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SEX RATIO, GROWTH AND RECRUITMENT OF THE PELAGIC SHRIMP *ACETES AMERICANUS* ON THE SOUTHEASTERN COAST OF BRAZIL

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ABSTRACT

We evaluated the population dynamics of *Acetes americanus* Ortmann, 1893 focusing on sex ratio, individual growth, longevity, and the juvenile recruitment period. Samples were collected monthly from January 2006 to June 2007 in the bay of Ubatuba, Brazil. Specimen growth was identified for each gender, and the chosen cohorts were fitted in a von Bertalanffy Growth Model (VBGM); longevity was estimated by the von Bertalanffy inverse equation, considering 99% of the asymptotic length. A total of 6881 individuals (2343 males and 4538 females) were captured. On average the body size (total length) was greater in females (14.64 ± 3.34 mm) than in males (12.27 ± 1.86 mm). The mean growth curves (obtained by grouping the cohorts for each sex), provided estimates of $TL_\infty = 19.33$ mm, $k = 0.02$ and $t_0 = -0.12$ days for females and $TL_\infty = 15.13$ mm, $k = 0.03$ and $t_0 = -0.07$ days for males, where TL_∞ is the asymptotic length, k is coefficient of growth and t_0 is the theorical age when the size is equal to 0. Longevity was estimated at 0.61 years for females and 0.50 years for males. The sex ratio tended to favor females, which corroborates with others studies of sergestids. Our finding that males of *A. americanus* have higher values of k and therefore achieve a smaller size relative to females has been observed in other penaeids. We concluded that this differential growth pattern between the sexes is found across Dendrobranchiata. The life cycles of penaeids have an average duration of approximately 1-2 years, but our results corroborate other studies that estimate a shorter longevity for *Acetes*, as species of this genus are typically smaller in size. We found continuous recruitment with two main peaks observed during the study period, corroborating previous studies of *Acetes*.

KEY WORDS: *Acetes americanus*, Dendrobranchiata, longevity, population dynamics, Sergestidae

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INTRODUCTION

Acetes americanus Ortmann, 1893 occurs in the western Atlantic from Praia de Guayana in Puerto Rico to Rio Grande do Sul, Brazil (D'Incao and Martins, 2000). The genus belongs to Sergestidae and plays an important role in the marine food chain, particularly in coastal waters (Xiao and Greenwood, 1993). In Asian and African countries, these shrimps have great economic importance because they are used by the aquaculture industry as feed and for human consumption (Omori, 1975; Ung and Itoh, 1989). Among the six species of shrimp that are responsible for 83% of world wide catches, the most important in relation to biomass is *Acetes japonicus* Kishinouye, 1905 (FAO, 2008).

Acetes is pelagic, with body lengths ranging from 10 to 40 mm (Omori, 1975). *Acetes* spp. inhabit estuaries and coastal waters of tropical, subtropical and temperate regions (Xiao and Greenwood, 1993). In Brazil, along the northern coast of the state of São Paulo, *A. americanus* has been found in coastal waters with salinities ranging from 22 to 38 and temperatures ranging from 16 to 30°C (Simões et al., in press).

Studies of the individual growth of crustaceans have been reported in the literature estimating age in relation to the size (Kirkwood and Sommers, 1984; Die, 1992; D'Incao and Fonseca, 1999; Pérez-Castañeda and Defeo, 2005). Previous studies (Fonseca and D'Incao, 2003; Dumont and D'Incao, 2004; Keunecke et al., 2007; Lopes-Leitzke et al., 2009; Arculeo et al., 2011) have demonstrated that understanding patterns in the growth and structure of crustacean populations is fundamental for deriving the life history necessary for the effective and sustainable management of these species. However, little information is available regarding the population parameters of *Acetes*, with the exception of studies by Zafar and Amin (2002), Oh and Jeong (2003) and Amin et al. (2008, 2009a, 2009b).

The aim of the present study was to evaluate the population dynamics of *A. americanus*, focusing on the sex ratio at different sample depths and times of year, juvenile recruitment, growth rates, and longevity between sexes. The

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longevity of *A. americanus* was compared with other species of the genus collected in different latitudes, and we checked whether this species is "r-selected or k-selected" according to the characteristics of longevity proposed by Pianka (1970).

Material and Methods

Biological Sampling

Monthly collections took place at Ubatuba Bay (23°25′00″S, 45°03′30″W), Ubatuba/SP, Brazil, from January 2006 to June 2007. Located along the northern coastline of the state of São Paulo, the Ubatuba region is an important area for crustacean research because of its species richness (Costa et al., 2000; Costa et al., 2003).

Diurnal samples were collected along 6 transects at depths of 1, 5, 9, 13, 17, and 21 meters (Fig. 1). Sampling was performed from an aluminum boat equipped with a 25-HP outboard motor. Collections were made with an "otter trawl" type net (with a 2-m opening and a 3-m length), and the captured organisms were stored in a collection cup attached at the far end. The mesh size diameters (inter-node distance) were 5 mm in the first half and 0.5 mm at the end of the net that included the collection cup. The net was pulled for 1.15 minutes (corresponding to a distance of approximately 50 meters), with three repetitions collected along each transect.

The collected samples were packed with seawater, labeled with the sample transect, and placed in coolers. The samples were subsequently transported to the laboratory in Ubatuba, where they were sorted and fixed in 10% formalin. Species were identified following D'Incao and Martins (2000) and Costa et al. (2003) and quantified for each transect and each month.

The measurement and analysis of individuals followed Omundsen et al. (2000), with 30 individuals selected at random from each sample (transect replicate). When a transect replicate contained less than 30 individuals, they were all measured. Total length (TL, from the tip of the rostrum on the carapace to the posterior edge of the telson) was measured using a stereo microscope connected to an imaging system (0.01 mm).

Tests for homoscedasticity (Levene Test) and normality (Shapiro-Wilk Test) were first performed as prerequisites for the statistical test, and the data were then log-transformed prior to analyses. Data sets were normally distributed with homogeneous variances. In general, the average length of individuals was compared between male and females using a Student's t-test (Zar, 1999).

Sex Ratio

The gender of individuals was identified according to morphological criteria; females lacked petasma, and males exhibited petasma. To determine whether the sex ratio differed from 1♂ : 1♀, we applied a chi-squared (χ^2) test ($p < 0.05$) (Sokal and Rohlf, 1995).

Individual Growth and Longevity

Individual growth was determined for male and female based on the von Bertalanffy Growth Model (VBGM) (von Bertalanffy, 1938) because this mathematical model correlates to age at length.

Initially, the modal values were determined in each TL frequency distribution (size classes of 0.50 mm) using the program PeakFit (Automatic Peak Fitting Detection and Fitting, Method I-Residual, no Data Smoothing) (Fonseca and D'Incao, 2003). Then, the modes were plotted on a scatter chart vs. time (age) to monitor the rhythm of growth of cohorts. Thereafter, the growth parameters (TL_∞, k and t_0) were estimated by the supplement Solver in Microsoft Excel for Windows 7 package, which applies the VBGM of: $TL_t = TL_\infty(1 - \exp^{-k(t-t_0)})$, where TL_t is total length (mm) in time t, TL_∞ is asymptotic length (mm), k is growth coefficient (day − 1), and t_0 is the theoretical age when the size is equal to 0. The criterion used to validate a growth of cohort was it similarity to values given in the literature for other *Acetes*. Finally, cohort data were pooled and the growth parameters were estimated for each gender. Comparisons of the growth curves were made using an F test ($p = 0.05$), according to Cerrato (1990).

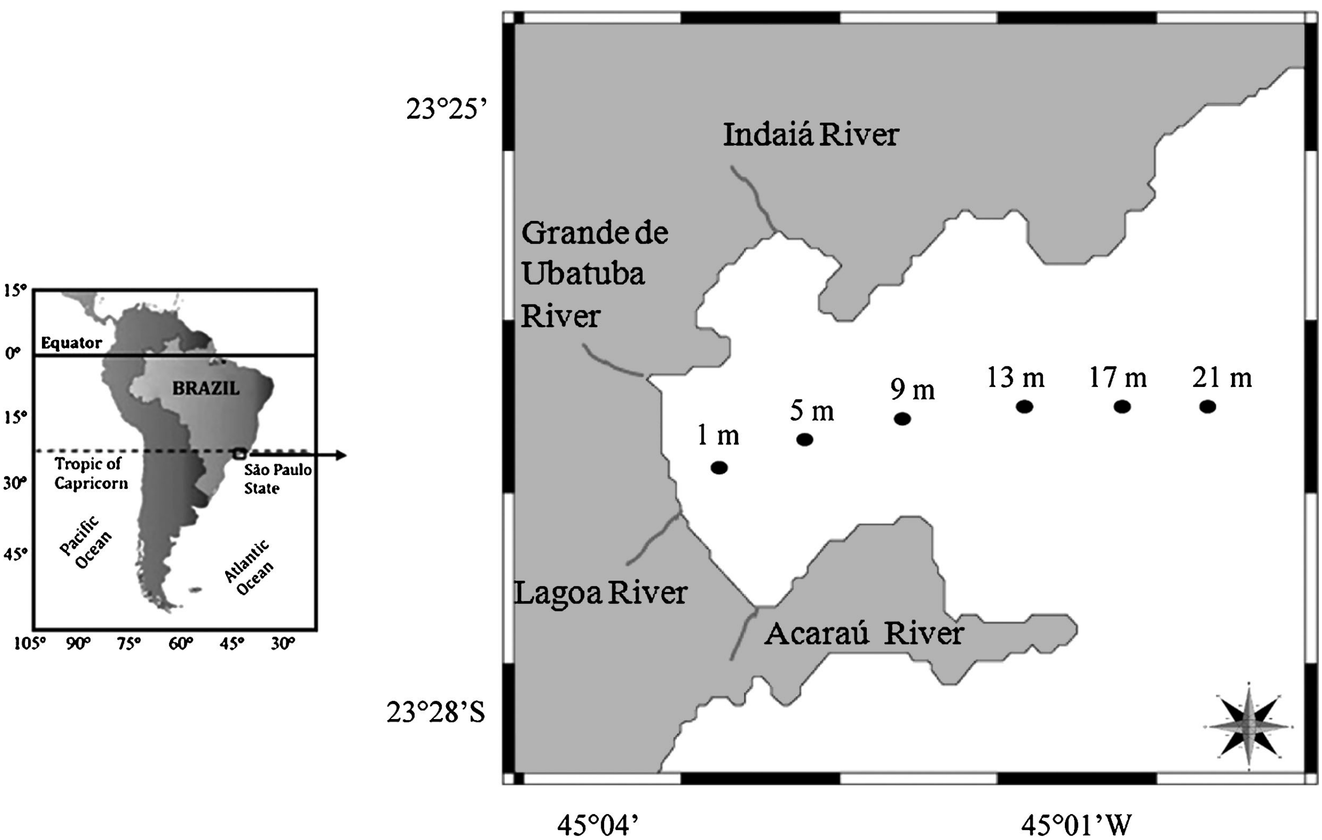

Fig. 1. Map of the region, indicating the collection sites.

Longevity was estimated by inverting the VBGM with the modification suggested by D'Incao and Fonseca (1999), considering $t_0 = 0$ and $TLt/TL_\infty = 0.99$. The equation of longevity is given by the following equation: longevity $= 0 - (1/k)\,\mathrm{Ln}[1 - (TL_t/TL_\infty)]$.

Recruitment

According to Bauer and Rivera Vega (1992) and Castilho et al. (2008), the recruitment of shrimps can be estimated by considering the proportion of the population sample in the smaller size classes of combined male/female size-frequency distributions and calculating the lower 25% of all the possible size classes (*A. americanus* = 9.0 mm TL). The period of recruitment was defined by the percentage of recruits ($\leqslant$9.0 mm TL) per month.

RESULTS

Population Structure

A total of 6881 individuals were collected during the survey period. Sizes (TL) ranged from 4.18 to 20.45 mm (mean = 14.64 ± 3.34 mm) for females and 5.74 to 17.36 mm (mean = 12.27 ± 1.86 mm) for males (Student's *t*-test, df = 3720, t = 29.79, p = 0.00). There was a notable decrease in the frequency of individuals of *A. americanus* in the smaller and larger size class intervals (Fig. 2).

Larger males were more frequently encountered along the deeper transects (9 to 17 m), whereas the size class frequency of females was more uniformly distributed across the depths examined. Few individuals of either sex were captured at a depth of 21 meters, and the majority of individuals collected at this depth were in the smaller size classes (Fig. 3).

Sex Ratio

During the two-year collection period, we captured a total of 2343 males and 4538 females. A significant difference between genders ($p = 2.72 \times 10^{-154}$) was observed, with a mean sex ratio of 0.52♂ : 1♀ during the collection period. The number of females also differed significantly in relation to the number of males captured at various depths ($p < 0.05$), with the sex ratio favoring females (Tables 1 and 2).

Individual Growth and Longevity

Visual inspection of the population structure graphs revealed a bimodal pattern for females, and this pattern was more pronounced during the months of January 06, April 06, July 06, September 06, January 07 and February 07. In comparison, the males exhibited a unimodal pattern. We identified 14 cohorts for the females and 9 cohorts for the males. The average growth curves derived by grouping the cohorts for each sex resulted in estimates of TL_∞ = 19.33 mm, k = 0.02 and $t_0 = -0.12$ days for females and TL_∞ = 15.13 mm, k = 0.03 and $t_0 = -0.07$ days for males (Figs. 4 and 5).

The maximum longevity was estimated to be 221 days (or 0.61 years) for females and 182 days (or 0.50 years) for males (Fig. 6), and the estimated growth curves for females and males showed a significant difference ($F_{calculated} = 105.07 > F_{critical} = 2.67$, $p = 1.15 \times 10^{-33}$).

Recruitment Pattern

Juveniles were captured during every month of the collection period, but main peaks were observed during the autumn (April, May and June 2006) and summer (January and February 2007) (Fig. 7).

DISCUSSION

Generally, populations tend to exhibit a normal distribution of size, i.e., there is a greater abundance in the intermediate classes and a lower frequency of individuals in the more extreme size classes, following a bell-shaped (Gaussian) curve. The size distribution of the captured shrimps followed this expected pattern, indicating that the complete life cycle of *A. americanus* occurs in the region of Ubatuba. The scarcity of individuals in the smaller and larger size classes is most likely the result of higher rates of natural mortality (Rodrigues and D'Incao, 2008). The variation in the abundance of smaller individuals may be related to the entry of the juvenile population that occurred throughout the study period.

According to Pianka (1983), approximately equal numbers of males and females are expected in dioecious organisms. However, Wenner (1972) found many deviations in the sex ratio in several species of crustaceans as a result of multiple factors, such as differences in growth rates between genders, breeding migrations, sex reversal, and greater feeding activity in one of the sexes. For Dendrobranchiata, Boschi

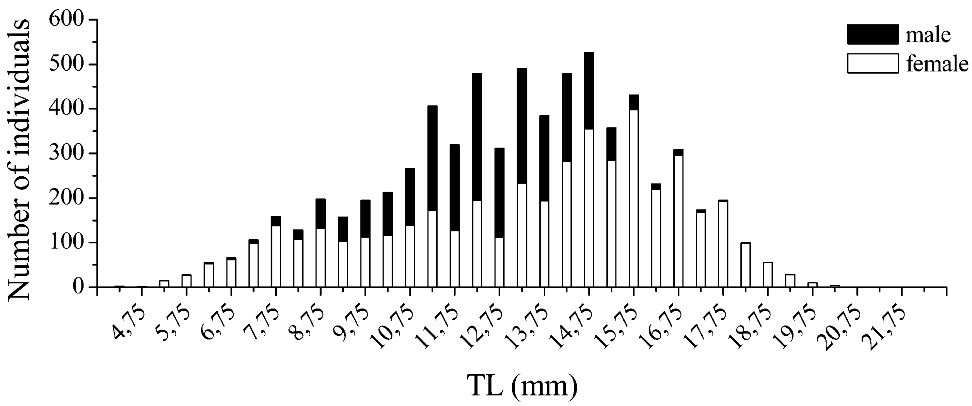

Fig. 2. Number of male and female *Acetes americanus* by size (TL mm) captured in the bay of Ubatuba, São Paulo, Brazil. The size class interval was 0.5 mm, with mean values presented for each class.

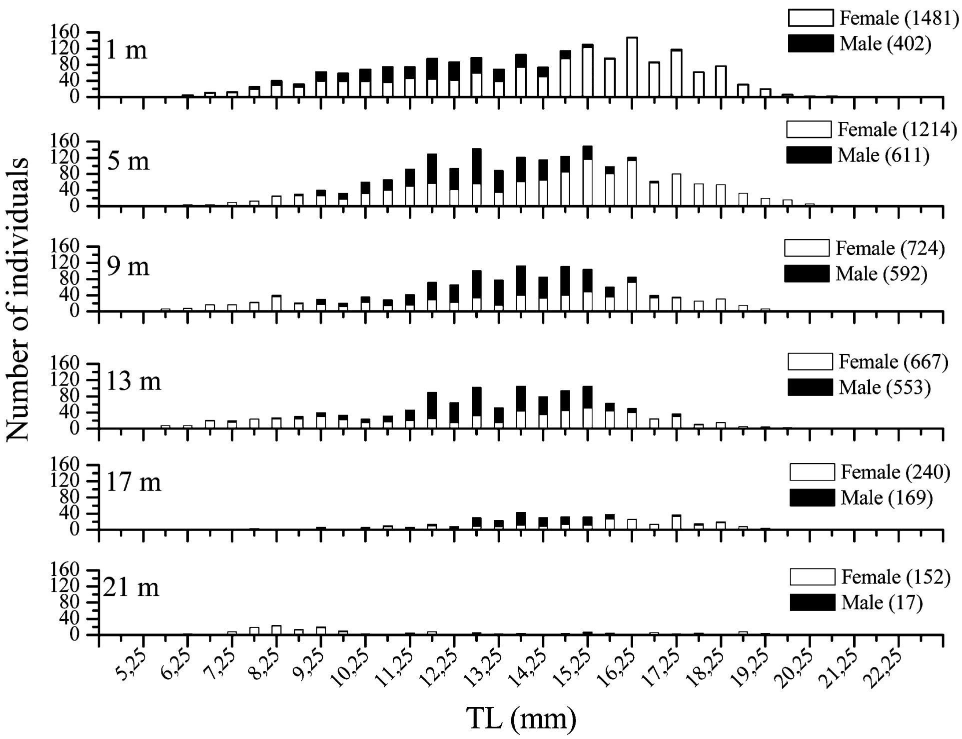

Fig. 3. Number of male and female *Acetes americanus* by size class (TL mm), captured along transects at a depth of 21 meters. The size class interval was 0.5 mm, with mean values presented for each class. The total number of individuals in each class is presented in the graph.

(1969), Gab-Alla et al. (1990), and Cha et al. (2002) suggested that higher male mortality skews the expected sex ratio in favor of females. Similar results were found in the sex ratio of other species of *Acetes* (Oh and Jeong, 2003; Amin et al., 2009c) and in addition our result about individual growth demonstrate a higher growth rate and smaller size for males, which may also influence the sex ratio in favor of females.

We found that females were larger than males, suggesting sexual dimorphism in this species. According to Boschi (1969), sexual dimorphism in length is a general characteristic of the Penaeidae. For example, Gab-Alla et al. (1990), Rodrigues et al. (1992), and Santos and Ivo (2000) found that the carapace of males develops differently from that of females and that this difference is related to the reproductive process. This difference in carapace has been observed in several penaeid species, such as *Rimapenaeus constrictus* (Stimpson, 1874); *Xiphopenaeus kroyeri* (Heller, 1862);

Table 1. Number of males (♂) and females (♀) of *Acetes americanus*, with the resulting sex ratio and χ^2 tests, captured between January 06 and June 07 in the bay of Ubatuba, São Paulo, Brazil.

	♂	♀	Total	Sex ratio (♂ : ♀)	χ^2 test	p
Jan/06	266	357	623	0.75 : 1	13.29	0.000267
Feb/06	108	205	313	0.53 : 1	30.06	$4.19x^{-08}$
Mar/06	221	260	481	0.85 : 1	3.16	0.075363
Apr/06	184	281	465	0.65 : 1	20.23	$6.85x^{-06}$
May/06	127	395	522	0.32 : 1	137.59	$8.94x^{-32}$
Jun/06	155	331	486	0.47 : 1	63.73	$1.42x^{-15}$
Jul/06	133	246	379	0.54 : 1	33.79	$6.46x^{-09}$
Aug/06	84	186	270	0.45 : 1	38.53	$5.38x^{-10}$
Sep/06	14	80	94	0.18 : 1	46.34	$9.94x^{-12}$
Oct/06	26	155	181	0.17 : 1	91.93	$8.94x^{-22}$
Nov/06	120	330	450	0.36 : 1	98.00	$4.18x^{-23}$
Dec/06	206	245	451	0.84 : 1	3.37	0.066293
Jan/07	152	298	450	0.51 : 1	47.36	$5.88x^{-12}$
Feb/07	122	240	362	0.51 : 1	38.46	$5.58x^{-10}$
Mar/07	95	255	350	0.37 : 1	73.14	$1.21x^{-17}$
Apr/07	49	210	259	0.23 : 1	100.08	$1.46x^{-23}$
May/07	114	220	334	0.52 : 1	33.64	$6.63x^{-09}$
Jun/07	168	244	412	0.69 : 1	14.01	0.000181
Total	2343	4538	6881	0.52 : 1	700.19	$2.72x^{-154}$

Table 2. Number of males (♂) and females (♀) of *Acetes americanus*, with the resulting sex ratio and χ^2 tests, captured along transects at depths of 1, 5, 9, 13, 17 and 21 meters in the bay of Ubatuba, São Paulo, Brazil.

Transects	♂	♀	Total	Sex ratio (♂ : ♀)	χ^2 test	p
1 m	402	1481	1883	0.27 : 1	618.35	$1.76x^{-136}$
5 m	611	1274	1884	0.48 : 1	233.28	$1.20x^{-52}$
9 m	592	724	1316	0.82 : 1	13.24	$2.74x^{-04}$
13 m	553	667	1220	0.83 : 1	10.65	$1.10x^{-03}$
17 m	169	240	409	0.70 : 1	12.32	$4.47x^{-04}$
21 m	17	152	169	0.11 : 1	107.77	$2.91x^{-25}$
Total	2343	4538	6881	0.52 : 1	700.77	$2.72x^{-154}$

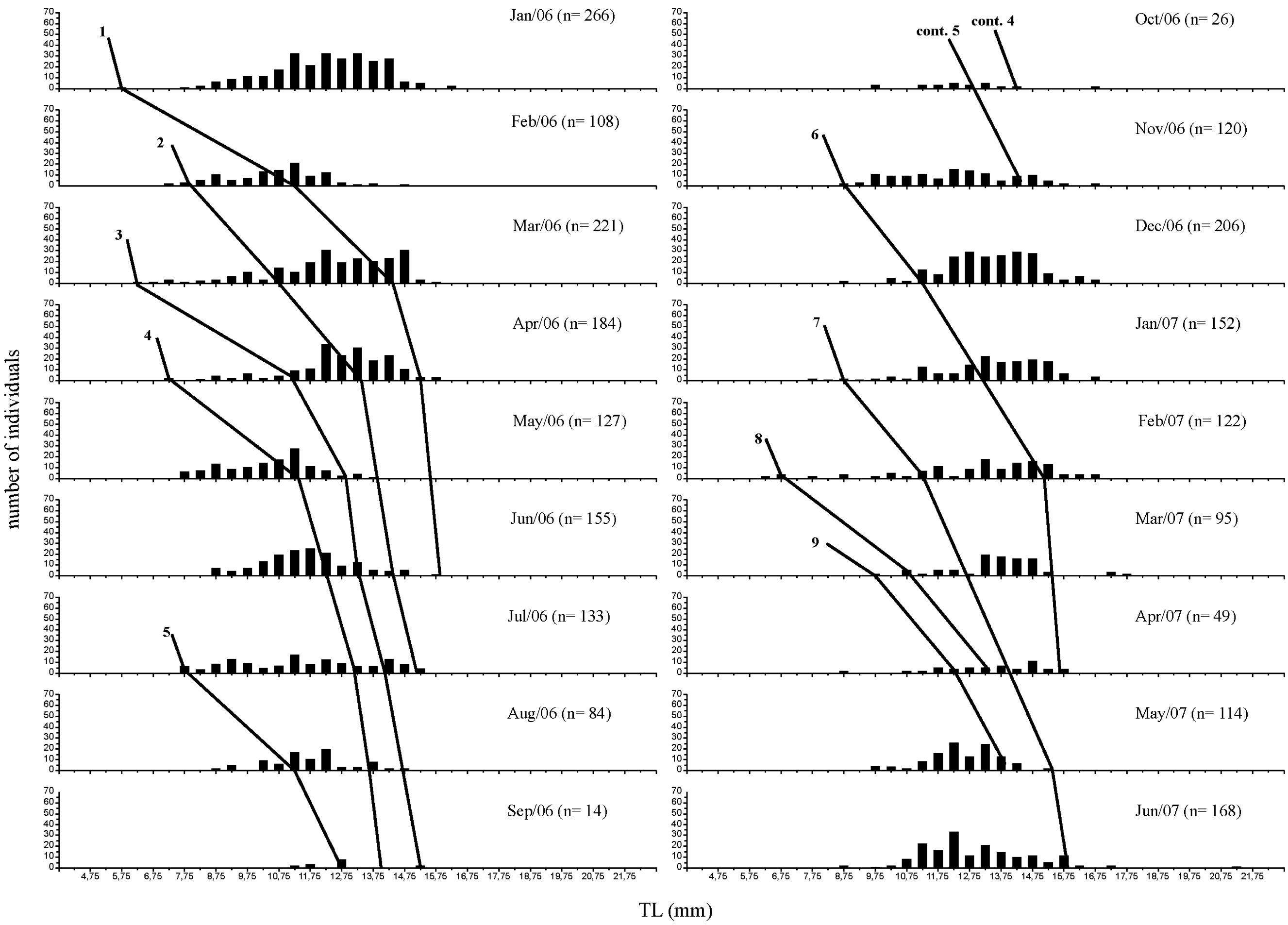

Fig. 4. Total length (TL) frequency histograms of male *Acetes americanus* in the bay of Ubatuba from January 2006 and June 2007. Lines represent the cohorts followed during the studied period to describe the individual growth.

and *Artemesia longinaris* Bate, 1888 (Costa and Fransozo, 2004; Castro et al., 2005; Castilho et al., 2007). In Sergestidae, Oh and Jeong (2003) found that the carapace length of *A. chinensis* Hansen, 1919 females was 11.12 mm compared to 10.39 mm in males. In Peninsular Malaysia, Arshad et al. (2008) found that females of *Acetes vulgaris* Hansen, 1919 had a total length of 23.91 mm, whereas the length of males was 23.18 mm. Therefore, this type of differential growth occurs in both superfamilies of Dendrobranchiata.

Males of Penaeidae commonly have larger growth coefficients (k) relative to females, and therefore achieve lower asymptotic lengths (Boschi, 1969; Gulland and Rotschild, 1981). We observed this pattern in *A. americanus*, confirming the results of Oh and Jeong (2003) and Amin et al. (2009a), who found greater values of k for males of *A. chinensis* and *A. indicus* Milne Edwards, 1830, respectively, relative to females of the same species.

Results obtained by Omori (1975), who studied species of *Acetes*, are presented in Table 3. We found maximum lengths of *A. americanus* similar to those reported by Omori (1975). Therefore, it appears that the samples collected at Ubatuba covered all size classes and are most likely the maximum sizes reached by individuals of this species along the coast of São Paulo.

The average life cycle of penaeids lasts approximately 1-2 years (Lindner and Anderson, 1956; Bauer and Lin, 1994), but the longevity of *Acetes* is generally shorter because species of this genus are typically smaller in size (Amin et al., 2009a). Our results support this theory along with the results presented by Yoshida (1949) and Oh and Jeong (2003), as the life cycle of *A. chinensis* was calculated to be approximately one year in both studies. In addition, one characteristic of “r-selected” species described by Pianka (1970) was noted in this study, because *A. americanus* showed a short length of life with longevity of less than one year. Although, studies by Amin et al. (2008, 2009b) in the waters around Malaysia found that the longevities of *Acetes intermedius* Omori, 1975 and *A. japonicus* Kishinouye, 1905 were approximately 2 and 2.14 years, respectively. Amin et al. (2009a) also found that the longevity differed between the sexes of *A. indicus*, i.e., 1.76 years for males and 2.50 years for females.

Bauer (1992) conducted a latitudinal study with three species of the genus *Sicyonia* Milne Edwards, 1830, whose results demonstrated a greater size and longevity in the

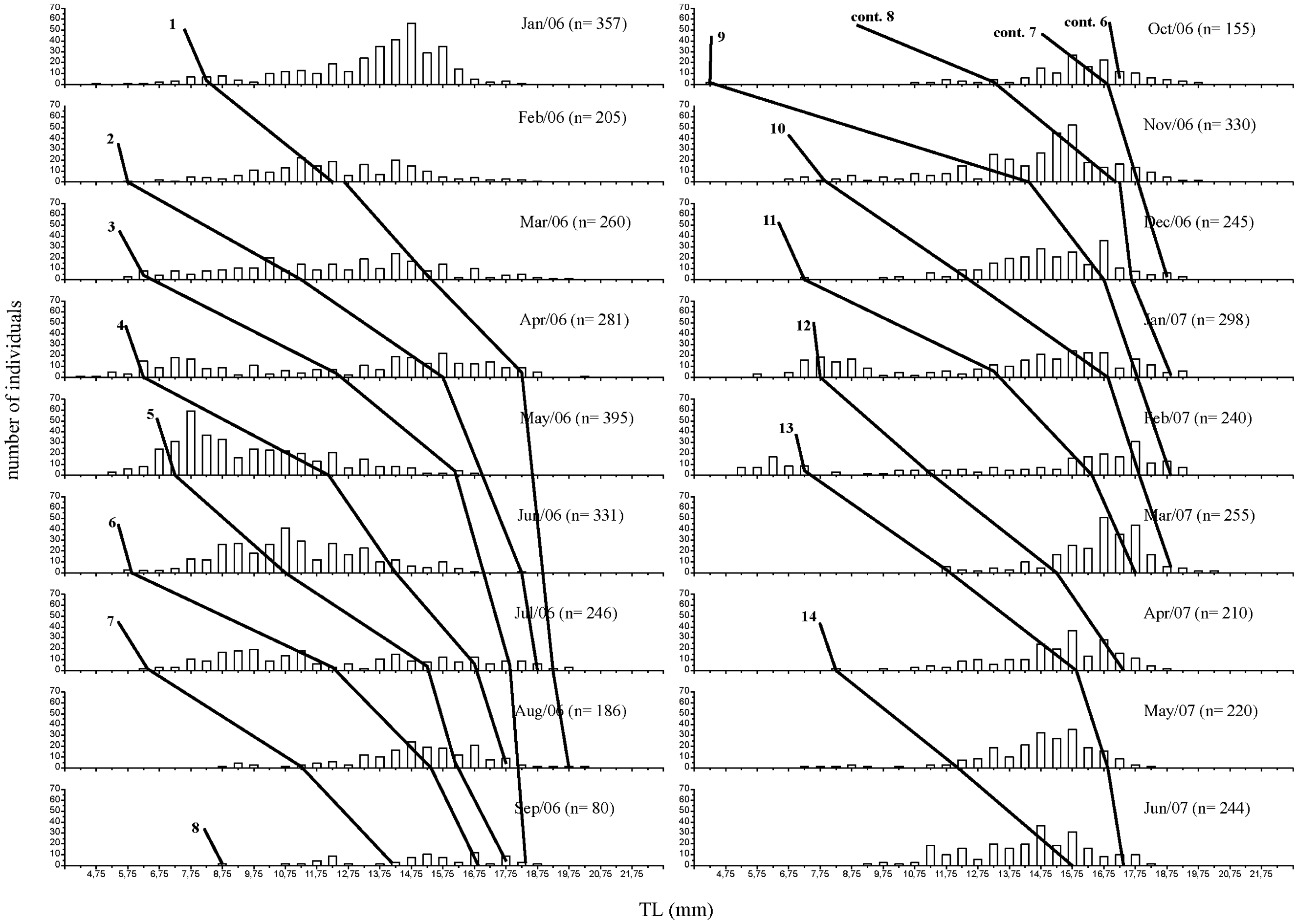

Fig. 5. Total length (TL) frequency histograms of female *Acetes americanus* in the bay of Ubatuba from January 2006 and June 2007. Lines represent the cohorts followed during the studied period to describe the individual growth.

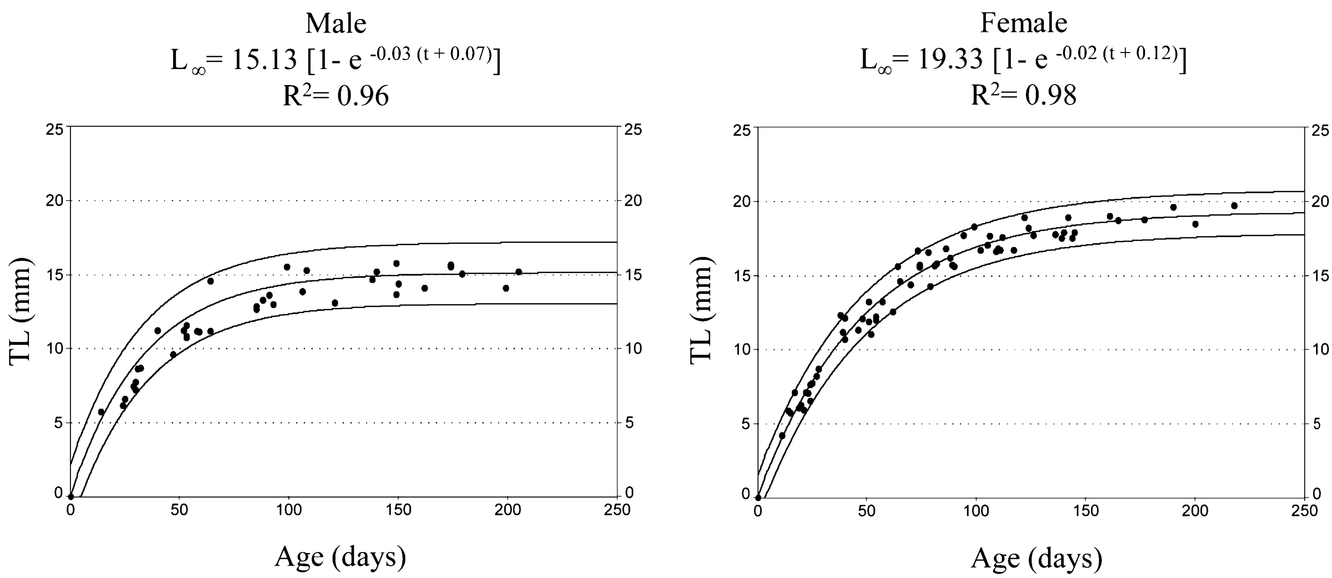

Fig. 6. Growth curve estimated for (left) males and (right) females using the von Bertalanffy growth model (internal line). 95% prediction interval is shown (external lines).

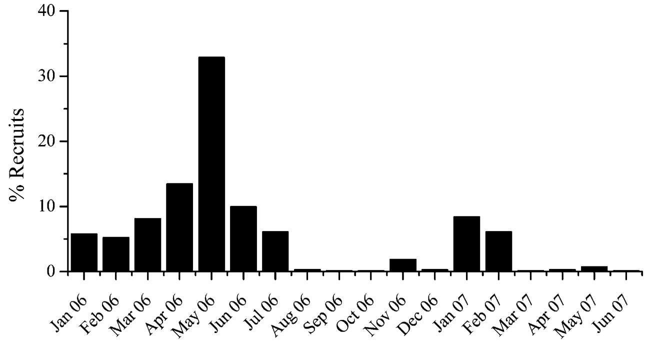

Fig. 7. Percentage of *Acetes americanus* juveniles captured between January 06 and June 07 in the bay of Ubatuba, São Paulo, Brazil.

Table 3. Comparison of the minimum and maximum total lengths of females and males of species of *Acetes* found by Omori (1975) compared to the specimens of *A. americanus* collected in the present study.

Species	TL (mm)	
	♀	♂
Acetes americanus (Ubatuba, Brazil) – Present study	4.1-20.4	5.7-17.3
Acetes americanus	17.0-19.5	15.5-17.0
Acetes americanus carolinae	14.0-17.0	10.0-16.0
Acetes binghami	8.0-12.0	8.0-9.0
Acetes chinensis	25.0-42.0	20.0-35.0
Acetes erythraeus	16.0-33.0	16.0-26.0
Acetes indicus	23.0-34.0	15.0-25.0
Acetes intermedius	20.0-26.0	17.0-24.0
Acetes japonicus	15.0-21.0	11.0-16.0
Acetes johni	–	15.0-25.0
Acetes marinus	17.0-23.0	13.0-19.0
Acetes natalensis	22.0-23.0	16.0-18.0
Acetes paraguayensis	18.0-22.0	16.0-21.0
Acetes serrulatus	15.0-21.0	12.0-17.0
Acetes sibogae sibogae	14.0-27.0	13.0-20.0
Acetes sibogae australis	18.0-34.0	18.0-25.0
Acetes sibogae sobogalis	18.0-21.0	16.0
Acetes vulgaris	20.0-34.0	17.0-26.0

species sampled in higher latitudes. The latitudinal effect does not seem applicable to the genus *Acetes*, since we've noted the opposite when three species of genus *Acetes* were compared in different latitudes. This fact can be due to different environmental conditions observed in the oceans where samples were taken or due to different methodology used for longevity calculation. It was noted a higher longevity in higher latitudes only when *A. americanus* (present study, Brazil) were compared with *A. chinenses* (Korea) (Table 4). Hence, further studies should be carried out in order to check, with similar analyzes, structural patterns of a community in different latitudinal gradients.

We observed continuous recruitment with two peaks during the study period. This finding corroborates results from previous studies, which also observed juveniles of *Acetes* spp. throughout the year (Oh and Jeong, 2003; Amin et al., 2008, 2009a, 2009b). According to Nataraj (1947) cited in Xiao and Greenwood (1993), *Acetes* spawn throughout the year in tropical and subtropical regions, with spawning peaks occurring during the warmer seasons. Because we found rapid growth of *A. americanus*, we assume that the continuous presence of juveniles captured in the bay of Ubatuba is the result of spawning that continues throughout the year.

Our results increase current understanding of the biology of *Acetes*. Other studies of morphology, larval settlement and gonad histology will provide answers to the hypotheses addressed here, contributing specific knowledge of the life history of this genus.

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Table 4. Comparison of the longevity of *Acetes* sp. in different latitudes. M = male, F = female, P = pooled.

Species	Location (latitude)	Longevity (years)	Methods	T (°C)	References
Acetes indicus	Malaysia 02°13.009′N	M: 1.76 F: 2.50	Pauly's formula (1984)	31	Amin et al., 2009a
Acetes intermedius	Malaysia 02°13.009′N	P: 2.00	Pauly's formula (1984)	31	Amin et al., 2008
Acetes japonicus	Malaysia 02°13.009′N	P: 2.14	Pauly's formula (1984)	31	Amin et al., 2009a
Acetes americanus	Brazil 23°25′S	M: 0.50 F: 0.61	Von Bertalanffy (inverse equation) (D'Incao and Fonseca, 1999)	23	Present study
Acetes chinensis	Korea 34°48′N	P: 0.75-1.00 (Summer) P: 0.58-0.83 (Winter)	–	–	Oh and Jeong, 2003

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