The squid *Loligo plei* around Santa Catarina Island, Southern Brazil: Ecology and Interactions With the Coastal Oceanographic Environment

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ABSTRACT


The ecological relationships of the loliginid squid *Loligo plei* in coastal shallow waters (<20 m) off southern Brazil, were studied from 13 summer sampling campaigns conducted in the “Pântano do Sul” Bight, south of Santa Catarina Island, between 1999 and 2001. The presence of the squid was affected by the coastal influence of three water masses: the Coastal Water (CW), the Shelf Water (SW) and the South Atlantic Central Water (SACW). The latter was associated to a wind-induced coastal intrusion/upwelling event and correlated positively with both plankton and squid concentrations. This pattern, coupled with the predominance of planktonic crustaceans and small clupeiform fish in the squid diet, suggested that SACW intrusion/upwelling around Santa Catarina Island may provide a temporarily attractive coastal feeding ground for *L. plei* favoring squid concentrations which sustain an opportunistic artisanal fishery during summer months off Santa Catarina.

ADDITIONAL INDEX WORDS: Cephalopods, upwelling, diet.

INTRODUCTION

The abundance of cephalopods in several fishing grounds around the world have been frequently correlated with local fluctuations of environmental conditions (SAUER et al., 1991; KAWAMURA and HIRA, 1993). Off Brazilian coast these relationships were firstly addressed by JUANCÓ (1979), who studied loliginid squids distribution and biology south of 23° S. After that, similar accounts concentrated principally on the squids *Loligo sanpaulensis*, *L. plei* and *Illex argentinus*, and the octopods *Eledone massyae*, *E. gaucha* and *Octopus vulgaris* off the coasts of Rio Grande do Sul (30°-34° S) and Rio de Janeiro States (23° S) (HAIMOVIČI and ANDRIGUETTO Fo., 1986; COSTA and HAIMOVIČI, 1990; ANDRIGUETTO Fo. and HAIMOVIČI, 1991; HAIMOVIČI and PEREZ, 1991a,b; COSTA and FERNANDES, 1993; PEREZ and HAIMOVIČI, 1995). Despite those efforts, however, potential associations between environmental factors and Brazilian cephalopod commercial fisheries have generally remained unclear.

Dense concentrations of the squid *L. plei* occurring off the northern coast of Santa Catarina State (26° S) currently sustains one of the most important cephalopod fishery of Brazil (PEREZ and PEZZUTO, 1998; PEREZ, 2002). Most catches are obtained from December to March by double rig and pair trawlers, which operate on 15 to 45 m deep grounds and produce annual landings widely oscillating from 100 to 890 mt (PEREZ, 2002). In addition, summer artisanal hand-jigging and trap fishery have long been reported in shallow areas and particularly around coastal islands (PEREZ et al., 1997; PEREZ et al., 1999). Economically important for local fishing communities, such activity has been regarded as opportunistic not only depending on inter-annual coastal abundance but also on intra-seasonal temporal and geographical variations of squid availability (PEREZ et al., 1999).

Suitable spawning habitats and favorable feeding and oceanographic conditions have been hypothesized as possible causes of *L. plei* shallow-water concentrations and their dynamics during summer months off Santa Catarina (PEREZ et al., 1997). Because underwater surveys have generally failed to detect benthic spawning beds, commonly formed by other loliginid squids (SAUER et al., 1992), in situ studies have alternatively addressed the association between shallow-water physical and biological environmental processes and squid occurrence on the artisanal fishing grounds (PEREZ et al., 1997; MARTINS, 2002).

Frequently observed during summer months, one of such relevant processes involves the intermittent wind-driven coastal upwelling of nutrient enriched South Atlantic Central Water (SACW). This process has been shown to enhance subsurface primary production on the continental shelf off southern Brazil and has been commonly associated with local fishing stocks life cycles (MATSUURA, 1996; BORZONE et al., 1999). In addition, off Santa Catarina and Rio de Janeiro State coasts there has been evidences that SACW upwelling influence may reach shallow water environments and affect cephalopod spatial distribution (COSTA and FERNANDES, 1993; CARVALHO et al., 1998).

The present work explores the relationship between this environmental event and the occurrence of summer shallow-water *L. plei* concentrations around Santa Catarina Island, southern Brazil.

METHODS

The relationship between the squid *L. plei* and their shallow-water environment was investigated through 13 sampling trips conducted in the “Pântano do Sul” Bight Santa Catarina Island, southern Brazil (27°47'S; 48°31'W) (Fig. 1). This area has been traditionally used by its local community as a squid summer fishing ground and has produced the bulk of Santa Catarina artisanal squid landings (PEREZ et al., 1999).

Trips were approximately 24 hours long and were carried out with two week intervals during three consecutive austral summers (December to March) between 1999 and 2001 (Table 1). The thermal and saline structure of the water column was described by vertical profiles obtained with a CTD, in six selected stations conducted at the beginning and at the end of each trip. In addition, temperature and salinity profiles were further obtained every two hours in a 6 m deep fixed “fishing point” (station #1, Fig. 1). Water masses were classified according with salinity and temperature ranges as defined by MATSUURA (1986) and CARVALHO et al. (1998). Thermal stratification coefficients of each vertical profile were calculated as $Cs = (Ts-Tb)/Tm$, where Ts, Tb and Tm are surface, bottom and mean temperatures respectively. Wind speed and direction were obtained from continuous records provided by the Santa Catarina State Meteorological Research Center (CLIMEHR).
Two parallel plankton tows were conducted in 6 and 12 m deep sampling stations at the beginning and at the end of each trip (stations #1 and #6, respectively; Fig. 1). Tows were 8 min long and were conducted using a 300 µ conic net at approximately 3 knots. The samples were stored in a 4% buffered formalin and brought to the laboratory where they were sorted into three size fractions: large (>2000 µm), medium (between 2000 and 1000 µm) and small (between 1000 and 300 µm). Humid weight within each size fraction was obtained and transformed into biomass values (in g m⁻²) according to BOLTOVSKOY (1999).

The presence of squid during trips was quantified by continuous hand-jigging fishing conducted at station #1. Nocturnal fishing was conducted under light attraction. Squid catch rate (SCR, squid fisherman⁻¹ hour⁻¹) was used as an abundance index for each sampling trip.

The relationships between the environmental conditions in the “Pântano do Sul” Bight and the presence of L. plei during the sampling trips was investigated by a Principal Component Analysis (PCA). Beside mean SCR, the analyses included the following environmental variables: large plankton fraction biomass (LP, g m⁻²), small plankton fraction biomass (SP, g m⁻²), wind direction (WD, scored numerically from E=1 to NE=8), wind speed (WS, m s⁻¹), stratification coefficient (SC) and minimum temperature (MT, °C). Environmental variables were averages obtained from all measurements taken during each sampling trip. All variables, except WD, were standardized as a proportion of the mean. A correlation matrix was calculated for the standardized variables and new axes (Factors) were extracted in the direction of greatest variance.

Food and feeding analyses included squid caught in the sampling trips and samples acquired from commercial fisheries. Squids had their dorsal mantle length (ML) measured to the nearest millimeter. Full stomachs were dissected and their food remains were examined under stereoscopic binocular microscope under 6.7 to 40 X magnification and identified to the lowest taxonomic level. Fish otoliths and squid beaks were measured and used to estimate prey size according to BASTOS (1990) and SANTOS (2000). The relative importance of different prey types in the squid's diet was analyzed from the number of stomachs containing each prey type expressed as a percentage of the total number of stomachs with food (HYSLOP, 1980). These frequencies were pooled by mantle length classes and compared using Chi-square statistics (ZAR, 1996).

**RESULTS**

The oceanographic characterization of the study site showed the influence of three types of water masses (Fig. 2): the Coastal

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### Table 1. Summary of environmental conditions observed in 13 L. plei sampling campaigns in the “Pântano do Sul” Bight, Santa Catarina Island, Southern Brazil in three consecutive summers from 1999 to 2001.

<table>
<thead>
<tr>
<th>Sampling Campaign</th>
<th>Duration (h)</th>
<th>Temperature °C</th>
<th>Salinity ppt</th>
<th>Cs</th>
<th>Wind Speed m s⁻¹</th>
<th>Direction</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
<th>Squid SCR Squid fisherman hour⁻¹</th>
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<tr>
<td><strong>Summer 1999</strong></td>
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<tr>
<td>14-15 Dec. (1)</td>
<td>25.0</td>
<td>20.20 - 22.60</td>
<td>33.09 - 35.60</td>
<td>0.0148</td>
<td>3.82 S</td>
<td>0.06 - 0.73</td>
<td>0.06 - 0.28</td>
<td>0.03 - 0.09</td>
<td>0.00</td>
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<tr>
<td>12-13 Jan. (2)</td>
<td>24.0</td>
<td>23.16 - 25.35</td>
<td>35.22 - 35.74</td>
<td>-0.0034</td>
<td>3.65 S</td>
<td>0.03 - 0.09</td>
<td>0.04</td>
<td>0.09 - 0.13</td>
<td>0.47</td>
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<tr>
<td>26-27 Jan. (3)</td>
<td>23.5</td>
<td>19.43 - 24.65</td>
<td>34.05 - 35.97</td>
<td>0.0807</td>
<td>4.27 SE</td>
<td>0.14 - 0.77</td>
<td>0.20 - 0.61</td>
<td>0.17 - 1.74</td>
<td>0.09</td>
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<tr>
<td>10-11 Feb. (4)</td>
<td>25.5</td>
<td>24.89 - 25.86</td>
<td>35.02 - 35.44</td>
<td>0.0048</td>
<td>3.85 NE</td>
<td>0.45 - 1.66</td>
<td>0.13 - 0.24</td>
<td>0.04 - 0.09</td>
<td>0.33</td>
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<tr>
<td>24-25 Feb. (5)</td>
<td>24.0</td>
<td>23.63 - 26.71</td>
<td>34.60 - 35.55</td>
<td>0.0030</td>
<td>1.87 SW</td>
<td>0.20 - 0.88</td>
<td>0.08 - 0.18</td>
<td>0.10 - 0.68</td>
<td>0.00</td>
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<td><strong>Total</strong></td>
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<td>19.43 - 26.71</td>
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<tr>
<td>20-21 Jan. (6)</td>
<td>23.5</td>
<td>17.09 - 26.11</td>
<td>34.82 - 35.93</td>
<td>0.0839</td>
<td>2.70 N</td>
<td>0.27 - 0.47</td>
<td>0.35 - 0.53</td>
<td>1.04 - 14.9</td>
<td>2.14</td>
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<tr>
<td>09-10 Feb. (7)</td>
<td>20.7</td>
<td>16.34 - 23.38</td>
<td>34.74 - 35.83</td>
<td>0.1914</td>
<td>2.42 E</td>
<td>0.42 - 1.88</td>
<td>0.09 - 0.23</td>
<td>0.62 - 1.52</td>
<td>1.48</td>
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<tr>
<td>15-16 Feb. (8)</td>
<td>17.8</td>
<td>19.94 - 21.04</td>
<td>32.43 - 34.60</td>
<td>-0.0081</td>
<td>6.17 S</td>
<td>0.66 - 1.10</td>
<td>0.25 - 0.41</td>
<td>0.71 - 0.88</td>
<td>0.59</td>
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<tr>
<td>02-03 Mar. (9)</td>
<td>23.0</td>
<td>16.91 - 19.49</td>
<td>35.55 - 35.86</td>
<td>0.0281</td>
<td>3.82 N</td>
<td>0.44 - 0.75</td>
<td>0.13 - 0.22</td>
<td>0.35 - 1.12</td>
<td>0.27</td>
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<tr>
<td><strong>Total</strong></td>
<td>16.34 - 26.11</td>
<td>32.43 - 35.93</td>
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<td><strong>Summer 2001</strong></td>
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<tr>
<td>06-07 Jan. (10)</td>
<td>23.5</td>
<td>18.29 - 24.73</td>
<td>34.64 - 36.21</td>
<td>0.1159</td>
<td>2.82 NW</td>
<td>0.67 - 0.92</td>
<td>0.22 - 0.62</td>
<td>1.50 - 2.34</td>
<td>0.33</td>
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<tr>
<td>26 Jan. (11)</td>
<td>3.5</td>
<td>18.97 - 26.05</td>
<td>35.04 - 36.15</td>
<td>0.0858</td>
<td>4.55 NE</td>
<td>0.84 - 1.45</td>
<td>0.49 - 0.53</td>
<td>7.59 - 15.22</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>02-03 Feb. (12)</td>
<td>25.0</td>
<td>18.32 - 27.90</td>
<td>34.12 - 36.25</td>
<td>0.1207</td>
<td>4.55 NE</td>
<td>0.27 - 0.30</td>
<td>0.08 - 0.09</td>
<td>0.26 - 0.30</td>
<td>0.22</td>
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<tr>
<td>02-03 Mar. (13)</td>
<td>19.0</td>
<td>16.72 - 19.59</td>
<td>35.52 - 36.26</td>
<td>0.0566</td>
<td>3.77 N</td>
<td>0.44 - 0.75</td>
<td>0.13 - 0.22</td>
<td>0.35 - 1.12</td>
<td>0.47</td>
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<tr>
<td><strong>Total</strong></td>
<td>16.72 - 27.90</td>
<td>34.12 - 36.26</td>
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Figure 1. Study area, showing (A) the Santa Catarina Island and (B) the Pântano do Sul Bight. Filled circles indicate the principal live-bait fishing grounds around the island, according to SANTOS & RODRIGUES-RIBEIRO (2000). Numbered dots represents the six selected oceanographic stations within the bight.
and high concentrations of both small and large plankton. The prominent and the trips scored in this quadrant would be SACW intrusion scenario. In quadrant II this scenario becomes low temperatures at the bottom, would score trips under an early passage of a cold-front and the beginning of the water column homogenization leading again to the scenario of the quadrant IV. Samples with large squid catches were positioned between quadrants II and III, whereas those when squid was scarce or absent concentrate in quadrant IV, suggesting that L. plei presence at the shallow waters of “Pântano do Sul” Bight was associated with the SACW intrusion scenario.

A total of 597 squids were examined for stomach contents including 273 males and 286 females ranging from 20 to 358 mm ML. Stomach contents were found in 247 squids, 41.4% of all caught individuals which was marginally affected by size and the predominant water masses (p=0.046 and p=0.045 respectively).

Fish was the principal food category, appearing in 75.3% of the stomachs, followed by crustaceans (47.4%), polychaetes (16.6%), squid (5.3%) and unidentified material (12.1%). Small engraulidids Anchoa lyolepis and A. tricolor were the commonest fish, followed by the small sciadnid Ctenoscaena gracilicirrhus. Crustaceans included mainly planktonic decapod larvae, amphipods and juveniles of the blue crab (Callinectes sp.). Both atocal (benthic) and epitocal (pelagic) forms of polychaetes were found in squid stomach contents, all included in the Family Nereididae. All cephalopod prey items were Loliginid squids, including L. plei and L. sanpaulensis. Fish and crustaceans were important prey items in all hydrographic regimes and size classes, the former being particularly dominant in large animals (Fig. 4). Squid was a minor prey item being observed in the stomach of animals larger than 70 mm ML (Fig. 4).

Estimated prey size was consistently small in all L. plei sizes (Fig. 4). The total length of three fish species (A. lyolepis, A. tricolor and C. gracilicirrhus) were compared as potential prey for each size L. plei. The data were subjected to PCA, which explained 68.6% of total variance (Fig 3). Factor 1, which explained 41.5%, was mainly defined by the elevated temperatures ranging between 19.4° and 29.7°C, and presented the lowest values of zooplankton biomass observed during the three studied seasons (Table 1). In contrast, northeasterly winds predominated in the 2000 and 2001 seasons and subsurface intrusions or upwellings of SACW were frequently observed (Fig. 2). Temperature ranged between 16° and 28°C and a pronounced stratification of the water column was predominantly found in both summers. Levels of zooplankton biomass, although widely variable, were in general higher than those found in the summer of 1999 (Table 1). Important L. plei concentrations were recorded principally in the summer of 2000 when catch rates up to 2.14 squid fisherman hour⁻¹ were obtained (Table 1). In the 1999 season L. plei was considerably scarce (Table 1).

The association between samples was analyzed from the scores produced by the first two rotated Factors of the PCA, that explained together 68.6% of total variance (Fig 3). Factor 1, which explained 41.5%, was mainly defined by the elevated loadings of minimum temperature and squid catch rate, which also correlated strongly with large plankton biomass and wind direction. Wind speed and the stratification coefficient, on the other hand, had the highest loadings on Factor 2, which explained 27.1% of total variance. From the spatial representation in Figure 3, it was possible to predict that a homogenized water column with low plankton concentrations and under the influence of moderate southerly winds, would define the environmental features of trips placed in quadrant IV. In quadrant III, the influence of moderate northerly winds and low temperatures at the bottom, would score trips under an early SACW intrusion scenario. In quadrant II this scenario becomes prominent and the trips scored in this quadrant would be influenced by strong northerly winds, a stratified water column and high concentrations of both small and large plankton. The influence of strong southerly winds in quadrant I, associated with a decrease in plankton concentration, would characterize the passage of a cold-front and the beginning of the water column homogenization leading again to the scenario of the quadrant IV.
related with squid’s active swimming. Despite these sources of variability, however, the species was shown to concentrate when the water column was under the influence of SACW intrusion and disperse as it became homogenized.

Associations between coastal upwelling events and squid concentrations have been reported for *L. vulgaris reynaudii* in the Southeastern coast of South Africa (ROBERTS and SAUER, 1994), *L. opalescens* in the coast of California (MACINNIS and BROENKOW, 1978) and *L. sanpaulensis* and *L. plei* off the coast of Cabo Frio, Rio de Janeiro State (COSTA and FERNANDES, 1993). Observed responses to such events have varied from (a) avoidance, possibly as ascending cold water masses decrease environmental temperature to growth limiting situations or even below physiological limits, to (b) concentration due to the formation of a dense prey field as sustained by primary production enhancement and concentration processes (MACINNIS and BROENKOW, 1978; BAKUN and CISRKE, 1998; PEREZ and O’DOR, 1998). Despite being considered a warm-water tropical species, *L. plei* was shown to occur at temperatures as low as 13°C near its southernmost distribution limit in the Atlantic, thus in environments considerably colder than the ones experienced around Santa Catarina Island during the summer (HAIMOVICI and PEREZ, 1991a,b). On the other hand, in the “Pântano do Sul” Bight, the species was generally associated with elevated concentrations of plankton, which were particularly available at upwelling scenarios. It is suggested that wind driven SACW intrusions in this shallow areas seem to provide an environment not only thermally tolerable, but also energetically attractive for *L. plei*, as a short pelagic trophic chain is temporarily established and highly available at the nutrient-enriched water column.

Feeding activity was evidenced in the bight, as food was found in nearly 41% of all caught squid, a frequency within a 30-60% range reported for many squid species at their feeding grounds (NIXON, 1987). Feeding squid were shown to be preying principally on pelagic clupeiform fish and planktonic crustaceans, a diet tipically found in Loliginidae in either inshore or offshore habitats (ROCHA et al., 1994; PIERCE et al., 1994). On the other hand, ingested prey were small regardless squid size, a pattern that contrasts with what has been equally demonstrated for loliginid species in offshore habitats, where prey size tends to increase in larger squid (COLLINS and PIERCE, 1996; SANTOS and HAIMOVICI, 1998). The availability of small components of the pelagic food chain, in association with a wind-driven primary production enhancement or concentration event in “Pântano do Sul” Bight, could explain such “shallow-water diet” of *L. plei*. In addition, inside the bight, squid may also benefit from benthic prey, moderately present in its diet, which may have also been particularly available in such a shallow water-column.

Either through the periodical influence of wind-driven biological production enhancement or the accessibility of both pelagic and benthic resources, it is likely that shallow-water habitats around Santa Catarina Island may actually constitute important summer feeding areas for energy demanding and highly mobile predators such as squid and maybe other similar predators. Interestingly, skipjack tuna (*Katsuwonus pelamis*) pole-and-line fishing vessels, may actually be characterized as one of such “predators”. Motivated by their demand for small clupeiform fish to be used as live bait in their fishing operations, these vessels tend to explore coastal habitats, concentrating their bait fishing in bights and bays along Santa Catarina coast (LIN, 1992). Studies conducted in 1988/89, 1993/94 and 1998/99 have demonstrated that the most visited bait fishing areas have consistently coincided with those where summer artisanal *L. plei* fishing takes place, including the “Pântano do Sul” Bight (Fig. 1) (LIN, 1992, 1998; SANTOS and RODRIGUES-RIEBEIRO, 2000). Although possible relationships between bait fish or squid catches and environmental conditions are not presently available, both fisheries are likely affected by the environmental scenarios described in this study. In fact, artisanal squid catches in Santa Catarina, have shown to be concentrated in short pulses in different areas within a single summer season, a pattern that could emerge as a response to the
influence of intermittent environmental fluctuations such as summer upwelling process (PEREZ et al., 1999).

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LITERATURE CITED


