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ZOOLOGY

Growth, longevity, and juvenile recruitment of the white shrimp *Litopenaeus schmitti* (Burkenroad, 1936) (Decapoda: Penaeoidea) in southeastern Brazil

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ABSTRACT. *Litopenaeus schmitti* is one of the most commercially exploited penaeids on the southeastern and southern Atlantic coast of Brazil. Information about juvenile recruitment and growth patterns of individuals is important for management programs. The present study estimated the growth parameters, longevity, and recruitment of *L. schmitti* in the region of Ubatuba, São Paulo State. The growth parameters of individuals were estimated by the Bertalanffy growth model, and longevity was estimated with the inverted Bertalanffy equation. The growth parameters were, for females and males respectively: CL_∞ = 53.10 mm and 43.23 mm, k = 1.82 $year^{-1}$ and 2.19 $years^{-1}$, t_0= 1.10 and 0.69. Longevity was calculated to be 2.27 years for females and 2.10 years for males. Juvenile recruitment occurred seasonally from December to April during the first year of sampling and from November to May in the second year. Although the large peak in juveniles seen in March 2007 in the estuarine regions coincided with the closed season, the reopening of the fishery in June may promote the capture of large numbers of newly grown adults who have not yet reproduced.

Keywords: Dendrobranchiata; shrimp fisheries; closed season; Bertalanffy; growth coefficient.

Crescimento, longevidade e recrutamento juvenil do camarão-branco *Litopenaeus schmitti* (Burkenroad, 1936) (Decapoda: Penaeoidea) na região Sudeste do Brasil

RESUMO. *Litopenaeus schmitti* é um dos peneídeos mais explorados comercialmente na costa do Atlântico Sudeste e Sul do Brasil. Desta forma, informações acerca do recrutamento juvenil e dos padrões de crescimento dos indivíduos são importantes para futuros programas de manejo. O presente estudo teve como objetivo estimar os parâmetros de crescimento, longevidade e recrutamento de *L. schmitti* na região de Ubatuba, Estado de São Paulo. Tais parâmetros foram estimados pelo modelo de crescimento de von Bertalanffy e a longevidade foi estimada por meio da equação inversa de von Bertalanffy. Os parâmetros de crescimento estimados para fêmeas e machos foram, respectivamente: CC_∞ = 53,10 mm e 43,23 mm, k = 1,82 $anos^{-1}$ e 2,19 $anos^{-1}$, t_0 = 1,10 e 0,69, e longevidade de 2,27 e 2,10 anos. O recrutamento juvenil ocorreu sazonalmente entre dezembro e abril no primeiro ano de amostragem e de novembro a maio no segundo ano. Embora o principal pico de juvenis, na região estuarina em março/2007, tenha coincidido com o período de fechamento da pesca, a reabertura da pesca em junho, possivelmente, promove a captura de grandes quantidades de recém-adultos, que ainda não participaram da primeira reprodução.

Palavras-chave: Dendrobranchiata; pesca de camarão; período de defeso; Bertalanffy; coeficiente de crescimento.

Introduction

Crustacean growth is a discontinuous process regulated by the molt cycle (ecdysis) (Hartnoll, 1982). The most commonly used model for growth studies in crustaceans was developed by Ludwig von Bertalanffy (1938) and provides information about theoretical maximum sizes for individuals as well as growth rate and longevity (D'Incao & Fonseca, 1999). Such information is important for understanding population dynamics and reproductive strategies (Heckler, Simões, Santos, Fransozo, & Costa, 2013; Henriques, Alves, Barreto, & Souza, 2014; Castilho et al., 2015), particularly for commercially exploited species (D'Incao & Fonseca, 1999), since it provides support for conservation (Vogt, 2012). On the coast of Brazil in the southeastern and southern regions, regulations already prohibit penaeid shrimp trawling from March 1 to May 31 of each year with the purpose of promoting the recovery of fish stocks

(*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis* [IBAMA], 2008).

Litopenaeus schmitti (Burkenroad, 1936) is distributed through the western Atlantic from Cuba to the Brazilian State of Rio Grande do Sul (Costa, Fransozo, Melo, & Freire, 2003). It is known as the white shrimp and is one of the most commercially exploited species in southern and southeastern Brazil, along with *Xiphopenaeus kroyeri* (Heller, 1862), *Farfantepenaeus paulensis* (Pérez-Farfante, 1967), and *Farfantepenaeus brasiliensis* (Latreille, 1817) (Perez, Pezzuto, Rodrigues, Valentini, & Vooren, 2001; Valentini & Pezzuto, 2006). According to data from the São Paulo State Fisheries Institute, the biomass of white shrimp landed at the coast of the state during 2012–2016 fluctuated from 57 tons in 2013 to 120 tons in 2014 (*Secretaria de Agricultura e Abastecimento*, *Online*).

The life cycle of *L. schmitti* is characterized as type II (Dall, Hill, Rothlisberg, & Sharples, 1990), with the species depending on estuarine, coastal, and marine habitats to complete its development stages and life cycle (Pérez-Castañeda & Defeo, 2001; Costa, Lopes, Castilho, Fransozo, & Simões, 2008). For this reason, white shrimp are targeted by artisanal fleets in estuaries as juveniles; as adults, they are targeted by the industrial fleet in coastal and marine areas (Santos, Sckendorff, & Amaral, 1988). In addition, when they migrate toward the sea, juveniles roam coastal regions up to 25 meters deep in areas where the seabob shrimp X. kroyeri is intensely fished. As a result, juvenile white shrimp may be captured, decreasing population stocks (Leite Jr. & Petrere Jr., 2006; Capparelli, Kasten, Castilho, & Costa, 2012; Bochini, Fransozo, Castilho, Hirose, & Costa, 2014).

Several studies related to *L. schmitti* have been conducted along the Brazilian coast: investigation of their life cycle in Pernambuco, on the northeastern coast of Brazil (Coelho & Santos, 1994), and ecological aspects, population structure, distribution and population dynamics on the southeastern coast of Brazil (Neiva, Santos, & Jankauskis, 1971; Capparelli et al., 2012; Bochini et al., 2014; Barioto, Stanski, Grabowski, Costa, & Castilho, 2017). However, studies related to growth parameters and longevity have only been performed in the northeastern region (Santos, Pereira, & Ivo, 2006) and in captivity (Henriques et al., 2014), with no studies on these parameters or estimated size of juveniles migrating from the estuary to the marine region in the northern São Paulo state.

The present study was aimed to estimate the growth parameters, longevity, and juvenile recruitment period of the population of *L. schmitti* on the northern coast of São Paulo, Brazil. We also determined the lifetime and size of juveniles when they migrate from the estuary to the marine region.

Material and methods

Samples were collected each month from July 2005 to June 2007 in the estuary formed by the Indaiá River and the Ubatuba Bay (23°25' – 23°27'S and 45°00' – 45°03'18'W) (Figure 1). In the estuary, shrimp were captured with a beach seine with a 3 m mouth aperture, equipped with a 5 mm mesh size net at both body and cod end. Each trawl was dragged 50 m to cover a sampling area of 150 m^2. In the inlet, sites with depths ranging from 5 to 20 m were sampled to coincide with depths influenced by fishing activity. In this region, a shrimp fishing boat equipped with two double-rig nets (mesh sizes 20 and 18 mm in the cod end) was used for trawling. Each station was trawled for 30 minutes, covering a total area of approximately 18,000 m^2.

The specimens were identified at the species level according to Costa et al. (2003). Here, we followed the classification proposed by Pérez-Farfante and Kensley (1997).

Carapace length (CL) was measured in all individuals, defined as the distance between the orbital angle and the posterior margin of the carapace (Capparelli et al., 2012). The sex of the individuals was determined by the presence of thelycum in females or petasma in males (Costa et al., 2003).

The model assumptions of homoscedasticity (Levene's test) and normality (Shapiro-Wilk test) were initially tested (Zar, 2010). To verify the difference between the average sizes reached by males and females, the Mann-Whitney (non-parametric) test was applied ($\alpha = 0.05$), using Statistica 7.0 software (StatSoft, Tulsa, OK, USA).

The growth analysis was conducted separately for males and females. For each sampled month, the length frequency (CL mm) was distributed into 1 mm size classes, and modes were selected based on their parameters, using Peak Fit software (PeakFit v. 4.06 SPSS Inc. for Windows Copyright 1991-1999, AISN Software Inc., Florence, OR, USA) and the automatic peak fitting detection and fitting procedure (method I-residual, no data smoothing) according to Fonseca and D'Incao (2003). Individual growth was calculated for each sex, and the cohorts were fitted with the Bertalanffy growth model (1938), namely $CL_t = CL_\infty [1-e^{-k(t - t0)}]$, where CL_t is the carapace length in time t, CL_∞ is the asymptotic length, k is the growth coefficient, and t_0 is the theoretical age at length zero. The growth parameters were estimated for the different cohorts using the "Solver" tool supplement in Microsoft Excel (version 2010) for Windows 7, according to Fonseca and D'Incao (2003), varying the equation parameters (CL_∞, k, and t_0). The criteria used to accept a cohort were based on biological coherence with longevity, growth coefficient and asymptotic length. The growth curves were compared using an F test ($p = 0.05$), according to Cerrato (1990).

Longevity was estimated using an inverted Bertalanffy equation with modifications suggested by D'Incao and Fonseca (1999), considering $t_0 = 0$ and $CL/CL_\infty = 0.99$. The longevity equation was $t = (t_0 - (1/k)\ Ln\ (1 - CL_t/CL_\infty)$.

Individuals smaller than 25.0 mm were considered juveniles, according to Zenger and Agnes (1977) and Capparelli et al. (2012). The recruitment period was defined by the monthly percentage of juveniles in relation to the total of individuals sampled in each month.

To estimate how long juveniles take to begin migrating to the marine region, we used the inverted Bertalanffy equation with modifications suggested by King (1995): $Tr = (t_0-(1/k)*Ln(1-(CL_r/CL_\infty)))$, where CL_r is the carapace length at the juvenile stage (25.0 mm), CL_∞ is the asymptotic length, k is the growth coefficient, and t_0 is the theoretical age at length zero, which were previously estimated in the growth analysis.

Results

A total of 1277 individuals was captured, 598 of which were females and 679 males. In general, the minimum, maximum, and mean carapace length measurements (CL mm) for males were 4.40–53.60 mm (20.58 ± 12.92 mm), while for females the values were 4.10–52.00 mm (19.02 ± 15.52 mm), with no significant difference between average sizes (Mann-Whitney, $p > 0.05$). However, when sizes were compared by region, significant differences were found (Mann-Whitney, $p < 0.05$) (Table 1).

The frequency distributions of length reflect the different cohorts that are incorporated into the population over time (Figure 2 and 3).

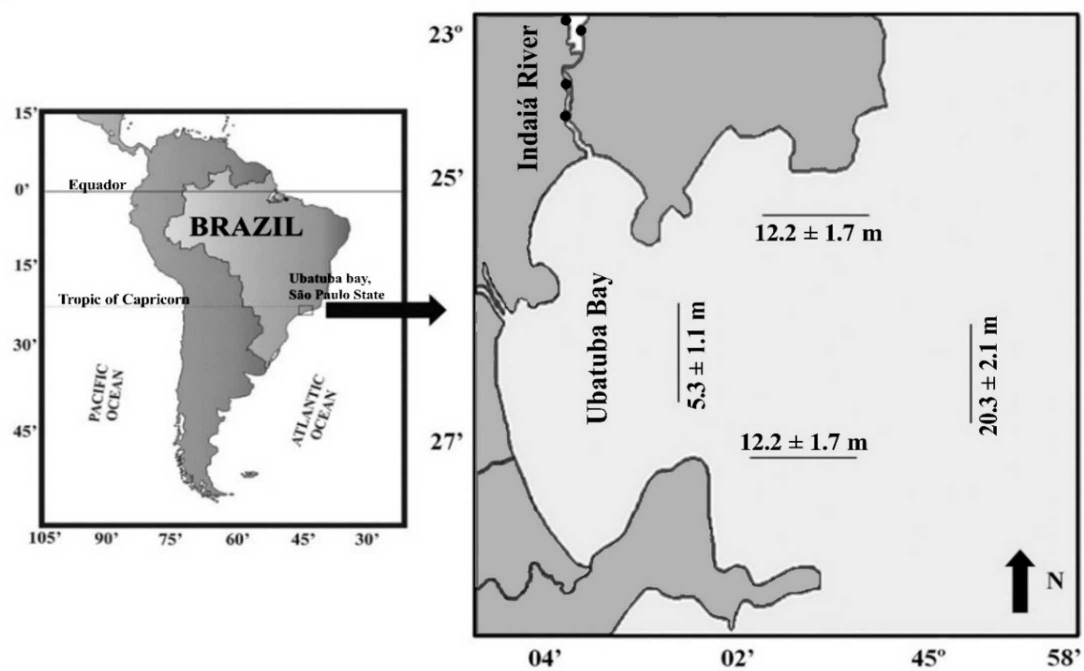

Figure 1. Map of the study area. Northern region of São Paulo state (left), Ubatuba Bay, and Indaiá Estuary. Lines indicate the sampling sites and their mean depths for bay sampling; black dots indicate the sampling sites in the estuary (Indaiá River) (adapted from Capparelli et al., 2012).

Table 1. *Litopenaeus schmitti* (Burkenroad, 1936) Abundance (N), mean, standard deviation (SD), and minimum and maximum values for carapace length (CL mm) by demographic category and region, for specimens sampled monthly in the Ubatuba region of São Paulo, Brazil, July 2005–June 2007.

	Demographic category	CL (mm)				Mann-Whitney test *p*
		N	Mean ± SD	Min.	Max.	
Estuarine region	Males	342	8.03 ± 1.81	4.40	13.90	0.020
	Females	385	7.75 ± 1.81	4.10	14.40	
Marine region	Males	337	33.33 ± 3.16	12.60	53.60	< 0.001
	Females	213	39.37 ± 5.11	18.80	52.00	
General	Males	679	20.58 ± 12.92	4.40	53.60	0.989
	Females	598	19.02 ± 15.52	4.10	52.00	

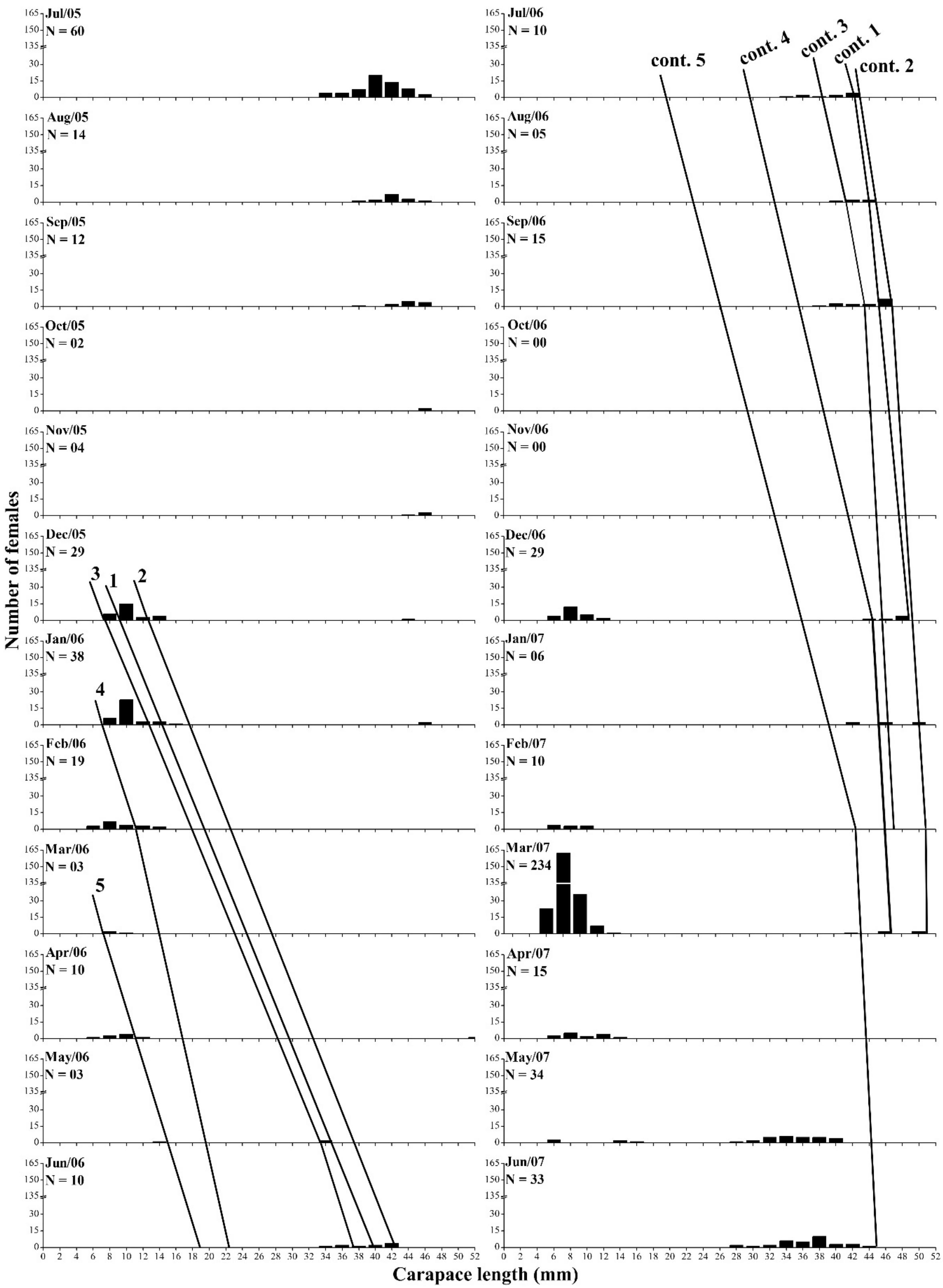

Figure 2. Carapace length (CL) frequency histograms of females *Litopenaeus schmitti* (Burkenroad, 1936) in the Ubatuba region of São Paulo, Brazil, from July 2005 to June 2007. Lines represent the cohorts followed during the study period to describe individual growth.

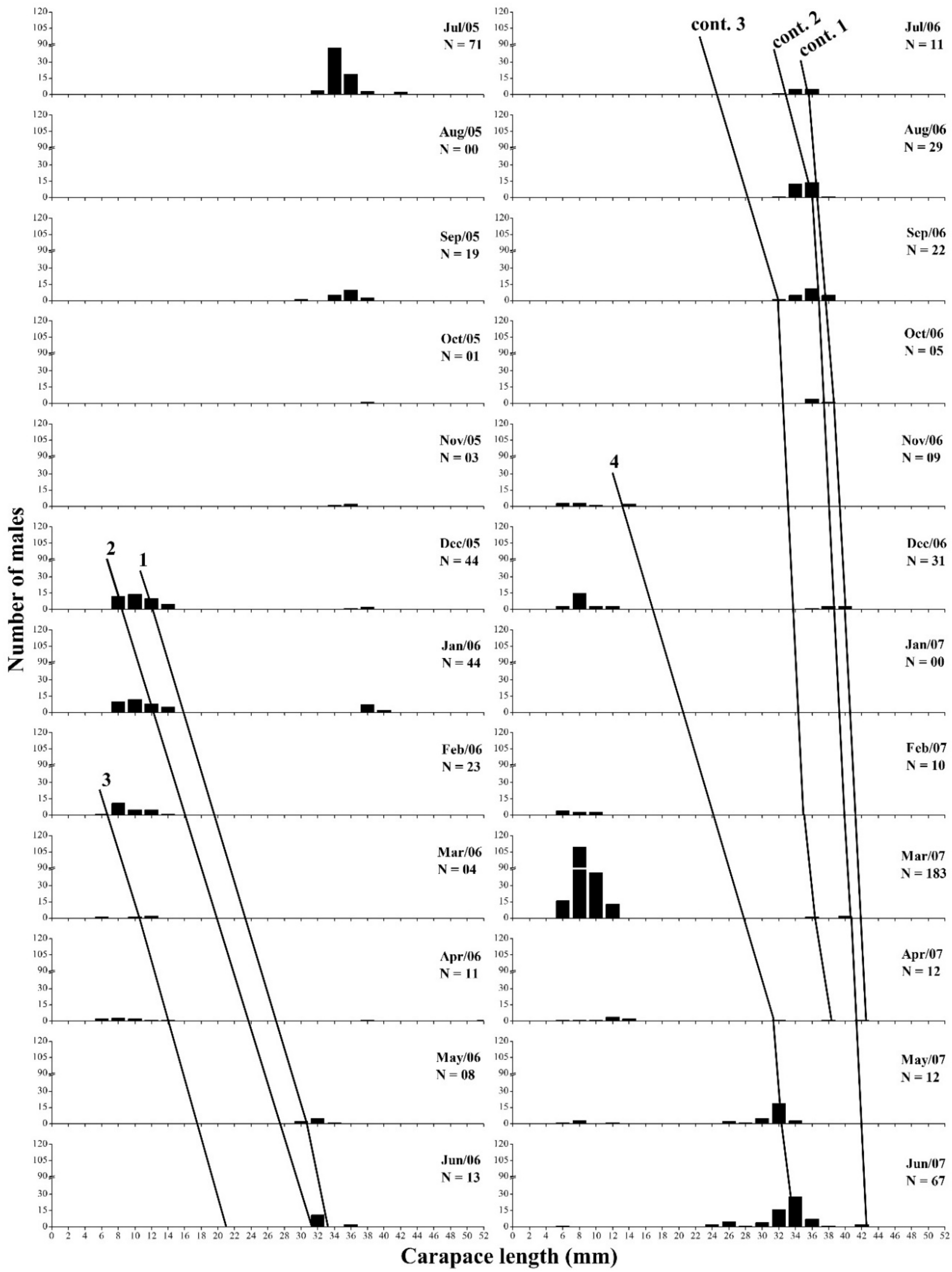

Figure 3. Carapace length (CL) frequency histograms of males *Litopenaeus schmitti* (Burkenroad, 1936) in the Ubatuba region of São Paulo, Brazil, from July 2005 to June 2007. Lines represent the cohorts followed during the study period to describe individual growth.

Four growth curves were adjusted for each sex cohort (Table 2). The growth parameters estimated for the female curve were $CL_\infty = 53.10$ mm, k = 1.82 year^{-1}, and $t_0 = 1.10$. For males, the estimated values were $CL_\infty = 43.23$ mm, k = 2.19 year^{-1}, and $t_0 = -0.69$ (Figure 4). The R^2 values were high: 0.96 for females and 0.93 for males. Maximum longevity was calculated to be 828 days (2.27 years) for females and 766 days (2.10 years) for males (Figure 4).

Table 2. Growth parameters according to the Bertalanffy Growth Model (CL_∞, k, and t_0) and maximum longevity (t_{max}), estimated for male and female cohorts of *Litopenaeus schmitti* (Burkenroad, 1936) in the Ubatuba Bay and Indaiá Estuary in São Paulo, Brazil, from July 2005 to June 2007.

Females					Males				
Cohort	CL_∞	k (day)	t_0 (day)	t_{max} (years)	Cohort	CL_∞	k (day)	t_0 (day)	t_{max} (years)
1	52.18	0.006	-29.03	1.88	1	42.73	0.006	-35.86	2.04
2	51.85	0.005	-20.16	2.27	2	44.76	0.005	-58.53	2.29
3	53.97	0.004	-26.68	2.65	3	39.02	0.007	-26.45	1.78
4	52.80	0.003	-44.06	3.74	4	38.93	0.008	-47.34	1.51
Mean	52.70	0.004	-29.98	2.63	Mean	41.36	0.006	-42.04	1.90

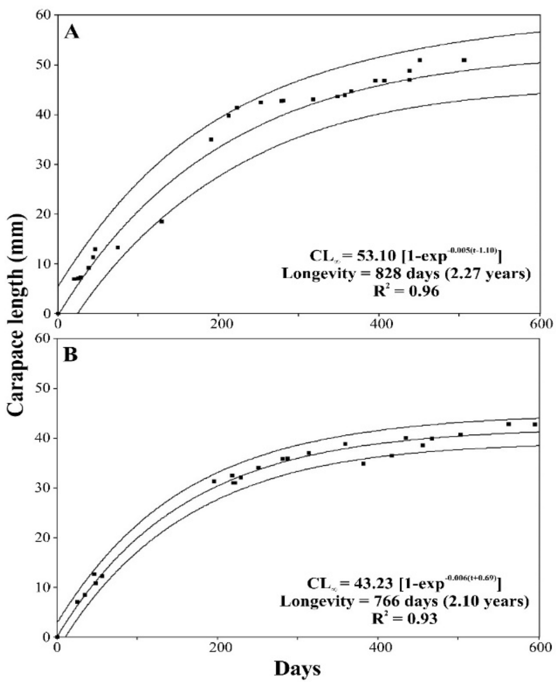

Figure 4. Growth curve estimated for females (A) and males (B) using the Bertalanffy growth model for *Litopenaeus schmitti* (Burkenroad, 1936) in the Ubatuba region of São Paulo, Brazil, from July 2005 to June 2007. The external lines are the prediction intervals (95%).

The estimated values for CL_∞ and k for both sexes showed that females exhibited lower growth rates, but also reached a higher asymptotic length and greater longevity. There was a statistically significant difference between male and female growth ($F_{calculated} = 0.09$ and $F_{critic} = 3.09$).

The presence of juvenile shrimp was seasonal over the study period. Juveniles were captured between December and April in the first year of sampling and from November to May in the second year, with the highest peak occurring in March 2007 (Figure 2 and 3).

Only juveniles were captured in the estuarine region. The CL of the largest male was 13.90 mm and for the largest female was 14.40 mm, suggesting that individuals start migrating to the marine region at these sizes. The CL of the smallest individual captured in the marine region was 24.20 mm, while in the largest this measurement was 53.60 mm. In addition, 98.9% of the shrimp captured at in this region were adults (Figure 5).

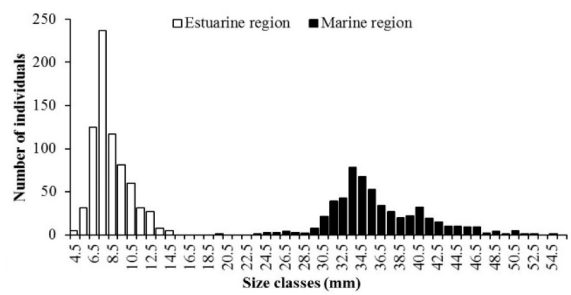

Figure 5. Mean frequency of *Litopenaeus schmitti* (Burkenroad, 1936) collected in the Indaiá Estuary (estuarine region) and Ubatuba Bay (marine region) of São Paulo, Brazil from July 2005 to June 2007, distributed into 0.5 mm size class intervals.

Based on the greater carapace lengths of the individuals captured in the estuary (13.90 mm for males and 14.40 mm for females), together with the growth parameters calculated for the individuals in this study, we estimated that females take 80.2 days (≈ 3 months) to migrate from the estuary to the bay, while males take 64 days (≈ 2 months).

Discussion

Sexual dimorphism in relation to size is common for species in the family Penaeidae (Boschi, 1969). This dimorphism is associated with the greater volume of the female cephalothorax, which permits greater production of oocytes and higher fecundity, since fertilization in penaeid shrimp is external (Boschi, 1969; Heckler et al., 2013; Carvalho, Martinelli-Lemos, Nevis, & Isaac, 2015). In the present study, females of *L. schmitti* had higher asymptotic lengths (CL_∞) than males, corroborating other studies concerning this species (Santos et al., 2006; Silva et al., 2018a) (Table 3).

The CL_∞ values estimated in the present study for both sexes were similar to those obtained for other regions of Brazilian coast: Santos et al. (2006) estimated 40 mm for males and 52 mm for females from Rio Grande do Norte (06°22'10"S), while and Silva et al. (2018a) estimated 43.0 mm for males and 51.6 mm for females from Pernambuco (08°35'57"S). The growth coefficient and longevity estimated for *L. schmitti* occurred within the range of values expected for penaeid shrimp life history, proposed by D'Incao and Fonseca (1999), with longevity values of 1.50 to 2.50 years and growth coefficients of 1.80–3.60/year suggested by Garcia and Le Reste (1981). The specific environmental factors of each region did not appear to influence the parameters analyzed for this species.

However, the use of different methodologies may possibly influence the estimates of such parameters. As reported in other studies (Fonseca & D'Incao, 2003; Leite Jr. & Petrere Jr., 2006; Taddei & Herrera, 2010), the ELEFAN and Battacharya routines performed in the FISAT program (FAO-ICLARM Stock Assessment Tools) have been shown to be less efficient in estimating longevity, since such routines tend to ignore the more extreme modal peaks (because these are comprised of very small sample numbers), but are essential to determine growth parameters. As a result, the selected cohorts end up constituting a smaller slope, resulting in an underestimated k value and consequently an overestimation of longevity. Dall et al. (1990) also reported that several studies using the ELEFAN routine had yielded very small k values, so it would take several years for the shrimp to reach its asymptotic length, thus contrasting with the longevity estimates. Consequently, the Peak Fit program has demonstrated greater coherence in relation to crustacean biology in estimating such values (Davanso, Taddei, Simões, Fransozo, & Costa, 2013; Simões, D'Incao, Fransozo, Castilho, & Costa, 2013; Castilho et al., 2015; Pescinelli et al., 2017; Silva, Santos, Costa, & Hirose, 2018b).

More juveniles were captured in the estuary, while the larger individuals considered adults (> 25 mm) were only sampled in the marine region. In the study area, we also confirmed the type II life cycle for the species proposed by Dall et al. (1990). The present study reinforces that early stages of *L. schmitti* need an estuarine environment to complete their life cycle, as reported by Capparelli et al. (2012). The estuary of the Indaiá River is consequently important for the development of juveniles of this species in this region.

The juveniles remained in the estuarine region until they reached approximately 14 mm in size. The low capture of individuals between 15.5 to 22.5 mm in size in this present study was probably because during migration to Ubatuba Bay, juveniles remain in areas shallower than 5 meters, where shrimp trawling is forbidden.

Based on the temporal distribution of juveniles and the results obtained by Capparelli et al. (2012), we can surmise that reproduction of white shrimp in the Ubatuba region is seasonal. Observing the growth curves, individuals reach 25.0 mm (corresponding to adult stage) in approximately 140 days. Spawning therefore probably occurred during spring (October–December). The period when juveniles entered the fishing area coincided with the current closed season, which in southeastern and southern Brazil spans March 1 to May 31 of each year (*Instituto Brasileiro do Meio Ambiente* [IBAMA], 2008). During this period, regulations prohibit the use of motor-drawn fishing trawls to catch the following penaeid shrimp species: *F. paulensis*, *F. brasiliensis,* and *Farfantepenaeus subtilis* (Pérez-Farfante, 1967), *X. kroyeri*, *L. schmitti*, *Pleoticus muelleri* (Spence Bate, 1888), and *Artemesia longinaris* Spence Bate, 1888 (IBAMA, 2008).

However, the reopening of the fishery in June may promote the capture of large amounts of young adults who have not yet reproduced, hindering the recovery of natural stocks of this species. Landing data provided by the São Paulo State Fisheries Institute show wide oscillations in the biomass of white shrimp captured in recent years (*Secretaria de Agricultura e Abastecimento*, *Online*). Dias-Neto (2011) reports a downward trend in the production of *L. schmitti*, in which there is no chance of recovering stocks despite current efforts to recover natural populations. Continuous studies on monthly variation in juvenile recruitment of this shrimp are therefore necessary in the southeastern and southern regions of Brazil to confirm the efficacy of the closed period.

Table 3. Growth parameters (CL_∞ and K) for *Litopenaeus schmitti* (Burkenroad, 1936) in different regions. (CL): Carapace length.

Location	CL_∞ (mm)		K ($year^{-1}$)		Longevity (year)		Methods	Reference
	Male	Female	Male	Female	Male	Female		
Rio Grande do Norte (Brazil) (06°22' 10" S)	40.0	52.0	1.80	1.66	-	-	Elefan I	Santos et al. 2006
Paraíba (Brazil) (06°54' 01" S)	38.2	52.0	1.65	1.60	-	-	Elefan I	Santos et al. 2006
Alagoas/Sergipe (Brazil) (10°26'- 10°55" S)	46.0	53.0	1.60	1.50	-	-	Elefan I	Santos et al. 2006
Pernambuco (Brazil) (08°35' 57" S)	43.0	51.6	1.00	1.20	-	-	Elefan I	Silva et al. 2018a
Ubatuba – São Paulo (Brazil) (23°26' 02" S)	43.2	53.1	2.19	1.82	2.10	2.27	Peak Fit	Present study

The paradigm of the latitudinal effect reported by Bauer (1992) points out that reproduction and recruitment tend to be continuous at tropical lower-latitude regions, and as latitude increases towards the subtropical and temperate regions, such population aspects become seasonal. This tendency was confirmed for several penaeid species, such as *Sicyonia* spp., *Rimapenaeus constrictus* (Stimpson, 1874), and *A. longinaris* (Bauer, 1992; Costa & Fransozo, 2004; Castilho, Costa, Gransozo, & Boschi, 2007a; Castilho et al., 2007b). However, for *L. schmitti* this paradigm cannot be applied because recruitment occurred seasonally, and resembled reports from nearby locations such as Santos, São Paulo (23°57'S) (Santos, Severino-Rodrigues, & Vaz-dos-Santos, 2008). On the coast of Pernambuco in northeastern Brazil (08°35'57"S), Silva et al. (2018a) also reported seasonal recruitment, and Lugo et al. (2014) reported the same in Venezuela (11°45'N). This absence of a latitudinal pattern may occur because the distinct populations of *L. schmitti* which are distributed along the Brazilian coast occur in areas where the water temperature is similar, as reported by Silva et al. (2018b) for *X. kroyeri*.

Conclusion

Our findings on the *L. schmitti* population from the Ubatuba region are in accordance with population structures previously analyzed for this species along the Brazilian coast. Moreover, our results contribute to knowledge of the life cycle of this species on the coast of São Paulo State, showing that the closed season partially protects the population. However, more detailed investigation on mortality is necessary for more adequate management of the species.

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