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NOTE

Reproductive dynamics of the southern pink shrimp *Farfantepenaeus subtilis* in northeastern Brazil

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ABSTRACT: This study focused on the reproductive dynamics of southern pink shrimp *Farfantepenaeus subtilis* populations off the coast of Pernambuco, northeastern Brazil. *F. subtilis* specimens were collected each month between August 2011 and July 2012 by an artisanal fishing vessel. A total of 1246 specimens were collected, of which the majority (56%) were females, and which were significantly larger than the males. Ovary maturation, based on histological and visual criteria, was classified into 4 stages — I: immature, II: maturing, III: mature, and IV: spent. Mature gonads were found in the females throughout the year, but at a higher proportion during the warmer months (October–March). A higher proportion of juveniles were observed between December and April. The mean total body length at first gonadal maturation in female pink shrimp was estimated to be 11.9 cm. These findings could be used to help guide the development of fishery management policies for *F. subtilis* in the region.

KEY WORDS: Reproduction · Maturation · Conservation · Sustainability

INTRODUCTION

The penaeid shrimps are a valuable crustacean fishery resource (Dall et al. 1990), comprising 42.2% of the total worldwide shrimp catch between 1970 and 2000 (FAO 2009). In Brazil, the catch of penaeids reached 38 373 t in 2010, with pink shrimp *Farfantepenaeus* spp. representing 17.9% of the total crustacean catch (MPA 2012). In the state of Pernambuco in northeastern Brazil, penaeids represent the second most important crustacean fishery resource after swimming crabs. In this region, artisanal shrimp fishing is typically carried out in small (8 to 12 m) wooden sailboats or motorboats (IBAMA 2005).

Reliable knowledge about the life cycle and biology of the southern pink shrimp *F. subtilis* is necessary in order to efficiently exploit this important fishery resource. A number of studies have focused on the reproductive biology of penaeid populations on the Brazilian coast (Peixoto et al. 2003, Santos et al. 2008, Almeida et al. 2012, Simões 2012, Heckler et al. 2013), with data on *F. subtilis* available from the

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northern (Isaac et al. 1992, Cintra et al. 2004) and northeastern regions of Brazil (Coelho & Santos 1993, 1995). However, no studies have focused on the reproductive dynamics of *F. subtilis* combined with a histological analysis of the ovaries, which provides a more precise evaluation of gonadal maturity. Given the biological and economic importance of *F. subtilis* in northeastern Brazil, the goal of the present study was to describe the reproductive dynamics of this species off the coast of Pernambuco.

MATERIALS AND METHODS

Our study focused on the principal shrimping grounds off the coast of the northeastern Brazilian state of Pernambuco, in the municipality of Sirinhaém (Fig. 1) Specimens of *Farfantepenaeus subtilis* were collected monthly from August 2011 through July 2012 by a vessel of the local artisanal shrimping fleet. The shrimp were caught by trawling during the day in the full moon phase using double trawl nets (length: 10 m; mouth: 6.10 m; body mesh: 30 mm; tail mesh: 25 mm). Specimens were collected in 3 trawls of 2 h each; approximately 70 shrimp were selected at random from each trawl. Once selected, individuals were immediately stored on ice until analysis.

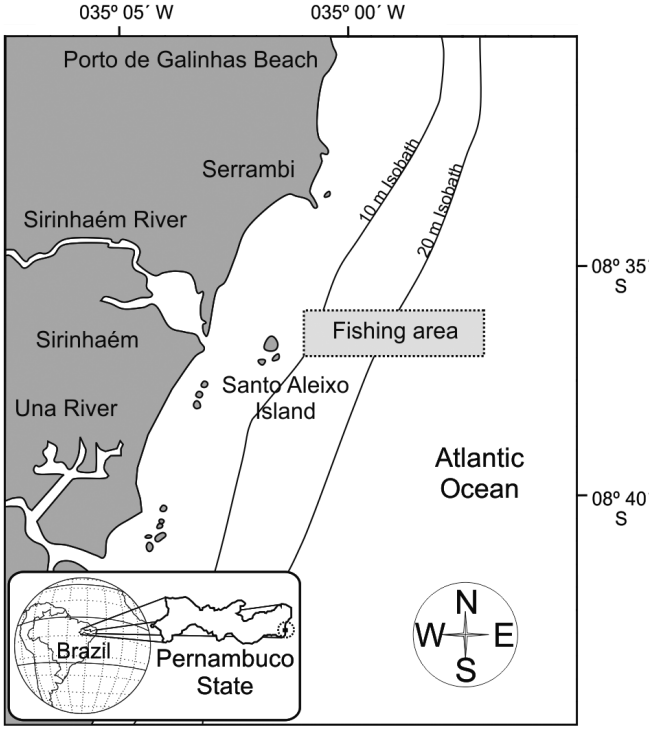

Fig. 1. Study area off the coast of Pernambuco, northeastern Brazil

The sex of each specimen was determined through the analysis of external traits (i.e. presence of a thelycum in females and the petasma in males). The length of the cephalothorax, along with the total length and total wet weight were recorded for each individual. The homogeneity of the sex ratio for the study period as a whole was tested using chi-squared analysis. Differences in mean (±SD) body length and weight between males and females were compared using a Student's *t*-test where the assumptions for a parametric test were satisfied.

Female gonadal development was evaluated based on the gonadosomatic index (GSI), which was calculated by dividing the weight of the dissected ovaries by that of the body, and the morphology and coloration of the gonads. The color of the fresh ovary was compared with a widely available chromatic scale (coated Pantone Matching System) to determine the most frequent color observed in the ovaries.

Females were selected according to their relative size and the shape of the ovary when observed through the exoskeleton using a flashlight. Samples of the median portion of the ovary were collected from 24 specimens for histological analysis. The tissue was fixed in Davidson solution for 24 h and then transferred to 70% ethanol before being set in paraffin at 58°C, sectioned (6 µm) and stained with hematoxylin-Eosin (Junqueira & Junqueira 1983, Bell & Lightner 1988).

Oocytes were classified according to their histological characteristics, based on descriptions available for other *Farfantepenaeus* species (Quintero & Gracia 1998, Peixoto et al. 2003). The proportion of each type of oocyte was calculated for each month and 30 oocytes representing each category (or the total number available, if less than 30) were measured using the software ImageTool v.2.0 for Windows (University of Texas Health Science Center San Antonio). Only oocytes with nuclei sectioned in the equatorial plane were selected for this analysis. Data were grouped into distinct maturation stages based on the most developed cell observed in each sample.

Total length (TL), cephalothorax length (CL), total weight (TW), weight of the ovary (WO), gonadosomatic index (GSI), frequency of each type of oocyte (FO), and oocyte diameter (OD) were compared among the different maturation stages of the ovaries using ANOVA, given the satisfaction of the assumptions for a parametric test. Tukey's HSD test was then applied to identify the maturation stages that were significantly different ($p < 0.05$) from one another.

In order to determine the breeding season of the species, the proportion of specimens in each stage of

maturity was determined each month through the macro- and/or microscopic classification of the gonads. TL at first gonadal maturation of the females was determined by plotting the relative frequency of adults in each 0.5 cm size class. Specimens were considered to be adults when they presented well-developed or spent gonads. Body length classes were then plotted against the percentage of adult females, adjusted by the iterative non-linear least squares technique to obtain the value of TL_{50} using the logistic equation described by King (1995).

RESULTS

During the study period, a total of 1246 *Farfantepenaeus subtilis* specimens were collected, comprising 701 females and 545 males (1.28:1) ($\chi^2 = 0.00001$; $p < 0.05$), which represented 56 and 44% of the total number of specimens collected, respectively. In addition to being more abundant, females were significantly larger (in TL and CL) than males ($p < 0.05$), with mean (±SD) TLs of 11.42 ± 1.61 cm (range: 1.5 to 18.5 cm) and 10.5 ± 1.62 cm for females and males, respectively.

Based on histological characteristics and visual observations, ovarian development of *F. subtilis* was divided into 4 distinct stages. Stage I (immature) is characterized by a predominance of basophilic oocytes (BOs), with a large nucleus surrounded by a number of nucleoli (Fig. 2A, Table 1). In this stage the gonads are very fine and flaccid, which impairs their visualization through the exoskeleton, and the ovary is translucent (Pantone catalog [PC] category 607 PC; Fig. 2A). In Stage II (maturing) the vitellogenic oocytes (VOs) are distributed about the periphery of the ovarian lobes (Fig. 2B, Table 1). During this stage, the ovary can be visualized through the exoskeleton due to an increase in the volume and consistency of the gonad, which now fills the abdominal cavity and cov-

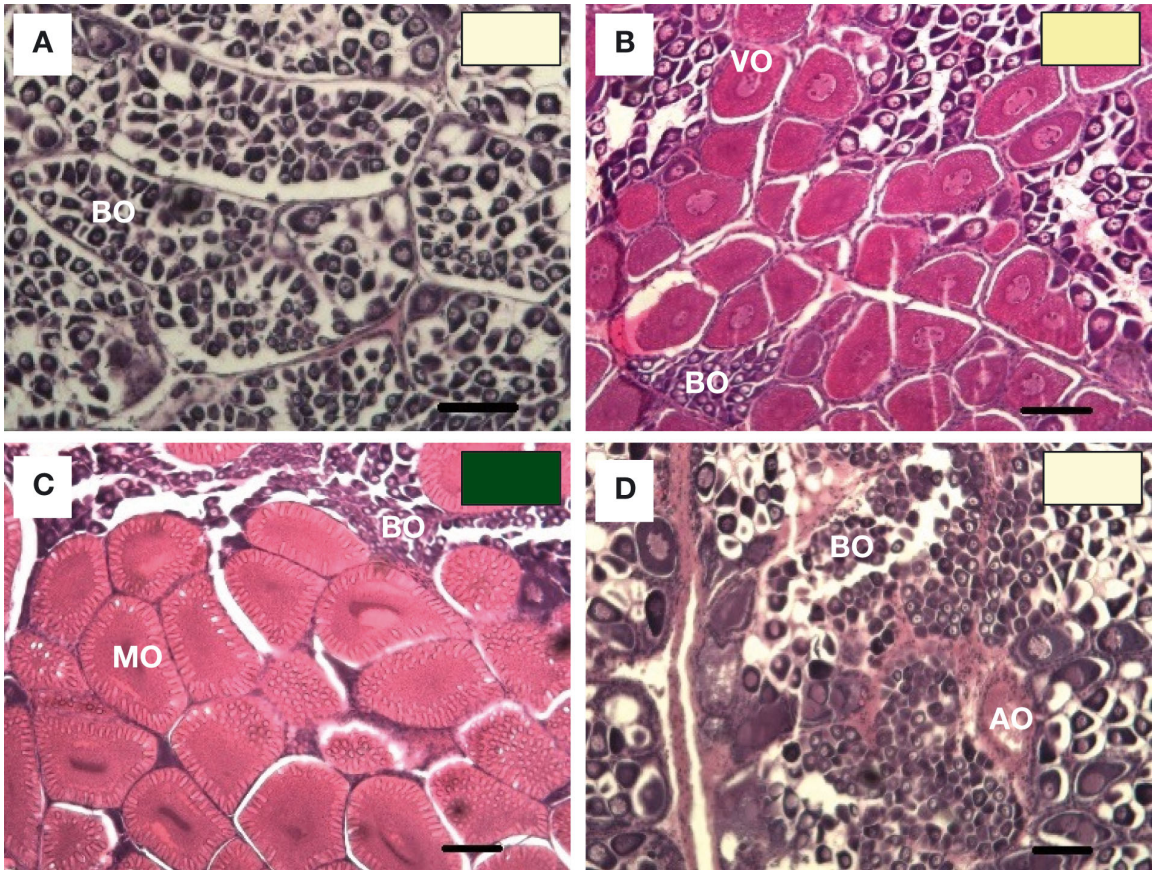

Fig. 2. Histological sections (10× magnification) showing colors representative of different development stages of the ovaries of the southern pink shrimp *Farfantepenaeus subtilis*. (A) Stage I (immature): basophilic oocytes (BO) and translucent ovary (Pantone catalog [PC]: 607 PC); (B) Stage II (maturing): vitellogenic oocytes (VO), ovary light yellow (386 PC); (C) Stage III (mature): mature oocytes (MO), dark green ovary (350 PC); (D) Stage IV (spent): atretic oocytes (AO), ovary same color as in Stage I. Scale bar: 100 µm

Table 1. Frequency and diameter (mean ± SD) of the basophilic (BO), vitellogenic (VO), mature (MO), and atretic (AO) oocytes observed in each stage of gonadal maturity (Stage I: immature; Stage II: maturing; Stage III: mature; Stage IV: spent) of female southern pink shrimp *Farfantepenaeus subtilis* specimens captured off Pernambuco, northeastern Brazil, between August 2011 and July 2012. Values in the same column marked with different superscript letters are significantly different ($p < 0.05$). NP: not present

	BO (%)	VO (%)	MO (%)	AO (%)	BO diameter (µm)	VO diameter (µm)	MO diameter (µm)
Stage I	100^{a}	0^{a}	0^{a}	0^{a}	31.08 ± 3.77^{a}	NP	NP
Stage II	73.56 ± 2.41^{b}	26.44 ± 2.41^{b}	0^{a}	0^{a}	34.96 ± 1.92^{a}	144.45 ± 12.98	NP
Stage III	66.00 ± 7.37^{c}	0^{a}	34.00 ± 7.37^{b}	0^{a}	33.51 ± 2.21^{a}	NP	219.09 ± 17.65
Stage IV	99.36 ± 0.11^{a}	0^{a}	0^{a}	0.64 ± 0.11^{b}	33.52 ± 3.83^{a}	NP	NP

ers part of the intestine in the cephalothorax region. The ovary is light yellow in color (category 386 PC; Fig. 2B). Stage III (mature) is characterized by the presence of mature oocytes (MOs) with peripheral cortical rods, which indicate the final stage of maturation (Fig. 2C, Table 1). The posterior lobes of the ovary occupy the entire abdominal cavity and the development of the lateral lobes can be observed in the cephalothorax. In this stage, the ovary is dark green (category 350 PC; Fig. 2C). Stage IV (spent) is characterized by the presence of atretic oocytes (AOs), which are mature oocytes in the process of being reabsorbed (Fig. 2D, Table 1). Macroscopically, the coloration of the ovary is equivalent to that of Stage I.

Table 2. Mean (±SD) total length (TL), cephalothorax length (CL), total weight (TW), ovary weight (OW), and gonadosomatic index (GSI) recorded in each stage of gonadal maturity in female southern pink shrimp *Farfantepenaeus subtilis* specimens captured off Pernambuco, northeastern Brazil, between August 2011 and July 2012. Values in the same column marked with different letters are significantly different ($p < 0.05$)

	TL (cm)	CL (cm)	TW (g)	OW (g)	GSI (%)
Stage I	10.65 ± 0.78^{a}	2.42 ± 0.28^{a}	10.52 ± 2.36^{a}	0.07 ± 0.04^{a}	0.66 ± 0.19^{a}
Stage II	12.53 ± 1.68^{a}	2.75 ± 0.26^{a}	14.55 ± 4.07^{a}	0.45 ± 0.18^{a}	2.96 ± 0.77^{a}
Stage III	12.93 ± 1.65^{a}	2.87 ± 0.46^{a}	18.45 ± 7.17^{a}	1.48 ± 0.95^{b}	6.60 ± 2.05^{b}
Stage IV	13.36 ± 1.87^{a}	2.87 ± 0.20^{a}	20.59 ± 10.20^{a}	0.31 ± 0.33^{a}	1.24 ± 0.86^{a}

BOs were observed in all histological sections, irrespective of the stage of maturation (Fig. 2), although they were significantly more abundant in Stages I and IV. In Stages II and III, as the ovary developed a significant reduction was observed in the concentration of BOs (Table 1). No significant differences were found in the diameter of the BOs among developmental stages. The VO, MO, and AO were found exclusively in developmental stages II, III, and IV, respectively (Table 1, Fig. 2). No significant variation was found in body size (TL, CL or TW) among the different stages of gonadal maturity, although WO and the GSI were significantly higher in Stage III compared to all other stages (Table 2).

Overall, 56% of the female specimens collected during the study were immature, 13% were maturing, 10% were mature, and 21% had spent ovaries. The distribution of these frequencies over the year (grouped bimonthly) indicates that female southern pink shrimp with mature gonads were present in the population throughout the year, but were relatively more abundant between October and March (Fig. 3). The TL_{50} of the females was estimated to be 11.9 cm (Fig. 4). The smallest adult females had a TL of 9.0 cm; all those with TL > 13.5 cm were adults.

DISCUSSION

The sex ratio of *Farfantepenaeus subtilis* recorded in this study was 1.28:1 (females:males). Deviations in sex ratios are common in crustaceans (Wenner 1972), and tend to be related to differences in life cycle, migration, mortality, growth rates and behavior between males and females. Other factors such as molt, dispersal, and reproductive patterns may also be important (Botelho et al. 2001). A female bias appears to be characteristic of most penaeid populations (Coelho & Santos 1993, 1995), principally during the breeding season or in spawning grounds in the open sea, resulting in an increase in the capture of individuals of one sex (although a ratio close to 1:1 may indicate an area in which mating occurs). Collected specimens were also sexually dimorphic, with females attaining larger body size than males. This sexual size dimorphism is typical of the penaeids (Boschi 1969). Gab-Alla et al. (1990) suggested that the higher growth rate observed in females is related to reproductive processes: the larger size of the fe-

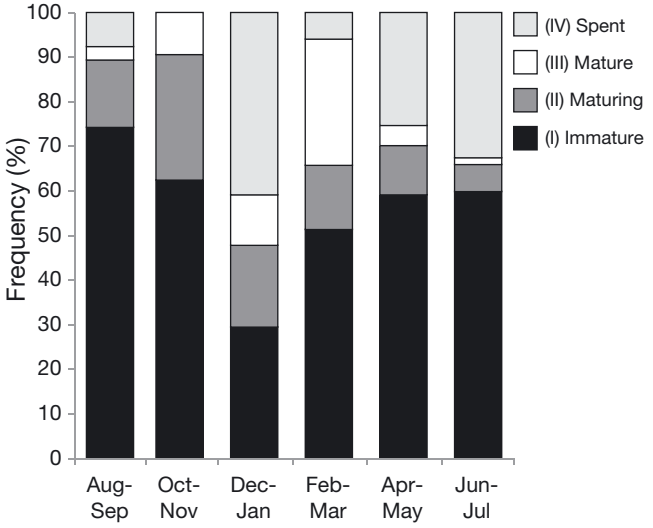

Fig. 3. Relative frequency of ovary developmental stages in southern pink shrimp *Farfantepenaeus subtilis* captured off Pernambuco, northeastern Brazil, between August 2011 and July 2012

males reflects the body space required for the development of ovaries and other reproductive structures (Hartnoll 1982).

The stages of ovarian development in a number of different penaeids have been defined based on the presence of basophilic, vitellogenic, mature, and atretic oocytes (Quintero & Gracia 1998, Peixoto et al. 2002, 2003, Dumont et al. 2007, Gonçalves et al. 2009). These criteria were also adopted for *F. subtilis* in the present study, to define 4 stages of ovarian development as immature, maturing, mature, and spent. BOs were observed in all developmental stages and did not differ significantly in diameter, although they were more abundant in the immature (100%) and spent (99.36%) stages. These similarities in the proportion of BOs hamper differentiation between the immature and spent stages in penaeids (King 1948, Quintero & Gracia 1998, Peixoto et al. 2003), which is reinforced by the difficulties involved in macroscopic observations of the gonad, given that it cannot be visualized through the exoskeleton in either stage (Castille & Lawrence 1991). However, a number of studies have shown that the presence of AOs is an important characteristic for the distinction of immature and spent ovaries (King 1948, Martosubroto 1974, Quintero & Gracia 1998, Peixoto et al. 2003). Palacios et al. (1999) and Peixoto et al. (2005) concluded that the reabsorption of MOs (atresia) has a significant impact on reproductive performance, since this represents the presence of oocytes that were not liberated during the spawning process.

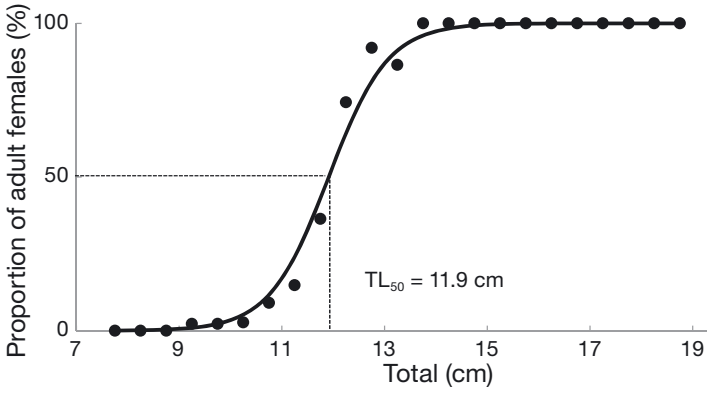

Fig. 4. Total length at first sexual maturity of female southern pink shrimp *Farfantepenaeus subtilis* captured off Pernambuco, northeastern Brazil, between August 2011 and July 2012

During ovarian development there is an increase in the size of the oocytes, which can be distinguished by their grainy cytoplasm, acidophilous reaction, and the presence of nucleoli arranged around the nucleus—that is, vitellogenic oocytes (Quintero & Gracia 1998, Peixoto et al. 2003). These modifications are accentuated when comparing the immature and maturing stages due to protein synthesis that occurs during this period (Quintero & Gracia 1998). Additionally, the color of the ovary during the maturation process in penaeids may range from yellow to green, depending on the degree of pigmentation (Dall et al. 1990, Browdy 1992, Quintero & Gracia 1998, Peixoto et al. 2003).

The presence of peripheral cortical rods in the cytoplasm of the MOs is commonly observed during oogenesis in other penaeids (Dall et al. 1990, Bell & Lightner 1988, Quintero & Gracia 1998, Ohtomi et al. 2003, Peixoto et al. 2003), and was also observed in the present study of *F. subtilis*. Clark et al. (1980) and Yano (1988) concluded that these rods exude their content after spawning, producing a gelatinous layer around the oocyte which probably guarantees the fixation of the sperm and the formation of the eclosion envelope.

Southern pink shrimp are known to reproduce continuously, with seasonal pulses in northern (Isaac et al. 1992, Cintra et al. 2004) and northeastern Brazil (Coelho & Santos 1993, 1995). A similar pattern was observed off Pernambuco in the present study—mature females were collected throughout the year, but a higher proportion were recorded during the hottest months (October–March), which is considered to be the reproductive peak. In the present study, 56% of the collected females were immature. This proportion could be related to the proximity of the collecting area to the estuary, which may have increased the probability of catching juveniles.

In *F. subtilis*, the TL_{50} at first sexual maturationwas estimated to be 11.9 cm in the present study. Coelho & Santos (1993) recorded a similar value (10.3 cm) from the Tamandaré region of Pernambuco, while Isaac et al. (1992) and Cintra et al. (2004) registered values of 11.0 and 12.65 cm, respectively, for populations from northern Brazil. Variations in the size of the shrimp at first maturity may be related to differences in the intensity of local fisheries, which may provoke precocious maturation (Sparre & Venema 1992, Fonteles-Filho 2011). Furthermore, Dall et al. (1990) suggested that size at first maturity was dependent on environmental parameters influenced by season, latitude and depth (Dall et al. 1990).

The findings presented here could be used to help guide the development of a fishery management policy for this species in the Pernambuco region, since this state has yet to implement legislation for the regulation of shrimp fisheries.

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