

Life history and initial assessment of fishing impacts on the by-catch species *Dules auriga* (Teleostei: Serranidae) in southern Brazil

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The life history of *Dules auriga*, a small hermaphrodite serranid species inhabiting deep waters and a frequent component of the discarded catch of bottom trawling in southern Brazil, was studied to assess the fishery effects on the stock through the estimation of the remaining spawning-potential ratio. Sampling was conducted throughout a year and included specimens to determine sex, maturity and age. Age was validated by the edge type and marginal-increment analysis. The oldest and the largest individuals were 9 years and 195 mm total length. Growth parameters fitted to the von Bertalanffy equation were $L_{\infty} = 178.34$ mm, $k = 0.641$ year⁻¹ and $t_0 = -0.341$ years. Length and age at first maturity were 140.72 mm and 2 years, respectively. The reproductive season was throughout the austral spring and summer. The assessment of the effects of fishing showed that it may have resulted in a loss of 50% of the spawning potential. This loss may be higher when taking into account the uncertainty in the life-history parameters and could be considered of concern for the population. Fast growth, moderate longevity, long spawning season, small size and age at maturity make *D. auriga* relatively resilient to the removal of biomass by fishing. When considering the uncertainty, however, the losses of the spawning potential have been severely reducing the population resilience in the face of ecosystem changes.

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Key words: data-poor stock; *Dules auriga*; non-target species; potential-spawning ratio; serranid.

INTRODUCTION

Monitoring and management efforts of exploited fishes are currently mainly focused on the commercially important species. Usually, non-target species receive lower priority in research, consequently, little is known about their life histories (Pope *et al.*, 2000). Non-target species, however, are also exposed to fishing mortality from by-catch (Cheung *et al.*, 2005), thus it is important to know their life histories to assess how fishing affects populations. The responses of fish populations to fishing are influenced by their life histories (Adams, 1980; Kirkwood *et al.*, 1994; Pope *et al.*, 2000). In general, species with faster life histories, *i.e.* earlier age at maturity and faster body growth, support higher fishing mortality than species with slower growth and delayed maturation (Reynolds *et al.*, 2001). Therefore, life-history parameters can be used to identify

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species that should receive attention by fisheries management (Reynolds *et al.*, 2001; Cheung *et al.*, 2005).

The small demersal serranid fish species *Dules auriga* Cuvier 1829 inhabits sand and consolidated bottoms on the south-western Atlantic Ocean continental shelf. The species is found between Rio de Janeiro state (Brazil) and Argentina, at depths ranging from 15 to 140 m (Fischer *et al.*, 2011). Their presence is relatively common in demersal bottom-trawl catches in the coastal waters of Argentina, Uruguay and southern Brazil (Militelli & Rodrigues, 2011). Despite its frequency in the catches, individuals of *D. auriga* are discarded after selection on board, since the species has no economic value. Those that are landed are used for the production of fish meal (Militelli & Rodrigues, 2011).

Until the present, little was known about the life history of *D. auriga*. It feeds mainly on crustaceans and the species is classified as a simultaneous hermaphrodite (Cussac & Molero, 1987), *i.e.* every individual has both male and female gonads. This characteristic was confirmed by the histological examinations of Militelli & Rodrigues (2011). Chaves (1989) reported the presence of functional gonads, with testicular portions aggregated to the ovaries in both sexually mature and immature individuals. Several other aspects of its life history, such as maximum age, growth, natural mortality and age and size of first maturity, however, remained unknown. These gaps prevent any assessment of fishery effects on its population.

The majority of fisheries across the globe are data-limited, as they lack data and the resources to generate statistical estimates of the stock status (Dowling *et al.*, 2016). Data poverty, however, should not be used as an excuse to forego the assessment of stock status, which is a fundamental step to develop any management strategy (Dowling *et al.*, 2016). Nowadays, many options exist to assess data-limited stocks with several levels of data requirements (Dowling *et al.* 2014). A recent one uses life-history information to build a hypothetical unexploited size composition and compares it with the updated size composition of the stock to estimate the spawning-potential ratio (SPR) (Hordyk *et al.*, 2015a, b).

In this context, the present research studied the life history of *D. auriga* in southern Brazil to estimate its remaining SPR. Life history was described by age, growth, age and length at first maturity, natural mortality and length frequencies. These variables were used to estimate the SPR using the method proposed by Hordyk *et al.* (2015a, b). The life history and the SPR information allows an initial assessment of the fishing impacts on *D. auriga* in southern Brazil.

MATERIALS AND METHODS

SAMPLING AND STUDY SITES

Individuals were collected monthly from September 2014 to April 2016, from the fishery landings in Rio Grande (Brazil). Landings were from the commercial fishing fleet equipped with bottom trawls that operate on the southern Brazil continental shelf between latitudes 28° 36' 14" S and 33° 44' 39" S at depths between 9 and 130 m (Fig. 1).

Measurements of total length (L_T , mm), total mass (M_T , g) and gonad mass (M_G , g) were obtained for each specimen. In addition, the pair of **sagittae otoliths** were removed, cleaned and stored dry for ageing in the laboratory.

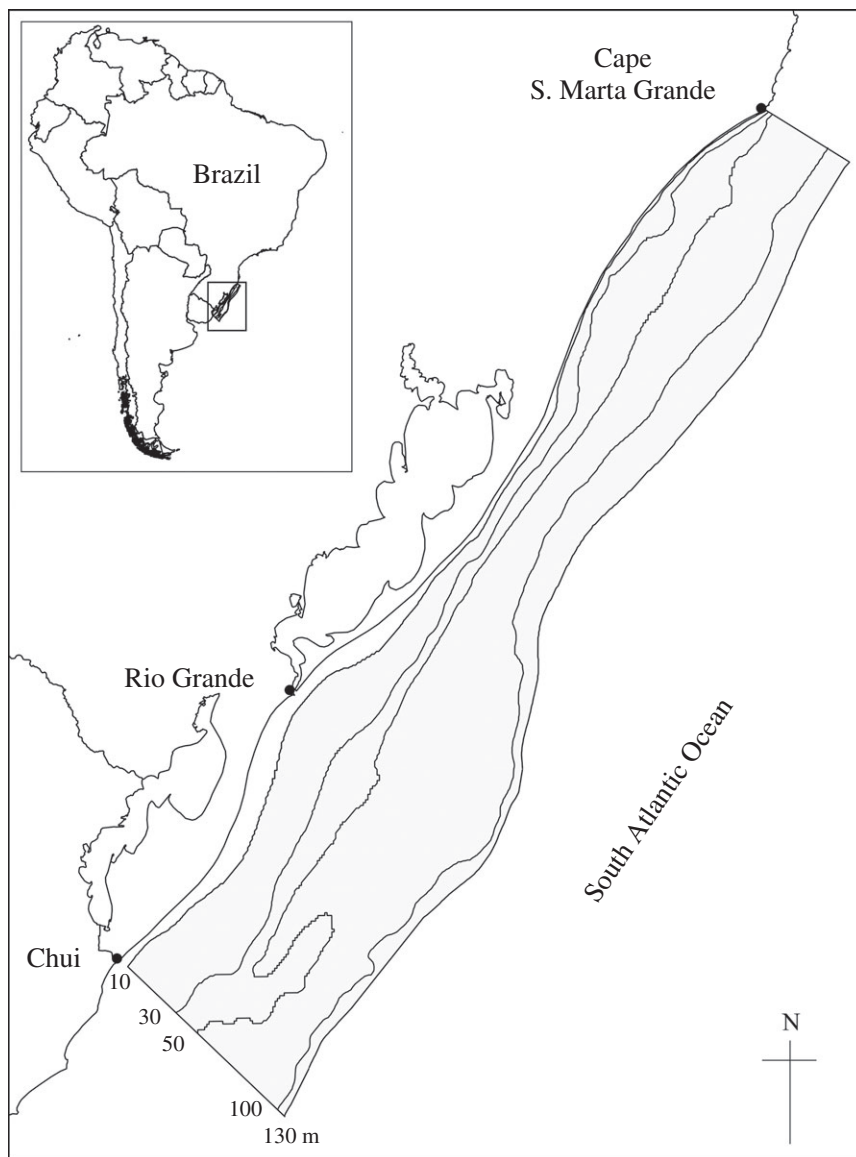


FIG. 1. Bottom pair-trawler fishing area (■) where *Dules auriga* form by-catch off southern Brazil.

AGEING

One otolith from each pair was embedded in a polyester resin, left to dry and then sectioned transversely through the nucleus using a low speed diamond saw. Sections of 0.2 mm were mounted on glass slides with synthetic mounting media. Sections were examined under a binocular stereoscopic microscope with reflected light over a black background and images were digitized, under which the opaque bands were counted (Fig. 2). Distances from the core to the end of each opaque band (R_i) and to the inner edge (R) of the otoliths along the dorsal border of the sulcus acusticus were recorded together with the type of band on the edge (opaque or translucent). Two readers read the number of opaque bands independently. If discrepant, a

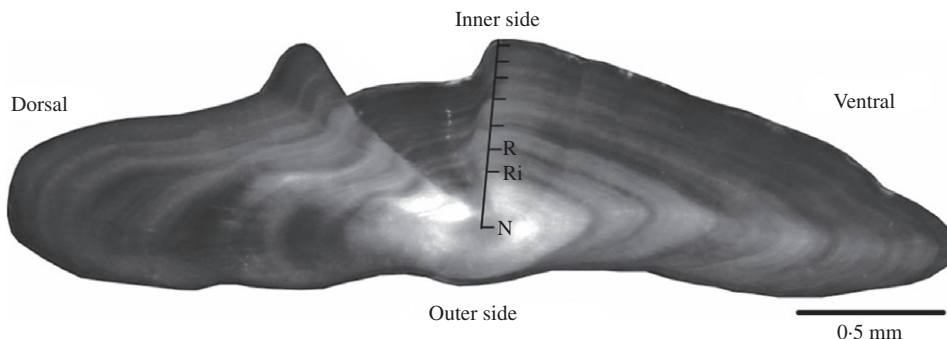


FIG. 2. Thin section examined with reflected light of a 6 year old (total length, $L_T = 194$ mm) *Dules auriga* from southern Brazil. Opaque bands appear as white bands whereas translucent ones appear as dark bands. The black scale side bars indicate the end of each opaque band. N , nucleus; R_i , the distance from the nucleus to the end of each opaque band; R , the distance from the nucleus to the inner edge.

third reading was made jointly. In cases on which disagreement persisted, the readings were discarded.

The mean c.v. was used to evaluate the precision of the age estimation between readings, following Campana & Jones (1992):

$$A_{C.V.j} = \left\langle \left\{ \sqrt{\sum_{i=1}^R [(x_{ij} - x_j)^2 (n-1)^{-1}]} \right\} x_j^{-1} \right\rangle 100.$$

where $A_{C.V.j}$ is the age precision estimate for the j^{th} fish; x_{ij} is the age determination of the j^{th} fish by the i^{th} reader; x_j is the mean age of the j^{th} fish and n is the number of readings.

Type of edge and marginal increment analysis (I_M) were used to validate the periodicity of formation of the opaque and translucent bands. The relative frequencies of each edge type were plotted monthly. The translucent I_M was calculated for each specimen by the formula: $I_M = (R - R_n)[R_n - (R_n - 1)]^{-1}$, where I_M is the marginal increment; R is the distance from the nucleus to the edge; R_n is the distance from the nucleus to the end of last opaque band and $R_n - 1$ is the distance from the nucleus to the end of the last but one opaque band. Monthly means I_M were calculated and its annual variation analysed.

GROWTH MODEL

The von Bertalanffy (1938) growth model was fitted using a Bayesian approach to describe the growth of *D. auriga*. It was assumed that the age–length data followed a log-normal distribution: $y_i = \log N(\mu_i, \sigma^2)$, where y_i is the length distribution with an average expected length at an age class (or band class) i with variance σ^2 . A logarithmic version of the von Bertalanffy equation was used for computational convenience: $\mu_i = \log(tL_\infty) + \log(1 - k^{(i-t_0)})$.

Uninformative priors were constructed: $p(\log tL_\infty) \sim \delta N(0, 0.001) I(-5, 5)$; $p(\log k) \sim \delta N(0, 0.001) I(-5, 5)$; $p(\log t_0) \sim \delta U(-3, 0)$; $p(\sigma) \sim \delta U(0, 5)$.

The posterior distribution of each estimated parameter was obtained via the stochastic process of Monte Carlo Markov chain (MCMC). After 10 000 burn-in runs, every second value of the remaining 31 000 was retained, resulting in a final sample of 10 500 in the posterior distribution $p(\log tL_\infty, \log k, \log t_0 | D)$ (Kinas & Andrade, 2010). The MCMC was performed by OpenBUGS, using the libraries R2WinBUGS (Sturtz *et al.*, 2005) and BRugs (Thomas *et al.*, 2006). All statistical analysis in this study were performed in R 3.1.3 (www.r-project.org).

The parameters of the mass–length equations ($M_T = aL_T^b$) were calculated using a linear regression, which was based on log transformed total masses (M_T) and lengths (L_T).

SEXUAL MATURATION ANALYSIS

The gonado-somatic index (I_{GS}) was calculated as $I_{GS} = (M_G M_T^{-1})100$ (Wootton, 1998). Mean I_{GS} values were calculated monthly to show the reproductive period. The maturation was also defined by the I_{GS} , since the absence of histological staging studies for the species and macroscopic analysis were suspected to have large errors (Flores *et al.*, 2015). The I_{GS} value in which individuals were considered mature was determined by the analysis of the dispersion of the index by month.

The total number (n_i) and the number of mature specimens (y_i) were calculated total length intervals of 10 mm and at each age. Only data for the breeding season was chosen to estimate the maturation ogives by length and age. If θ_i denotes the probability of an individual of the i^{th} age or i^{th} length class being, y_i was assumed to follow a binomial distribution $\text{Bin}(n_i, \theta_i)$.

Data were fitted to a logistic model, defined by a logit-link function that transforms the parameter θ_i , restricted to the range $[0, 1]$ in the binomial distribution, in m defined between $(-\infty, +\infty)$ (Kinas & Andrade, 2010). The logistic model was defined as: $m_i = g(\theta_i) = \log[\theta_i(1 - \theta_i)^{-1}]$; $m_i = \beta_0 + \beta_1 \cdot x_{1+}$, where m_i is the probability that an individual in age or length class x_i is mature. From this model, the age at first maturation (A_{50}) and the length at first maturation (L_{50}) were defined as: A_{50} or $L_{50} = -\beta_0 (\beta_1)^{-1}$.

The posterior distribution $p(\beta_0, \beta_1 | D)$, where $D = [(y_i, n_i, x_i); i = 1, \dots, k]$, was obtained via the stochastic process of MCMC. To obtain the posterior distribution of β_0 and β_1 , they were considered independent and normally distributed with mean 0 and with a large variance (1000), used as *a priori* distribution. The number of simulations and sample selection to obtain the posterior distribution was the same as used for the estimation of the von Bertalanffy growth parameters.

SPAWNING POTENTIAL RATIO ASSESSMENT

The spawning potential ratio (SPR) in the population was estimated by the length-based SPR method (Hordyk *et al.*, 2015a, b), which is calculated as the difference between the expected length composition in a virgin situation and the observed one from the catch. The expected length composition is calculated from the life-history parameters such as the natural mortality (M), the von Bertalanffy growth parameters L_∞ and k and the size at 50 and 95% maturity.

The current size structure was obtained by measuring the L_T of 590 individuals from commercial bottom pair-trawl fishing and were considered to be representative of the population. The natural mortality was calculated as the average of results from three methods that use maximum ages as a predictor of M (Then *et al.*, 2014). M was calculated for three values of maximum age: that observed at the otolith readings, 25% higher than the maximum observed age and 50% higher. This was done because the bottom pair-trawl fishery has operated in the region for, at least, 50 years (Haimovici, 1998; Haimovici & Cardoso, 2016) and the removal of older age classes *via* fishing occurs at even moderate levels of exploitation (Berkeley *et al.*, 2004).

The SPR were estimated considering the uncertainty in the growth (tL_∞ and k) and maturity parameters (L_{50} and L_{95}). For this, SPR values were calculated for each of the three natural mortality values considering the lower and upper confidence intervals for the mentioned parameters.

RESULTS

AGE AND GROWTH

Overall, 973 specimens measuring from 77 to 195 mm L_T were sampled for reproductive analysis. From these, 409 had otoliths examined for age. The initial coincidence between the readers was 56%, but after the joint reading this coincidence increased to 87% and the mean c.v. 7.69%. Of the 409 otoliths examined, 54 were excluded from the analysis because of the absence of agreement among readings.

The readings of the sectioned otolith images showed an alternating pattern in the formation of bands: narrow translucent and wide opaque bands (Fig. 2). The analysis of

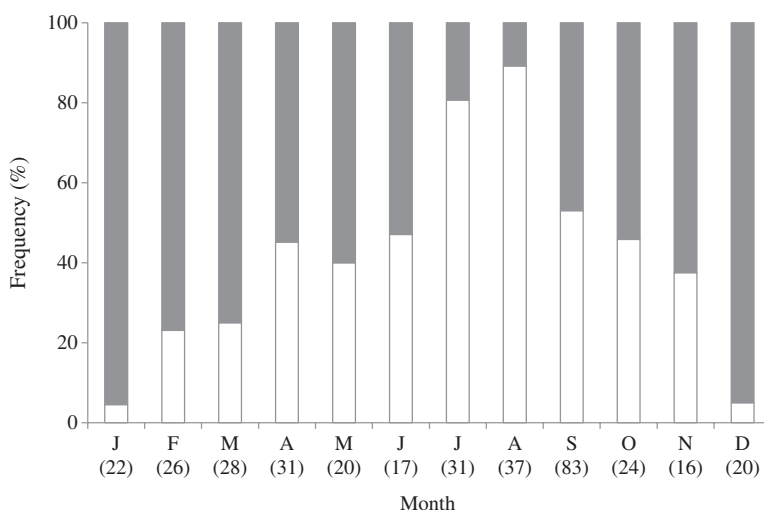


FIG. 3. Frequency distribution by month (with sample size in parentheses) of opaque (■) and translucent (□) edges of the otoliths thin sections of *Dules auriga* in southern Brazil.

the edge type indicated a greater frequency of otoliths with opaque edges from October to June, reaching peaks in December and January (both values of 95%), while the translucent edges occurred more frequently in July, August and September (81, 89 and 53%, respectively) (Fig. 3). The mean translucent marginal increment (I_M) confirmed the seasonal pattern of translucent band formation, in July and August. The I_M values were very low in December and January and increased gradually to reach higher values in July and August followed by a decreasing trend to December (Fig. 4).

This alternating and seasonal pattern of opaque and translucent edges formation validates the ageing of *D. auriga* from southern Brazil. Spawning of *D. auriga* in southern Brazil and opaque-band formation in its otoliths takes place in spring and summer and the number of opaque zones represents approximately the number of years of life. Owing to this coincidence, it was possible to assume 1 January as the birth date of all specimens and calculate decimal ages using the opaque band counts and the date of capture.

Based on 355 readable otoliths, *D. auriga* ages ranged from 1 to 9 years. Most of the sampled specimens were between 3 and 4 years, accounting for 53% (Table I). The three older fish sampled, were 9 years old and measured 173, 182 and 183 mm L_T . The von Bertalanffy growth model applied to length-at-age data showed that the species grows fast, attaining its asymptotic length and mass in the fifth year of life (Table II and Fig. 5).

The mass-length relationship was (Fig. 6): $M_T = 4(10^{-6})L_T^{3.29}$; $r^2 = 0.95$, $n = 1669$. Based on this relationship the asymptotic mass was estimated at 100.47 g (95% credible intervals = 93.02–110.91 g).

SEXUAL MATURATION ANALYSIS

The mean monthly gonado-somatic index (I_{GS}) values were higher between October and March, indicating a period of reproductive activity that peaked in December and

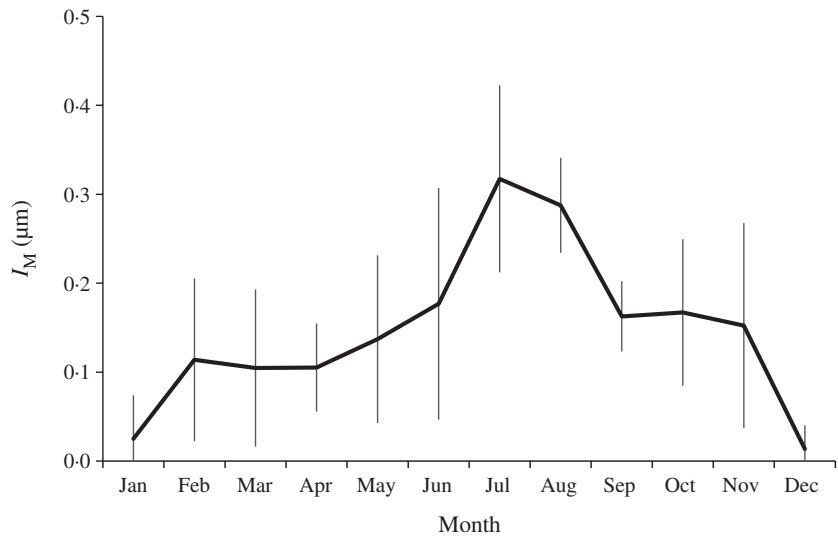


FIG. 4. Mean translucent marginal increment (I_M) of sectioned otoliths of *Dules auriga* in southern Brazil. Vertical bars indicate the confidence interval (C.I.) ($\alpha = 0.05$).

January (Fig. 7). In non-reproductive months, no fish had I_{GS} values >3.5 . Therefore, the individuals with a $I_{GS} > 3.5$ were considered mature.

From the logistic model, the mean age and length at first maturation (A_{50} and L_{50}) were estimated in 2.29 years and 140.72 mm, respectively (Table III and Fig. 8).

SPAWNING POTENTIAL RATIO ASSESSMENT (SPR)

The estimated natural mortality (M) was 0.61 considering 9 years old as the maximum age and the remaining spawning potential ratio (SPR) of the *D. auriga* from southern Brazil was 61%, varying from 42 to 92% when considering the uncertainty in the

TABLE I. Observed mean total length at age (L_T , mm) and calculated mean L_T at age of *Dules auriga* in southern Brazil

Age class (year)	<i>n</i>	Mean L_T (mm)		
		Observed	95% C.I.	Calculated (mm)
1	24	116.6	7.8	97.6
2	55	138.7	5.6	138.3
3	91	157.4	3.2	158.6
4	98	168.5	2.1	168.6
5	45	173.8	2.7	173.6
6	26	180.4	3.1	176.1
7	9	179.6	7.2	177.4
8	4	183.0	4.9	178.0
9	3	179.3	6.2	178.3

TABLE II. von Bertalanffy growth parameters and their credible intervals for *Dules auriga* from southern Brazil

Parameter	Mean	Credible interval	
		2.5%	97.5%
L_{∞}	178.34	172.44	186.04
k	0.641	0.482	0.796
t_0	-0.341	-0.778	-0.040

estimated life-history parameters (tL_{∞} , k , L_{50} and L_{95}) (Table IV). M was 0.46 for age 11 years and the SPR was 53%, varying from 36 to 85%, when considering the uncertainty in the life-history parameters. M was 0.37 for 13 years and the SPR was 47%, varying from 31 to 79%, when considering the uncertainty in the life-history parameters. This can be interpreted as losses of 39, 47 and 53% of the spawning potential with significant variation when considering the uncertainty of the life-history parameters.

DISCUSSION

The present study has generated valuable life-history data for *D. auriga* by providing validated age and growth parameters, age and size at maturity and an estimate of the spawning potential ratio of the stock. All this information allows an initial estimate of fishery effects on this species, even with few data available. In this study, the otolith

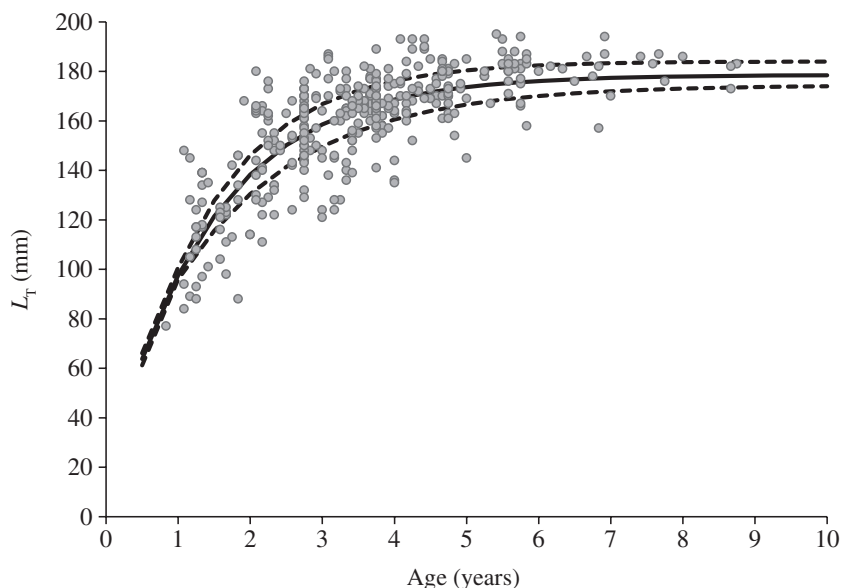


FIG. 5. Observed total length (L_T)-at-age data for *Dules auriga* from southern Brazil and fitted von Bertalanffy growth curve. Mean growth in length (—) and credible intervals (---) of 2.5 and 97.5%.

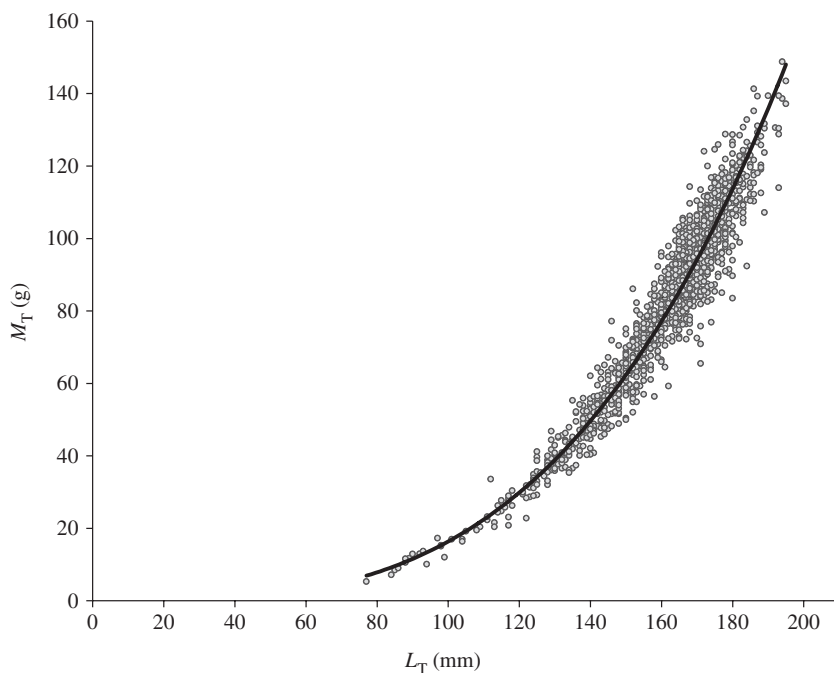


FIG. 6. Total length (L_T)–total mass (M_T) relationship of *Dules auriga* from southern Brazil. Continuous black line indicates the regression line.

reading precision between readers (c.v. = 7.7%) agreed with the average precision value (c.v. = 7.6%) presented by many ageing studies analysed by Campana (2001). Both edge type and marginal increment analysis consistently showed an annual periodicity in the formation of an opaque band from spring to summer and of a translucent one from autumn to winter, which allowed consistent ageing validation of *D. auriga* in southern Brazil. This pattern may occur due to a combination of endogenous and exogenous factors (such as water temperature, reproduction and feeding regime) that influence the alternating deposition of mineral-deficient and mineral-rich bands with an annual periodicity in most species (Morales-Nin, 2000; Green *et al.*, 2009). The deposition of opaque bands in *D. auriga* coincides with peaks in its spawning season. The seasonal pattern of band formation is also in agreement with the same process in other demersal fish species from the study area: *Macrodon atricauda* (Günther 1880) (Cardoso & Haimovici, 2011), *Epinephelus marginatus* (Lowe 1834) (Concini *et al.*, 2014), *Cynoscion guatucupa* (Cuvier 1830) (Vieira & Haimovici, 1993) and *Umbrina canosai* Berg 1895 (Haimovici & Reis, 1984).

As the genus *Dules* Cuvier 1829 is monospecific, its growth strategy was compared with other small-sized species of the genus *Serranus* Cuvier 1816: *Serranus cabrilla* (L. 1758), *Serranus hepatus* (L. 1758), *Serranus atricauda* Günther 1874 and *Serranus scriba* (L. 1758) (Table V). In Fig. 9, their relative L_T at ages ($L_i L_\infty^{-1}$) were plotted against ages to evaluate the speed that each species approximates to L_∞ . It can be observed that *D. auriga* grows much faster than the other species, achieving 43% of L_∞ in the first half year, 58% at the end of the first year of life and 80% at the end

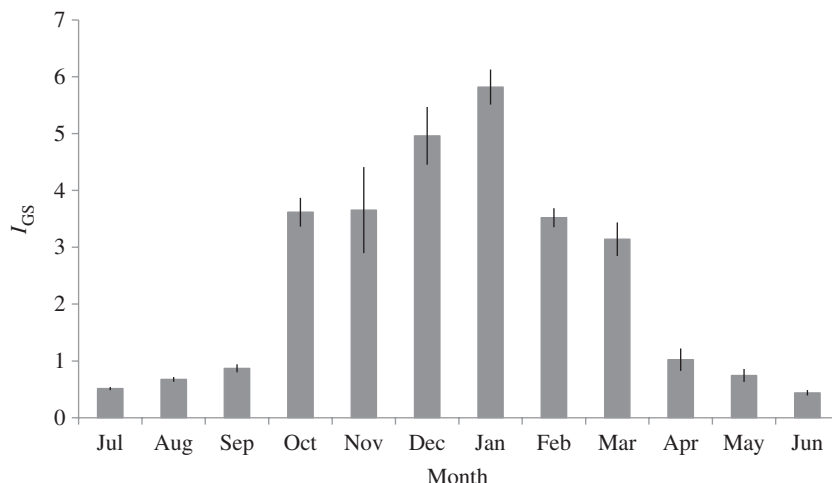


FIG. 7. Mean gonado-somatic index (I_{GS}) by month for *Dules auriga* from southern Brazil and the C.I. ($\alpha = 0.05$).

of the second year. In contrast, *Serranus* spp. reach 17–46% and from 29–64% at the end of the first and second year of life, respectively. Faster growth can be attributed both to the environmental characteristics of their habitat and to specific evolutionary pressures. It is noteworthy that each of the species compared comes from sites with different environments and population structures, which may influence the observed differences between the growth parameters.

Before this study, *D. auriga* was considered a little-known species and for assessment of fishery effects, as a data-poor stock. The estimation of its basic life history (maximum ages, reproduction, growth and natural mortality) combined with a representative size structure of the population allowed assessment of the spawning potential ratio (SPR) of the stock by applying the length-based SPR method developed by Hordyk

TABLE III. Mean and credible intervals for model parameters (β_0 and β_1) and estimated maturation indices of *Dules auriga*

Parameters	Mean	Credible interval	
		2.5%	97.5%
$A_{50} \beta_0$	-0.93	-1.91	0.05
$A_{50} \beta_1$	0.39	0.10	0.68
A_{50} (years)	2.29	-0.14	3.30
$L_{50} \beta_0$	-4.49	-6.59	-2.69
$L_{50} \beta_1$	0.03	0.02	0.05
L_{50} (mm)	140.72	129.27	148.87

$A_{50} \beta_0$ and $A_{50} \beta_1$ are the estimated logistic model parameters for the calculation of the age at which 50% of the population reach first maturity (A_{50}). Similarly, $L_{50} \beta_0$ and $L_{50} \beta_1$ are the estimated logistic model parameters for the calculation of total length at which 50% of the population reach first maturity (L_{50}). All parameters and indexes are presented as the mean of their posterior distribution obtained *via* stochastic procedure.

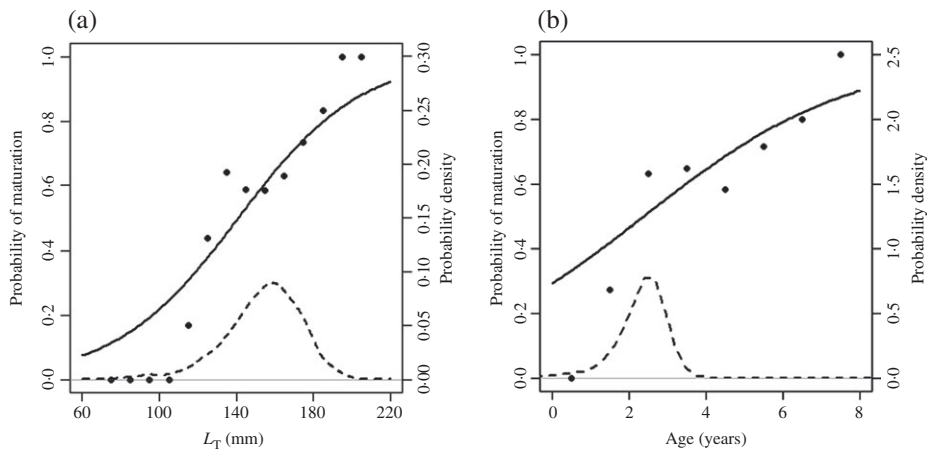


FIG. 8. (a) Total length (L_T) and (b) age–maturity ogives (—) with their respective posterior distributions of the estimated L_T and age at first maturity (---) of *Dules auriga* from southern Brazil.

et al. (2015a). This model has several assumptions such as: equilibrium conditions, length data representative of the exploited stock, asymptotic selectivity, normally distributed length at age in unfished conditions, fixed k and the egg production is assumed to be proportional to mass and the cubed length (L^3). Some of these assumptions are fulfilled by the data used since the length frequencies came from bottom trawling which can be considered a less selective fishing gear with an asymptotic selectivity. The fulfilling of the other assumptions cannot be assessed and are related to theoretical issues of the model. Nevertheless, this approach is one of many methods of great importance

TABLE IV. Input values of *Dules auriga* life-history parameters used to fit the length-based spawning potential ratio (SPR) model (Hordyk *et al.*, 2015a, b) and the output SPR values for each parameter combination

M	k	Mk^{-1}	L_{∞}	L_{50}	L_{95}	SPR (C.I.)
Estimated average values						
0.61	0.69	0.88	17.9	14	16	61% (57–65%)
0.46	0.69	0.67	17.9	14	16	53% (49–57%)
0.37	0.69	0.54	17.9	14	16	47% (43–51%)
Lower credibility interval						
0.61	0.482	1.27	17.2	13	15	92% (86–97%)
0.46	0.482	0.95	17.2	13	15	85% (79–91%)
0.37	0.482	0.77	17.2	13	15	79% (72–86%)
Upper credibility interval						
0.61	0.796	0.77	18.6	15	17	42% (38–47%)
0.46	0.796	0.58	18.6	15	17	36% (32–40%)
0.37	0.796	0.46	18.6	15	17	31% (27–35%)

M , Natural mortality; L_{∞} , asymptotic length from von Bertalanffy (vB) growth model; k growth rate from vB growth model; L_{50} and L_{95} , total length at 50 and 95% of maturity, respectively.

TABLE V. The von Bertalanffy (vB) growth parameters of *Dules auriga* from this study compared with the parameters of four small-sized *Serranus* spp.: *Serranus cabrilla*, *S. hepatus*, *S. atricauda* and *S. scriba*

Species	Study site	Ageing structure	<i>n</i>	Age range (years)	<i>L_T</i> range (mm)	<i>L_∞</i> (mm)	<i>k</i> (year ⁻¹)	<i>t₀</i> (years)	Reference
<i>Dules auriga</i> <i>S. cabrilla</i>	Southern Brazil Mediterranean Sea-Crete	Sectioned otolith	356	1–8	77–195	178.34	0.641	–0.341	This study Tserpes & Tsimenides (2001)
		Whole otolith	864	1–5	63–197	222.93	0.39	–0.59	
<i>S. hepatus</i>	Adriatic Sea-Croatia	Scale	440	2–7	58–130	148.10	0.217	–1.672	Dulčić <i>et al.</i> (2007)
<i>S. atricauda</i> <i>S. scriba</i>	Canary Islands	Whole otolith	406	2–16	162–432	438.75	0.16	–0.158	Tuset <i>et al.</i> (2004)
		Whole otolith	336	2–11	150–294	341.80	0.13	–2.5	Tuset <i>et al.</i> (2005)

L_T, Total length; *n*, sample size; *L_∞*, asymptotic length from von Bertalanffy (vB) growth model; *k* growth rate from vB growth model; *t₀*, theoretical age of zero length from vB growth model.

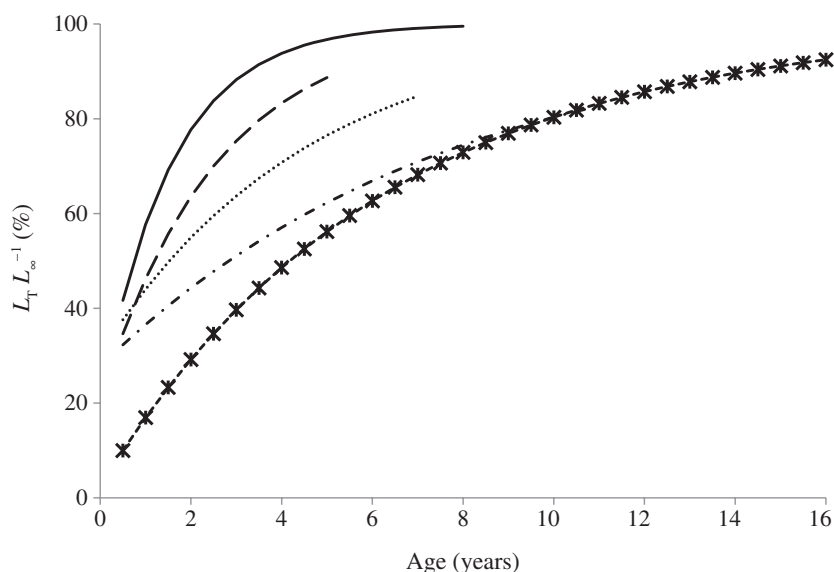


FIG. 9. Total length (L_T) at age relative to the asymptotic lengths (L_∞) of *Dules auriga* (—) from southern Brazil and four *Serranus* spp.: *S. cabrilla* (— —) and *S. atricauda* (-*-*) from the Canary Islands, *S. hepatus* (.....) from the Croatian Adriatic Sea, and *S. scriba* (- . -) from Crete, eastern Mediterranean (von Bertalanffy growth functions are given in Table V).

that have been developed recently to assess data-limited stocks (Carruthers *et al.*, 2014; Newman *et al.*, 2015).

The values of spawning potential ratio (SPR) estimated for the *D. auriga* population from southern Brazil were sensitive to the maximum age used to calculate M . Depending on the assumed longevity (9, 11 or 13 years old) the removal by fishing may have resulted in losses of approximately 39, 47 or even 53% of the spawning potential respectively. It is plausible to assume that the maximum age of the species is higher than the maximum observed age. *Dules auriga* is a non-target species, but occurs in 32% of tows of the pair-trawl fishery in southern Brazil (L. G. Cardoso, pers. comm.) which makes its population susceptible to fishery effects. The bottom-trawl fishery has operated in the region for at least 50 years (Haimovici, 1998; Haimovici & Cardoso, 2016) and the removal of older age classes is one of the first population effects of exploitation (Berkeley *et al.*, 2004). Thus, it is safe to assume that fishing had removed at least 50% of the spawning potential of the *D. auriga* population from southern Brazil. Considering the uncertainty in the estimated life-history parameters, however, this removal may have been higher, which could be considered of concern for the population. This uncertainty in the estimated SPR values show the importance of further monitoring and assessments of the species, with more data and of higher quality, as, *e.g.* from scientific bottom-trawl surveys.

The results presented here highlight the importance of long-term monitoring of *D. auriga* and other by-catch species. Although *D. auriga* may seem to be a resilient species due to its life-history characteristics (long spawning period, early maturity at small sizes and fast growth), it probably has been affected by fishing mortality operating in the past 40 years in southern Brazil. These effects render populations less resilient to

stochastic effects such as climatic variations by reducing storage effects. Furthermore, fishing may affect its functional role, for instance, availability as prey for other species, causing negative effects on the food web.

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