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Abundance and distribution of *Loligo sanpaulensis* Brakoniecki, 1984 (Cephalopoda, Loliginidae) in southern Brazil*

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SUMMARY: *Loligo sanpaulensis* is the most abundant coastal squid in southern Brazil. This paper analyzes its distribution and abundance in the continental shelf off Rio Grande do Sul state. Samples were taken during four groundfish cruises of the RV Atlântico Sul in 1982 and 1983, one in each season, and covered latitudes from 30° 40′ to 34° 30′ S at depths ranging from 10 to 120 m, using a bottom trawl with 52.9-m footrope and a 50-mm cod-end mesh size. *Loligo sanpaulensis* was present in all seasons over the whole shelf. Highest catches were taken in spring, averaging 7.8 kg/h +/− 44 %; total abundance was estimated to be 3,554 metric tons. Significantly higher densities were found between 40 and 80 m in the southern part of the survey area, at bottom temperatures less than 18 °C. Larger specimens, up to 190 mm dorsal mantle length in the case of males, were taken at intermediate depths in winter and spring, when length distributions showed two modes. Bottom water temperature was an important distribution factor. *Loligo sanpaulensis* was associated with colder, more productive areas of water masses fronts, namely the Subtropical Water and the northern influence limit of the Subantarctic Water of the Malvinas Current. The species has some potential as a fishing resource off south Brazilian coast.

Key words: Loligo, squid, distribution, abundance, fishing resources, Subtropical Convergence, oceanographic systems, Brazil.

RESUMEN: ABUNDANCIA Y DISTRIBUCIÓN DE *Loligo sanpaulensis* Brakoniecki, 1984 (Cephalopoda, Loliginidae) en el sur de Brasil. — *Loligo sanpaulensis* es el calamar costero más abundante del sur de Brasil. Este trabajo analiza su distribución y abundancia en la plataforma interna del Estado de Río Grande do Sul. Los datos fueron obtenidos en cuatro campañas de pesca demersal en 1982 y 1983, uno en cada época del año, entre 10 m y 120 m de profundidad entre las latitudes de 30° 40′ S y 34° 30′ S. Se utilizó una red de arrastre de fondo con malla de 50 mm entre nudos opuestos y relinga inferior de 52,9 m. *Loligo sanpaulensis* apareció durante todas las épocas en toda la plataforma. Las mayores capturas se obtuvieron en primavera, alcanzándose 7,8 kg/h +/− 44 %. La abundancia total se estimó en 3554 toneladas. Las mayores densidades se observaron entre 40 m y 80 m al sur de Río Grande, con temperaturas inferiores a 18 °C. Los mayores ejemplares (190 mm de longitud dorsal del manto para machos) se capturaron a profundidades intermedias en invierno y primavera, cuando las distribuciones de tallas fueron bimodales. La temperatura de fondo fue un importante factor de distribución. *Loligo sanpaulensis* se asoció a las áreas más frías y productivas de los frentes de masas de agua: el Agua Subtropical y el límite norte de influencia del Agua Subantárctica de la Corriente de Malvinas. La especie resulta un recurso potencial pesquero en el sur de Brasil.

Palabras clave: Loligo, calamar, distribución, abundancia, recursos pesqueros, convergencia subtropical, sistemas oceanográficos, Brasil.

INTRODUCTION

Loliginid squids are typically coastal water inhabitants, with broad distribution on continental shelves both in tropical and in temperate regions (ROPER *et al.*, 1984). Two species are common in southern Brazil: *Loligo plei* Blainville, 1823 (sin. *Doryteuthis plei*) and *Loligo sanpaulensis* Brakoniecki, 1984 (sin. *Loligo brasiliensis*) (JUANICÓ, 1979; HAIMOVICI and PÉREZ, in press).

Most research on *Loligo sanpaulensis* has been done in Argentina (CASTELLANOS, 1967; CASTELLA-

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NOS and MENNI, 1969; VIGLIANO, 1985) and Uruguay (LETA, 1983, 1987; NION *et al.*, 1986). Studies in Brazil have focused on taxonomy (VOSS, 1964; PALACIO, 1977, 1978). Despite the ecological and economic importance of cephalopods (see, for example, ROPER *et al.*, 1984 and CADDY, 1983), the only work with an ecological approach is that of JUANICÓ (1979), dealing with squid species on the continental shelf from Rio de Janeiro to Mar del Plata.

Fishery potential of squids is poorly known in Brazil. In a review for South America, JUANICÓ (1980) pointed out the lack of reliable data for Brazilian waters. COSTA and HAIMOVICI (1990) summarized available statistics for cephalopod landings from Rio de Janeiro (lat. 21°S) to Rio Grande do Sul (lat. 34°S). Squid statistics included both *Loligo* species and increased from 487 tons in 1979 to 2193 tons in 1986.

Loligo sanpaulensis is the most abundant coastal squid in southern Brazil (JUANICÓ, 1979; HAIMOVICI and ANDRIGUETTO, 1986; ANDRIGUETTO, 1989), as well as in northern Argentina (CASTELLANOS, 1967; VIGLIANO, 1985). This paper analyzes data from four seasonal groundfish cruises of the RV Atlântico Sul in southern Brazil between latitudes 30°S to 34°S. It is interesting to note that this survey area lies roughly in the middle of the species known distribution range, from latitudes 20°S to 42°S (ROPER *et al.*, 1984). Abundance estimates, and size and sex composition are presented, as well as their seasonal variations. The relationship between hydrographic conditions and distribution patterns is discussed. A strong association was found between the stock of *Loligo sanpaulensis* and the western edge of the Subtropical Convergence, where waters of the Brazil and Malvinas Currents meet.

MATERIALS AND METHODS

Samples were obtained in four groundfish cruises of the RV Atlântico Sul in 1982 (January, cruise 1/82) and 1983 (April, cruise 4/83; August, cruise 9/83 and November, cruise 13/83). Surveys covered the inner continental shelf, at depths ranging from 10 to 120 m, between the lighthouses of Solidão (30° 30′S) and Chui (34° 30′S) (Table 1, Fig. 1). A total of 171 samples were collected with a bottom trawl with a 52.9-m footrope, 31.3-m headrope, and a 50-mm stretch-mesh cod end. Trawl tows were 30 to 60 minutes long at a speed of three knots. All tows were made between dawn and dusk. Bottom and surface temperatures were recorded after each trawl.

All, or a known proportion of, the catch of *Loligo sanpaulensis* was weighed and counted. The weight of some samples was estimated from length-weight relationships. Dorsal mantle lengths (ML) of a total of 2,526 individuals were measured in milimeters, and then they were fixed in 10 % buffered formalin in sea water and transferred to 70 % ethanol after no less than 24 hours.

The first three cruises covered approximately 58 000 km^2, the last covering aproximately 46 000 km^2 (Fig. 1). The survey area was divided into four coastal zones perpendicular to the coastline and five depth strata with boundaries at 20, 40, 60, 80 and 120 m (Fig. 1). Mean density, in numbers and weight per hour, was calculated for each cruise according to the methodology described in SAVILLE (1977) and FOGARTY (1985), using depth strata areas and average densities (Table 2). Total abundance for each cruise was estimated by the swept-area method, considering the horizontal opening of the trawl as equivalent to 43 % of the footrope (ALVERSON, 1971).

RESULTS

Loligo sanpaulensis was caught in 143 (84 %) of the 171 tows, at all depths and in all seasons. Frequency of ocurrence was lower in shallow water down to 20 m in the spring and down to 40 m in the austral summer (Table 2). Most of the 28 hauls in which the species was absent ocurred south from Rio Grande (32°S), in the summer cruise. Nineteen of them were made at depths less than 40 m, and only five at depths greater than 50 m. Larger concentrations were found

TABLE 1. — Summary data of R/V Atlântico Sul's cruises off southern Brazil. ML, dorsal mantle length of *Loligo sanpaulensis*; FO, percent occurrence of squid.

Cruise	*Period*	*Latitudes (south)*	*Depth (m)*	*Bottom temp. (°C)*	*No. of tows*	*FO (%)*	*ML (mm)* *Min.*	*mean*	*max.*
1/82	14 to 22/01/82	30°46′ – 34°14′	12-119	12.8-22.9	42	69.0	20	58.4	160
4/83	16 to 26/04/83	30°51′ – 34°18′	13-122	15.5-22.6	41	95.1	20	52.5	110
9/83	09 to 30/08/83	30°54′ – 34°19′	12-160	11.3-17.8	54	87.0	10	76.2	190
13/83	08 to 19/11/83	30°46′ – 33°36′	10-100	12.6-20.2	34	85.3	20	80.5	170

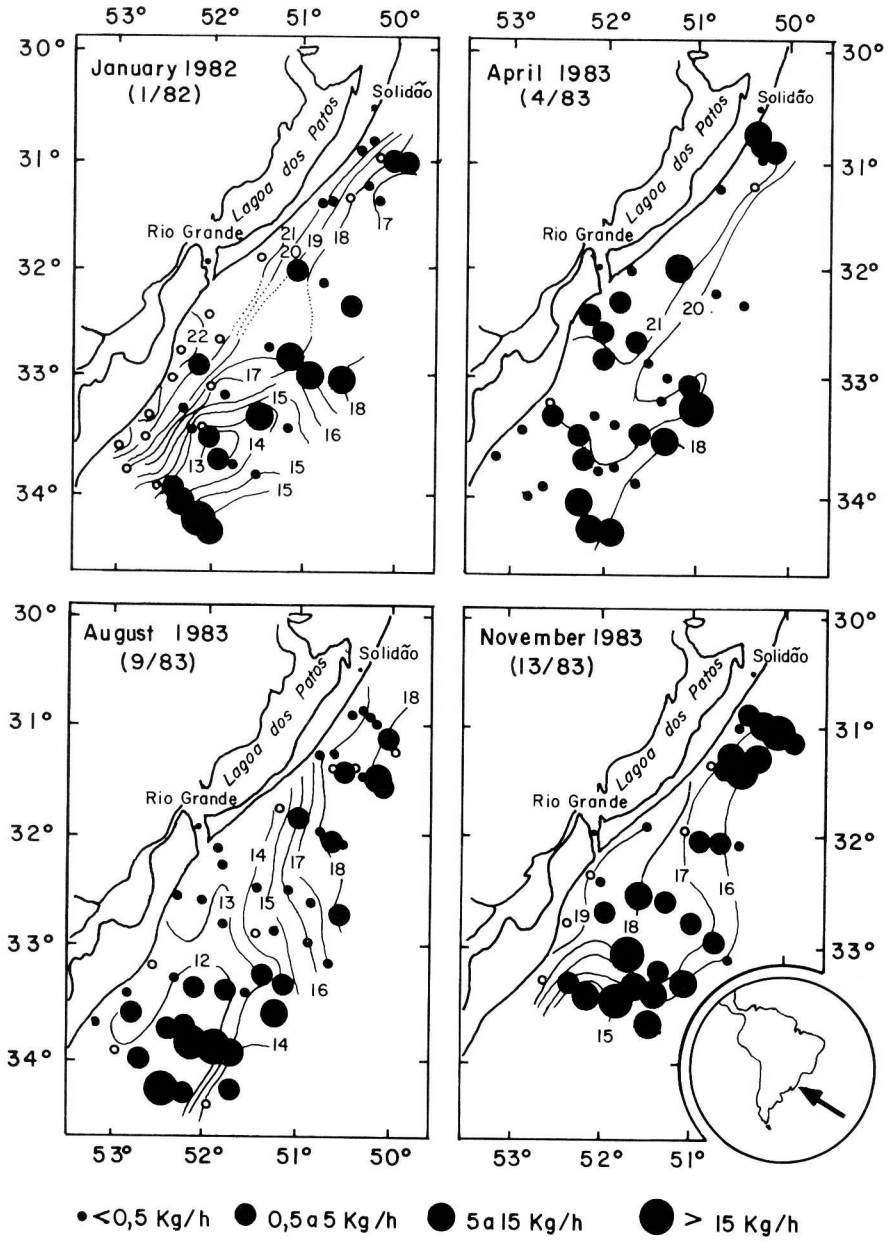

FIG. 1. — Catches in kilograms per hour (kg/h) of *Loligo sanpaulensis* and bottom isotherms in four seasonal surveys off southern Brazil. The arrow in the inset indicates the location of the survey area in South America.

TABLE 2. — Mean catch and percentual frequency of occurrence (FO) of *Loligo sanpaulensis* per depth strata in four seasonal demersal surveys off southern Brasil. Parentheses enclose the total number of hauls in each depth stratum.

Depth (m)	*Stratum area (km²)*	*Summer 1/82*		*Fall 4/83*		*Winter 9/83*		*Spring 13/83*		*Mean FO (%)*
		kg/h	*FO (%)*	*kg/h*	*FO (%)*	*kg/h*	*FO (%)*	*kg/h*	*FO (%)*	
0 — 20	9223	0.49	46 (13)	2.73	86 (7)	0.15	78 (9)	0.08	43 (7)	61
20 — 40	12186	0.00	0 (4)	1.85	100 (9)	0.34	83 (6)	2.61	100 (5)	79
40 — 60	11326	5.10	80 (10)	1.42	100 (9)	7.69	85 (13)	19.52	83 (6)	87
60 — 80	12268	3.90	100 (8)	1.85	100 (9)	2.10	92 (13)	6.83	100 (7)	97
80 — 120	13020	3.41	100 (7)	5.84	86 (7)	3.42	85 (13)	5.01	100 (9)	92
Average		3.2	69 (42)	2.7	95 (41)	3.8	87 (54)	7.8	85 (34)	84

TABLE 3. — Mean densities and total abundance estimates (millions of individuals and tons) of *Loligo sanpaulensis* per season off southern Brazil. Spring values are significantly higher ($p < 0,005$). (% CI, 95 % confidence interval as percentage of the estimates; No./h, numbers per hour; kg/h, kilograms per hour).

Season	*No./h*	*Millions*	*CI%*	*Kg/h*	*Ton*	*CI%*
Summer	256.3	117.6	58	3.2	1477	48
Fall	291.5	133.8	48	2.7	1242	51
Winter	199.1	91.4	49	3.8	1728	63
Spring	333.2	156.0	33	7.8	3554	44

in the southern part of the survey area, at intermediate depths.

Seasonal variations in abundance

Abundance in weight in the inner shelf was significantly greater in the austral spring, as determined by Kruskal-Wallis test (Table 3). Mean number of individuals was maximum and the stratified mean catch per tow in kg/h was at its highest. A second peak of density in numbers ocurred in the autumn, but this was coupled with the lowest density in weight. Total abundances (metric tons) were calculated for spring in table 3 considering the areas covered by the other cruises in all depth strata. This overcame any underestimation resulting from the smaller area covered by cruise 13/83 (Fig. 1). The procedure is justified, since lower catches to the south are improbable, considering the pattern observed in the other cruises.

Only squid over 28 mm ML were sexed and a 1:1 sex ratio was observed throughout the year. Juveniles ocurred in small numbers in the autumn; largest males, up to 190 mm, and females, up to 160 mm, were caught in the winter (Table 1). Size ranges were greater in winter and spring, and the size distribution had two modes during these seasons, the largest group composed only of males. Only the smaller modal group was observed in summer and autumn (Fig. 2).

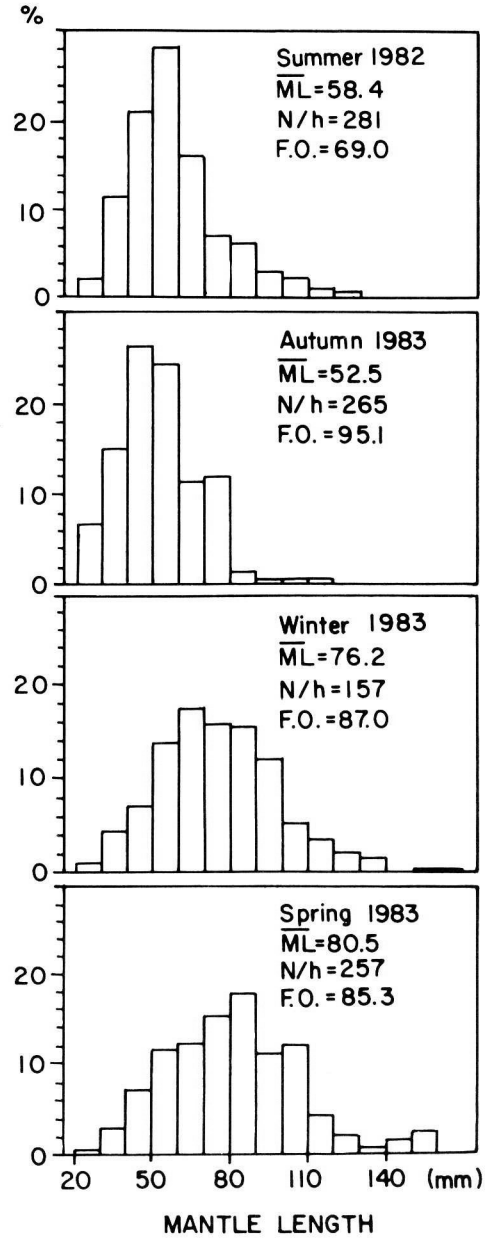

FIG. 2. — Mantle length composition of *Loligo sanpaulensis* in four seasonal demersal surveys off southern Brazil (ML, mean mantle length; N/h, mean catch in numbers per hour; F. O., percentual frequency of occurrence).

Spatial distribution

Catches in kg/h and n/h differed significantly between depth zones in all seasons, except for autumn (cruise 4/83) (Fig. 3). Kendall's Rank Correlation test indicated a positive, significant correlation between catch and depth. In autumn, highest catches were obtained at 80 m. In the other seasons, the stock concentrated in the 40-60 m zone, specially in the spring, when average catch attained 15 kg/h.

Highest catches were taken in the southern half of the survey area (Fig. 3). Differences were greater and significant in the winter, when catches averaged 1.5 kg/h in the northern half of the shelf, and 7 kg/h in the south. High catches between 32.5°S and 33.5°S in cruise 13/83 suggest that the spring stock size may be underestimated, despite the correction factor used for the area (see above).

The distribution pattern shown by mean catches in terms of numbers was slightly different. Means we-

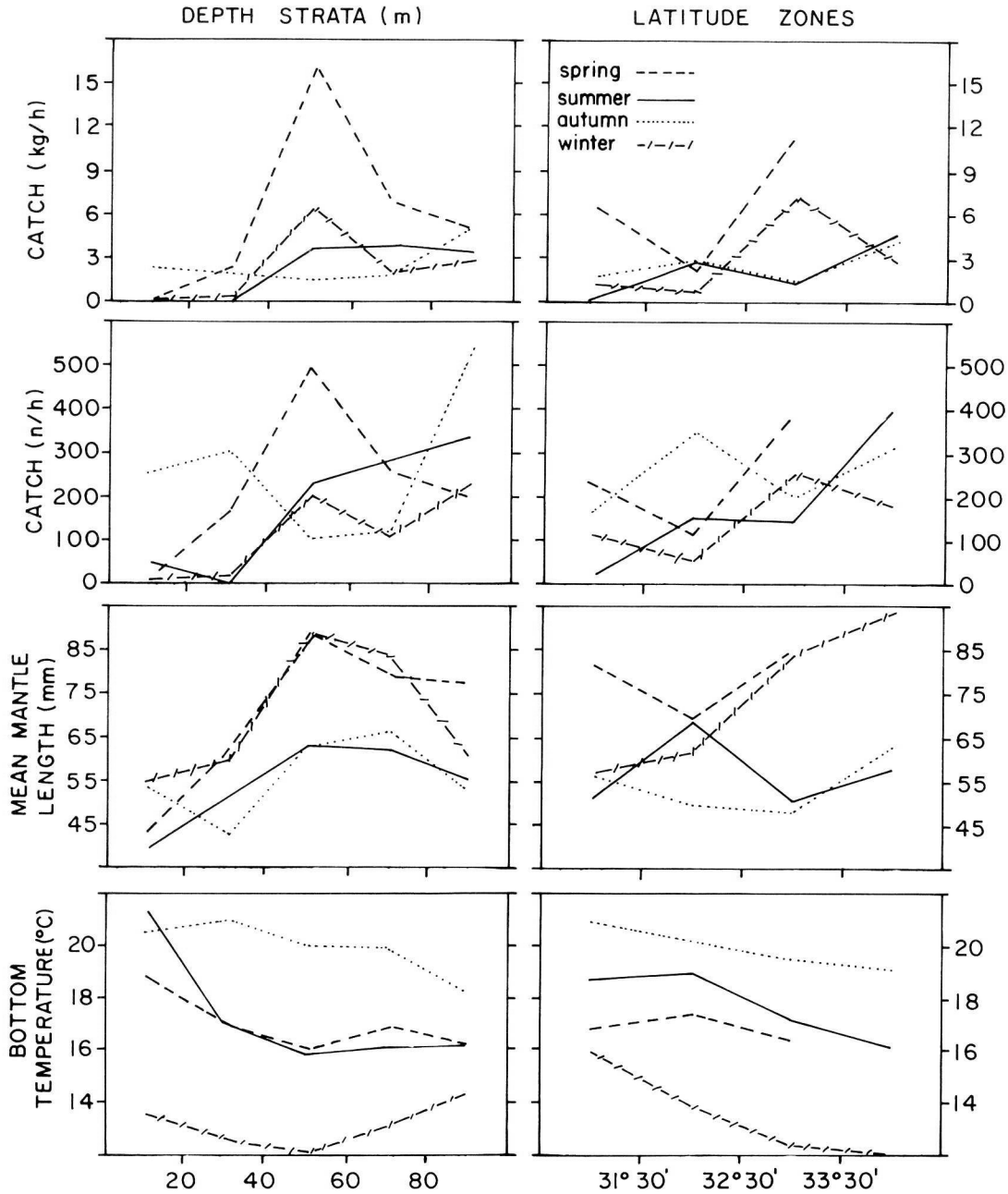

FIG. 3. — Mean catches in kilograms and numbers per hour, mean mantle length of *Loligo sanpaulensis*, and mean bottom temperatures per depth strata and latitude intervals in four seasonal surveys off southern Brazil.

re higher in depths of 80-120 m in summer and autumn. In the autumn, a second peak of concentration of smaller squid ocurred inshore, in less than 40 m, in the intermediate latitudinal zones.

A segregation of sizes and sexes of *L. sanpaulensis* with depth was observed in all seasons (Fig. 3 and Table 4). Largest specimens and maximum mantle length averages, from 63 to 88 mm, were found between 40 and 80 m in all cruises. A chi-square test indicated significant association between depth and sex proportion, females prevailing in lower depths. All juveniles were taken in more than 80 m.

TABLE 4. — Sex ratio of *Loligo sanpaulensis* in bottom fishing hauls off southern Brazil pooled per depth strata and season. (F, females; M, males; *, ratios significantly different from 1:1 ($p < 0,05$)).

Depth (m)	*Summer* M F *n = 254*	*Fall* M F *n = 632*	*Winter* M F *n = 208*	*Spring* M F *n = 361*
0 – 20	–	14 82*	15 85*	25 75*
21 – 40	–	44 56	56 44	43 57
41 – 60	–	49 51	45 55	43 57
61 – 80	–	65 35	55 45	64 36
81 – 120	–	49 48	60 40	63 37
Total	60 40	50 49	49 51	53 47

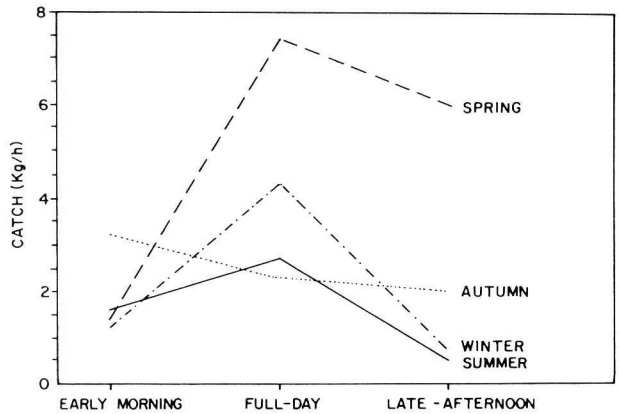

FIG. 4. — Mean catches in kilograms per hour of *Loligo sanpaulensis* per period of the day in four seasonal demersal surveys off southern Brazil (see text for period definitions).

Latitudinal differences in length distributions ocurred only in the winter, when mean ML increased significantly from north to south (Fig. 3). Males and females ocurred in the same proportions all along the coast in all cruises.

Diel variation in catch

Changes in catch rates by time of day were observed in this study. Except in the autumn cruise, the average catch of tows beginning until two hours after dawn and of those ending two hours or less before sunset was 1.2 to 6 times lower than the average in the full day period (Fig. 4). More than 75 % of the survey catch of squid was obtained during full day. However, analysis by Kruskal-Wallis test did not show significant differences between dawn, daytime and sunset.

Nevertheless, in order to test the effects on distribution trends of such variations in catchability, we corrected dawn and dusk catches, multiplying each value by a factor calculated for each cruise. The whole analysis of abundance and distribution was then repeated with the new values. No major modifications were observed in previous trends in spatial distribution, but seasonal trends became more pronounced. Corrected values are shown in Table 3.

Distribution related to water temperature

Loligo sanpaulensis was found along the whole bottom temperatures range recorded in the shelf, but concentrated in colder waters during most of the year (Fig. 3). Highest catches (over 15 kg/h) in winter and spring were obtained in six tows with bottom temperatures lower than 16°S. In summer and spring, when bottom temperatures up to 22°C were observed, tows yielding at least 0.5 kg/h of squid were mostly taken in water between 14.5 and 18°C. In those seasons, mean catches differed significantly between bottom temperature classes, while Kendall's Rank Correlation was negative and significant for all cruises. Except in the summer, a segregation by size with temperature was also observed, smaller squid being taken in warmer waters.

DISCUSSION

Abundance estimates for *L. sanpaulensis* in southern Brazil are of the same magnitude as those for other loliginids elsewhere. SERCHUK and RATHJEN (1974) reported a maximum of 22 700 tons for *L. pealei* in an area approximately 3.5 times larger than our survey area. OTERO *et al.* (1983) estimated that *Loligo gahi* in southern Argentina attained 96 500 tons in winter, in an area of 207 000 km^2, twice the stock density we observed in spring for *L. sanpaulensis*. Our abundance estimates were obtained with fishing gear which was not ideal for efficient squid capture, thus it is expected that a small fishery for *Loligo sanpaulensis* could be developed off south and southeast Brazil.

The spatial distribution showed a remarkable relationship with bottom water temperature (Fig. 3). Bottom temperatures of hauls with squid ranged from 11 to 18°C, but larger animals were found in colder waters. A similar relation was observed for other loliginids, such as *L. pealei* (SERCHUK and RATHJEN, 1974), and *L. pealei* and *L. plei* (WHITAKER, 1980).

The higher densities of small squid found in autumn were closely related to warmer coastal waters with lower salinities in the bottom. According to AMARATUNGA (1983), juvenile squids are commonly found in relatively warmer environments. Although the phenomenon could be related only to water depth, it is interesting to note that the highest bottom temperature average in winter was observed between 80 and 120 m, stratum in which mean ML dropped sharply in relation to intermediate depths.

Squid populations often take advantage of ocean currents systems to optimize energy expenditures with movements of adults and juveniles, and make better use of productivity in their distribution ranges (CADDY, 1983; COELHO, 1985; AMARATUNGA, 1987). The distribution of *L. sanpaulensis* is similarly related to the oceanographic system of the Brazil and Malvinas Currents. Main features of this system off Rio

Grande do Sul are the influence of continental drainage flowing out of Rio de La Plata and Lagoa dos Patos (a coastal lagoon in Brazil), and the presence of the western edge of the Subtropical Convergence, formed in the boundary of the Tropical Water of Brazil Current, flowing southward, with Subantarctic Water of Malvinas Current, flowing northward (MIRANDA *et al.*, 1973; CASTELLO and MOLLER, 1977; HUBOLD, 1980a and b). Bottom temperatures in this study match the typical seasonal, patterns described by those authors (Fig. 1). Coastal Water and Subantarctic Water predominate on the shelf in the southern part of the survey area. Both water masses are cold and nutrient-rich. The slope and the northern portion of the shelf suffer greater influence of the surface, southward running Tropical Water, with higher salinity and temperature, and lower planktonic productivity, under which runs northward the Subtropical Water. Thermoclines on the shelf occur in summer and autumn, around depths of 50 m, but the stratification disappears or reverses in winter.

Both the Subtropical Water and the Subantarctic Water appear in the spring, summer and autumn profiles in CASTELLO and MOLLER (1977) as a core or tongue of colder, nutrient-rich water close to the bottom. The position occupied by those cores coincides with the depth strata in which *Loligo sanpaulensis* was more abundant. In winter, the western edge of the Subtropical Convergence moves northward and a strong surface temperature gradient, between 13°C and 19°C isotherms, occurs at the latitude of Rio Grande (32°S). This may explain the difference in catch rates between the southern and northern halves of our survey area, as well as the species dispersion over the upper slope documented by HAIMOVICI and PÉREZ (1991). In addition, the smallest animals and the tows without squid in summer and spring occurred in an area where Tropical and Coastal Waters mix, characterized by bottom temperatures up to 23°C, and low nutrient contents.

The concentration of larger squid at certain depth zones, generally to the south, thus seems associated with the Subtropical Water and the northern limit of the Subantarctic Water of the Malvinas Current. These areas of mixing are characterized by high productivities, with high *a*-chlorophyll and zooplankton densities, as reported by HUBOLD (1980a and b), who, interestingly enough, found higher productivities in winter and spring. Accordingly, TEIXEIRA *et al.* (1973) and NAVAS-PEREIRA (1973) reported that highest zooplankton and *a*-chlorophyll densities for the winter and spring of 1972 occurred on the southern half of Rio Grande do Sul shelf, and for the summer and autumn of the same year in the area of greater continental drainage influence. ANDRIGUETTO (1989) reported high proportions of full stomachs of *Loligo sanpaulensis* south from Rio Grande. It is possible then that the shelf between Rio Grande and Chui is an important feeding ground, what explains the consistent higher squid catch rates in the area, specially in spring and winter.

Existing information expands the distribution picture for *L. sanpaulensis* in a way that is coherent with our observations. JUANICÓ (1979) and VIGLIANO (1985) worked in the continental shelf respectively to the north and to the south of the area in this study, while HAIMOVICI and PÉREZ (1991) report data on the distribution over the upper slope adjoining our survey area.

JUANICÓ sampled in September and November, 1975, from latitudes 23°S to 30°S, up to depths of 132 m. Unfortunately, differences in fishing gear prevent a detailed comparison, but frequence of ocurrence was clearly lower, and so were the maximum lengths attained (144 mm for males) when comparing the same season with our results. In Juanicó's survey, the species concentrated in depths under 40 m and over 100 m, associated with bottom water temperatures lower than 19°C. We found a similar pattern in the autumn, and in both cases, *Loligo plei* prevailed at intermediate depths (JUANICÓ, 1981; HAIMOVICI and ANDRIGUETTO, 1986).

In Argentina, *Loligo sanpaulensis* is caught as a bycatch in the shrimp beam trawl artisanal fishery around Mar del Plata, Bahia Blanca and Rawson, where the species can be found from 10 to 135 m (CASTELLANOS, 1967; VIGLIANO, 1985). Squid length frequency distributions for the coast of Mar del Plata reported by VIGLIANO (1985) are similar to those in this study, for all seasons except spring. Maximum mantle lengths were also higher in that season, but frequency distributions showed a massive concentration of individuals 25 to 60 mm long, juveniles prevailing over adults. The seasonal variations in length distributions and abundance indexes observed in our study suggest that animals larger than 60 mm may migrate northward to Rio Grande do Sul shelf, probably starting in the winter, but peaking in the region in the spring.

The upper slope seems to be the lower bathymetric distribution limit of *L. sanpaulensis* in Rio Grande do Sul. According to HAIMOVICI and PÉREZ (1991), the species occurred in higher frequencies and abundances in winter and spring cruises on the slope, being taken at depths up to 200 m. However,

the squids were smaller than in the shelf. In autumn and summer, when tropical waters penetrate from the north, *L. sanpaulensis* is not taken beyond 140 m. In winter, mean abundances in number of individuals on the upper slope up to 200 m were similar to those reported here for the shelf, if the difference in horizontal opening of the nets in both surveys is considered. Besides natural mortality, such a spreading of the population over the upper slope may explain the decrease in numerical density on the shelf.

ANDRIGUETTO (1989) found evidence for peaks of reproduction of *Loligo sanpaulensis* off Rio Grande do Sul in winter and summer. Therefore, the increase in squid numbers in the autumn, considering their small size, could be due to recruitment. In the other seasons, the distribution pattern of *Loligo sanpaulensis* seemed to be strongly influenced by the oceanographic regime, the population remaining in the limits of colder, more productive waters.

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