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Distribution, abundance and biological interactions of the cutlassfish *Trichiurus lepturus* in the southern Brazil subtropical convergence ecosystem

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Abstract

The distribution, abundance and biological interactions of the cutlassfish *Trichiurus lepturus* in the southern Brazil subtropical convergence ecosystem were studied from demersal trawl surveys conducted along the continental shelf and upper slope from Cape Santa Marta Grande (28°36′S) to Chui (34°45′S) between 1981 and 1987. *Trichiurus lepturus* was more abundant at bottom water temperatures of over 16°C and in the 40–120 m depth range. From late spring to fall, juveniles of 5–30 cm total length (*TL*) were found in coastal waters, subadults (*TL* 30–70 cm) mainly in inner shelf waters and adults (*TL* > 70 cm) in coastal, inner and outer shelf waters. Higher catches of subadults and adults were found associated with thermal fronts in the western boundary of the Subtropical Convergence or with a shelf break upwelling observed in summer. The standing stock in a 58 000 km^2 shelf area estimated by the swept area method, ranged from 3066 t (±46% *CI*) in September 1981 to 37 814 t (±22% *CI*) in January 1982. Correlation between occurrences of different size groups of cutlassfishes and other fishes caught in 250 bottom trawl hauls was analyzed. A positive correlation between cutlassfish and juvenile weakfish, *Cynoscion guatucupa*, was associated with similar spatial distribution but also indicated trophic competition. © 1997 Elsevier Science B.V.

Keywords: *Trichiurus lepturus*; Distribution; Southern Brazil; Subtropical convergence; Biological interactions

1. Introduction

The continental shelf off southern Brazil is influenced by the western boundary of the Subtropical Convergence between the Brazil and Falklands/Malvinas currents (Hubold, 1980a). The main feature of the region is the alternate influence of subantarctic and tropical waters, resulting in important variations in the physical environment and the associated biological production (Hubold, 1980a,b; Lima and Castello, 1995; Ciotti et al., 1995).

Hydrographic features were described by Emilssom (1961), Thomsen (1962), Miranda et al. (1973) and Castello and Möller (1977) and related to the demersal fish fauna distribution patterns by Haimovici et al. (1994, 1996), showing that in the

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shelf and shelf break demersal trawl surveys off southern Brazil the cutlassfish ranged second in frequency of occurrence and it was one of the five most abundant (CPUE) bony fishes. It is regularly caught in the coastal trawl fishery but has been almost totally discarded at sea by commercial fisherman (Haimovici and Palacios, 1981). More recently, offshore trawlers began to freeze it on board, landing 1255 t in 1992 (CEPERG, 1994). Its importance to the marine ecosystem off southern Brazil was also stressed by Mello et al. (1992), who showed it belonged to the main pelagic association in winter and spring together with *Engraulis anchoita, Trachurus lathami, Cynoscion guatucupa, Thyrsitops lepidopoides* and *Loligo sanpaulensis*.

Trichiurus lepturus is a cosmopolitan coastal species fished in warm and warm–temperate waters around the world (Nakamura and Parin, 1993). Nominal worldwide catches in 1992 reached 825 013 t (FAO, 1994). In the western Atlantic it occurs from Cape Cod (40°N) to the Rio de la Plata (37°S) (Fischer, 1978; Cousseau, 1985).

Some aspects of the distribution in relation to the environmental conditions of this species have been studied off western South Africa (Mikhaylin, 1976), Japan (Munekiyo and Kuwahara, 1983, 1984, 1986; Munekiyo, 1990), Taiwan (Lee, 1979), Korea (Baik and Park, 1986) and China (Dekun and Cungen, 1987). These papers show that this species is rather abundant in subtropical waters, (between 25 and 35° latitude). The occurrence of cutlassfish near thermal fronts in this latitudinal range indicates that oceanographic and biological interactions can be critical to define optimum environmental conditions for this species.

Cutlassfish are voracious predators. Large concentrations of this species has been associated with low catches of important commercial fishes by southern Brazilian fisherman, such as the white croaker (*Micropogonias furnieri*), the Argentinean croaker (*Umbrina canosai*) and the weakfish (*Cynoscion guatucupa*), suggesting some mechanism of trophic competitive exclusion. These hypotheses have been supported by the presence of a variety of prey in its diet including pelagic (nekton and plankton) and benthic species, i.e. large numbers of small fishes, zooplanktonic and benthic crustaceans and cephalopods (Martins, 1992).

In this study we examine the abundance and distribution of cutlassfish in relation to oceanographic conditions to explain this pattern of higher abundance in subtropical waters. We also investigate the influence of the cutlassfish on the presence and abundance of other fish species of the demersal shelf community off southern Brazil.

2. Material and methods

Most of the samples were obtained from ten bottom trawl cruises conducted by the R/V 'Atlântico Sul' off southern Brazil. The first six were from Solidão (30°43′S) to Chui (33°45′S) between isobaths of 10 and 160 m and using nets with ground-ropes of 52.9 m in 1981 and 49.3 m in 1982–1983. The last four cruises (1986–1987) were in outer shelf and upper slope waters between Chui (34°30′S) and Cape Santa Marta Grande (28°40′S), with trawling carried out at depths ranging from 124 to 587 m (Fig. 1), using a bottom trawl net of 23.4 m foot rope geared with 40 cm steel bobbins. All nets used V-shaped metallic otter boards of 450 kg and mesh, in the cod end, of 50 mm stretched between opposite knots. Hauls were of 1 h duration at 3.0 knots and were conducted between dawn and dusk. An additional 196 hauls not considered for abundance estimates was conducted to study dial changes in catches.

After each haul, bottom and surface temperatures were recorded with Nansen bottles and profiles of temperatures were recorded with a bathythermograph. The catch was sorted by species and the fish measured and weighed. When catches were too large to process before the next haul, a random subsample of 30–60 kg was taken and processed in the same manner. The total length (*TL*, cm) of each specimen of *Trichiurus lepturus* in the samples or subsamples was measured between the anterior lower jaw projection and end of the caudal fin. The fish was then weighed and sexed. Three size categories of cutlassfish were defined according to gonadal maturity: juveniles (*TL* 5–30 cm), subadults (*TL* 30–70 cm), adults (*TL*: over 70 cm) (Martins, 1992).

The abundance in number per hour, biomass as weight per hour (kg h^{-1}) (CPUE) and size composition of all fish species were estimated.

Biomass and density by the swept area method for shelf cruises was assessed following the procedure described in Saville (1977) for a stratified random sample design as the hauls were placed along perpendicular lines to the coast to ensure reasonable bathymetric and latitudinal cover. The swept area was calculated as 43% of the foot rope (22.8 and 21.2 m). This value was based on the similarity in the foot rope/head rope ratio and on the estimated vertical opening between the nets in our survey, described in Vooren (1983) and the typical bottom trawls used in the eastern and western US groundfish surveys (Alverson and Pereyra, 1969). Swept areas for standard hauls were estimated as the product of 43% of the ground ropes (22.8 and 21.2 m), multiplied by the distance traversed in 1 h (5.6 km), estimated at 0.1264 km^2 for the 1981 cruises and 0.1180 km^2 for the 1982 and 1983 cruises. The total area surveyed was 58 000 km^2, divided into five depth strata: 0–20 m (9200 km^2), 20–40 m (12 200 km^2), 40–60 m (11 300 km^2), 60–80 m (12 300 km^2) and 80–120 m (13 000 km^2).

Catches in each stratum were log transformed ($\ln x+1$) to normalize catch distributions. The algorithm proposed by Pennington (1983) with correction for null catches was used to estimate the variances of the estimates and allow statistical comparisons (Fogarty, 1985). It is possible that abundance was underestimated owing to escape from upper trawl and mesh openings, mainly by juveniles. An opposite effect is aggregation of fish caused by otter boards and ground cables (Glass and Wardle, 1989). Owing to the impossibility of quantifying these effects, the catchability coefficient (q) was considered equal to 1.

To detect possible competitive interactions of cutlassfish with demersal nekton, Pearson's correlation coefficients of numeric abundance (Ludwig and Reynolds, 1988) were calculated between three different size classes of *Trichiurus lepturus* and 25

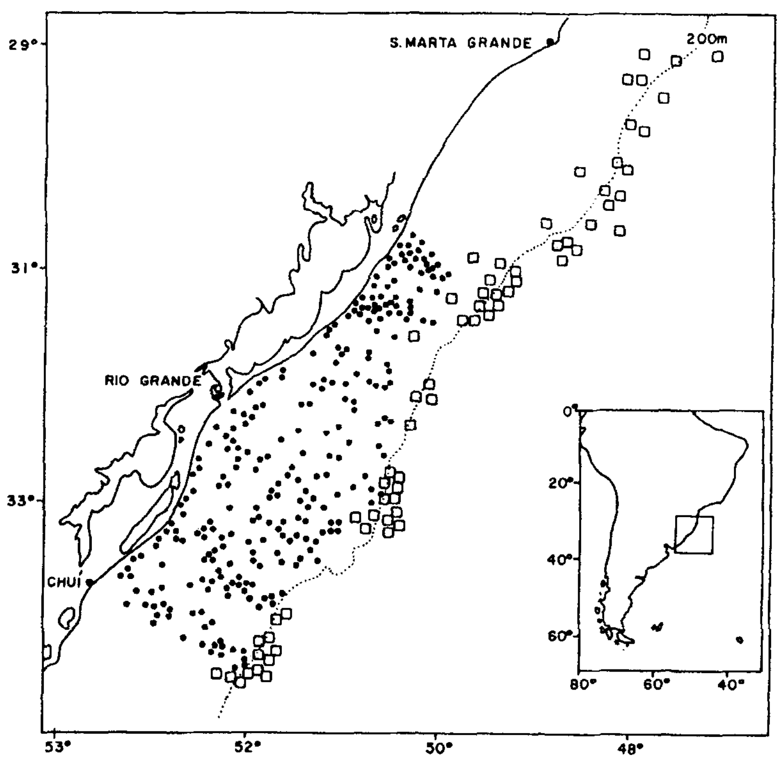

Fig. 1. Study area of the bottom trawl survey series conducted along the continental shelf (●) and outer shelf–upper slope (□) off southern Brazil.

demersal teleost and elasmobranch species caught in more than 20% of shelf hauls or that together represented 95% of accumulated CPUE from 250 bottom trawl hauls in the shelf cruises. Significance of the correlation coefficients was assessed with Student's *t*-test. Positive and negative correlation was accepted for t values significantly higher than those corresponding to table values for $P < 0.05$ and was indicative of possible biological interactions for potential prey, predators or competitors. The hypothesis of exclusion of other fishes from areas where *Trichiurus lepturus* was abundant was tested examining the association of high percentages of cutlassfish in the total catch with species richness of the hauls.

3. Results

3.1. Survey area

Bottom temperatures measured during the six shelf cruises ranged from 8.9 to 22.9°C (Fig. 2). The highest temperatures were found during autumn in all study areas except the most shallow waters, where the highest temperatures were found during summer. The lowest temperatures were found in the middle shelf during winter, spring and summer. The difference between winter and summer temperatures at depths of less than 80 m was around 8°C but decreased to about 4°C at 200 m.

During the autumn cruises, inner shelf waters were mostly around 20°C. In 1981 a marked thermal front (from 21 to less than 17°C) was found. Typical winter conditions were temperatures of less than 15°C in the inner southern shelf. In both winter cruises, a strong thermal front was observed in September 1981 at the north end of the study area and in August 1983 oblique to the coast at 32°S. Summer and spring bottom temperatures between 18 and 22°C prevailed in the 20–50 m depth range and a strong temperature gradient was observed at the southern end of the study area. This cold water along the bottom may originate from upwelling processes

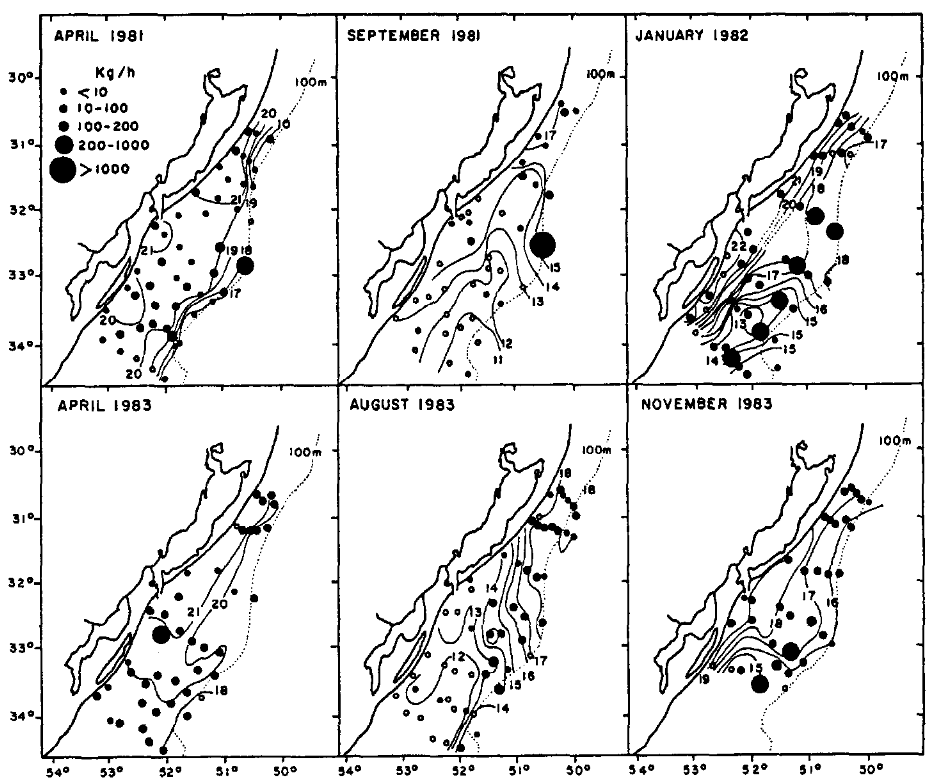

Fig. 2. Catches (kg h^{-1}) of *Trichiurus lepturus* and bottom isotherms during six demersal cruises along the continental shelf off southern Brazil.

in the shelf break (Podestá, 1990; Lima and Castello, 1995; Bakun, 1993) (Fig. 2).

Shelf cruises were classified according to season and bottom temperatures as 'warm water cruises' (April 1981 and 1983), 'cold water cruises' (August 1981 and September 1983) and 'transitional water cruises' (January 1982 and November 1983).

The outer shelf and upper slope cruises showed a mixture of subantarctic and subtropical waters, with intermediate antarctic waters at greater depth. The temperature decreased gradually to less than 10°C at 400 m and 6.2°C at 500 m (temperature profiles are shown in Haimovici et al., 1994).

3.2. Vertical distribution

Diel changes in CPUE were studied in a set of 446 hauls from 1980 to 1987 (including 196 hauls from previous cruises, not used in abundance estimates). Data from all seasons and depth strata were lumped owing to the small sample size. Mean CPUE was significantly higher during the day and lower at night (Tukey's test, 95% confidence level) (Fig. 3).

3.3. Geographical distribution and abundance

Trichiurus lepturus was caught over the entire shelf and shelf break at depths ranging from 10 to 291 m and occurred in 231 of the 298 hauls (77.5%) in this depth range. Its relative abundance, measured

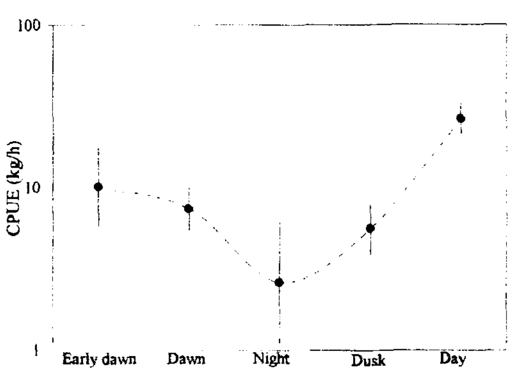

Fig. 3. Mean catches (kg h^{-1}) of *Trichiurus lepturus* with 95% confidence intervals (vertical lines) per period of day in 446 fishing hauls along the continental shelf off southern Brazil. Early dawn, 1–2 h before down; Dawn, 1 h before to 2 h after down; Night, full night hauls; Dusk, 1 h before to 2 h after dusk; Day, full day hauls.

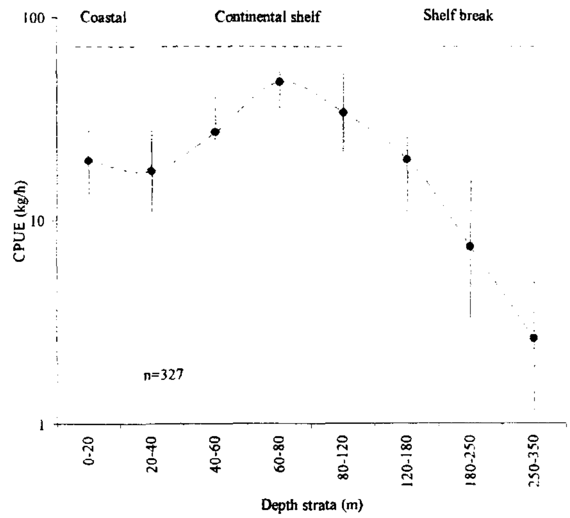

Fig. 4. Mean CPUE (kg h^{-1}) of *Trichiurus lepturus* and 95% confidence intervals for ten depth strata in 327 diurnal fishing hauls along the continental shelf and upper slope off southern Brazil.

in kilograms per hour (CPUE) was higher between 40 and 120 m depth (Fig. 4). The mean CPUE increased from less than 10 kg h^{-1} at 11°C to around 100 kg h^{-1} at temperatures up to 16°C, remaining

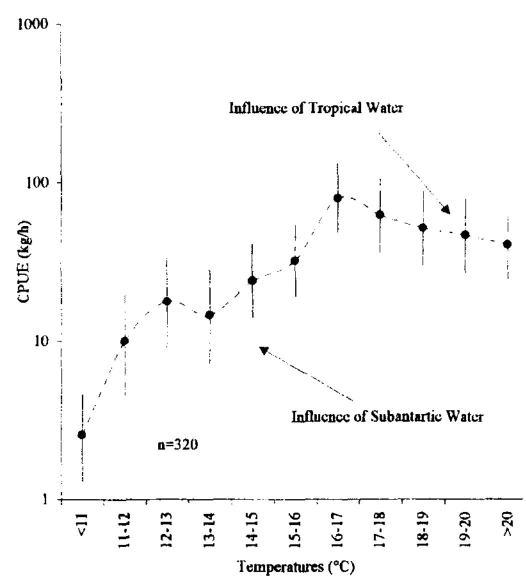

Fig. 5. Mean catches (kg h^{-1}) of *Trichiurus lepturus* and 95% confidence intervals for 11 bottom temperature categories recorded in 320 fishing hauls along the continental shelf and upper slope off southern Brazil.

Table 1
Estimated mean density and mean biomass of *Trichiurus lepturus* in six surveys in the continental shelf off southern Brazil, with 90% confidence intervals (*CI*)

Survey	Thermic condition	No. of hauls	Percentage occurrence	Density ($kg\ km^{-2}$)	Estimated biomass (t)	90% *CI*
April 1981	Warm waters	50	98.0	170.6	9896	16.1
September 1981	Cold waters	42	40.5	52.8	3066	47.0
January 1982	Transitional waters	42	92.9	697.9	40492	21.9
April 1983	Warm water	41	95.1	195.2	11328	12.9
August 1983	Cold waters	54	72.2	136.3	7908	23.8
November 1983	Transitional waters	34	94.1	519.9	30164	20.6

high in warmer waters but showing a decreasing trend (Fig. 5). It was not caught at bottom temperatures below 11°C.

The species occurred in 97.8% of warm water hauls, in 53.6% of cold water hauls and 93.4% of transitional water hauls. Higher biomass and densities were observed in transitional water cruises in November and January (more than 30000 t). A lower biomass was found in cold water cruises (less than 8000 t) with intermediate values in warm water cruises (around 10000 t) (Table 1).

Warm water cruises showed large catches (more than 100 kg h^{-1}) on the inner shelf south of 32°S, and along the thermal front at the outer shelf. During

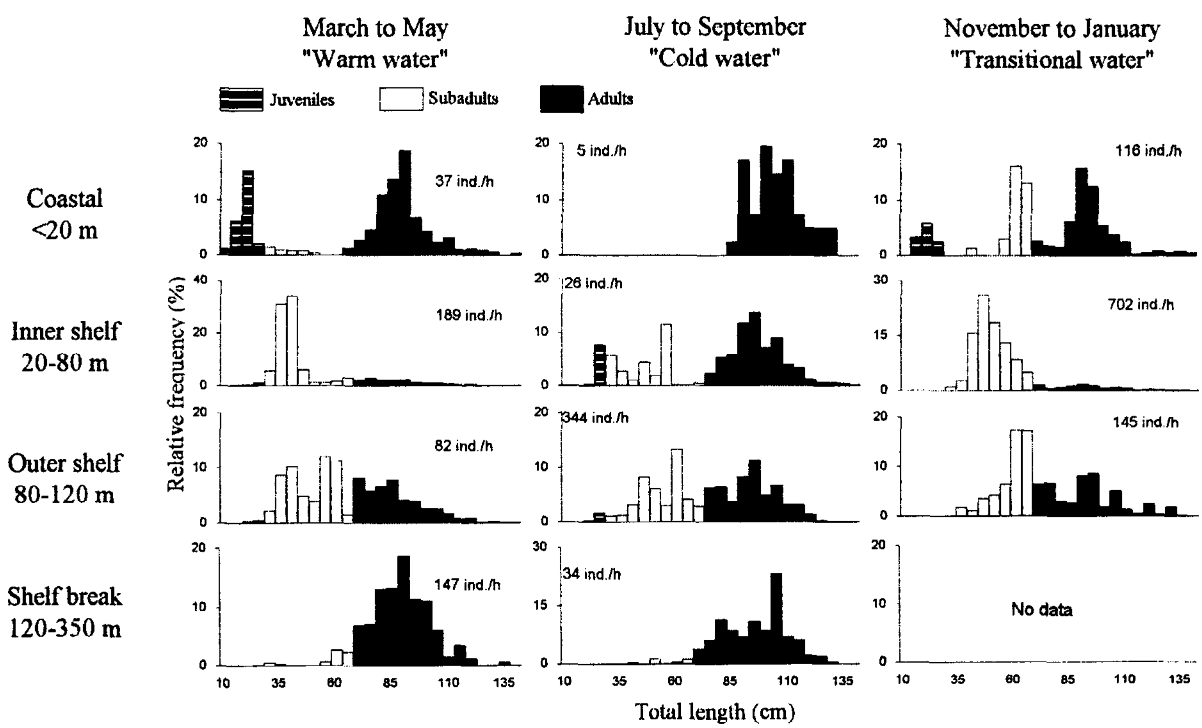

Fig. 6. Length-frequency distribution of juveniles, subadults and adults of *Trichiurus lepturus* in ten demersal cruises along the continental shelf and shelf break off southern Brazil arranged by depth strata and thermal conditions. Also given within each graph is the average catch rate (number of individuals per hour).

the cold water cruises, higher catches occurred north of 32°S. Large catches were taken along the thermal front of the outer shelf corresponding to the western boundary of the subtropical convergence. Transitional water cruises showed catches of more than 200 kg h^{-1} in the inner shelf (Fig. 2).

Juveniles occurred mainly near the coast in warm and transitional water cruises. Subadults were abundant on the inner and outer shelf areas, while adults occurred in variable numbers from the coast to the shelf break in warm, cold and transitional waters (Fig. 6). On the shelf break mainly adults were found, with catches usually ranging from 10 to less than 100 kg h^{-1} except for two catches over 200 kg h^{-1} in the warm water cruises of March and May.

3.4. Biological interactions

The correlation coefficients were significant for seven species (Table 2). The abundance of juvenile cutlassfish was negatively correlated with adult *Cynoscion guatucupa*. The abundance of subadults was correlated positively with *Ctenosciaena gracilicirrhus* and juvenile *Cynoscion guatucupa* and negatively with *Micropogonias furnieri*. Adults were correlated negatively with *Cynoscion jamaicensis* and

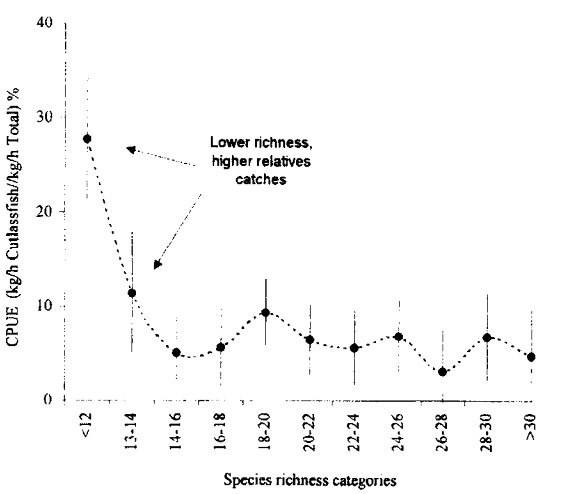

Fig. 7. Mean percentage of CPUE of *Trichiurus lepturus* in relation to the total fish CPUE with 95% confidence intervals (vertical lines) by 11 categories of fish species richness observed in 263 fishing hauls along the continental sheff off southern Brazil.

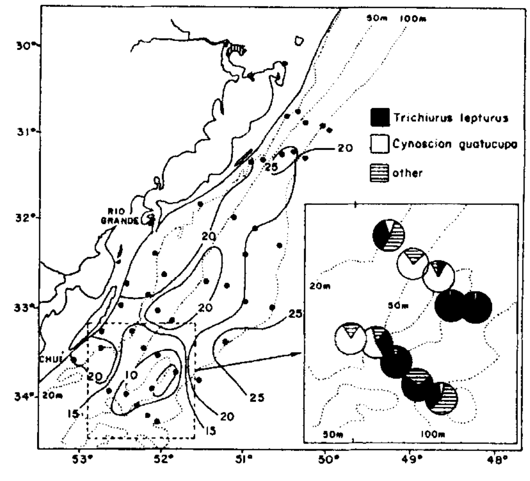

Fig. 8. Number of fish species caught per hour of tow during a bottom trawl cruise in January 1982 (isolines). Inset: an area of low species richness. Relative CPUE of *Trichiurus lepturus*, *Cynoscion guatucupa* and other fish species are represented.

Trachurus lathami and correlated positively with *Paralonchurus brasiliensis*.

Fig. 7 shows that hauls with species richness under 15 were associated with high percentages of cutlassfish in the catches (15–30%). This pattern was better observed in a series of hauls in a low temperature nucleus in the cruise of January 1982 where catches comprising 70–90% *Trichiurus lepturus* were associated with less than ten species. In the same region but in shallower waters, large concentrations of juvenile *Cynoscion guatucupa*, amounting to 77–85% of total catches, were also found associated with low numbers of species (Fig. 8).

4. Discussion

Trichiurus lepturus was more abundant along the western boundary of the subtropical convergence during the cold water cruises and in the shelf break during the warm water cruises. Larger catches of cutlassfish in areas with sharp temperature gradients and anomalies were also observed in the East China Sea (Baik and Park, 1986). This kind of association is well known for pelagic fish such as tuna (Laevastu and Hayes, 1981) and is currently explained by

Table 2
Pearson correlation coefficient significantly different from zero ($P > 95\%$) calculated for numeric abundances between pairs of species. Values in parentheses indicate the number of co-occurrences with *Trichiurus lepturus*

Species with correlations significantly different from zero	*Trichiurus lepturus*			Explanations for interaction	Ref. [a]
	Juveniles 1–30 cm	Subadults 30–70 cm	Adults 70–150 cm		
Ctenosciaena gracilicirrhus	–	+0.39 (54)	–	Similar spatial and temporal distribution. No feeding overlap	1, 3, 4
Cynoscion jamaicensis	–	–	−0.30 (45)	Different spatial distribution	1
Cynoscion guatucupa (adults)	−0.59 (11)	–	–	Different seasonal distribution, No feeding overlap	1, 2, 3
Cynoscion guatucupa (juveniles)	–	+0.29 (75)	–	Feeding overlap, tropic competition	2, 3, 4
Micropogonias furnieri	–	−0.34 (44)	–	Different seasonal distribution	1
Paralonchurus brasiliensis	–	–	+0.33 (51)	Similar spatial and temporal distribution. No feeding overlap	1, 3, 4
Trachurus lathami	–	–	−0.28 (51)	Different seasonal distribution	1, 4

[a] 1, Haimovici et al. (1996); 2, Vieira (1990); 3, Martins (1992); 4, this paper.

particle aggregations; plankton and particulate suspended organic matter, responsible for higher densities of potential prey in frontal regions (Mann and Lazier, 1991; Bakun, 1993). Cutlassfish feed heavily on the euphausid *Euphausia similis* (Martins, 1992) which is associated with subtropical convergence waters (Ramirez, 1971).

The absence of *Trichiurus lepturus* when bottom temperatures were less than 10°C may be related to the physiological tolerance of the species as there are no records of occurrence of this species at such temperatures. Off southern Brazil, bottom temperatures at depths of more than 300 m are usually under 11°C (Castello and Möller, 1977) and since part of the cutlassfish diel cycle includes near bottom waters, temperature may to be one of the barriers to its offshore dispersion. Furthermore, over the slope, *Trichiurus lepturus* is replaced by other trichiurids of genera *Lepidopus, Benthodesmus* and *Evoximetopon* (Haimovici et al., 1994), that according to Nakamura and Parin (1993), are all benthopelagic fishes adapted to slope and sea mountain habitats.

The spatial distribution of the three size classes reflects the distribution of preferred prey such as euphausids for subadults and mysidacean and sergestids for juvenile cutlassfish (Martins, 1992) and the reproductive requirements of adults. Spawning occurs in thermally stratified waters with surface temperatures over 18°C that are usually found along the coast in spring and summer and over the shelf break all year round (Martins, 1992).

CPUE and biomass estimates showed a consistent seasonal pattern; catches were significantly higher in transitional water cruises in comparison with warm and cold water cruises. The abundance of 519.9–697.9 kg km^{-2} in the late spring and early summer cruises indicates that this species may have commercial potential off southern Brazil during this season.

Competition patterns between marine fishes are difficult to assess compared with less mobile or sessile benthic organisms, whose spatial and trophic relationships can be better established. Despite these constraints, the co-occurrence or exclusion of cutlassfish with other demersal fish in the surveyed area reveals both spatial and trophic patterns of association. Negative correlation can be explained by different seasonal or spatial distribution patterns while positive correlation may be due to similar spatial distribution but could also indicate trophic competition. The diets of the species with positive correlation were compared with the diets of juvenile, subadult and adult cutlassfish (Table 3). Relative frequency of the main prey items in the diet of juvenile *Cynoscion guatucupa* and adult *Trichiurus lepturus* overlapped, both preying on similar proportions of fish (mainly anchovy) and planktonic microcrustaceans (mainly *Euphausia similis*). This pattern suggests a competitive interaction between *Trichiurus lepturus* and juveniles of *Cynoscion guatucupa*. Furthermore, adult *Trichiurus lepturus* also prey on younger *Cynoscion guatucupa* (Martins, 1992). These two species together accounted for 47% of the

Table 3
Relative occurrence of six categories of food items found in the stomachs of *Trichiurus lepturus*, *Cynoscion guatucupa*, *Paralonchurus brasiliensis* and *Ctenociaena gracilicirrhus*

Food category	*T. lepturus* juveniles [a] ($n = 180$)	*T. lepturus* subadults [a] ($n = 135$)	*T. lepturus* adults [a] ($n = 345$)	*C. guatucupa* juveniles [b] ($n = 317$)	*C. guatucupa* adults [b] ($n = 226$)	*P. brasiliensis* [c] ($n = 242$)	*C. gracilicirrhus* [c] ($n = 64$)
Nekton (fishes)	* * * *	* * * *	* * * * *	* * * * *	* * * * *	* *	* * *
Zooplanktonic microcrustaceans	* * * * * *	* * * * * *	* * * *	* * * *	* * *	* * *	* * * *
Benthonic macrocrustaceans	*		* * *	* *	* * * * *	* * * * *	* * * *
Nekton (cephalopods)	*	*	* *	*	*	*	*
Infaunal benthonic invertebrates				*	* *	* * * * * *	* * *
Benthonic microcrustaceans					*	* * * * *	* * * * *

[a] From Martins (1992).
[b] From Vieira (1990).
[c] Unpublished data. (Martins, A.S. and Haimovici, M., 1996)
*, less than 2%; * *, 2–10%; * * *, 10–20%; * * * *, 20–50%; * * * * *, 50–80%; * * * * * *, 80% or over.

total estimated bony fish biomass in the study area (Haimovici et al., 1996), showing that the interaction between these two species is important in the food web in the continental shelf environment. The aggregation pattern observed in January 1982 (Fig. 8) shows a spatial exclusion between the two species, and was associated with feeding preferences and environment tolerances. The association of cutlassfish with the penetration of colder waters shows that this population is well adapted to sudden thermal changes, within its tolerance limits, as larger catches were associated with temperature gradients.

Higher niche overlapping in fish assemblages is expected to occur in productive environments with low diversity because chances for specialization are low (Ross, 1986). In an environment such as the southwestern Atlantic subtropical convergence ecosystem, predators adapted to temperature changes, with a non-specialized diet, such as *Trichiurus lepturus*, may be efficient.

This study showed that the cutlassfish tends to explore less abundant and diverse feeding resources in adverse and highly variable physical conditions. In fact, this trophic and environmental flexibility may explain why this species is found in different temperate and tropical continental shelves around the world.

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