Lat. Am. J. Aquat. Res., 42(3): 534-546, 2014
DOI: 103856/vol42-issue3-fulltext-13

Research Article

Changes in population structure and growth of skipjack tuna, *Katsuwonus pelamis* during 30 years of exploitation in the southwestern Atlantic

Thais Garbin[1] & Jorge P. Castello[1]
[1]Instituto de Oceanografia, Universidade Federal do Rio Grande
Av. Itália Km 8 s/n, Campus Carreiros, Rio Grande, RS, Brazil

ABSTRACT. The skipjack tuna is the main tuna species caught in Brazil with pole and live-bait. Samples taken during 1984-1986 and the 2004-2009 periods provided length, weight and age data. A comparison of the population structure was made showing a decrease in the median and means of fork length in the 80`s (median: 55 cm) and recent years (median: 51 cm), an increased participation of smaller individuals (40 cm) in recent catches, a high variability of lengths in each year class and a decrease of the condition factor K. These results indicate alterations in the population structure and dynamics. The von Bertalanffy growth parameters calculated for the recent years were L_∞ = 669 mm; k = 0.24 yr^{-1}; t_o = -3.8. CPUE data for the studied period seems to be stable (mean annual catch of 20,000 ton). However, the unit of effort used in Brazil (fishing days) does not reflect changes in fishing power and technology properly as occurred during 30 years of exploitation. It is concluded that the present situation requires a close monitoring of the fishery.

Keywords: *Katsuwonus pelamis*, skipjack, population structure, weight-length relationship, condition factor, growth, CPUE, southwestern Atlantic.

Cambios en la estructura poblacional y crecimiento del barrilete, *Katsuwonus pelamis*, durante 30 años de explotación en el Atlántico sudoccidental

RESUMEN. El barrilete es la principal especie de atún capturada en Brasil con caña y cebo vivo. Muestras tomadas durante la década de los 80 y durante el periodo 2004-2009 proporcionan información sobre tamaño, peso y edad. Una comparación entre ambos periodos mostró una disminución en las medianas de los tamaños, 55 cm en los 80 y 51 cm en el período más reciente, una mayor participación de ejemplares menores (40 cm) y una disminución en el factor K de condición. Estos resultados indican que pueden estar ocurriendo alteraciones en la estructura y dinámica del stock. Los parámetros de von Bertalanffy más recientes fueron de L_∞ = 669 mm; k = 0.24 $año^{-1}$; t_o = -3.8. Los datos de CPUE para el periodo estudiado parecen indicar una estabilidad en el stock (20.000 ton de captura media). Sin embargo, la unidad de esfuerzo utilizada en Brasil (días de pesca), no refleja adecuadamente los cambios en tecnología y poder de pesca que ocurrieron durante 30 años de explotación. Se concluye que la situación actual del stock requiere un monitoreo estricto de sus condiciones.

Palabras clave: *Katsuwonus pelamis*, barrilete, estructura de la población, relación longitud-peso, factor de condición, crecimiento, CPUE, Atlántico sudoccidental.

Corresponding author: Jorge P. Castello (docjpc@furg.br)

INTRODUCTION

The skipjack tuna (*Katsuwonus pelamis*) pole and live-bait fishery in Brazil started in 1979 with boats operating from Rio de Janeiro (RJ; 23ºS). In a couple of years this fleet expanded its operations to southern Brazil (34ºS) and now regularly fishes along the south/southeast region. Landing ports for this fishery are located at Rio de Janeiro (RJ), Itajaí (SC) and Rio Grande (RS) (Meneses de Lima *et al.*, 2000) (Fig. 1). At the present time, 80% of the total catch comes from waters off the states of SC and RS. Production oscillates between 16,000 and 27,000 ton yr^{-1} (ICCAT, 2012).

The skipjack tuna is considered to be a resilient species (ICCAT, 2006). However, in 2008, the Review Panel formed by ICCAT members reported that there was not enough knowledge and information on skipjack tuna in order to take any measures of management for this fishery (Hurry *et al.*, 2008). The Panel considered that "the skipjack tuna fisheries should be managed in such a way as not to cause conservation concerns for other species, particularly including other species of tunas" (*sic*).

Over the last decades the Brazilian skipjack bait boat fishery has been considered to be a stable one. It is believed that the expansion of this fishery is limited by the availability of the juveniles sardines used as live baits and the long sailing distance from the fishing grounds to coastal areas of juvenile sardine occurrence (Castello *et al.*, 2009). Most of the fishing boats operate with pole and live bait. Brazilian fishery regulations determine that fishing boats must catch their own live baits. This regulation and difficulties on getting the bait has prevented effort increases and, possibly, the overfishing of the skipjack tuna stock. However, this apparent sustainability can be fragile, as increasing political pressure made by purse seiner owners, can introduce changes on the present legislation.

Skipjack catches in southern Brazil (29-34ºS) show seasonal variability. Migratory schools are influenced by the cyclicity of the Subtropical Confluence (interaction of Brazil-Malvinas currents) and the sea surface temperature distribution (Castello & Habiaga, 1988; Andrade & Garcia, 1999). During winter, cold and less saline waters originated from the Malvinas current, are found on the continental shelf of southern Brazil. Skipjack schools migrate to the north searching for warmer waters during late autumn. At the peak of the winter season the highest catches are found at waters off 26ºS. During the late spring and summer, cold waters retreat to the south, and skipjack schools return to higher latitudes following the warmer waters. At this time the highest catches are found off 33ºS (Andrade, 2003).

During the late eighties, Castello & Habiaga (1988) and Vilela & Castello (1991) carried out studies on the occurrence, seasonal distribution and population dynamics of the skipjack tuna. Age studies using cross sections of the first dorsal fin spine (n = 1074 individuals), verified that vascularization in the inner portion of the spine does not interfere with age determination. Age validation was performed studying the monthly frequency distribution of the hyaline/opaque border of the spines cross sections. Results led the authors to establish the occurrence of two pairs of hyaline-opaque rings per year. The von Bertalanffy (vB) growth parameters were calculated (L_∞ = 871 mm and k = 0.22 yr^{-1}). Using natural and fishing mortality estimates, it was concluded that the stock was under a moderate exploitation rate (E = 0.55). The targets of this fishery were individuals of age 2 and older (Vilela & Castello, 1993). On the other hand, Andrade *et al.* (2004) using a smaller sample (n = 312) of cross sections of the first dorsal fin spine of skipjack tunas landed at Itajaí (SC), obtained different results. They proposed a single growth ring by year and concluded that because of vascularization a corrective model was needed.

According to ICCAT (2006), growth models for eastern Atlantic skipjack tunas were calculated during 1979 to 1982. It was concluded that fishes at the equatorial areas grew with a slower rate than those at the subtropics (Bard & Antoine, 1986). Recent studies confirm this variability on growth according to latitude (Gaertner *et al.*, 2008).

In this paper we assess whether the sustained skipjack fishing during 30 years at southern Brazil have introduced any changes in the skipjack tuna population structure with regard to weight, length and age of recruitment.

MATERIALS AND METHODS

Samples were obtained from commercial landings at the Leal Santos Company piers in Rio Grande (RS) during the period 2004-2009. The company fleet has six dedicated boats geared for the pole and live-bait skipjack fishery and keep records of its fishing operations. Figure 1 show the sample positions spread over the seasons of the year in the south-southeastern region of Brazil.

Samples

Fork length (FL) random samples were taken from landed catches (1 cm class intervals), whenever possible, with a weekly frequency in the period 2004 to 2009. Catches of the Leal Santos Company followed skipjack schools displacements and our samples reflect this fact (Fig. 1). After fork length sampling, random sub samples were taken in order to obtain weight (W in g) determine sex and collect the first dorsal fin spine (Table 1). In all cases, fork length (FL) frequency distributions were weighted by the catch landed. For comparison purposes samples obtained at Rio Grande landings during 1984-1986 and from Itajaí (SC) landings obtained during 1995-1996 and 2002-2004 (kindly provided by H.A. Andrade/UFRPE) were used.

Condition factor (K)

The condition factor K (King, 2007) was calculated as: K = weight $length^{-b}$; (weight in g and length in mm). Where "b" is the exponent for the weight-length relationship calculated for each year in question. For comparisons between periods, the condition factor for FL of 50 cm was used, as this length class is well represented along the whole period.

Age and growth determination

The first dorsal fin spine was used for age interpretation. A cross thin section of the spines was cut

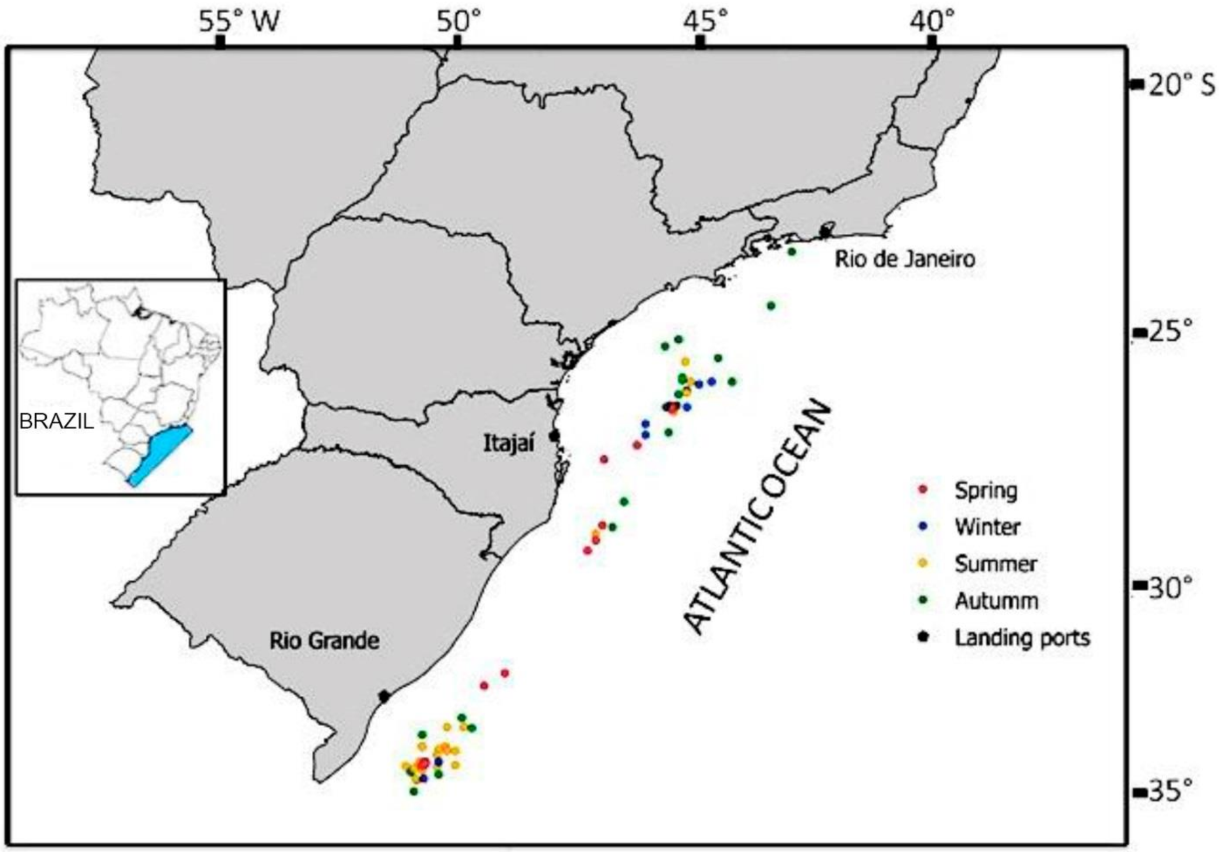

Figure 1. Area of SW Atlantic showing the principal landing ports: Rio Grande (RS), Itajaí (SC) and Rio de Janeiro (RJ) in Brazil and the catches of Leal Santos Company performed in the four seasons during the period 2004-2009.

Table 1. Samples by year and months of skipjack tuna landings of the Leal Santos Company. The first sampling stage corresponds to random samples of FL (cm) and the secondary samples, to weight data and collection of the first dorsal fin spine.

Year	Month												Weight-Length	n spines
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
2004	X	X	X		X	X	X			X	X		X	497
2005	X		X	X		X	X					X		-
2006	X		X	X	X	X		X			X	X		-
2007	X	X	X	X	X	X							X	287
2008			X	X	X	X				X	X	X	X	265
2009				X	X		X					X	X	197

near the condyle articulation. The resulting pieces (n = 1049) were included in crystal polyester resin cubes and slices of 0.8 mm thickness obtained with a metallographic cutter. Slices were fixed (with Entelan ®) on a histological slide for observation under a stereoscopic microscope using transmitted light. Hyaline rings were counted by two readers and following Vilela & Castello (1993) we considered that two pairs of a hyaline-opaque ring define a year growthzone. When independent readings were not coincident a third joint reading was performed. If results between these readers were still different data was excluded (n = 132).

Bhattacharya`s method

Age/length multimodality was assessed after applying the Bhattacharya's method (routine available in the program FISAT of Gayanilo *et al.*, 1995) to all age data in order to separate normal components.

The von Bertalanffy (vB) growth model adjustment

In order to fit a vB growth model to age and length data, the Bayesian inference (Kinas & Andrade, 2010) using the Gibbs Sampling performed by the software OpenBUGS (Lunn *et al.*, 2009) in the R program (R, 2012) was applied.

A Markov Chain Monte Carlo (MCMC) simulation using a joint posterior distribution provided a chain of 31,000 samples. The first 10,000 steps ("burn in") were rejected to eliminate the autocorrelation, and the subsequent 20,000 were thinned at a rate of 2. The posterior mean and probability intervals (25% and 75%) were calculated for the 10,500 remaining samples. To describe the model, we first assumed that the age-length data followed a log-normal distribution: $y_i = \log N(\mu_i, \sigma^2)$, where y_i is the length distribution with a mean expected length at an age class *i* with variance = σ^2. A logarithmic version of the vB equation was used for computational convenience:

$$\mu_i = \log(L_\infty) + \log(1^{-k(age_i - t_0)})$$

Uninformative priors were constructed and restricted to positive numbers. Prior distributions were truncated to improve numerical efficiency, but did not impact the results because the truncated areas had no posterior support:

$$p(\log L_\infty) \sim dN(6{,}0.001)I(4{,}10)$$
$$p(\log k) \sim dN(0{,}0.001)I(-5{,}5)$$
$$p(t_0) \sim dU(-5{,}0)$$
$$p(\sigma) \sim dU(0{,}5)$$

Back calculation

Samples from the years 2004, 2007 and 2008 were used for back-calculation studies with lengths ranging between 500 and 730 mm (FL). Transversal measurements (N: 177) (mm) in the slice were taken (Fig. 2) between the spine core and the distant border of the hyaline rings (Rn) that were formed on the spine. Measurements were made using the BELView software (Version 6.2.3.0). With this information, the fish fork-length corresponding to each hyaline ring was back calculated from the fork-length of each individual, using the following linear proportion with a correction factor:

$$FL_n = C + \frac{R_n}{R_t} \cdot (FL_t - C)$$

where FL_n (mm) is the back calculated fork-length for each age n; R_n (mm) is the measured distance as explained before; R_t (mm) is the total distance between the core to the edge of spine; FL_t (mm) is the fork-length of the fish and C is the correction intercept value as explained by Everhart *et al.* (1975) and Carlander (1981). A data set of back-calculated fork-lengths at age was produced and the vB growth model was adjusted to these data.

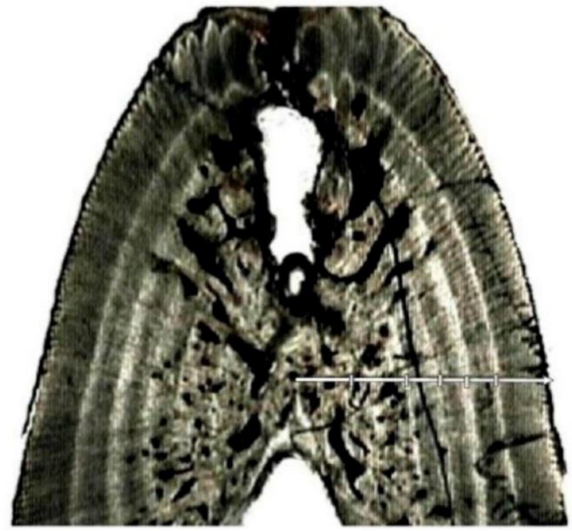

Figure 2. Photograph of a spine section of skipjack. The inner hyaline rings (in the reabsorbed zone) are still visible (six hyaline rings are observed).

Mortality estimates

The total mortality rate, Z, was estimated using the linearized catch curve based on age composition data for 2004 (Sparre *et al.*, 1989), which is the year best represented (n = 382).

$$\ln H_t = g - Z \cdot t$$

H_t is the frequencies of skipjacks for age *i*, g is the intersection line term, Z is the slope, of the linear regression and t is age in years.

Natural mortality rate (M) was estimated following the Rikhter & Efanov (1976), Pauly (1980) and Cubillos (2005) according to the following expressions:

Rikhter & Efanov (1976):

$M = 1.521/(T_{m50}{}^{0.720}) - 0.155$; where T_{m50} is considered the age at which 50% of the population is mature (2.5 years)

Pauly (1980):

$M = 0.8^{-0.0152-0.279\ln L_\infty + 0.6543\ln k + 0.463\ln T}$; where T is the mean sea surface temperature (23°C) for the skipjack habitat, and

Cubillos (2005):

$M = (b \cdot k(1-0.62))\, 0.62^{-1}$; where b is the weight-length relationship exponent,

The rate of fishing mortality (F) was obtained by subtraction from total mortality as in the expression: Z = F + M. And the exploitation rate was estimated following Ricker (1975): E = F/Z.

Catch per unit of effort data (CPUE): Landing and effort data for the Brazilian bait boat fishery was extracted from the ICCAT' site (ICCAT, 2012). In this data-set catch is expressed in tons and effort in "fishing days".

Data comparison between periods

In order to assess the effect of exploitation on the population structure of skipjack, comparisons were made between different periods for two data sources: (1) Length, weight and age composition data obtained at Rio Grande-RS (from Vilela & Castello, 1991, 1993) during the period 1984-1986, and (2) Length and weight composition data obtained from the commercial landings at Itajaí-SC in the period 1995-2004 (kindly provided by H.A. Andrade/UFRPE).

After confirming the prerequisite of normality for the length data of 2004-2009, heterocedastic data was transformed through a nonparametric ranking of the dependent variable (FL). The analysis of variance was applied for this length data and a highly significant difference for the lengths structure between the periods (1984-1986, 2004-2009) was found.

RESULTS

Length composition

FL distributions for the landed skipjack tuna in the period 2004-2009 are shown in Figure 3. Three years (2004, 2008 and 2009) showed length multimodality. In 2004, a mode of smaller individuals (47 cm) is apparent. In 2008, two modes are evident, one of larger individuals (62 cm) and another of smaller (49 cm). In 2009, two modes are also present (56 and 49 cm). The FL distributions for 2005 to 2007 are more symmetrical than the other ones. In 2005, a defined mode on 54 cm is seen and in 2006 and 2007 samples they are spread around 52 cm (Fig. 3).

For skipjack tuna landed at Itajaí (SC) in the period 2002-2004, two size modes (51 and 59 cm) were observed in 2004 (Fig. 4). These size modes at Itajaí are similar and slightly higher than those observed at Rio Grande. Fork length distributions for samples of the late '80 showed larger modes (55 cm) in comparison with the most recent ones (Fig. 5). In order to highlight this difference, cumulative frequencies were calculated. The median founded for 80`s years was 55 cm while for recent years, the median is smaller, 51 cm. The mean sizes for the period of 80`s years and for the recent ones shows a clear decrease (Fig. 6). In order to emphasize these differences, a comparison for fork-lengths grouped in 10 cm intervals (Fig. 7) was made. An increase of the occurrence of smaller individuals (40 cm) and a decrease for the larger ones (50 and 60 cm) is evident.

Age composition

Ageing comparisons between independent readers produced low percentages of discarded age readings (13% in 2004; 16% in 2007 and 8% in 2008). Most of the specimens presented a central vascularization zone, which usually tends to "erase" previous rings that existed in this area. However, in all the examined specimens, vascularization was partial and moderate and the inner hyaline rings were partially visible (Fig. 2). This result was also found by Vilela & Castello (1991) who could identify and compute the vestigial rings. Therefore, we considered that there is no need for any age correction.

Table 2 shows the matrix of age-length for the years 2004, 2007 and 2008. Figure 8 shows the age-length distribution for 2004, 2007 and 2008. The results of the Bhattacharya analysis confirmed the multimodality for ages 3 to 5 (Fig. 9). Age class 2 showed a unique mode, but this is not an entirely recruited age group (Vilela & Castello, 1993).

Weight composition and condition factor (K)

Weight-length curves also showed important differences. Curves for the 80's years contrasted with the latter ones, as weights at length for this period were higher (Fig. 10).

Comparisons of the condition factor (K) also showed differences. The period of the 80`s years has the highest values, followed by 1995-1996 (Itajaí data) and 2004 and 2007 that has the smallest value for K. The condition factor returns to rise in the next following years. However, without reaching the K values for the 80 and 90 decades (Fig. 11).

Back calculation between the hyaline rings and correspondent length

The linear relationship between the skipjacks lengths and spine ray was $R_t = 6 \cdot 10^{-3} FL_t - 1.35$ (R^2 = 0.89). The correction factor (C) for the back-calculation expression as obtained from the regression line was found to be 227 mm.

The von Bertalaffy (vB) growth model

The vB growth model was applied to the observed age's data for 2004, 2007, 2008, and to a pool of back calculated lengths at age data. The summary of results is shown in Table 3. It can be observed that the values for L_∞ and k were different for each year. Data from 2004, which is the best sampled year, has the higher accuracy in age readings and the minor mean standard error (Table 4).

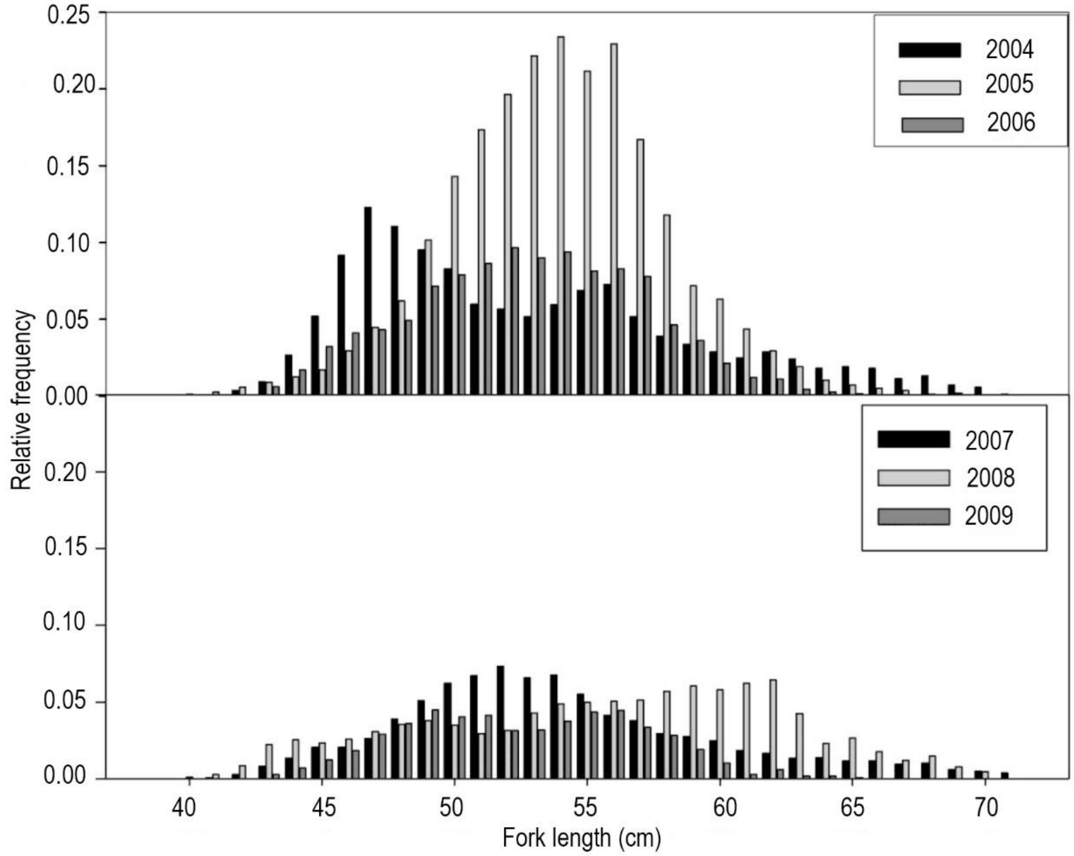

Figure 3. Frequency distribution of landed skipjack fork lengths for the period 2004-2009 at the Leal Santos Company (Rio Grande-RS). Years 2004, 2008 and 2009 showed length polimodality.

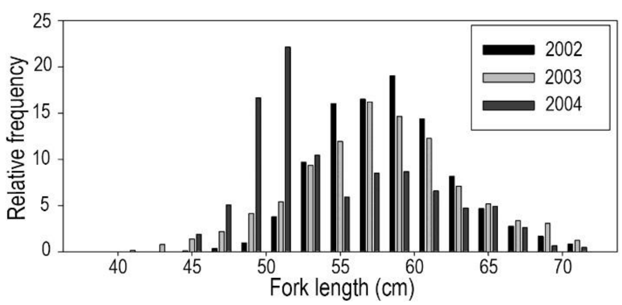

Figure 4. Frequency distribution of fork length (cm) for landings at Itajaí-SC for the period 2002-2004. Two size modes were found in 2004, the smaller with 51 cm and the other one with 59 cm.

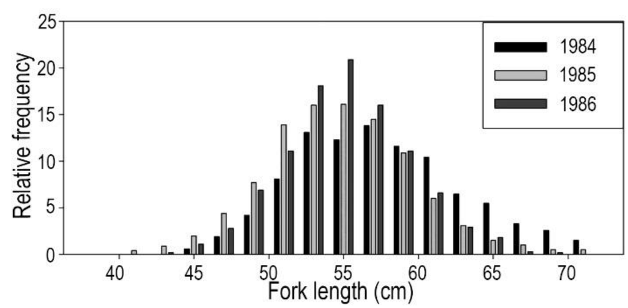

Figure 5. Frequency distribution of fork length for the 80 decade (data from Vilela & Castello, 1993). Size modes were larger than the recent ones and no multimodality was observed.

Fishing and natural mortalities

The linearized catch curve based on age composition data for 2004 showed a full recruitment age to the fishery at 3 years (Fig. 12). Age 2 was excluded from the regression line as this age is not fully recruited. From this regression, Z was estimated to be 1.69 yr^{-1}. Natural mortality, M, was estimated following Rikhter & Efanov (1976), Pauly (1980) and Cubillos (2005), with different results (Table 5) ranging respectively from 0.41 to 0.63 yr^{-1}. The exploitation rate E calculated showed $E > 0.5$ for the three possible values founded for M (Table 5).

Catch per unit of effort (CPUE)

According to data available on the web site of ICCAT (2012), the CPUE for the Brazilian fishery in the period 1983-2008 does not show any definite trend, neither rising nor decreasing along the period (Fig. 13). In ge-

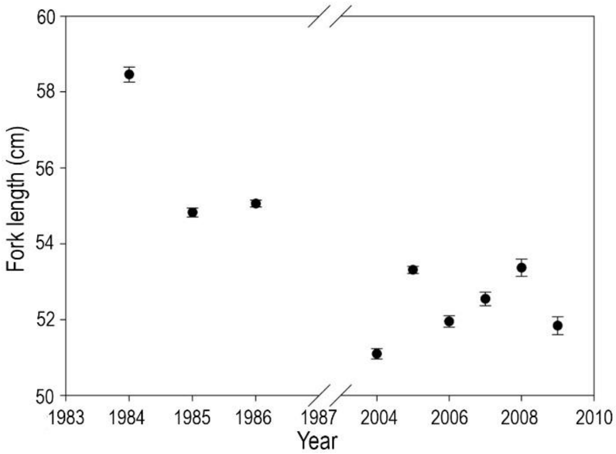

Figure 6. The mean and 95% confidence intervals for the fork lengths distributions in the Rio Grande landings during the periods 1984-1986 and 2004-2009. The mean FL`s for the earlier years were noticeably higher than the recent ones.

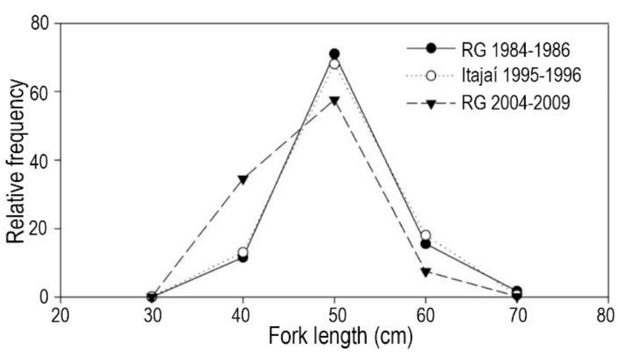

Figure 7. Comparison for fork lengths composition grouped in 10 cm intervals between periods. Recent compositions show increasing proportion of smaller individuals.

neral, this has led to assume (ICCAT, 2012) that the skipjack tuna stock exploited by the Brazilian live-bait fishery is in a stable condition. The Brazilian live-bait fishing fleet catches more than 98% of the production. In 2005, about 4 or 5 boats started to fish skipjack tuna with purse seine; but their catches represented only 1.9% of the total production.

DISCUSSION

Length composition

The comparisons among the three decades showed an evident alteration in the lengths composition *i.e.*, the actual increase of smaller individuals in the catches, demonstrated by the drop in mean and medians lengths. We suggest that the "El Niño" events may have influenced the oceanographic conditions in the south-western Atlantic affecting the abundance and distribution of the skipjack recruits, as shown by the abundance of smaller individuals in the lengths composition of 2004.

Paes & Moraes (2007) suggested that after intense "El Niño" events, an increase in the primary production and in the pelagic fisheries of the southern Brazilian region may have occurred. During 2005 a severe drought occurred in the Amazon basin, which was associated with the earlier strong "El Niño" event of 2002-03 (Zeng *et al.*, 2008). Interestingly, Lehodey *et*

Table 2. Age-length matrix of 2004, 2007 and 2008, furcal length (FL) in cm and age in years.

FL	Ages (years)					
	I	II	III	IV	V	VI
39		1				
40						
41			1			
42		3	2	1		
43		6	5	2		
44		10	8	2		
45		17	15	1		
46		12	14	6	1	
47		18	27	14		
48		13	45	8	2	
49		9	31	17	4	
50		3	22	24	5	1
51		1	21	25	6	
52		1	13	15	4	
53		3	10	23	7	
54			11	16	2	1
55		2	12	22	9	1
56			12	13	5	1
57			4	12	7	4
58			7	11	7	2
59			9	18	8	4
60			7	10	7	2
61			2	17	6	2
62			3	8	5	2
63			2	10	7	3
64			2	9	7	3
65			1	13		2
66				4	6	3
67				5	3	3
68				4	4	4
69				2	2	
70				1	1	1
71					4	
72					1	
73						
74					1	
Total	0	99	286	313	121	39

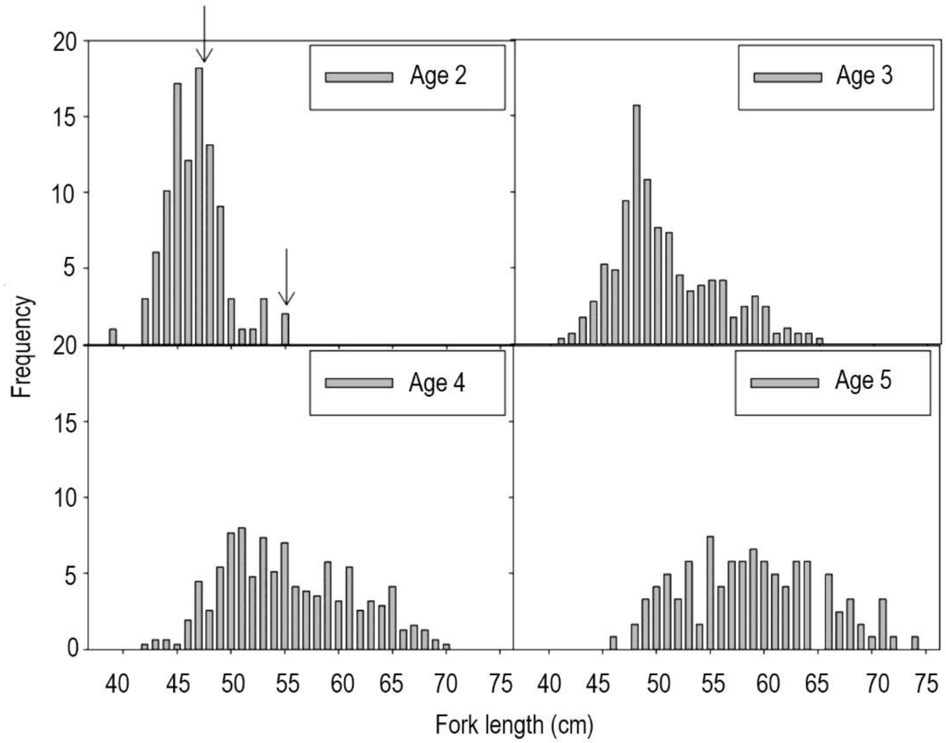

Figure 8. Frequency distributions of fork length (cm) for ages 2 to 5. The first arrow represents the recruitment length in recent years (47 cm) and the second, the recruitment length in the 80`s years (55 cm).

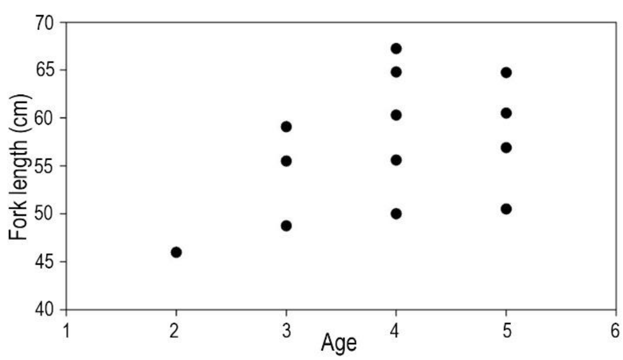

Figure 9. Means (cm) of the normal components in the age-length distributions for each age class (2 to 5) identified by the Bhattacharya's method, illustrating the multimodality found in ages 3 to 5. A single mode was found for age 2.

al. (2004) showed that sea surface temperature anomalies, after "El Niño" events on the western and central Pacific, correlated with an increase on the skipjack tuna recruitment stock.

Weight composition and condition factor (K)

The weight/length skipjack analysis reveals that there is a difference between periods; the present weights at lengths of skipjacks are lower. Specimens in the 80` years were heavier and exhibited higher values for the condition factor K. That is, to reach a certain length (50 cm, for example), the 80` years specimens took a relative shorter time (2 years) compared to specimens of recent years (3.3 years). This fact places in evidence that the present caught skipjacks have a different weight/length/age structure. They incorporated less biomass with time and seem to have a slower growth rate.

Around 1990, pole and live-bait fishermen started to deploy fishing attracting devices (FAD) in order to get aggregations of skipjack tuna. It is known that the FAD's (Hallier & Gaertner, 2008; Dagorn *et al.*, 2010) induce a negative ecological effect on fishes associated with drifting FADs. Research showed that they were less healthy than those in free schools, (Hallier & Gaertner, 2008) presented smaller sizes and their stomach fullness indicated that tunas associated with FADs eat less than those in free schools. Therefore, differences in growth rate and condition could be the consequence of altered feeding patterns. At the present time the use of FAD is a common practice, but the percentage of the fleet that uses FADs and its effect has been not monitored (Marco Bailon technical adviser to SINDIPI [(*)], *pers. comm.* and data kindly provided by P.R. Schwingel; UNIVALI-SC).

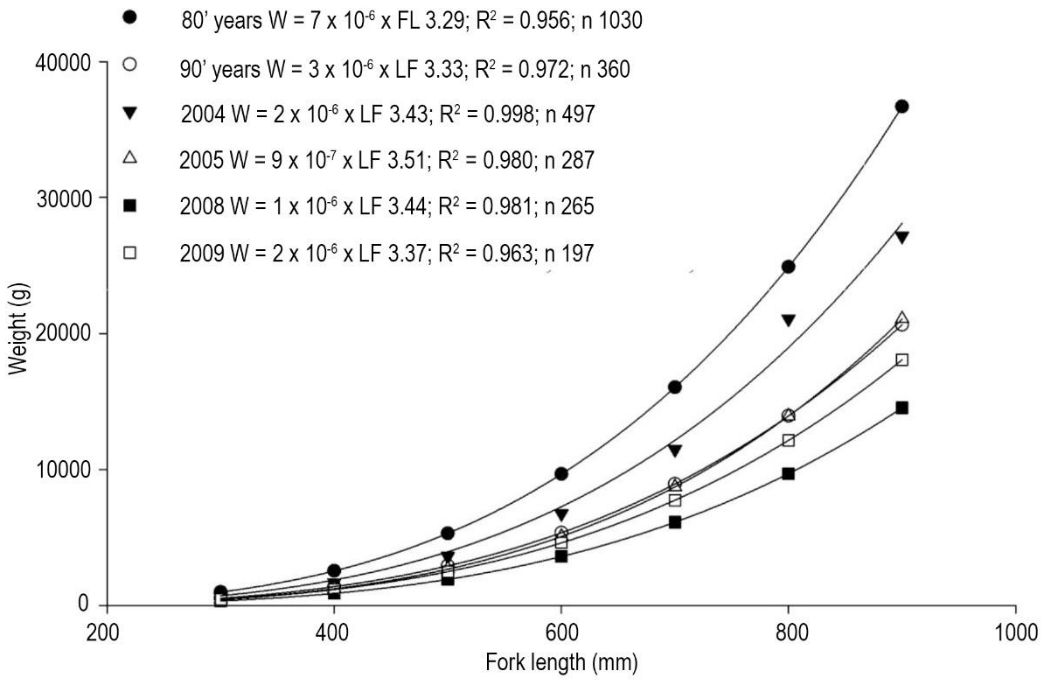

Figure 10. Comparison of the weight-length curves and relationships; weight in grams (g) and length in millimeters (mm). Symbols represent: ● (80`s years); ○ (1995-1996 Itajaí); ▼ (2004); Δ (2005); ■ (2008) and □ (2009).

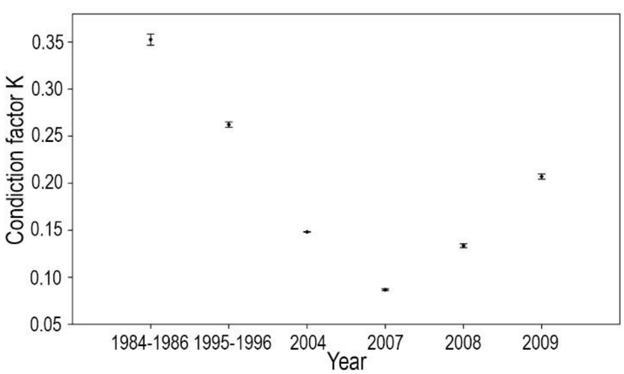

Figure 11. Mean and the 95% confidence intervals for the condition factor K calculated at fork length of 50 cm.

However, Rätz & Lloret (2003) working with cod stocks, called the attention to the condition of the different fish stocks. Stocks with better conditions are characterized by specimens with greater weights at age, have good recruitment potential that can support higher levels of exploitation than those in poor conditions. In our case, it is not possible to conclude about the actual causes for these changes in the weight as the condition factor is an index of complex interpretation. As indicated by Rätz & Lloret (2003) several effects (biological, ecological and environmental) can affect the condition factor and they can result in important implications on growth and reproduction.

Age composition

We interpret that different length modes for the same age class are the result of different cohorts growing simultaneously, but with distinct speeds. As stated by Cayré & Farrugio (1986), skipjacks are "opportunistic" spawners, therefore within a given year, several cohorts may exist. The Bhattacharya method showed up to 3 components for ages between 3 and 5. This fact brings about an increase in the variance of the mean length at age. However, for age 2, not fully recruited, no multimodality was observed. We interpret this fact as a consequence of hook size selection.

After thirty years of continuous fishing a selection process tends to remove the largest and fast grown individuals from each age class in the population. It is interesting to mention that Vilela & Castello (1993) did not observe any multimodality in the age-length distribution of the 80's. Their principal conclusion was that the fishery was mainly supported by fishes between 1 and 3 years. At the 80's years recruitment length was 55 cm (corresponding to age 2), but in the present study this same age is represented by the mean length of 47 cm and, as explained above, is not fully recruited (see arrows in Fig. 8).

Growth

The Bayesian inference incorporates the uncertainties through a probabilistic form. Some studies on fish

Table 3. Summary of results for L_∞, k and t_0 for the observed ages of 2004, 2007, 2008 and the back calculation (BC) data. Mean and confidence intervals (25 and 75%) as obtained from the Bayesian inference.

		Mean	25%	75%
2004	L_∞ (mm)	668.5	636.6	698.1
	k	0.241	0.186	0.267
	t_0	-3.8	-4.4	-3.3
2007	L_∞ (mm)	854.2	774.6	919.8
	k	0.151	0.114	0.176
	t_0	-3.9	-4.6	-3.4
2008	L_∞ (mm)	725.1	695.9	747.4
	k	0.333	0.281	0.381
	t_0	-1.2	-1.5	-0.8
BC	L_∞ (mm)	924.6	804.3	1021.4
	k	0.161	0.117	0.195
	t_0	-2.9	-3.3	-2.5

growth were made using this emerging inference, showing good results (Helser & Lai, 2004; Siegfried & Sansó, 2006; Zhang *et al.*, 2009; Hillary, 2011). The vB growth parameters calculated in the period 1984-1986 showed a highest L_∞ (871 mm) compared with the recent ones (669 mm) whilst the growth rate was similar but slightly higher for recent years (0.24 yr^{-1}) compared with 1984-1986 (0.22 yr^{-1}).

Hilborn & Minte-Vera (2008) simulated the effect of prolonged fishing on the growth rate of fish stocks. They did not found a relationship between the evolutionary impacts of fishing on growth rate and affirmed that weight at age, mean length at age and length/age at maturity are more important than looking for changes on growth rate. This is in fact what we are finding in our results. As shown in table 6, the vB's parameters taken from the literature for different skipjack stocks and compared with the present results show great variability. This seems to be related to particular characteristics of each region and state of the different exploited stocks.

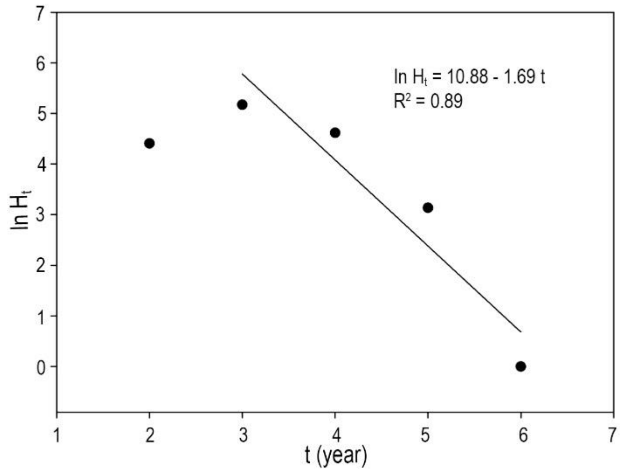

Figure 12. Catch curve. Slope of the regressed line (b) is an estimator of total mortality rate (Z).

Mortality

Vilela & Castello (1993) found a natural mortality rate of 0.46 using Pauly's polynomial and 0.77 using Rikhter & Efanov (1976). However, they considered that M values below 0.6 would be improbable for skipjacks, and choose to work with M = 0.77. In our results (Table 5) the Rikhter & Efanov (1976) equation also provided the higher estimate (0.63) while the Pauly's expression resulted in an estimative of 0.41. ICCAT (2006) provided estimates of 0.8 for M and Z values between 1.8 and 2.3 for the eastern Atlantic fishery. M is highly uncertain for most fish populations and is commonly assumed to be constant throughout the ages. In fact, the best moment for M estimation is when fishing does not occur, *i.e*. the stock is virgin. However, Hampton (2000) found different values of M that varied with the length, the average value of M for skipjack tunas for the smallest individuals (21-30 cm) and largest (>70 cm) was an order of magnitude higher than those of the central classes (41-70 cm). Our results indicate a total mortality Z of 1.7. The exploitation rates (E) derived from these estimates are all higher than 0.5

Table 4. Mean (furcal length, mm), SE (standard error) and n (number) for age classes 2 to 6 in 2004, 2007 and 2008. The mean standard error was calculated for each year.

		Age 2	Age 3	Age 4	Age 5	Age 6	mean SE
2004	mean FL	474.80	506.85	546.53	559.43		
	SE	2.70	1.12	5.63	10.27		4.93
	n	82	176	101	23		
2007	mean FL	449.75	524.80	549.40	591.98	614.43	
	SE	17.03	5.25	5.14	10.48	13.84	10.35
	n	4	82	137	53	14	
2008	mean FL	444.62	495.20	582.64	608.40	628.00	
	SE	8.05	10.25	5.86	6.53	8.34	7.81
	n	13	30	75	45	24	

Table 5. Rates of natural (M), fishing mortality (F) and exploitation (E). Values were calculated for a total mortality rate of Z = 1.69.

	M	F	E
Pauly (1980)	0.41	1.29	0.76
Rikhter & Efanov (1976)	0.63	1.07	0.63
Cubillos (2005)	0.50	1.19	0.70

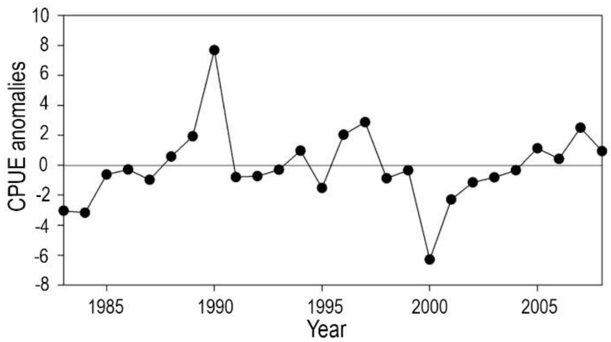

Figure 13. CPUE anomalies for the period 1983 to 2008.

(Table 5). Usually E is considered as an expectation of death by fishing in a given cohort (Gulland, 1977; Everhart *et al.*, 1975), as well as the fraction of fish present at the start of a year that are to be caught during that year. Its validity as a decision tool in management, however, may be compromised by variations in recruitment and availability between years. Therefore, in this case, we only use E as a preliminary indication of the exploitation status of the fishery.

Catch per Unit of Effort (CPUE)

We understand that fishing days as the only effort unit available in the Brazilian fishery does not properly reflect the actual scenario. Along the time period here considered (30 years), fishing days do not rightly account for the fishing power increase that occurred. Incorporation of modern technologies like GPS navigation, use of satellite images with information of the sea surface temperature (SST), sonar detection and tracking of skipjack schools certainly have increased the fishing power and efficiency of catches. Additionally, several skippers started to use fish attracting devices (FAD) since 1990. At the present is a common practice, which also contributed to increase the efficiency on catches (Schroeder & Castello, 2007).

Table 6. Comparison of the von Bertalanffy`s growth parameters according to several authors in different regions and the results of this work (L_∞ in cm and K in years^{-1}).

Authors	L_∞	k	Area
Bard & Antoine (1986)	80	0.32	E. Atlantic G. of Guinea (Equatorial)
Bard & Antoine (1986)	80	0.60	E. Atlantic N. Trop (Tropical)
Vilela & Castello (1991)	87.12	0.22	W. Atlantic - South Brazil
Pagavino (1997)	94	0.38	W. Atlantic - Caribbean Sea
Tanabe *et al.* (2003)	93.6	0.43	W. Pacific
Andrade *et al.* (2004)	97.9	0.14	W. Atlantic - South Brazil
Hallier & Gaertner (2006)	97.3	0.25	E. Atlantic - Senegal
Gaertner *et al.* (2008)	112.34	0.14	E. Atlantic Equatorial
Gaertner *et al.* (2008)	89.38	0.38	E. Atlantic Tropical
Wang *et al.* (2010)	70.6	0.64	W. and Central Pacific
Present work	92.5	0.16	W. Atlantic - South Brazil

As explained before, the reduction in the mean sizes could be a consequence of FAD's effects on the skipjack caught length structure. On the other hand, the observed general reduction in the condition factor can not be explained by the use of FAD's.

Andrade & Garcia (1999) commented that the available data on CPUE may be a good indicator of the availability of skipjack tuna for this specific fishing gear (pole and live-bait), but they argued that it should not be used as a measure of abundance. We understand that the present CPUE unit used in Brazil is not the appropriate indicator of skipjack abundance and this is a problem that requires attention. After 30 years of exploitation and modernization of the fishing fleet the vulnerability ("*q*") of skipjack has increased. "Fishing days" ignore time searching the schools and the technological advances that certainly contributed for an increase in the fishing power. Therefore, it is necessary to look for new and alternative units of effort. Fisheries literature shows several examples of unsuccessful management because of unreliability of CPUE as an abundance indicator (Hannesson, 1996; Mackinson *et al.*, 1997; Clark, 2010).

CONCLUSION

The size reduction of length modes and means, the decrease of the condition factor, the change of age for full recruitment, seem to be a consequence of 30 years of continuous exploitation and the introduction of new fishing technologies. We argue that the continuous selection process removing larger and older individuals has altered the length and age composition of the skipjack stock and its vulnerability. Our growth results, when compared with those available in the literature, showed that great variability exist depending on stocks and environmental conditions. The three estimates for the exploitation rate gave us values for E > 0.5, therefore close attention should be paid to this indicator.

An apparent stable condition for the Brazilian skipjack fishery may be a misleading artifact because this is not consistent with the observed changes in the population structure and growth rates observed in this study.

ACKNOWLEDGEMENTS

This study was financially supported by CNPq. Special thanks are given to: Leal Santos Company for providing sampling facilities and catch data; Dr. H. Andrade and Dr. P.R. Schwingel for providing the Itajaí landing data; Dr. P. Kinas is acknowledged for the help in the formulation of the vB model on the Bayesian approach and M.R. Bailon for providing FAD information. Two anonymous reviewers provided helpful observations and comments.

REFERENCES

Andrade, H.A. 2003. The relationship between the skipjack tuna (*Katsuwonus pelamis*) fishery and seasonal temperature variability in the south-western Atlantic. Fish. Oceanogr., 12(1): 10-18.

Andrade, H.A. & C.A.E. Garcia. 1999. Skipjack tuna fishery in relation to sea surface temperature off the southern Brazilian Coast. Fish. Oceanogr., 8(4): 245-254.

Andrade, H.A., J.L. Abreu-Silva & M. Duarte-Pereira. 2004. Crescimento do bonito listrado (*Katsuwonus pelamis*) e um método para a correção de vícios decorrentes da vascularização central dos espinhos das nadadeiras dorsais. Notas Téc. FACIMAR, 8: 83-93.

Bard, F.X. & L. Antoine. 1986. Croissance du listao dans l'Atlantique Est. Proc. ICCAT Intl. Skipjack Yr. Prog., 1: 301-308.

Carlander, K.D. 1981. Caution on the use of the regression method of back-calculating lengths from scale measurements. Fisheries, 6(1): 2-4.

Castello, J.P. & R.P. Habiaga. 1988. The skipjack fishery in southern Brasil. Col. Vol. Sci. Pap. ICCAT, 30(1): 6-19.

Castello, J.P., P.S. Sunyé, M. Haimovici & D. Hellebrandt. 2009. Fisheries in southern Brazil: a comparison of their management and sustainability. J. Appl. Ichthyol., 25: 287-293.

Cayré, P. & H. Farrugio. 1986. Biologie de la reproduction du listao (*Katsuwonus pelamis*) de l'Océan Atlantique. Proc. ICCAT Intl. Skipjack Yr. Prog., 1: 252-272.

Clark, C. 2010. Challenges in marine capture fisheries. In: R.G. Grafton, R. Hilborn, D. Squires, M. Tait & M. Williams (eds.). Marine fisheries conservation and management. Oxford University Press, New York, pp. 638-645.

Cubillos, L.A. 2005. An approach to estimate the natural mortality rate in fish stocks. Naga, 26(1): 17-19.

Dagorn, L., K.N. Hollandb & J. Filmaltera. 2010. Are drifting FADs essential for testing the ecological trap hypothesis? Fish. Res., 106(1): 60-63.

Everhart, W.H., A.W. Eipper & W.D. Youngs. 1975. Principles of fishery science. Cornell University Press, London, 288 pp.

Gaertner, D., A.D. Molina, J. Ariz, R. Pianet & J.P. Hallier. 2008. Variability of the growth parameters of the skipjack tuna (*Katsuwonus pelamis*) among areas in the eastern Atlantic: analysis from tagging data within a meta-analysis approach. Aquat. Living Resour., 21: 349-356.

Gayanilo, J.F., P. Sparre & D. Pauly. 1995. FAO/ ICLARM stock assessment tools (FiSAT). User's guide Report Nº8. FAO, Rome, 262 pp.

Gulland, J.A. 1977. Fish population dynamics. John Wiley & Sons, London, 335 pp.

Hallier, J.P. & D. Gaertner. 2008. Drifting fish aggregation devices could act as an ecological trap for tropical tuna species. Mar. Ecol. Prog. Ser., 353: 255-264.

Hampton, J. 2000. Natural mortality rates in tropical tunas: size really does matter. Can. J. Fish. Aquat. Sci., 57(5): 1002-1010.

Hannesson, R. 1996. Fisheries mismanagement. The case of the North Atlantic cod. Fishing News Book, Oxford, 160 pp.

Helser, T.E. & H. Lai. 2004. A Bayesian hierarchical meta-analysis of fish growth: with an example for North American largemouth bass, *Micropterus salmoides*. Ecol. Model., 178: 399-416.

Hillary, R.M. 2011. A new method for estimating growth transition matrices. Biometrics, 67: 76-85.

Hilborn, R. & C.V. Minte-Vera. 2008. Fisheries-induced changes in growth rates in marine fisheries: Are they significant? B. Mar. Sci., 83(1): 95-105.

Hurry, G.D., M. Hayashi, J.J. Maguire. 2008. Report of the independent review citations of Internet sources. [http://www.publicintegrity.org/assets/pdf/IndependentReviewofICCAT2008.pdf]. Reviewed: 2 March 2013.

International Commission for the Conservation of Atlantic Tuna (ICCAT). 2006-2009. Manual, International Commission for the Conservation of Atlantic Tuna Publications. [http://www.iccat.int/en/ICCATManual.htm]. Reviewed: 24 October 2012.

International Commission for the Conservation of Atlantic Tuna (ICCAT). 2012. Statistical databases: nominal Catch Information, International Commission for the Conservation of Atlantic Tuna. [http://www.iccat.es/en/accesingdb.htm]. Reviewed: 26 July 2012.

Kinas, P.G. & H.A. Andrade. 2010. Introdução à análise Bayesiana (com R). maisQnada, Porto Alegre, 258 pp.

King, M. 2007. Fisheries biology, assessment and management. Fishing New Books, London, 341 pp.

Lehodey, P., J. Alheit, M. Barange, T. Baumgatner, G. Beaugrand, K. Drinkwater, J.M. Fromentin, S.R. Hare, G. Ottersen, R.I. Perry, C. Roy, C.D. Van der Lingen & F. Werner. 2006. Climate variability, fish, and fisheries. J. Climate, 19: 5009-5030.

Lunn, D., D. Spiegelhalter, A. Thomas & N. Best. 2009. The BUGS project: Evolution, critique and future directions. Stat. Med., 28(25): 3049-3067.

Mackinson, S., U.R. Sumaila & T.J. Pitcher. 1997. Bioeconomics and catchability: fish and fishers behaviour during stock collapse. Fish. Res., 31: 11-17.

Meneses de Lima, J.H.M., C.F. Lin & A.A.S. Menezes. 2000. A description of the bait boat fishery off the south and southeast Brazil. Col. Vol. Sci. Pap. ICCAT, 51(1): 416-462.

Paes, E.T. & L.E.S Moraes. 2007. A new hypothesis on the influence of the El Niño/La Niña upon the biological productivity, ecology and fisheries of the Southern Brazilian Bight. Pan-Am. J. Aquat. Sci., 2(2): 94-102.

Received: 2 April 2013; Accepted: 26 May 2014

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer, 39(2): 175-192.

R Development Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL [http://www.R-project.org/].

Rätz, H. & J. Lloret. 2003. Variation in fish condition between Atlantic cod (*Gadus morhua*) stocks, the effect on their productivity and management implications. Fish. Res., 60(2-3): 369-380.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Department of the Environment Fisheries and Marine Service, Ottawa, 382 pp.

Rikhter, V.A. & V.N. Efanov. 1976. On one of the approaches to estimation of natural mortality of fish populations. In: P. Sparre, E. Ursin & S.C. Venema (eds.). 1989. Introduction to tropical fish stock assessment. Part 1: manual, FAO Fish. Tech. Pap., 306(1): 337 pp.

Schroeder, F.A. & J.P. Castello. 2007. Cardume associado: nova modalidade de pesca de atuns do sul do Brasil-descrição e comparação. Pan-Am. J. Aquat. Sci., 2(1): 66-74.

Siegfried, K.I. & B. Sansó. 2006. Two Bayesian methods for estimating parameters of the von Bertalanffy growth equation. Environ. Biol. Fish., 77: 301-308.

Sparre, P., E. Ursin & S.C. Venema. 1989. Introduction to tropical fish stock assessment. Part 1: Manual, FAO Fish. Tech. Pap., 306(1): 337 pp.

Vilela, M.J.A. & J.P C. Castello. 1991. Estudio de la edad y del crecimiento del barrilete (*Katsuwonus pelamis*) en la region Sur y Sudeste de Brasil. Frente Marítimo, 9(A): 29-35.

Vilela, M.J.A. & J.P.C. Castello. 1993. Dinámica poblacional del barrilete (*Katsuwonus pelamis*) explotado en la región sudeste-sur del Brasil en el periodo 1980-1986. Frente Marítimo, 14(A): 111-124.

Zhang, Z., J. Lessard & A. Campbell. 2009. Use of Bayesian hierarchical models to estimate northern abalone, *Haliotis kamtschatkana*, growth parameters from tag-recapture data. Fish. Res., 95(2): 289-295.

Zeng, N., J. Yoon, J.A. Marengo, A. Subramaniam, C.A. Nobre, A. Mariotti & J.D. Neelin. 2008. Causes and impacts of the 2005 Amazon drought. Environ. Res. Lett., 3: 9 pp.