ZOOLOGIA 42: e24053
ISSN 1984-4689 (online)
scielo.br/zool

RESEARCH ARTICLE

Life-history traits and population structure of *Stellifer stellifer* (Actinopterygii: Sciaenidae) in a subtropical estuary in southern Brazil

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https://zoobank.org/4DD6D744-6F43-4F56-8200-D0124A4D7EF9

ABSTRACT. This study aimed to characterize the population structure and critical life history parameters of *Stellifer stellifer* (Bloch, 1790) in a Brazilian subtropical estuary. Environmental variables such as pH, salinity, and dissolved oxygen were the most strongly correlated, revealing a spatial gradient in the west-east direction. A total of 1,363 individuals were captured, with the innermost sampling point yielding the highest capture rate (76.8%). Total length ranged from 8.2 to 22.3 cm in females and from 8.5 to 21.1 cm in males, considering both juvenile and adult specimens, and histological analysis revealed five stages of ovarian and testicular development. The reproductive period occurred in spring and summer, characterized by fractional (batch) spawning. Environmental variables, particularly temperature, significantly influenced the monthly distribution of gonadal maturation stages. Natural mortality rates were 1.12 and 1.01 year^{-1} for females and males, respectively. The age of the population ranged from eight months to six years, with juveniles accounting for 3.3% of the total catch. Females predominated in the smallest and largest length classes, while males were more prevalent in intermediate-length classes. Our results suggest that the abundance and distribution of *S. stellifer* play a crucial role in maintaining the balance of estuarine ecosystems. Despite being exploited as bycatch in shrimp fishing, the species exhibits a well-defined reproductive process influenced by seasonality and demonstrates rapid growth.
KEYWORDS. Age, growth, longevity, mortality, reproduction.

INTRODUCTION

The life history of a species is defined by traits adapted to a specific ecosystem, where viable populations persist due to the species' adaptive phenotypic plasticity (Acasuso-Rivero et al. 2019). Studying the reproductive characteristics of a species, one of these life history traits provides valuable insights for population monitoring and informs sustainable fishing practices, crucial for developing effective management and conservation plans (Baldé et al. 2022). Other life history traits are derived from fish biometrics, utilizing weight and length data to yield essential information about species ecology and population dynamics (Famoofo and Abdul 2020).

Length-weight relationships and condition factors are essential biometric tools in fisheries studies, providing crucial information on fish species' growth, condition, and habitat suitability (Santos et al. 2022). However, species behavior and biology may change in response to natural environmental conditions or anthropogenic influences, including interannual and latitudinal variations. These changes can manifest in modified reproductive tactics and strategies, declining length-at-age and size at first maturity, altered body condition, and other life history traits (Albo-Puigserver et al. 2021). Human activities, particularly fishing, can significantly influence the variation in life history characteristics of both target and non-target fish populations (Kuparinen et al. 2016). Using non-selective fishing gear often results in bycatch, leading to incidental fishing. This practice remains a threat to numerous species around the world (Pons et al. 2021).

Among the fish species captured as bycatch in Brazil, Sciaenidae are particularly prominent. These fish are frequently caught during trawling for the seven-bearded shrimp, *Xiphopenaeus kroyeri* (Heller, 1862) (see Freire et al. 2020, Viana et al. 2021), one of the primary marine resources exploited along the Brazilian coast. Shrimp trawling is notorious for its lack of selectivity, posing a considerable threat to marine ecosystems due to the capture of non-target species. Even when these incidental catches are immediately released, the physical damage inflicted upon the organisms can significantly reduce their survival rates. Studies on bycatch associated with shrimp fishing have been predominantly conducted in the coastal regions of Paraná. Viana et al. (2021) evaluated the effects of bottom trawling duration on mortality, physical damage, and oxidative stress in two sciaenid species, *Stellifer rastrifer* (Jordan, 1889) and *Paralonchurus brasiliensis* (Steindachner, 1875). Their findings revealed a high fish mortality rate of approximately 70%, with the physical damage index (CDI) as a valuable predictor of fish mortality.

Our study focuses on the marine-estuarine sciaenid *S. stellifer*, which is distributed in the western Atlantic from western Venezuela to southern Brazil. This species is frequently part of the bycatch in shrimp trawling operations along the Brazilian northeastern and southern coasts (Beserra et al. 2015, Souza and Chaves 2007). While species of *Stellifer* are categorized as having a low risk of extinction on the IUCN Red List due to their small size and not being directly targeted by fishing activities, they remain subject to incidental capture, including *S. stellifer* (see Chao et al. 2015, Freitas et al. 2023).

Despite its low commercial importance, *S. stellifer* is crucial in estuarine ecosystems, contributing significantly to community structure and ecosystem balance, representing up to 7% of catches (Barletta et al. 2008). This ecological importance and the species' vulnerability to bycatch underscores the need for comprehensive life history studies. Thus, this research aimed to describe the life-history traits, population structure, and reproductive biology of *S. stellifer* captured in a subtropical estuary in southern Brazil. By providing these fundamental insights, our findings offer essential information for developing effective conservation strategies, informing fisheries management decisions, and potentially using *S. stellifer* as a bioindicator of ecosystem health and anthropogenic impacts in estuarine systems.

MATERIAL AND METHODS

The study was carried out in the Guaratuba Bay estuary, located at coordinates 25°52'S; 48°39'W, with an area of approximately 45 km^2, on the coast of the state of Paraná, a subtropical region in southern Brazil (Fig. 1). The bay communicates with the sea through an opening of approximately 500 m, extends inland for approximately 15 km in the east-west direction, and has a maximum width of 5 km in the north-south direction. According to the Koeppen classification, the region's climate is Cfa, defined as mesothermal humid subtropical with hot summers, with summer being the wettest period and winter the driest, mainly between July and August (Lana et al. 2001).

Sampling was conducted from November 2012 to October 2013 at six points (P1–P6) along the east-west axis of the Guaratuba Bay estuary, spanning approximately 12 km between P1 and P6. Authorizations were granted by Instituto Água e Terra (formerly Instituto Ambiental do Paraná, license 456.12) and Instituto Chico Mendes de Conservação da Biodiversidade (SISBIO/ICMBio license 36818-1). Specimens were collected with 10-minute bottom trawls at each point using a net 8.0 m wide and 7.0 m long, with mesh sizes of 2.5 cm in the wings and 1.2 cm in the cod-end, and doors of ~8.0 kg each, at depths ranging from 1.6 to 4.8 m. The specimens collected were euthanized by medullary section. Randomly, 30 individuals were analyzed per sampling point in each collection month, and the surplus was counted and weighed as biomass. The analyzed specimens had the morphometric data of total length (cm), total weight (g), and weight of the gonads (g) recorded.

Water temperature, dissolved oxygen, pH, salinity, transparency, depth, and rainfall were recorded while collecting biological material. Water samples were collected from the bottom with a Van Dorn bottle. The pH data were obtained using a digital pH meter, with an accuracy of 0.01; for dissolved oxygen, a digital oximeter with a precision of 0.1 was used; water temperature was measured with a digital thermometer with a precision of 0.1 °C. Salinity was measured using a refractometer; depth was determined, using an echo sounder, and transparency was assessed using a Secchi disk. The Sistema de Tecnologia e Monitoramento Ambiental do Paraná (SIMEPAR) provided the average monthly rainfall data for the study period.

The abiotic data were analyzed through principal component analysis (PCA), seeking to explore the spatial and temporal patterns of the sampling points. Depth data were included in the PCA to certify that this variable did not influence the segregation of sampling points. After constructing

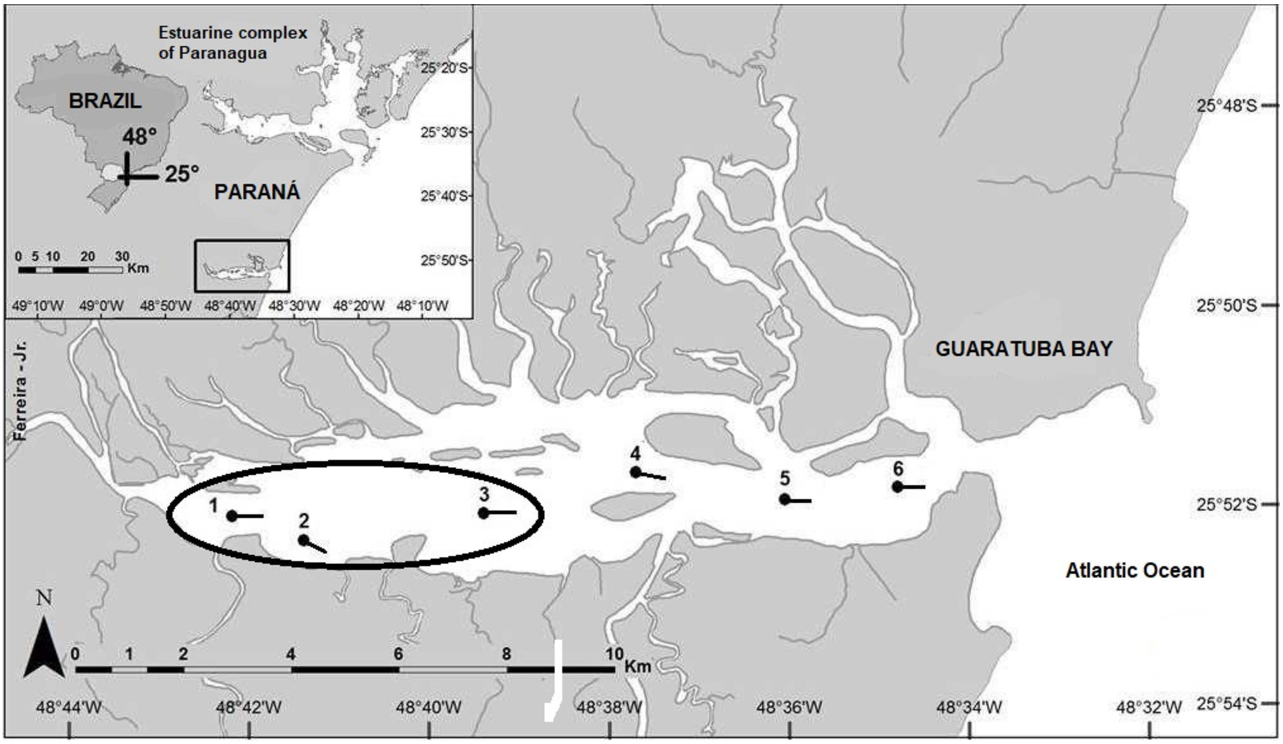

Figure 1. Study area with the location of the six sampling points along the east-west axis of Guaratuba Bay, Paraná, Brazil (Zanlorenzi 2016). The circled area indicates the three points in the innermost region of Guaratuba Bay.

the PCA matrix, we assessed the assumptions of multivariate normality and collinearity among the abiotic variables; the normality was evaluated using the Shapiro-Wilk test and visual inspection of Q-Q plots, while collinearity was examined through Variance Inflation Factor (VIF) analysis. These checks ensured that the data met the necessary assumptions for PCA, allowing for more reliable interpretation of the results (Quinn and Keough 2002).

The environmental variables in the PCA matrix were normalized by subtracting the mean and dividing by the standard deviation. After performing the PCA, using all the measured environmental parameters, it was found that the transparency and the accumulated rainfall did not present a good relationship with the sample points and were removed from the analysis to obtain a better explanation of the data, avoiding noise. The Broken-Stick model was used to determine which principal component axes would be retained for interpretation (Caron 2016). According to the criterion of this model, only axes with eigenvalues higher than those generated by the model may be interpreted.

Sex and gonadal development were determined macroscopically and later confirmed through histological analysis of the gonads. Histological slides were prepared by routine histological processing, and the biological material was fixed in ALFAC (80% Alcohol, Formaldehyde, and Acetic Acid), embedded in paraffin, and stained with hematoxylin-eosin. The microscopic analyses were based on and adapted from studies developed by Vazzoler (1996) and Brown-Peterson et al. (2011).

The gonadosomatic index (GSI) was determined for each specimen using the formula: GSI = (GW/TW) x 100, where GW is the weight of the gonads and TW represents the total weight of the individuals. From the individual GSI, the monthly average GSI was determined to prepare the maturation curve for separate sexes. The distribution of the monthly percentage frequency of the stages of gonadal development was performed for each sex based on the histological characterization of the gonads.

To assess the period of peak energy allocation to the reproductive process, the total condition factor (K) and the somatic condition factor (K') were determined, respectively, through the expressions: $K = TW/TL^b$ and $K' = CW/TL^b$, where TL is total length, TW is the total weight, CW is the total weight of the specimen, except for the weight of the gonads, and b corresponds to the allometry coefficient, determined through the weight-length relationship (Vazzoler 1981). The energy allocated to reproduction is calculated as the difference between K–K'. Thus, the higher the value obtained, the greater the energy allocated to reproduction.

To determine the length at first maturation (L_{50}) and maximum maturation length (L_{100}), only those with immature gonads were considered juvenile individuals and adults with gonads in the other stages of gonadal development (Fávaro et al. 2003, Oliveira and Fávaro 2011). The determination was made by using the expression $Fr = 1 - (e^{-aLmb})$, where Fr is the relative frequency of adult individuals; e the base of the neperian logarithm, a and b the coefficients estimated by the least-squares method, transforming the variables involved; and Lm = midpoint of the length classes.

The monthly sex ratio and size class were determined by the absolute frequency distribution and analyzed by the chi-square test (χ^2), with a degree of freedom and significance of 0.05 ($\chi^2 > 3.84$).

The weight and length of the specimens were used to calculate age and growth using mathematical models. The relationship between total length (TL) and total weight (TW) was estimated for separate sexes through the equation: $TW = aTL^b$, where a is the linear coefficient and b is the allometry coefficient used to determine the type of growth of a species. The Von Bertalanffy growth model is commonly used in fish age and growth studies (Cailliet et al. 2006). The growth curve to be studied for the species *S. stellifer* followed the traditional growth model from the length distribution (Vazzoler 1981): $L_t = L_{inf} (1 - e^{-k(t-t0)})$; where L_t o length of individuals at age (t) in years, L_{inf} is the maximum asymptotic size (cm) that the fish can reach, k is the growth coefficient ($year^{1}$), and t_0 is the theoretical age (years) at length zero. The Linf and k parameters were estimated using the ELEFAN I routine (Electronic Length Frequency Analysis) contained in the FAO-ICLARM Stock Assessment Tools – FISAT II Program (Gayanilo et al. 2005).

Longevity or maximum age ($T_{0.95}$) in years, defined as the time it takes an individual to reach 95% of L_{inf}, was estimated from the Taylor (1958) formula: $T_{0.95} = 3/k$.

The proportion of juvenile and adult fish was calculated using the absolute frequency distribution and analyzed using the chi-square test, with a degree of freedom and significance of 0.05 ($\chi^2 > 3.84$).

Mortality rates were calculated according to the ELEFAN II routine of the FISAT II program, using the following methods: total mortality (Z) using the frequency distribution data by length class and the obtained growth parameters L_{inf} and k; natural mortality (M) related to the average water temperature (T) and to the growth parameters calculated from the equation: $\text{Log}(M) = -0.0066 - 0.279 * \log(L_{inf}) + 0.6543 * \log(k) + 0.4634 * \log(T)$.

The Z and M values are required to calculate the capture probabilities (C25%, C50%, and C75%) from the capture curve by the length in the FISAT II program, inserted in the Mortality Estimation routine, by the method of capture curve linearized from length (Pauly 1983). The seasonal seasons used in the analysis of this study corresponds to Spring (October, November, and December), Summer (January, February, and March), Autumn (April, May, and June), and Winter (July, August, and September).

RESULTS

Monthly analysis of abiotic parameters at each sampling point revealed the highest values of dissolved oxygen and lowest values of other measured factors, such as pH, transparency, and salinity, in the inner region of the estuary (Table 1). The sample points P1, P2 and P3 corresponds to the sites with the highest captures of *S. stellifer*.

The PCA, applied to environmental data (not using transparency and accumulated rainfall), accounted for 78% of the variation, indicating the existence of spatial and temporal segregations for the sample points analyzed. According to the Broken-Stich (BS) criterion, only axis 1 was significant

Table 1. Mean values and standard deviation of abiotic data recorded at sampling points (P1–P6) in the Guaratuba estuary, Paraná, Brazil.

Abiotic data	P1	P2	P3	P4	P5	P6
Dissolved oxygen (mg. L^{-1})	8.7 ± 0.7	8.3 ± 0.9	8.1 ± 0.9	7.8 ± 0.9	7.5 ± 0.9	7.5 ± 0.9
pH	7.4 ± 0.4	7.5 ± 0.3	7.8 ± 0.4	8 ± 0.4	8.3 ± 0.3	8.4 ± 0.3
Salinity (ppm)	15.4 ± 3.1	17.5 ± 4.1	21.2 ± 3.7	23.3 ± 4.2	28 ± 3.8	28.5 ± 3.8
Temperature (°C)	21.9 ± 4.6	22.6 ± 3.8	22.5 ± 4.1	22.7 ± 3.9	22.6 ± 3.7	22.7 ± 3.7
Transparency (cm)	1.2 ± 0.4	1.1 ± 0.3	1.3 ± 0.4	1.4 ± 0.4	1.4 ± 0.3	1.5 ± 0.3
Depth (m)	3.7 ± 0.6	2.3 ± 0.5	3.2 ± 0.5	2. 7 ± 0.6	5.3 ± 0.4	5.8 ± 0.7

and retained in the analysis, representing a variation of 56% of the data. The variables pH, salinity, and dissolved oxygen were the most correlated with the axis, showing the formation of a spatial gradient in the west-east direction. Axis 2 of the PCA, despite not meeting the BS criterion to explain the variation in the data, represented a variation of 22%, with the temperature being the variable most correlated with the axis. This variable was negatively correlated with axis 2 of the PCA, showing a trend in the formation of the seasonality of the environment (Table 2). The lowest temperature values occurred between July and October, when the highest dissolved oxygen values were also observed. Pearson's correlation detected that temperature was negatively correlated with water oxygen ($r = 0.64$; $p < 0.05$).

Table 2. Eigenvalues from principal components analysis (PCA) and eigenvalues calculated by the Broken-Stick model, with the variation explained for each axis. Below, the correlation of environmental variables in axes 1 and 2 of the PCA, based on environmental data collected in the east-west axis of Guaratuba Bay, a subtropical region in southern Brazil. In bold are the most correlated variables in each PCA axis.

	Axis 1	Axis 2
Eigenvalues	2.801	1.097
Broken-Stick	2.283	1.283
Variation explained (%)	56.0	22.0
Eigenvectors		
Dissolved oxygen (mg/l)	**0.7762**	0.2914
pH	**0.8798**	-0.0095
Salinity (‰)	**0.8594**	0.2514
Temperature (°C)	0.3712	**-0.7894**
Depth (m)	0.4687	0.4294

A total of 1,363 specimens of *S. stellifer* were captured, particularly in the three innermost points of the Guaratuba Bay estuary (99% of the total collected), with the innermost point (P1) being the site of greatest capture (76.8%). The highest captures occurred in winter and spring, respectively.

Of the 1,363 captures, 747 specimens of *S. stellifer* with visually identified sex were used in the reproductive analyses. The minimum and maximum total length values for females were 8.2 cm and 22.3 cm, and for males, 8.5 cm and 21.1 cm, respectively. Of the total, 616 specimens were considered undetermined due to the difficulty of identifying the sex by the size of the gonads, with the minimum length recorded in the capture being 7.3 cm.

Through microscopic analysis of the gonads, five stages of ovarian and testicular development were characterized for *S. stellifer*: Immature (A), Maturation (B), spawning capable (C), partially spawned /partially spermated (female/males) (PS), and Spawned (D)/ Emptied (E) (females/males). The spawned and emptied stages, respectively, for females and males, comprise the gonads that eliminate gametes and the subsequent phases of gonad regeneration. We recorded split spawning in the species based on the presence of partially spawned ovaries and testes in the examined specimens (Fig. 2).

The influence of environmental variables on the monthly distribution of gonadal maturation stages was observed through cluster analysis. The first two axes of the CCA explained 44 and 68% of the variation in distribution for females and males, respectively. Temperature was considered one of the most significant variables for both sexes, while transparency and pH were exclusive for females and males, respectively (Table 3).

Table 3. Result of canonical correspondence analysis (CCA) of gonadal maturity stages of females and males of *Stellifer stellifer* with environmental variables of Guaratuba Bay, southern Brazil.

Abiotic factors	Female			Males		
	Axis 1	Axis 2	r^2	Axis 1	Axis 2	r^2
pH	0.33	-0.70	0.27	**-0.54**	**0.70**	0.47*
Transparency	**-0.83**	0.02	0.62*	0.11	-0.77	0.27
Temperature	**-0.51**	**-0.75**	0.64*	**-0.86**	-0.34	0.59*
Dissolved oxygen	0.25	0.69	0.34	0.52	0.01	0.19
Salinity	-0.30	-0.69	0.25	-0.27	0.21	0.06
Depth	-0.27	-0.62	0.19	0.29	0.10	0.01
Variation explained (%)	30	14	–	38	30	–

*Significant to $\alpha = 0.05$.

The higher occurrence of developing females was in July, a time of low temperature. Partially spawned or partially spermated specimens occurred in greater quantity in December, a time of high temperature and transparency, and post-spawned specimens in March, a time of low transparency. Males in the developing stage occurred from July to September, months of low temperature and pH. Males in the post-sperm stage occurred between March and May, a time of higher temperature and pH. Females in the immature and mature stages did not present a significant relationship with the environmental variables, nor did mature and partially spermated males. No males in the immature stage were collected.

The analysis of the reproductive cycle of the species, determined through the monthly average values of the

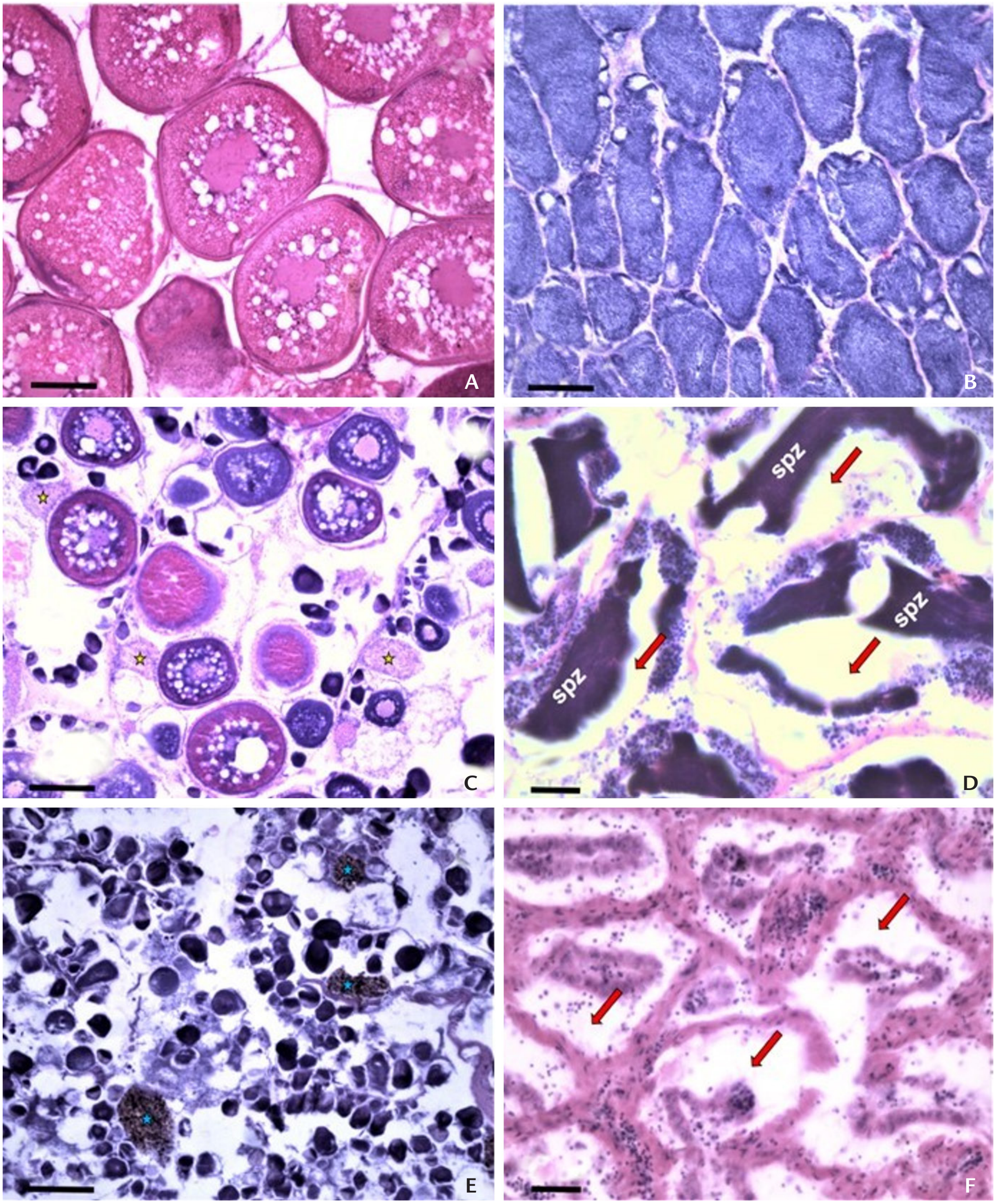

Figure 2. Histological analysis of ovaries and testes of *Stellifer stellifer* obtained from Guaratuba Bay, Paraná, Brazil: (A) Reproductive-capable Ovary – full of mature oocytes; (B) Reproductive-capable Testis – seminiferous tubules containing sperm; (C) Partially Spent Ovary – oocytes in different developmental stages and presence of post-ovulatory follicles (yellow star); (D) Partially Empty Testis – seminiferous tubules showing sperm (spz) and spaces (red arrows) indicating partial elimination of male gametes; (E) Spent Ovary – disorganization of oogenic lamellae and presence of residual body (blue star); (F) Empty Testis – seminiferous tubules containing separated germ cells, showing total sperm elimination. Hematoxylin-Eosin staining. Scale bars: A–C, E = 180 µm, D, F = 43 µm.

GSI and the monthly distribution of the frequency of gonadal development stages, showed that the reproductive period occurred at the end of winter and during spring, from September to December for both sexes. This period corresponded to the highest average GSI values, which was further supported by the higher frequency of gonads in stages suitable for reproduction and partially spawned/partially spermated. The energetic investment in gonadal development was higher during the reproductive period for both sexes, coinciding with elevated GSI values and the highest frequencies of gonads in reproductive activity (Table 4).

Table 4. Mean values and standard deviation of monthly gonadosomatic index (GSI), energy allocated to the reproductive process (K–K'), and monthly distribution of frequency (%) of ovarian and testicular development stages of *Stellifer stellifer* captured in Guaratuba Bay, Paraná, Brazil. (A) immature, (B) developing, (C) mature, (PS) partially spawned female/partially spermated male, (D) post-spawned female, (E) post-sperm male.

Months	Females		Stages of ovarian development (%)				
	GSI	K–K'	A	B	C	PS	D
Nov-12	**1.10 ± 1.1**	**0.00010**	**12**	**0**	**0**	**32**	**56**
Dec-12	**2.0 ± 0.9**	**0.00018**	**7**	**0**	**11**	**0**	**82**
Jan-13	0.74 ± 0.2	0.00007	7	0	0	93	0
Feb-13	0.73 ± 0.2	0.00006	10	0	0	90	0
Mar-13	0.56 ± 0.3	0.00005	20	0	0	80	0
Apr-13	0.75 ± 0.2	0.00007	0	0	0	100	0
May-13	0.66 ± 0.2	0.00007	7	0	0	93	0
Jun-13	0.80 ± 0.3	0.00007	14	0	0	86	0
Jul-13	0.85 ± 0.3	0.00008	6	33	0	61	0
Aug-13	**1.01 ± 0.3**	**0.00010**	**0**	**21**	**0**	**8**	**71**
Sep-13	**3.60 ± 2.0**	**0.00036**	**3**	**0**	**65**	**9**	**23**
Oct-13	**2.05 ± 1.7**	**0.00021**	**0**	**9**	**33**	**30**	**28**
Months	Males		Stages of testicular development (%)				
	GSI	K–K'	A	B	C	PS	E
Nov-12	**1.1 ± 0.7**	**0.00008**	**0**	**0**	**25**	**75**	**0**
Dec-12	**1.1 ± 0.4**	**0.00008**	**0**	**0**	**50**	**47**	**3**
Jan-13	0.3 ± 0.1	0.00002	0	0	0	25	75
Feb-13	0.2 ± 0.03	0.00002	0	0	0	10	90
Mar-13	0.14 ± 0.1	0.00001	0	10	0	10	80
Apr-13	0.16 ± 0.1	0.00001	0	0	0	0	100
May-13	0.15 ± 0.1	0.00001	0	5	0	10	85
Jun-13	0.13 ± 0.04	0.00001	0	0	0	0	100
Jul-13	0.3 ± 0.2	0.00003	0	80	0	0	20
Aug-13	0.51 ± 0.2	0.00004	0	100	0	0	0
Sep-13	**1.771 ± 0.9**	**0.00015**	**0**	**30**	**50**	**0**	**20**
Oct-13	**2.08 ± 0.6**	**0.00017**	**0**	**0**	**100**	**0**	**0**

The length at first maturation (L_{50}) of females was 11.8 cm, and the length where all specimens participate in the reproductive process (L_{100}) was 15.6 cm (Fig. 3). Because juvenile males were not obtained in the samples, we could not calculate the L_{50} for males.

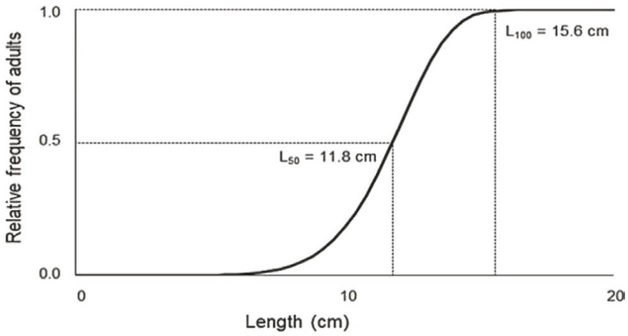

Figure 3. Length at first maturity (L_{50}) estimated for female *Stellifer stellifer* collected in Guaratuba Bay, Paraná, Brazil.

The analysis of the monthly sex ratio showed no clear trend throughout the year or during the reproductive period. However, there were significant differences with a predominance of females in March, July, and October and a predominance of males in December, April and August. When the sex ratio was analyzed seasonally, it showed that in the reproductive period (winter and spring), there was no significant difference between the sexes ($\chi^2 < 3.84$). However, during the summer and autumn a significant difference was found ($\chi^2 > 3.84$), with a predominance of females in summer and males in autumn. The sex ratio by length class revealed a predominance of females in both the smallest and largest length classes and a predominance of males in the intermediate length classes, ranging from 10.5 to 16.7 cm (Table 5).

We examined the weight-length relationship to understand the growth patterns of the species. This analysis allowed us to identify key characteristics of its development. We characterized the positive allometric growth (b > 3) of both sexes through the weight-length relationship, which was confirmed by the expressions $y = 0.01x^{3.06}$ and $y = 0.008x^{3.14}$, respectively, for females and males.

Obtaining the asymptotic length (L_{inf}) and the growth coefficient (k) made it possible to determine the growth curve for age calculation, which is represented by the expression $Lt = 24.5\ (1 - e^{-0.53\ (t-t0)})$ and $Lt = 22.8\ (1 - e^{-0.44\ (t-t0)})$ for females and males, respectively (Fig. 4). Table 6 summarizes the parameters of the species' population structure.

In the studied environment, specimens were obtained with ages ranging from eight months to five years for females and from one to six years for males. For females, only 5% of

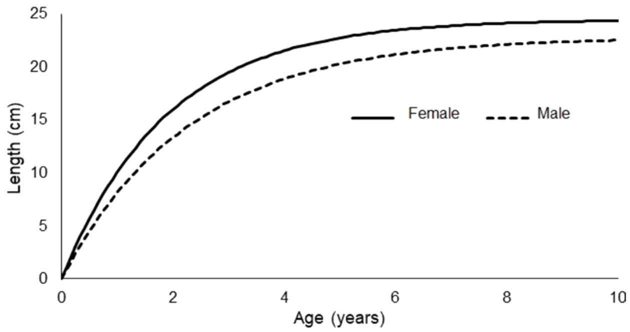

Figure 4. Length growth curve (cm) as a function of the age of females and males of *Stellifer stellifer*, collected in Guaratuba Bay, Paraná, Brazil.

Table 5. Monthly sex ratio and sex ratio by length class of *Stellifer stellifer* in Guaratuba Bay, Paraná, Brazil.

	Females	Males	χ^2
Months			
Nov–12	9	16	1.96
Dec–12	28	72	19.36*
Jan–13	30	27	0.16
Feb–13	31	24	0.89
Mar–13	50	31	4.46*
Apr–13	20	42	7.81*
May–13	30	30	0.00
Jun–13	7	14	2.33
Jul–13	49	13	20.90*
Aug–13	14	43	14.75*
Sep–13	35	30	0.38
Oct–13	65	35	13.7*
Class of length			
7.3–8.8	7	0	7.00*
8.9–10.4	14	8	1.64
10.5–11.9	11	25	5.44*
12.0–13.5	24	52	10.32*
13.6–15.1	10	24	5.76*
15.2–16.7	28	67	16.01*
16.8–18.3	72	94	2.92
18.4–19.8	75	71	0,11
19.9–21.4	58	19	19.75*
21.5–23.0	25	1	22.15*
23.1–24.6	2	0	2.0

*Significant difference ($\chi^2 > 3.84$).

Table 6. Population structure parameters used to determine the life history traits of *Stellifer stellifer*, in the Guaratuba Bay estuary, southern Brazil. (n) Number of specimens, (Ct_{min}) Minimum total length (cm), (Ct_{max}) Maximum total length (cm), (Pt_{min}) Minimum total weight (g), (Pt_{max}) Maximum total weight (g), (L_{inf}) Asymptotic length (cm), (k) Growth coefficient, ($T_{0.95}$) Longevity and b value of the weight-length relationship.

Sex	n	Ct_{min}	Ct_{max}	Pt_{min}	Pt_{max}	L_{inf}	K	$T_{0.95}$	b value
Female	370	7.3	22.3	4.63	154.22	24.46	0.53	5.65	3.06
Male	377	9.7	21.1	8.17	114.34	22.78	0.44	6.81	3.14

the specimens collected were young-of-the-year, and more than 80% were between one and three years old. Juvenile males who were older than one year were not collected; 26% were one year old, and 66% were between two and four years old. The Number of juvenile fishes collected (n = 25) corresponded to 3.3% of the total, with a higher frequency of adults throughout the study period ($\chi^2 > 3.84$; df = 1; $p < 0.05$).

However, both sexes' natural mortality (M) was greater than 1, with values lower than the total mortality (Z). The 25% and 50% capture probabilities identified similar lengths for males and females, but there was a slight difference at the 75% probability, with 18.6 cm for males and 19.4 cm for females (Table 7).

Table 7. Mortality parameters ($year^{-1}$) and capture probabilities (cm) used to determine the life-history traits of *Stellifer stellifer*, in the Guaratuba Bay estuary, southern Brazil. (n) Number of specimens, (Z) Total mortality rate, (M) Natural mortality rate and the probabilities of capture (C25%, C50%, C75%).

Sex	n	Z	M	$C_{25\%}$	$C_{50\%}$	$C_{75\%}$
Female	370	1.5	1.12	16.1	17.7	19.4
Male	377	1.6	1.01	16.1	17.4	18.6

DISCUSSION

Our results indicate the presence of an environmental gradient in the Guaratuba Bay estuary, with decreasing values from the outer to the inner sector, as shown by the abiotic data. This spatiotemporal variation led to the highest occurrence and abundance of *S. stellifer* in the inner estuary, particularly during winter and spring. Similar patterns have been reported for *Micropogonias furnieri* (Desmarest, 1823) (Sciaenidae) and other species of Engraulidae, which use estuaries as a winter refuge (Pessanha and Araujo 2003). The seasonal environmental gradient observed in the study area, influenced by variations in pH and dissolved oxygen, has also been reported in other estuaries in subtropical and tropical regions of Brazil (Costa et al. 2018, Santos et al. 2020), supporting our findings. The appearance of an environmental gradient allows the species under study to occupy different habitats and niches, avoiding competition for resources and allowing the occurrence of distinct populations (Dantas et al. 2015). About 55% of fish species that are studied as bycatch recorded a positive allometric growth related to environmental conditions or morphological characteristics, in addition to a condition factor close to one, showing a general state of well-being of the fish species (Santos et al. 2022) as was also recorded for *S. stellifer* in this study.

Regarding reproductive characteristics, microscopic analyses of the gonads resulted in the same maturity scales already established for other species in studies carried out in a subtropical estuary in southern Brazil (Oliveira and Fávaro 2010, 2011, Possamai and Fávaro 2015, Carvalho et al. 2021). The observation of partially spawned and partially spermated gonads allowed the characterization of split spawning in *S. stellifer*, the same reproductive pattern reported for its congeners *S. rastrifer* and S. *naso* in a tropical environment (Camargo and Isaac 2005). Due to the high abundance of juvenile specimens and the lack of adults in the captures, some authors did not describe the gonadal stages of the species (Rodrigues-Filho et al. 2011, Pombo et al. 2012, Silva-Junior et al. 2015).

The reproductive period, characterized by the end of winter and all spring (September to December), has occurred during the same period of higher energy investment for gonadal development. Furthermore, the reproductive period coincides with the highest abundances in captures, demonstrating the use of the environment in the reproductive process of the species. There is a significant correspondence between the reproduction of the species under study and that of the seven-bearded shrimp, *X. kroyeri*, in the Guaratuba region. This species of shrimp reproduces throughout the year, with two periods of high reproductive frequency, between September and December, and in April and May (Natividade 2006). This overlap between reproductive periods is essential for understanding fishing activity, fisheries management, and its implications for both populations. Since fishing gear is often not highly selective, fishing activities can simultaneously impact multiple species during their most vulnerable stages. This may lead to a decrease in reproductive success, affecting the maintenance of fishery resource stocks and, consequently, the long-term sustainability of populations. However, to assess the real impact, it would be necessary to conduct long-term studies that monitor the population trends of both species.

Regarding the distribution of the species in the estuary Guaratuba, Costa et al. (2012) recorded a predominance of larvae in the internal region of the estuary using a conical net with a 200 µm mesh. This information complements our results on the distribution of juveniles and adults in the reproductive season inside the estuary. Furthermore, the occurrence of larvae is a pattern described in estuaries for several species of Sciaenidae, including species of *Stellifer* (Santos and Severi 2019).

The sex ratio results are influenced by the selective nature of the trawl gear and mesh size, chosen because bottom trawling is the primary method for capturing shrimp, the main fishery resource in the region. Shrimp fishing also generates a large bycatch of Sciaenidae species, including *S. stellifer*, which accounted for over 19% of the total catch in the study by Zanlorenzi (2016). Our results showed that although females of *S. stellifer* reach larger sizes than males, males tend to live longer. These findings are crucial for monitoring how the population uses the estuarine environment, supporting reproductive success and environmental balance, and thus sustaining a viable population and fishery stock.

Most captured individuals were adult males, mainly in the length classes 16.2–19.1 cm, although the largest specimens were females. The fishing gear used had little effect on the capture of immature individuals; more than 90% of the specimens were adults between one and four years of age, representing the portion of the population most active in reproduction. Along the Paraná coast, shrimp is the primary fishery resource, and the nets used for shrimp capture are also responsible for the bycatch of *S. stellifer*. Our results indicate that *S. stellifer* completes its life cycle inside the Guaratuba estuary and, despite being exploited as bycatch, shows a reproductive process marked by seasonality and rapid growth. The data obtained can support management and conservation plans for both the species and the estuarine environment.

Although the data were collected some years ago, they provide a valuable historical baseline for understanding the biology and ecology of the species, supporting the evaluation of long-term population dynamics under increasing anthropogenic pressures and climate change. Given the limited life history data for estuarine species in subtropical Brazil, this study helps address a significant knowledge gap. Considering ongoing environmental changes in the region, further research on this topic is warranted.

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Submitted: August 13, 2024
Accepted: June 4, 2025
Editorial responsibility: Paulo Andreas Buckup

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SBCC, LFF: Conceptualization, Data curation, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. DZ, FWCK: Conceptualization, Data curation, Methodology, Writing – review & editing.

Competing Interests

The authors have declared that no competing interests exist.

Data Availability

Datasets related to this article are available upon request to the corresponding author.

Funding

This work was funded by the "Vice-chancellor's fund for support of research activities" at the Universidade Federal do Paraná (PRPPG 04/2018 and PRPPG 02/2020). SBCC and DZ was funded by and acknowledges the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES Finance Code 001).

How to cite this article

Casado-del-Castillo SB, Zanlorenzi D, Chu-Koo FW, Fávaro LF (2025) Life-history traits and population structure of *Stellifer stellifer* (Actinopterygii: Sciaenidae) in a subtropical estuary in southern Brazil. Zoologia 42: e24053. https://doi.org/10.1590/S1984-4689.v42.e24053

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