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The growth of the common two-banded seabream, *Diplodus vulgaris* (Teleostei, Sparidae), in Canarian waters, estimated by reading otoliths and by back-calculation

By J. G. Pajuelo and J. M. Lorenzo

Departamento de Biología, Universidad de Las Palmas de Gran Canaria, Campus Universitario de Tafira, Las Palmas de Gran Canaria, Canary Islands, Spain

Summary

The yearly nature of increment formation in the otoliths of 1–9-year-old seabream, *Diplodus vulgaris* (E. Geoffrey Saint-Hilaire 1817), from the Canary Islands was validated. The marginal increment method showed that the opaque rings were formed in summer, and the translucent rings in winter. The Brody Proportional Hypothesis and the power length–radius relationship used to back-calculate the growth trajectories of *D. vulgaris* showed that this growth model could provide reasonable growth estimates in this species. Growth back-calculation and growth estimates obtained by direct otolith readings were similar. Data on age and size used to estimate the parameters of the von Bertalanffy growth model for *D. vulagris* from the Canary Islands showed that males and females had similar growth rates.

Introduction

In the Canary Islands, members of the family Sparidae are very common and represented by 24 species (Brito, 1991). In this region, sparids are subject to a high commercial exploitation and constitute the main target family of small-scale demersal fisheries (Pajuelo, 1997).

The common two-banded seabream, *Diplodus vulgaris* (E. Geoffrey Saint-Hilaire 1817), is a demersal sparid fish commonly found in the Canarian Archipelago. This species is widely distributed in the Eastern Atlantic, from France to South Africa and around the Canary, Cape Verde and Madeira islands, and is also common in the Mediterranean and Black seas (Bauchot and Hureau, 1990). It generally forms schools that occupy various habitats constituted of rocks, sand and seagrass beds, at depths ranging from 0 to 150 m. In the Canarian Archipelago this species is characterized by a rudimentary hermaphroditism with a low proportion of protandry sex reversal.

In the Canary Islands, the common two-banded seabream is caught mainly with traps deployed on the sea bottom at depths ranging from 1 to 100 m. This species is captured throughout the year with significant seasonal differences in the landings; highest catches are in the winter months and the lowest in the summer months (Pajuelo, 1997). No bag limits are currently imposed on its fishery.

Data on growth are important for fisheries management (Pauly, 1983). Unfortunately, information published on the growth of the common two-banded seabream is very scarce and limited to the Mediterranean Sea (Girardin, 1978; Gordoa and Molí, 1997). This study investigates the aspects of age and growth of the common two-banded seabream off the Canary Islands, important for the management of the fishery.

Materials and methods

A total of 624 individuals of the common two-banded seabream were collected from commercial catches off the Gran Canaria Island (Canary Islands, Central-east Atlantic, 27°57′24″N–15°35′23″W) between April 2000 and March 2001 (Table 1). Total length (TL, mm) and total weight (W, 0.1 g) of each individual were measured. The individuals were sexed by macroscopic examination of the gonads as males, females, immatures and intersexual (individuals with ovarian and testicular tissues developed simultaneously). Sagittal otoliths were removed, cleaned and stored dry in code-numbered envelopes.

Otoliths were immersed in a solution of alcohol and read whole under a compound microscope at 10× magnification using reflected light. Opaque rings from the nucleus to the margin were counted along the longest axis of the otolith. As a rule, each otolith was read twice by the senior author, and only coincident readings were accepted. The index of average percentage error (IAPE), developed by Beamish and Fournier (1981), was used to evaluate the precision of age determinations. Low values of the index indicated a good precision of age estimation.

To determine the periodicity in the formation of the rings, the marginal increment method was applied. This method is based on estimating the marginal increment of the otolith of each fish for age class and estimates the profile of the mean monthly marginal increment. The marginal increment (MI, 0.01 mm) was measured as the distance from the inner margin of the outermost translucent ring to the periphery of the otolith. Measurements were always made along the longest axis. The marginal otolith increment increases when an opaque band forms and drops to zero when a new translucent band begins to form. If increments are formed yearly, the mean marginal increment over time should show one mode and the peak should correspond to the time the yearly opaque ring formed; in this case, the age corresponds to the increment. The size of the growth zone varies both with time of sampling during the year and the age of the fish. Because younger fish grow faster than older individuals, a larger marginal increment is expected. For this reason, quantitative marginal increment

Table 1
Month sample size, mean length and mean weight for all fish of *D. vulgaris* off the Canarian Archipelago (April 2000–March 2001)

Month	Sampling size	Length			Age		
		Mean	SD	Range	Mean	SD	Range
April 2000	43	178	42.35	128–308	1.4	0.66	1–6
May 2000	71	210	61.52	128–343	2.2	0.83	1–8
June 2000	63	178	24.11	154–277	1.5	0.54	1–4
July 2000	89	191	54.83	131–365	2.1	0.91	1–9
August 2000	40	204	29.58	160–300	2.2	0.70	1–6
September 2000	32	206	28.67	163–262	2.1	0.55	1–4
October 2000	57	193	17.73	165–250	1.9	0.53	1–4
November 2000	36	195	31.80	165–282	1.8	0.68	1–5
December 2000	43	201	21.52	174–286	1.8	0.52	1–5
January 2001	34	185	40.61	171–272	1.7	0.62	1–4
February 2001	51	183	52.42	168–298	1.6	0.71	1–5
March 2001	39	162	38.83	140–272	1.3	0.57	1–4

analyses should be standardized for age. Our study was therefore carried out by age class. Because of the wide range of ages encountered, however, there were insufficient samples to accomplish this standardization fully. It was necessary to combine the ages in two or more age groups representing fast, moderate and slow-growing individuals.

Once rings were confirmed as annual, each fish was aged and assigned a year class taking into account the date of capture, the annuli formation period, and the reproductive biology of the species in the area, with a spawning peak between December and January. Thus, 1 January was considered as the birth date. The von Bertalanffy growth curve was fitted to data of the resulting age–length key by means of Marquardt's algorithm for non-linear least squares parameter estimation (Saila et al. 1988). The growth performance index (Φ), developed by Pauly and Munro (1984), was used to compare the values of the growth parameters obtained in the present paper with those values reported by other authors for the same species (Pauly and Munro, 1984). This index allows comparison of the growth performances of fish in terms of length growth.

Back-calculation analysis was undertaken using a body proportional hypothesis applied to a power relationship between fish length and otolith radius (Francis, 1990). The radius of the *i*th band (Ri, 0.01 mm), which is the distance from the centre of the otolith to the outer margin of the translucent ring, and the radius of the otolith at capture (Rc, 0.01 mm), which is the distance from the centre of the otolith to the periphery, were measured. Measurements were always made along the longest axis of the otolith. The relationship between the radius of the otolith (R) and the total length was estimated as a power function. It was estimated by fitting the data by regression of log (TL) on log (R), consistent with the body proportional hypothesis (BPH). The length of an individual when the *i*th band was laid down (Li, mm) was calculated as $\mathrm{Li} = (\mathrm{Ri}/\mathrm{Rc})^{v}\,\mathrm{Lc}$, where Lc is the length at capture and v is a constant derived from the power function which describes the relationship between the radius of the otolith and the total length of the fish (Francis, 1990). The von Bertalanffy growth curve was fitted to the back-calculated mean length-at-age by applying Marquardt's algorithm for non-linear least squares parameter estimation (Saila et al., 1988).

Results

The number, mean, maximum, minimum and SD values of the total length and total weight for immatures, males, females and intersexual individuals are presented in Table 2. Similar length ranges, and similar length-at-age were observed for males and females. No significant differences were found between males and females in mean size (Student's t-test, $t = 0.97 < t_{0.05,493} = 1.65$) or weight (Student's t-test, $t = 1.45 < t_{0.05,493} = 1.65$).

Of the total otoliths examined, 519 (83.2%) yielded useful age estimates, with 105 (16.8%) discarded because they were either broken or difficult to interpret. The concentric pattern of opaque and translucent zones was readily distinguishable in the otoliths and easily interpreted. The low value of the IAPE (4.8%) indicated high precision in the ageing.

The profile of the mean monthly marginal increments in otoliths with one translucent ring (n = 213), two and three translucent rings (n = 220), and more than three translucent rings (n = 55) is shown in Fig. 1. The same pattern was observed for the three categories. The values increased from April to July, reached a peak and then decreased from July to September and stabilized at low values for the entire winter. Thus, irrespective of the number of translucent rings in the otoliths, one mode was observed during the 12-month period.

Table 2
Number, mean, maximum, minimum and SD values of the total length and total weigth for immatures, males, females and intersexuals individuals of *D. vulgaris* off the Canarian Archipelago (April 2000–March 2001)

	Length (mm)			Weight (g)			n
	Min.	Max.	Mean (±SD)	Min.	Max.	Mean (±SD)	
Males	131	360	192 ± 42.7	43.7	805.3	140 ± 121.1	228
Females	140	365	202 ± 46.8	47.1	892.3	171 ± 145.1	267
20 Intersexual	178	250	197 ± 20.4	100.3	280.2	162 ± 16.1	16
Immatures	128	201	162 ± 16.1	36.8	154.2	77.4 ± 25.5	113

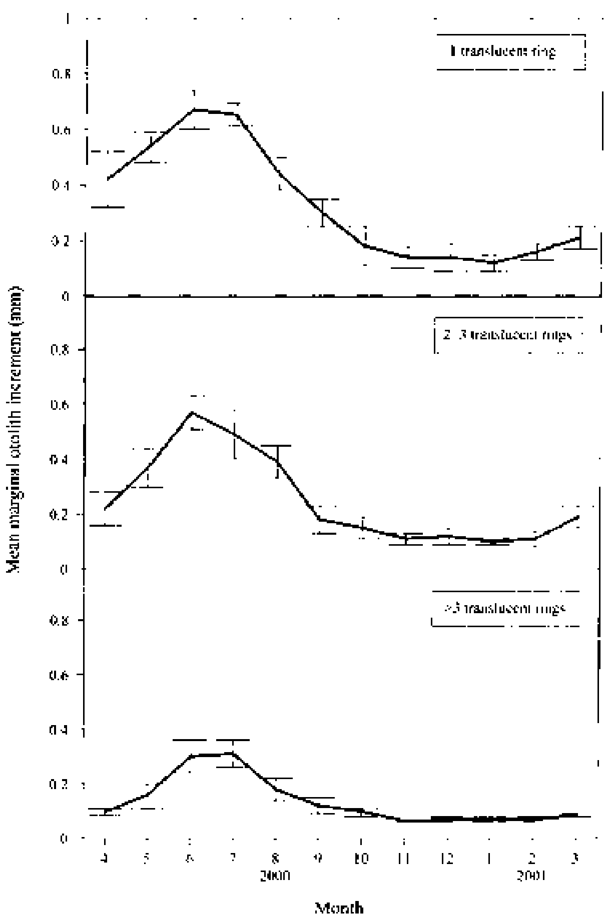

Fig. 1. Mean monthly evolution of the marginal increment in the otoliths of *D. vulgaris* off the Canarian Archipelago (April 2000–March 2001)

Therefore, it was assumed that each translucent ring represented an annulus with a year's growth represented by an opaque ring and an adjacent hyaline ring. Yearly increments were observed for males, females, intersexual and immature fish.

Fish 1–9 years of age were observed in the samples (Table 3) respectively, male mean = 2.1; SD = 0.66 and female mean = 2.2; SD = 0.61. Intersexual individuals ranged in age from 2 to 4 years (mean = 2.5; SD = 0.20). Immature fish ranged in age between 1 and 2 years (mean = 1.2; SD = 0.11). No significant differences were found between the mean age of males and females when using a Student's *t*-test ($t = 0.83 < t_{0.05,486} = 1.65$).

Fish total length and otolith radius were closely correlated (Fig. 2). The value of $v = 0.709$ was different from 1 (Student's *t*-test; $t = 2.34 > t_{0.05,486} = 1.65$). The observed length-at-age, the curve estimated from the observed length at age, the mean back-calculated length-at-age and the curve estimated from the mean back-calculated length-at-age are shown in Fig. 3. The estimated length-at-age was slightly higher than mean back-calculated lengths for individual age groups; however, the error values indicated that the back-calculated model did not underestimate the fish length.

The von Bertalanffy growth parameters estimated by reading otoliths for all fish were: $L_\infty = 397$ mm; $k = 0.231$ year^{-1}; $t_0 = -0.908$ year^{-1}($r^2 = 0.953$; n = 488). No significant differences in the growth parameters were found between males and females (Hotelling's T^2-test; $T^2 = 5.53 < T^2_{00.05,3,432} = 7.89$). The value of the growth performance index obtained for all individuals was $\Phi = 4.56$. The von Bertalanffy growth parameters estimated by back-calculation for all individuals were: $L_\infty = 399$ mm; $k = 0.215$ year^{-1}; $t_0 = -0.928$ year^{-1} ($r^2 = 0.999$; $n = 9$). No significant differences in the growth parameters were found between males and females (Hotelling's T^2-test; $T^2 = 6.34 < T^2_{00.05,3,16} = 9.56$). The value of the growth performance index obtained for all individuals was

Table 3
Age–length key for all fish of *D. vulgaris* off the Canarian Archipelago (April 2000–March 2001)

Size (mm)	Age groups (years) I	II	III	IV	V	VI	VII	VIII	IX
130	7								
140	20								
150	43	3							
160	75	7							
170	59	21							
180	27	38	1						
190	9	44	3						
200	3	26	2						
210	1	12	8						
220		3	11						
230			14						
240		1	12	1					
250			11	6					
260			2	9					
270			1	6	2				
280				3	3				
290				2	4				
300					3	2			
310					1	2			
320						1	2		
330						1	1		
340							1	1	
350								1	
360								1	1
370									1

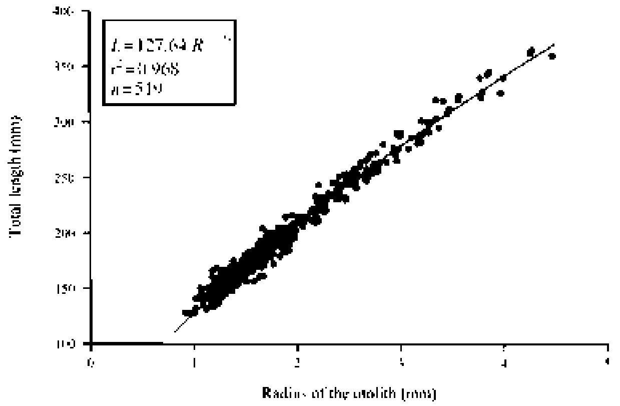

Fig. 2. Relationship between the otolith radius and the total body length of *D. vulgaris* off the Canarian Archipelago (April 2000–March 2001)

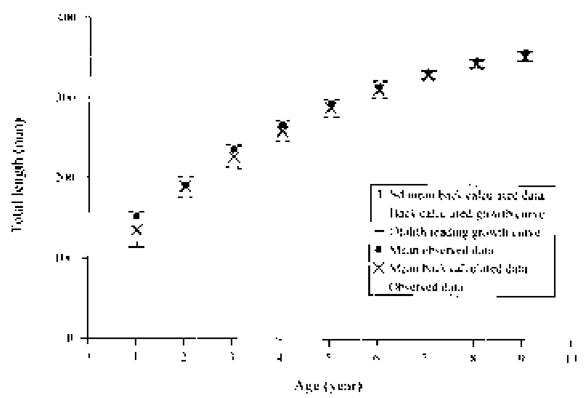

Fig. 3. The observed length-at-age, the mean observed length-at-age, the curve estimated from the observed length-at-age, the mean back-calculated length-at-age and the curve estimated from the mean back-calculated length-at-age of *D. vulgaris* off the Canarian Archipelago (April 2000–March 2001)

$\Phi = 4.52$. No significant differences between the growth parameters estimated by reading otoliths and using the back-calculation method were found in any individual (Hotelling's T^2-test; $T^2 = 5.22 < T^2_{00.05,3,495} = 7.89$).

Discussion

In many sparid species age determination is difficult because otoliths are very thick and cloudy so that light cannot pass through (Buxton and Clarke, 1991; van der Walt and Beckley, 1997); however, in the case of the common two-banded seabream from the Canary Islands the translucency of the otoliths allows assessment of ageing with relative ease. Otoliths of the common two-banded seabream show the ring pattern common in teleost fishes, with one opaque and one translucent ring formed each year in winter and summer, respectively. Similar findings have been recorded in other studies carried out in the Canarian Archipelago on other sparids such as *Dentex gibbosus*, *D. annularis, Pagellus acarne*, *P. erythrinus*, *Pagrus pagrus* and *Spondyliosoma cantharus* (Pajuelo and Lorenzo, 1995, 1996, 1998, 1999, 2000, 2001). Seasonal growth cycles might be related to physiological changes produced by the influence of temperature, feeding regime and reproductive cycle (Morales-Nin and Ralston, 1990; Newman et al. 2000).

The results obtained using the back-calculation method are very satisfactory and demonstrate the validity of using otoliths for estimating the growth of the common two-banded seabream. As ring formation is regular and, therefore, the otoliths can be used for age determination and because the fish length and otolith size are closely correlated, it is judged as valid to permit the use of measurements to previously formed marks to back-calculate the growth history (Campana, 1990; Francis, 1990).

Results showed that the von Bertalanffy growth model explained more than 95% of the growth pattern observed in the common two-banded seabream. Similar results were obtained by Gordoa and Molí (1997) for *D. vulgaris* off the Catalan coast. However, in all published works on this species in which the von Bertalanffy growth model was applied, the estimations of t_0 tended to be negative and different from zero. These estimations suggest that the von Bertalanffy growth model does not accurately describe growth in early stages (Gordoa and Molí, 1997). The longevity (9 years) exhibited by the common two-banded seabream from the Canary Islands is slightly longer than on the Catalan coast (6 years) (Gordoa and Molí, 1997) and in the Gulf of Lion (3 years) (Girardin, 1978). The growth parameters obtained in the present work also differ from those obtained by Gordoa and Molí (1997) on the Catalan coast ($L_\infty = 287$ mm, $k = 0.389$ year^{-1}) and by Girardin (1978) in the Gulf of Lion ($L_\infty = 267$ mm, $k = 0.255$ year^{-1}). This might be attributed to the maximum length sampled in those studies. The maximum length sampled in the present study (365 mm) is greater than that observed on the Catalan coast (280 mm) by Gordoa and Molí (1997) and in the Gulf of Lion (220 mm) by Girardin (1978). Probably the asymptotic length in these studies was underestimated because of the absence of individuals larger than 280 mm TL and, as a consequence, the growth rate was overestimated. However, by calculating a growth performance index, the results in this study showed similar values to those reported in the Gulf of Lion ($\Phi = 4.30$) by Girardin (1978) and on the Catalan Coast ($\Phi = 4.50$) by Gordoa and Molí (1997). The observed differences between these studies could also be attributable to the differences in the environmental conditions between the Mediterranean and the Atlantic Ocean as well as the ageing procedure and the procedure used to fit the data to the von Bertalanffy growth equation.

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Author's address: J. G. Pajuelo, Departamento de Biología, Universidad de Las Palmas de Gran Canaria, Campus Universitario de Tafira, P.O. Box 550, E-35017 Las Palmas de Gran Canaria, Canary Islands, Spain.
E-mail: pajuelo@ccbb.ulpgc.es