

Short communication

Length-weight and length-length relationship for three marine fish species of commercial importance from southwestern Atlantic Ocean coast

Fernanda G. Biolé¹, Alejandra V. Volpedo^{1,2} & Gustavo A. Thompson¹

¹CONICET, Universidad de Buenos Aires, Instituto de Investigaciones en Producción Animal (INPA)
Buenos Aires, Argentina

²Centro de Estudios Transdisciplinarios del Agua (CETA), Facultad de Ciencias Veterinarias
Universidad de Buenos Aires, Argentina

Corresponding author: Alejandra V. Volpedo (avolpedo@gmail.com)

ABSTRACT. Length-weight (LWR) and length-length (LLR) relationships were described for three marine fish species *Odontesthes argentinensis* (Valenciennes, 1835), *Urophycis brasiliensis* (Kaup, 1858) and *Brevoortia aurea* (Spix & Agassiz, 1829) from the southwestern Atlantic Ocean coast, among sampling sites between 36 and 38°S. These species have commercial importance in fisheries. Latitudinal change in LWR could suggest the existence of different subpopulations throughout their distribution ranges. A total of 2,167 specimens were collected between August 2015 and October 2018 using lift nets (mostly 10 mm mesh size) and fishing rods 100-200 m offshore. Both relationships were highly significant ($P < 0.0001$) for all species and produced robust coefficients of determination ($R^2 > 0.94$). The latitudinal trend of a and b parameters of LWR showed different patterns for each species. This study provides a new maximum length for *B. aurea* and describes the variation of the regression parameters. New length-length relationships of these species were reported.

Keywords: *Brevoortia aurea*; *Odontesthes argentinensis*; *Urophycis brasiliensis*; morphometrics relationship; coastal fish; southern Atlantic

Length-weight relationship (LWR) and length-length relationship (LLR) are useful tools for fish ecology, fish resource assessment, and fisheries management (Froese, 2006). Different length measures of fishes are required for particular applications. Standard length (SL) may be useful as a principal length measure for scientific purposes because the total length (TL) is not always available (*e.g.*, the tail was bitten off). On the other hand, the SL is more commonly used in fisheries management, such as defining minimum legal lengths for commercial and recreational fisheries. Therefore, reliable length-length relationships are required for data conversions.

The southwestern Atlantic Ocean coast is an important commercial, artisanal and recreational fishery area. *Odontesthes argentinensis* (Valenciennes, 1835), *Urophycis brasiliensis* (Kaup, 1858), and *Brevoortia aurea* (Spix & Agassiz, 1829) are important in fisheries as transnational marine resources. *O. argentinensis* is a marine species distributed between

Rio de Janeiro, Brazil (22°S), and Rawson, Argentina (43°S) (Dyer, 2000; Di Dario *et al.*, 2014). *U. brasiliensis* is a euryhaline species found in the western Atlantic between southern Brazil (23°S) and southern Argentina (San Jorge Gulf; 45°S) (Bovcon *et al.*, 2011; Lemes *et al.*, 2016). *B. aurea* is distributed between Bahia, Brazil (22°S), and Bahia Blanca, Argentina (39°S) (Segura & Diaz de Astarloa, 2004). Despite these wide distributional ranges, most of LWR were reported for Brazil and the Uruguay coast, with very few studies for the Argentinean marine coast (Molina, 2012; Llompert *et al.*, 2013; Solari *et al.*, 2016). LWR are widely used to transform the survey data into estimates of the biomass, relevant information for modeling aquatic ecosystems (Froese, 2006). Also, spatial variation in length-weight relationships could be associated with the existence of different subpopulations of fish (Ma *et al.*, 2017). This information is essential in fisheries science. Therefore, this study reports the length-weight relationships for the three

species in diverse geographic coastal areas of southwestern Atlantic Ocean and analyses the variation of the regression parameters among sampling sites and seasons and tests for differences in parameter values along the latitudinal gradient.

Three fish species (*O. argentinensis*, *U. brasiliensis*, and *B. aurea*) were collected from the southwestern Atlantic Ocean coast, in north Argentinian waters (36–38°S), between August 2015 and October 2018. Five sampling sites were selected: Samborombón Bay (SB), San Clemente del Tuyú (SCT), Lucila del Mar (LL), Villa Gesell (VG), and Mar del Plata (MdP) (Fig. 1). Samples were carried out overnight using lift nets (mostly 10 mm mesh size) and fishing rods 100–200 m offshore. Fish were identified up to the species level, according to Menni *et al.* (1984), Nelson (1994) and Segura & Díaz de Astarloa (2004). For each specimen, TL and SL were measured to the nearest 0.1 cm using a digital caliper, and whole wet weight (W) was recorded to the nearest 0.1 g using an electronic balance. Although sex was recorded, the number of males sampled of each species was not enough to evaluate LWR parameters, so sex was not considered for further analyses.

Our main aim was to compare the length-weight relationships (LWR) of the three species across different places and time points in different climatic seasons (fall, winter, spring-summer). Generalized linear models (GLM) based on the Gamma distribution with the inverse link function were employed to explore the effects of the categorical predictors, sampling place and sampling season, and the explanatory variable, total length (TL, in cm), on the response variable, wet weight (W, in g). All data were included in these models, even if the sampling design was not fully crossed due to logistical constraints, which resulted in a zero degree of freedom for the interaction term (Table 1). GLM for the three species showed that LWR parameters were not affected by a two-way interaction between place and season, and also showed that season was not a significant term (Table 1). Therefore, the pattern for the entire sampling period for each species, and each place was examined by defining the length-weight relationship for the whole data set (common slope and intercept). In this sense, LWR were considered to follow growth models of the type $W = a \times TL^b$, where a and b are parameters.

Parameter estimation was conducted by least-squares linear regression on \log_{10} - \log_{10} transformed data; $\log_{10}(W) = \log_{10}(a) + b \log_{10}(TL)$, where b is the slope and $\log_{10}(a)$ the intercept (Froese, 2006). The coefficient of determination (Pearson r-squared, R^2) was used as an indicator of the linear regression quality. The LWR is said to be isometric when $b = 3$ (Froese

2006), so the b value of each species was tested with the 2-tailed Student's t-test ($\alpha = 0.05$) to detect differences from the isometric value. The statistical significance, standard error (SE) for parameters a and b were also determined. The fitted parameters [b and $\log_{10}(a)$] for a species occurring in different sampling sites were tested against each other using Welch's approximate t-test (Zar, 1999). Length-length relationships were also established using linear regression analysis: $TL = a + b \times SL$.

All analyses were performed using InfoStat software (Di Rienzo *et al.*, 2018). This software implements an interface of the R platform version 3.4.1 (R Core Team, 2017) to estimate generalized linear models through GLM and GLMER procedures from the stats and lme4 libraries (Bates *et al.*, 2013).

The parameters found were compared with those recorded in the literature by other authors in the distribution range of each of the species.

A total of 2,167 specimens belonging to three species (1,137 for *O. argentinensis*, 570 for *U. brasiliensis*, and 460 for *B. aurea*) were collected in five sampling sites (Fig. 1). Table 2 summarizes LWR parameters showing the wide range of LT and W data used. The values for the allometric coefficient varied between 2.66 and 3.33. All relations were highly significant ($P < 0.0001$), and except for *B. aurea*, R^2 values were higher than 0.94, suggesting the robustness of coefficient estimates. According to FishBase data, the present work reports a new maximum TL (41.5 cm) for *B. aurea*, which was superior in 7.1 cm than what has been registered so far.

Table 2 shows that *O. argentinensis* (SB), *U. brasiliensis* (LL and MdP) and *B. aurea* (SB and LL) presented positive allometry ($b > 3$) (large specimens that have increased in height or width more than in length); *O. argentinensis* (LL) and *U. brasiliensis* (VG) presented isometry; the rest of the specimens showed negative allometry ($b < 3$). Moreover, fish that gave negative allometry (large specimens that have changed their body shape becoming more elongated or small) were in better nutritional condition at the time of sampling. *O. argentinensis* and *U. brasiliensis* presented either positive allometry or isometry, depending on the geographic area sampled. *B. aurea* presented both negative and positive allometries, which also depended on the area sampled. There was no latitudinal pattern for negative or positive allometry. Eight of the 10 comparisons among geographic areas were significant at $\alpha = 0.05$ for both regression coefficients; only for *B. aurea*, there were no significant differences between the two places with negative allometry values and between the two sites with positive values (Table 3a-b).

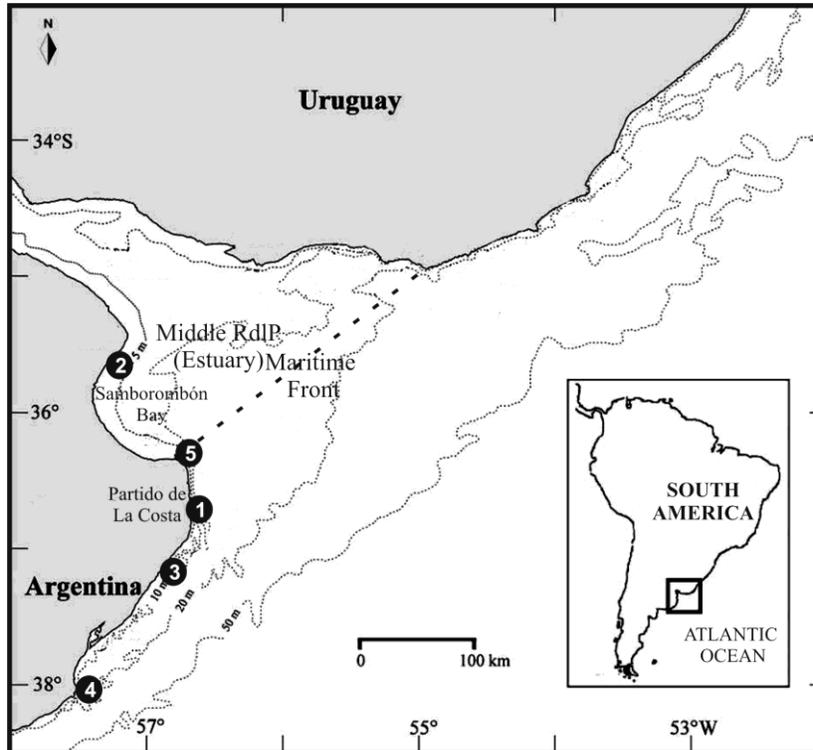


Figure 1. Geographic location of study place. 1) Lucila del Mar, 2) Samborombón Bay, 3) Villa Gesell, 4) Mar del Plata, and 5) San Clemente del Tuyú.

Table 1. Generalized linear model to test for differences in length-weight relationship in each species studied. X^2 values and degrees of freedom in brackets are shown for each fixed factor and their interaction. *** $P < 0.001$; + $P > 0.05$.

Species	Factors		
	Place	Season	Place*Season
<i>Odontesthes argentinensis</i>	17.71*** (1)	7.74+ (3)	<0.01+ (0)
<i>Urophycis brasiliensis</i>	2.92+ (2)	7.08+ (3)	<0.01+ (0)
<i>Brevoortia aurea</i>	234.95*** (3)	0.73+ (2)	<0.01+ (0)

Table 4 summarizes LLR relationship parameters for each species, like in LWR, all relations were highly significant ($P < 0.0001$), and robust coefficients (R^2) were determined.

The biological information associated with LWR parameters mostly for Brazilian and Uruguayan populations is limited, notwithstanding the wide distribution range of the three species (Table 5). Our study, together with reported parameters of the LWR for these three species (Table 5 and references therein), showed that b values estimated for LWR remained within the expected range 2.5 and 3.5 for fish (Froese, 2006). The extreme b -values (>3.3) may be caused by the presence of only juveniles in the samples (*U. brasiliensis* at MdP and *B. aurea* at LL, Table 2), a situation which has also been reported by Passos *et al.* (2012). Moreover, these two species have been sampled

only on one or two occasions (Table 5); thus, this fact could also be associated with the extreme b -values observed (Froese, 2006).

Our results, together with reported works, confirmed the existence of a strong interrelationship between both parameters suggested by Froese (2006). The interdependence resulted in a linearized relationship in a plot of $\log a$ over b for the three species (Fig. 2a). The only exception to this linearized relationship was the parameters of *O. argentinensis* belonging to Samborombón Bay (not included in the estimation of the R^2 ; Fig. 2). Froese (2006) indicated that this type of WLRs could be questionable because of sampling problems (narrow size range, few data with high variance, or outliers in the respective sample) and should be removed. However, our LWR parameters were almost the same reported by Solari *et al.* (2016) in

Table 2. Descriptive statistics and estimated parameters of length-weight relationships for fish species collected from Argentine coastal waters. LL: Lucila del Mar; SB: Samborombón Bay; VG: Villa Gesell; MdP: Mar del Plata, and SCT: San Clemente del Tuyú. n: sample size; TL: total length; W: total body weight; a : intercept; b : the slope of the linear regression; SE: standard error; SD: standard deviation; R^2 : coefficient of determination. *Significant 2-tailed Student's t-test, which indicated that $b =$ allometric. Bold: new maximum length.

Species	n	TL range (cm) (mean \pm SD)	W range (g) (mean \pm SD)	$\log_{10}a$	SE($\log_{10}a$)	b	SE (b)	R^2
<i>O. argentinensis</i> (SB)	174	9.6-35.5 (20.7 \pm 8.8)	5-348 (92.5 \pm 97.6)	-2.475	0.027	3.203*	0.021	0.993
<i>O. argentinensis</i> (LL)	963	4.0-36.0 (14.0 \pm 5.6)	0.3-330 (25.5 \pm 36.2)	-2.225	0.009	3.004	0.009	0.992
<i>U. brasiliensis</i> (LL)	50	20-51 (37.3 \pm 9.6)	60-1141 (538 \pm 332)	-2.272	0.126	3.128*	0.080	0.969
<i>U. brasiliensis</i> (MdP)	221	5.8-24.3 (16.7 \pm 3.2)	12-125 (39.4 \pm 23.4)	-2.538	0.025	3.336*	0.020	0.992
<i>U. brasiliensis</i> (VG)	299	26.7-52 (42.7 \pm 4.2)	175-1365 (726 \pm 204)	-1.978	0.069	2.959	0.042	0.943
<i>B. aurea</i> (SB)	42	32.6-41.5 (36.5 \pm 2.5)	265-945 (467 \pm 131)	-2.287	0.573	3.163*	0.366	0.642
<i>B. aurea</i> (SCT)	168	24.2-41.4 (34.6 \pm 3.7)	160-917 (446 \pm 139)	-1.528	0.154	2.703*	0.100	0.813
<i>B. aurea</i> (LL)	104	5.0-12.2 (7.7 \pm 2.2)	0.93-16 (4.8 \pm 4.2)	-2.376	0.035	3.306*	0.039	0.985
<i>B. aurea</i> (MdP)	146	19.4-28.6 (22.6 \pm 1.6)	83-206 (135 \pm 26.7)	-1.491	0.096	2.668*	0.071	0.906

Table 3a. Probabilities associated with Welch's approximate t-tests comparing slopes b and intercepts $\ln(a)$ among sampling places (LL: Lucila del Mar; SB: Samborombón Bay; VG: Villa Gesell; MdP: Mar del Plata and SCT: San Clemente del Tuyú) for *Odontesthes argentinensis* and *Urophycis brasiliensis*.

Species	LL-SB		LL-VG		LL-MdP		MdP-VG	
	b	$\ln(a)$	b	$\ln(a)$	b	$\ln(a)$	b	$\ln(a)$
<i>O. argentinensis</i>	<0.0001	<0.0001						
<i>U. brasiliensis</i>			0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table 3b. Probabilities associated with Welch's approximate t-tests comparing slopes b and intercepts $\ln(a)$ among sampling places (LL: Lucila del Mar; SB: Samborombón Bay; VG: Villa Gesell; MdP: Mar del Plata and SCT: San Clemente del Tuyú) for *Brevoortia aurea*.

Species	LL-SB		LL-MdP		LL-SCT		MdP-SB		MdP-SCT		SB-SCT	
	b	$\ln(a)$	b	$\ln(a)$	b	$\ln(a)$	b	$\ln(a)$	b	$\ln(a)$	b	$\ln(a)$
<i>B. aurea</i>	0.07	0.23	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.18	0.19	<0.0001	<0.0001

the same area (Samborombón Bay; Table 5). This similarity suggested that our result could not be questionable, according to Froese's (2006) arguments; however, the significance of this fact remains to be elucidated and could be related to particularities of the environment (Rio de la Plata Estuary, Fig. 1).

Isometric growth registered for *O. argentinensis* agreed with the recorded data reported by Thompson & Volpedo (2018) in the same place but only with summer samples. Other reports for this species from Brazil (Haimovici & Velasco, 2000), Uruguay (Gurdek

& Acuña, 2014), and Argentina (Molina, 2012; Llompart *et al.*, 2013) suggested positive allometric growths. The latitudinal trend showed a bell-shaped curve type for $\log_{10}(a)$ (Fig. 2b) and an inverse bell curve type for b (Fig. 2c). Positive allometric growth seemed to be related to the northern and southern evaluated distributional range (Fig. 2c). To the best of our knowledge, this is the first evidence of such a latitudinal gradient in *O. argentinensis* b parameters of LWR. Positive allometric growth for *U. brasiliensis* was also suggested for Uruguay (Acuña & Verocai, 2001;

Table 4. Relationship between total length and the standard length of fishes collected from Argentine waters. n: sample size; TL: total length; SL: standard length; SD: standard deviation; *a*: intercept; *b*: the slope of the linear regression; CI: confidence limits; R²: coefficient of determination.

Species	n	TL range (cm) (mean ± SD)	SL range (cm) (mean ± SD)	L-L regression parameter		
				<i>a</i>	<i>b</i>	R ²
<i>Odontesthes argentinensis</i>	1137	4.0-36.0 (14.0 ± 5.6)	3.4-31.0 (11.5 ± 4.6)	-0.029	1.222	0.999
<i>Urophycis brasiliensis</i>	570	5.8-52.0 (32.2 ± 13.3)	5.0-46.0 (27.7 ± 11.7)	0.948	1.127	0.995
<i>Brevoortia aurea</i>	146	5.0-41.5 (16.0 ± 13.3)	4.1-32.0 (12.5 ± 9.9)	-0.633	1.335	0.991

Table 5. Spatial, temporal location, frequency of sampling, number of individuals (n), minimum and maximum lengths (cm) and parameters of the length-weight and length-length relationships for three species in this study and values reported for previous studies. ND: No Data.

<i>Odontesthes argentinensis</i>									
Place	Lat. range	Time range	Freq.	LT range	n	log(<i>a</i>)	<i>b</i>	R ²	Reference
Lucila Mar, Argentina	36°30'S	2015-2017	Bimonthly	4-36	963	-2.2259	3.00	0.992	Present work ¹
Samborombón Bay, Argentina	35°30'S	08/17-08/18	Aug (3 samplings)	9.6-35.5	174	-2.4756	3.20	0.993	Present work ²
Lucila Mar, Argentina	36°30'S	2013-2014	Summer	4.5-35	595	-2.2218	3.01	0.991	Thompson & Volpedo (2018) ^A
Anegada Bay, Argentina	40-41°S	06/08-05/09	Monthly	16.1-44.1	876	-2.5086	3.13	0.950	Llompart <i>et al.</i> (2013) ^B
Anegada Bay, Argentina	41°S	2008	Autum	12-37.6	138	-2.7375	3.22	0.960	Molina (2012) ^C
Pando, Uruguay	34°47'S	05/02-06/03	Monthly	3.2-42	74	-2.2848	3.06	0.991	Gurdek & Acuña (2014) ^D
Rio Grande, Brazil	28°-34°S	1975-1994	Yearly	2.8-42.1	53	-2.3858	3.07	0.992	Haimovici & Velasco (2000) ^E
<i>Urophycis brasiliensis</i>									
Place	Lat. range	Time range	Freq.	SL range	N	log(<i>a</i>)	<i>b</i>	R ²	Reference
Samborombón Bay, Argentina	35°30'S	08/17-08/18	Aug (3 samplings)	8-31	174	-2.1800	3.18	0.992	Present work ²
Samborombón Bay, Argentina	36°S	09/07-08/09	Bimonthly	2.5-24.8	279	-2.1800	3.23	0.99	Solari <i>et al.</i> (2016)
Lucila Mar, Argentina	36°30'S	2013-2016	6 Samplings	20-51	50	-2.2720	3.13	0.969	Present work ¹
Villa Gesell, Argentina	37°S	10/15-10/18	Yearly	26.7-52	300	-1.9781	2.96	0.943	Present work ³
Mar Del Plata, Argentina	38°S	2018	July	5.8-24.3	220	-2.5382	3.34	0.992	Present work ⁴
La Paloma, Uruguay	35°S	1984-1994	ND	22.6-51.2	1506	-2.3261	3.13	0.967	Acuña & Verocai (2001) ^F
Punta Diablo, Uruguay	33°54'-34°04'	2006-2010	ND	4.8-52.2	867	-2.5229	3.22	0.970	Segura <i>et al.</i> (2012) ^G
Ubatuba, Brazil	26°11'S	10/03-09/04	Monthly	4.3-18.9	20	-2.0458	2.91	0.959	Freitas <i>et al.</i> (2011) ^H
Southern Brazil	22-35°S	1997-1998	ND	18-63	515	-2.1494	3.02	0.970	Andrade <i>et al.</i> (2005) ^I
Parana, Brazil	25°	08/04-07/05	Monthly	5-16.1	74	-2.3665	3.14	0.978	Passos <i>et al.</i> (2012) ^J
Sao Paulo, Brazil	23°30'-24°	1993-1995	5 Samplings	9-53.2	51	-2.3261	3.15	0.984	Muto <i>et al.</i> (2000) ^K
Rio Grande, Brazil	28°-34°S	1975-1994	Yearly	8.7-58.6	252	-2.4001	3.21	0.982	Haimovici & Velasco (2000) ^E
Rio Grande, Brazil	30°S	1990-1993	ND	ND	2763	-2.4802	3.25	ND	Haimovici & Mendonca (1996) ^L
Southeastern, Brazil	23°18'-23°58'S	1995-1996	ND	5-42	16	-2.7959	3.47	0.994	Vianna <i>et al.</i> (2004) ^M
<i>Brevoortia aurea</i>									
Lucila Mar, Argentina	36°30'S	2016	Mar and Dic	5-12.2	104	-2.3762	3.31	0.985	Present work ¹
Samborombón Bay, Argentina	36°S	2016-2017	Mar and Sep (2 sampl.)	32.6-41.5	42	-2.2868	3.16	0.65	Present work ²
Mar Del Plata, Argentina	38°S	2018	Feb	19.4-28.6	146	-1.4907	2.67	0.907	Present work ⁴
San Clemente Tuyú, Argentina	36°21'S	2018	January	24.2-41.4	168	-1.5278	2.70	0.814	Present work ⁵
Pando, Uruguay	34°47'S	05/02-06/03	Monthly	3-34.4	113	-2.0250	3.05	0.995	Gurdek & Acuña (2014) ^D
Southern Brazil	22°50'S	2011	Feb-Aug	1.9-12	1467	-2.2218	3.11	0.980	Franco <i>et al.</i> (2014) ^N
Place	Lat. range	Time range	Freq.	SL range	n	log(<i>a</i>)	<i>b</i>	R ²	Reference
Samborombón Bay, Argentina	36°S	2016-2017	Mar and Sep (2 sampl.)	24.5-32	42	-1.2215	2.69	0.51	Present work ²
Samborombón Bay, Argentina	36°S	09/07-08/09	Bimonthly	2.6-7.3	387	-2.1300	3.46	0.99	Solari <i>et al.</i> (2016)

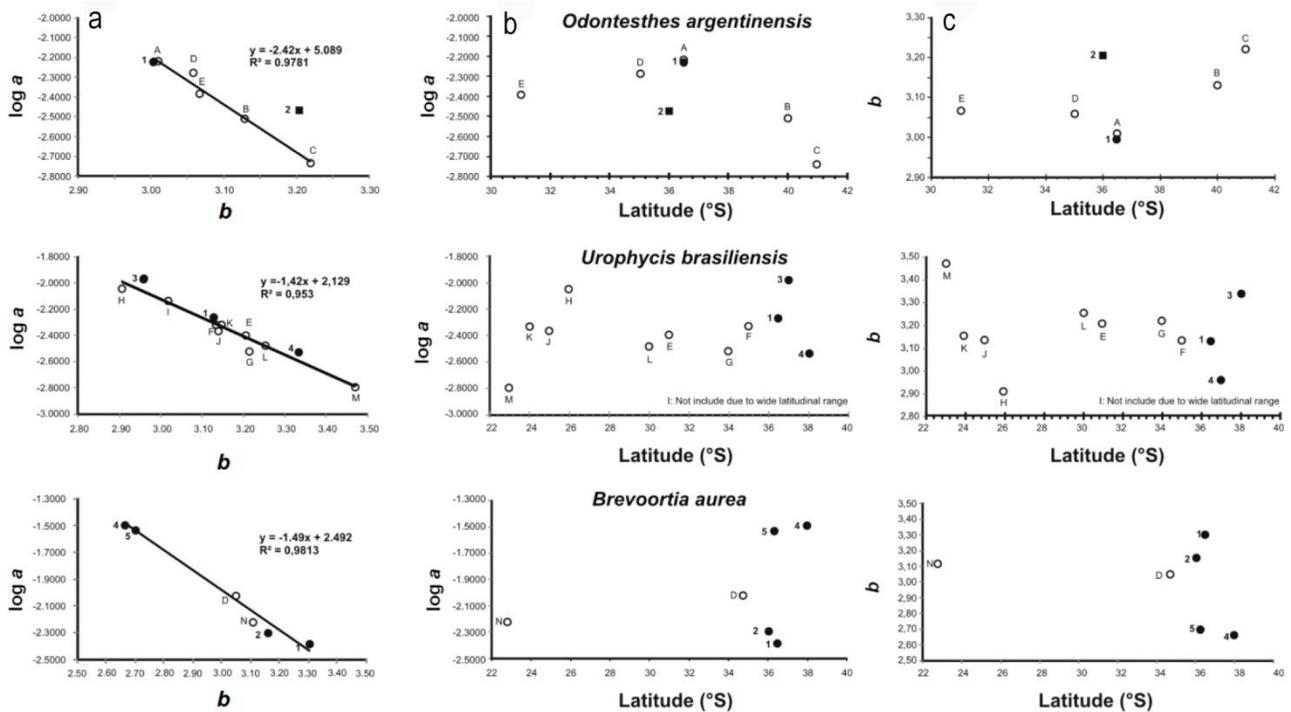


Figure 2. a) Plot of $\log a$ over b for weight-length relationships, b) plot of $\log a$ with respect to latitude, c) plot of b with respect to latitude. Locality: 1 Lucila del Mar, 2 Samborombón Bay, 3 Villa Gesell, 4 Mar del Plata, 5 San Clemente del Tuyu. References, A: Thompson & Volpedo (2018) (Lucila del Mar, Argentina); B: Llompарт *et al.* (2013) (Bahía Anegada, Argentina); C: Molina (2012) (Bahía Anegada, Argentina); D: Gurdek & Acuña (2014) (Pando, Uruguay); E: Haimovici & Velasco (2000) (Rio Grande, Brazil); F: Acuña & Verocai (2001) (La Paloma, Uruguay); G: Segura *et al.* (2012) (Punta Diablo, Uruguay); H: Freitas *et al.* (2011) (Ubatuba, Brazil); I: Andrade *et al.* (2005) (southern Brazil); J: Passos *et al.* (2012) (Parana, Brazil); K: Muto *et al.* (2000) (Sao Paulo, Brazil); L: Haimovici & Mendonça (1996) (Rio Grande, Brazil); M: Vianna *et al.* (2004) (southeastern Brazil); N: Franco *et al.* (2014) (southwestern Brazil).

Segura *et al.*, 2012) and Brazil (Haimovici & Mendonça, 1996; Haimovici & Velasco, 2000; Muto *et al.*, 2000; Vianna *et al.*, 2004; Passos *et al.*, 2012) populations. Also, isometric and negative allometric growth has been reported in Brazil (Andrade *et al.*, 2005 and Freitas *et al.*, 2011, respectively). The latitudinal trend of a and b did not show any patterns, except for a tendency to a latitudinal decrease (increase) of b values in the northern (southern) latitudinal range (Fig. 2c). Negative allometric growth is recorded for *B. aurea* for the first time in the present work, since previous records suggested positive allometric growth for Brazil (Franco *et al.*, 2014), Uruguay (Gurdek & Acuña-Plavan, 2014) and Argentinian waters (Solari *et al.*, 2016). The latitudinal trend of a and b did not show any patterns (Figs. 2b-c).

It should be acknowledged that LWR parameters could be affected by several factors such as differences in the sample size, length range, growth phase, sex, gonadal maturity, fishing gears, seasonality and variation in salinity, temperature and food (Haimovici &

Velasco, 2000; Froese 2006; Solari *et al.*, 2016). However, the analysis of the influence of these factors is beyond the purpose of this report. To our knowledge, there are no previous reports on LLR for this marine fish species.

The present work contributes reliable morphometric relationships for three marine fish species of great commercial, artisanal and recreational importance in the southwestern Atlantic Ocean.

Finally, this study provides additional information on the southwestern Atlantic Ocean ichthyofauna, contributing to important basic data for regional sustainable fisheries management.

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