AGE AND GROWTH OF THE BLUE JACK MACKEREL, *Trachurus picturatus* BOWDICH, 1825 (PISCES: TELEOSTEI) OFF MADEIRA ARCHIPELAGO

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Between 1984 and 1986, 630 pairs of *sagitta* otoliths were collected to determine the age and growth of the blue jack mackerel, *Trachurus picturatus* from Madeiran waters. The oldest specimen in this study was nine years old and the largest was 46 cm of total length (TL). The parameters of the von Bertalanffy growth curve were estimated for the whole period studied for all fish ($L\infty$=42.32 cm, k=0.161 year-1, t0= -2.563 year; r2=0.743) for males ($L\infty$=39.57 cm, k=0.194 year-1, t0=-2.282 year; r2=0.722) and for females ($L\infty$=49.78 cm, k=0.114 year-1, t0=-3.052 year; r2 = 0.747). There was no significant differences in mean lengths (t–test, p>0,05) and in the von Bertalanffy growth curves (F-test, p>0,05) between sexes. The validity of otolith readings for estimating age and growth was supported by results from backcalculation method. No significant differences were found in the Bertalanffy growth curves between direct reading of otoliths and backcalculation. Growth parameters estimated from backcalculated sizes-at-age were: for both sexes, $L\infty$=48.28 cm, k=0.135 year-1, t0=-2.898 year and r2=0.999; for males, $L\infty$=44.79 cm, k=0.143 year-1, t0=-3.207 year, r2=0.999; and females, $L\infty$=44.63 cm, k=0.163 year-1, t0=-2.430 year, r2=0.999. The relationship between length and weight was calculated for all fish (Wt=0.00764Lt3.05746; r2=0.951), for males (Wt=0.01271Lt2.90807; r2=0.915) and for females (Wt=0.00604Lt3.12613; r2=0.948).

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INTRODUCTION

The blue jack mackerel (*Trachurus picturatus* Bowdich, 1825), belongs to the Carangidae family. It is a pelagic species, ranging in depth to at least 370 meters and is often confined to neritic zones of island shelves, banks, seamounts and open waters around islands. This species is most abundant between Southern Bay of Biscay and Mauritania including Azores, Canaries, Madeira and Western part of Mediterranean. The blue jack mackerel can also be found in the South-eastern Atlantic at Tristan da Cunha and Gough Is. Along its distribution, this species is found in schools (BAUCHOT & PRAS 1980; BENGURIA et al. 1975; SMITH-VANIZ 1986; SMITH-VANIZ & BERRY 1981).

Trachurus picturatus has a considerably commercial interest in Madeiran archipelago (latitudes 32º30' to 33º30'N and longitudes 16º30' to 17º30'W) (Fig. 1). Annual landings of blue jack mackerel have decreased from 2006 tonnes in 1986 to 653 tons in 2004. On the contrary, the economic value has increased since 1995, representing an important income for local economies (Fig. 2).

The blue jack mackerel is caught south off the Island with purse-seine nets during the night. The fish are concentrated and attracted to the net by chumming (locally called "engodo"), which is made of a mixture of triturated raw fish, and by intense spotlights ("candeio"), a very efficient method to catch pelagic species (JESUS 1992).

Despite its fishing importance there are few studies on age and growth of this species in the Atlantic (ISIDRO 1990; JESUS 1992), using length-frequency analysis and otolith growth rings. ISIDRO (1990) studied the age and growth of 2,530 individuals of *Trachurus picturatus* from Azores, sampled between late 1983 and early 1987. In Madeiran waters, a total of 3,768 blue jack mackerels were used to study the growth and reproduction of this species by JESUS (1992). The present study intends to be a complement to the results obtained for age and growth by the previous authors through the use of backcalculation to validate the age.

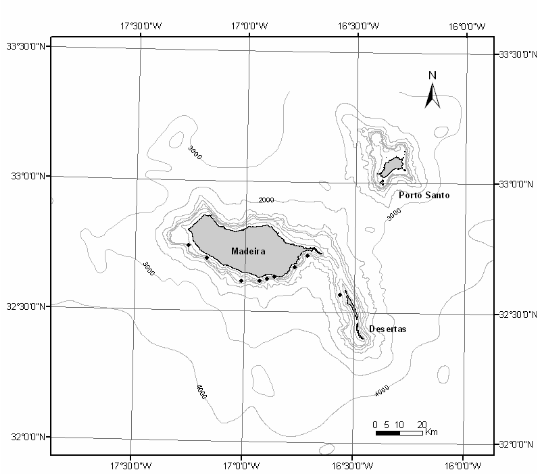

Fig. 1. Location of the fisheries zones (black dots) for *Trachurus picturatus* in the Madeira archipelago (software ArcGIS 8.3)

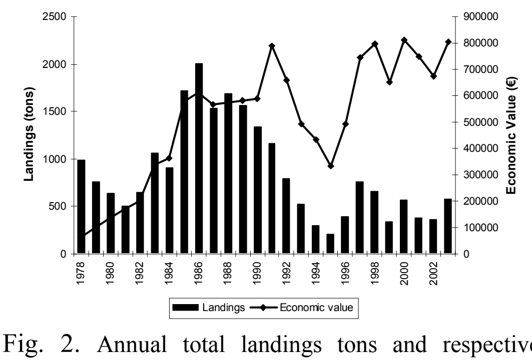

Fig. 2. Annual total landings tons and respective economic value for *T. pic*turatus off the Madeira archipelago between 1978 and 2003 (source DSRP).

By contrast, *Trachurus trachurus* (L., 1758), abundant in the eastern Atlantic, has been much more studied (ARRUDA 1982, 1984; BORGES 1991; BORGES & GORDO 1991; ELTINK 2001; ELTINK & KUITER 1989; ICSEAF 1986; LETACONNOUX 1951; MACER 1968; MARECOS 1986; VILLAMOR et al. 1997).

In general, otoliths of blue jack mackerel are very difficult to read due to: their transparency or opacity; the weak contrast of the alternating growth rings; the presence of sometimes very distinct false *annuli*; and difficulty in detecting the first *annulus* (ISIDRO 1990; JESUS 1992).

Age estimates from band counts on aging structures (such as otoliths) and validation of the periodicity of their deposition are basic requirements to obtain growth rates, ages at maturity and recruitment, longevity and natural mortality rates (PERES & HAIMOVICI 2004).

The objective of this study was to analyse the age and growth of the *Trachurus picturatus* population in the Madeira archipelago.

MATERIAL & METHODS

Sampling

A total of 630 individuals of *Trachurus picturatus* were collected between 1984 and 1986, from commercial landings off Madeira. In order to obtain a complete representation of all size groups caught in Madeira, monthly samples were selected at random from purse seine commercial landings.

All specimens were measured fresh to the nearest millimetre for total length (Lt) and weighed to the nearest centigram for total body weight (Wt). Sex was determined through macroscopic examination of gonads. *Sagitta* otoliths were removed, cleaned and preserved dry in labelled vials.

Age determination

Age was estimated by interpreting and counting growth rings on whole otoliths according to the presence of false rings and problems with identifying the first growth ring.

For readings purposes, the whole otoliths were examined under a compound microscope (6.4x) with reflected light and kept submerged in

70º alcohol against a dark background. Under reflected light the bands formed during the summer season, when there is increased growth, have a white appearance (opaque zones), while those formed during the periods of slow growth, winter season, have a dark appearance (translucent zones).

The translucent rings were counted preferably in the anterior part (*rostrum*) of the otolith.

Each otolith was read twice, with a two-week interval between each reading, without knowledge of the size and sex of the specimens or previous counts. Only coincident readings were accepted. When there was a discrepancy between the two readings, a third reading was carried out. Unreadable (broken and too tick) otoliths were excluded from the study.

Once growth rings were identified, it was necessary to determine the age classes according to the birth date, considered to be the 1st. January, time of capture and *annuli* counts ("one ring-one year"). It was assumed that this species forms one true translucent ring and one true opaque zone every year. The formation of the complex of both zones takes place in one year and is defined as an annulus (DAWSON 1991; ICES 1995; LUCIO 1997; MORALES-NIN 1987; NEJA 1990).

Age length key was elaborated for all fish and study period (1984-1986). Mean lengths at age and the corresponding standard deviation were calculated.

Backcalculation

Besides the number of annuli on each otolith, the otolith radius (distance from the nucleus to the posterior end) and the distance from the nucleus (center of the otolith) to the distal edge of each translucent zone (left otolith) were recorded from 246 individuals.

The measurements were determined using the Leica Image Manager 500 software and always made along the longest axis of the otolith (Fig. 3).

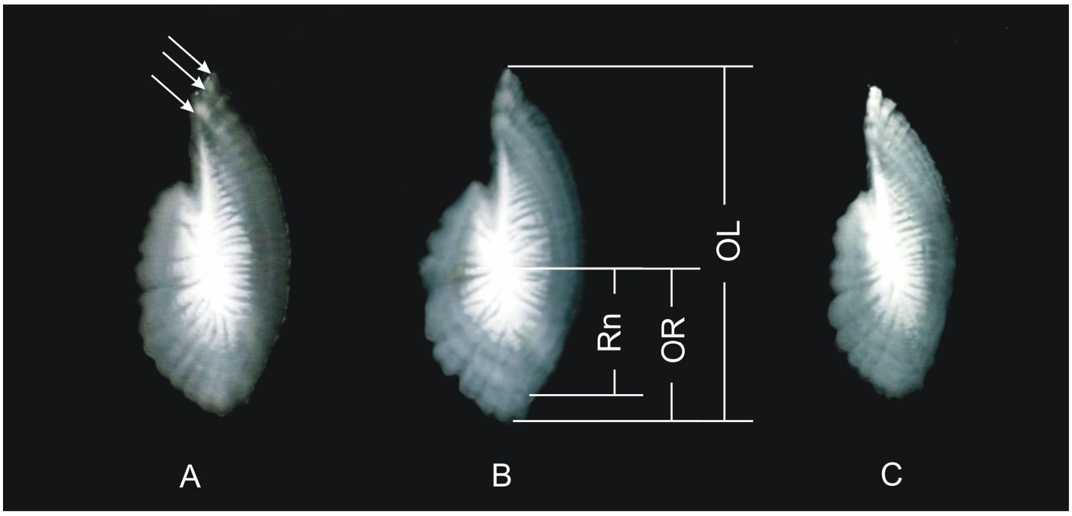

Fig. 3. *Sagitta* otoliths of *T. picturatus* collected in Madeiran archipelago: A) from a three-year-old (290 mm; 10x); (B) from a four-year-old (276 mm; 10x); and (C) from a five-year-old (280 mm; 8x). *OL* is the otolith total length, *OR* is the otolith radius at time of capture and R_n is the radius of the *annulus* n (distance from the center of the otolith to the outer margin of the *annulus*)

Thereafter, the relationship between the otolith radius (OR) and the total length of the fish (Lt) was established by a linear regression, using the least squares method.

The backcalculation method was applied as an independent mean of validating the otolith-based age determinations (MORALES-NIN 1989). Only the annual rings were considered to determine the backcalculated lengths at age.

Backcalculated size of each fish at the time of formation of each annulus was determined by a backcalculation formula recommended by BAGENAL & TESCH (1978), CAMPANA (1990) and FRANCIS (1990), the Fraser-Lee formula (1):

$$Lti = c + (Ltc - c)\ Rn/OR \qquad (1)$$

Were:
Lti = fish total length (mm) at time of ring n formation;
Ltc = total length a time of capture (mm);
Rn = radius of the annulus n (mm);
OR = otolith radius at time of capture (mm);
c = correction factor.

Growth parameters estimation

The von Bertalanffy growth function (2) has been by far the most studied and most used of all length-age models in fish biology. It describes the relationship between age and length as follows (GULLAND 1983):

$$Lt = L\infty\ [1 - e\text{-}k\ (t\text{-}t0)] \qquad (2)$$

Were:
Lt = the mean length at age t (cm);
L∞ = the asymptotic mean length (cm);
k = body growth coefficient (year-1);
t0 = the age at which mean length is zero (years);
t = fish age (years)

The body growth coefficient (k) describes the curvature of a growth curve while t0 acts as an adjustment factor moving the curve to the left or right (BAGENAL & TESCH 1978; JONES 2002).

The model was fitted to data and to the backcalculated mean length-at-age by the Gauss-Newton method using the mean square function (software Statistica 6.0).

Weight-length relationship

Length and weight data combined with age information can be used to construct growth curves (ABAUNZA et al. 2003).

The estimation of weight-length relationship (3) was made by the adjustment of an exponential curve to the data (JONES 2002; RICKER 1973):

$$Wt = qLtb \qquad (3)$$

Where:
Wt = total weight (g);
Lt = fish total length (cm);
q = constant (condition factor);
b = power coefficient.

The parameters q and b of weight-length relationship were estimated by a simple linear regression analysis on log-transformed data.

Data Analysis

The null hypothesis of no difference between the mean lengths estimated for males and females was tested using the Student's t-test (ZAR 1996).

Von Bertalanffy growth curves obtained for males and females were compared using the F-test (ZAR 1996).

The mean lengths at age and the von Bertalanffy growth parameters estimated by otolith reading and backcalculation were compared using the student's t-test (ZAR 1996) and the index of growth performance ϕ' (PAULY 1997), respectively.

The mean lengths estimated in this paper (all fish, period 1984-1986) were compared with those obtained from the study of *T. picturatus* in the same area, using the Student's t-test (ZAR 1996).

The F-test was also applied to compare weight between males and females (ZAR 1996).

RESULTS

Of the all individuals examined, 271 were males and 311 females. The sex of the remaining 48 individuals could not be identified macroscopically.

Of the 630 otoliths processed for annual age determination, 9 (1.43%) were considered unreadable and rejected from the analysis. Of the remaining 621 otoliths, 507 (81.64%) of the readings were coincident twice while 114 of the otoliths were read a third time.

Length frequency

The size range of the individuals was between 170 and 460 mm total length. Males ranged in size between 170 and 460 mm and females between 180 and 440 mm in length.

The dominant size class in the length frequency distribution from the commercial landings of all three years together was the [290-300[mm size class (Fig. 4). For each year separately, the dominant size classes were: [300-310[mm for 1984, [280-290[mm for 1985 and [200-210[and [220-230[mm for 1986.

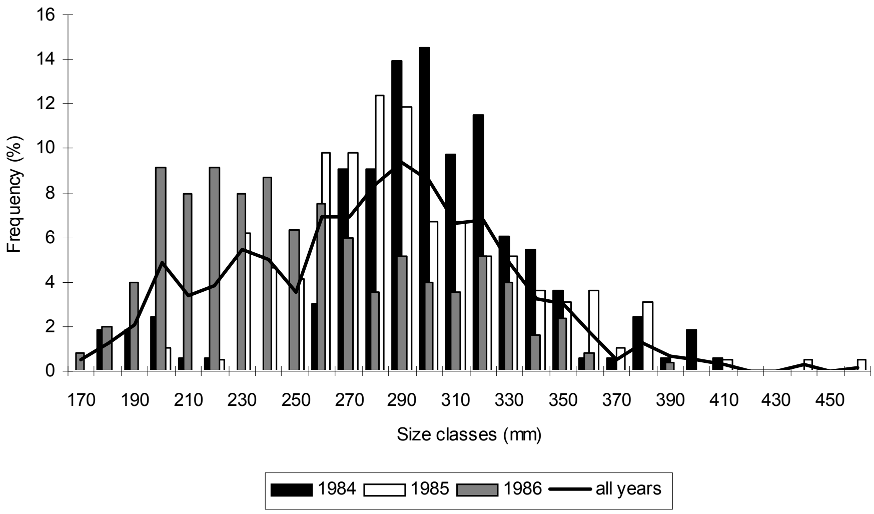

Fig. 1. Length frequency distribution of the *T. picturatus* off Madeiran archipelago caught between the 1984 and 1986

Age determination

Sagitta otoliths of *T. picturatus* show the ring pattern common to teleost fishes. One opaque and one translucent ring are deposited each year on the otoliths, with the first opaque bands being notably wider. These growth rings are formed during alternative periods of fast and slow growth (ABAUNZA et al. 2003; MORALES-NIN 1987; WILLIAMS & BEDFORD 1974).

The age of the fish studied ranged from 0 to 9 years (Table 1). The age group 4 was the best represented (n=182). The distribution of the otolith radius lengths of 246 otoliths are shown in Fig.5.

The frequency distribution corresponding to the radii identified as annual rings are shown in Fig. 6.

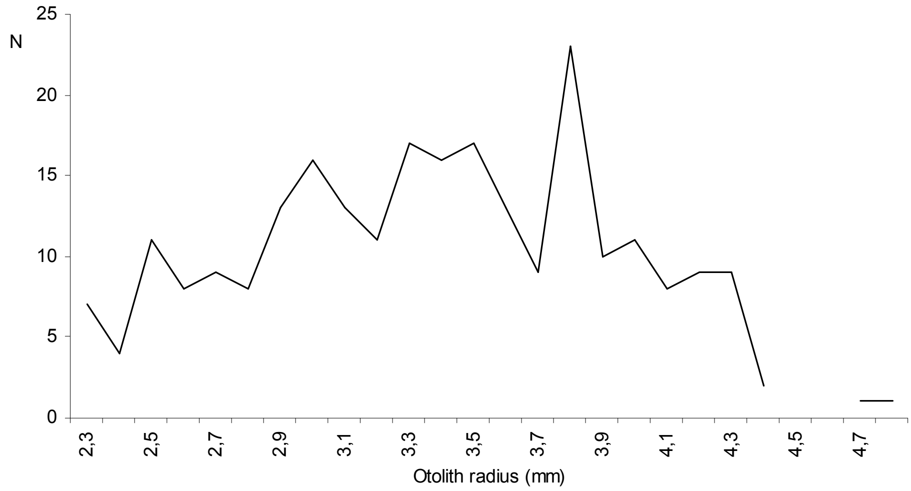

Fig. 2. Frequency distributions of otolith radius lengths of 246 otoliths of *T. picturatus* off the Madeira archipelago.

Table 1
Length-age key for all fish of *T. picturatus* off Madeiran archipelago, sampled from January 1984 to December 1986

LT (cm)	Age group (year)										Total
	0	1	2	3	4	5	6	7	8	9	
17-	3										3
18-	5	3									8
19-	4	8	1								13
20-	8	14	8								30
21-	6	4	11								21
22-		3	18	3							24
23-		8	15	10	1						34
24-		5	11	6	8	1					31
25-			4	7	10	1					22
26-		1	4	8	28	3					43
27-			4	17	16	4	1				43
28-			2	18	21	9	1	1			52
29-			3	12	30	10	2	1			58
30-				16	22	7	6		2		53
31-			2	5	13	11	8	2	1		41
32-					14	8	13	7			42
33-					7	10	6	5	2		30
34-					3	7	7	1	2		20
35-					5	4	7	2	1		19
36-					2	3	5	1			11
37-					1			2			3
38-						1	4	2	1		8
39-					1		1	2			4
40-							1		1	1	3
41-									1	1	2
42-											0
43-											0
44-									1	1	2
45-											0
46-									1		1
Total	26	46	81	102	182	79	62	26	13	4	621
Mean	19.35	21.00	23.09	27.15	28.85	30.86	33.05	33.69	36.08	39.00	
Increment	19.35	1.65	2.09	4.06	1.70	2.01	2.19	0.64	2.39	2.92	
Standard deviation	1.354	1.988	2.330	2.463	2.934	2.885	2.737	2.936	5.267	5.598	

Table 2
Backcalculated length-at-age of 230 individuals of *T. picturatus* off Madeiran archipelago at the time of *annulus* formation

Observed age	n	Annulus								
		1	2	3	4	5	6	7	8	9
1	27	19.66								
2	36	19.75	22.25							
3	33	20.26	24.14	27.10						
4	75	19.23	23.19	26.51	28.64					
5	22	19.22	22.77	26.28	29.01	30.93				
6	24	19.25	23.18	26.12	28.86	31.41	33.16			
7	10	20.14	23.45	26.40	29.21	31.70	34.07	35.88		
8	2	20.62	23.64	26.01	28.14	29.93	31.72	33.67	34.81	
9	1	19.14	24.43	28.21	30.53	33.09	36.31	38.20	39.12	40.00
Total		230	203	167	134	59	37	13	3	1
Mean		19.70	23.38	26.66	29.07	31.41	33.82	35.91	36.97	40.00
Increment		19.70	3.68	3.28	2.41	2.34	2.41	2.09	1.06	3.03
Standard deviation		0.538	0.703	0.769	0.809	1.154	1.923	2.264	3.047	0

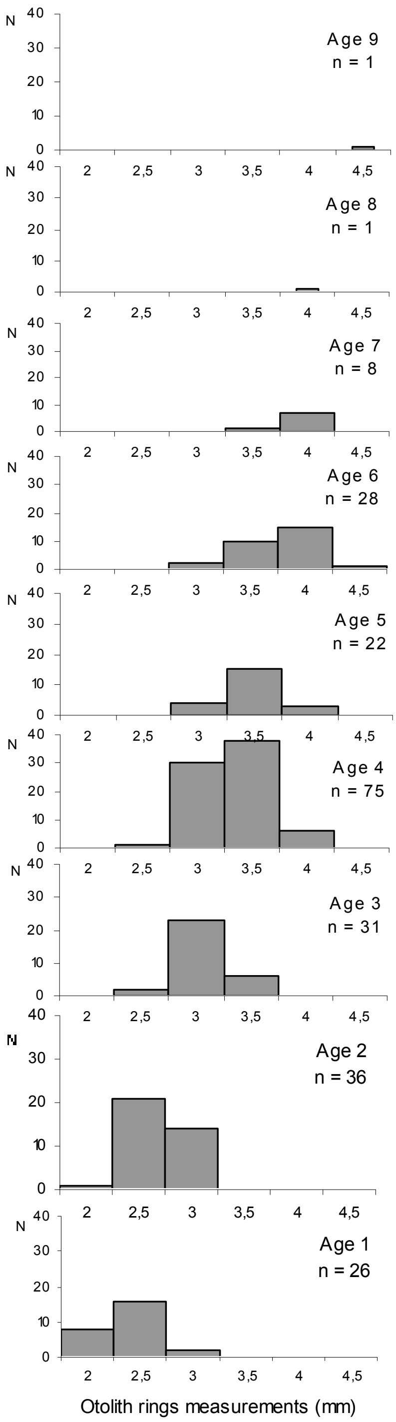

Fig. 3. Frequency distribution of otolith rings measurements of *T. picturatus* off the Madeira archipelago

Backcalculation

Fish total length and otolith radius were closely correlated (Fig. 7).

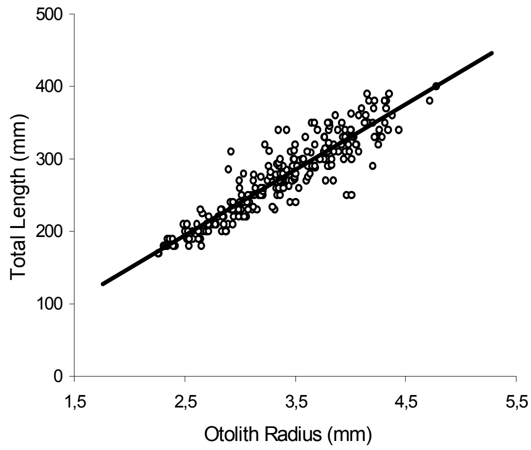

Fig. 4. Relationship between the otolith radius and the total length of *T. picturatus* off the Madeira archipelago.

Backcalculated total lengths at the beginning of a new year's growth season (corresponding to approximately 1st of January) by age for all individuals are shown in Table 2.

There was no indication of Rosa Lee's phenomenon in which computed sizes at a given age tend to be smaller when derived from measurements on older fish (FRANCIS 1990).

The backcalculated lengths were slightly higher than observed lengths in the age groups 3 to 9 and for ages 1 and 2 slightly smaller.

Growth parameters

Age groups 0, 8 and 9 were not considered for the estimation of the von Bertalanffy parameters (L_∞, k and t_0) due to insufficient data.

The growth parameters of the von Bertalanffy model estimated, for the whole period studied, by otolith reading and backcalculation for females, males and both sexes are represented in Table 3.

The fitted von Bertalanffy growth curves estimated by otolith reading and by backcalculation are represented in Fig. 8.

Table 3
Parameters of the von Bertalanffy growth curve for females, males and all fish of *T. picturatus* off Madeiran archipelago estimated by otolith reading and by backcalculation (based on ages 1 to 8)

Method	L_∞ (cm)	k ($year^{-1}$)	t_0 (year)	ϕ'	r^2	n
Age reading						
Females	49.78	0.114	-3.052	2,45	0.747	295
Males	39,57	0.194	-2.282	2,48	0.722	248
Both sexes	42.32	0.161	-2.563	2,46	0.743	578
Backcalculation						
Females	44.63	0.163	-2.430	2,51	0.999	131
Males	44.79	0.143	-3.207	2,46	0.999	89
Both sexes	48.28	0.135	-2.898	2,50	0.998	229

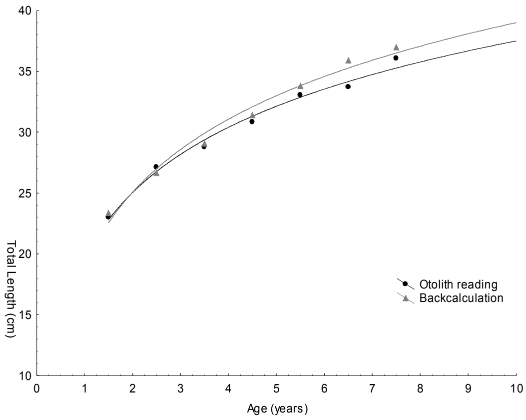

Fig. 5. The von Bertalanffy growth curves estimated by otolith reading and by backcalculation for all individuals of *T. picturatus* off the Madeira archipelago.

Weight-Length relationship

The weight-length relationship obtained for females, males and both sexes are represented in Table 4.

Table 3
Parameters of the weight-length relationship estimated for females, males and all fish of *T. picturatus* off Madeiran archipelago based on monthly sampling in 1984, 1985 and 1986

	q	*b*	r^2	n
Females	0.00604	3.12613	0.948	126
Males	0.01271	2.90807	0.915	95
All fish	0.00764	3.05746	0.951	621

Data Analysis

There was no significant differences in mean lengths at age (*t*-test, p>0,05) and in the von Bertalanffy growth curves (*F*-test, p>0,05) between sexes.

The mean lengths estimated by otolith reading and by backcalculation (*t*-test, p>0,05) showed no significant differences. The backcalculated growth parameters are in close agreement with the one estimated from otolith readings (Table 3).

Comparison of the mean lengths between this study and Jesus (1992) revealed significant differences (t-test, p<0.05).

The growth parameters estimated in this study are different from those obtained by Isidro (1990) and Jesus (1992) (Table 5).

There were no significant differences in weight between females and males (F-test, p>0.05).

DISCUSSION

In the Madeiran archipelago, *T. picturatus* grows relatively fast during the first three years of life, attaining approximately forty percent of its maximum length during the third year. The highest growth took place above all in the first year of life, when length reaches around 20 cm. After the second year, however, the annual growth rate drops rapidly, maybe related to physiological changes caused by factors such as temperature and food availability and sexual maturity (BOND 1979; HUET 1983; JONES 1976; MOYLE & CECH 1996). Hence, energy seems to be diverted to reproduction, with less energy available for somatic growth.

Age determination was often proved difficult because whole otoliths were too thick for light to pass through, presence of false rings and problems with identifying the first growth ring. The application of others methods (such as the broken-burnt method or the slicing methods) in future works, may be interesting in the treatment and preparation of otoliths of *Trachurus picturatus* in order to facilitate their readings.

Age estimation in fishes is complicated by the phenomenon of "stacking" of growth zones towards the otolith margin, particularly in older fish (VAN DER WALT & BECKLEY 1997).

The general distribution of otolith radius lengths (Fig. 5) presents a sequence of modes which are coincident with distribution patterns of lengths of each radii identified as annual (Fig. 6). This is particularly clear for the younger ages (1 to 4), except for age 0. Over age 7 the low annual increments in the otolith length produce the overlap of the length distributions of radii, making impossible the identification of annual components. This is in agreement with the observations of JUNQUERA (1988).

According to SHABONEYEV & RYAZANTSEVA (1977) and SHABONEYEV & KOTLYAR (1979) sexual dimorphism does not exist in blue jack mackerel. The results obtained in this study supported the fact that there are no significant differences in the mean lengths at age (*t*-test; $p>0.05$) and in the von Bertalanffy growth curves (*F*-test, $p>0.05$) estimated for females and males.

The results obtained using the backcalculation method were very satisfactory and corroborated the use of otolith for estimating the age and growth of the *T. picturatus* off Madeiran archipelago. The use of measurements to previously formed marks to backcalculate the growth history in this study is valid because the fish length and otolith size are closely correlated and because the rings formation is regular (BAGENAL & TESCH 1978; CAMPANA 1990; FRANCIS 1990).

No significant differences were found in mean lengths at age and in Bertalanffy growth curves estimated for all individuals by otolith reading and using backcalculation method.

The growth parameters (Table 5) and consequently the growth curves (Fig. 9) estimated in this paper for blue jack mackerel are different from those obtained by ISIDRO (1990) and JESUS (1992). This maybe a consequence of the lack of very small and very large fish in the present study in comparison to the studies referred.

Table 4

Growth parameters of *T. picturatus* (both sexes) from our and other studies (TL: total length; FL: fork length)

Study	Location	Length	Size range (cm)	n	$L\infty$ (cm)	k (year^{-1})	t_0 (year)	ϕ'	r^2
This study	Madeira	TL	17-46	578	42.32	0.161	-2.563	2.46	0.743
JESUS (1992)	Madeira	TL	10-41	489	44.3	0.316	-	2.79	0.93
ISIDRO (1990)	Azores	FL	12-43	516	52.9	0.2	-0.23	2.75	-

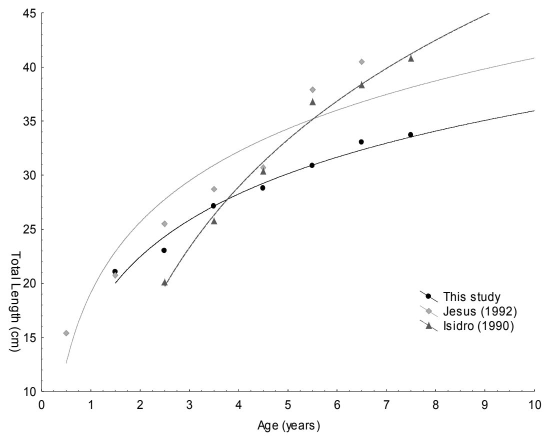

Fig. 9. Comparison of the growth curves for the *T. picturatus* estimated in this study and by other authors.

The differences in the k values obtained in this study, by JESUS (1992) and by ISIDRO (1990) might be explained by the difficulties in obtaining both very small and very large fish. This affects estimates of t_0 and L_{∞}, and consequently of the k (KING 1995).

The t_0 value obtained in this study, for sexes combined, was strongly negative when compared to those estimated by other authors. This might indicate that the von Bertalanffy growth model does not fit the data for small fish or maybe due to the absence of small fishes in the sample or barely because the age 0 has been omitted from the analysis.

The b parameter value of the weight-length relationship obtained in this study was different to those estimated by JESUS (1992) and ISIDRO (1990) (Table 6). Data also indicated that weight increases isometrically with length for all individuals in this study and in JESUS (1992) and ISIDRO (1990) increases allometrically.

Given that *Trachurus picturatus* is a not often studied species, further studies will be important to compare these results with the last few years and to obtain the growth of the different cohorts and thus be able to see whether there are differences not only between different seasons but also between different cohorts.

Table 5
Weight growth parameters estimated in this study and by others authors for *T. picturatus*

Study	Location	n	q	b	r^2
This study	Madeira	621	0.0076	3.06	0.951
JESUS (1992)	Madeira	3401	0.0044	3.20	0.999
ISIDRO (1990)	Azores	1934	0.0082	3.11	0.988

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