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Population dynamics of the white shrimp *Litopenaeus schmitti* (Burkenroad, 1936) on the southern coast of Pernambuco, north-eastern Brazil

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This study describes the structure, growth, mortality and stock status of Litopenaeus schmitti *in north-eastern Brazil. A total of 1169 specimens were captured (491 males and 678 females) from August 2011 to July 2012. Specimens were weighed and the length of carapace (CL) and total length were measured. The biometric relationships were estimated through regression analysis and growth was described through the von Bertalanffy model. Additionally, total mortality (Z), natural mortality (M), fishing mortality (F), length at first capture (Lc), maximum yield per recruit (E_{RMY}) and longevity were determined. Females were larger (3.07 ± 0.51 cm) than males (2.68 ± 0.25 cm) and dominant in the largest CL classes. The biometric relationships for males, females and both sexes grouped showed a negative allometric growth. Females showed larger L_∞ (asymptotic length) and k (coefficient of growth) (L_∞ of 5.00–5.16 cm and k of 1.20–1.26 year^{-1}) when compared with males (L_∞ of 4.25–4.30 cm and k of 1.00–1.02 year^{-1}). In general, the mortality of males (Z = 1.93–5.48 year^{-1}; M = 1.59–1.61 year^{-1} F = 0.32–0.3.89 year^{-1}) and longevity (1.11–2.16 years) were higher than those estimated for females (Z = 1.84–3.76 year^{-1}; M = 1.70–1.77 year^{-1}; F = 0.07–1.99 year^{-1}; 1.07–1.78 years). Results indicated that* L. schmitti *stock is relatively close to the state of full exploitation. Moreover, the CL of first capture of females (2.44–2.51 cm) is below the length of first sexual maturation of the species. The lack of legislation governing shrimp fishing in the area makes this stock even more vulnerable.*

Keywords: Penaeids, growth, mortality, biometric relationship, sustainability

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INTRODUCTION

The penaeid shrimp accounted for around 40% of world catches of shrimp in 2015 (FAO, 2017). In Brazil, the white shrimp *Litopenaeus schmitti* (Burkenroad, 1936) is one of the most important penaeid species in terms of fishery biomass (Caparelli *et al*., 2012; Bochini *et al*., 2014). Moreover, landings of *L. schmitti* rank second in small-scale fisheries of crustaceans in the state of Pernambuco, being surpassed only by the fishery of *Callinectes* spp. (IBAMA, 2007), representing an important socio-economic activity for coastal communities, as they operate in areas with low employment opportunities (Lagares *et al*., 2016).

Litopenaeus schmitti is distributed throughout the western Atlantic, from Cuba (23°30′N) to the Brazilian State of Rio Grande do Sul (29°45′S) (Perez-Farfante & Kensley, 1997). The species is usually found in coastal areas from shallow depths up to 30 m, and its distribution has been related to environmental factors, mainly salinity, in the south-eastern Brazilian coast (Bochini *et al*., 2014; Barioto *et al*., 2017).

Knowledge of growth, mortality and reproductive parameters are essential not only for the ecological information, but also for use as an input to the application of stock assessment models required for fisheries management (Hartnoll, 1982; Siddeek *et al*., 2001). As decapod crustaceans lack structures that can provide information about ageing and have a discontinuous growth, frequently interrupted by successive ecdyses, methods based on length-frequency distributions are the most useful and commonly employed (Petriella & Boschi, 1997).

The development of fisheries has shown the need for studies on the state of exploitation of stocks, as the commercial extinction and genetic changes of *L. schmitti* populations in Cuba demonstrates the high vulnerability of this species to overfishing (Borrel *et al*., 2007). However, although studies have been performed on population dynamics and distribution of *L. schmitti* populations from the coast of Cuba (Borrell *et al*., 2004, 2007), Venezuela (Andrade & Pérez, 2004; Diaz *et al*., 2013, 2014) and south-eastern Brazil

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(Capparelli *et al.*, 2012; Bochini *et al.*, 2014; Barioto *et al.*, 2017), little information is available for this species in north-east Brazil (Santos *et al.*, 2006). Moreover, lack of information on this resource and lack of legislation in the state of Pernambuco that regulates shrimp fishing both result in a potential risk to the sustainability of the species and the maintenance of the fishing activity.

In this context, due to the biological and economic importance of *L. schmitti* in north-eastern Brazil, this study provides information about the population structure, period of recruitment, biometric relationships, growth, mortality and yield per recruit for the species on the southern coast of Pernambuco, north-eastern Brazil, increasing the overall knowledge of the species.

MATERIALS AND METHODS

Data collection

Data collection was performed in the main shrimp fishing area of Pernambuco state, located in the municipality of Sirinhaém, near the mouth of the Sirinhaém River (08° 35′ 57″ S–08° 36′ 57″ S and 034° 56′ 58″ W–035° 00′ 48″ W, Figure 1).

Specimens of *L. schmitti* were collected monthly from August 2011 to July 2012 in daytime during the full moon. Fishing was held using an artisanal boat from the local fleet, which operated with double trawling with 10-m long nets, with mouth of 6.10 m and mesh size of 30 and 25 mm in the body and codend, respectively. Monthly, around 120 shrimps were collected within the three trawls, lasting 2 hours each, carried out for each sampling. Approximately 40 shrimps per trawl were randomly selected. Shrimp were immediately cooled on ice until the analysis.

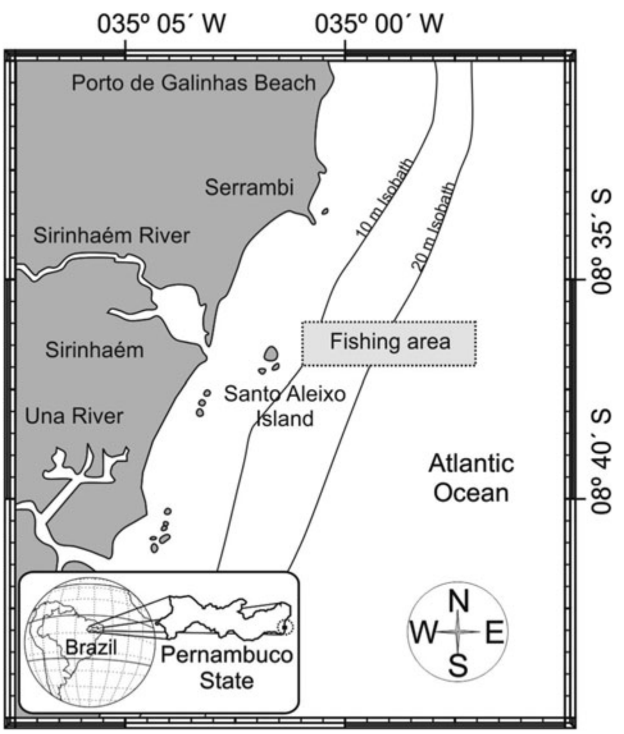

Fig. 1. Geographic location of the study site (fishing area) on the coast of Pernambuco, north-eastern Brazil.

The sex of the animals was identified based on external characters (presence of thelycum in females and petasma in males). The carapace length (CL, from the base of the rostrum to the posterior edge of the carapace) and total length (TL, from the tip of the rostrum to the posterior end of the telson) were measured using a digital calliper (mm) and total weight (TW, wet total weight) was measured with an analytical balance (accuracy of 0.1 g).

Population structure

The population structure has been described considering the months and sex. To determine significant differences in CL between them, two-way ANOVA was used, considering the necessary normality (Kolmogorov–Smirnov test) and homogeneity (Levene test) assumptions. The Bonferroni test was used to determine significant differences between sexes and months ($P < 0.05$). The sex ratio in relation to CL classes of 0.1 cm was compared using the chi-square test ($P < 0.05$).

Biometric relationships

Biometric relationships were estimated for separated and grouped sexes through regression analysis, where TL was the independent variable and the CL and TW were dependent variables. The regressions were adjusted by the least squares method, with 95% significance level (Sokal & Rohlf, 1987).

The relationship between TL and CL was calculated using linear regression ($CL = a + b TL$), where a is the intercept and b is the allometric coefficient (positive allometric growth when $b > 1$; negative allometric when $b < 1$ and isometric when $b = 1$). To evaluate the relationship between TL and TW, a potential regression was performed ($TW = aTL^b$), where a is the intercept and b is the allometric coefficient (positive allometric growth when $b > 3$; negative allometric when $b < 3$ and isometric where $b = 3$). The Student's t-test was used to compare the coefficient b of these relations with 1 and 3, respectively, for the linear and potential regressions, as well as to compare the relationships between the sexes (Zar, 2009).

Growth

The frequency of CL data was analysed using the computer package FISAT II (FAO/ICLARM Stock Assessment Tools) (Gayanilo *et al.*, 2005), and the growth was described through the von Bertalanffy model (1938), according to the following equation:

$$L_t = L_\infty\left[1 - \exp\{-k(t - t_0)\}\right]$$

where L_t is the carapace length (cm) at age t (month); L_∞ is the asymptotic full length (cm); k is the growth coefficient ($year^{-1}$); t_0 is the age at which the carapace length of the animal is zero. For our study, we consider $t_0 = 0$, a practice widely used for penaeids (Leite & Petrere, 2006; Lopes *et al.*, 2014; Silva *et al.*, 2015).

The parameters of the von Bertalanffy growth curve were determined through the distribution of CL measures of males, females and both sexes grouped divided into 0.1 cm class intervals for each month in order to set the average lengths by age, using the method of Bhattacharya (1967).

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Afterwards, the tool 'linking of means' (FISAT II) was used to identify the increase in size during growth. Growth parameters were estimated using the method Length-at-age. Moreover, for the best fit of the von Bertalanffy growth model, the length frequencies were also restructured through ELEFAN (Gayanilo *et al.*, 2005), available at FISAT II. The Kimuras likelihood ratio test was used to compare the growth curves between males and females ($P < 0.01$) (Kimura, 1980). The Kimuras test was performed using R version 3.3.3 (R Core Team, 2016), package 'fishmethods'.

Mortality

The total mortality (Z) was estimated through the catch curve (Pauly, 1984) and Beverton and Holt's model (Beverton & Holt, 1956). The Natural mortality (M) was estimated by using Pauly's empirical relationship (Pauly, 1980), and the fishing mortality (F) by the difference between Z and M.

The exploitation rate was estimated by the ratio between F and Z. The length at first capture (Lc) was estimated as the length corresponding to 50% capture probability. The maximum yield per recruit (E_{RMY}) was estimated using the model of relative yield per recruit (Y/R) (Beverton & Holt, 1966) and longevity through the Hoening's method (1982).

RESULTS

Population structure

During the study period, a total of 1169 specimens of *L. schmitti* were collected, corresponding to 678 females

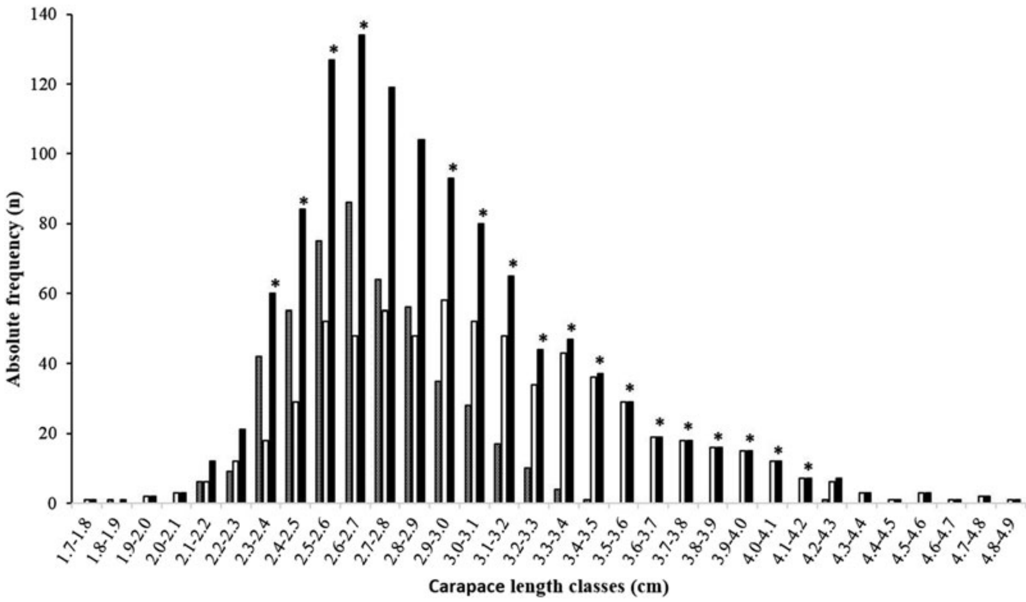

Fig. 2. Absolute frequency distribution per length classes of males, females and pooled sexes for white shrimp *Litopenaeus schmitti*, captured in the period of August 2011 to July 2012, on the coast of Pernambuco, north-eastern Brazil. *Significant differences between males and females within length classes.

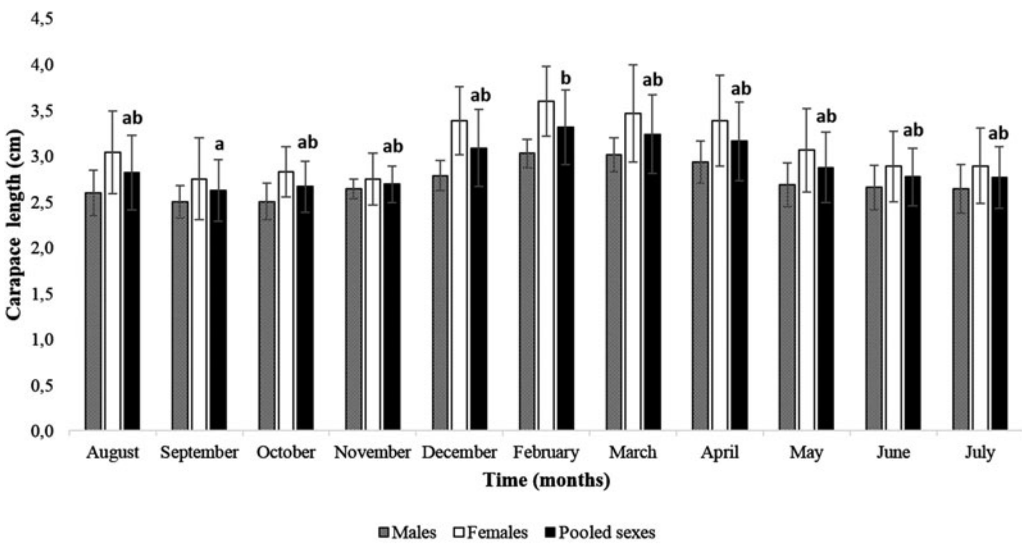

Fig. 3. Monthly average (±S.D) of the carapace length (CL) (cm) of males, females and pooled sexes for white shrimp *Litopenaeus schmitti*, captured in the period of August 2011 to July 2012, on the coast of Pernambuco, north-eastern Brazil. Different letters indicate significant differences between months.

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(58%) and 491 males (42%), except for January, when no specimens were captured. In general, females were larger (3.07 ± 0.51 cm) than males (2.68 ± 0.25 cm) ($P < 0.05$).

The highest absolute frequency of CL was observed in the class 2.6–2.7 cm, with a higher frequency of males ($P < 0.05$) (Figure 2). However, females dominated in larger size classes, as observed from the class 2.9–3.0 cm onwards (Figure 2).

The largest shrimps were observed in February, with an average CL of 3.32 ± 0.41 cm, significantly differing only from animals captured in September ($P < 0.05$) (Figure 3). No significant differences were observed between the animals caught in the other months (Figure 3). The animals with smaller size classes were observed in the months of September to October and June to July (Figure 4).

Biometric relationships

The TL and CL relationship was significant for males, females and both sexes showing a negative allometric growth ($P < 0.01$), as the shrimps grow more in total length than in carapace length. The coefficient '*b*' of the TL-CL equation, which represents the type of growth, showed significant differences between males and females ($P < 0.01$) (Table 1). The relationship between TL and TW for males, females and both sexes grouped was significant, with a negative allometric growth ($P < 0.01$), where the animal grows less in weight than in length. The coefficient '*b*' of the equation TL-TW showed significant differences between males and females ($P < 0.01$) (Table 1).

Growth

Two cohorts were identified for females and males, with a higher growth for females (Figure 4). The growth curves of males and females were statistically different ($P < 0.01$). The values of L_∞ estimated by different methods were higher for females (5.00–5.16 cm) than males (4.25–4.30 cm). Similarly, females achieved higher k value (1.20–1.26 year^{-1}) than males (1.00–1.02 year^{-1}) (Table 2). The growth parameters estimated by Length-at-age and ELEFAN methods were used as input for the models of mortality estimation and maximum yield per recruit.

Mortality

Mortalities Z (1.84 to 5.48 year^{-1}), M (1.58 to 1.77 year^{-1}) and F (0.07 to 3.89 year^{-1}) varied according to the different methodologies. Generally, mortality rates were higher when the growth parameters derived from the ELEFAN method were used as input, rather than the parameters estimated by Length-at-age. Z mortality estimated by the catch curve had higher values compared with the Beverton and Holt method (Table 3).

In general, mortality of males was higher than females regardless of the method. Similarly, the exploitation rates (E) of males (0.70–0.71) were higher than the females (0.53–0.54) with the catch curve method. The value for maximum yield per recruit (E_{RMY}) was estimated at 0.93–0.94 and 0.84–0.87 for males and females, respectively (Table 3). The Beverton and Holt method estimated exploitation rate values lower than the maximum yield per recruit.

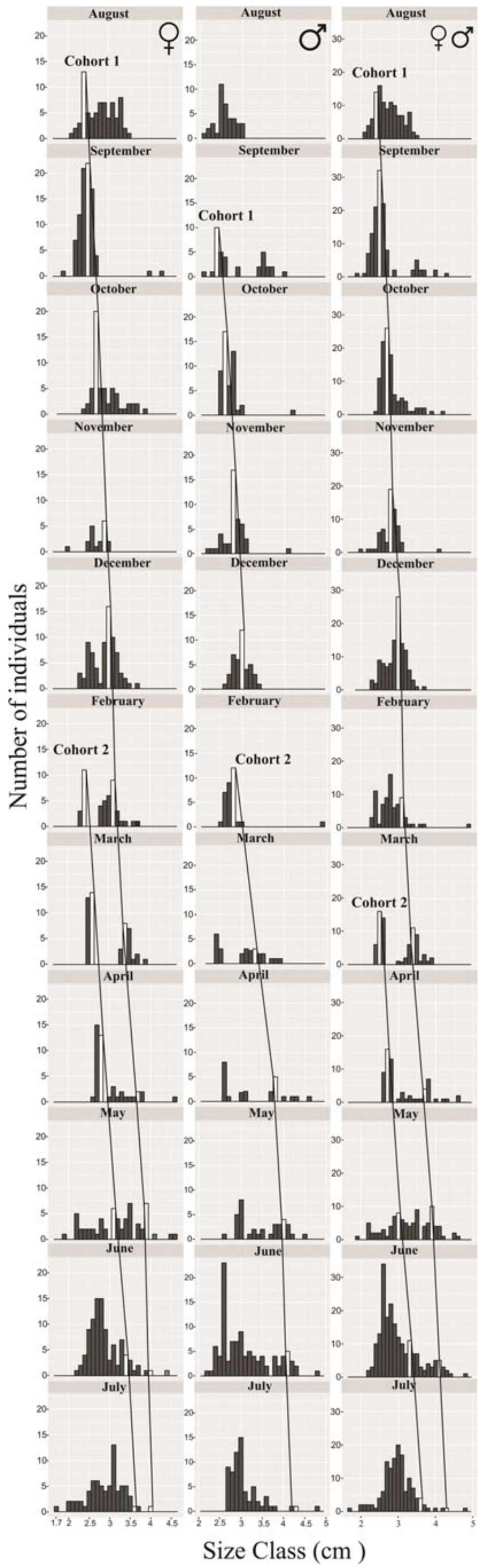

Fig. 4. Carapace length classes of males, females and pooled sexes of white shrimp *Litopenaeus schmitti*, captured in the period of August 2011 to July 2012, on the coast of Pernambuco, north-eastern Brazil.

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Table 1. Mean values (±SD) of total length (TL), carapace length (CL) and total weight (TW), and biometric relationship equations (TL-CL and TL-TW) and descriptive statistics for *Litopenaeus schmitti* from the coast of Pernambuco, north-eastern Brazil.

	Males	Females	Pooled sexes
TL (cm)	12.93 ± 1.07	14.10 ± 1.96	13.61 ± 1.74
CL (cm)	2.68 ± 0.25	3.07 ± 0.51	2.91 ± 0.46
BW (g)	17.49 ± 4.45	23.73 ± 10.42	21.12 ± 8.98
TL-CL	CL = 0.2098TL + 0.0244	CL = 0.2362TL + 0.2544	CL = 0.2426TL + 0.3874
TL-CL (r^2)	0.80	0.81	0.83
TL-CL (t-test)	$P < 0.01$	$P < 0.01$	$P < 0.01$
TL-TW	$TW = 0.014TL^{2.7774}$	$TW = 0.0089TL^{2.9594}$	$TW = 0.0092TL^{2.9417}$
TL-TW (r^2)	0.81	0.94	0.92
TL-TW (t-test)	$P < 0.01$	$P < 0.01$	$P < 0.01$
Growth type	Allometric (-)[a]	Allometric (-)[b]	Allometric (-)

Different superscript letters indicate significant differences between males and females.

Table 2. Estimation of growth parameters L_∞ (cm) and k ($year^{-1}$) (±S.E) and growth performance index (ϕ') through Length-at-age and ELEFAN methods for males, females and pooled sexes for *Litopenaeus schmitti* captured in the period of August 2011 to July 2012 in the coast of Pernambuco, north-eastern Brazil.

Methods	Sex	L_∞ (cm)	K ($year^{-1}$)	ϕ'
	Males	4.25 ± 2.70	1.02 ± 1.97	1.26
Length-at-age	Females	5.00 ± 2.11	1.26 ± 1.65	1.49
	Pooled sexes	5.00 ± 1.89	1.06 ± 1.27	1.42
	Males	4.30	1.00	1.26
ELEFAN	Females	5.16	1.20	1.50
	Pooled sexes	5.19	1.10	1.47

The length at first capture was higher in males (2.79–2.80 cm) than females (2.44–2.51 cm). Males survived longer than females, regardless of the methodology used (Table 3).

DISCUSSION

In the southern coast of Pernambuco, females of the white shrimp *L. schmitti* were dominant and larger than males, showing a higher growth coefficient and greater asymptotic length. As in other penaeids (Grabowski *et al.*, 2014; Castilho *et al.*, 2015), the growth curves of males and females were statistically different. Although females were also more dominant than males (1.5:1) in the Gulf of Venezuela, the total length range (9–24 cm) was similar between sexes (Diaz *et al.*, 2014). According to Garcia & Le Reste (1986), penaeid females tend to show higher numbers in the largest size classes, which is in line with the results observed in the present study. Sexual dimorphism is characteristic in penaeids where females are larger and heavier than males (Dall *et al.*, 1990; Gopal *et al.*, 2010). Gab-Alla *et al.* (1990) argued that the largest size of the carapace and abdomen of females may correspond to the further development of the ovaries and increased production of oocytes and fertility. Smaller individuals were observed from September to October and from June to July, indicating a possible recruitment during these months, which is in accordance with the main spawning season of the species observed by Peixoto *et al.* (in press) from August to November and February to March in the same region.

In this study, *L. schmitti* presented a negative allometric growth in TL-CL and TL-TW relationships. The same tendency was observed for *Farfantepenaeus subtilis* in the north-east region (Silva *et al.*, 2015), and for *Farfantepenaeus brasiliensis* and *Farfantepenaeus paulensis* in the south-east coast (Leite & Petrere, 2006). However, the TL-TW relation indicated a positive allometry for *L. schmitti* in Venezuela (Diaz *et al.*, 2014). The body size of crustaceans increases in different ratios for each organism and these differences are often related to sex and maturational stage of the animal

Table 3. Estimates of total mortality (Z-$year^{-1}$), natural mortality (M-$year^{-1}$), fishery mortality (F-$year^{-1}$), exploitation rate (E), length at first catch (L_C-cm), longevity (Long. $year^{-1}$) and maximum recruitment yield (E_{MRY}) through both the Length-Converted Catch Curve and the Beverton and Holt method for males, females and pooled sexes of *Litopenaeus schmitti*, captured in the period of August 2011 to July 2012 in the coast of Pernambuco, north-eastern Brazil.

	Length-Converted Catch Curve						Beverton and Holt					
Methods	Z	M	F	E	L_C	Long.	Z	M	F	E	Long.	E_{MRY}
Males												
Length-at-age	5.42	1.61	3.81	0.70	2.79	2.15	1.93	1.61	0.32	0.16	1.11	0.94
ELEFAN	5.48	1.59	3.89	0.71	2.80	2.16	1.95	1.59	0.36	0.18	1.12	0.93
Females												
Length-at-Age	3.76	1.77	1.99	0.53	2.44	1.78	1.84	1.77	0.07	0.04	1.07	0.87
ELEFAN	3.67	1.70	1.97	0.54	2.51	1.76	1.90	1.70	0.2	0.10	1.10	0.84
Pooled sexes												
Length-at-age	3.53	1.58	1.95	0.55	2.41	1.72	1.91	1.58	0.33	0.17	1.10	0.83
ELEFAN	3.75	1.60	2.15	0.57	2.48	1.78	2.16	1.60	0.56	0.26	1.23	0.79

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(Hartnoll, 1982). Immature or developing organisms in the habitat can explain the lower increase in weight relative to the length observed in this study (Peixoto *et al.*, in press).

The growth parameters obtained by the Length-at-age and ELEFAN methods in this study showed similar results for *L. schmitti*. The L_∞ and k was higher for females (5.00–5.16 cm; 1.20–1.26 $year^{-1}$) than males (4.25–4.30 cm; 1.00–1.02 $year^{-1}$). Penaeid males usually have a lower value of L_∞ and higher k value than females (Garcia & Le Reste, 1986; Dall *et al.*, 1990). Diaz *et al.* (2014) observed L_∞ of 22.2 cm for females and 20.1 cm for males of *L. schmitti* in Venezuela, however, a lower k value for males (1.40 $year^{-1}$) than females (1.69 $year^{-1}$) was reported, which is in agreement with the results observed in the present study. This trend was also registered in the Persian Gulf as Niamaimandi *et al.* (2007) found a higher k value for females for *Penaeus semisulcatus.*

The instantaneous rate of total mortality (Z), and hence the fishery mortality (F) estimated in this study, varied with the methods of the catch curve and Beverton and Holt, as well as growth methods, used as input. Mortality values estimated with the Beverton and Holt method were lower than those obtained with the catch curve. Moreover, the use of growth parameters estimated by ELEFAN provided higher values of mortality than those estimated by the Length-at-age. Regardless of the methodological scenarios used, mortality was higher for males (1.93–5.48 $year^{-1}$) than females (1.84–3.76 $year^{-1}$). Similar results was observed by Diaz *et al.* (2014) for the same species in Venezuela (Z of 5.41 and 3.96 $year^{-1}$ for males and females, respectively), given the same trend of k and $L\infty$ observed in relation to our study. The fishing mortality (F) was higher in relation to M coefficients only when the length-converted catch curve was used, and varied from 0.07 to 3.89 $year^{-1}$. Similar values and wide ranges of F observed in this study were also reported for *L. schmitti* females (0.36–2.57 $year^{-1}$) and males (2.01–4.14 $year^{-1}$) in Venezuela, as a consequence of the wide variations of M among different methods (Diaz *et al.*, 2014). The longevity values in this study varied from 1.07 (Beverton and Holt for females) to 2.16 (catch curve for males), but were within the longevity estimates observed for penaeids. Niamaimandi *et al.* (2007) estimated longevity of 1.3–1.8 years to *P. semisulcatus*. For *F. subtilis*, Silva et al. (2015) estimated a longevity of 1.88–2.20 years, while Lopes *et al.* (2014) observed longevity of 1.55–2.40 years for *Xiphopenaeus kroyeri*. Dall *et al.* (1990) report that the life cycle of penaeids is estimated at about 2 years; and Garcia & Le Reste (1986) suggested that the longevity of penaeids is 1.3–2.5 years.

According to Fernandes *et al.* (2011), growth parameters (and hence mortality estimates) may vary spatially and temporally for the same species and may be associated with intrinsic (genetic) and extrinsic (environmental) factors, as well as geographic location, sex and stage of life. Also, uncertainty does exist when using FISAT for growth performance estimates. Therefore, it is acknowledged that the use of these methods entails great uncertainty; however, the use of multiple methods may reduce the bias imposed by any of the methods used (Hewitt *et al.*, 2007). Despite the numerical differences between mortality rates and exploitation, the results obtained from the different inputs converged with respect to the level of sustainability of this fishing stock. Both indicated that the rate of exploitation of *L. schmitti* is relatively close to, but not at the maximum exploitation possible. It is also observed that the length of first capture of females (12.29–12.81 cm TL – 3.15–3.28 cm CL) in this study is below the length of sexual maturation, estimated at 14.2 cm TL–3.61 cm CL by Peixoto *et al.* (in press). Moreover, the other target species (*Farfantepenaeus subtilis*, *X. kroyeri* and *Litopenaeus schmitti*) caught within the shrimp trawler fishery in the region, are either close to or at maximum exploitation rates (Lopes *et al.*, 2014; Silva *et al.*, 2015) and this fishery is hence increasingly vulnerable. Therefore, a reduction in the fishing effort on this stock is needed by reducing the number of vessels, which would not only protect *L. schmitti* but also other penaeids and main by-catch that are exploited in this region and show a similar biological pattern, as already observed by previous studies in the area (Lopes *et al.*, 2014; Silva *et al.*, 2015; da Silva *et al.* 2015).

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