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Growth of the Anchovy *Anchoa tricolor* in a brazilian subtropical estuary

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ABSTRACT

This study aimed to describe the growth parameters of *Anchoa tricolor* in a subtropical estuary. From August 2010 to July 2011, 10.009 specimens of the anchovy *Anchoa tricolor*, mean total length 4.2 cm (±1.45), were captured in the intertidal region of the Estuarine Complex of Paranaguá (25º 15’ - 25° 35’ S and 48° 20’ - 48° 45’ W). Species´s weight/length relationship for grouped genders was described as follow: $W = 0.0000591.Lt^{3.282}$ (length in centimeters; weight in grams) showing a positive allometric growth pattern (b>3; P=0.000). Significant differences concerning weight/length relationship for males, females and unsexed individuals were identified. Parameters of the length to age growth curve were estimated by adjusting a von Bertalanffy growth equation from aged individuals from a length-frequency distribution: $L\infty = 10.06\ (1-e^{-17715(t\ +\ 0.205)})$ (length in centimeters, age in years). The age to attain 95% of the asymptotic length (A_{95}; longevity *sensu* Taylor) was estimated at 1.7 years. Size frequency distributions indicate that *A. tricolor* uses the estuarine area as reproductive and growing grounds, especially during the first year of the life cycle, where the species represent a key element for ecosystem functioning due to relatively high abundance and energy transference from plankton to top predators.

Key words: Bertalanffy, engraulidae, longevity, weight/length relationship.

INTRODUCTION

The Engraulidae, commonly known as broadband anchovy (“manjuba” in Brazil), comprise a family of 16 genera and 139 species, all small marine or estuarine fish species distributed worldwide in tropical and subtropical waters. The family constitutes a very important connection in marine food webs, feeding mainly on plankton and sustaining several top-level predators (Whitehead et al. 1988).

Species of the genus *Anchoa* are distributed in the Pacific and Atlantic oceans. A summary of available data concerning growth parameters and longevity estimates for *Anchoa* is presented in Table I (Froese and Pauly 2016). Von Bertalanffy growth rate (K) vary between 0.21 and 2.8 ($\bar{K} = 1.21\,year^{-1}$)

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and the asymptotic length ($L\infty$) between 8.0 and 25.3 cm ($\bar{L}\infty = 13.3 cm$). Maximum total length (TL) ranged between 7.5 and 24.0 cm ($\bar{T}_L = 12.4 cm$) and life span (t_{max}) between 1 and 13.3 years ($\bar{t}_{max} = 2.4 years$).

Eight to nine species of *Anchoa* are described on the Brazilian littoral (Carvalho 1950, Whitehead et al. 1988, Froese and Pauly 2016) where the genus is described as food source for several species as the dolphin *Sotalia fluviatilis,* the common tern *Sterna hirundo,* the whitemouth croaker *Micropogonias furnieri* and the swordfish *Trichiurus lepturus* (Santos et al. 2002, Bugoni and Vooren 2004, Giberto et al. 2007, Bittar et al. 2008).

Anchoa tricolor (Spix and Agassiz 1829) is abundant along the Brazilian coast, occurring between the northeastern region of Brazil (03°40' S) to the Mar del Plata in Argentina (37°58' S) (Froese and Pauly 2016), with described captures in the Brazilian states of Rio de Janeiro, São Paulo and Paraná (Silva and Araújo 2003, Cardoso and Nordi 2006) as by-catch of the shrimp-hauling fleet (Graça Lopes et al. 2002, Souza and Chaves 2007), or used as live bait in tuna boats (Dos Santos and Rodrigues-Ribeiro 2000).

Concerning habitat occupation, *A. tricolor* is classified both as marine or estuary migrant species (Araújo et al. 2008b, Vilar et al. 2011). Presence of juveniles and young of the year have been reported in Sepetiba Bay and in the Estuarine Complex of Paranaguá, with the occurrence of adults in open beaches outside Sepetiba Bay (Araújo et al. 2008a, Contente et al. 2011). The spatial and temporal distribution of the species may be affected by salinity and temperature (Pessanha and Araújo 2003, Silva et al. 2004). Maximum registered length is 11.8 cm with isometric growth pattern (Vaz-dos-Santos and Rossi-Wongtschowski 2013, Franco et al. 2013). The reproductive period is registered

TABLE I

Growth parameters, longevity and distribution occurrence of *Anchoa* species. Data from Fishbase (Froese and Pauly 2013) only featuring species provided with growth parameters from original publications (*) or as estimated from the life history tool from maximum registered total lengths.

Species	LT máx. (cm)	K	L∞ (cm)	Life Span (years)	Occurrence
A. argentivittata	12.5	1.13	13.3	2.4	Eastern Pacific
A. cayorum	11.0	1.27	11.7	2.2	Western Central Atlantic
A. colonensis	14.0	1.02	14.9	2.8	Western Central Atlantic
A. cubana	10.0	1.39	10.7	2.0	Western Atlantic
A. curta	8.9	1.55	9.5	1.8	Eastern Pacific
A. delicatissima	12.0	1.18	12.8	2.4	Eastern Central Pacific
A. eigenmannia	8.0	1.71	8.6	1.6	Eastern Central Pacific
A. exigua	7.5	1.82	8.0	1.5	Eastern Pacific
A. filifera	12.0	1.18	12.8	2.4	Western Atlantic
A. hepsetus	15.3	0.94	16.2	3.0	Western Atlantic
A. januaria	7.5	1.82	8.0	1.5	Western Atlantic
A. mitchilli *	10.0	0.60	11.0	4.6	Western Atlantic
A. mundeola *	12.5	0.21	16.0	13.3	Eastern Central Pacific
A. mundeoloides	15.0	0.96	15.9	2.9	Eastern Central Pacific
A. panamensis *	12.5	2.79	11.4	1.0	Eastern Central Pacific
A. spinifer	24.0	0.63	25.3	4.6	Western Atlantic
A. tricolor	11.8	1.19	12.6	2.4	Southwest Atlantic
A. walkeri	14.5	0.99	15.4	2.8	Eastern Central Pacific

from September to February (Araújo et al. 2008b), and the life span is estimated as 2.3 years (Froese and Pauly 2016).

In the present work, we intend to describe the weight/length relationship, the growth pattern according to age, and estimate the life span of *A. tricolor* in the Estuarine Complex of Paranaguá, southern Brazil.

MATERIALS AND METHODS

Collections of *A. tricolor* were conducted monthly between August 2010 and July 2011, at 17 sites along the Estuarine Complex of Paranaguá (ECP), Paraná State (25º 15' - 25° 35' S and 48° 20' - 48° 45' W) (Fig. 1). Samplings were performed along the day (morning and afternoon) at neap tides through a beach seine net 5 m long, 2 m high and 2.5 mm between opposite knots. Each sample, at each sampling site, comprised a 30 m trawling parallel to the coastline at around 1 m depth. Specimens were ice kept until processing at laboratory.

The specimens were identified (Pinheiro et al. 1994, Menezes and Figueiredo 2000), measured for total length (*Lt*; to nearest 0.1 cm), weighed (*W*; to nearest 0.01g) and identified macroscopically for sex determination according to Vazzoler (1996).

The weight/length relationship (Froese 2006) was adjusted as follow: $W = a.\ Lt^b$, where W is the weight (g) of the specimens; Lt is total length (cm); a is the coefficient of proportionality; b is the coefficient of allometry. Equation parameters were estimated through the Levenberg-Marquardt algorithm (SPSS 17.0) from 8928 specimens of unsexed individuals, 395 males and 685 females. Null hypothesis of isometry was tested by comparing b values to 3 by using t test. Null hypothesis of no difference among genders and unsexed individuals (mostly juveniles) was tested with one way ANOVA, by comparing residuals from a single (pooled) weight/lengths relationship for the full data set, with post hoc discrimination by using Tukey test.

Frequency distributions of total length at each sampling month were plotted (class interval of the 1 cm), aiming to identify age-group modal progression. Relative age (years) for each age-group was set as the time interval between the month of the sample and the month of first appearance of the age-group (age of the first appearing age-group equal to zero). All individuals (n=7344) belonging to a specific age-group were considered as being the same age.

Length to age relationship (length growth curve) was obtained by adjusting the von Bertalanffy´s (1938) mathematical expression: $L_t = L\infty\ [1- e^{k.(t-t0)}]$, where L_t is total length (cm) at age t (years); $L\infty$ is the asymptotic length (cm); k is the instantaneous growth rate (year^{-1}); t_0 is the age (years) in which fish have the theoretical length equal to zero. Equation parameters were estimated through the Levenberg-Marquardt algorithm (SPSS 17.0) by using individual information of length to presumed age. Following this procedure, t_0 estimates incorporate uncertainties concerning the first age-group age determination (set as zero) and could be interpreted as the first age-group presumed age. Estimates of the species' longevity as the time to reach 95% of $L\infty$ (Taylor 1958) was computed as follow: $A_{95} = -2.96/k$.

RESULTS

Anchoa tricolor were captured throughout almost the entire sampling program, except for winter months of August and September 2010 and July 2011. A total of 10008 specimens were sampled, total length ranging from 2.2 to 8.5 cm ($\overline{Lt} = 4.2\,cm$; SD=1.45cm) and weight between 0.03 and 3.83 g, averaging 0.60 g (SD ± 0.72g).

Parameters of the weight/length relationship for the full data set, for males, females and unsexed individuals are presented in Table II. A scatter plot

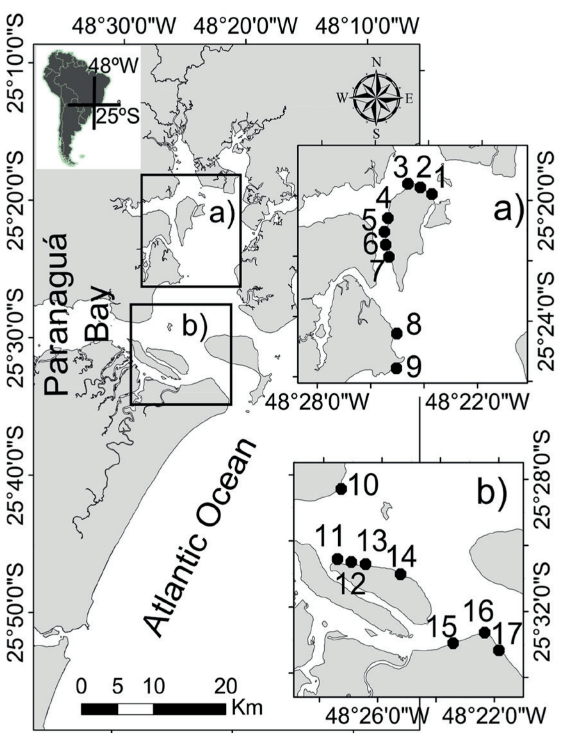

Figure 1 - Map of the Paranaguá Estuarine Complex showing the sampling sites.

of the weight/length relationship and respective residual distributions are available at Fig. 2. By exanimating the residual distributions for the full data set, for males, females and unsexed individuals, no patterns could be identified, indicating an overall good adjustment of the simple power function.

Significant differences concerning weight/length relationships for males, females and unsexed individuals were identified by comparing residual values from a pooled (all data set) adjusted function (ANOVA, P=0.000; Tukey, P=0.000). By comparing estimated allometric coefficients with the reference isometric value (b=3), significant differences (positive allometry) were obtained for the full data set (b=3.282, P=0.000), for unsexed individuals (b=3.199, P=0.000) and for males (b=3.189, P=0.022), but not for females (b=2.979, P=0.672).

Figure 3 shows a length frequency distribution of *A. tricolor* on a monthly basis, beginning from February 2011. From February to April, only unsexed individuals were captured, with the first identifiable males and females appearing on May, due to the beginning of gonadal differentiation. From October, most of the captured individuals were clearly sexed by presenting reproductive gonads. A clear modal displacement could be observed until June 2011, with just one age-group sampled each month. As the sampling program finished on June 2011, the length frequency distributions from October to December 2010 were displayed in sequence. Although do not representing the modal displacement of the same age-group (the 2011 cohort), a clear general displacement for the 0+ group could be verified. On November 2010, two age-groups could be identified, with the appearance of new recruiters (new 0+ age-group) and suggesting the beginning of the recruitment season. On December, the age-group representing the older (1+) individuals disappeared, suggesting mortality or displacement to areas do not covered by the sampling program. Although not represented in Fig. 3, the reproductive period of *A. tricolor* seems to be long, since a continuous recruitment of animals in the 2.5-3.5 mm size-class was identified in all sampled months from November to March.

The parameters of the von Bertalanffy growth model are presented in Table III, and a graphical representation of the growth pattern could be seen in Fig. 4. *Anchoa tricolor* attains an asymptotic length ($L\infty$) of 10 cm at a rate (K) of 1.77 year^{-1} and lasting 1.7 years to reach 95% of the maximum length (A_{95}). The correction *t0* value, estimated as -0.2 years, suggest an age of approximately two months for the February cohort, in accordance with the identified +0 age-group first appearance in November.

A general view of the estimated growth rate and longevity of *A. tricolor* in relation to other *Anchoa* species could be seen in Fig. 5 (data from FishBase.org). For most species, growth rate (K) and longevity values were obtained from the FishBase Life-history tool, estimated empirically

TABLE II
Weight/length parameters of *Ancha tricolor* in the Estuarine Complex of Paranaguá, southern Brazil.

	All data set	Males	Females	Unsexed individuals
Sample Size (n)	6330	395	680	5255
Proportionality coefficient (a)	0.00348	0.00434	0.00636	0.00394
"a" Standard Error	0.0000591	0.000713	0.000626	0.0000537
Alometric Coefficient (b)	3.282	3.189	2.979	3.199
"b" Standard Error	0.00884	0.0823	0.0496	0.00756
T test for allometry (P; b≠3)	0.0000	0.0222	0.6721	0.0000

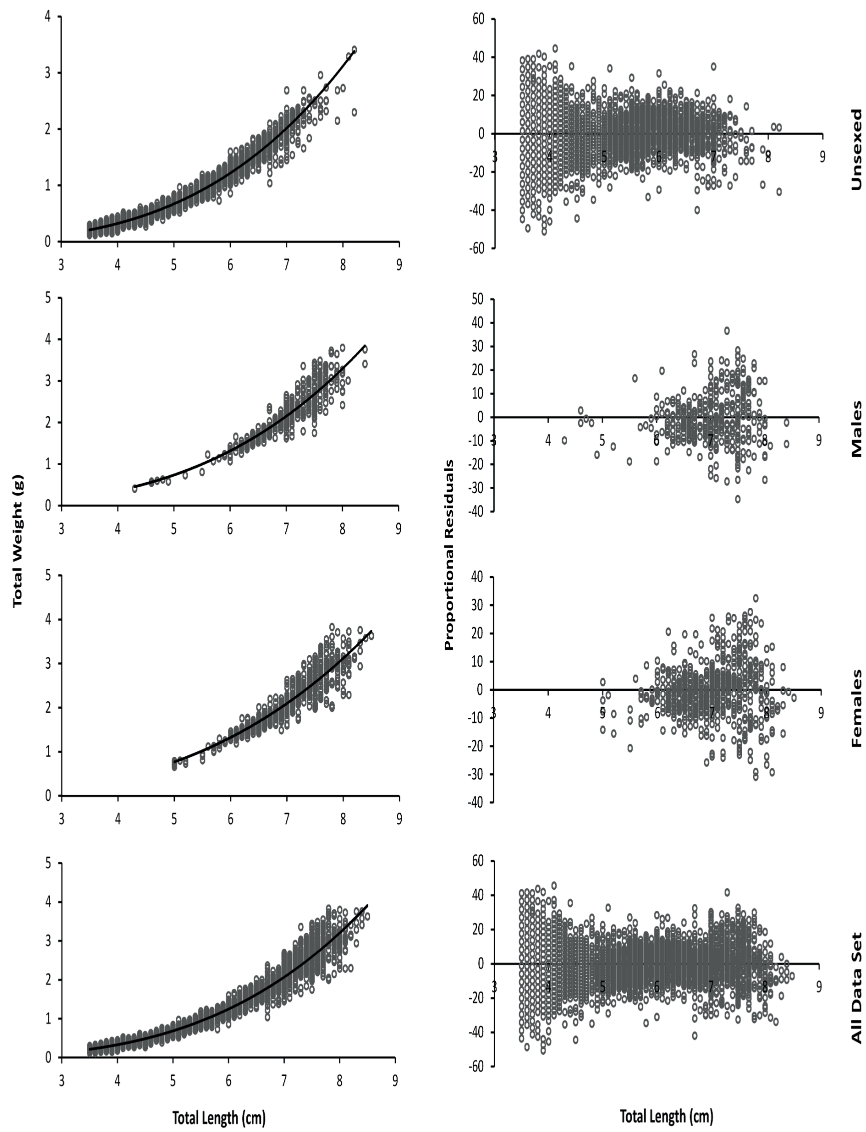

Figure 2 - Weight/length relationship of *Anchoa tricolor* in the Estuarine Complex of Paranaguá, southern Brazil.

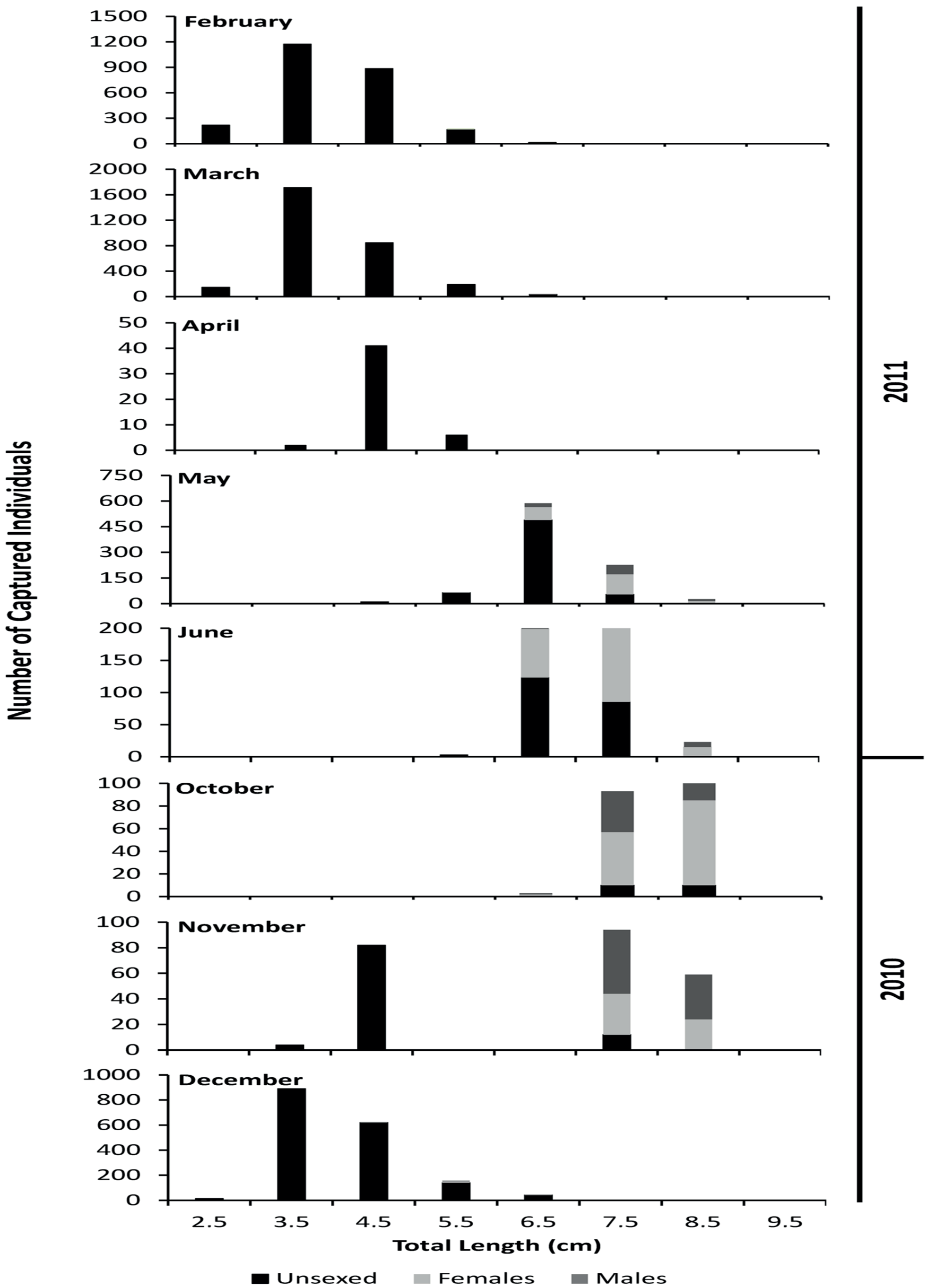

Figure 3 - Total length frequency distribution by sampling month of *Anchoa tricolor* in the Estuarine Complex of Paranaguá, southern Brazil.

TABLE III
Growth parameters of von Bertalanffy's equation for *Anchoa tricolor* in the Estuarine Complex of Paranaguá, southern Brazil.

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
L∞	10.06	1.994	9.67	104.52
K	1.771	0.077	1.620	1.92
T0	-0.208	0.005	-0.218	-0.197

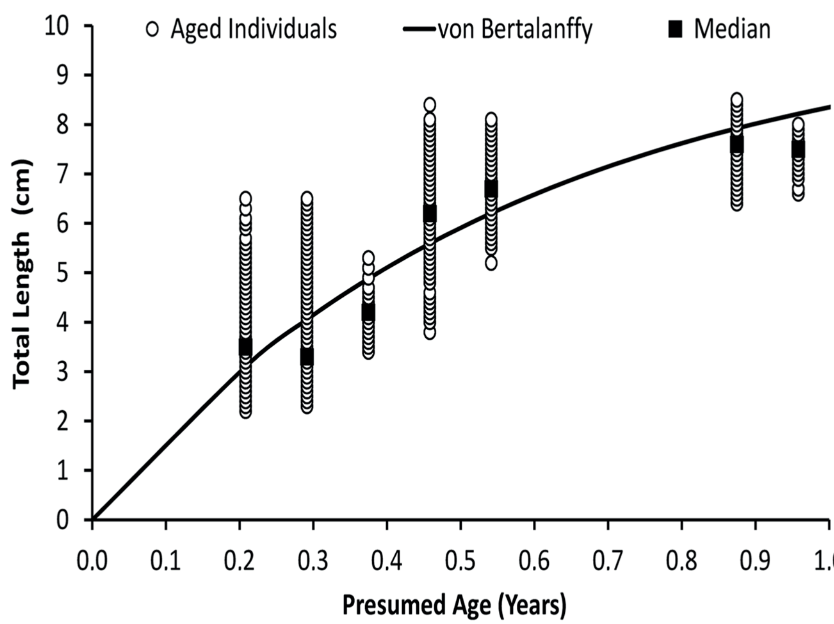

Figure 4 - Growth curve according to von Bertalanffy's model for *Anchoa tricolor* in the Estuarine Complex of Paranaguá, southern Brazil.

from the general models proposed by Pauly et al. (1998) and Taylor (1958) (Table I). For *Anchoa*, the relationship between empirical growth rate values (*K*) and maximum registered total length (Fig. 5a) follows a perfect power function ($K=11.639Lt^{-0.922}$; R^2=0.9999), a simpler equation that emulate the more general relationship proposed by Pauly et al. (1998). According to the FishBase dataset (Table I), *A. tricolor* has a maximum total length of 11.8 cm, resulting on a *K* value estimate of 1.19 $year^{-1}$ (gray spot). Maximum captured size at Paranaguá estuarine complex was 8.5 cm, and the adjusted growth curve *K* value, at 1.77, is very close to the predicted trend line. Three other species, *A. mitchilli, A. mundeola* and *A. panamensis*, with direct estimates of *K* values from dedicated sampling programs, presented *K* estimates very far from the proposed general model. The same general pattern could be observed for Longevity (A_{95}) values (Fig. 5b). From FishBase (Table I), *A. tricolor* has a longevity of 2.4 years, although we estimate the maximum life span as 1.77 years. Nevertheless, both estimates follow the same general empirical power trend ($A_{95}=0.2213L^{-0.552}$; R^2=0.9966) derived from FishBase dataset. As for *K* estimates, Longevity values derived from

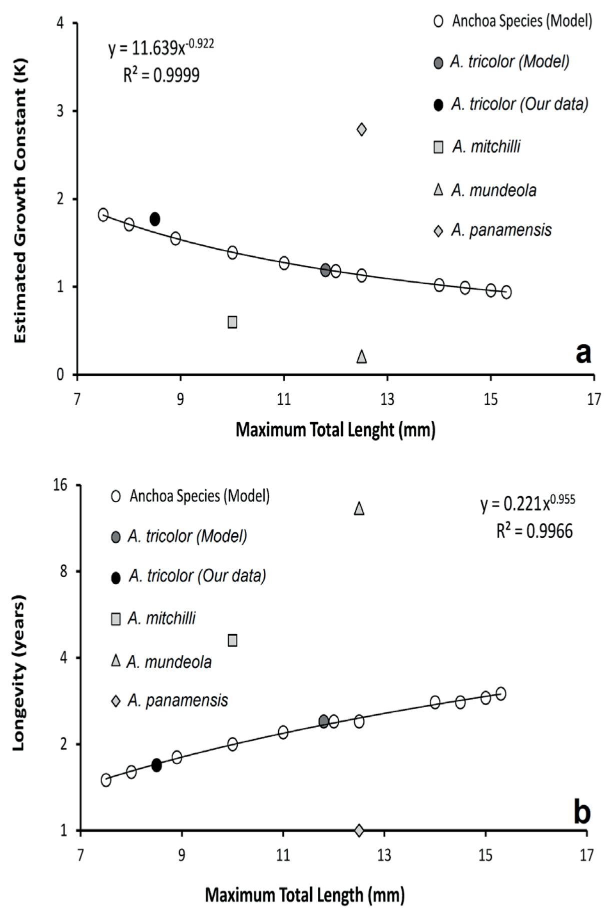

Figure 5 - General patterns for the von Bertalanffy growth rate (K)(**a**) and longevity *sensu* Taylor (A_{95})(**b**) for *Anchoa* species in relation to maximum registered total length (data from FishBase.org).

dedicated sampling programs are all very far the general empirical trend line.

DISCUSSION

According to our data, if analyzed the full dataset, the weight/length relationship of *A. tricolor* indicates an allometric growth pattern (b=3.282; SE=0.0088), different to results previously published by Vaz-dos-Santos and Rossi-Wongtschowski (2013) (b=3.043; SE=0.046; n=218); by Franco et al. 2013 (b= 3.016; SE=0.121; n= 13), both suggesting isometry (b≅3.0). Nevertheless, if analyzed apart, juveniles and males presented positive allometric growth (b>3), whereas females growth isometrically. So, the diverging published estimates could be the result of different gender/size sampling mixtures: if adult females are dominant in the sample; allometry estimates get to around 3.0; but if juveniles or males are dominant; an alometric pattern is achieved. This isometric pattern of females could be the result of additional energy expenses related to egg production, depleting somatic reserves, a pattern already described for most fish species once reproduction is achieved.

Some few studies analyzed the weight/length relationship of *Anchoa* species on the Brazilian coast, including *A. marinii* (b= 3.22, no SE, Haimovici and Velasco 2000); *A. hepsetus* (b= 3.09, SE=0.0024, Giarrizzo et al. 2006; b= 3.482, SE=0.049, Joyuex et al. 2008), *A. parva* (b= 3.194; SE=0.019, Joyuex et al. 2008); and *A. januaria* (b= 3.418; SE=0.010, Franco et al. 2013), indicating that positive allometry is a dominant aspect of the genus on the Brazilian coast. Nevertheless, divergent data for *A. hepsetus* (Giarrizzo et al. 2006, Joyuex et al. 2008) suggest again that results could be affected by size profile and gender proportion of the samples.

Growth and longevity data in current research reveal a lower asymptotic length, increased growth rates and reduced life expectancy than those registered by the Fishbase (Froese and Pauly 2016) for the species (Tables I and III). FishBase estimates were based on maximum total length registered at 11.8 cm, longer than 8.5 cm as presently observed. One could argue that the captures restricted to estuarine shore areas may had limited the available size profile for *A. tricolor*. Nevertheless, the capture of returning adults in November and the perfect balance regarding maximum size, growth rate and life-span, as presented in Fig. 5, suggest that our estimates could tell a life-history that perfectly match the available data.

Spawning of *A. tricolor* for the Rio de Janeiro coastal areas use to happen on the shallow internal platform by the end of winter and the start of spring (Araújo et al. 2008a). Although we have no data concerning reproductive cycle of the species directly from our data, recruitment of the young of the year was recorded from November to March (Fig. 3), sustaining an even longer reproductive season comprising spring and summer. The spring/summer recruitment of *A. tricolor* was also sustained by S. Koblitz (unpublished data) due to a large amount of larvae during this period in the Estuarine Complex of Paranaguá. This high amount of juveniles of *A. tricolor* from November to March in the Paranaguá bay demonstrates the importance of estuaries for the growth and reproduction of the species.

Felix et al. (2006) reported a concentration of adult specimens of *A. tricolor* in October, although our data shows that adult individuals were also present in November. By merging information concerning *A. tricolor* biological cycle, it becomes clear that the species has a long (spring/summer) recruitment period. Modal displacement, identified from February to June (Fig. 3), shows clearly the species growth pattern, with just one age-group present on the estuarine shallow areas. From July to September, the species disappear from shallow (shore) estuary, suggesting migration to deeper waters, and returning as adults on October/November, with two age-groups visible in November, the returning adults and the newborn recruits. This missing period could be related to reproductive activities, as gonadal maturation, although Araújo et al. (2008b) already reported spawning in final winter in shallow coastal waters. This adult preference for the shallow internal platform, albeit with small migration flows to the adjacent estuarine systems was already reported by Souza and Chaves (2007), Araújo et al. (2008a) and Hackradt et al. (2009). After returning to estuary in October/November, adult specimens disappear on December, suggesting the conclusion of a life-cycle a little longer than one year, sustained by the longevity estimate (A_{95}) at 1.7 years.

Anchoa tricolor is considered an important fishery resource for traditional fishery communities of southern São Paulo littoral area (Cardoso and Nordi 2006). Although do not representing a commercial stock in Paranaguá Bay, the studied population could be functioning as a source stock for the nearby fishing grounds of southern São Paulo. Beyond the economical role, the species represent a key element for transferring energy from plankton to several top predators as already described by Santos et al. (2002), Bugoni and Vooren (2004), Giberto et al. (2007) and Bittar et al. (2008). In this regard, *A. tricolor* may represent a key estuarine species for ecosystem functioning due to its relatively high abundance, annual occurrence in estuarine areas as reproductive and growing grounds, as well as a foraging resource for several species from fishes to birds.

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