GROWTH, AGE ESTIMATION AND CORROBORATION OF NORTHEAST ATLANTIC CHUB MACKEREL (*SCOMBER COLIAS*) IN NORTHERN IBERIAN WATERS: A FIRST ATTEMPT

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ABSTRACT

Updated information on growth of Atlantic chub mackerel in several areas of its distribution is required for the first stock assessment.

Its growth pattern in Northern Iberian waters (2011-2017) is here analysed with different approaches: those based on otolith analyses (direct age estimation-DAE, back-calculation-BC and otolith marginal analyses) and those based on length frequency analyses (Bhattacharya, SLCA and PROJMAT methods).

Two main different growth patterns are obtained, a “slow” one based on DAE, BC and LFDA from surveys; and a “fast” one based on Bhattacharya and LFDA from commercial landings. The divergence between both patterns begins to be evident at age 3 and older.

Otolith marginal analyses that show an annual periodicity in the formation of the hyaline and opaque edge, the unimodal distribution of the annuli radius and the similarity of the back-calculated mean lengths to those obtained by DAE, support the age estimation criteria used in our analysis.

The VBGF growth parameters (L_∞=45.34, k =0.28, t_0=-1.18) obtained by otolith age estimation are available for the upcoming stock assessment process.

KEY WORDS

Scombridae, Atlantic Ocean, length frequency analysis, Bhattacharya, direct age estimation, back-calculation, growth curve, otolith edge analysis

1. INTRODUCTION

Atlantic chub mackerel, *Scomber colias*, in Eastern Atlantic is mostly captured in African waters (FAO, 2020), although landings and importance of this species in the Iberian Atlantic Peninsula have increased notably since 2007 (Villamor et *al.*, 2017).

ICES recommends the stock assessment of this species in European waters (ICES, 2020a) and validated or corroborated age estimation criteria are necessary to provide unbiased growth information for the analytical assessment.

The growth of *S. colias* in the NE Atlantic has been studied based on otoliths (estimated mainly from direct age estimation and/or back-calculation) (Martins *et al.*, 1983; Lorenzo, 1992; Martins, 1996; Carvalho *et al*., 2002; Vasconcelos, 2006; Velasco *et al.*, 2011; Jurado-Ruzafa *et al.*, 2017) and length frequency analyses (Lorenzo, 1992; Vasconcelos, 2006).

The age estimation criteria in otoliths of Atlantic chub mackerel were internationally standardized in 2015 (ICES, 2016) although just a few age validation/corroboration studies to support it were available (Villamor et *al.*, 2019; ICES, 2020b).

Considering the scarcity of recent studies, updated growth parameters are required, as well as the use of methodologies to corroborate or validate the growth pattern obtained, as the recent workshop on Atlantic chub mackerel recommended (ICES, 2020a).

The present work studies the growth pattern and parameters of this species in Northern Iberian Atlantic waters using different approaches: i) methods related with the direct age estimation in otoliths (DAE), including back-calculation (BC) and otolith marginal analyses (nature of the edge and marginal distance analyses); and ii) length frequency distribution analyses (MPA and LFDA); as well as to assess whether these methods corroborate the current age estimation criteria of this species.

2. MATERIAL & METHODS

2.1. Sampling

A total of 10403 *S. colias* from the Northern Iberian Atlantic waters (ICES Div. 8.c, 9.a N) were analysed (Fig.1). The total length (TL) and the otoliths of each specimen were collected from landings (8272 specimens) in Spanish fish markets (Santander, A Coruña and Vigo) from 2011-17, and in scientific acoustic surveys "PELACUS" (Massé *et al*., 2018) (2131 specimens) organized by the IEO on board of the R/V "Miguel Oliver" during March-April in 2011 and 2013-17.

Length distributions of *S. colias* from commercial landings by quarter were additionally measured in the fish markets from northern Atlantic Spanish harbours from 2011-17, as well as the length distributions from the aforementioned surveys "PELACUS".

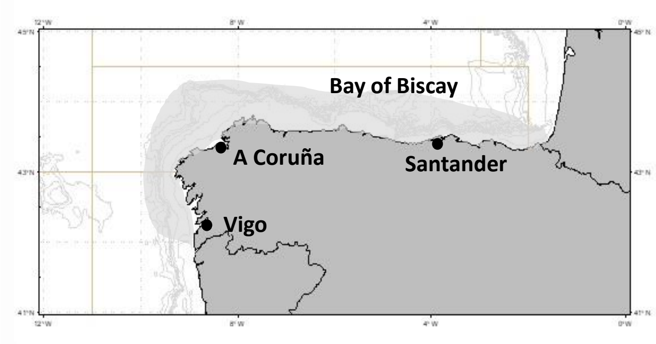


Figure. 1. Area of study (gray shading) corresponding to the area covered by the pelagic surveys PELACUS and where the commercial fleet operates, highlighting the fishing harbours of origin of the biological samples.

2.2. Age estimation

Whole otoliths mounted on black slides covered with transparent resin were observed under reflected light with a binocular microscope (Villamor *et al*., 2015) (Fig. 2). Otoliths were aged twice by the same reader and those with disagreement in age estimations were examined again. 6867 otoliths were aged (5029 from commercial landings and 1838 from surveys) following standardized criteria (ICES, 2016).

Biannual Age-Length Keys (ALK) from the commercial landings were built per year and applied to the respective biannual length distribution (LD). Each ALK from the PELACUS survey was applied to the respective LD surveys catches. Thus, mean lengths (ML) at age based on the Direct Age Estimation (DAE) were averaged for the time series and compared to those obtained from back-calculation and length frequency analyses.

2.3. Age corroboration studies

The methodologies of back-calculation (BC) and frequency distribution of annuli distances in the otoliths were used to analyse the consistency of the age estimation on otoliths. The corroboration of the age was analysed based on the otolith marginal analysis and the length frequency analyses (LFA) (ICES 2020b).

2.3.1. Back-calculation and frequency distribution of annuli distance analyses

The total otolith radius (OR) and the annuli radius (AR) were measured in 423 otoliths from 2011-12, covering the whole length range of catches (Fig. 2).

To verify the regularity in annuli formation and to demonstrate the consistency in age interpretation, the considered annual growth increments were analysed.

The TL-OR relationship was estimated fitting a power equation. The BPH (Body Proportional Hypothesis) method and the Fraser-Lee method were applied (Ricker, 1992) for obtaining back-calculated lengths:

1) Fraser-Lee equation: $\ln L_i = \frac{\ln R_i}{\ln R_t}(\ln L_t - \ln a) + \ln a$
2) Body Proportional Hypothesis (BPH): $\ln L_i = \frac{\ln L_t(\ln a + b \ln R_i)}{\ln a + b \ln R_t}$

where, L_i is the TL when the OR was R_i (cm); L_t the TL when the specimen was caught (cm); R_i the OR of the annulus i (mm); R_t the OR when the specimen was caught (mm); a and b are the parameters of the power regression.

2.3.2. Otolith marginal analyses

The following analyses were performed to determine the seasonality in the annuli formation:

- Nature of the edge: the percentage of hyaline (H) and opaque (O) edge was estimated by month in 8852 otoliths from 2011-17.

- Marginal distance analysis: the absolute marginal distance (AMD - from the end of the last hyaline annulus to the edge); the distance between the last two hyaline annuli ($D_{i,i-1}$) and the relative marginal distance (RMD = ratio of the AMD and $D_{i,i-1}$) (Panfili *et al.*, 2002) (Fig. 2) were obtained in 423 otoliths from 2011-12.

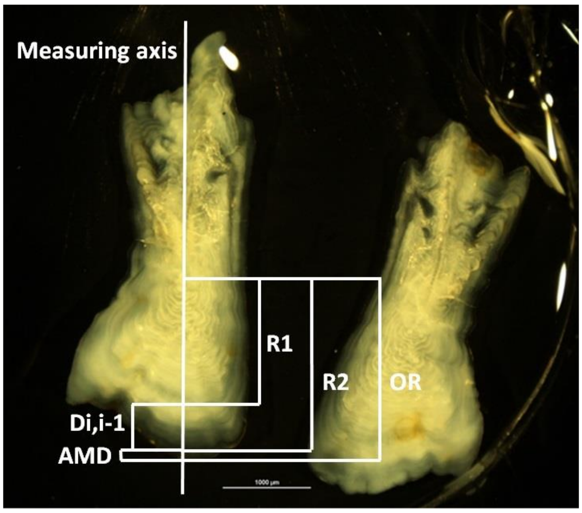


Figure. 2. Measurement axis and otolith measures of *S. colias* from Northern Iberian waters: AMD (Absolute Marginal Distance), $D_{i,i-1}$ (distance between the last two hyaline annuli), OR (otolith radius) and R_i (annuli radius).

2.3.3. Length-frequency analyses

Both LD from surveys and commercial landings were analyzed separately. The commercial landings of *S. colias* represent a wider length range, especially of larger specimens, providing a complementary information to surveys information. Although the pelagic survey series PELACUS data offer less biased information about juvenile *S. colias* length distributions than the commercial data, these surveys are focused on other small pelagic species (mackerel, horse mackerel, sardine or anchovy), not being *S. colias* a target species (Massé *et al*., 2018).

The methods used were: i) the Modal class Progression Analysis (MPA), by the Bhattacharya's method (Bhattacharya, 1967) included in the FISAT II program (Gayanilo *et al.*, 2005), and three methods of length frequency analysis included in the software package Length Frequency Distribution Analysis (LFDA) (MRAG, 2001): ii) Shepherd's Length Composition Analysis (SLCA), iii) Projection Matrix Method (PROJMAT) and iv) Electronic Length Frequency Analysis (ELEFAN). The MPA analyses were performed, on the one hand, for the six years data of surveys, and on the other hand, for the first semester of the seven years of commercial landings, in each case pooled as a single distribution (1 LD). The LFDA methods were applied to the six years of length distributions of surveys and to the seven years of length distributions of the first semester of commercial landings, corresponding, with a scenario with six and seven LD, respectively.

2.4. Annual growth pattern and growth parameters

The growth parameters of the von Bertalanffy growth function (VBGF) were estimated for both sexes combined of *S. colias*, according to the equation:

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

where L_t is the TL at age t; L_∞ is the mean asymptotic fish length; k is the instantaneous growth coefficient; t is the age; and t_0 is the age at which the TL is 0.

The VBGF were estimated from DAE, BC lengths at age and mean lengths at age obtained by MPA. In the case of the LFDA analyses, the parameters were provided directly by the program.

Growth curves for both sexes combined and each method were compared using the Likelihood Ratio Test (Kimura, 1980). This test was conducted using equivalent age ranges as recommended by Haddon (2001), and the growth parameters were recalculated for it, using SPSS (IBM Corp. Released 2017), from their ML at age.

The growth performance index (ϕ') (Pauly and Munro, 1984), that takes into account the correlation between L_∞ and *K*, was used to compare growth parameters among *S. colias* studies:

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

where L_∞ and k are the parameters of the VBGF.

3. RESULTS

3.1. Direct age estimation

Age was estimated in 6867 otoliths (5029 from commercial landings and 1838 from surveys), ranging 14-50 cm in length and 1-14 years in age. The ML at age from surveys (March-April) and those from the first semester of commercial landings showed similar values (Table 1).

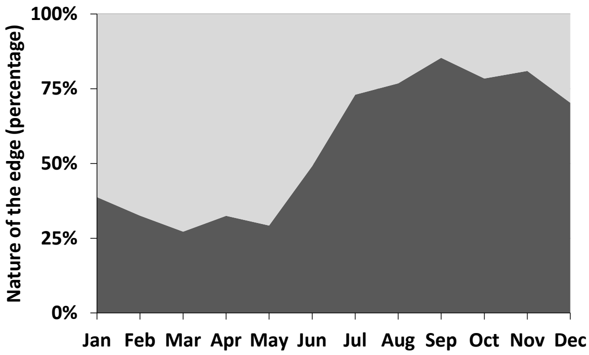
Table 1. ML at age (cm), obtained from direct age estimation (DAE), back-calculation (BC), Bhattacharya method and LFDA packet (PROJMAT and SLCA methods) of surveys (surv) and commercial landings (land) of *S. colias* in Northern Iberian waters. Sem1: first semester; Sem2: second semester.

	DAE			BC	Bhattacharya		PROJMAT	SLCA
Age group (years)	surv	land		surv + land	surv	land	surv	land
	Sem1	Sem1	Sem2	Sem1	Sem1	Sem1	Sem1	Sem1
1	21.3	23.8	26.7	21.9	21.8	21.5	21.8	23.3
2	26.4	27.7	29.3	28.3	27.4	28.4	27.8	30.0
3	31.8	31.0	33.1	32.1	33.6	34.9	32.4	35.0
4	34.4	35.1	36.5	35.7	39.0	38.2	36.0	38.7
5	36.8	37.6	38.3	37.5	42.5	41.5	38.8	41.5
6	39.3	38.4	40.8	38.5		44.5	41.0	43.5
7	39.9	39.7	39.9	40.3		46.5	42.7	45.0
8	40.5	41.3	41.1	43.7			44.1	46.1

3.2. Age corroboration studies

3.2.1. Otolith marginal analyses

The otoliths showed opaque edge mainly from June to December, in agreement with the higher AMD and RMD values in that period (Fig. 3).



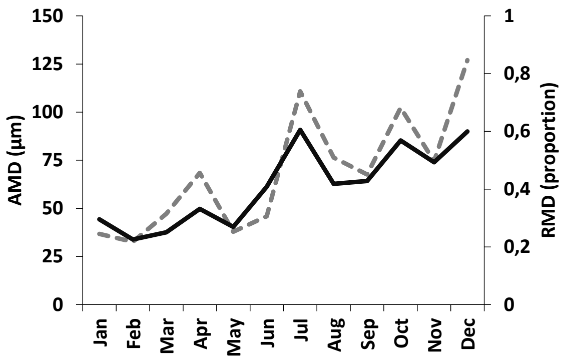


Figure 3. Otolith marginal analyses of *S. colias:* monthly proportion of opaque (dark) and hyaline (light) edge (left); monthly mean values of RMD (continuous line) and AMD (discontinuous line) in otoliths from Northern Iberian waters (right).

3.2.2. Back-calculation and frequency of annuli distance analyses

The relationship between total fish length (TL) and otolith radius (OR) fitted to the power model:

$TL = 13.29 \cdot OR^{1.283}$ (r^2=0.87, p<0.005).

A total of 1341 back-calculated lengths were estimated by both BC methods (Fraser-Lee, BPH), with very similar values between them and closed to the values of the ML at age based on DAE in the most abundant age groups (up to age 5) (Table 1). Unimodal distributions were found in the measures of the considered annual growth increments.

3.2.3. Length-frequency analyses

MPA of surveys was performed by sum of percentages of the length distribution for the time series to reduce the abundance influence of some extremely abundant years (Fig.4a). MPA of length distribution of commercial landings (first semester) was performed by absolute values for the time series pooled data (Fig.4b). ML of both sources showed closed values between them (Table 1).

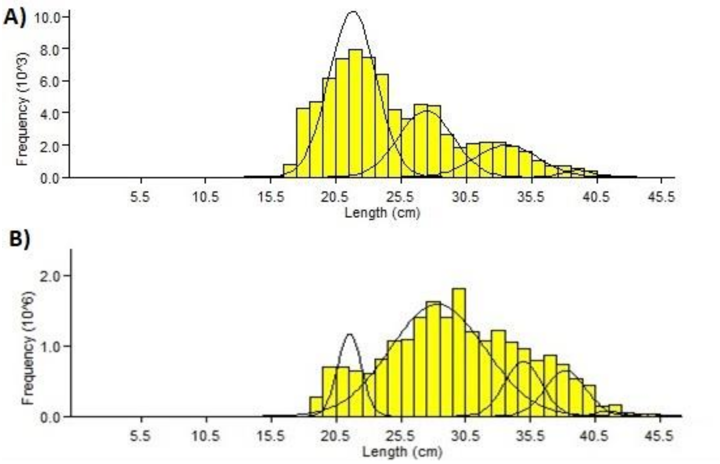


Figure 4. Plots obtained by Bhattacharya method (FISAT II) from A) relative values of length distributions from the six years pooled together (2011, 2013-2017) of the scientific surveys PELACUS; and B) absolute values of length distributions of the first semester from the seven years pooled together (2011-2017) of commercial landings. Rectangles: length classes frequencies; black lines: log-plots of the slopes between successive size-components

Regarding the Length Frequency Distribution Analysis (LFDA), the optimal growth parameters obtained by the program, based on the maximization of a goodness-of-fit function through iterations, were obtained by the PROJMAT method (Score: -0.983) for the survey data and by the SLCA method (Score: 6472) for the commercial landings data. The estimated ML are shown in Table 1.

3.3. Annual growth pattern and growth parameters

Two different growth patterns were obtained, with similar ML at ages 1 and 2, but divergent growth from age 3 (Table 1):

- A **slower growth pattern**, based on age estimation in otoliths (DAE and BC), showed similar ϕ' values (2.76-2.79) (Table 2), and no significant differences ($p>0.05$) between both growth curves according to the likelihood ratio test. The PROJMAT length-frequency analysis based on surveys data showed a ϕ' value of 2.77, a growth pattern close to that of DAE-BC, but with significant differences ($p<0.001$). Likelihood test showed no differences between the growth curves of both BC methods, and only BPH method was considered for the rest of the study in back-calculation.

- A **faster growth pattern**, from the length-frequency approaches performed by the Bhattacharya method (MPA), both for surveys and commercial landings, and by SLCA in commercial landings, all of them showing a ϕ' value of 2.86 and similar mean lengths at age (Table 1, Table 2). No significant differences ($p>0.05$) between Bhattacharya from landings and SLCA were found, but significant ones ($p<0.01$) in the other comparisons performed (Bhattacharya surveys-Bhattacharya landings; Bhattacharya surveys - SLCA).

Table 2. Growth parameters obtained by different methods in the present and previous studies of *S. colias* in the NE Atlantic. DAE: Direct age estimation; BC: Back-calculation; surv: surveys; land: commercial landings.

Author	Present study						Martins et al., 1983	Martins, 1996	Velasco et al., 2011	Carvalho et al., 2002	Vasconcelos, 2006		Lorenzo, 1992			Jurado-Ruzafa et al., 2017
Area	N & NW Iberian Peninsula						Portuguese coast	Portuguese coast	Gulf of Cadiz	The Azores	Madeira		The Canary Islands			Mauritanian waters
Years	2011-2012	2011-2017					1981-1982	1986-1995	Oct. 2003-Sept. 2004	1996-2002	2002-2003		1988-1990			2005-2011
Methodology	BC	DAE	Bhattacharya		PROJMAT	SLCA	BC	DAE	DAE-BC	DAE	DAE	ELEFAN	DAE	BC	Bhattacharya	BC
	surv + land	surv + land	surv	land	surv	land										
L_∞	**42.63**	**45.34**	**55.00**	**53.26**	**48.74**	**49.30**	53.83	58.52	43.00	57.52	50.08	38.00	50.69	49.22	49.22	48.40
K	**0.33**	**0.28**	**0.24**	**0.26**	**0.25**	**0.30**	0.17	0.10	0.27	0.20	0.25	0.50	0.21	0.21	0.22	0.25
t_0	**-0.96**	**-1.18**	**-0.77**	**-0.78**	**-0.87**	**-0.63**	-2.03	-3.68	-1.10	-1.09	-1.34		-1.45	-1.40		-1.51
ϕ'	**2.78**	**2.76**	**2.86**	**2.86**	**2.77**	**2.86**	2.7	2.55	2.7	2.82	2.8	2.86	2.73	2.71	2.73	2.76
n	**409**	**6867**					533	883	121	349	2115		878	538		163
ɜngth range (cr	**16-48**	**14-50**	**14-46**	**18-49**	**14-46**	**18-49**		16-54	16-43	9-56	13-41	13-41	4-42		4-48	12-49

4. DISCUSSION

The scarcity of updated and corroborated/validated information about the growth pattern and parameters in *S. colias* in the NE Atlantic makes the results here obtained very relevant because improve biological knowledge about this species as well as provide inputs for its future analytical assessment. *S. colias* stock assessment requires knowledge on the status of their populations in European Atlantic waters for sustainable fisheries and ecosystem management. The present study offers this updated and validated information on growth of *S. Colias*.

4.1. Direct age estimation, otolith marginal analyses, back-calculation and frequency of annuli radius analyses

The increasing of the ML at age between both semesters from DAE supports the age estimation criteria applied on otoliths age reading used here. This age estimation criterion is also supported by the consistency of the annual periodicity of formation of opaque and hyaline increments found, as a result of the otolith edge analysis. The predominance of opaque edge observed is in agreement with an overall geographical gradient from South to North observed in Iberian waters, starting its deposition in the Gulf of Cadiz from March/April to September/October (Rodriguez-Roda, 1982; Velasco et *al*., 2011), then Portugal from May to August (Martins et *al*., 1983) until the North western and North Iberian Peninsula from June to December (present study).

In relation to the back-calculation, the fish length-otolith radius relationship in *S. colias* showed a better fit to a power model in the present and previous studies (Lorenzo, 1992; Velasco *et al.*, 2011; Jurado-Ruzafa *et al.*, 2017). The unimodal distribution showed by the analysis of annuli radius frequency in addition to the back-calculation results also supports the consistency of the age estimation criteria used.

4.2. Length-frequency analyses

A general consistency was observed in the mean values estimated in both MPA analyses (surveys and commercial landings). Differences were found between our results based on the different length-frequency analyses and those obtained in previous studies using the same methods (Lorenzo, 1992; Vasconcelos, 2006), although differences in the time-series amplitude, sample size and length range analyzed among the studies can influence.

4.3. Annual growth pattern and growth parameters

The otolith edge, the back-calculation and the frequency distribution of annuli radius analyses performed in the present study, support the consistency of the age estimation in otoliths of *S. colias* based on ageing standardized criteria (“**slow” growth hypothesis**). Compared with previous studies, the “slow” growth pattern (DAE/BC) here obtained (ϕ‘: 2.76-2.78) is within the total range of ϕ` obtained for the species ($\phi$`: 2.55-2.82, mainly 2.70-2.80) (Table 2). Geographical and temporal differences, differences in the time series, sample size or length range analysed could explain the diversity of growth parameters among all studies.

However, our length frequency analyses results from MPA and SLCA (“**fast” growth hypothesis**) do not support the pattern observed in age estimation (from age group 2). Some difficulties have been already reported in the estimation of growth based on length frequencies in migratory pelagic species, as in the congener *S. scombrus*, where growth differences were found in relation to its annual migration (Dawson, 1986), what could also be relevant in *S. colias* when length frequency analyses are used. Furthermore, if the faster growth rate hypothesis here obtained by length frequency analyses is true, the age interpretation in otoliths would have to be biased due, for example, to the presence of checks that could be misinterpreted as true annuli. However, this seems to be quite unlikely due to the aforementioned evident and regular decreasing growth pattern of increment widths observed in *S. colias* otoliths.,

Taking into account all the aforementioned, and considering the Precautionary Principle of stock assessment, we recommend the use of the “slow” growth parameters in the upcoming stock assessment process, (DAE parameters: L_∞=45.34, k=0.28, t_0=-1.18). However, it would also be interesting to carry out some assay in the assessment model using the “fast” growth hypothesis (ej. SLCA parameters: L_∞=49.30, k =0.30, t_0=-0.63) to test the impact of differential growth in the assessment results, especially the impact of differences between both models in the cohort tracking.

Delivering more corroboration/validation studies on *S colias* growth in other areas, as well as providing updated growth information, will contribute to a more complete understanding of the growth of this species throughout its distribution area what is an essential input for analytical assessment models.

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