


# Modelling the growth of a protogynous sparid species, *Spondyllosoma cantharus* (Teleostei: Sparidae)

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**Abstract** Age determination of fish species is a key process for fisheries management and the accuracy of assessments is highly dependent on age estimates. To model complex life histories such as protogynous hermaphroditism, the growth curve to fit the age-length data should be carefully chosen. For the first time, the first annual growth increment of *Spondyllosoma cantharus* was validated and several growth functions were applied, in order to find the best growth model. *S. cantharus* specimens ranged from 2.1 to 38 cm total length and were aged from 0 to 17 years. For the growth functions applied, the hyperbolic modifications of von Bertalanffy curve showed the best fit to the data. Under this model, a change in growth occurs at 8 years, which corresponds to the average age for sex reversal in the species. Estimated total mortality was similar for the two years studied, varying between 0.65 and 0.69 year<sup>-1</sup>. Natural mortality was estimated by the updated Hoenig<sub>nl</sub>  $t_{\max}$ -

based estimator and the Pauly<sub>nl</sub>-T estimator, ranged between 0.26 and 0.37 year<sup>-1</sup>. Fishing mortality (0.28–0.43 year<sup>-1</sup>) and exploitation rate (0.43–0.62) were relatively high, indicating that although the species is not a main target its management needs careful attention.

**Keywords** Growth modelling · Hermaphroditism · Mortality · Von Bertalanffy curve modifications

## Introduction

Sustainability of marine resources relies on a secure stock assessment of marine fisheries. Age studies are very important when addressing a fish stock's population dynamics, as this information is critical for studying population characteristics such as growth, recruitment, mortality, and reproduction, and it is necessary for detailed studies on life history strategies and ecology can be carried out (Labropoulou & Papaconstantinou, 2000).

Most age studies involve the count of growth increments in hard body parts. Otolith formation involves seasonal variations in the deposition of organic matrix and carbonate crystals, resulting in the formation of macroscopic opaque and translucent zones (Morales-Nin, 2001), which promote the wide use of these structures for age assignment studies.

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The most used model for describing fish growth is the von Bertalanffy model (von Bertalanffy, 1938), which presuppose an equal growth parameter throughout life, and therefore does not take in account differences in energy allocation for reproduction and somatic activities at different life stages (Charnov, 2008). In sequential hermaphrodites, energy invested from maturing one type of gonads, sex transition and maturation of the second set of gonads will probably undergo several shifts. Also, for territorial protogynous species, size will be an advantage for territory protection and therefore an increased investment in growth will precedes the investment in reproductive output (Hoffman et al., 1985).

To model such complex life histories, the ideal curve to fit should be carefully chosen. Over the years, several authors have proposed modifications of the basic von Bertalanffy model, in order to accommodate smooth transitions between growth rates at a given moment of life, where the surplus energy is partially allocated to reproduction and partially to growth (Minte-Vera et al., 2016). To overcome possible ineffective growth modelling of species, different methods available on the literature should be tested and their adjustment to the data compared and the best model should be considered as an enhancement to parameters estimation.

Black seabream, *Spondyliosoma cantharus* (Linnaeus, 1758), is a sparid species with a distribution from Scandinavia to Angola, occurring in Madeira, Cape Verde, Canary Islands and in Mediterranean Sea. It is a gregarious species found over seagrass beds both in rocky and sandy bottoms, from depths <50 up to 300 m (Bauchot & Hureau, 1986). Black seabream is a protogynous hermaphrodite, with sex change from female to male occurring at various ages (Pajuelo & Lorenzo, 1999). Despite the large distribution range, little information exists on its biology, and no information on the stock structure is available. Information on the growth of the species is scarce and mainly available for the Tunisian coast (Mouine-Oueslati et al., 2015), Adriatic Sea (Dulčić & Kraljević, 1996), Canary Islands (Lorenzo & Pajuelo, 1997), and southern Portuguese coast (Abecasis et al., 2008). These studies have only applied the traditional version of the von Bertalanffy model, and no validation studies were ever attempted (even indirectly) on deposition of the first annulus. Mortality parameters for the species

are only available for the Canary Islands (Pajuelo & Lorenzo, 1999).

In order to gather information on *S. cantharus* for the Portuguese western coast, this study has 4 main goals: (1) estimate the size of the species at the end of the first year of life, and validate the first annual growth increment; (2) validate the assigned ages; (3) model the growth of the species; and (4) estimate natural and total mortality, in order to obtain an initial approximation of the exploitation level for this species.

## Materials and methods

### Sampling

Monthly samples were collected between April 2014 and June 2015 from commercial landings at Peniche, one of the main commercial ports on the Portuguese mainland (Fig. 1). Samples were taken from several gears: trawl, trammel net, traps, hooks, and lines. A summary of sampling methodology is given in Table 1.

In order to follow the first year cohort growth and establish the first annual growth increment, additional samples from Óbidos lagoon (Fig. 1) were collected from April to December 2014, using a beach seine. This lagoon, located on the West coast of Portugal ca 20 km from Peniche, is a shallow estuarine system, with a mean depth of 1.5–2 m (Gordo & Cabral, 2001) and is considered the largest coastal lagoon on the Portuguese coast.

Total length (TL, to the nearest 0.1 cm) and eviscerated weight (EW, to the nearest 0.01 g) were measured, and the *sagitta* otoliths (hereinafter mentioned as otoliths) were removed, cleaned with water, air dried, and stored in tagged vials. The gender of each fish was assessed by histological analysis of the gonad. For mortality estimates, length distribution of landings was recorded twice a month at Peniche from May 2014 to December 2015, covering a large number of boats operating with different fishing gears that capture the species.

### Length–weight relationship

The relationship between TL (cm) and EW (g) was calculated using a power function:



**Fig. 1** Map of sampling sites location on the Portuguese coast. *Black circle* indicates Peniche and *black square* indicates Óbidos Lagoon

**Table 1** Sampling strategy summary

	Sampling place	Sampling duration		Number of individuals sampled		Fishing gear
		2014	2015	2014	2015	
Ageing	Peniche and Obidos Lagoon	Mar–Dec	Jan–Dec	535	213	Tr; TN; Tp; H; L
Validation of first age growth increment	Obidos Lagoon	Apr–Dec		1342		BS
Length–Weight relationship	Peniche and Obidos Lagoon	Mar–Dec	Jan–Dec	547	213	Tr; TN; Tp; H; L
Mortality	Peniche	May–Dec	Jan–Dec	1749	1714	Tr

*Tr* trawl, *TN* trammel net, *Tp* traps, *H* hooks, *L* lines, *BS* beach seine

$$EW = a \times TL^b,$$

where  $a$  is the intercept and  $b$  is the allometric exponent. Allometry in growth was investigated by the Student's  $t$  test (Zar, 1996).

#### First annual growth increment validation

Length–frequency data obtained from Óbidos Lagoon samples were grouped into 1 cm intervals, from 2 to 13 cm, and evaluated by modal progression analysis (MPA). MPA infers growth from the apparent shift of the modes or means in a time series of length–frequency samples (Gayanilo et al., 2005). This analysis was performed with the Bhattacharya's

method using the routine in FAO-ICLARM Fisheries Assessment Tools (FiSAT II version 1.2.2) software (Gayanilo et al., 2005). The Bhattacharya method is based on approximating the assumed normal curve of a length–frequency distribution as a parabola, which is then converted to a straight line with the form:

$$dt(\ln[N]) = a + b(L),$$

where  $dt(\ln[N])$  is the difference between the natural logarithms of the number in one length class and the number in the preceding length class, and  $L$  is the upper limit of the preceding length class. The Bhattacharya plot is a graphical method of separating a length–frequency distribution into a series of normal distributions or pseudo-cohorts (King, 2007).

An image from the right otolith of 230 individuals, ranging from 2.6 to 13.0 cm TL, was captured at  $\times 40$  magnification using a visual image analysis system (Leica DFC 290). The radius of each otolith was recorded using ImageJ software 1.48v (available at <http://imagej.nih.gov/ij/>, Rasband, 1997–2016), measured from the nucleus towards the edge of the posterior region. The relationship between fish TL and otolith radius was investigated, in order to estimate the width of the first annual growth increment.

#### Ageing methodology, precision and bias

Right otoliths were read immersed in 1:1 glycerine–ethanol blend, under reflected light against a dark background to enhance the differentiation of annual increments, with a  $\times 18$  magnification. The annual periodicity of annuli formation was validated through Marginal Increment Ratio (MIR) (Samamé, 1977). If the increments are annual, the mean width of the latest increment (normalised by the otolith radius) will follow a periodic trend across the year (Panfili & Morales-Nin, 2002).

Ageing was performed with the *sulcus acusticus* side down and towards the posterior region of otoliths. A subsample of 186 otoliths (10 by 1 cm length classes, whenever possible) was read by two of the authors to find an interpretation pattern and ensure consistency (Campana, 2001). Readings were compared through the average percentage error (APE) (Beamish & Fournier, 1981), the coefficient of variation (CV) (Chang, 1982), and the percentage of perfect agreement (PAgree). Bias was evaluated based on age-bias plots (Campana et al., 1995), which allow an insight on departures from the 1:1 equivalence line, and systematic differences on assigned ages between readers were assessed with the Bowker-type test for symmetry (Hoenig et al., 1995). Since the achieved agreement between readers was good, the remaining otoliths were read twice by the first author. A third reading was performed for all divergent readings and if this differed from the previous two, the otolith was discarded.

#### Growth models

Beside the typical von Bertalanffy curve, biphasic models and the five parameter von Bertalanffy model were fitted to length-at-age data for *S.*

*cantharus* (Table 2). Biphasic models include a hyperbolic function that modifies either  $L_{\infty}$  or  $K$  as age increases (Soriano et al., 1992); the five parameter von Bertalanffy model allows a modification on growth rate at some moment of the lifespan (Alós et al., 2010). Models were implemented in R (cran.r-project.org), using the packages FSA (Ogle, 2016) and nlstools (Baty et al., 2015), and were compared using the Akaike Information Criterion (AIC, Akaike, 1973).

#### Mortality

Total instantaneous mortality rate,  $Z$ , was estimated using the Chapman–Robson mortality estimator (Chapman & Robson 1960), with the first age group used being 1 year older than the age of peak abundance. According to Smith et al. (2012), this is the preferred estimator for age–frequency simulation data. Only data from trawl landings were used (1749 records from 2014 and 1714 from 2015), since this gear represents more than 60% of total landings. To estimate the instantaneous natural mortality rate ( $M$ ), the updated Hoenig<sub>nl</sub>  $t_{\max}$ -based estimator,  $M = 4.899 \times t_{\max}^{-0.916}$  and the Pauly<sub>nl-T</sub> estimator,  $M = 4.118 \times K^{0.73} \times L_{\infty}^{-0.33}$ , were used (Then et al., 2015). Temperature was not included in Pauly's equation since it did not appear to bring any information to the model (Gislason et al., 2010; Then et al., 2015). Fishing mortality ( $F$ ) and exploitation rate ( $E$ ) were estimated as  $F = Z - M$  and  $E = F/Z$ . Mortalities were estimated using the R package FSA (Ogle, 2016).

## Results

#### Length–weight relationship

Among the 758 individuals examined, 174 were immature, 312 were female, 3 were bisexual, and 268 were male. Total length ranged between 2.6 and 13.1 cm (mean  $8.2 \pm 1.8$  cm), 9.1–33.2 cm (mean  $22.6 \pm 3.3$  cm), 20.9–23.9 cm (mean  $22.8 \pm 1.7$  cm), and 20.0–38.0 cm (mean  $27.6 \pm 3.5$  cm), respectively. Eviscerated weight varied between 0.19 and 33.2 g (mean  $8.0 \pm 5.7$  g), 9.67–504 g (mean  $164.3 \pm 74.4$  g), 140–210 g (mean  $177.0 \pm 35.0$  g), and 115–841 g (mean  $309.9 \pm 131.6$  g), respectively.

**Table 2** Models fitted to length-at-age data for *Spondyliosoma cantharus*

Model	NP	Equation
VBGF	3	$TL = L_{\infty} \times (1 - \exp(-K \times (\text{Age} - t_0)))$
VB-hyper $L_{\infty}$	5	$TL = L_{\infty} \times \left(1 - \left(\frac{h}{((\text{Age} - t_h)^2 + 1)}\right)\right) \times (1 - \exp(-K \times (\text{Age} - t_0)))$
VB-hyperK	5	$TL = L_{\infty} \times \left(1 - \exp\left(-K \times \left(1 - \left(\frac{h}{((\text{Age} - t_h)^2 + 1)}\right)\right) \times (\text{Age} - t_0)\right)\right)$
5 VBGF	5	$TL = \begin{cases} L_{\infty} \times (1 - \exp(-K_0 \times (\text{Age} - t_0))) & \text{if } \text{Age} < t_1 \\ L_{\infty} \times (1 - \exp(-K_0 \times (\text{Age} - t_0) - K_1 \times (\text{Age} - t_1))) & \text{if } \text{Age} \geq t_1 \end{cases}$

VBGF von Bertalanffy growth function, VB-hyper  $L_{\infty}$  hyperbolic modification of von Bertalanffy growth function for  $L_{\infty}$ , VB-hyperK hyperbolic modification of von Bertalanffy growth function for K, 5 VBGF five parameter von Bertalanffy growth function, NP number of parameters estimated,  $L_{\infty}$  is the maximum asymptotic length,  $K$  is the relative growth rate,  $t_0$  is the theoretical age for time at which length is zero,  $h$  is an expression of the difference between each phase in the growth curve,  $t_h$  and  $t_1$  are the age at which the nature of the curve changes,  $K_1$  is the relative growth rate for the second phase of life

Black seabream showed a strong relationship between TL and EW ( $r^2 = 99.7$ ) expressed by the equation:  $EW = 0.0073 \times TL^{3.1944}$ . This species shows a positive allometric growth ( $t$  test = 10.3,  $df = 758$ ,  $P < 0.001$ ).

#### First annual growth increment validation

A total of 1342 individuals, ranging from 2.1 to 13.6 cm TL, were collected during the sampling period. MPA detected three cohorts in Óbidos Lagoon (Fig. 2a). Larger individuals were sporadic (only 2% above 10 cm), suggesting that individuals stay in the lagoon mainly for the two first years of life. On average, black seabream individuals had reached  $7.8 \pm 0.9$  cm TL by the end of their first year of life.

Body and otolith size followed a positive linear relationship (Fig. 2b,  $r^2 = 94.6$ ) which allowed the estimation of the first annual growth increment width at  $1.65 \pm 0.16$  mm.

#### Ageing methodology, precision, and bias

The deposition pattern of growth increments varied with otolith size: typically the first three increments were wider, becoming thinner, and closer together with age. For some individuals, the first growth increment was not clearly marked. MIR analyses showed an annual pattern in growth increment formation, with an increasing trend from January to July of the marginal increment followed by a decreasing trend (Fig. 3). The highest values of MIR occurred between

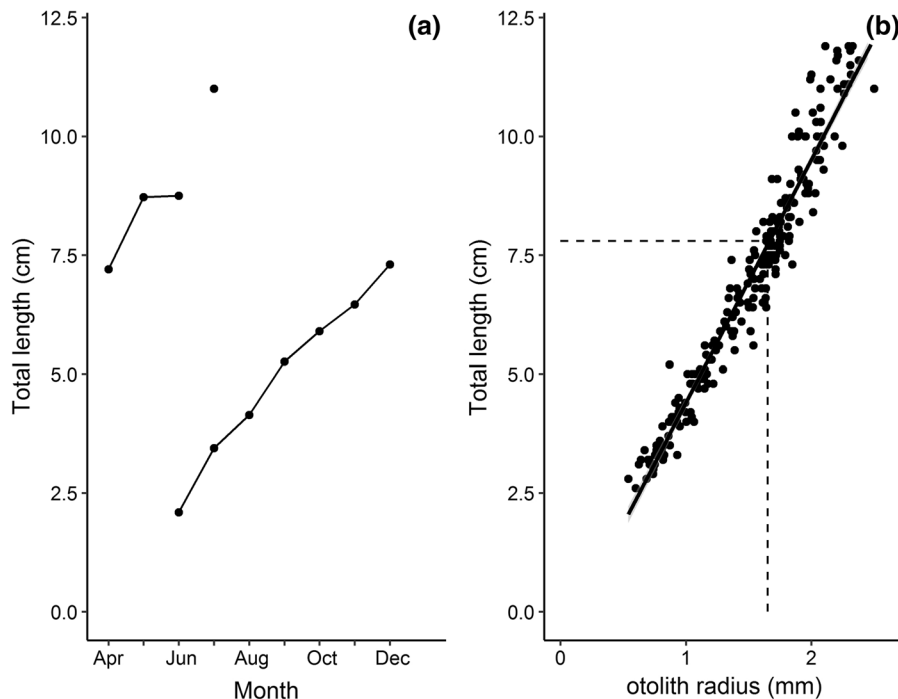
May and September, which points this as the period when new increments are formed.

Indices of precision within and between readers (Table 3) revealed a fair precision of age readings. Age-bias plots (Fig. 4) and the test of symmetry ( $\chi^2_{R1} = 20.1$ ,  $df = 18$ ,  $P = 0.3248$ ;  $\chi^2_{R1vsR2} = 21.2$ ,  $df = 16$ ,  $P = 0.1709$ ) showed a random error pattern for age disagreement between readers.

#### Growth models

For age estimation, 188 immature individuals (2.8–12.8 cm TL), 301 females (9.1–33.2 cm TL), 3 bisexuals (20.9–23.9 cm TL), and 256 males (19.6–38 cm TL) were used. Only 2.2% individuals showed non-interpretable otoliths. Age assignments varied from 0 to 17 years. The frequency composition of TL and age are shown in Fig. 5.

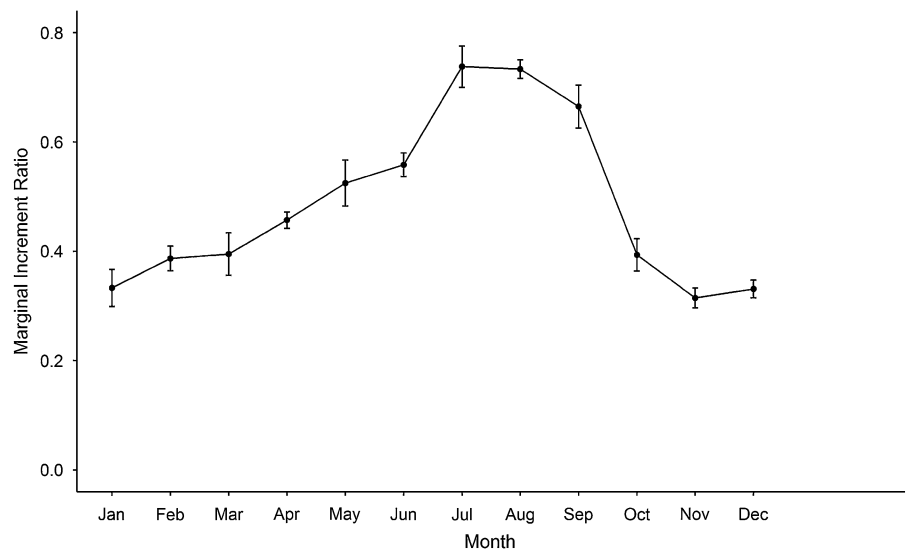
Uniphasic and biphasic versions of von Bertalanffy growth function were fitted to length-at-age data for *S. cantharus*. Biphasic models provided better fits to the data than the uniphasic model, as they presented lower AIC (Table 4). The best models were the hyperbolic modifications of von Bertalanffy curve, both with very similar estimates for the parameters and pointing for a change in growth strategy to occur during the eighth year ( $t_h = 7.46$ – $7.51$ ), corresponding to a TL around 24.5 cm. The five parameter von Bertalanffy curve provided an unrealistic estimate for  $L_{\infty}$ , since it was lower than the largest individual sampled. Moreover, the age estimated for the change of growth pattern appears to be overestimated by this model.



**Fig. 2** **a** Bhattacharya plot for length–frequency data of black seabream, *Spondylosoma cantharus*, obtained from Óbidos Lagoon and **b** relationship between total length (TL) and otolith

radius (OR) from black seabream, *S. cantharus*, sampled in Óbidos Lagoon. Solid line is the linear regression, dashed lines correspond to values of TL and OR for the first year of life

**Fig. 3** Monthly evolution of marginal increment ratio (MIR) in otoliths of black seabream, *Spondylosoma cantharus*, from the Portuguese continental waters. Dots are the mean values and whiskers are  $\pm$  standard error



### Mortality

Total mortality was estimated for two years:  $Z_{2014} = 0.65 \pm 0.06$  and  $Z_{2015} = 0.69 \pm 0.05$  year<sup>-1</sup>. Estimated natural mortality ranged between 0.26 year<sup>-1</sup> (Pauly<sub>nls-T</sub> estimator) and 0.37 year<sup>-1</sup> (Hoenig<sub>nls</sub>  $t_{\max}$ -

based estimator). Estimates of fishing mortality varied between 0.28 and 0.39 year<sup>-1</sup> for 2014 and 0.32–0.43 year<sup>-1</sup> for 2015. The exploitation rate was very similar for both years, with values between 0.43 and 0.60 and 0.46 and 0.62 for 2014 and 2015, respectively.

**Table 3** Indices of precision for age readings of black seabream, *Spondyliosoma cantharus* within and between readers

Index	Index comparison (%)	
	Reader 1	Between Readers
APE	1.89	2.14
CV	2.67	3.03
PAgree	75.6	77.3

APE is the mean percentage error, CV is the mean coefficient of variation and PAgree is the percentage of perfectly agreement

## Discussion

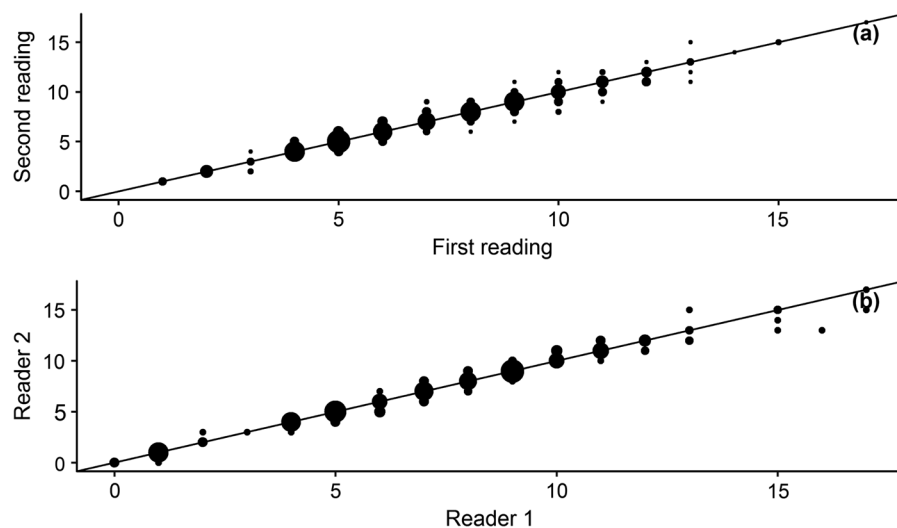
*Spondyliosoma cantharus* is a protogynous hermaphrodite species and all analyses were conducted over the entire sample, without sex sorting. However, it is likely that some individuals spent most of their life with a single sex, since males of 20 cm were found and females sampled reached almost 34 cm.

This species showed a positive allometric growth on the Portuguese western coast, as already noticed for the Canary Islands (Pajuelo & Lorenzo, 1999), Algeria (Derbal et al., 2010; Boughamou et al., 2015), Tunisia (Mouine-Oueslati et al., 2015), and the Adriatic Sea (Dulčić & Kraljević, 1996). Bilge et al. (2014) found a negative allometry for the black seabream population in Aegean Sea, but the small sample (79 individuals)

and narrow length range analysed (8.6 to 18.7 TL) might justify the opposite result for this area.

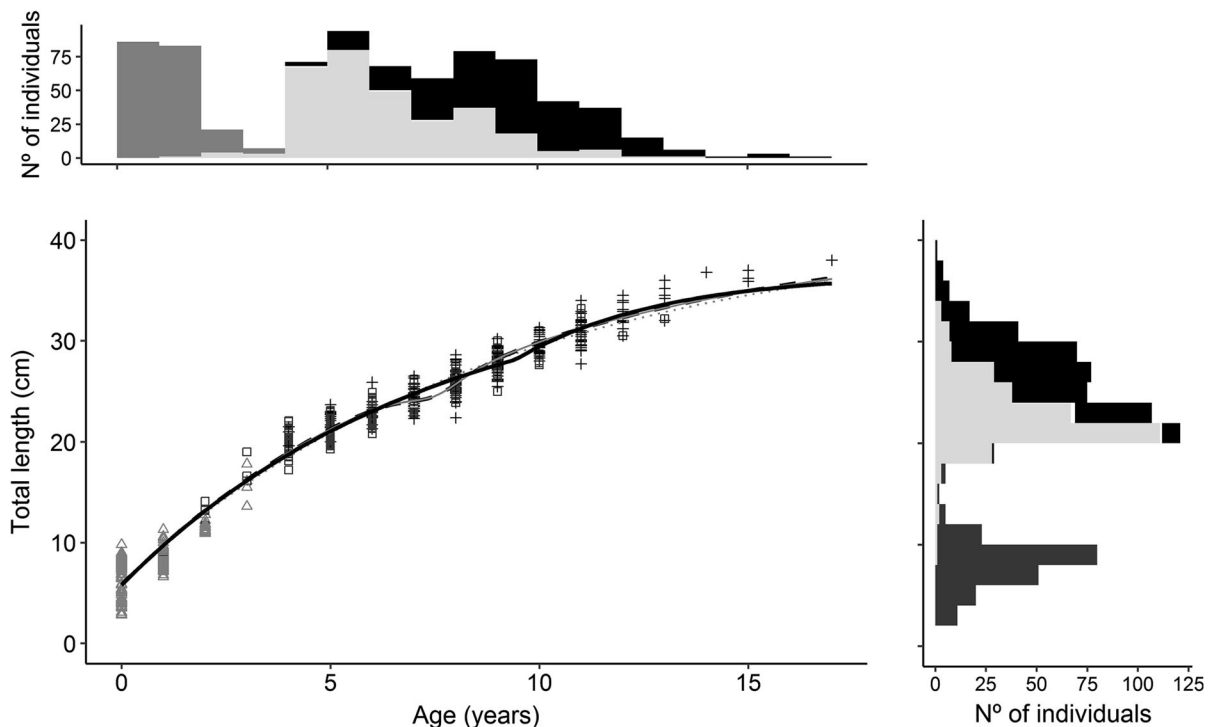
The age estimation of fish species is fundamental for the accuracy of assessments in fisheries management. It is therefore essential that age estimates will be as accurate as possible. One important component of any age validation study is the identification of the first annual growth increment (Campana, 2001). From the several age validation methods, only a subsample possess, in practice, the necessary precision to be used in the identification and validation of the first annual growth increment (Campana, 2001). Release of known age or chemically marked young-of-the-year fish, modal progression, and daily increment counts are the most suited for this type of application (Campana, 2001). In this study, the modal progression was used to validate the first annual growth increment by following the first year cohort in Óbidos Lagoon. Individuals reached their first year of life with a mean size of  $7.8 \pm 0.9$  cm TL and an otolith radius of  $1.65 \pm 0.16$  mm. The validation of first annual growth increment is important to understand the pattern of deposition of growth increments, especially since this first growth increment was not always well defined, possibly due to the longer or shorter permanence of the fish in the lagoon.

Otolith edge analysis demonstrated that black seabream deposited one annulus per year, showing a clear larger increment during the summer months.



**Fig. 4** Age-bias plots for the readings comparisons within (a) and between (b) readers for black seabream, *Spondyliosoma cantharus*. The 45° line represents 100% agreement and dot size represents number of observations





**Fig. 5** Frequency distribution of the observed TL and age and fit of the four growth models to the black seabream, *Spondyliosoma cantharus*, data. Dark grey and triangles are juveniles, light grey and squares are females, and black and plus

symbol are males. Grey dotted line is the typical von Bertalanffy curve; black dashed line is  $L_{\infty}$  hyperbolic biphasic model; grey solid line is K hyperbolic biphasic model; and black solid line is five parameter von Bertalanffy model

**Table 4** Summary of von Bertalanffy growth parameters resulting from the four models fitted to black seabream, *Spondyliosoma cantharus*, data

Parameters	VBGF	VB-hyper $L_{\infty}$	VB-hyperK	5 VBGF
$L_{\infty}$ (cm)	41.19 (0.7383)	40.66 (0.6325)	40.49 (0.6352)	36.16 (0.8441)
$K$ (years <sup>-1</sup> )	0.11 (0.0040)	0.12 (0.0040)	0.12 (0.0041)	0.14 (0.0064)
$t_0$ (years)	-1.41 (0.0512)	-1.26 (0.0399)	-1.27 (0.0465)	-1.25 (0.0502)
$h$	na	0.07 (0.0077)	0.12 (0.0130)	na
$t_h$ (years)	na	7.46 (0.0871)	7.51 (0.0854)	na
$K_1$ (years <sup>-1</sup> )	na	na	na	0.13 (0.0385)
$t_1$ (years)	na	na	na	8.73 (0.1827)
AIC	2638.94	2557.74	2560.91	2600.74
$\Delta$ AIC	81.20	0.00	3.17	43.00

Standard error of parameters is given in parenthesis. AIC is the Akaike Information Criterion;  $\Delta$ AIC is the rescaled information criterion.  $\Delta$  AIC valued as zero indicates the most appropriate model

There was a small number of rejected otoliths and the precision obtained both within and between readers was much better than the reference values (CV < 7.6% and APE < 5.5%) suggested by Campana (2001). Hence, the otolith structure of the black seabream allows an adequate identification of its

growth pattern. Nevertheless, the discrepancies found in the literature, with assigned ages varying between 7 years for a 35 cm specimen (Boughamou et al., 2015) and 17 years for a 38 cm specimen (this study), point to a need to improve age reading methods and age determination between different research groups.



For the first time, several growth models were applied to *S. cantharus* age–length data. Ontogenetic transitions such as sex change can disrupt energy allocation, such that the period before and after the change become identifiable as distinct life phases (Higgins et al., 2015). It is therefore important to search alternative methodologies to better understand growth in such species. In the present study, the hyperbolic modifications of von Bertalanffy curve showed the better fit to the data. The estimated von Bertalanffy  $K$ ,  $0.12 \text{ year}^{-1}$ , was lower than those reported for the species in the Canary Islands ( $0.23 \text{ year}^{-1}$ ; Lorenzo & Pajuelo, 1997), southern Portugal ( $0.21$  and  $0.26 \text{ year}^{-1}$ , estimated for scales and otoliths readings, respectively; Abecasis et al., 2008), Algerian eastern coast ( $0.52 \text{ year}^{-1}$ ; Boughamou et al., 2015), and Adriatic sea ( $0.18 \text{ year}^{-1}$ ; Dulčić & Kraljević, 1996), but similar to those reported for Tunisian coasts ( $0.10$ – $0.14 \text{ year}^{-1}$ ; Brađai et al., 1998; Mouine-Oueslati et al., 2015). Although it is natural for species to show different growth patterns for each region, due to environmental/habitat characteristics, the differences reported between geographic areas may also reflect divergences in species ageing.

The estimated age at which the curve changes shape corresponds to the average time at which black seabream undergoes sex reversal (Neves, unpublished data). This observed deceleration in growth is probably caused by the allocation of energy towards the development and maturation of new gonadal tissue.

In stock assessment models, the mean length and variation of length in particular for the oldest ages are highly influential on the estimated fishing mortality and abundance levels (Maunder & Piner, 2015). Therefore, it is important to improve the performance of growth models and get the growth curve correct for the greater ages (Minte-Vera et al., 2016).

Most studies on mortality estimation use catch-curve analysis, which assumes the following: a) constant recruitment and mortality after fish enter the fishing area (recruitment age), being the specimens then equally vulnerable to fishing and sampling; and b) no age estimation errors (Ricker, 1975). These assumptions are unlikely to be met. Some attempts have been made to verify the performance of catch-curve mortality estimators in response to several error types in simulated scenarios, and in most scenarios the better performance was achieved by Chapman–

Robson estimator (e.g. Dunn et al., 2002; Murphy 1997; Smith et al., 2012). In the present study, we assume that the black seabream population is in equilibrium with no significant variation in recruitment or mortality across time, and we attempt to minimise age estimation errors by following precision and bias methodology. *S. cantharus* is caught by multiple fishing gears, but only trawl, the most representative one, was used for the mortality study, since the number of individuals caught by other gears was low and variable along the year. Trawl selectivity is generally characterised by logistically shaped curves (e.g. Huse et al. 1999; Zuur et al. 2001), but a knife-edge selectivity was assumed, according to the above-mentioned assumptions. The estimated  $Z$  values were very similar for the two years analysed, whereas  $M$  presented some variation depending on the method used. This was expected since according to Then et al. (2015), the Hoenig<sub>nlis</sub> model gives generally higher  $M$  estimates than the Pauly<sub>nlis-T</sub> method for stocks that experience  $M$  rates higher than  $0.2 \text{ year}^{-1}$ . Although several authors defend that estimates of  $M$  should take variations over age and size into account (e.g. Gillsason et al., 2010; Johnson et al., 2015), a single value for  $M$  can provide a useful representation of mortality and the assumption of a constant  $M$  in stock assessments is still very useful (Then et al., 2015).

The estimated values for  $Z$  and  $M$  in this study were much lower than the ones reported for the Canary Islands (Pajuelo & Lorenzo, 1999), even though both areas presented high exploitation rates. Although this species is not a main target for a specific fishery, it is caught by several fishing gears that operate near the coast. These non-selective gears catch individuals of different populations from the ecosystem and may lead to an overfishing of some species.

This species has a 23 cm (TL) minimum legal size ruled in the Portuguese fishery (DGRM, 2016), which is above the estimate of size at 50% maturity for the species females for the Portuguese coast (Gonçalves & Erzini, 2000). However, 24% of the specimens landed in Peniche were smaller than the minimum legal size. As mentioned above, most landings of black seabream come from trawl fisheries, which have as target species mainly the horse mackerel, *Trachurus trachurus* (Linnaeus, 1758), Atlantic chub mackerel, *Scomber colias* Gmelin, 1789, Atlantic mackerel, *Scomber scombrus* Linnaeus, 1758, pouting, *Trisopterus luscus* (Linnaeus, 1758), and European hake, *Merluccius*

*merluccius* (Linnaeus, 1758) (Campos et al., 2007). These species have smaller minimum landing sizes, varying from 15 to 20 cm (DGRM, 2016), which explains the large number of small black seabream landed.

In protogynous species such as *S. cantharus*, the overfishing scenario can be even more problematic since the catch can truncate size distributions and at an extreme, virtually remove males from the population and thus lead to the population collapse by sperm limitation (Alonzo & Mangel, 2004). In the Portuguese coast, it seems that smaller individuals, consisting mostly of females, are the most vulnerable to the fishery. The overexploitation of these smaller individuals will affect the reproductive potential, with a negative impact for the stock. As referred by Gonçalves & Erzini (2000) more than a change in the legal minimum fish length, there needs to be a reinforcement of the actual legislation, in order to obtain a sustainable management of this species. Studies on short-term hooking mortality showed a low percentage of dead after release for black seabream juvenile individuals (Veiga et al., 2011). This suggests that if individuals under the minimum legal size were released, the rate of survival would probably be high. Enhanced fishermen awareness on this subject is called for, to better preserve this species.

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