ORIGINAL RESEARCH

Age structure and biological parameters of southern blue whiting (*Micromesistius australis*) in its main concentration area in the southwestern Atlantic Ocean in 2019

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Marine and Fishery Sciences MAFIS

ABSTRACT. A comprehensive understanding of a species life history is fundamental for effective fisheries management. This study contributes crucial, up-to-date information by analyzing the age structure and key biological parameters of southern blue whiting (*Micromesistius australis*) in the area defined by the 52° S-56° S parallels, based on data collected in 2019. It determined the population structure, growth parameters, and natural mortality using data from 2019 commercial bottom trawls and one research cruise. Analyzed specimens ranged from 26 to 59 cm total length (TL) in males and 26 to 64 cm TL in females. Length-frequency distributions were similar between sexes, with a main mode between 45 and 47 cm TL. Age analysis of 2,378 otoliths indicated a minimum age of two years and maximum ages of 20 years old. Significant differences in growth parameters were observed between sexes, primarily due to females having a larger asymptotic length. Von Bertalanffy growth function parameters were: females $L_\infty = 63.93$ cm, $K = 0.18$ year^{-1}, and $t_0 = -1.41$ years; and males, $L_\infty = 57.43$ cm, $K = 0.21$ year^{-1}, and $t_0 = -1.39$ years. The length-weight relationship also showed a significant sex difference. Length and age at 50% maturity were estimated at 35.25 cm TL and 2.93 years, respectively, with no significant differences between sexes. Estimates of instantaneous natural mortality ranged from 0.27 to 0.33 year^{-1}. These findings provide valuable insights into *M. australis* life history in the region, relevant for future stock assessments and sustainable management strategies. The inclusion of Malvinas Islands data significantly enhances the robustness and applicability of these findings across the Southwest Atlantic.

Key words: Length frequency, age determination, growth, maturity, mortality.

OPEN ACCESS

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Received: 28 May 2025
Accepted: 17 September 2025

ISSN 2683-7595 (print)
ISSN 2683-7951 (online)

https://ojs.inidep.edu.ar

Journal of the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP)

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Estructura de edad y parámetros biológicos de la polaca (*Micromesistius australis*) en su área de concentración principal en el Océano Atlántico Sudoccidental en 2019

RESUMEN. Una comprensión integral del ciclo de vida de una especie es fundamental para una gestión pesquera eficaz. Este estudio aporta información crucial y actualizada al analizar la estructura de edad y los parámetros biológicos clave de la polaca (*Micromesistius australis*) en el área definida por los paralelos 52° S-56° S, con base en datos recopilados en 2019. Se determinó la estructura de la población, los parámetros de crecimiento y la mortalidad natural utilizando datos del arrastre de fondo comercial de 2019 y de un crucero de investigación. Los especímenes analizados variaron de 26 a 59 cm de longitud total (LT) en machos y de 26 a 64 cm de LT en hembras. Las distribuciones de frecuencia de longitud fueron similares entre sexos, con una moda principal entre 45 y 47 cm de LT. El análisis de edad de 2.378 otolitos indicó una edad mínima de dos años y una edad máxima de 20 años. Se observaron diferencias significativas en los parámetros de crecimiento entre sexos, principalmente debido a que las hembras tenían una mayor longitud asintótica. Los parámetros de la función de crecimiento de von Bertalanffy fueron: hembras, $L_\infty = 63{,}93$ cm, $K = 0{,}18$ años^{-1} y

t_0 = -1,41 años; y machos, L_∞ = 57,43 cm, K = 0,21 años^{-1} y t_0 = -1,39 años. La relación longitud-peso también mostró una diferencia sexual significativa. La longitud y la edad al 50% de madurez se estimaron en 35,25 cm LT y 2,93 años, respectivamente, sin diferencias significativas entre sexos. Las estimaciones de mortalidad natural instantánea oscilaron entre 0,27 y 0,33 años^{-1}. Estos hallazgos proporcionan información valiosa sobre el ciclo de vida de *M. australis* en la región, relevante para futuras evaluaciones de stock y estrategias de gestión sostenible. La inclusión de datos de las Islas Malvinas mejora significativamente la solidez y la aplicabilidad de estos hallazgos en todo el Atlántico Sudoccidental.

Palabras clave: Frecuencia de longitud, determinación de edad, crecimiento, madurez, mortalidad.

INTRODUCTION

The southern blue whiting, *Micromesistius australis* (Norman 1937) is a demersal-pelagic species typically found in cold waters of the Malvinas Current. It is distributed throughout the southern cone of America in both the Atlantic and Pacific oceans (Bellisio et al. 1979; Perrota 1982; Aguayo et al. 2010), in the Scotia Sea, around the South Georgia, South Shetland, and South Orkney Islands (Otero 1976; Cousseau and Perrotta 2000). In the Atlantic, this species is found between 37° S and 47° S on the slope region, and between 47° S and 56° S on the slope and shelf (Otero 1976; Perrotta 1982; Cousseau and Perrotta 2000). Its bathymetric distribution ranges from 100 m to approximately 800 m (Madirolas 1999; Wöhler et al. 2004).

This species is an important commercial fishery resource in the southwestern Atlantic, with its highest abundances found south of 45° S. Commercial vessels mostly catch it between 52° S and 55° S (Wöhler and Marí 1999; Wöhler et al. 2004; Gorini et al. 2021; Ruocco et al. 2023; Alemany et al. 2024). In the 1990s, the southern blue whiting was the second most important commercial fish species in the southwestern Atlantic in terms of catch volume, accounting for around 100,000 t year^{-1} (Wöhler et al. 2004; Zavatteri et al. 2023). Following this period, intense fishing pressure led to a decline in the stock's abundance and landings. More recently, total catches have gradually recovered, averaging around 15,000 t year^{-1} (Ramos and Winter 2023; Zavatteri et al. 2023). These results may be consequence of decreased fishing effort in the southwestern Atlantic Ocean (Ramos and Winter 2023; Zavatteri et al. 2023).

In the southwestern Atlantic, *M. australis* is known to reproduce south and southwest of the Malvinas Islands, at depths of 200 to 500 m, with spawning occurring from August to October and a marked increase in reproductive activity in September (Perrotta 1982; Sánchez et al. 1986; Pájaro and Macchi 2001; Agnew 2002; Macchi et al. 2005). This long-lived species reaches a maximum age of 23 years, as determined by counting growth rings in otoliths (Barrera-Oro and Tomo 1988; Cassia 1996, 2000, 2006). However, subsequent studies have revealed shorter longevity (Ruocco 2022; Ruocco et al. 2024).

Determining the age and growth of fish allows for a better understanding of their life cycle, reproductive patterns, mortality, longevity, and individual and population responses to habitat changes. This information is essential because these biological parameters form the basis of age-structured stock assessment models used for the sustainable management of fisheries.

Although there have been biological studies on the southern blue whiting in the area, such as population composition, reproduction, and growth, these data are limited and, in some cases, lacks specific information from the Malvinas Islands area. To further investigate and expand previous research on *M. australis*, this study provides a comprehensive analysis of the species' most important life history aspects within its main concentration area of the southwestern Atlantic (52° S-56° S), including records from the Malvinas Islands. This integration of information is fundamental for understanding the biology of the species and provides a unique opportunity to comprehend the dynamics of this resource, which is particularly relevant considering that the Malvinas Island is the species' reproductive zone in the Atlantic Ocean. Therefore, this study aimed to characterize the population structure of the southern blue whiting by length and age, as well as to determine growth parameters in length, the length at which 50% of males and females reach maturity, and the instantaneous rate of natural mortality.

MATERIALS AND METHODS

Data were obtained from commercial bottom trawls every month and one research cruise in 2019. The 'VA2019/08' acoustic survey cruise provided supplemental data for September and aimed to estimate spawning stock biomass of *M. australis* (Figure 1).

For each specimen, total length to the nearest centimeter (TL, cm), weight (g), sex, and gonadal maturity stage were recorded. Gonadal maturity was determined macroscopically using the scale that includes the following stages: 1) Virgin, 2) Maturing, 3) Spawning/Running, 4) Spent, and 5) Resting (Macchi and Acha 1998). *Sagitta* otoliths were extracted, cleaned and stored dry in paper envelopes for subsequent age determination. The only processing technique for the otolith, before age reading, was hydration. To improve the contrast between hyaline and opaque bands, they were submerged in freshwater for 24 h before reading, following the methodology of Zumpano and Ruocco (2018). Each sample was analyzed while submerged in water on a black surface with reflected light. Otolith readings were taken using a stereomicroscope at 10X magnification. Only otoliths with legible rings were considered.

Age (A) estimates were determined by counting hyaline rings from the nucleus along the internal axis to the edge of the otolith (Figure 2). The interpretation of annual rings followed the methodology of Barrera-Oro and Tomo (1988). The validation of annual growth ring formation has been previously conducted for the species (Cassia 2006), and the first annual ring has been validated by analyzing daily ring readings in the otoliths (Cassia and Morioka 1999). Based on data collected from these readings, the age of each specimen was determined within its corresponding age group and annual

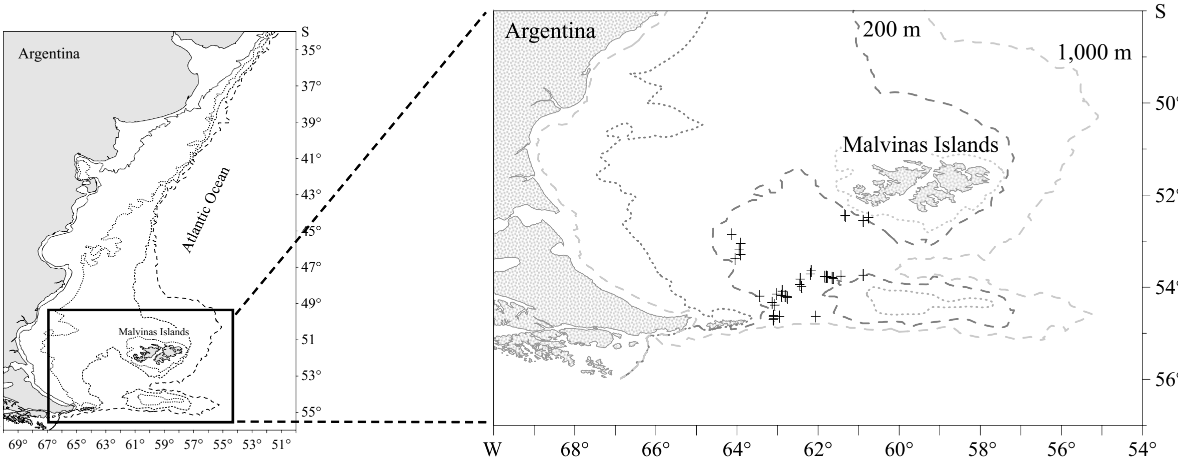

Figure 1. Study area in the southwestern Atlantic Ocean showing the location of sampling sites for *Micromesistius australis* during 2019.

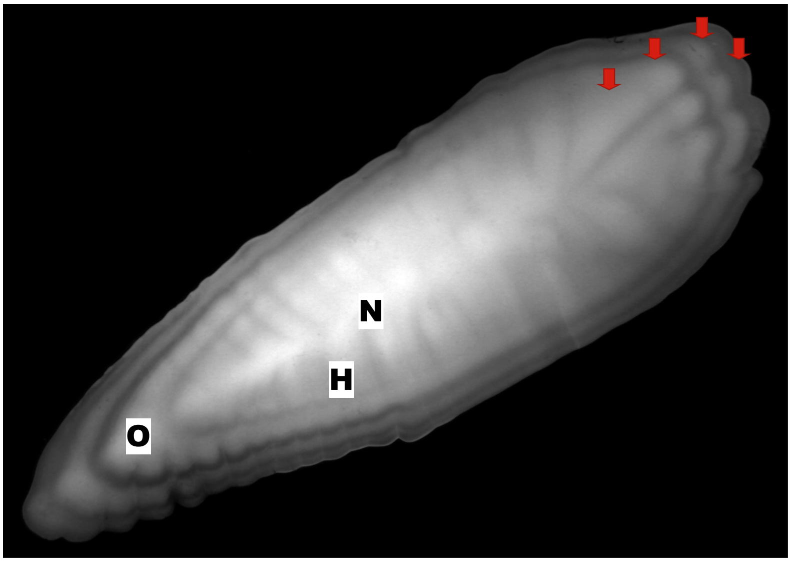

Figure 2. *Sagitta* otolith of *Micromesistius australis*. N: nucleus. O: opaque rings. H: hyaline rings. Age group 4, female 41 cm TL.

class. For this purpose, August 1st was designated as the birthday (Cassia 2006).

Length and age distributions for male and female southern blue whiting were determined for the study year using 2,378 specimens (1,213 females, 1,165 males). Length-age keys were constructed for the entire sample and for each sex (sexes combined). Subsequently, the number of individuals within each age group, mean lengths and their respective variances were calculated. These data were used to estimate the von Bertalanffy growth function (1938):

$$TL = L_{\infty}\ (1\text{-exp}^{(-K\ (t\ -\ t_0))})$$

where TL corresponds to the total length of the fish at age t. The first parameter in the von Bertalanffy growth function (VBGF), L_{∞}, represents the theoretical maximum mean length rather than the absolute maximum length attainable by an individual fish. Some individuals may exceed L_{∞}. The second parameter, K, refers to how quickly the growth function approaches L_{∞}. Although K is often referred to as a growth coefficient, it is not a growth rate in the traditional sense. The third parameter, t_0, represents the x-intercept of the VBGF curve and is essential to fit the model. However, t_0 does not have a biological meaning because no fish can have a length of zero.

To investigate potential differences in growth parameters between sexes, eight distinct models were fitted to VBGF, following the methodology outlined by Ogle (2016). The most complex model allowed all three parameters to vary between sexes (L_{∞}, K, t_0), while the simplest model assumed no such differences (Ω). Intermediate models included three in which only two parameters differed between sexes (models 2, 3 and 4), and other three in which only one parameter varied (models 5, 6 and 7) (Table 1). These models were compared using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The model with the lowest IC value was considered the best fit to the data (Burnham and Anderson 2002).

Parameters for the weight-length relationships were calculated using the equation $W = a * TL^b$, where W represents weight, a is the intercept value, and b is the slope. Linear regression on log-transformed data was used to estimate parameters a and b for both sexes, as well as females and males

Table 1. Models fitted to consider potential differences in growth parameters between sexes. L_∞, K, t_0 growth parameters, Ω: null model (no parameter differs between groups).

Model	VBGF parameter variation	Model
1	L_∞, K, $_t0$	$TL_t = L_\infty[Sex]*(1\text{-exp }(-K[Sex]*(^{t - t_0}[Sex])))$
2	L_∞, K	$TL_t = L_\infty[Sex]*(1\text{-exp }(-K[Sex]*(^{t - t_0})))$
3	L_∞, t_0	$TL_t = L_\infty[Sex]*(1\text{-exp }(-K*(^{t - t_0}[Sex])))$
4	K, t_0	$TL_t = L_\infty*(1\text{-exp}(-K[Sex]*(^{t - t_0}[Sex])))$
5	L_∞	$TL_t = L_\infty[Sex]*(1\text{-exp }(-K*(^{t - t_0})))$
6	K	$TL_t = L_\infty*(1\text{-exp}(-K[Sex]*(^{t - t_0})))$
7	t_0	$TL_t = L_\infty*(1\text{-exp }(-K*(^{t - t_0}[Sex])))$
8	Ω	$TL_t = L_\infty*(1\text{-exp }(-K*(^{t - t_0})))$

individually. These relationships were compared between sexes using an analysis of covariance (ANCOVA) conducted in R (version 4.3.1).

The TL_{50} and A_{50} at which 50% of individuals reached maturity were estimated for males, females and sex combined using maximum likelihood methods. These estimations were based on the proportions of mature individuals within each length class and age group, respectively. The analysis considered only the reproductive months (August, September and October). Data from August and October were obtained from commercial catches, while September data were collected during a research survey. During this survey, gonadal stages were determined macroscopically on board and subsequently confirmed and refined microscopically using histological techniques. Maturity parameters between sexes were compared using a χ^2 test.

The instantaneous rate of natural mortality (M) was determined using global estimators. The methods considered were:

- Pauly (1980):

$$M = 10^{(-0.0066-0.279\log_{10}(L_\infty) + 0.645\log_{10}(K) + 0.463\log_{10}(T))}$$

where K and L_∞ (cm) are parameters from VBGF, and T is the average annual sea surface temperature measured at 9 °C. It is regarded a factor influencing natural mortality and the growth parameters L_∞ and K.

- Hoenig et al. (1983):

$$M = e^{1.46-1.01\log_e(t_{max})}$$

where t_{max} is the maximum age of the fish in the stock.

Then et al. (2015) recommended M = 4,899 $t_{max}^{-0.916}$ when t_{max} is possible to determine; if t_{max} cannot be obtained, this function can be used: M = 4,118 $K^{0.73}$ $L_\infty^{-0.33}$. To determine the maximum age or longevity of a fish (t_{max}), the equation of Taylor (1958) was employed: $t_{max} = t_0/K$, where 0.95 is the theoretical maximum age (t_{max}) or time required for the fish to reach 95% of its maximum length L_∞.

These meta-analysis estimation equations were included and have been coded in metaM from FSA. All analyses were performed in R program (version 4.3.1), with the methodology employed by Ogle (2016) as a guide.

RESULTS

Individuals ranged from 26 to 59 cm TL in males and from 26 to 64 cm TL in females (Figure 3). The

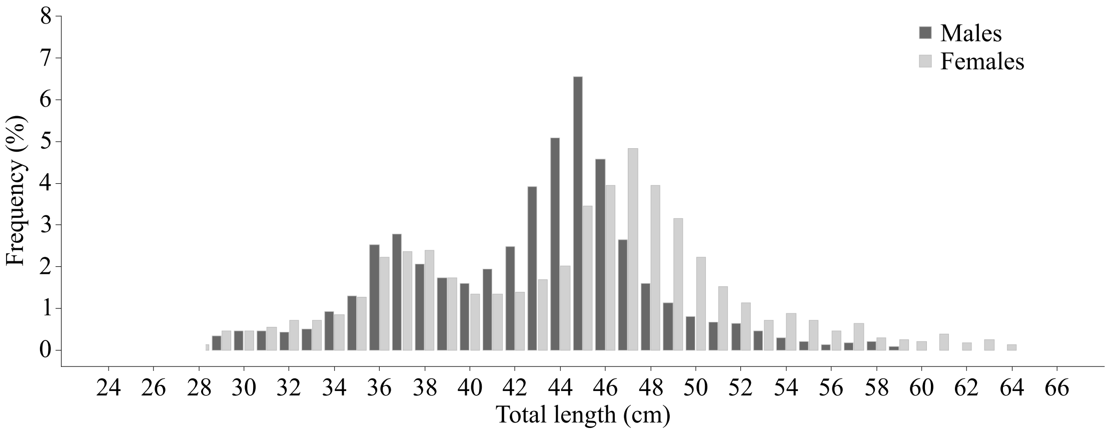

Figure 3. Total length frequency distribution of southern blue whiting females and males. Year 2019.

length distribution exhibited two primary modes in both sexes. The main mode comprised individuals measuring 45 cm TL in males and 47 cm TL in females, while the secondary mode, occurring at a lower frequency, was found between 36 and 38 cm TL in both sexes. In both size ranges, a shift in the female modal value relative to males was evident; however, this shift was more pronounced in larger specimens (Figure 3).

Age analyses were performed on 2,368 specimens (1,206 females and 1,162 males). Ten individuals were excluded due to unidentifiable growth rings. The minimum age recorded was two years for both sexes, while maximum ages reached 17 years for males and 20 years for females. Females exhibited a greater mean TL at each age compared to males (Table 2; Figure 4). Similar age structures were evident between sexes, with age six being the most frequent, although a secondary peak was observed at age four. Age six comprised 16% of males and 13% of females, whereas age four constituted approximately 10% in both. Individuals younger than three and older than seven years were scarce in both sexes (Figure 4).

Von Bertalanffy growth parameters for females presented a larger L_∞ than males, while the opposite trend was observed for the K parameter. The t_0 values were similar between sexes (Table 3; Figure 5).

The statistical comparison between sexes indicated significant differences ($\chi^2 = 305.3$; $p < 2.2e-16$) across parameters considered. The best model explaining difference in growth between sexes was model 2, in which L_∞ and K varied between groups. This model had the lowest AIC and BIC values (Table 4). Further analysis revealed that these differences were solely driven by L_∞ ($\chi^2 = 229.06$; $p < 0.05$), with females having a greater one than males.

Females ranged in weight from 90 g (27 cm TL, two years old) to 2,066 g (61 cm TL, 15 years old) while males weighed between 100 g and 1,600 g, with extreme values observed at 26 cm TL (two years) and 58 cm TL (16 years), respectively (Figure 6). A significant length-sex interaction was found ($p < 0.032$), indicating a slight difference in the length-weight relationship between males and females (Table 5). This relationship was modeled as $W = 0.0045 * TL^{3.07264}$ for males and $W = 0.0030 * TL^{3.18107}$ for females. Correlation coefficients indicated a good fit to the power model for both sexes (males $R^2 = 0.8963$, females $R^2 = 0.9344$).

The estimated length and age at maturity did not differ significantly between males and females in southern blue whiting (TL_{50}: $\chi^2 = 1.52$, df = 1, p = 0.217, n = 768; A_{50}: $\chi^2 = 1.12$, df = 1, p = 0.289, n = 763; Table 6). When sexes were combined, the

Table 2. Mean total length (TL, cm), variance (Var), and number of specimens (N) by age and sex of southern blue whiting. Total: both sexes combined. Year 2019.

	Males			Females			Total		
Age	Mean TL	Var	N	Mean TL	Var	N	Mean TL	Var	N
2	30.0	7.7	8	28.4	5.3	5	29.4	6.9	13
3	34.3	7.5	163	34.5	8.1	198	34.4	7.8	361
4	38.7	4.4	241	39.2	5.3	232	39.0	4.9	473
5	43.3	2.6	162	44.7	2.2	120	43.9	2.9	282
6	45.0	1.9	388	46.7	3.1	301	45.7	3.1	689
7	47.4	5.0	103	49.1	3.9	199	48.5	4.9	302
8	49.6	5.0	27	51.3	6.8	40	50.6	6.7	67
9	49.9	8.5	15	53.2	3.7	22	51.9	8.2	37
10	51.8	3.8	27	55.0	4.8	36	53.7	6.9	63
11	52.0	4.5	9	56.9	5.9	16	55.1	10.9	25
12	54.2	3.8	6	58.9	6.5	14	57.5	10.5	20
13	55.5	6.3	4	62.0	1.0	3	58.3	15.6	7
14	57.2	2.2	6	60.7	5.6	7	59.1	7.1	13
15	58.0	-	1	60.0	1.0	5	59.7	1.5	6
16	58.0	-	1	61.3	4.9	4	60.6	5.8	5
17	57.0	-	1	62.5	4.5	2	60.7	12.3	3
18	-	-	-	-	-	-	-	-	-
19	-	-	-	64.0	-	1	64.0	-	1
20	-	-	-	63.0	-	1	63.0	-	1

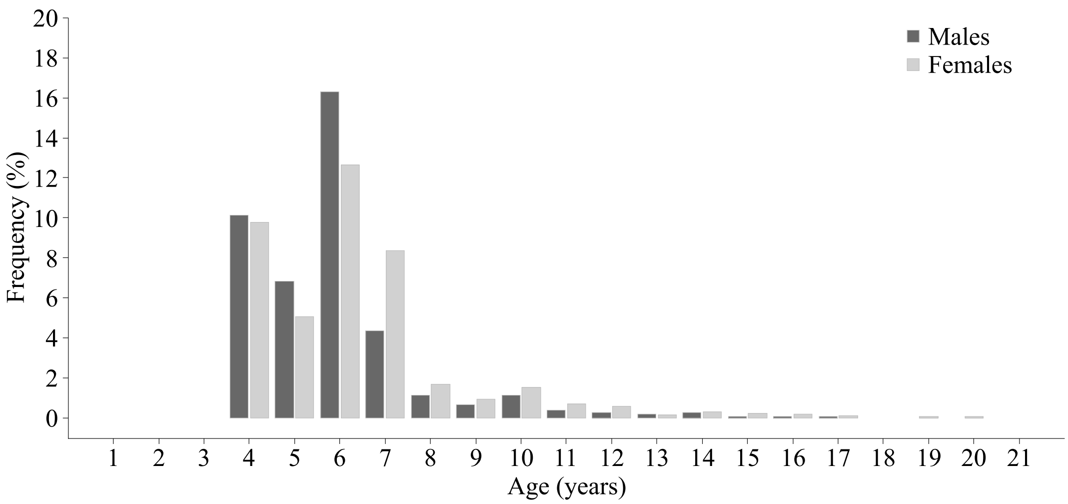

Figure 4. Age frequency distribution of southern blue whiting females and males. Year 2019.

Table 3. Southern blue whiting length growth parameters estimated from the von Bertalanffy model for males, females, and combined sexes (total). CI: confidence intervals 95%. Year 2019.

Growth parameters	Males	Females	Total
L_∞	57.43	63.93	62.30
CI (lower)	56.24	62.65	61.25
CI (upper)	58.76	65.35	63.44
K	0.21	0.18	0.18
CI (lower)	0.19	0.16	0.16
CI (upper)	0.23	0.19	0.19
t_0	-1.39	-1.41	-1.61
CI (lower)	-1.69	-1.66	-1.82
CI (upper)	-1.12	-1.18	-1.41

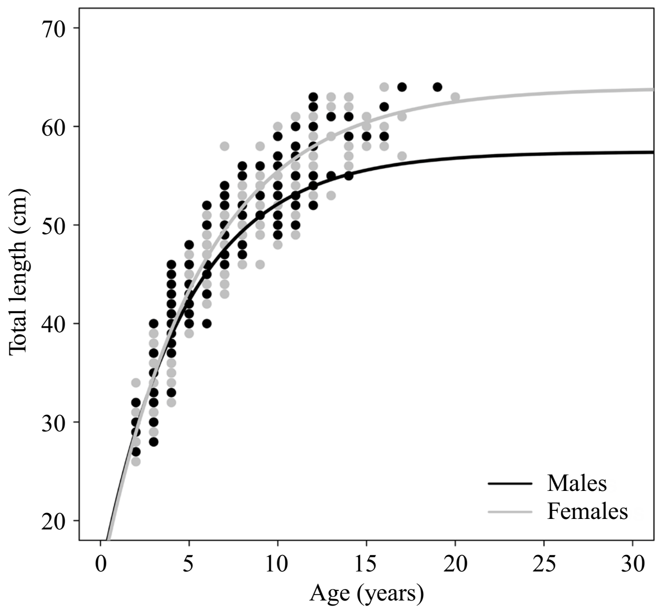

Figure 5. Total length-at-age relationship for female and male southern blue whiting with fitted von Bertalanffy growth curves. Year 2019.

overall length and age at maturity were estimated at 35.25 cm TL and 2.93 years, respectively (Table 6; Figure 7).

The instantaneous rate of natural mortality estimates for the southern blue whiting by different methods analyzed showed similar values, ranging from 0.27 to 0.33 year^{-1} (Table 7).

DISCUSSION

This research offers an integrated analysis of the most significant life history characteristics of the southern blue whiting in its current main

Table 4. Comparison of von Bertalanffy models explaining growth variation between sexes, in southern blue whiting. Degrees of freedom (df), Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The best model is highlighted in bold.

Model	VBGF parameter variation	df	AIC	BIC
1	L_∞, K, t_0	7	10,255.50	10,295.89
2	**L_∞, K**	6	**10,253.50**	**10,288.12**
3	L_∞, t_0	6	10,260.01	10,294.63
4	K, t_0	6	10,291.86	10,326.48
5	L_∞	5	10,325.07	10,353.92
6	K	5	10,386.59	10,415.44
7	t_0	5	10,447.74	10,476.59
8	Ω	4	10,550.99	10,574.07

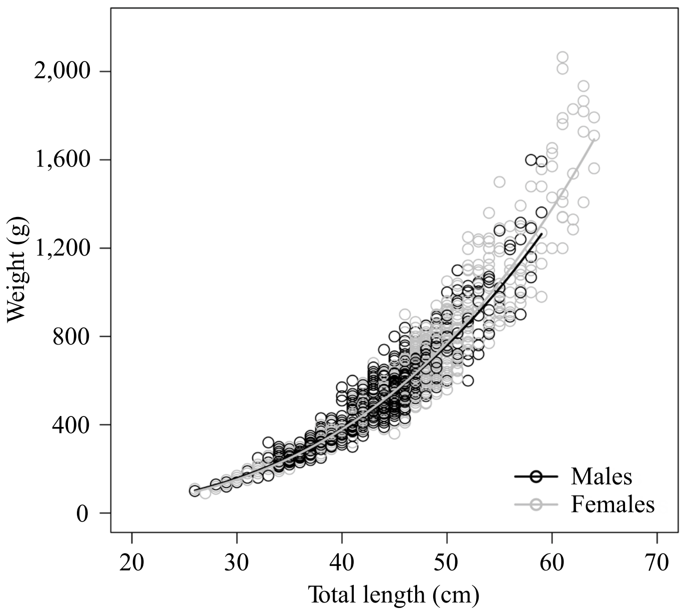

Figure 6. Total length-weight relationship of southern blue whiting females and males. Year 2019.

aggregation zone of the southwestern Atlantic (52° S-56° S), with a contribution from records from the Malvinas Islands. This incorporation of previously unavailable data is fundamental to advance in the knowledge of the species biology and provides an opportunity to enhance it about the resource dynamics in this area, which is essential for applied management strategies.

Length distributions of samples collected in 2019 displayed a typical structure for the species, with minimum and maximum lengths recorded at 26 cm and 64 cm, respectively. These extreme values were consistent with findings from prior investigations in the Atlantic Ocean (Perrotta 1982; Sánchez et al. 1986; Barrera-Oro and Tomo 1988; Cassia 2000; Pájaro and Macchi 2001; Wöhler et

Table 5. Analysis of Covariance (ANCOVA) examining relationship between the logarithm of weight as a function of total length (TL) and sex in southern blue whiting. Sum Sq: sum of squares. df: degrees of freedom, F statistic, and P-value. Significant results are in bold.

Variables	Sum Sq	df.	F value	P > F
Log (TL)	294.595	1	16641	2.0E-16
Sex	0.001	1	0.042	0.836
Log (TL) * Sex	0.081	1	4.594	**0.032**
Residuals	25.332	1431		

Table 6. Total length (TL_{50}, cm) and age (A_{50}, years) at first maturity for female, male, and combined sexes (total) for southern blue whiting during the reproductive season.

Maturity	Females	Males	Total
TL_{50}	35.74	34.79	35.25
A_{50}	3.06	2.76	2.93

al. 2004; Ramos and Winter 2023), and similar maximum lengths have also been reported for the species in the Pacific Ocean (Aguayo et al. 2010; Contreras-Reyes et al. 2014).

A maximum longevity of 23 years has been reported for this species (Barrera-Oro and Tomo 1988; Cassia 2000; Wöhler et al. 2004). The present study found lower maximum ages (20 years for females and 17 for males), although these older individuals were uncommon, supporting recent investigations (Ruocco 2022; Ruocco et al. 2024) and other similar studies (Cassia 1996, 2000; Hanchet and Uozumi 1996). Furthermore, females exhibited a greater mean total length at each age compared to males, principally after reaching maturity, a pattern also observed by other authors (Stott 1982; Barrera-Oro and Tomo 1988; Cassia 2000).

Estimates of growth parameters were consistent with previous investigations from the southwestern Atlantic Ocean (Perrotta 1982; Barrera-Oro and Tomo 1988; Cassia 1996, 2000; Wöhler et al. 2004; Ruocco 2022; Ruocco et al. 2024). This study also found that females reach a larger asymptotic length than males, supporting a pattern of differential growth between sexes, similar to findings from other studies in the southwestern Atlantic Ocean (Stott 1982; Barrera-Oro and Tomo 1988; Cassia 1996, 2000; Ruocco 2022; Ramos and Winter 2023; Ruocco et al. 2024), Chile (Aguayo et al. 2010; Contreras-Reyes et al. 2014) and New Zealand (Hanchet and Uozumi 1996). A similar pattern has also been observed in the closely related species *M. poutassou* from the northwest Mediterranean (Mir-Arguimbau et al. 2020). The contrasting growth parameters between sexes suggest a divergence in life-history strategies. The higher L_∞ observed in females indicates their potential to reach a larger maximum length compared to males, while the lower K suggests a slower growth rate throughout their lifespan, requiring more time to approach their asymptotic length. This prioritization of larger body size in females is likely linked to increased fecundity, where more energy is allocated to somatic growth via a slower growth trajectory. Conversely, the faster growth in males may be driven by the need to reach maturity and reproduce at an earlier age.

Parameters of the length-weight relationship remained almost constant relative to previous findings in the Atlantic Ocean (Perrotta 1982; Cassia 1999; Ruocco 2022; Ruocco et al. 2024) and were slightly higher than those found in the Pacific Ocean (Aguayo et al. 2010).

In this study, the size at maturity of southern

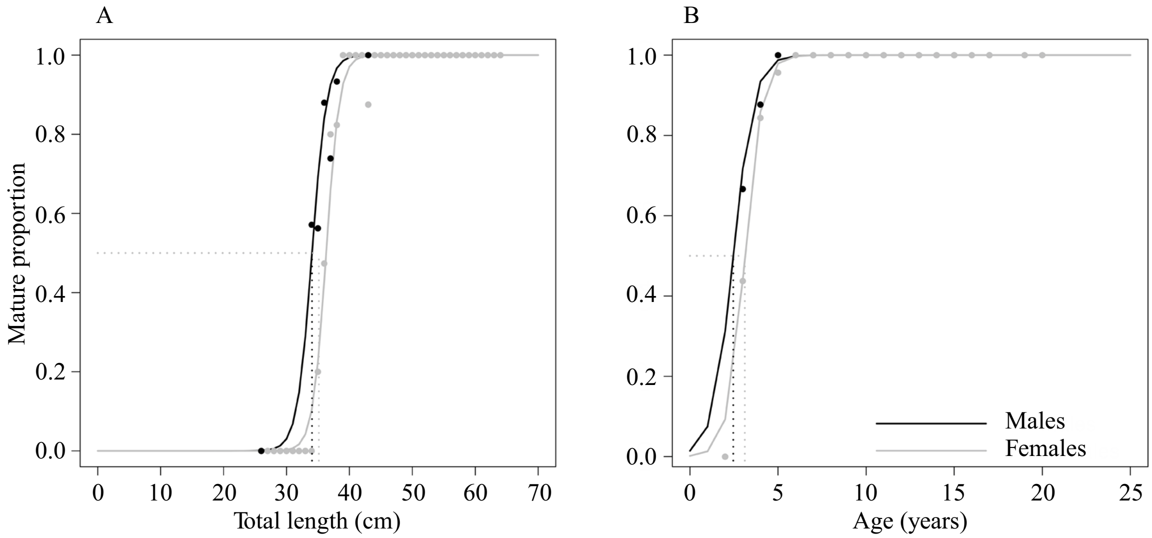

Figure 7. Proportion of mature individuals by length (A) and age (B) for females and males southern blue whiting using data from the reproductive period. Year 2019.

Table 7. Natural mortality rate (M) estimates for southern blue whiting derived from different methods. Then et al. (2015) method is presented (a) with the determined and incorporated t_{max}, and (b) without it value.

Method	M
Pauly (1980)	0.275
Hoenig et al. (1983)	0.271
Then et al. 2015(a)	0.330
Then et al. 2015(b)	0.295

blue whiting were consistent with previous studies conducted between 1980 and 1990 in the same area, which also considered histological analysis during the reproductive season (Perrotta 1982; Sánchez et al. 1986; Cassia 1999; Machinandiarena 1999). Furthermore, our findings for length (35.25 cm TL) and age at 50% maturity (2.93 years) align with those reported by Ramos and Winter (2023) for females in the Malvinas Islands waters (1990-2021 time series). Nevertheless, the observed size was slightly smaller when compared to other investigations (Pájaro and Macchi 2001; Ruocco 2022; Ruocco et al. 2024). Several factors might explain this discrepancy, such as the use of macroscopic maturity scales, data being pooled across the entire year (including periods with resting fish), the application of a different microscopical maturity scale, or studies on the Argentine continental shelf without data from the Malvinas Islands.

The instantaneous natural mortality rate estimates for southern blue whiting were consistent across different analytical methods, showing values from 0.27 to 0.33 $year^{-1}$. These estimates correspond with values documented in other studies (Cassia 1999, 2000; Wöhler et al. 2004; Aguayo et al. 2010; Ruocco 2022; Ruocco et al. 2024) and a typical physiological range for the species.

This integrated analysis of southern blue whiting life history in the southwestern Atlantic is significantly bolstered by the inclusion of data from the Malvinas Islands. This research enhances the biological information essential for effective resource management. These biological insights are therefore fundamental for refining stock assessments and developing more precise, adaptive management strategies to ensure the long-term sustainability of this important fishery.

This is INIDEP contribution no 2448.

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