

## **Anexo I: Artigo científico para submissão**

### **Age, growth and mortality of the mullet, *Mugil liza* (Valenciennes, 1836), in the south and southeastern coastal regions of Brazil.**

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#### **Abstract**

In Brazil, there is a growing concern about the state of exploitation of the mullet fishery resource. Currently the industrial catches exceeded the artisanal catches and there is a growing trend caused by the overexploitation of other resources and commercialization of mullet roes. This study attempts to complement the existing life cycle information with estimation on growth and mortality rates for the mullet stock. The mullet has more characteristics of K-strategists, showing a relatively low growth rate ( $K = 0.17 \text{ year}^{-1}$ ), a 10.5 years longevity and an asymptotic length of 662 mm. Based on the age-length structure mullet caught at sea (coastal area and continental shelf) are significantly larger and older than mullet caught by Patos Lagoon estuarine artisanal fishing. There are two mortality rates ( $Z$ ) for the mullet, one belonging to the estuarine specimens ( $Z = 0.48$ ) and the other to the sea specimens ( $Z = 0.31$ ).

#### **Introduction**

The mullet, *Mugil liza*, is a pelagic fish belonging to the Mugilidae family. Occurs in the western Atlantic ocean from Venezuela to Argentina (Menezes, 1983; Whitfield *et. al.* 2012). Recently, Menezes *et. al.* (2010) affirmed that *Mugil platanus* and *M. liza*, previously considered as distinct species, should be treated as a single one, being *M. liza* the more appropriate name. It is a catadromous fish, which for the Patos Lagoon estuary

(PLE), has a reproductive migration to the sea, starting in the autumn (April-May), induced by the passage of cold fronts and the cooling of surface waters (Vieira & Scalabrin, 1991). In this season, southern winds become more intense, causing a temperature decrease by about 5 °C which is followed by the intrusion of a saline wedge into the estuary (Miranda, 1971). The spawning area is not clearly identified. However there is an important area situated in the north of Santa Catarina state, where reproduction reaches a peak in May-June. Between 2 to 4 months after spawning, the larvae and juveniles return in a passive movement to the south carried by the coastal surface currents (Vieira & Scalabrin, 1991).

The mullet is a fisheries resource shared among Argentina, Uruguay and Brazil. In Brazil, it is exploited from Rio Grande do Sul (33° 40 'S) to Rio de Janeiro (21 °S) (Miranda *et. al.*, 2006) caught by boats from the artisanal fishery using gill nets and casting nets and by the purse seiners from the industrial fleet. Commercial catches varied between 2 to 6 thousand tonnes from 1986 to 2003. El Niño events also affect the mullet abundance in Patos Lagoon estuary and consequently, their catches. The large discharge of fresh water caused by heavy rains during these events prevents the entry of juvenile mullet in the estuary, as well as the aggregation of reproductive shoals, causing the declining on catches (Vieira *et. al.*, 2008).

The industrial fishery pressure is increasing as a consequence of the overexploitation of other resources, notably of the *Sardinella brasiliensis* exploited by this same fleet (purse seiners) which catches the mullet during the northward migration. Over the last years the commercial interest in mullet roes intensified the pressure over this fishery (IBAMA/CEPSUL, 2007). In 2004, the mullet was declared in state of overexploitation (Anexo II IN MMA n° 05 21/05/2004), and up to the present, no

specific regulation for this resource (IBAMA/CEPSUL, 2007) has been established, in part due to the lack of information about the structure and dynamics of the mullet population.

The first contribution on age and growth determination was made with specimens from Cananéia (SP), Brazil. The following von Bertalanffy (vB) parameters were obtained:  $L_{\infty} = 734$  mm,  $K = 0.24$  year<sup>-1</sup> and  $t_0 = 0.18$  year (Miranda *et. al.*, 2006). Recently, González-Castro *et. al.* (2009) analyzed 290 specimens from Mar Chiquita coastal Lagoon/Argentina and concluded that the otoliths provided a good structure to estimate the age, being that the hyaline rings are formed during the cold period of the year (June to November). They demonstrated that the *M. platanus/liza* is a moderate to fast growing species ( $K = 0.30$  year<sup>-1</sup>) with a moderate longevity (10 years), reaching a  $L_{\infty} = 563.8$  mm and a high natural mortality ( $M = 0.297$ ). Moreover, the authors proposed the first hypothetical model for the life history of the adult stock of this mullet species.

Hsu & Tzeng (2009) validated the annual marks on otoliths and scales of *Mugil cephalus* in southwest of Taiwan and show that the hyaline rings are formed in winter. Hsu *et. al.* (2009) identified in juveniles otoliths of *M. cephalus* an “accessory primordium” preceding the first growth check. This accessory primordium was validated when the juvenile mullets migrated from offshore to fresh waters and had been formed after recruitment into the estuary. The authors believe that the formation of the “accessory primordium” was also the result of behavioral changes from the pelagic to the benthic environment.

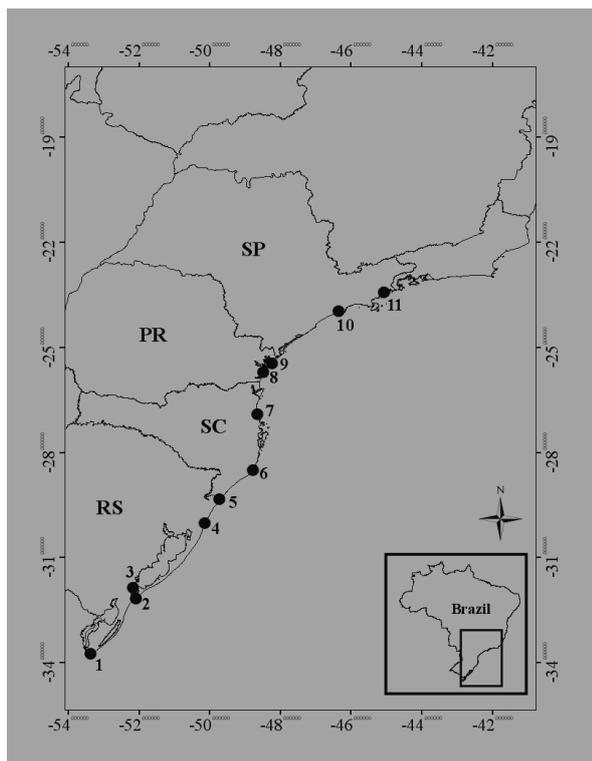
Objectives of this work are (1) determine the age-length composition of *Mugil liza* in southern Brazil, (2) estimate the vB growth parameters ( $L_{\infty}$ ,  $K$  and  $t_0$ ), (3) validate the

mullet age, (4) verify the presence of a juvenile mark on otoliths (5) calculate mortality rates, and (6) supply new information about the life cycle.

### **Methodology**

The mullet specimens were obtained from 3 different sources: (1) the artisanal gill net and casting net fleet at Patos Lagoon estuary (PLE); (2) the semi-industrial fleet using gill net at the adjacent coastal area and (3) the industrial purse seine fleet. Specimens from a wide area of the Brazilian shore in the south and southeastern regions (Figure 1) were obtained covering the entire Brazilian reproductive migration, comprising the states of Rio Grande do Sul (Chuí, Rio Grande, PLE, Tramandaí and Torres), Santa Catarina (Laguna and Itajaí), Paraná (Paranaguá and Pontal do Paraná) and São Paulo (Santos and Ubatuba) (Figure 1).

Samples were obtained between April/2010 to February/2012. From each specimen total length (mm), weight (g), sex and the pair of *sagittae* otoliths were obtained. For 658 specimens was obtained the sex.



#	Localities	Fishing Gear
1	Chuí	Purse seine
2	Rio Grande	Purse seine
3	PLE	Gill and Casting net
4	Tramandaí	Gill and Casting net
5	Torres	Beach seine/ Casting net
6	Laguna	Casting net
7	Itajaí	Purse seine
8	Pontal do Paraná	Purse seine
9	Paranaguá	Purse seine
10	Santos	Purse seine
11	Ubatuba	Purse seine

Fig. 1. South and southeastern regions of Brazil, the 11 sampling locations for mullets and the fishing gear used in each place.

### Age determination

Each pair of otoliths collected were cleaned, dried and stored in 1 ml Eppendorf microtubes. The otoliths were immersed on water in a Petri dish with a black background and observed under a stereoscopic microscope using incident light. Hyaline rings were counted from the core outwards. Age readings were performed independently by two readers and the average percentage error was calculated (Campana, 2001):

$$APE = N^{-1} [R^{-1} (\sum |r_{ij} - r_j|/r_j)];$$

Where **N** is the total number of otoliths readings, **R** is the number of times each fish is aged, **r<sub>ij</sub>** = is the *i*th age determination of the *j*th fish and **r<sub>j</sub>** is the mean age estimate of the *j*th fish.

The otoliths that did not provide good readings were separated and cross-sections of 0.8 mm thickness for these specimens and included in polyester resin. Sections were polished with water on a series of abrasive paper with decreasing roughness (up to 600  $\mu\text{m}$ ) and observed under a stereoscopic microscope using incident light with a black background.

### **Adjustment of data to the vB growth model**

Two procedures were used in order to fit age and length data to the vB's growth model: the maximum likelihood method (Hilborn & Walters, 1992) using the Solver routine in Excel and the Bayesian inference (Kinas & Andrade, 2010) using the Gibbs Sampling performed by the software OpenBUGS (Lunn *et. al.*, 2009) in R program (R, 2012). A Markov Chain Monte Carlo (MCMC) simulation of the joint posterior distribution allowed obtaining a chain of 31,000 samples. The first 10 thousands steps ("burn in") were rejected, to ensure the stability of the algorithm in the simulations, and the following 20 thousands were thinned in a rate of 2. The posterior mean and probability intervals (25% and 95%) were calculated with these 10,500 remaining samples. In order to describe the model, we first assumed that the age-length data follow a log-Normal distribution:  $\text{length}[i] \sim \text{logNormal}(\mu[i], \sigma^2)$ , where  $\mu[i]$  is the mean length at an age class  $[i]$  with variance  $= \sigma^2$ . A logarithmic version of the vB equation was used for computational convenience:

$$\mu[i] = \log(L_{\infty}) + \log(1 - \exp(-k(\text{age}[i] - t_0)))$$

Uninformative priors were constructed and restricted to positive numbers and set intervals:

$$p(\log L_{\infty}) \sim \text{dnorm}(4, 0.001) \text{ I}(4, 10);$$

$p(\log k) \sim \text{dnorm}(0, 0.001) \text{ I}(-5, 5)$ ;

$p(t_0) \sim \text{dunif}(-5, 0)$  and

$p(\sigma) \sim \text{dunif}(0, 5)$ .

After testing different combinations between the 11 sampling sites, 3 distinct groups of these 11 localities were grouped to verify differences in growth rates according to the latitudinal variations.

### **Juvenile ring**

Less than half of the otoliths, 43.2 % (N = 490), presented a mark very close to the otolith's nucleus. Using the BELView software (Version 6.2.3.0), measurements (mm) were taken between the otolith center and the distant border of this first ring ( $R_j$ ). With this information, the fish total length corresponding to the juvenile ring was back calculated from the total length of each individual, assuming the following proportionality relation ( $R_t/L_t - C = R_j/L_j - C$ ) with a correction factor C:

$$\mathbf{L_j - C = R_j/R_t (L_t - C)}$$

Where  $\mathbf{L_j}$  (mm) is the back calculated length for the formation of the juvenile ring;  $\mathbf{R_j}$  (mm) is the measured distance of the otolith center to the juvenile ring;  $\mathbf{R_t}$  (mm) is the total distance between the center to the edge of otolith and  $\mathbf{L_t}$  (mm) is the total length of the fish and  $\mathbf{C}$  is the correction factor, as explained by Everhart *et. al.* (1975).

### **Mortality and Exploitation rate**

Total mortality rate ( $Z$ ) was estimated using the length-converted catch curve (Sparre *et. al.*, 1989):

$$\ln [H_{(L_1, L_2)} / \Delta t_{(L_1, L_2)}] = H - Z [t_{(L_1)} + t_{(L_2)} / 2];$$

Where H is the harvest between length class intervals ( $L_1$  to  $L_2$ );  $\Delta t$  is the age interval between these correspondent length classes and Z (total mortality) is the slope  $b$  of the linear regression. The rate of natural mortality (M) was estimated according to five methods:

$$M = 2.996 (t_{0.95})^{-1}; \text{ where } t_{0.95} = 2.996 (K+t_0)^{-1}; \text{ Taylor (1959);}$$

$$M = 1.521 (t_m^{0.720})^{-1} - 0.155; \text{ where } t_m \text{ is the longevity, Rikhter \& Efanov (1976);}$$

$M = 0.8 * \exp \{-0.0152 - 0.279 (\ln L_\infty) + 0.6543 (\ln K) + 0.463 (\ln T)\}$ ; where T is the mean temperature ( $^{\circ}\text{C}$ ) for the mullet habitat, Pauly (1980);

$$M = -\ln (0.01) (t_m)^{-1}; \text{ where } t_m \text{ is the longevity, Alagaraja (1984);}$$

$M = (bK (1-0.62)) 0.62^{-1}$ ; where  $b$  = allometric coefficient of the weight-length relationship, Cubillos (2003);

The rate of fishing mortality (F) was obtained by subtraction from total mortality as in the expression:  $F = Z - M$

The rate of exploitation (E) was calculated using Ricker (1975) as:  $E = F / Z$ , where F is the fishing mortality and Z is the total mortality.

## Results

### Age-length composition

A total sample of 1327 mullets was obtained from which 116 specimens were discarded because of unclear age readings. The otoliths proved to be a good structure for age readings as it was possible to observe the growth rings in direct reading (Figure

2), without the use of any additional treatment. In 26 cases, in which the growth rings were not satisfactory legible, their cross-sections proved to be a good alternative (Figure 3) in order to unravel the ageings. The average percentual error (APE) of readings was relatively low for all localities (7.3%) (Table 1), and specimens from Paranaguá showed the highest APE, 11.9%, these otoliths had not the growth rings so clear. The range of total lengths was 240 to 650 mm and the total range of ages was 1.5 to 10.5 years. The central and more represented ages were 3 to 8 years. Table 2 shows the mean length-at-age for these 1211 specimens.

Table 1. The average percentual error (APE %) calculated for the 11 different localities and the correspondent total number (N) for each one.

<b>Point</b>	<b>Localities</b>	<b>APE (%)</b>	<b>N</b>
<b>1</b>	Chuí	4.5	55
<b>2</b>	Rio Grande	8.7	172
<b>3</b>	PLE	6.5	269
<b>4</b>	Tramandaí	7.7	167
<b>5</b>	Torres	6.3	16
<b>6</b>	Laguna	8.4	304
<b>7</b>	Itajaí	8.8	52
<b>8</b>	Paranaguá	11.9	44
<b>9</b>	Pontal	6.3	34
<b>10</b>	Santos	5.8	49
<b>11</b>	Ubatuba	1.9	49
	Data Pool	7.3	1211

Table 2. The mean total length (TL in mm), the standard deviation (SD), the range (in mm) and the total number (N) for each age class for the data pool.

<b>Age (years)</b>	<b>N</b>	<b>TL (mm)</b>	<b>SD</b>	<b>Range (mm)</b>
1	-	-	-	-
2	50	281.3	3.36	240-300

3	104	307.8	20.3	250-430
4	110	395.9	25.3	270-530
5	239	423.7	22.9	270-580
6	313	465.5	13.2	310-620
7	205	491.6	27.5	290-650
8	126	507.6	21.9	370-630
9	42	544.2	41.9	420-640
10	15	561.9	24.5	490-590
11	7	559.1	35.04	490-590
12	-	-	-	-
<b>TOTAL</b>	<b>1211</b>			

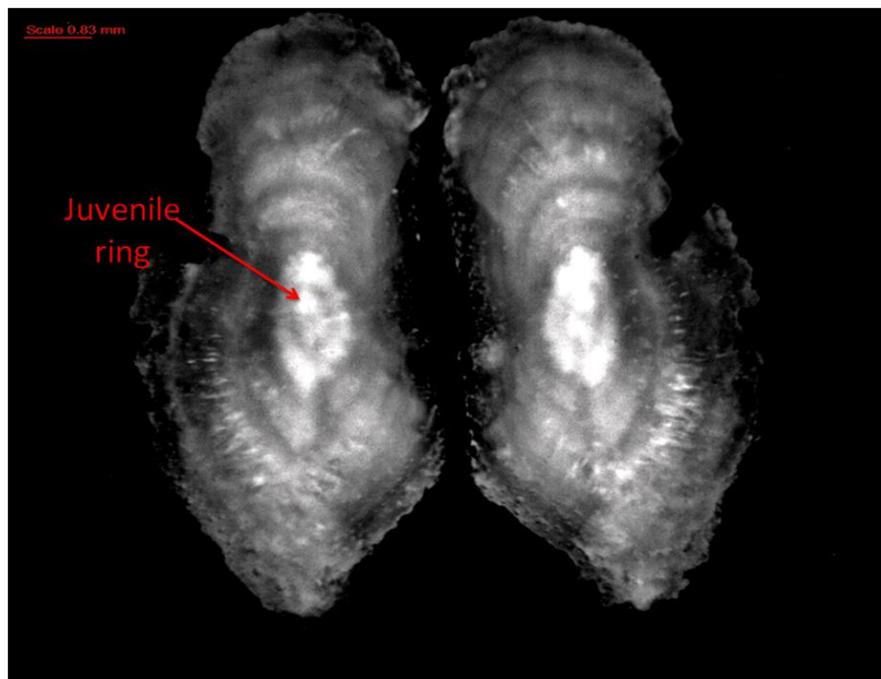


Fig. 2. Photography of a pair of otoliths, this specimen had 447 mm and 5.5 years. The red arrow is showing the juvenile ring very closed to the core.

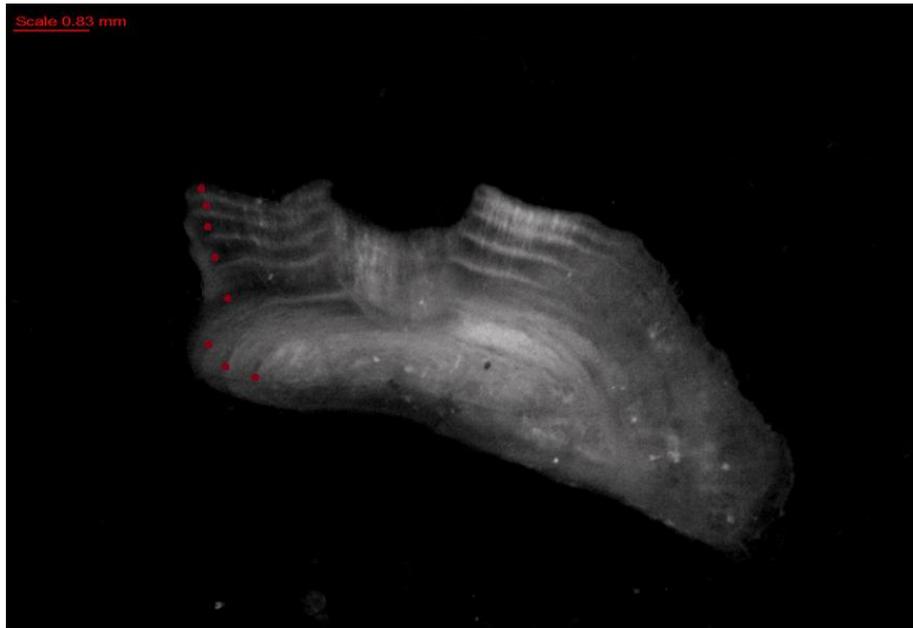


Fig. 3. Photography of a cross-section of an otolith, this specimen had 640 mm and 8 years, the red dots indicate the hyaline rings.

The dispersion for the age by the total length show differences between the 11 localities, where the samples were obtained with different fishing gears (Figure 1 and 4).

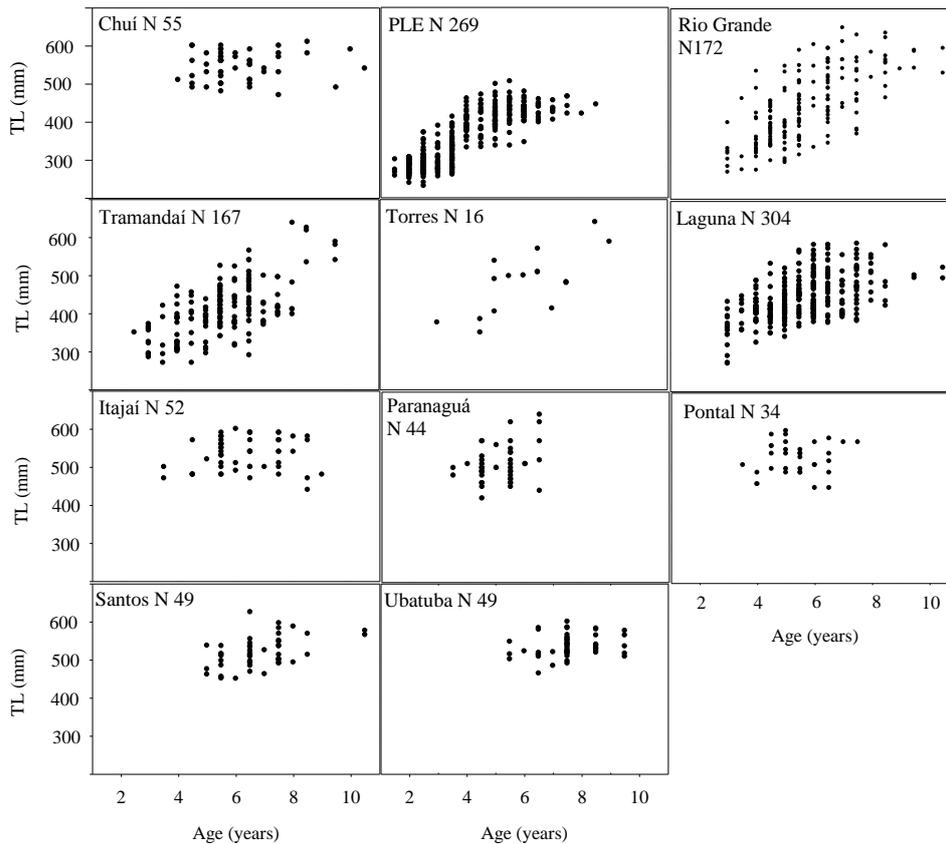


Fig. 4. Dispersion of age (in years) by the total length (TL in mm) for the 11 different localities.

### Age validation

The otoliths that presented uncertainties about the nature of the border were discarded from this analysis (N = 55 otoliths). The annual frequency of the nature of the border in the otoliths showed a single peak for the hyaline rings (slow growth) occurring in the spring season (September – November) and a single peak for the opaque rings (fast growth), corresponding to the winter season (June – August) (Figure 4). The opaque rings followed by the hyaline ring are formed annually. It can be noted that the condition factor K reached the highest values in late autumn and beginning of

the winter (May and June) and then, started to decrease up to October, coinciding with the hyaline ring peak.

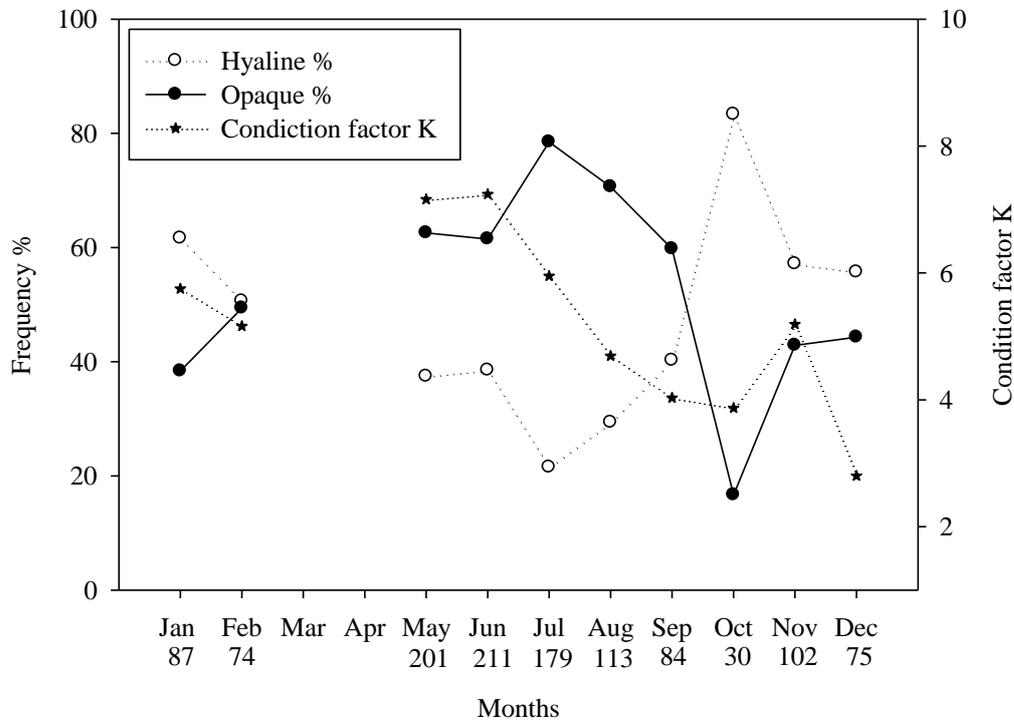


Fig. 5. Frequency distributions of the hyaline and opaque rings on the border of the otoliths and the condition factor K, along 11 months. (N) number of samples for each month.

### The vB growth model adjustment

Both methods (maximum likelihood and bayesian analysis) provided similar, results for  $L_{\infty}$  and K, (Tables 3 and 4). However, the maximum likelihood showed a higher variability depending on the used seed values. Figure 6 shows the possible results for  $L_{\infty}$  and K for the data pool when using the maximum likelihood method. Males and females were also analyzed separately. As expected, it can be noted the inverse relationship of  $L_{\infty}$  and K as these values are autocorrelated (Figure 6). Males

and females showed different growth parameters. Females growing slower and reaching larger sizes than males. The weight-length relationship was also calculated and the males showed a lower value for the allometric coefficient  $b$  compared with the females and data pool (Table 5).

Table 3. The estimates to vB growth parameters obtained from the maximum likelihood method, the mean and the confident intervals lower (CI -) and upper (CI +) limits for the 95% confident intervals were given;  $L_{\infty}$  in mm,  $K$  in year<sup>-1</sup> and  $t_0$  in year.

Maxima Likelihood estimate										
	$L_{\infty}$			$K$			$t_0$			N
	CI -	Mean	CI +	CI -	Mean	CI +	CI -	Mean	CI +	
<b>Data Pool</b>	618	<b>649</b>	681	0.139	<b>0.172</b>	0.206	-2.1	<b>-1.5</b>	-0.9	1211
<b>Females</b>	689	<b>838</b>	987	0.049	<b>0.079</b>	0.109	-5.6	<b>-4.4</b>	-3.2	290
<b>Males</b>	524	<b>578</b>	633	0.075	<b>0.119</b>	0.164	-8.0	<b>-5.9</b>	-3.9	368
<b>South</b>	-	<b>605</b>	-	-	<b>0.304</b>	-	-	<b>0.7</b>	-	227
<b>Central</b>	538	<b>646</b>	755	0.062	<b>0.128</b>	0.194	-4.9	<b>-3.2</b>	-1.5	487
<b>North</b>	648	<b>668</b>	687	0.097	<b>0.114</b>	0.13	-8.3	<b>-7.3</b>	-6.4	98

Table 4. The estimates to vB growth parameters made with the bayesian method, the posterior mean and the credible intervals lower (CI 2.5%) and upper (CI 97.5 %) limits for the 95% posterior credibility interval were given;  $L_{\infty}$  in mm,  $K$  in year<sup>-1</sup> and  $t_0$  in year.

Bayesian estimate										
	$L_{\infty}$			$K$			$t_0$			N
	CI 2.5%	Mean	CI 97.5%	CI 2.5%	Mean	CI 97.5%	CI 2.5%	Mean	CI 97.5%	
<b>Data Pool</b>	581	<b>662</b>	817	0.090	<b>0.168</b>	0.193	-3.4	<b>-1.7</b>	-0.4	1211
<b>Females</b>	627	<b>851</b>	1309	0.040	<b>0.091</b>	0.166	-4.9	<b>-3.9</b>	-1.8	290
<b>Males</b>	474	<b>527</b>	586	0.129	<b>0.189</b>	0.344	-4.9	<b>-3.8</b>	-1.3	368
<b>South</b>	613	<b>766</b>	1259	0.100	<b>0.155</b>	0.200	-3.1	<b>-0.9</b>	-0.3	227
<b>Central</b>	527	<b>655</b>	834	0.100	<b>0.137</b>	0.300	-4.9	<b>-3.2</b>	-0.9	487
<b>North</b>	546	<b>585</b>	645	0.146	<b>0.262</b>	0.422	-4.9	<b>-2.4</b>	-0.1	98

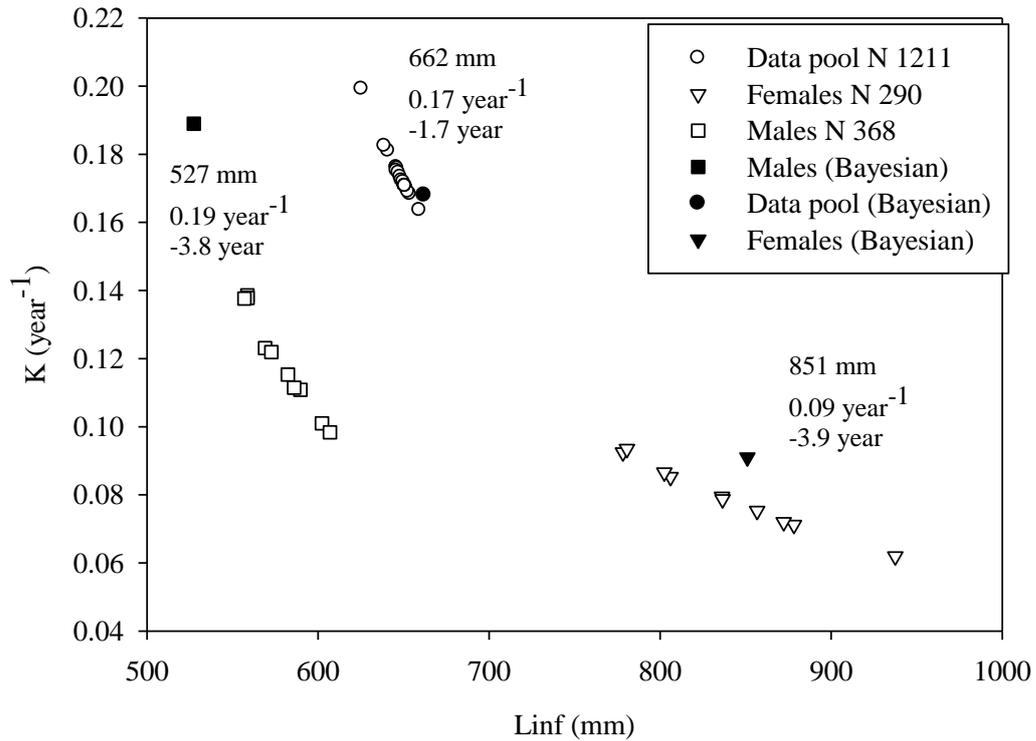


Fig. 6. Linf and K distribution for the results obtained with the maximum likelihood method and the single estimate obtained with the bayesian method. The values for  $L_{\infty}$ , K and  $t_0$  presented in the graph are the posterior means from the bayesian analysis.

Table 5. Weight-length equation obtained for the data pool, females and males, weight (in g) and length (in mm).

	Weight-length equation	R <sup>2</sup>
<b>Data pool</b>	$W = 6e^{-6} \times TL^{3.062}$	0.9342
<b>Females</b>	$W = 7e^{-6} \times TL^{3.034}$	0.9167
<b>Males</b>	$W = 4e^{-5} \times TL^{2.768}$	0.8309

The 11 sampling sites were grouped into 3 distinct regions: South (Chuí + Rio Grande); Central (Tramandaí + Torres + Laguna) and North (Santos + Ubatuba).

Specimens from the south region reach larger sizes ( $L_{\infty} = 766$  mm) followed by specimens from the central and north locations. Mulletts from the north region presented the highest K value ( $0.26 \text{ year}^{-1}$ ) compared with the south, central and the pool data (Figure 7 and Table 4). For these 3 regions, the tables 3 and 4 show the vB parameter estimations, the 95% credible intervals obtained with the bayesian method and the estimation obtained with the maxima likelihood method and the corresponding 95% confidence intervals (lower and upper).

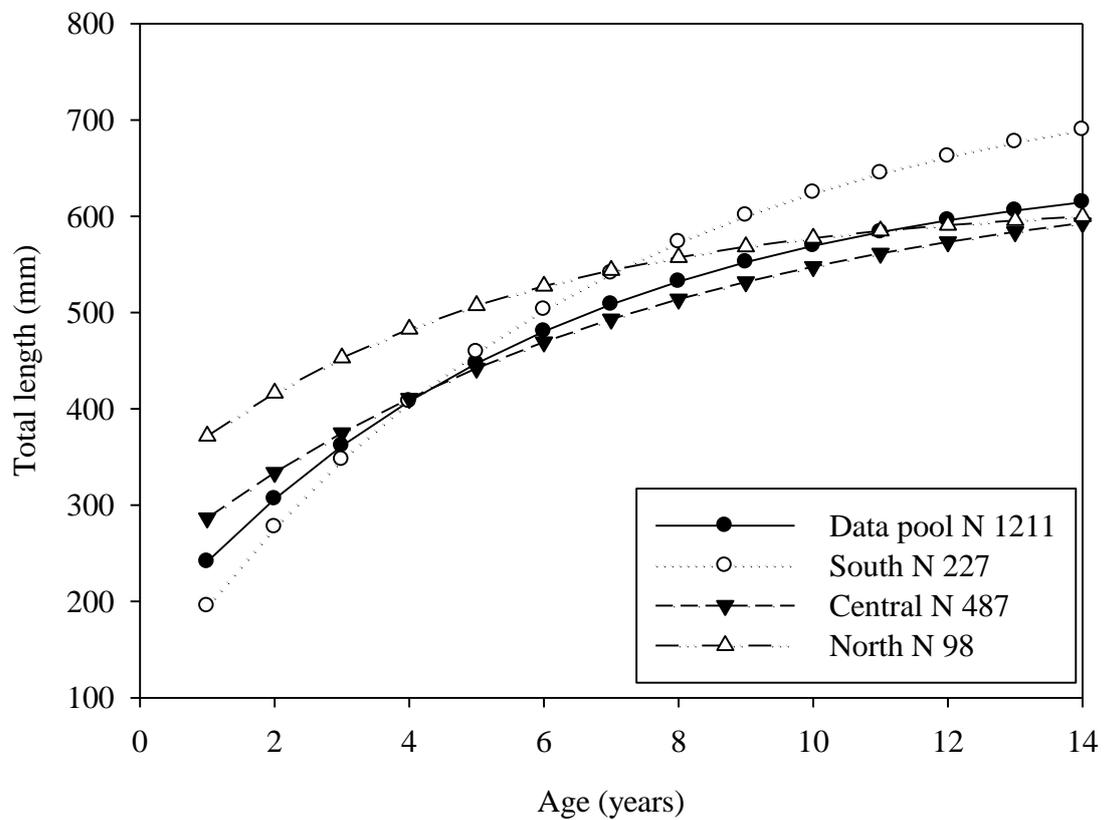


Fig. 7. The vB growth curves (bayesian estimate) for the data pool and the South, Central and North regions.

### Juveline marks

The juvenile mark is a ring that appears very close to the otolith center (Figure 2). From the complete data set, 43.2% (N = 490) of the otoliths presented clearly the juvenile ring; of these, 305 otoliths were used to make the back calculation of the length related to the formation of the juvenile ring. The logarithmic relationships of the total fish length and the total otolith size were given in Figure 8. The correction factor (C) was calculated from the logarithmic equation ( $C = 27.5$  mm), and was subtracted from the linear proportion as explained before. The mean back calculated length of the formation of the juvenile ring was 21.2 mm ( $CI_{95\%} = 19.8 - 22.6$  mm).

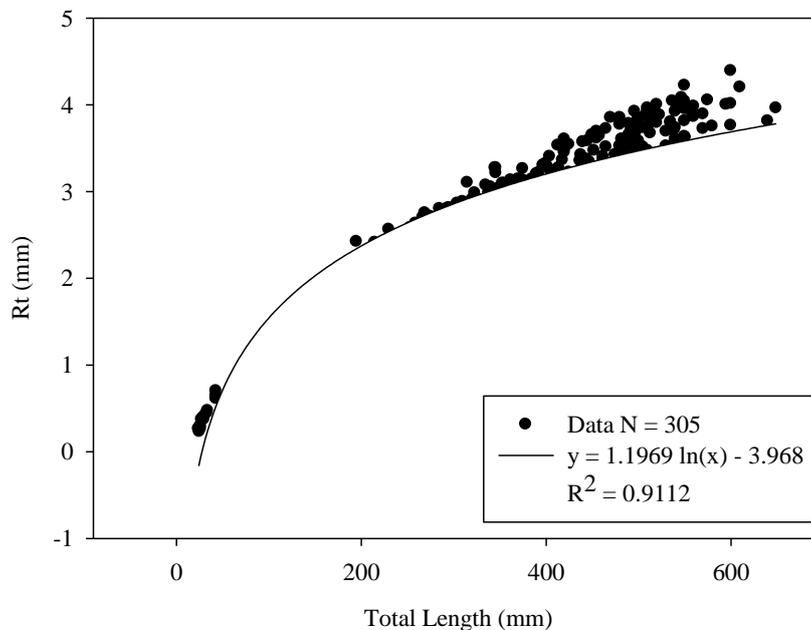


Fig. 8. The logarithmic relationship between the total length of otoliths (Rt in mm) and the total length of the fishes (TL in mm).

### **Mortality estimates**

The length-converted catch curve, for the data pool, showed a broken line indicating two ages of recruitment to the fishery 3.8 and 6.3 years; the first one

corresponds to a length of 405 mm and the second one to 495 mm (Figure 9). Therefore 2 catch curves with different characteristics should be considered separately.

Analyzing the age-length structure, we also can observe that there is a difference between the specimens caught at sea (from Chuí-RS to Ubatuba-SP) and in the Patos Lagoon estuary (Figure 10). The individuals catch at sea are bigger and older, reaching 650 mm and 10.5 years. And in the estuary the specimens reach up to 500 mm and 8.5 years. The slope values are the estimates for total mortality (Z); 0.48 to the first line correspond to the individuals caught in the estuary, and 0.31 for the second, which refer to fishes caught at sea.

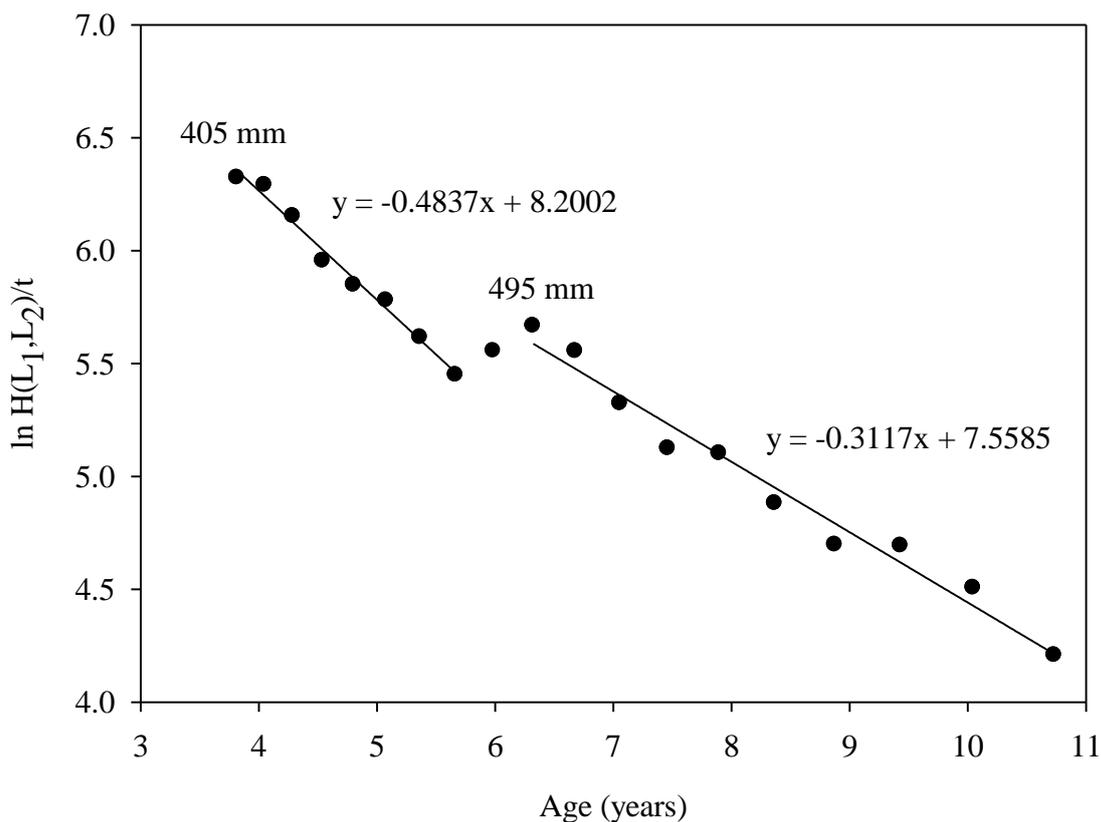


Fig. 9. The length converted catch curves for the data pool showing two recruitment ages to fishery and the regression equation obtained from these two distinct curves.

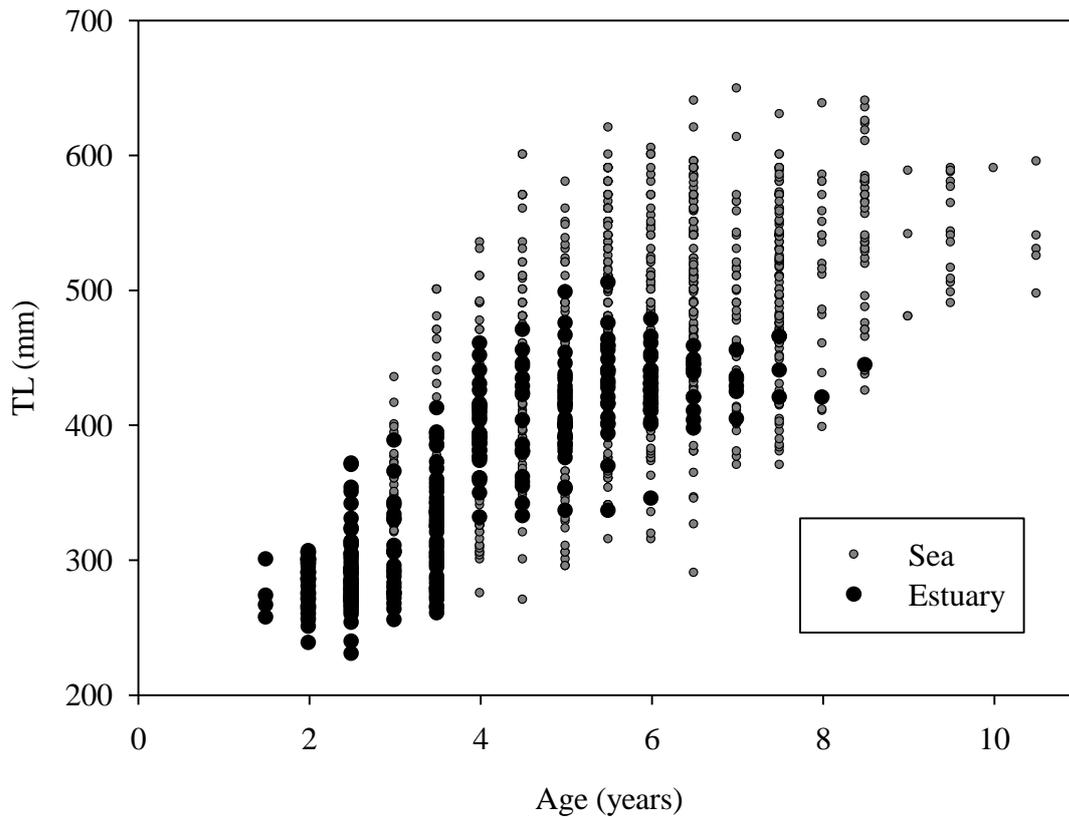


Fig. 10. Data on age-length distributions for the specimens catch at sea (Chuí-RS to Ubatuba-SP; N = 942), and in the estuary (N = 269).

The natural mortality (M) estimated by the five methods: Taylor (1959), Rikhter & Efanov (1976), Pauly (1980), Alagaraja (1984) and Cubillos (2003) show different results (Table 6), ranging for 0.17 to 0.37.

Table 6. Different results obtained for Natural mortality (M) following several authors.

<b>Natural mortality</b>	
Taylor (1959)	0.19
Rikhter & Efanov (1976)	0.24
Pauly (1980)	0.17
Alagaraja (1984)	0.37
Cubillos (2003)	0.32

As the results for the natural mortality were inconclusive, we tested 3 different scenarios to illustrate how the fishing mortality and the rate of exploitation would behave. In test 1 we used the mean (0.18) from the lower M values (0.17 and 0.19). In test 2 we used the intermediate M value, 0.24, and in test 3 the mean of the larger M values (0.37 and 0.32). Considering the 2 values for total mortality rate Z the larger at the PLE ( $Z = 0.48$ ) and the lower estimate ( $Z = 0.31$ ) at sea, the above three scenarios area applied in order to calculate the exploitation rates (Table 7).

In all scenarios the exploitation rates in PLE were higher. Under the test 1 scenario, the exploitation rate,  $E_{\text{estuary}} = 0.63$ , exceeds the value for a sustainable exploitation rate ( $E > 0.5$ ; based on the maximum sustainable yield); at sea,  $E_{\text{sea}} = 0.43$  exploitation rate seems to be reasonable. Under the test 2 scenario the exploitation rate,  $E_{\text{estuary}} = 0.47$ , is close to 0.5. Lastly, under the test 3 scenario (high M), the analysis resulted in unreal values for both the  $E_{\text{sea}}$  and  $E_{\text{estuary}}$  (Table 7).

Table 7. Estimates of values for Z (total mortality), M (natural mortality), F (fishing mortality) and E (exploitation rate) for the 2 recruitment ages (PLE and Sea) of the mullet fishery.

	<b>Recruitment age (years)</b>	
	<b>3.8 (PLE)</b>	<b>6.3 (Sea)</b>
Test 1: low M rates		
<b>Z</b> (Total mortality)	0.48	0.31
<b>M</b> (Natural mortality)	<b>0.18</b>	<b>0.18</b>
<b>F</b> (Fishing mortality)	0.31	0.13
<b>E</b> (Exploration rate)	0.63	0.43
	<b>Recruitment age (years)</b>	
	<b>3.8 (PLE)</b>	<b>6.3 (Sea)</b>
Test 2: intermediate M rates		
<b>Z</b> (Total mortality)	0.48	0.31
<b>M</b> (Natural mortality)	<b>0.26</b>	<b>0.26</b>
<b>F</b> (Fishing mortality)	0.23	0.06

<b>E</b> (Exploration rate)	0.47	0.18
<b>Recruitment age (years)</b>		
Test 3: high M rates	<b>3.8 (PLE)</b>	<b>6.3 (Sea)</b>
<b>Z</b> (Total mortality)	0.48	0.31
<b>M</b> (Natural mortality)	<b>0.34</b>	<b>0.34</b>
<b>F</b> (Fishing mortality)	0.14	-0.03
<b>E</b> (Exploration rate)	0.29	-0.10

## Discussion and Conclusion

Mullet have different growth rates for each sex. Females grow slower, reach larger sizes and live longer than males. Females living longer and getting older was documented by Thomson (1951) and Ibanez *et. al.* (1999) stated for *Mugil dobula* and *Mugil curema* respectively.

Results also showed a latitudinal gradient. The three regions (south, central and north) showed differences in the vB growth parameters. In the south region growth rate is slower and mullets reach larger sizes. In the north region mullets grow faster and reach smaller sizes. The central region shows intermediate growth parameters values. However, this analysis must be done with care, because Tramandaí, Laguna and Rio Grande have a range of lengths and ages more wide and better represented than the other localities (Figure 4), making the estimates of vB growth parameters for the south and central region proposal, more concrete. The northern region does not have this feature, because the amplitude of lengths and ages was represented only by individuals greater than 450 mm of CT, being representing only a portion of this population, and this fact does not sustain a good comparison.

Vieira & Scalabrin (1991) suggest that the mullets start their seaward reproductive migration from the Patos Lagoon estuary during April and May. It is known that the

months of highest catches occur on the shelf area between June and October along the Brazilian coast with peaks of capture moving northward in time. Our results showed that in April and May the mullets presented their highest values for the condition factor. As the season advances and the migration proceeds, the K value decreases, reaching the lowest values in October, when the commercial harvest of the mullet comes to its end. We interpreted this fact as the end of the reproductive event as did by Vieira & Scalabrin (1991). At this time we observed the highest frequency of hyaline rings in the otoliths edges. From this time on, the mullets would retake its cycle returning to the estuarine areas and go through a feeding period until the next winter. González-Castro *et. al.* (2009) found high frequencies of opaque rings in the months of April and May (autumn), coinciding with the feeding period. Our results demonstrate that the opaque rings (fast growth) were formed in the winter and the hyaline rings (slow growth) were formed in the spring.

Some fish species have a time delay between the otolith growth and the actual detection of opaque rings. Stewart *et. al.* (1999) stated that the opaque rings formed in the winter become visible only at the beginning of the summer for the yellowtail and blue mackerel. Fablet *et. al.* (2011) working with 2 cod populations found that “neither of these populations conforms to the generally assumed interpretation, i.e. slow-growth winter translucent zones and fast-growth summer opaque ones”. They also found that the Barents sea cod forms a later translucent zone induced by migration to warmer waters rather than slow-growth conditions, they stated that different scenarios of specific populations were more important than feeding and temperature conditions. Smith & Deguara (2003) working with *M. cephalus* found that the formation of opaque rings occurred during winter, although they found it unlikely because this is the period

of slow growth when the mullet expend a lot of energy in migration and spawning, likely wise for our results. In the present work there is a time gap between the periods of slow and rapid growth and the formation of hyaline and opaque rings.

### **Juvenile mark**

The back-calculated total length at the formation of the juvenile ring found in this work (21.2 mm) was rather similar to the length found in Hsu *et. al.* (2009) for *M. cephalus* (27 mm). The change of habitat is registered in the otoliths, both by the change of the salinity gradient and the change in feeding habits, when the young mullet moves from the pelagic to the benthic environment (Hsu *et. al.*, 2009). This fact is observed in the Patos Lagoon estuary, Vieira & Scalabrin (1991) stated that the juveniles consume a large amount of fine sediment to stay near the bottom and cross the channel of the estuary. Shen & Tzeng (2002) found similar results with the amphidromous goby that marked changes in otolith microstructures resulting from a habitat shift and change in feeding habits.

Another question deals with the constant supply of recruits (juveniles smaller than 35 mm) captured by beach seine nets in the PLE adjacent area during all months of the year, as was observed by Vieira (1985). *M. liza* is reported as a total spawner, but the presence of recruits throughout the year puts in question whether this species is, in fact, a total spawner. Detailed studies of the ovary maturation cycle may provide the answer to this question.

### **Mortality**

There is a difference in age-length structure between the specimens caught at sea (continental shelf from Chuí-RS to Ubatuba-SP) and in the Patos Lagoon estuary. This

difference is noted also in the length-converted catch curves, showing two distinct total mortalities ( $Z$ ). We identify the first recruitment age to the fishery (3.8 years – 405 mm) as belonging to specimens caught in the estuarine area (PLE). The second one (6.3 years – 495 mm) is referred to specimens caught on the continental shelf during the reproductive migration. The length of first maturation which is 450 mm TL for females and 436 mm for males (González-Castro *et. al.*, 2011), translates to an age between 5 to 6 years and therefore correspondent to the second recruitment age to the fishery.

The five methods used for natural mortality calculation gave different results; however we decided to keep all of them. According to Gulland (1977) and Ricker (1975), natural mortality estimates are hard to assess with the only exception for virgin stocks. Nevertheless, it is good practice to postulate one or more natural mortality rates that seem reasonable, even if they seem inconsistent (Gulland, 1977). The worrying fact of this result is that the estuarine fishery exhibits a greater mortality fishing rate ( $F$ ) when compared to that at sea (Table 6). The PLE is an important nursery and feeding area of mullets, and should be an environment with preservation priorities. A high fishing pressure on the mullet within the estuary may compromise the population of the adult stock. The precautionary principle, makes us pay attention to the exploitation rate obtained for scenarios of tests 1 and 2 in the essay.

These findings pose a couple of questions about the life cycle of the mullet. First, if individuals who have just spawn return to the estuary to recover for the next reproductive event, then why these bigger and older individuals do not appear in the artisanal catches of the PLE? Are these fishes not accessible to the gill nets of the artisanal fleet? If these older and larger mullets are in the estuary, why would the PLE fishers ignore them? Whenever the use of a larger mesh size in the gill-nets should catch

these fishes. Three possible logical conclusions are here submitted. A: for no explanation the older mullets do not return to the PLE so they do not appear in the artisanal catch. B: they do return but migrate upward into the lagoon in the limnic northern area of the Patos Lagoon and, therefore, are not available in the southern estuarine area of the lagoon. C: The sample method was not appropriated. New studies are needed in order to prove or disprove these hypotheses.

The study allow as to conclude that, after spawning at sea, the juveniles enter the estuary with TL of about 22 mm and after 6 years, when they reach 465 mm, are fully recruited to the adult stock, participating in 1 reproductive event per year. The age-length structure showed that the Patos Lagoon estuary fishing has a higher mortality than the sea fishery. The mullets have an estimated lifespan of 11 years, reaching up to 650 mm in TL. Larger and older specimens are not accessible to the Patos Lagoon estuarine fishery.

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