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PRIMARY RESEARCH PAPER

Changes in the population structure, growth and mortality of striped weakfish *Cynoscion guatucupa* (Sciaenidae, Teleostei) of southern Brazil between 1976 and 2002

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Abstract Changes in the population structure, growth, and mortality of the striped weakfish *Cynoscion guatucupa* of southern Brazil were studied based on data collected from commercial landings in Rio Grande between 1976 and 2002. Mean length in the trawl fishery decreased abruptly while mean ages decreased steadily in recent years. Most abundant age classes in recent landings were 2 and 3 years old in the paired-trawl catches, one to three for otter and double rig trawls, and 5 and 6 years old in the gill net catches. Oldest fishes caught were aged 18 years and no fish over 14 years old was caught since 1985. The growth rate tended to increase over the course of the study, especially in the last analysed period (1999–2002). The total mortality instantaneous coefficient Z calculated from the paired trawls data catch curves increased from 0.36 in 1976 up to 0.92 in 2002 and the exploitation rate E increased from 0.31 up to 0.73 if a natural mortality coefficient M of 0.25 is assumed. The changes were attributed to the increase of the fishing on the striped weakfish stock, shared by Brazil, Uruguay and Argentina and are suggestive of overfishing.

Keywords Population structure · Growth · Mortality · *Cynoscion guatucupa* · Fishery induced changes

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Introduction

The stripped weakfish *Cynoscion guatucupa* (Cuvier) (syn. *C. striatus*) known locally as ''pescada-olhuda'' or ''maria-mole'' is a demersal species found along the continental shelf of the south-western Atlantic Ocean, from Rio de Janeiro (22° S), in Brazil, to the San Matias Gulf (43° S), in Argentina (Cousseau & Perrotta, 2000; Menezes et al., 2003). The inner shelf between these latitudes is wide, covered mostly by soft sediments and under the influence of the runoff of the De la Plata River, Patos Lagoon and other minor fresh water sources (Calliari, 1998; Piola et al., 2000). In this low salinity, cold subtropical/warm temperate enriched environment, sciaenid fishes are dominant and *C. guatucupa* is the second in importance, after *Micropogonias furnieri* (Desmarest) (Haimovici et al., 1996; Martins, 2000; Jaureguizar et al., 2006).

Adults of *C. guatucupa* perform seasonal movements: between autumn and spring (April–September) they go northward from the fishing grounds of Uruguay and Argentina to the coastal waters of southern Brazil and back southward in summer. Small juveniles recruit in spring and summer to coastal waters less than 25 m depth and move when around 10 cm total length in autumn to deeper waters (25–50 m) where they spend the next 1–2 years before joining the adult stock seasonal movements (Haimovici et al., 1996). Spawning is multiple in all the region from Bahía Blanca area (41° S) to Southern Brazil (30° S), with peaks in spring and early autumn (Cassia, 1986; Vieira & Haimovici, 1997). Several studies have shown that the striped weakfish is a relatively slow growing fish that matures around age 3 and reaches over 15 years old (Ciechomski & Cassia, 1978; Cassia, 1986; Vieira & Haimovici, 1993, 1997; Lopez Cazorla, 2000). Young stripped weakfish feed in the water column on zooplankton and juvenile fishes and gradually shift to a diet of fish and shrimp and other benthic invertebrates as they grow larger (Martins, 2000).

Cynoscion guatucupa have been fished between 30° S and 41° S since the 1950's (Yesaki & Bager, 1975; Arena & Gamarra, 2000; Ruarte & Aubone, 2004; Vasconcellos et al., 2005). Its annual commercial landings in the early 1970's were under 5,000 t and increased sharply to oscillate between 20,000 and 48,000 t since then. In the decade between 1995 and 2004 total landings were on average 36,154 t, of which 28% were caught by the coastal bottom trawl and gill-net fisheries in Southern Brazil and 72% by the coastal otter trawl fishery of Uruguay and Argentina (Sources: Brazilian National Environment and Fisheries Agency—IBAMA/Brazil, State Department of Agriculture, Cattle, Fishery and Food—SAGyPA/Argentina and National Agency of Aquatic Resources—DINARA/Uruguay).

Catch-per-unit-effort data (CPUE) for this species do not show a clear trend. The strong fluctuations of catches and CPUE (Ruarte et al., 2001; Vasconcellos et al., 2005) may be due to changes in the carrying capacity of the ecosystem for this species, to changes in the fishing effort or to both. In order to have a better understanding of the state of the stock of *C. guatucupa*, we analysed the changes in the population structure, growth and mortality of the stock exploited in southern Brazil between 1976 and 2002. This was possible because the commercial landings in Rio Grande (32° S) of *C. guatucupa* as well as other species have been periodically sampled since 1976 (Haimovici, 1987, 1998). The results show a consistent change in the age structure, mean size and total mortality that suggest the risk of collapse and the necessity to reduce the fishing intensity on this species.

Materials and methods

Landings of striped weakfish at the port of Rio Grande were obtained from published and unpublished reports by IBAMA (Brazilian National Environment and Fisheries Agency).

Data for length, age and sex structure of *C. guatucupa* were obtained as part of a long-term assessment program of the coastal demersal fishery along the shelf of Southern Brazil (34° S–28°40′ S) (Haimovici et al., 1989; Haimovici, 1998; Haimovici & Miranda, 2005). Samplings were obtained from the landings of fishing vessels with otter trawls, paired trawls and bottom gillnet in several time periods between 1976 and 2002 (Table 1). These samplings included the measurement of the total length (TL, mm) of 100–300 fishes randomly collected along the landings. Besides the size frequencies, a smaller number of fish were sampled for total length, total weight (W, g), sex and the *sagittae* otoliths preserved for ageing (for details on the sampling procedures, see Haimovici, 1987). In its first years, sampling was more intense to characterize the fisheries and is still in progress to keep a record of the long time changes in the size and age composition of the main target species among which is *C. guatucupa.* Overall, length distributions were recorded in 870 samples adding up to 253,000 measured specimens, examined for age 6,981 specimens grouped in four periods: 1976–1980, 1981–1987, 1988–1994 and 1997–2002 (Table 1).

Otoliths are routinely used for ageing many fishes after the periodicity in the deposition of layers of different transparency is validated

Table 1 Number of samples and specimens of *C. guatucupa* sampled for size and for age in each year from 1976 to 2002

Year	Periods of study	Length samples		Aged samples	
		Number of samples	Number of specimens	Number of samples	Number of specimens
1976	1	3	1233	2	–
1977	1976–1980	47	12155	16	668
1978		73	27380	13	552
1979		36	12293	11	580
1980		50	17157	11	818
1981	2	38	13569	7	619
1982	1981–1987	31	10808	8	803
1983		42	12515	7	479
1984		58	17181	8	321
1985		69	18738	7	319
1986		61	17245	–	–
1987		37	9599	–	–
1988	3	31	6813	–	–
1989	1988–1994	29	8768	3	85
1990		21	5712	1	–
1991		26	7480	–	–
1992		47	15354	9	849
1993		29	8163	–	–
1994		7	1662	–	–
1995	4	–	–	–	–
1996	1997–2002	–	–	–	–
1997		40	8561	–	–
1998		11	1068	–	–
1999		36	8300	4	362
2000		–	–	–	–
2001		41	10032	16	464
2002		7	1176	1	62
Total		870	252962	124	6981

(Casselmann, 1983; Beckman & Wilson, 1995). The employed teminology of their layers of growth was the same proposed by Casselmann (1983), where translucent or hyaline layers are the ones that allow light through while opaque layers reflect it. The otoliths of *C. guatucupa* were sectioned transversally through the nucleus and examined under a 10× binocular microscope with lateral transmitted light.

The number of opaque zones along the otolith polished surface and the type of deposit (opaque or translucent) on the otolith margin were recorded for each otolith. The otoliths were read by two different readers or on two different occasions by the same reader with a month interval. When counts differed, otoliths were read a third time by both readers and discarded from further analyses if the difference in readings persisted.

Out of 6,981 otoliths examined, 94.9% were considered legible and the ages were assigned assuming January 1st as their birthdates, following Vieira & Haimovici (1993). In all four periods, the monthly proportion of sectioned otoliths with translucent margins were higher than 90% from May to August and lower than 30% between December and January validating the annual periodicity in the formation of one translucent and one opaque layer each year, also demostrated by Vieira & Haimovici (1993). The age structure in the landings of each sampling period and gear was calculated combining the mean length compositions with the corresponding length-age keys.

Growth was described by the von Bertalanffy equation (1938): $L_t = L_\infty(1 - e^{-K(t-t_0)})$, where L_t is the total length at time t; L_∞ is the asymptotic or maximum attainable size; K is the growth coefficient and t_0 is a correction on the time axis. Parameters of the growth equation were estimated by using a non-linear regression, with an iterative algorithm that minimises the sum of squares of the residuals, implemented by Solver (*Excel 2002, Microsoft Corporation*). The growth equation, for each time period, was calculated using individual data of total length at age and for pooled sexes. Growth of the striped weakfish differs between sexes (Foggetta & López, 1981; Vieira & Haimovici, 1993; Miranda, 2003). However, these differences, although significant are small and do not justify the analysis of growth changes separately for each sex. The significance of the differences among the growth parameters of the different periods was tested by applying the likelihood ratio test (Cerratto, 1990; Aubone & Wöhler, 2000).

The instantaneous total mortality coefficients Z were estimated from yearly catch curves in all years with samples (Ricker, 1975; Gulland, 1983). The length and age composition from the paired trawl fishing vessels commercial landings were assumed to best represent the population structure, since it is the least selective fishing gear, catching from juveniles to older fish. The instantaneous natural mortality coefficient M cannot be determined from commercial fishing data but can be estimated indirectly using different approaches described in Sparre & Venema (1997). For the striped weakfish an educated guess was made based in three differents methods: (1) method proposed by Taylor, based in the growth parameters K and t_0; (2) method proposed by Hoenig whose graphic method relates logarithms of known natural mortalities estimates and maximum observed ages; and (3) method proposed by Alagaraja who suggested an empirical equation that assumed the life span of fish species as the age at which 99 or 99.9% of a cohort had died if it had been exposed to natural mortality only, defining this mortality as $M_{1\%}$ and $M_{0.1\%}$, respectively.

Results

Length structure

Paired trawl fishing vessels caught mostly individuals between 20 and 55 cm TL. The otter trawls caught a larger proportion of sub-adults with a higher number between 20 and 45 cm TL. The individuals caught by gillnets were on average larger than those caught by other fishing gear in the same period (Fig. 1a).

The mean length of the individuals caught by paired trawls varied between 41.6 cm in 1976 and 30.1 cm in 2001 (Fig. 2). For the otter trawls landings, the striped weakfish mean length was always lower than the paired trawls landings and varied between 34.8 cm in 1988 and 28.0 cm in 2002. For both fishing gears the annual mean length remained at the same level up to 1997, but decreased in the following 5 years. This reduction is more evident for the individuals caught by paired trawls in 1999 and 2001.

Age structure

Age structure by fishing gear for all periods of study is showed on Fig. 1b. The maximum observed age was 18 years old, but after 1985 only individuals up to 14 years old occurred. Recruitment to the landings from trawl nets began at age one and to the bottom gillnets at age 3.

The age frequency distributions of different fishing gears (Fig. 1b) were compared between periods by Kolmogorov–Smirnov two-sample test (K–S test). A strong decrease of older fishes in the catches was observed along the years. This decrease can be illustrated by the proportion of individuals at age 4 or older caught by paired trawls that accounted for around 50% until 1987 and decreased to 25% in the last period analysed (D: 0.3007; $p < 0.01$). Mean age decreased from 4.5 years old in 1981–1987 to 3.0 years old in 1997–2002. The individuals aged one became more abundant in the otter trawl catches from 1988 (D: 0.2108; $p < 0.01$) and the mean age decreased from 3.2 years old between 1981 and 1987 to 2.3 years old for the period 1997–2002.

There were a few samples from the gillnet fishing up to 1994. Since 1997, most the individuals caught by this gear ranged from 3 to 11 years old and the most frequent were between 5 and 6 years old.

It may be concluded that trawl fishery caught mainly sub-adults and young adults while adults are most affected by gillnet fishery. Moreover,

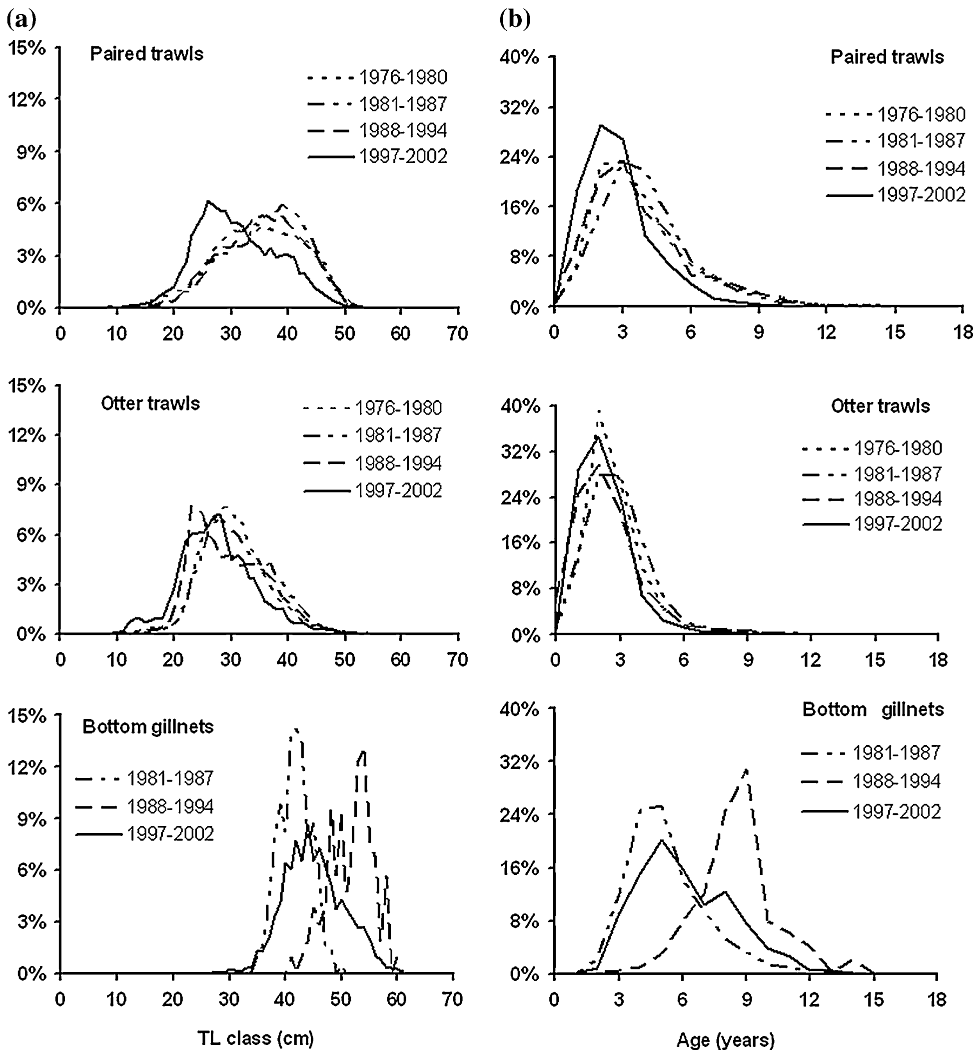

Fig. 1 Length (**a**) and age (**b**) composition of *C. guatucupa* in the commercial landings in Rio Grande caught by commercial fishing vessels in southern Brazil using different gears: paired trawls, otter trawls and bottom gillnets for the periods 1976–1980, 1981–1987, 1988–1994 and 1997–2002

there was a decrease of the mean age of the fishes caught with all gears in the last years of the analysed period.

Sex ratio

Sex ratio was calculated by length classes and by time periods and compared using a χ^2-test. Except for two cases, female percentages were significantly higher than 50% ($p < 0.01$). No significant difference between periods and length classes was observed (Table 2).

Growth

Observed mean lengths at each age showed an increasing trend along the periods (Table 3) that was more evident for oldest. The percent increase in weight of the last period of study (1997–2002) compared with the first one (1976–1980) was less than 10% in individuals aged 2–5 and between 20 and 25% to individuals at age 10 or older, showing that it had an increase of the growth rate. The von Bertalanffy growth curves of *C. guatucupa* to different periods are showed on Fig. 3.

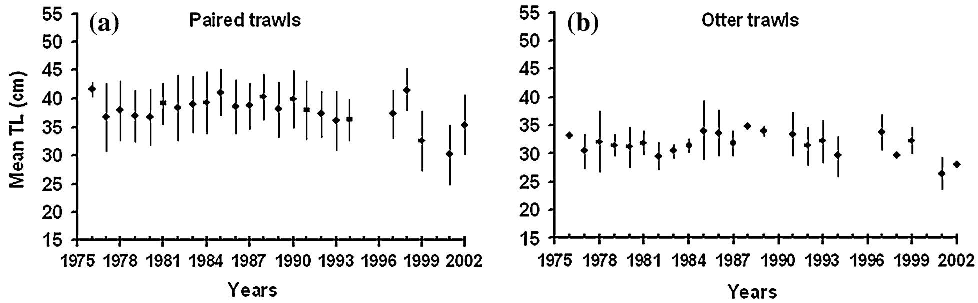

Fig. 2 Mean annual sizes of *C. guatucupa* fished in southern Brazil by paired and otter trawls between 1976 and 2002. Vertical lines represent the standard deviation

The growth parameters were estimated by non-linear regression methods that allow the simultaneous variation of all parameters. Between the second and the fourth periods there was an increase of L_∞ and a decrease of K (Table 4). Values of t_0 varied around—0.9 and it was equal to—1.62 for the third analysed period. Comparison of the growth parameters between periods 1 and 2, periods 1 and 3 and periods 1 and 4 resulted in null hypothesis (equal parameters) rejected in all cases ($\chi^2_{\text{observed}} >$ (χ^2_{critical}). The most significant difference was observed between time periods 1 and 4 (Table 5).

For all parameters varying freely the K values did not reflect the higher growth rate because the negative correlation between K and L_∞. However, fixing L_∞ at 52.5 cm, the coefficient K increased from 0.22 in the first three periods to 0.28 in the last one.

Mortality

Catch curve estimated Z values varied between 0.36 in 1976 and 0.92 in 2002 and indicated a clear increasing trend in all the analysed periods (Fig. 4Left). The slope of regression between yearly estimates of Z and years was significantly greater than zero ($F_{(1,22)} = 87.33$; $p < 0.01$).

Instantaneous natural mortality coefficient M was estimated at 0.26 by Taylor's method using the growth parameters obtained for the period between 1977 and 1980 ($K = 0.238$ and $t_0 = -0.972$), and at 0.23 by using the regression proposed by Hoenig assuming that the maximum observed age was 18. To apply the Alagaraja method, a $t_{\max}$ of 18 years old was used and the values of $M_{1\%}$ and $M_{0.1\%}$ were 0.26 and 0.38, respectively. Based on the estimated values of Z, on the biologic aspects of the striped weakfish and comparing theses results with the estimated M of other teleosts of the same region, it was assumed that values of instantaneous natural mortality coefficient of *C. guatucupa* fell in the 0.20–0.30 range with a most likely value of 0.25 year^{-1}.

Yearly exploitation rates ($E = F/Z$) were calculated considering the Z values obtained from catch curves from paired trawls landings and

Table 2 Total number and percentage of females of *C. guatucupa* for length classes and periods of study from 1976 to 2002

TL (cm)	1976–1980		1981–1987		1988–1994		1997–2002		Total	
	N	%F	*N*	%F	*N*	%F	*N*	%F	*N*	%F
20–29	574	58	360	51**	167	70	84	69	1185	58
30–45	1414	55	1564	54	519	55**	502	61	3999	55
>45	372	76	304	66	213	61	261	63	1150	68
Total	2360	59	2228	55	899	59	847	62	6334	58

** The marked values were the cases where female percentage was not significantly higher than 50% (χ^2-test; H_0: % females ≤ 0.5; level of significance = 0.01)

Table 3 Number (N), mean total length (TL) and standard deviation (SD) for age classes (pooled sexes) and period for *C. guatucupa* caught in southern Brazil between 1976 and 2002

Age	1976–1980			1981–1987			1988–1994			1997–2002		
	N	Mean TL	SD	*N*	Mean TL	SD	*N*	Mean TL	SD	*N*	Mean TL	SD
0	52	17.8	3.3	29	19.6	3.8	9	24.4	0.9	2	20.7	3.7
1	218	23.5	4.6	181	23.7	4.5	85	27.3	2.8	38	23.6	2.5
2	574	29.4	3.7	330	29.7	4.6	167	30.7	3.7	76	29.3	3.3
3	512	33.8	4.0	497	34.5	4.0	172	34.9	4.0	163	35.6	3.3
4	371	37.9	4.0	481	38.1	3.8	108	39.0	3.4	146	39.9	3.9
5	221	40.6	3.1	331	41.2	3.2	100	47.8	3.0	141	42.6	2.9
6	156	43.3	3.0	174	43.3	2.5	56	44.0	3.1	101	44.5	2.9
7	120	45.3	2.3	128	45.0	2.3	67	46.1	2.5	59	46.9	2.8
8	91	46.3	2.4	72	45.7	2.0	61	47.5	2.2	63	49.1	3.2
9	75	47.3	2.5	51	46.7	2.4	41	47.8	2.6	35	50.9	3.1
10	55	47.4	2.4	22	47.4	2.1	21	48.0	2.6	18	52.2	4.1
11	25	48.6	2.0	20	48.6	1.9	7	49.0	2.9	11	53.4	3.6
12	22	49.9	2.6	10	48.2	1.5	5	49.0	2.5	2	55.3	1.5
13	15	49.6	2.3	7	50.6	2.2	1	45.2		2	53.6	1.6
14	11	50.0	3.4	3	48.6	2.9	2	48.5	3.8	1	56.9	
15	4	50.8	3.4									
16	2	20.3	3.1	1	47.0							
17				2	54.0	4.9						
18	1	49.5		1	50.5							

M values ranging from 0.20 to 0.30. The *E* ranged from 0.17 to 0.44 in 1976 and increased from 0.67 to 0.78 in 2002 (Fig. 4Right).

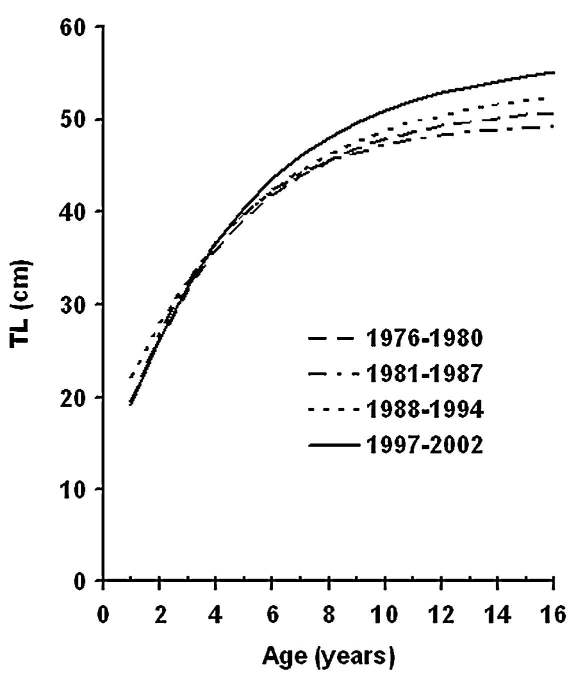

Fig. 3 Growth curves for pooled sexes of *C. guatucupa* in southern Brazil in the periods 1976–1980, 1981–1987, 1988–1994 and 1997–2002

Discussion

Clear changes in the age structure, growth and mortality of striped weakfish have been observed since 1976. These changes occurred along a time period in which the yields in shouthern Brazil demersal fishery decreased sharply (Vasconcellos et al., 2005). These changes are consistent with an increase in the fishing mortality in the same time period. A similar temporal change in the commercial landings of this species in Mar del Plata was recorded by Ruarte & Aubone (2004), who observed a decrease in the mean length after 1994.

The sharp decrease in the mean length of *C. guatucupa* landed in southern Brazil after 1997 may not be completely explained by changes in the age structure. An alternative cause could be

Table 4 Von Bertalanffy's model growth parameters for *C. guatucupa* by analysed period and their confidence interval for $\alpha = 0.05$

	L_∞	K	t_0
1976–1980	51.65 ± 0.72	0.24 ± 0.01	–0.97 ± 0.12
1981–1987	49.71 ± 0.62	0.28 ± 0.01	–0.75 ± 0.11
1988–1994	54.02 ± 1.00	0.20 ± 0.01	–1.62 ± 0.20
1997–2002	56.60 ± 0.95	0.21 ± 0.01	–0.95 ± 0.15

Table 5 Comparisons of Von Bertalanffy growth parameters applying a likelihood ratio test between periods (pooled sexes) for *C. guatucupa* caught in southern Brazil. Sum of squares of residuals of general model (SSRG—simultaneous variation of all parameters) and of restricted model (SSRR—considering equal parameters), $\chi^2_{observed}$, $\chi^2_{critical}$ and if the null hypothesis (equal parameters) was rejected or not are indicated

	Comparisons between periods		
	1 and 2	1 and 3	1 and 4
SSRG	59941.25	42612.41	40774.92
SSRR	60420.44	43204.04	42411.22
chi obs	37.71	45.90	129.53
chi tab 1%	11.34	11.34	11.34
Probability	0.000	0.000	0.000
H0	Rejected	Rejected	Rejected

the displacement of the trawlers to deeper waters, described by Miranda (2003), where smaller individuals are more frequent (Haimovici et al., 1996).

Higher growth associated with increased exploitation (Fig. 4 Right) suggests that decreasing abundance lowers intraspecific competition. This is a common effect in moderately exploited stocks. It was also observed for the other main components of the southern Brazil demersal fishery *Umbrina canosai* (Berg) (Haimovici et al., 2006) *Macrodon ancylodon* (Bloch & Schneider) (Martins-Juras, 1980; Haimovici, 1988) and *M. furnieri* (Haimovici & Ignácio, 2005).

The *C. guatucupa* growth changes were more evident at highest ages, contrary to expectations when density-dependent regulation affects the stock (Jennings et al., 2001). This could be explained by differences in distribution areas and diet according to age. The diet of juveniles is composed by small pelagic crustaceans and for this reason prey availability did not change that much for the adults, whose diet is composed by small pelagic fish, demersal fish and benthic shrimps (Cousseau & Perrota, 2000; Martins, 2000).

Concomitantly, recent changes in the ecosystem structure in the Front of De La Plata River with a decrease of *Merluccius hubbsi* (Marini) density north of 41° S (Aubone et al., 2000) could have favoured striped weakfish growth, due to interspecific competition decrease. Food availability for *C. guatucupa* could have increased, since both species present a partial overlap of niches and habitat use (Martins, 2000).

Estimated instantaneous total mortality coefficients showed a clear increasing trend over the years. Estimated exploitation rates indicate that the catches of *C. guatucupa* were higher than sustainable even for a non-conservative goal (E = 0.5) and for instantaneous natural mortality coeficient ranging from 0.20 to 0.30 year^{-1}, at least since the beginning of the 1980s (Fig. 4 Right). Values of M higher than this would not be consistent with the Z estimated values of the 1970's. Moreover, this value seems to be adequate when compared with estimations of M for other teleosts of the same region. For example, these values are lower than the estimated values of M for *Paralichthys patagonicus* (Jordan) as 0.35 year^{-1}

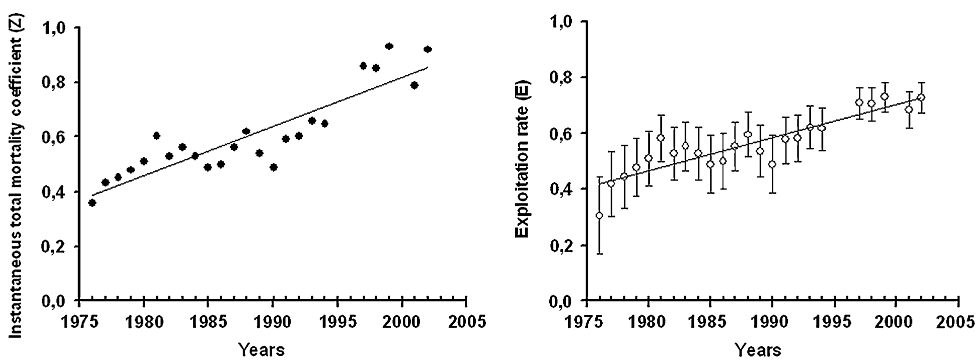

Fig. 4 Linear regression of (Left) instantaneous total mortality coefficient Z values and (Right) exploitation rate E per year for *C. guatucupa* fished in southern Brazil and landed in Rio Grande between 1976 and 2002. Lower, mean and upper points represent E values calculated respectively for M values of 0.30, 0.25 and 0.20

for females and 0.42 $year^{-1}$ for males, whose maximum observed ages were 13 and 11, respectively (Araújo & Haimovici, 2000) and higher than estimated for *U. canosai*, around 0.20 $year^{-1}$, with a life expectancy over 20 years (Haimovici & Reis, 1984).

Correlation of total mortality coefficients from catch curves against time was relatively high and suggest that there was not pronounced recruitment variation that should result in low correlations or concave catch curves (Ricker, 1975).

It could be argued that a natural mortality or recruitment increase could explain the greater relative frequency of younger and smaller fish in the catches and thus, the inclination of the catch curves. If there were a recruitment increase, it should have reflected in higher catch per unit of effort (CPUE) of weakfish in the commercial landings, and this was not observed (Vasconcellos et al., 2005). Moreover, because of the reproductive strategy of this species, with a long spawning period in an extensive geographic area (Cassia, 1986; Cordo, 1986; Vieira & Haimovici, 1997; Ruarte et al., 2000), large interannual fluctuations in the recruitment are unlikely. On the other hand, decreased competition and increased availability of food may decrease natural mortality. So, the main cause for increased Z appears to be fishing. However, a combination of increasing fishing mortality and higher carrying capacity for *C. guatucupa* must be considered.

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