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Reproductive cycle of *Loligo sanpaulensis* Brakoniecki, 1984 (Cephalopoda; Loliginidae) in southern Brazil*

JOSÉ MILTON ANDRIGUETTO[1] and MANUEL HAIMOVICI[2]

[1]Departamento de Zootecnia, Universidade Federal do Paraná, Rua dos Funcionários, 1540, CEP 80.035-050, Curitiba, PR, Brazil.
[2]Departamento de Oceanografia, Fundação Universidade do Rio Grande, C.P. 474, CEP 96.201-900, Rio Grande, RS, Brazil.

SUMMARY: *Loligo sanpaulensis* is the most abundant coastal squid in southern Brazil. The reproduction of the species was studied from 2,340 specimens obtained in eight groundfish surveys from 1981 to 1987 along the coast of southern Brazil (28°35' S to 34°40' S), at depths from 10 to 587 m. On the shelf, ripe specimens and mated females were found in all seasons, being less frequent in autumn. Most squids caught on the slope during all seasons were immature. The high frequency of fully mature females, and the occurrence of spent males, egg masses and loliginid paralarvae suggested that the species spawns off Southern Brazil. Mature individuals were mostly smaller than 80 mm mantle length (ML) in summer and autumn. In winter and spring, two spawning groups, with 50 - 80 mm ML and larger than 100 mm ML, were detected at depths under and over 40 m respectively. Off southern Brazil, the species has a long spawning period, with peaks in summer and winter/spring. The squid migrates across and along the shelf, taking advantage of the Brazil and Malvinas Currents system to reach suitable spawning and feeding grounds. It is hypothesized that summer spawners may find adequate feeding grounds in winter in the outer shelf while winter spawners may recruit in part to the southern range of the species in northern Argentina in spring, eventually returning northward to reproduce.

Key words: Loligo, squid, reproduction, fishing resources, life cycles, migration, Brazil, subtropical convergence.

RESUMEN: CICLO REPRODUCTOR DE *LOLIGO SANPAULENSIS* BRAKONIECKI, 1984 (CEPHALOPODA; COCIGINIDAE) EN EL SUR DE BRASIL. – *Loligo sanpaulensis* es el calamar costero mas abundante sobre la plataforma continental del sur de Brasil. Su ciclo reproductivo fue estudiado a partir de muestras obtenidas en ocho cruceros de pesca exploratoria de arrastre de fondo realizados de 1981 a 1987 entre las latitudes de 28°35' S y 34°40' S y profundidades de 10 a 587 m. Fueron examinadas las gonadas de 2.340 ejemplares capturados en diferentes épocas del año. Ejemplares maduros y hembras fecundadas fueron encontrados en todas las estaciones, con menos frecuencia en el otoño. Sobre la plataform externa y talud superior la mayoría de los machos y todas las hembras capturados eran inmaduros. La elevada proporción de hembras completamente maduras, de machos en estado de post-freza y la presencia de puestas y paralarvas de loliginidos indican que esta espécie se reproduce en la región estudiada. Los individuos maduros encontrados en verano y otoño eran en su mayoría menores de 80 mm de manto. En invierno y primavera se observaron dos grupos de desovantes, uno a profundidades inferiores a 40 m, compuesto de ejemplares de 50 - 80 mm y otro a profundidades superiores de ejemplares mayores de 100 mm. El período de puesta es prolongado, con probables picos en verano e invierno/primavera. Se concluyó que este calamar realiza migraciones a lo largo de la plataforma aprovechando el sistema formado por las corrientes de Brasil y Malvinas para la alimentación y desove. Varias evidencias incidentales sugieren que los desovantes de verano pueden encontrar areas adecuadas para alimentacion en la plataforma externa en invierno mientras que grupos de los desovantes de invierno pueden reclutarse en primavera al sur, llegando al litoral norte de Argentina en primavera y eventualmente regresar hacia el norte para la reproducción.

Palabras clave: Loligo, calamar, reproducción, recursos pesqueros, ciclos de vida, migración Brasil, convergencia tropical.

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INTRODUCTION

Loligo sanpaulensis Brakoniecki, 1984 (sin. *L. brasiliensis*) is distributed in the Western South Atlantic along the coasts of Brazil, Uruguay and Argentina, approximately between latitudes 20º S and 42º S (Roper *et al.*, 1984; Haimovici and Perez, 1991a). The species is common from Buenos Aires Province in Argentina to Rio de Janeiro (Castellanos, 1967; Juanicó, 1979; Vigliano, 1985; Costa and Haimovici, 1990). It is the most abundant coastal squid in southern Brazil, whereas *Loligo plei* Blainville, 1823 (sin. *Doryteuthis plei*) occurs only in the warm season and on the outer shelf (Juanicó, 1979; Haimovici and Andriguetto,1986; Haimovici and Perez, 1991b). The fishery potential of both species along southern and southeastern Brazil is poorly known but they have been increasingly exploited by artisanal fishermen as well as commercial shrimpers. Landings for both species are reported together and attained 2,193 tons in 1986 (Costa and Haimovici, 1990). The standing stock of *L. sanpaulensis* between 30º40' S and 34º20' S was estimated to have reached approximately 3,600 tons (+/- 44 %) in the spring of 1983 (Andriguetto and Haimovici, 1991).

Reproduction of *Loligo sanpaulensis* has been formerly studied in Argentina (Castellanos, 1967; Vigliano, 1985). In Brazil, Juanicó (1979) studied the species distribution, population structure, reproductive cycle and feeding from Rio de Janeiro to Mar del Plata. Costa and Fernandes (1993) studied the reproductive cycle off Cabo Frio, Rio de Janeiro (23º S).

In an earlier paper, the abundance, distribution, size and sex structures of *Loligo sanpaulensis* were reported, with data from eight seasonal groundfish cruises on the shelf and upper slope off southern Brazil (Andriguetto and Haimovici, 1991). In this paper, maturation and reproductive cycle, related to size, season, depth ranges and latitudes along southern Brazil are described and discussed, based on data from the same surveys.

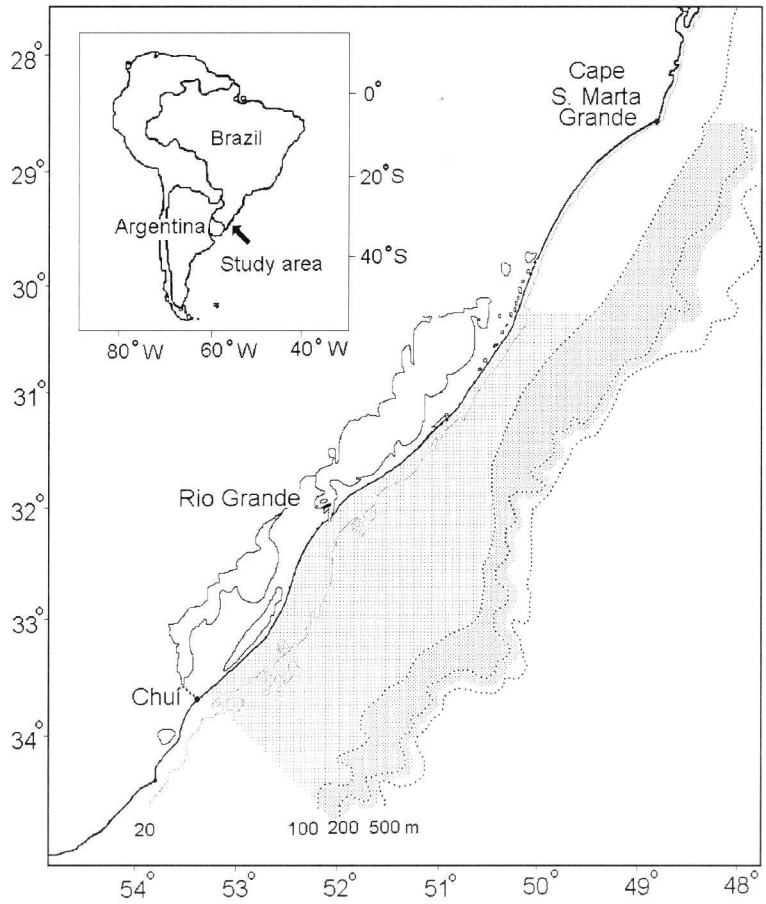

FIG. 1.– Areas surveyed by the R/V Atlântico Sul on the continental shelf (lighter shading) and upper slope (darker shading) off Rio Grande do Sul State, southern Brazil, from 1981 to 1987.

TABLE 1.– Summary data of the cruises in which data on the reproduction of *Loligo sanpaulensis* were collected (frequency of occurrence, % of tows with *L. sanpaulensis;* ML, dorsal mantle length; (*), bottom temperature range between 100 and 200 m, from Haimovici and Perez, 1991b).

Cruise period	Latitude range (south)	Depth range (m)	Bottom temp. range (°C)	Number of tows and frequecy of occurrence		Mantle length (mm) minimum	mean	maximum
14 to 22/01/82	30°46' - 34°14'	12-119	12.8 - 22.9	42	69.0%	20	58.4	160
16 to 26/04/83	30°51' - 34°18'	13-122	15.5 - 22.6	41	95.1%	20	52.5	110
09 to 30/08/83	30°54' - 34°19'	12-160	11.3 - 17.8	54	87.0%	10	76.2	190
08 to 19/11/83	30°46' - 33°36'	10-100	12.6 - 20.2	34	85.3%	20	80.5	170
19/07 to 02/08/86	31°58' - 34°33'	130-504	14.0 - 16.0*	17	35.3%	20	50.1	90
06 to 15/09/86	28°35' - 31°11'	128-510	14.5 - 17.3*	19	26.3%	30	47.3	70
14 to 21/03/87	30°47' - 34°31'	128-498	14.7 - 17.5*	18	11.1%	20	45.4	80
14 to 19/05/87	28°53' - 31°15'	140-575	15.0 - 19.0*	12	8.3%	20	33.0	40

MATERIALS AND METHODS

Samples of *L. sanpaulensis* were obtained at depths ranging from 10 to 220 m in eight groundfish cruises of the RV Atlântico Sul, four on the inner shelf and four on the outer shelf and upper slope off Rio Grande do Sul state between latitudes 28º35' S and 34º S (Fig. 1). Depth, latitude and bottom temperature ranges for all surveys are given in Table 1. Additional shelf samples were taken from former cruises in January 1981 (summer) and April 1981 (fall).

Samples were collected with bottom trawls in tows 30 to 60 minutes long at a speed of three knots, both on the slope and on the shelf. All tows were made between dawn and dusk. Bottom and surface temperatures were recorded after each trawl. A total of 2,340 specimens from all cruises and representative of different fishing depths and latitudes were fixed in 10% buffered formalin sea water and transferred into 70% ethanol after no less than 24 hours. In the laboratory, the dorsal mantle length (ML) was measured in millimeters, and sex, maturity stage and spermatophore presence and position on mated females were also recorded. Total weight, and length of testicles (TL) and nidamental glands (NGL) were recorded in at least ten individuals per 10-mm mantle length (ML) class in each sample.

Sexual maturity was recorded with a five-stage scale (Juanicó, 1983; Lipinski, 1979) adapted to preserved material (J, juveniles; A, immature; B, maturing; C, mature; D, spent). Individuals were considered to be juveniles when no sexual organs could be recognized under a binocular microscope. Numeric maturity indices were also calculated: for males a testicular length index (TI=TL/ML), and for females a nidamental gland length index (NGI=NGL/ML) (Durward *et al.*, 1979; Macy, 1982a). Fig. 2 shows a good agreement between maturity stages and index values, validating the equivalence of both indicators, and the results of those analysis where only one of them could be used.

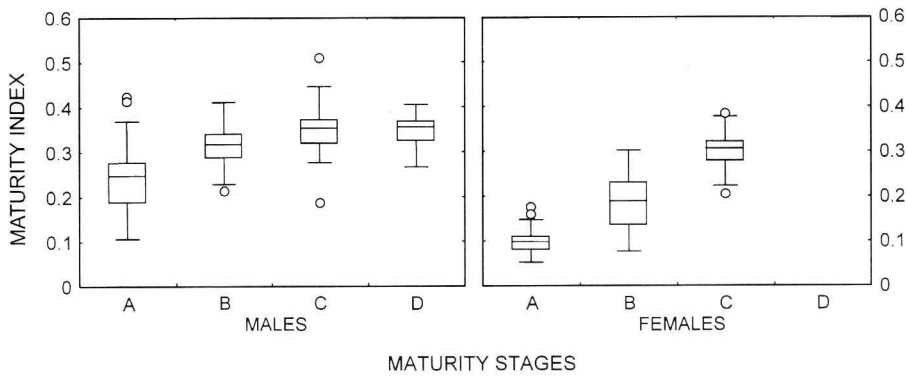

FIG. 2.– Box-and-whiskers plots of testicular length index and nidamental gland length index of *Loligo sanpaulensis* per maturity stage off southern Brazil (A, immature; B, maturing; C, mature; D, spent; box shows quartiles and median).

TABLE 2.– Relative frequencies (%) of maturity stages of *Loligo sanpaulensis* by sex, season and location off southern Brazil. Maturity stages: A, immature; B, maturing; C, mature; D, spent (males only); S, mated females with spermatophores.

	SUMMER		FALL		WINTER		SPRING	
Maturity stages	Inner Shelf	Upper Slope	Inner Shelf	Upper Slope	Inner Shelf	Upper Slope	Inner Shelf	Upper Slope
	Males (N=918)							
A	24	67	40	-	20	44	7	75
B	51	24	48	-	24	23	49	23
C	20	9	12	-	50	33	44	2
D	5	0	0	-	6	0	0	-
	Females (N=875)							
A	20	55	44	-	9	50	9	52
B	46	45	27	-	48	50	42	48
C	34	0	29	-	43	0	49	-
S	35	0	15.5	0	30.3	0	40.5	0

RESULTS

Mature individuals and mated females were found throughout the year on the shelf, with higher frequency in winter and spring (Table 2). Spermatophores always occurred in the buccal pouch of mature and maturing females, except for two individuals caught during summer in 1981, in which the spermatophores were attached to the inner wall of the mantle. Maturity indices were higher in spring and summer on the shelf (Fig. 3). No spent females were found, while the percentage of spent males was 5% in summer and 6% in winter. On the slope, more than 90% of the sampled animals were immature or maturing, and no mated females were found. Juveniles, smaller than 28 mm ML, occurred in small numbers during fall on the shelf (1.6%), between 80 and 120 m, and during summer and fall on the slope (3.3%).

Mantle length distributions of squids in different stages of maturation overlapped greatly. The smallest mature males were 45 mm and the smaller females 40 mm ML. Some individuals of both sexes remained immature until they reached 90 mm ML. Squids larger than 105 mm ML were all mature.

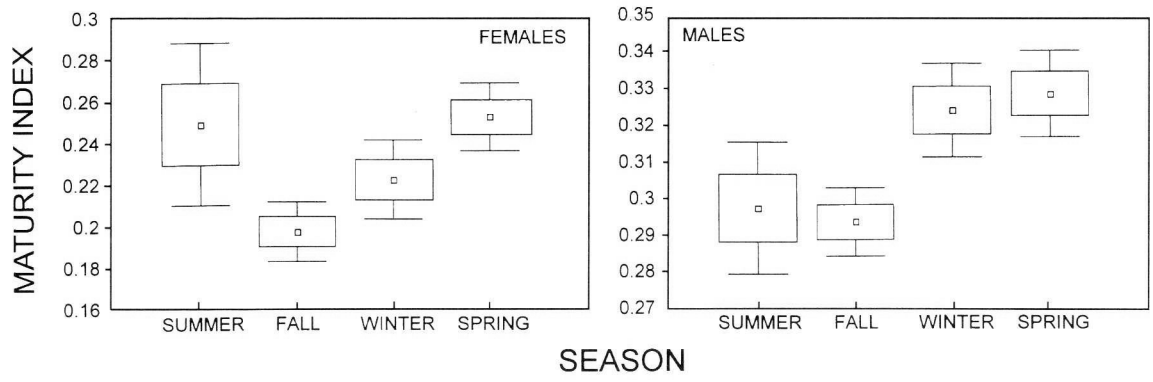

FIG. 3.– Box-and-whiskers plots of sexual maturity indices of *Loligo sanpaulensis* per season on the shelf off southern Brazil. Box shows 95% confidence intervals and average.

Fig. 4 shows that in summer and fall maturation is reached at lengths around 80 mm. In winter and spring there seems to be a group of animals maturing between 50 and 80 mm ML and a second group maturing at lengths larger than 100 mm. Frequency of mated and mature females by size class showed good correspondence (Fig. 4). Only females larger than 30 or 40 mm were mated in all seasons. Minimum lengths of spent males were 40 mm in summer and 70 mm in winter.

Highest percentages of mature males and females and mated females were found at intermediate depths or inshore, depending on the season (Fig. 5). On the slope, no mature females were found and a few mature males were caught only during winter (Table 2). An offshore - inshore migration seems to occur during maturation. Latitudinal variations were observed on the shelf only in winter, when 72% of males and 57% of females were mature in the south, compared to 32% and 15%, respectively, in the north.

An association between length and maturation was found associated with depth ranges. The 40-m isobath separates the smaller winter - spring maturing squids from those maturing at larger sizes that occur only beyond that depth (Fig. 6). This phenomenon was observed for females in all seasons, and for males during fall and winter.

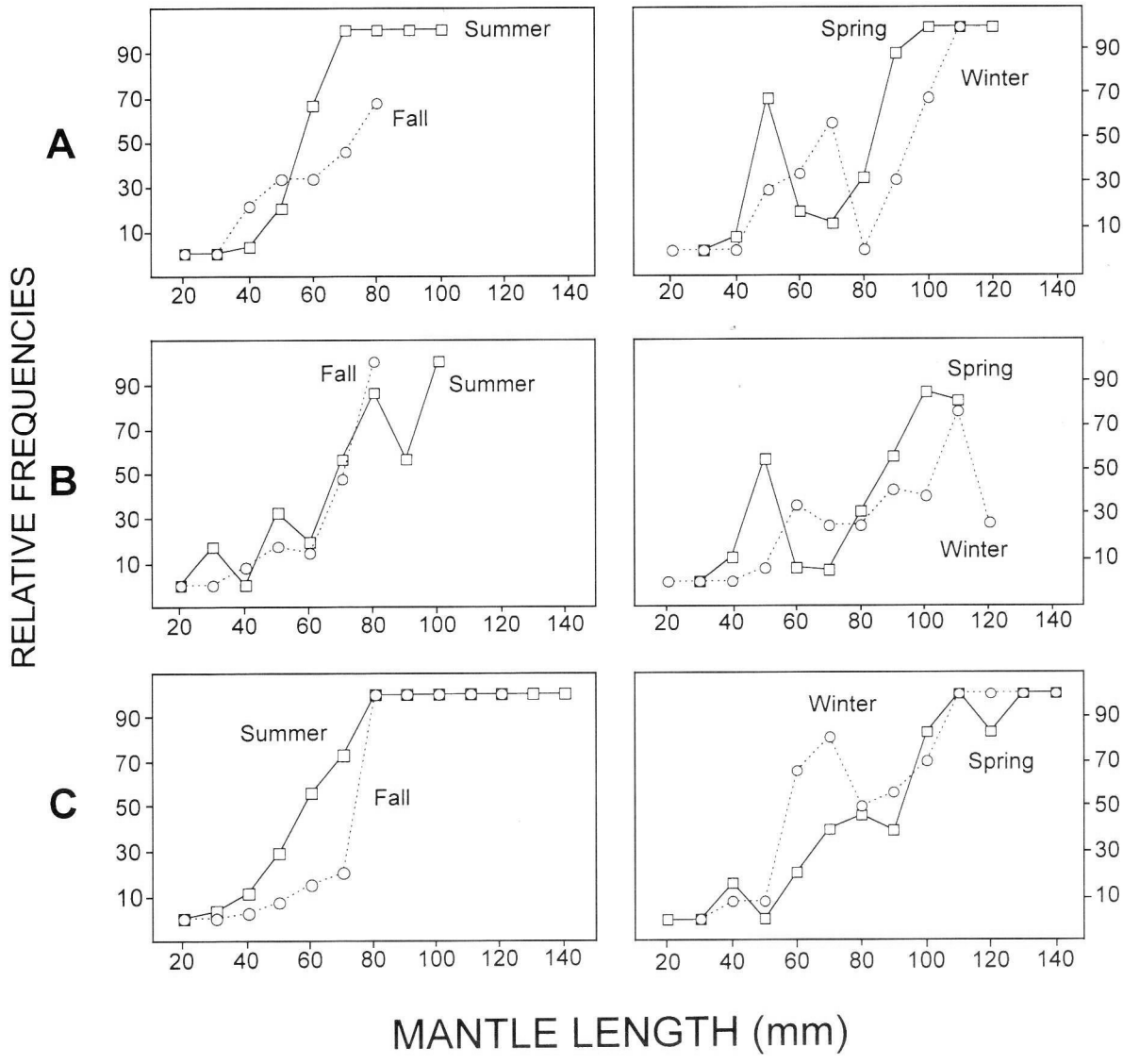

FIG. 4.– Relative frequencies (%) of mature individuals and mated females of *Loligo sanpaulensis* by size class and season on the shelf off southern Brazil. A, mature females; B, mated females; C, mature males.

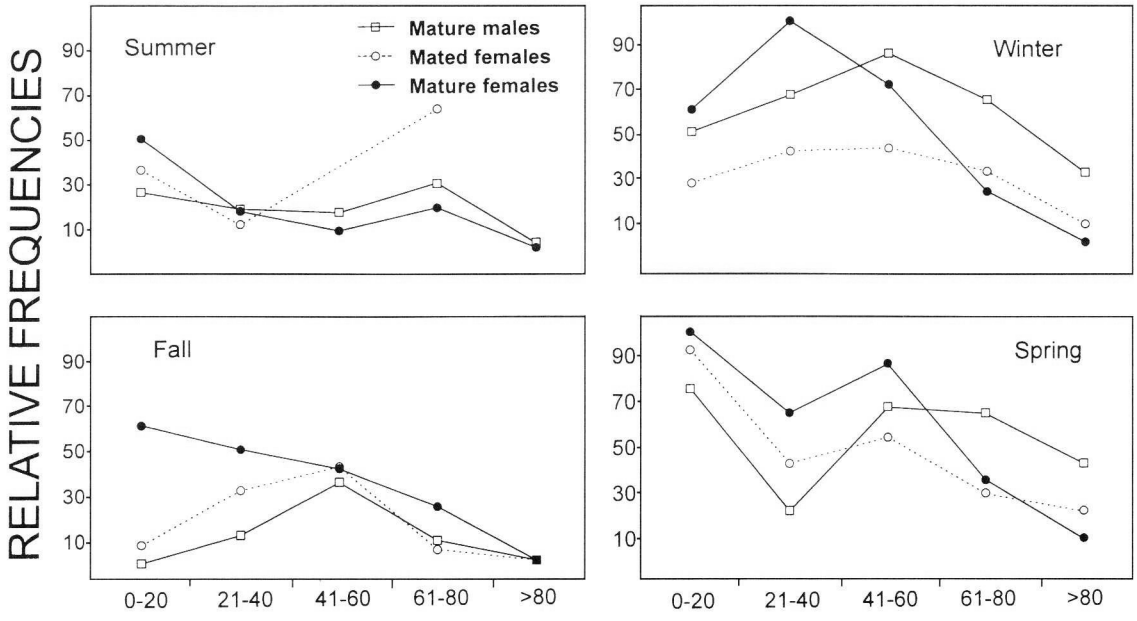

FIG. 5.– Relative frequencies (%) of mature individuals and mated females of *Loligo sanpaulensis* by depth stratum and season on the shelf off southern Brazil.

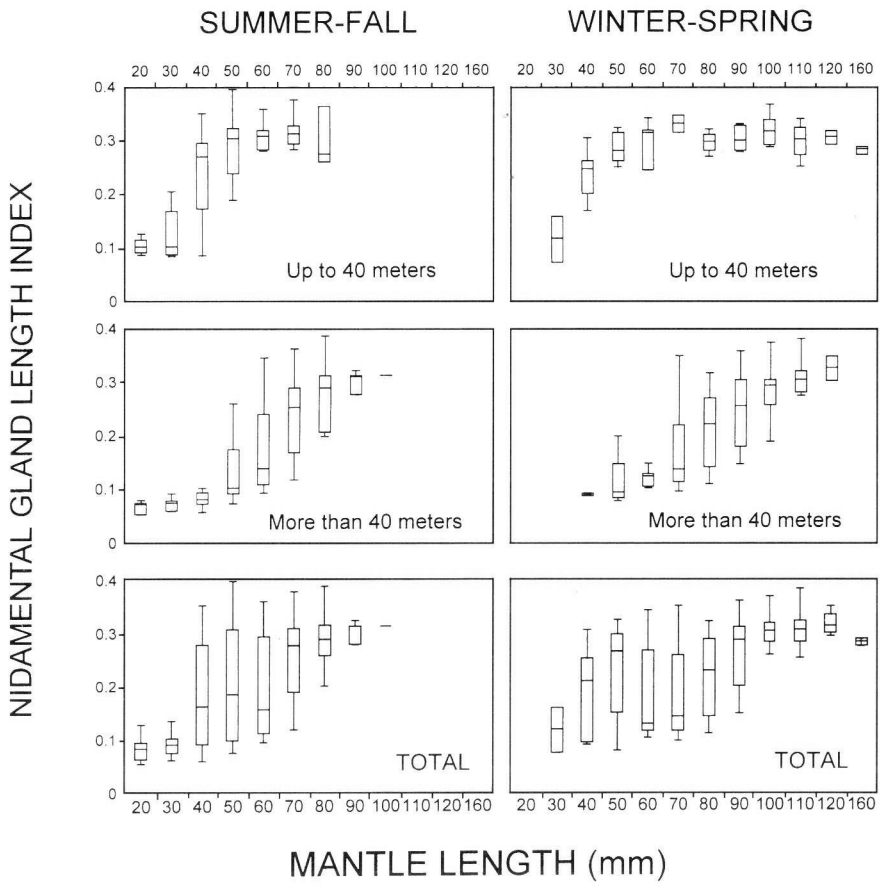

FIG. 6.– Box-and-whiskers plots of nidamental gland length index values for female *Loligo sanpaulensis* by size class, season and depth zone on the shelf off southern Brazil. Box shows quartiles and median.

DISCUSSION

Reproductive activity in *L. sanpaulensis* spans the whole year off southern Brazil. Spawning is suggested by the occurrence in all seasons of oviducts full of mature eggs. This was also supported by the occurrence of loliginid paralarvae in plankton surveys (Haimovici and Perez, 1991b) and of egg masses characteristic of Loliginidae, in two tows in spring at depths of 55 and 62 m, and bottom temperatures of 17.5 and 17.8°C. Although there was no positive identification, *Loligo sanpaulensis* was the only loliginid caught in the same spring cruise. The high proportion of mated females, as indicated by the presence of spermatophores in the buccal pouch, may indicate that mating continues until just prior to or during spawning.

From the above information, it is possible to fit the reproductive cycle of *Loligo sanpaulensis* off southern Brazil in the category of "extended seasonality" in the classification of Mangold (1987, p. 190). The data series available for this study suggest that there are two peaks of spawning in summer and in winter/spring. Intensity of reproduction seems to be lower in fall, in coincidence with recruitment evidenced in other works. Juanicó (1979) caught spent females and a large proportion of small squids in samples off Rio Grande (32° S) in March, while Andriguetto and Haimovici (1991) found highest numeric abundance and smallest mean sizes in the April 1983 survey. Accordingly, Andriguetto (1989) observed decreased feeding activity during the same season.

Spawning grounds of *L. sanpaulensis* also occur further north, between Rio Grande do Sul and Cabo Frio (Juanicó, 1979). That author found concentrations of juveniles from Santa Catarina Island (27° S) to Rio de Janeiro (22° S) in surveys from September to November, but provided no data on the duration and location of spawning. In the southern range of the distribution of *L. sanpaulensis*, off northern Argentina, Castellanos (1967) and Castellanos and Menni (1969) proposed year-round spawning, with higher intensity from November to March (spring to summer). However, Vigliano (1985), who took regular monthly samples, found higher frequencies of juveniles in spring, but no spent females off Mar del Plata (lat. 38° S). He concluded that there is no spawning in that region, and that the spawning period of the juveniles recruited off Mar del Plata was long, with peaks in spring and summer.

The reproductive strategy of *L. sanpaulensis* seems to be strongly influenced by the environment. In a localized seasonal upwelling system off Cabo Frio, Rio de Janeiro (Lat. 22° S), the species has a short seasonal reproductive cycle and a single maturing size (Costa and Fernandes, 1993). That contrasts with a wide size range of spawners and the protracted spawning season observed in southern Brazil, which lies roughly in the middle of the species known distribution range.

Existing data, combined with results of this study, allow migration patterns to be inferred. Haimovici and Perez (1991a) report that *Loligo sanpaulensis* is found on the outer shelf and upper slope only during winter and spring, where no mature animals occurred. Andriguetto and Haimovici (1991) suggest that animals larger than 60 mm migrate northward from Argentinian waters in winter and spring, following the dynamics of the Subtropical Convergence, in agreement with the conclusions by Vigliano (1985, *op. cit.*). In the present study, mature animals concentrated south of the Convergence only in winter. Juanicó (1979) found population groups beginning maturation at different sizes and segregated by latitude. Such groups also suggest migration along the coast, since there was no evidence for geographic populations. Thus, it seems that squids move along the shelf, and also inshore-offshore, shifting between spawning grounds in the inner shelf, probably to the north of our survey area, and feeding grounds along the front between the cold, rich waters of the Malvinas Current and warmer waters of tropical origin. Squids also move towards the outer shelf and upper slope in winter and spring, along the western boundary of the Subtropical Convergence.

Although the life cycle of *Loligo sanpaulensis* off southern Brazil still cannot be fully explained, available information fits into an alternate generations model similar to that proposed by Mangold (1966) for Sepia officinalis and by Mesnil (1977) for *Loligo pealei*, posing a major hypothesis for future research. The alternating longer and shorter generations in the model would account for the two reproduction peaks observed, and the different ML distributions between summer and winter/spring mature animals. Age determinations should be necessary to test if the two groups suggested by the two modes on the ML distributions of winter and spring mature squids in Fig. 4 satisfy a condition of the model, namely, the simultaneous existence of two spawning groups,

with different ages and sizes. This hypothesis is favored by the fact that the two size groups are segregated by depth with the smaller mature squids inshore and larger ones off the 40-m isobath, specially in spring (Fig. 6). Future research on the reproductive pattern and life cycle of *L. sanpaulensis* should also require the localization of spawning grounds and age determination of spawners in different places and seasons.

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