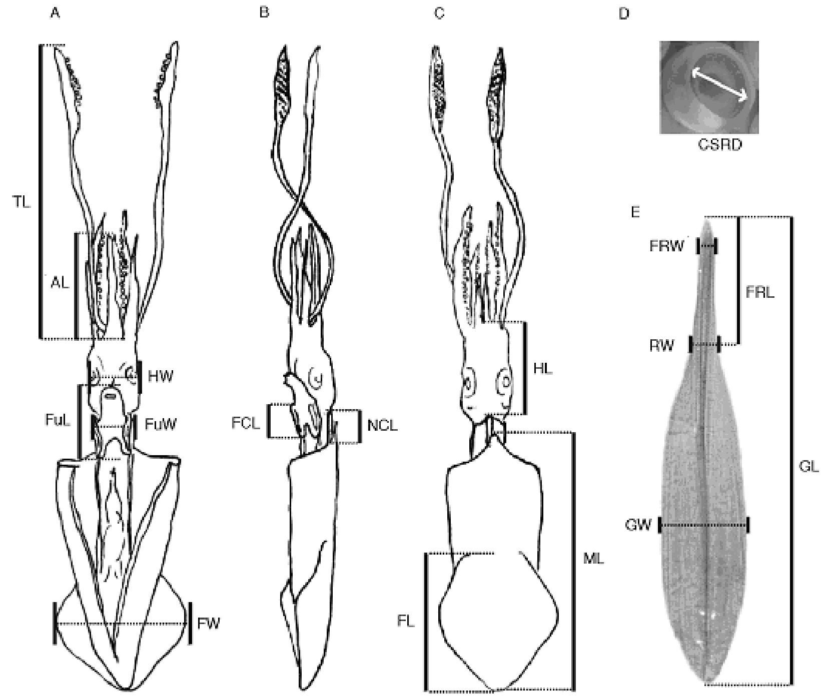

Figure 2. Morphometric characters recorded on *Loligo gahi* and *Loligo sanpaulensis*. (A) Ventral view; (B) lateral view; (C) dorsal view; (D) tentacles' sucker; (E) gladius. AL, arm IV length; FCL, funnel cartilage length; FL, fin length; FRL, free rachis length; FRW, free rachis width; FuL, funnel length; FuW, funnel width; FW, fin width; GL, gladius length; GW, gladius width; HL, head length; HW, head width; ML, mantle length; NCL, nuchal cartilage length; RW, rachis width; TL, tentacle length. The mantle was dissected along the mid-ventral line to allow the observation of the funnel cartilages.

Table 1. *Variables and indices recorded on* Loligo gahi *and* Loligo sanpaulensis.

Variable	Notation	Description
Weight	W	Fresh weight of the squid taken to the nearest 0.01 g
Mantle length	ML	Length of the dorsal mantle from the anterior to the posterior extremes
Fins length	FL	Length of the fins from the midpoint of an imaginary line joining the anterior margin of the fins to the posterior extreme of the mantle
Fins width	FW	Greatest width of the fins between their lateral margins
Head length	HL	Length of the head from the anterior margin of the nuchal cartilage to the base of the arms I
Head width	HW	Greatest width of the head at the level of the eyes (with the head compressed laterally with the fingers)
Funnel cartilage length	FCL	Greatest length of the right funnel cartilage length from the anterior to the posterior ends
Funnel length	FuL	Length of the funnel from its anterior extreme to the midpoint of an imaginary line joining the funnel cartilage posterior extremes
Funnel width	FuW	Greatest width of the funnel between its lateral margins
Nuchal cartilage length	NCL	Length of the nuchal cartilage from the anterior to the posterior ends
Tentacle length	TL	Length of the right tentacle from the junction of arms III and IV to the distal extreme
Arm length	AL	Length of the arm IV measured from the junction of both arms IV to the distal extreme of the right one
Central sucker ring diameter	CSRD	Ring diameter of the largest sucker on the carpus of the tentacle
Marginal sucker ring diameter	MSRD	Ring diameter of the sucker lying at the lateral margin of the largest central sucker on the tentacles' carpus
Free rachis width	FRW	Width of the free rachis at the level of the anterior end of the lateral ribs
Rachis width	RW	Width of the rachis at the level of the anterior end of the vanes
Gladius width	GW	Greatest width of the gladius between its lateral margins
Free rachis length	FRL	Length of the free rachis from the anterior extreme of the vanes to its anterior end
Gladius length	GL	Length of the gladius from the anterior to the posterior extremes
Teeth number on the sucker rings	TN	Maximum number of teeth from the largest three sucker rings on the right tentacle

Indices
W/ML, FL/ML, FW/ML, FW/FL, HL/ML, HW/ML, NCL/ML, FCL/ML, TL/ML, AL/ML, CSRD/MSRD, FRW/ML, GW/ML, RW/ML, FRL/GW.

Table 2. *Results of the regression analysis and tests of slopes, intercepts and isometry for the morphometric and meristic variables of* Loligo gahi *and* Loligo sanpaulensis.

Regression		*Loligo gahi*							ML range	*Loligo sanpaulensis*							ML range		
		a	a_{sex}	b	b_{sex}	al	r^2	N	(mm)	a	a_{sex}	b	b_{sex}	al	r^2	N	(mm)	a_{sp}	b_{sp}
ln Won	All	−5.80		1.98		+	0.93	1346	32–291	−8.31		2.57		+	0.97	1501	12–200	**	**
ln ML	Males	−5.53	*	1.92	**	+	0.94	169	32–291	−8.12	*	2.52	**	+	0.97	618	15–200	**	**
	Females	−6.27		2.08		+	0.93	176	56–202	−8.44		2.61		+	0.97	878	13–150	**	**
ln FL on	All	−1.92		1.23		+	0.97	290	32–291	−1.58		1.23		+	0.99	1490	12–200	**	ns
ln ML	Males	−1.80	ns	1.20	**	+	0.98	126	32–291	−1.54	ns	1.22	**	+	0.99	615	15–200	**	ns
	Females	−2.11		1.27		+	0.96	164	56–202	−1.60		1.23		+	0.99	873	12–157	**	ns
ln FW on	All	−1.23		1.09		0+	0.92	112	46–291	−1.03		1.11		0+	0.97	426	9–200	ns	ns
ln ML	Males	−1.11	ns	1.06	ns	0	0.93	55	46–291	−1.10	ns	1.13	ns	0+	0.97	166	9–200	ns	ns
	Females	−1.58		1.16		0+	0.89	57	63–192	−0.99		1.10		0+	0.96	259	13–150	*	ns
ln HL on	All	0.35		0.60		–	0.80	117	32–291	−0.52		0.79		–	0.83	437	9–200	**	**
ln ML	Males	0.33	ns	0.60	ns	–	0.87	58	32–291	−0.42	ns	0.77	ns	–	0.83	170	9–200	**	**
	Females	0.28		0.62		–	0.67	59	63–192	−0.59		0.81		–	0.83	267	12–150	*	*
ln HW on	All	0.66		0.49		–	0.70	116	32–291	0.08		0.63		–	0.82	439	9–200	**	**
ln ML	Males	0.94	ns	0.43	*	–	0.73	57	32–291	0.12	ns	0.61	ns	–	0.81	169	9–200	**	**
	Females	0.22		0.59		–	0.65	59	56–192	0.06		0.63		–	0.83	269	12–150	ns	ns
ln NCL on	All	−0.44		0.73		–	0.90	120	32–291	−0.73		0.79		–	0.94	371	9–200	ns	ns
ln ML	Males	−0.44	ns	0.73	ns	–	0.94	59	32–291	−0.72	ns	0.79	ns	–	0.96	148	9–200	ns	ns
	Females	−0.46		0.74		–	0.81	61	56–192	−0.74		0.79		–	0.92	223	12–150	ns	ns
ln FuL on	All	−0.05		0.71		–	0.77	118	32–291	−0.01		0.69		–	0.87	366	9–200	ns	ns
ln ML	Males	0.27	ns	0.64	*	–	0.77	60	32–291	0.04	ns	0.68	ns	–	0.85	142	9–200	ns	ns
	Females	−0.65		0.84		0–	0.76	58	56–192	−0.04		0.70		–	0.88	224	13–150	ns	*
ln FuW on	All	−0.01		0.60		–	0.77	54	46–291	−0.43		0.67		–	0.90	270	9–200	ns	ns
ln ML	Males	−0.04	ns	0.61	ns	–	0.90	30	46–291	−0.44	ns	0.68	ns	–	0.93	104	9–200	ns	ns
	Females	0.48		0.48		–	0.45	24	63–160	−0.41		0.67		–	0.88	166	18–150	ns	*
ln FCL on	All	−0.29		0.64		–	0.89	122	32–291	−0.35		0.65		–	0.91	376	9–200	ns	ns
ln ML	Males	−0.20	ns	0.62	ns	–	0.88	60	32–291	−0.48	ns	0.69	*	–	0.92	148	9–200	ns	ns
	Females	−0.52		0.69		–	0.89	62	56–192	−0.26		0.63		–	0.90	228	12–150	ns	ns
ln TL on	All	0.29		0.97		0	0.80	96	46–291	−0.22		1.10		0+	0.82	331	9–200	ns	ns
ln ML	Males	0.34	ns	0.96	ns	0	0.85	49	46–291	−0.17	ns	1.08	ns	0+	0.86	127	9–200	ns	ns
	Females	0.23		0.98		0	0.66	47	56–192	−0.23		1.11		0+	0.79	202	12–150	ns	ns
ln AL on	All	−0.74		0.98		0	0.83	116	32–291	−1.10		1.09		0+	0.91	418	9–200	ns	*
ln ML	Males	−0.14	*	0.86	**	0–	0.87	57	32–291	−0.96	ns	1.05	ns	0+	0.91	165	9–200	*	**
	Females	−1.44		1.13		0	0.79	59	63–192	−1.20		1.11		0+	0.90	252	12–150	ns	ns
ln CSRD on	All	−3.40		0.84		0–	0.77	64	46–291	−4.47		1.09		0+	0.90	200	12–200	**	**
ln ML	Males	−3.36	ns	0.83	ns	0–	0.86	33	46–291	−4.29	ns	1.02	*	0	0.89	78	16–200	*	*
	Females	−3.68		0.91		0	0.59	31	63–192	−4.61		1.13		0+	0.92	122	13–150	ns	ns
ln MSRD on	All	−4.46		0.90		0	0.87	30	70–291	−5.32		1.18		+	0.90	158	13–169	ns	**
ln ML	Males	−4.35	ns	0.88	ns	0	0.89	19	80–291	−5.12	ns	1.11	*	0+	0.92	58	16–169	ns	*
	Females	−4.19		0.83		0	0.57	11	70–160	−5.47		1.23		+	0.91	100	13–150	ns	ns
ln FRW on	All	−3.23		1.01		0	0.95	71	32–291	−2.94		0.93		0–	0.96	92	15–200	ns	*
ln ML	Males	−3.21	ns	1.01	ns	0	0.96	41	32–291	−3.05	ns	0.95	ns	0	0.96	36	15–200	ns	ns
	Females	−3.47		1.07		0	0.92	30	81–192	−2.83		0.91		0–	0.96	56	17–150	ns	*
ln GW on	All	−0.88		0.78		–	0.92	69	53–291	−1.23		0.89		0–	0.95	97	9–200	ns	*
ln ML	Males	−0.96	ns	0.79	ns	–	0.94	41	53–291	−0.90	*	0.79	**	–	0.97	41	9–200	ns	ns
	Females	−1.19		0.85		0–	0.93	28	81–192	−1.67		1.00		0	0.96	56	21–150	ns	ns
ln RW on	All	−3.43		1.07		0	0.95	74	32–291	−3.14		0.98		0	0.97	97	15–200	ns	*
ln ML	Males	−3.31	ns	1.04	*	0	0.95	43	32–291	−3.24	ns	1.00	ns	0	0.97	40	15–200	ns	ns
	Females	−4.04		1.20		0+	0.94	31	81–192	−3.03		0.96		0	0.97	57	17–150	*	**
ln FRL on	All	−0.59		0.70		–	0.90	42	53–291	−0.37		0.70		–	0.94	49	15–200	ns	ns
ln ML	Males	−0.60	ns	0.71	ns	–	0.92	25	83–291	−0.51	ns	0.73	ns	–	0.96	18	15–200	ns	ns
	Females	−0.42		0.67		–	0.80	17	83–192	−0.23		0.67		–	0.93	31	21–150	ns	ns
ln GL on	All	0.22		0.96		0–	1.00	40	53–291	0.22		0.95		0–	0.99	43	15–200	ns	ns
ln ML	Males	0.18	ns	0.97	ns	0–	1.00	24	53–291	0.11	ns	0.97	ns	0	0.99	16	15–200	ns	ns
	Females	0.30		0.94		0–	0.99	16	83–192	0.33		0.93		0–	0.99	27	21–150	ns	ns
ln MSRD on	All	−0.83		0.99		0	0.93	30	70–291	−0.44		1.09		0+	0.99	155	13–169	**	*
ln CSRD	Males	−0.77		0.96		0	0.93	19	80–291	−0.44		1.10		0+	0.99	57	16–169	**	**
	Females	−0.82	ns	0.87	ns	0	0.86	11	70–160	−0.45	ns	1.08	ns	0+	0.99	98	13–150	**	*

Variable acronyms are detailed in Table 1; a and b, intercept and slope of the regression line; a_{sex}/a_{sp}, significance of intercepts test for both sexes from one species/the same sex of both species; b_{sex}/b_{sp}, significance of slopes test for both sexes from one species/the same sex of both species; al, allometry; r^2, determination coefficient; N, sample size; *, $P<0.05$; **, $P<0.01$; ns, $P>0.5$; +/−, positive/negative allometry; 0+/0−, isometry with slight positive/negative tendency to allometry; 0, isometry. Methodological details are explained in the text.

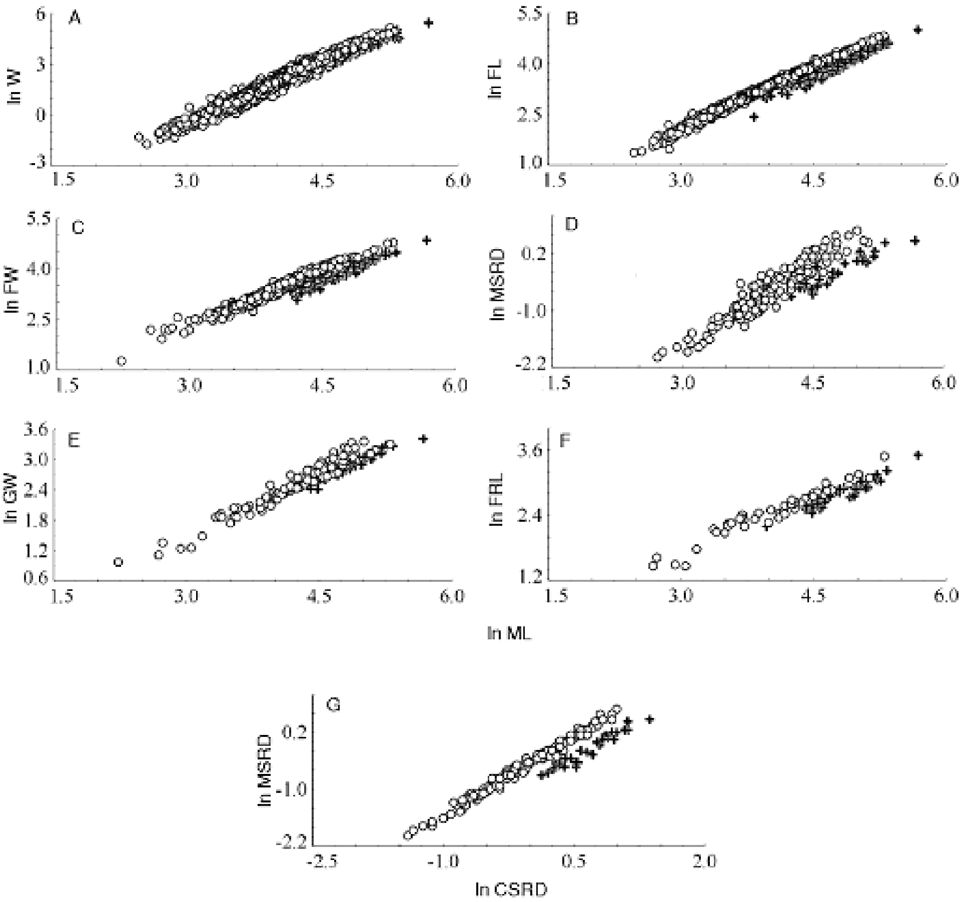

Figure 3. Scatter plots of some morphometric variables of *Loligo sanpaulensis* (o) and *Loligo gahi* (+). (A) ln weight (ln W) on ln mantle length (ln ML); (B) ln fin length (ln FL) on ln mantle length; (C) ln fin width (ln FW) on ln mantle length; (D) ln marginal sucker ring diameter (ln MSRD) on ln mantle length; (E) ln gladius width (ln GW) on ln mantle length; (F) ln free rachis length (ln FRL) on ln mantle length; (G) ln marginal sucker ring diameter (ln MSRD) on ln central sucker ring diameter (ln CSRD).

Table 3. *Results of the comparison of morphometric indices and meristic character (TN) of* Loligo gahi *and* Loligo sanpaulensis.

Index	Mann–Whitney *U*-test for index values				Kolmogorov–Smirnov two sample test for ML distributions						
	L. gahi	*L. sanpaulensis*			*L. gahi*			*L. sanpaulensis*			
	Rank sum	Rank sum	*U*	s.l.	Mean	SD	N	Mean	SD	N	s.l.
W/ML	38,943	52,863	15,938	**	99.4	28.0	214	99.5	28.1	214	ns
FL/ML	15,444	45,981	44	**	106.5	26.4	175	106.8	26.1	175	ns
FW/ML	2636	7804	8	**	98.1	26.9	72	98.2	26.5	72	ns
FW/FL	5003.5	5436.5	2376	ns	97.1	23.8	72	97.1	24.0	72	ns
HL/ML	5384	5347	2646	ns	95.3	26.0	73	95.2	25.7	73	ns
HW/ML	5198	5533	2497	ns	94.9	26.4	73	94.7	26.0	73	ns
FCL/ML	4905	4686	2271	ns	93.8	27.2	69	93.7	26.8	69	ns
NCL/ML	5131.5	3913.5	1636	**	94.6	27.3	67	94.6	26.9	67	ns
AL/ML	4739	6586	1889	**	95.6	25.8	75	94.6	26.9	67	ns
TL/ML	3217.5	4285.5	1327	**	97.3	26.7	61	95.4	25.4	75	ns
CSRD/MSRD	1456	497	1	**	95.6	27.8	31	96.9	26.2	61	ns
FRW/ML	1510	975	345	**	101.5	26.3	35	101.6	25.2	35	ns
RW/ML	1909	1017	276	**	105.6	30.8	38	105.3	29.5	38	ns
GW/ML	919.5	1855.5	216.5	**	107.7	28.6	37	107.2	27.4	37	ns
FRL/ML	489	1222	54	**	99.5	33.8	29	98.5	32.5	29	ns
FRL/GW	640	738	289	ns	97.7	35.2	26	97.3	34.2	26	ns
TN	13,975	23,700	47	**	122.5	40.1	57	59.7	29.9	217	**

Variable acronyms are detailed in Table 1; s.l., significance level; SD, standard deviation; N, sample size; *U*, value of Mann–Whitney test; ns, $P>0.05$; **, $P<0.01$.

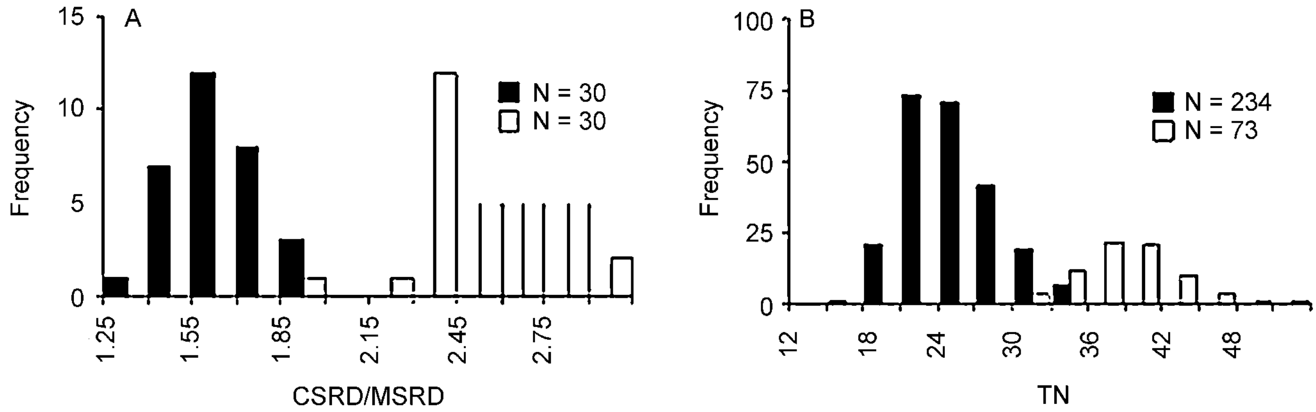

Figure 4. Histograms of (A) ratio of central sucker ring diameter on marginal sucker ring diameter (CSRD/MSRD); and (B) teeth number (TN), for *Loligo sanpaulensis* (full bars) and *Loligo gahi* (empty bars).

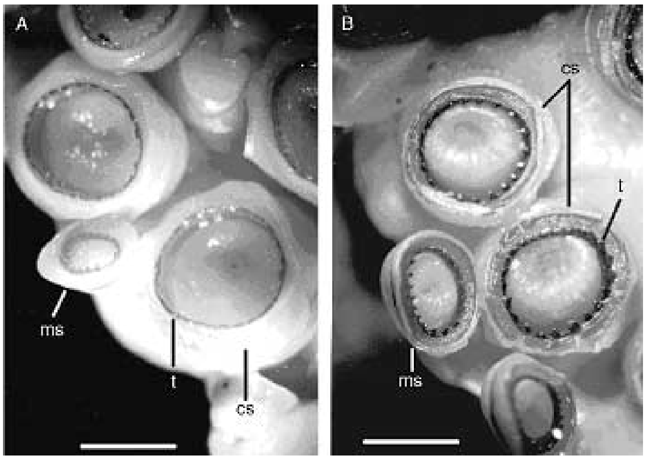

Figure 5. Compared aspect of the tentacles' sucker rings of (A) *Loligo gahi* and (B) *Loligo sanpaulensis*; cs, central sucker; ms, marginal sucker; t, teeth on the sucker ring margins. Scale bars: 2 mm.

NCL (nuchal cartilage length) show negative allometric growth relative to ML (Table 2). The growth rates of HL and HW relative to ML are slightly higher in *L. sanpaulensis* than in *L. gahi*. However, these variables show the lowest determination coefficients and the lines fitted to both species intersect (Table 2). The growth rates of FuL, FuW, FCL and NCL relative to ML are not significantly different between species and between sexes within each species (Table 2). The growth of TL (tentacle length) and AL (arm length) relative to ML is generally isometric in *L. gahi* and slightly allometric in *L. sanpaulensis* (Table 2). The comparatively low determination coefficients of the regressions of ln TL on ln ML (Table 2) show that this relationship is rather variable. The growth rate of AL relative to ML is higher in the males of *L. sanpaulensis* than in those of *L. gahi*, and similar in the females of both species (Table 2). However, AL measurements on both species' males widely overlap. A similar pattern is observed for the relationship between CSRD (central sucker ring diameter) and ML (Table 2). On the contrary, the growth of MSRD (marginal sucker ring diameter) relative to ML is positively allometric in *L. sanpaulensis* and isometric in *L. gahi*, allowing a good separation between species (Table 2; Figure 3). Also, the regression of ln MSRD on ln CSRD permits clear separation between both species (Table 2; Figure 3). The growth rates of FRW (free rachis width) and RW (rachis width) relative to ML are slightly higher in the females of *L. gahi* than in those of *L. sanpaulensis*, and not significantly different between males of both species (Table 2). The regressions of ln FRW and ln RW on ln ML show high determination coefficients, but the lines fitted to both species intercept

Table 4. *Results of the discriminant analysis using three different combinations (a, b and c) of morphometric variables of the mantle/fins complex of* Loligo gahi *and* Loligo sanpaulensis.

Sample information

Loligo gahi
Mean ±SD = 98.2 ±25.4 mm ML, N=100
Loligo sanpaulensis
Mean ±SD=94.6 ±26.9 mm ML, N=100
Kolmogorov–Smirnov two samples test: $P>0.1$

Classification matrix (individuals correctly classified)

Selected variables	(a) ln FL ln ML	(b) ln FW ln ML	(c) ln FW ln FL In ML
Total	98.75%	98.75%	100%
Loligo gahi	100%	97.5%	100%
Loligo sanpaulensis	97.5%	100%	100%

Coefficients of the classification functions

	(a) F *Lg*	(a) F *Ls*	(b) F *Lg*	(b) F *Ls*	(c) F *Lg*	(c) F *Ls*
ln ML	798.7	668.6	247.9	202.2	794.8	663.0
ln FL	−613.5	−504.4			−635.8	−535.9
ln FW			−163.0	−121.4	28.1	39.7
Constant	−689.6	−515.8	−261.9	−214.8	−691.8	−520.2

F *Lg*, classification function for *L. gahi*; F *Ls*, classification function for *L. sanpaulensis*. Analysis sample: 60 individuals from each species; test sample: 40 individuals from each species.

Table 5. *Results of the discriminant analysis using the morphometric variables of the gladius of* Loligo gahi *and* Loligo sanpaulensis.

Sample information		
Loligo gahi		
Mean ±SD = 96.4 ±28.7 mm ML, N=30		
Loligo sanpaulensis		
Mean ±SD = 94.7 ±31.6 mm ML, N=30		
Kolmogorov–Smirnov two samples test: $P>0.1$		
Classification matrix (individuals correctly classified)		
Selected variables	ln FRL ln GL ln GW	
Total	90%	
Loligo gahi	90%	
Loligo sanpaulensis	90%	
Coefficients of the classification functions		
	F *Lg*	F *Ls*
ln FRL	−91.0	−52.6
ln GL	201.7	159.7
ln GW	−99.0	−82.6
Constant	−212.6	−170.6

F *Lg*, classification function for *L. gahi*; F *Ls*, classification function for *L. sanpaulensis*. Analysis sample: 20 individuals from each species; test sample: ten individuals from each species.

Table 6. *Results of the discriminant analysis using the morphometric variables of the tentacles' suckers of* Loligo gahi *and* Loligo sanpaulensis.

Sample information		
Loligo gahi		
Mean ±SD = 125.7 ±49 mm ML, N=30		
Loligo sanpaulensis		
Mean ±SD = 104.3 ±24.5 mm ML, N=30		
Kolmogorov–Smirnov two samples test: $P>0.1$		
Classification matrix (individuals correctly classified)		
Selected variables	ln MSRD ln CSRD	
Total	100%	
Loligo gahi	100%	
Loligo sanpaulensis	100%	
Coefficients of the classification functions		
	F *Lg*	F *Ls*
ln MSRD	−90.5	−44.5
ln CSRD	101.7	53.2
Constant	−41.7	−12.0

F *Lg*, classification function for *L. gahi*; F *Ls*, classification function for *L. sanpaulensis*. Analysis sample: 20 individuals from each species; test sample: ten individuals from each species.

Table 7. *Fin length as a percentage of mantle length (FL/ML×100) for* Loligo gahi *and* Loligo sanpaulensis *individuals classified in 10-mm size- (ML) classes.*

	Loligo gahi				*Loligo sanpaulensis*			
ML (mm)	N	Minimum	Mean	Maximum	N	Minimum	Mean	Maximum
0–10					2	17.6	25.3	32.9
10–20					35	24.3	36.6	51.4
20–30					161	32.4	42.5	53.9
30–40	1		34.8		224	38.7	46.3	55.6
40–50	1		35.7		324	40.2	50.0	57.0
50–60	3	36.8	38.2	40.2	245	43.5	52.2	58.8
60–70	9	32.0	37.3	40.6	188	44.6	53.4	63.0
70–80	10	37.5	39.2	40.4	135	48.2	54.9	60.7
80–90	28	32.2	39.8	46.8	67	52.1	56.1	61.0
90–100	38	34.2	41.5	45.6	54	53.2	57.5	68.3
100–110	26	38.0	42.3	48.4	34	52.3	58.1	60.9
110–120	40	36.6	42.7	50.8	33	52.3	59.4	66.6
120–130	47	38.8	43.9	48.9	10	55.6	59.8	62.2
130–140	35	40.8	45.0	51.3	13	57.0	59.7	62.8
140–150	18	41.2	45.9	49.9	9	58.5	60.1	61.5
150–160	18	41.2	46.2	51.7	3	59.5	63.1	65.1
160–170	8	43.5	47.5	49.5	5	59.0	62.1	64.5
170–180	5	46.2	47.0	47.8	3	61.4	63.6	67.2
180–190	11	44.9	48.3	51.2	1		64.3	
190–200	5	47.7	48.6	49.4	4	59.5	61.6	63.2
200–210	1		46.9					
210–220	1		52.5					
290–300	1		51.3					

(Table 2). The growth rate of GW (gladius width) relative to ML is higher in *L. sanpaulensis* than in *L. gahi*, but this difference is not significant when only males or females of both species are compared (Table 2). Nevertheless, the relationship allows some degree of between-species discrimination (Figure 3). The growth of FRL (free rachis length) relative to ML is negatively allometric and shows identical rates in both species (Table 2). The scatter-plot of ln FRL on ML shows that this is a useful relationship to discriminate both species (Figure 3). The growth of GL (gladius length) relative to ML is slightly allometric, and the measurements for both species overlap over most of the size range. The regressions of TN (teeth number) on ML were not significant for *L. gahi* (P=0.06; N=57) and for *L. sanpaulensis* (P=0.92; N=217), showing that this character does not vary with size.

Indices and meristic characters

All morphometric indices were significantly correlated with ML ($P<0.05$). Only five out 16 indices showed no significant differences between species (Table 3). From all indices, CSRD/MSRD was the one that showed minimum distribution overlap between species (Table 3; Figure 4). Teeth number (TN), the only meristic character analysed, showed no significant correlation to ML, and significantly higher values in *L. gahi* than in *L. sanpaulensis* (Table 3; Figures 4 & 5).

Discriminant analysis

The discriminant analysis performed on the variables of the mantle/fins complex permitted correct classification of 100% of both species individuals (Table 4). The stepwise procedure showed that ln FW was the most discriminant variable, followed by ln ML and ln FL. Furthermore, when only two variables were included in the analysis (ln ML and ln FL, or ln ML and ln FW), 98.75% of the individuals in the test sample were correctly classified (Table 4). The discriminant analysis incorporating the variables of the gladius allowed to correctly classify 90% of the individuals (Table 5). Only ln FRL, ln GL and ln GW showed highly significant differences between species when they were incorporated into the discriminant function, ln RW and ln FRW being excluded by the stepwise procedure. The discriminant analysis including the variables of the tentacles' suckers allowed correct classification of 100% of the individuals employing only two variables (Table 6). In all of these analyses, the classification successes were significantly higher than those obtained by the maximum randomness criterion (Press' Q-test, $P<0.05$). The discriminant functions incorporating the morphometric variables of the remaining structures (head, extremities, funnel and cartilaginous structures) did not allow correct classification of more individuals than those correctly classified by the maximum randomness criterion (Press' Q-test, $P>0.05$), reflecting the low discriminating potential of these body structures.

DISCUSSION

In the present study, from 18 regressions performed in each species only six showed determination coefficients lower than 0.85 in *Loligo gahi*, and three did it in *Loligo sanpaulensis*, the greatest dispersion not explained by the regression models being observed in structures whose measurement is intrinsically variable (head, tentacles and funnel). The higher growth rates of W relative to ML in females of both species compared to males have been previously reported for these species (Vigliano, 1985; Cardoso et al., 1998) and other loliginids (Holme, 1974; Sánchez et al., 1996). This reflects the greater gain of weight of the females' reproductive organs at the onset of maturity, already documented for both species (Hatfield, 1992; Barón & Ré, in press). On the other hand, when comparisons were made between both species' males or females, the growth rate of W on ML was greater in *L. sanpaulensis*, reflecting that maturation is attained at lower sizes in this species. Other differences noted were that *L. gahi* has shorter and narrower fins, smaller marginal suckers on the tentacles' clubs, and a narrower gladius with a shorter free rachis. Also, this species has more teeth on the three largest suckers of the tentacles (TN) (30–51, mean=36.7) than *L. sanpaulensis* (15–33, mean=22.8). Castellanos & Cazzaniga (1979) reported between-species differences in the number of teeth on the suckers of the tentacles (25–35 for *L. gahi* and 15–25 for *L. sanpaulensis*), but they only counted the teeth on the largest sucker. Given that TN is the only variable not correlated to ML, it can be of great utility to identify the juveniles of both species.

Indices can be strongly influenced by the size composition of the samples (Voight, 1991, 1994). In this study, the size bias was removed by comparing subsamples with similar ML distributions. If possible, this procedure should be considered in the future if indices comparisons or discriminant analysis will be used.

The discriminant analysis using the morphometric variables of the mantle/fins complex showed that the combinations of ln FL and ln ML or ln FW and ln ML, have both the same efficiency to discriminate *L. gahi* and *L. sanpaulensis*. However, FL was measured more easily, its use being more practical in field studies. For the samples obtained, the discriminant capacity of the pair of variables ML and FL can be easily visualized by simply classifying *L. gahi* and *L. sanpaulensis* individuals in 10 mm ML-classes, and comparing the percentages of ML occupied by FL (FL/ML×100) within each class (Table 7). It is observed that in *L. gahi*, FL exceeds 50% of ML only at sizes greater than the maximum size reported for *L. sanpaulensis* (200 mm), while in the last species, most individuals at the 40–50 mm ML-class attain this percentage. In the discriminant analysis performed using the morphometric variables of the gladius, ln FRL was the variable that maximized the separation between species. However, this variable and ln FRW required a careful control of outliers. As was noticed by Toll (1998) for the gladius of *Loligo pealei* LeSueur (1821), in *L. gahi* and *L. sanpaulensis* the anterior extension of the gladius vanes converge to the rachis borders, making it difficult to distinguish the point that marks the beginning of the free rachis. Finally, the discriminant analysis performed using CSRD and MSRD confirms the greater importance of the last variable to discriminate *L. gahi* from *L. sanpaulensis*.

In some of the previous papers on the morphometry of *L. gahi* and *L. sanpaulensis*, only a few morphometric variables of one species were examined (Castellanos, 1967; Castellanos & Menni, 1968; Andriguetto & Haimovici, 1988). The only published study that compared the morphometry of both species' soft parts (Castellanos & Cazzaniga, 1979) was based on samples subjected to different preservation methods, being of limited utility. For *L. sanpaulensis*, the morphometric characterization performed by Vigliano (1985) included many variables. However, this author only used linear regression models, limiting the accuracy of his results. For *L. gahi*, the reduced size range of the samples has imposed the most severe limitation on morphometric studies (Carvalho & Pitcher, 1989).

The geographic variability of the morphometric characters is a common feature in the cephalopods (Carvalho & Nigmatullin, 1998). However, this variability can be insignificant in some species, even for distant populations such as those of *L. pealei*, from the Caribbean Sea/Gulf of Mexico and the northern Atlantic coast of the United States (Cohen, 1976). Analysis performed on *Loligo plei* Blainville, 1823, and *L. pealei* have shown that the morphometric characters of these species show the greatest similarity in the geographic range where they are sympatric (Cohen, 1976). This could be related to a phenotypic response to common environmental conditions or to some degree of inter-species hybridization (C. Roper & M. Vecchione, personal communication). The present work provides a detailed description of the morphometry of the northern Patagonian populations of *L. gahi* and *L. sanpaulensis*, which could be used in subsequent studies to detect geographic variation. Given that these populations are sympatric, greater morphometric resemblance should be expected in comparison to non-sympatric populations.

We would like to express our gratitude to the people that provided their help during this study. Juan C. Berón and the captains and crews of the vessels 'Stella Maris' and 'Marta Esther' made it possible to conduct the on-board sampling. Luisa Kuba and Alejandra Monsalve participated in the laboratory activities. Manuel Haimovici, Atila Gosztonyi, Ana Parma and two anonymous referees provided constructive comments on different versions of the manuscript.

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Submitted 26 September 2001. Accepted 26 January 2002.