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**Age, growth and natural mortality of Atlantic chub mackerel *Scomber colias* Gmelin 1789 (Perciformes: Scombridae), from Mauritania (NW Africa)**

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**ABSTRACT:** Age, growth and natural mortality were analyzed for Atlantic chub mackerel *Scomber colias* Gmelin 1789, collected from commercial landings from Mauritanian waters between 2005 and 2011. A total of 4599 specimens were sampled, ranging from 12.4 cm to 49.0 cm of total length. Length-weight relationships showed statistically significant differences between sexes. Ages were estimated by counting growth bands on otoliths, with specimens from 0 to 7 years. The mostly absence of 0-age individuals led to use the backcalculation method to estimate the growth parameters, and no statistically significant differences were found between sexes. Natural mortality rate was estimated through empirical methods with a mean value of 0.47 years<sup>-1</sup>. Those results provide important updated biological information for fisheries assessment of a species that plays a key role in the local and foreign economy and in the surrounding ecosystem.

**Keywords:** Atlantic chub mackerel, *Scomber colias*, age and growth, natural mortality, Mauritania.

**RESUMEN:** Se ha estudiado la edad, el crecimiento y la mortalidad natural de la caballa *Scomber colias* Gmelin 1789 a partir de las muestras de descargas comerciales entre 2005 y 2011, procedentes de aguas mauritanas. Se muestreó un total de 4599 individuos con tallas totales comprendidas entre 12,4 cm y 49,0 cm. Las relaciones talla-peso mostraron diferencias estadísticamente significativas entre sexos. Las edades se estimaron a partir del número de bandas de crecimiento en los otolitos, con ejemplares entre 0 y 7 años. La práctica ausencia de individuos de clase de edad 0 condujo a utilizar método del retrocálculo para estimar los parámetros de crecimiento, y no

se encontraron diferencias estadísticamente significativas entre sexos. La tasa de mortalidad natural fue estimada a partir de métodos empíricos, con un valor medio de 0,47 años<sup>-1</sup>. Estos resultados suponen una actualización de información biológica importante para la evaluación de una especie que juega un papel clave en la economía local y foránea, así como en el ecosistema.

Palabras clave: caballa, *Scomber colias*, edad y crecimiento, mortalidad natural, Mauritania.

## INTRODUCTION

The Atlantic chub mackerel *Scomber colias* Gmelin 1789 is a very important fishery resource widespread and abundant in many parts of its broad geographic distribution, which includes the Atlantic Ocean (eastern and western coasts), the Mediterranean Sea and southern Black Sea. This is a coastal pelagic species, and to a lesser extent epipelagic to mesopelagic over the continental slope. It forms schools, also with *Sarda* species, bonitos, jacks, and clupeids. *S. colias* feeds on copepods and other crustaceans, fishes and squids. In Mauritania, it is reported to stay near the bottom during the day and goes up to the open water at night (Collette and Nauen, 1983; Maigret and Ly, 1986; Collette, 1995).

The Atlantic chub mackerel was originally thought to be a subspecies of the chub mackerel *Scomber japonicus colias*, but is now recognized as distinct from the Indo-Pacific *Scomber japonicus* Houttuyn, 1782 (Collette, 1999; Infante *et al.*, 2007; Catanese *et al.*, 2010; Cheng *et al.*, 2011). Although in the Fishery Committee for the Eastern Central Atlantic (CECAF) it has been corrected recently (FAO, 2016), in most cases catches statistics from the eastern Atlantic fishing grounds are referred to *S. japonicus* and literature maintain this mistaken nomenclature (ter Hofstede and Dickey-Collas, 2006; Martins, 2007; Cengiz, 2012). The greatest landings reported are from the eastern central Atlantic, where an important European pelagic trawler fleet from several countries operates (e.g. Russia, Netherland, Ukraine, Poland, Lithuania, among others), mainly in the rich Mauritanian fishing ground. The total catch of chub mackerel fluctuated over the time period 1990-2014 in the Mauritanian waters, showing an overall increasing trend since 2003. Peaks in catches were observed in 1996, 2002 and 2003 ( $\geq 100000$  tonnes). The bulk of catches are mainly taken by industrial pelagic trawler fleet (mainly foreign, through fisheries partnership and private agreements), and by an increasing artisanal sector (FAO, 2016).

Member States of the European Union (EU) must report basic fishery data from European fisheries in order to contribute to the Data Collection Framework (Council Regulation (EC) No 1543/2000 and Council Regulation (EC) N° 199/2008). Moreover, *S. colias* catches are becoming more important in the northern areas in the last decade, what has increased the EU interest in its biological knowledge in order to initiate the way to assess the resource status (ICES, 2016).

Last published studies about the species in this area are dated on the nineties (Maxim, 1990; Provorotova (1998) in Failler *et al.*, 2006). Therefore, the present work provides updated growth parameters and natural mortality estimations for the Atlantic chub mackerel *S. colias* from Mauritania.

## MATERIAL AND METHODS

Monthly samples of *S. colias* were collected between 2005 and 2011. Total length (TL, 0.1 cm), total weight (TW, 0.1 g) and sex were registered for a total of 1244 individuals. The length-weight relationship was calculated by the equation:  $TW = a \cdot TL^b$ . Analysis of covariance was performed to test differences between sexes with GraphPad Prism version 4.03 for Windows. Growth patterns were tested through the modified t-Student test by (Pauly, 1984).

In addition, saggital otoliths were extracted, cleaned and preserved for age determination. Whole otoliths were mounted on black slides, concave side up, covered with resin Eukitt®. Age was determined by two readers, under reflected light using a binocular microscope (magnification 10X), with no knowledge of the length of the specimen. General criteria from FAO (2002) was used: *i*) the date of birth was considered to be 1<sup>st</sup> January according with the reproduction season (winter (Castro and Santana, 2000)); *ii*) each year an opaque and a translucent band are deposited on the otolith (Lorenzo *et al.*, 1995; Carvalho *et al.*, 2002; Vasconcelos *et al.*, 2011); *iii*) the age of the fish corresponds to the number of complete translucent bands.

Due to the scarcity of small individuals in catches (0-age class), it was not possible to assess the evolution of the marginal ring. Besides, this conditioned the growth curve fitting on the left side. The use of backcalculation method solved the estimation of previous length-at-age. For back-calculations of growth only otoliths showing clear increment patterns were assessed along the actual radius of the otolith. Total otolith radii ( $R_o$ , distance from the focus to the otolith posterior end) and partial annuli radii ( $r$ ) were measured from 163 otolith images with agreement between two readers and high readability security. A non-linear relationship between the total length of fish and the total otolith radius ( $R_o$ ) was considered (Monastyrsky, 1930):

$$L_i = (r/R_o)^v \cdot TL$$

where  $L_i$  is length at the age  $i$ ,  $r_i$  the otolith radius at the age  $i$  (or annulus radius  $i$ ),  $R_o$  the total otolith radius,  $v$  the constant of allometry and  $LT$  the total length.

Fish size is considered a non-linear function of radius size (power relationship):

$$TL = u \cdot R_o^v$$

where  $v$  and  $u$  are derived from the linearised equation. These parameters are obtained by a geometric mean regression (GMR) (Ricker, 1992; López-Abellán *et al.*, 2008).

The age-length relationship was established for all individuals using 1-cm size intervals (rounding off to the lower centimeter). The mean size and the standard deviation by age class were estimated taking as a reference the midpoint of the size interval. Backcalculated length-at-age values were adjusted to the von Bertalanffy growth equation and parameters (VBGP) were estimated for the total, females and males:

$$TL_t = L_\infty (1 - e^{-k(t-t_0)})$$

where  $L_t$  is length (TL) at time  $t$  (years),  $L_\infty$  the asymptotic length,  $k$  the growth coefficient and  $t_0$  the hypothetical time when fish length is zero.

Differences between sexes growth parameters were tested by the Hotelling's  $T^2$  multivariate method (Bernard, 1981; Cerrato, 1990; Tuset, 2000).

The partial radii of each annuli were used to assess the coherence of the age determination criteria used in relation to the seasonal regularity of the growth pattern assumed for this species in close areas (Lorenzo *et al.*, 1995), as recommended by May (1965, *in* Morales-Nin, 1991)

In order to analyze geographical variations, growth parameters of *S. colias* from other areas were compared through the growth performance index (Pauly and Munro, 1984):

$$\phi' = 2 \cdot \log_{10} L_{\infty} + \log_{10} k$$

Natural mortality rate ( $M$ ) was estimated by empirical methods (Pauly, 1980; Jensen, 1996):

1. Pauly (1980):  $\log M = -0.0066 - 0.279 \cdot \log L_{\infty} + 0.6543 \cdot \log k + 0.4634 \cdot \log \text{SST}$   
Mean value of SST for the area was obtained from IGOSS IRI database (Reynolds *et al.*, 2002).
2. Jensen (1996):  $M = 1.5 \cdot k$

## RESULTS

TL and TW ranged from 12.4 cm to 49.0 cm, and from 12.6 g to 1512 g, respectively (Table I).

Parameters of TL-TW relationships are presented in Table II. ANCOVA analysis showed statistically significant differences between sexes ( $F=5.98$ ;  $p>0.01$ ), and all the relationships resulted allometric positive ( $p<0.001$ ).

The TL-Ro relationship is given by the equation  $TL = 8.33 \cdot Ro^{1.523}$  (Fig. 1). The proportion between fish growth and otolith size increase were closely correlated ( $R^2=0.82$ ), allowing the use of backcalculation to estimate fish lengths.

Age classes from 0 to 7 years were assigned (Fig. 2). Due to only the readings with high security were accepted, 163 otoliths were used to the backcalculation (excluding 11 otoliths assigned to the 0-age class).

Summary of the partial radii ( $r$ ) measurements and the backcalculated lengths by age class are presented in the tables III and IV, respectively. As expected, the mean values for the correlative annuli were increasing. The mean radius for the first ring was  $1.907 \pm 0.123$  mm (corresponding to  $22.3 \pm 2.5$  cm of TL), and  $2.232 \pm 0.131$  mm for the second one (corresponding to  $28.3 \pm 3.2$  cm of TL).

Estimated growth parameters (BVGP) are shown in table V. The Hotelling's  $T^2$  test results corroborated that BVGP can be assumed as statistically equal between sexes ( $F=15.4$ ,  $p<0.01$ ). Therefore, BVGP for the total can be used for any further analysis.

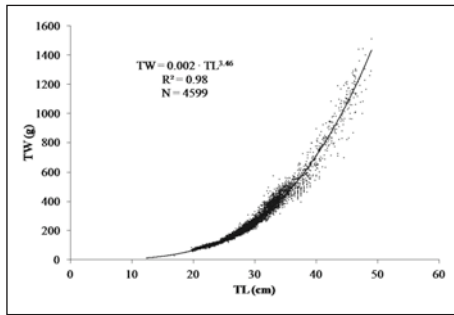
The representation of the partial radii ( $r$ ) frequencies (Fig. 3) showed well differentiated and decreasing first distributions, what verify the coherence of the ageing criteria used (Morales-Nin, 1991).

**Table I.-** Summary of Total Length (TL) and Total Weight (TW) of *S. colias* from Mauritania. s.d.: standard deviation.

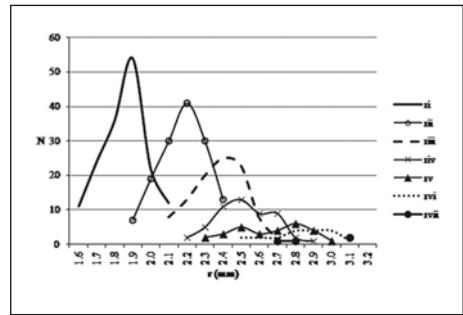
N	TL (cm)		TW (g)	
	Mean value±s.d.	Min-Max	Mean value±s.d.	Min-Max
4599	29.8±5.3	12.4-49.0	295.3±203.6	12.6-1512.0

**Table II.-** Total Length-Total Weight (TL-TW) relationships for females, males and the total of *S. colias* from Mauritania.

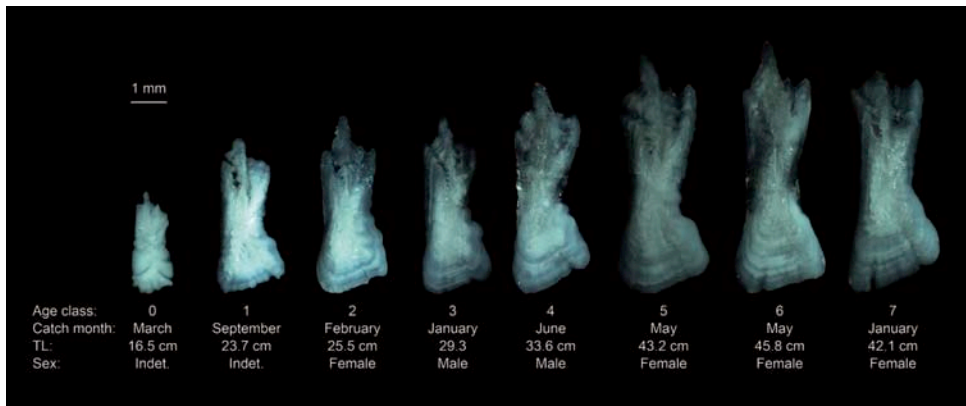
	N	a	b	R <sup>2</sup>
Total	4599	0.002	3.460	0.98
Females	1790	0.002	3.427	0.98
Males	1413	0.002	3.374	0.97



**Figure 1.-** Total Length (TL) and otolith radius (Ro) relationship for the *S. colias* analyzed from Mauritania.



**Figure 3.-** Frequency distributions of annuli radii (r), in otoliths of *S. colias* from Mauritania.



**Figure 2.-** Otoliths of *S. colias* from Mauritania. TL: total length.

**Table III.-** Summary of the measures of the otolith partial radii (for each annulus) by age class. N: number of measurements; Ro: otolith radius; s.d.: standard deviation.

Age class	N	Annulus						
		i	ii	iii	iv	v	vi	vii
I	19	1.905						
II	39	1.931	2.212					
III	52	1.918	2.238	2.401				
IV	25	1.877	2.234	2.440	2.551			
V	11	1.829	2.163	2.360	2.476	2.563		
VI	12	1.890	2.287	2.542	2.694	2.792	2.868	
VII	5	1.953	2.310	2.522	2.675	2.793	2.897	2.977
N		163	144	104	53	28	18	5
Mean Ro (mm)		1.907	2.232	2.433	2.589	2.718	2.874	2.977
Increment (mm)		1.907	0.326	0.201	0.156	0.130	0.156	0.103
s.d. (mm)		0.123	0.131	0.150	0.164	0.205	0.191	0.204

**Table IV.-** Summary of backcalculated total lengths (TL), by age class. N: number of measurements; TL: total length; s.d.: standard deviation.

Age class	N	Annulus						
		i	ii	iii	iv	v	vi	vii
I	19	22.3						
II	39	22.6	27.7					
III	52	22.5	28.5	31.8				
IV	25	21.6	28.1	32.2	34.4			
V	11	21.9	28.3	32.3	34.7	36.6		
VI	12	22.2	29.6	34.8	38.0	40.1	41.8	
VII	5	22.1	28.6	32.7	35.8	38.2	40.4	42.1
N		163	144	104	53	28	18	5
Mean TL (cm)		22.3	28.3	32.4	35.6	38.7	41.5	42.1
Increment (cm)		22.3	6.0	4.1	3.2	3.1	2.8	0.6
s.d. (cm)		2.5	3.2	3.6	3.4	3.9	3.5	1.2

**Table V.-** Growth parameters of *S. colias* from Mauritania for females, males and the total.

	$L_{\infty}$ (cm)	$k$ (year <sup>-1</sup> )	$t_0$ (years)	R <sup>2</sup>	N
Total	48.4	0.247	-1.514	0.997	163
Females	49.5	0.238	-1.470	0.993	84
Males	47.8	0.249	-1.598	0.998	79

**Table VI.-** Summary of the growth parameters estimates of *S. colias* in FAO Area 34.

Area	Length	$L_{\infty}$ (cm)	$k$ (years <sup>-1</sup> )	$t_0$ (years)	R <sup>2</sup>	$\phi'$	Source
NW Africa	FL	55.37	0.118	-3.178	n.a.	2.56	Staicu and Maxim (1974)
Zone A+B	TL	35.78	0.270	-0.780	0.89	2.54	FAO (2016)
Zone C	TL	45.06	0.290	-0.750	0.92	2.77	FAO (2016)
The Canary Islands	TL	49.20	0.210	-1.400	0.97	2.70	Lorenzo <i>et al.</i> (1995)
Mauritania-Senegal	TL	48.74	0.201	-2.963	n.a.	2.78	FAO (1983)
	FL	47.70	0.202	-1.688	n.a.	2.66	Maxim (1990)
Mauritania	TL	65.75	0.109	-2.447	n.a.	2.67	Provorotova (1998 in Failler <i>et al.</i> (2006))
	TL	61.18	0.136	-1.764	n.a.	2.70	
	TL	64.13	0.112	-2.450	n.a.	2.66	
	TL	48.40	0.247	-1.514	0.99	2.76	This study

Growth parameters for the species in close areas are presented in the table VI. The growth performance index  $\phi'$  varies from 2.54 to 2.78.

For the studied period, a mean value of 22.85°C was found for the SST. Natural mortality rate ( $M$ ) resulted in 0.57 years<sup>-1</sup> and 0.37 years<sup>-1</sup> for the Pauly (1980) and the Jensen (1996) estimators, respectively.

## DISCUSSION

The results in the allometry of the length-weight relationships are in agreement with the results obtained by most of other studies about *S. colias* in close areas, with  $b$  values higher than 3 (Vasconcelos *et al.*, 2011; Jurado-Ruzafa *et al.*, 2016).

The opaque-translucent pattern in the otoliths analyzed seemed match with the one-ring deposition described for the Atlantic chub mackerel in close areas. Most difficulties are related to the identification of the first and second annuli, due to the presence of many “false rings”, what is common in otoliths of this species. The use of measurements to previously formed marks were useful to backcalculate the individual growth histories. Radii measures

could be used as reference in future age determination for *S. colias* in the area, as recommends the International Council for the Exploration of the Sea (Lorenzo and Pajuelo, 1995; ICES, 2016).

Although Navarro *et al.* (2012) found individuals with 65 cm of TL (and 20 years old) in the NE Atlantic, *S. colias* has been described as a fast-growing species, which matures at 2-3 years of age. But it is relatively long-lived, typically 8-10 years (Collette, 1999; Collette *et al.*, 2011). Growth parameters can vary from stock to stock, i.e., they can exhibit different values throughout its distribution. With the exception of Provotorova (1998, in Failler *et al.*, 2006) who estimated a  $L_{\infty}$  noticeable greater (>60 cm), the results obtained in the present work were similar to the estimations by other authors in close areas, with the oldest fish estimated to be 7 years old. Moreover, more than 45% of the maximum length is attained during the first year and a noticeable decreasing in the growth from 2 to 3 years matches with the first maturation.

The growth performance index ( $\phi'$ ) provides an indication of estimation reliability, since it has been suggested that  $\phi'$  values are similar for the same species and genera. The result obtained in the present study (2.76) was in the range to those obtained for *S. colias* in other close areas.

Estimation for  $M$  is referred for the species from Mauritania, with a value of 0.40 years<sup>-1</sup> (Maxim, 1990), very similar to the result obtained in the present study, based in the Jensen estimator. Anyway, the mean value of 0.47 years<sup>-1</sup> is close to the value adopted by CECAF (0.5 years<sup>-1</sup>) (FAO, 2016).

It is unknown the possible connections among populations of the Atlantic chub mackerel in the NW African coast. In this sense, two units are considered in the annual assessments carried out by CECAF: the northern stock between Cape Boujador and the north of Morocco in the Atlantic, and the southern stock between Cape Boujador and the south of Senegal. Nevertheless, owing to a lack of more information on migration and possible exchanges between the two stocks, they proceed with a joint assessment of the two stocks in its general distribution area (FAO, 2016). In addition, some Atlantic Archipelagos in the Macaronesian region should be considered in a great and international effort, in order to find out how many stocks should be considered (Lorenzo *et al.*, 1995).

The results of this study represent an updated contribution to the life history traits of *S. colias* in Mauritanian waters. However, future studies need to address issues, such as age validation and stocks identification in the CE Atlantic region.

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