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Modulating reproduction of Penaeidae shrimps: ecological responses of two sympatric species (Decapoda: Dendrobranchiata) on south-eastern Brazilian coast

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The present study investigated the reproductive biology of the pink shrimp Farfantepenaeus brasiliensis *and* Farfantepenaeus paulensis *captured offshore and at two important fishing grounds, Guanabara Bay and Araruama Lagoon both on the south-eastern Brazil coast. The females' size at first maturation was 37.90 mm of carapace length (CL) for* F. brasiliensis *and 41.95 mm of CL for* F. paulensis*. Both species presented continuous reproduction with two spawning peaks. For* F. brasiliensis *these peaks occurred during summer and winter and for* F. paulensis *during summer and autumn. The sex-ratio of the pink shrimp was favourable to the number of females which can be a strategy to guarantee the reproduction.*

Keywords: Araruama Lagoon, Guanabara Bay, reproduction, size at first maturation, sex-ratio

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INTRODUCTION

The pink shrimp is a commercial fishing category composed of *Farfantepenaeus brasiliensis* (Latreille, 1817) and *Farfantepenaeus paulensis* (Pérez-Farfante, 1967), which are typical penaeids species exhibiting a short life cycle of anfibiotic type, where reproduction and spawning typically occurs offshore and the development phase, from post-larvae to juvenile, occurs into estuaries and coastal lagoons, which are considered nursery areas (Dall *et al.*, 1990; Pérez-Castañeda & Defeo, 2004). *Farfantepenaeus brasiliensis* is widely distributed from North Carolina to Rio Grande do Sul, whereas *Farfantepenaeus paulensis* is distributed from Cabo Frio to the North of Argentina (Pérez-Farfante, 1969).

The penaeid exploitation is of major global economic importance and represents the largest part of the fishery market's demand of the world. Brazil is the 14th most productive country on the shrimp fisheries (Gillet, 2008) and *F. brasiliensis* and *F. paulensis* are among the mostly exploited species of this group (D'Incao, 1991; Valentini *et al.*, 1991; Severino-Rodrigues *et al.*, 1992; D'Incao *et al.*, 2002; Costa *et al.*, 2005). Despite their presence in the list of 'National Fishes and Aquatic Invertebrate Species Overexploited and Threatened of Overexploitation' (IBAMA, 2004) both species still represent 20–30% of the annual shrimp landing on the Brazilian coast according to 'The Brazilian Institute of Environment and Renewable Natural Resources'—IBAMA, between 2000 and 2007 (IBAMA, 2007).

Besides the species coexistence and the economic and social importance of the category, studies are essentially conducted on the southern Brazilian coast, specifically at Santa Catarina and Rio Grande do Sul States. Moreover, they recurrently focus only on *F. paulensis* (D'Incao *et al.*, 1991; Peixoto *et al.*, 2003, 2005; Dumont *et al.*, 2007), leaving a regional gap of knowledge on their biology and behaviour in south-eastern Brazil. In order to have an appropriate management, which guarantees the stocks' livelihood it is mandatory to know about the life cycle of the species on regional scale (Fernandes-Góes *et al.*, 2005), and particularly the reproductive dynamics because it is the process of population renewing (Dumont & D'Incao, 2004). For example, the size at first maturation is used as minimum landing size of the commercially exploited species (Vazzoler, 1996) and its estimation allows the expectation of each individual to reproduce at least once during its life, ensuring the maintenance of the resource (López-Martínez *et al.*, 2005). Therefore, the aim of this work is to present the reproductive patterns of *F. brasiliensis* and *F. paulensis* indicating the reproductive period and the estimates of the size at first maturation for these

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species contributing with significant information to promote the development of an appropriate management for the pink shrimp fisheries in south-eastern Brazil.

MATERIALS AND METHODS

The surveys were conducted monthly from September 2007 to August 2009 at three sampling areas (Figure 1): Guanabara Bay (22°24′ and 22°57′S and 42°33′ and 43°19′W), between four and 18 m deep; Araruama Lagoon (22°50′ and 22°57′S and 42°00′ and 42°44′W) at 1 m deep; and the collections offshore occurred between 40 and 80 m deep between Maricás Islands (west limit—23°04′40″S and 43°04′53″W) and Macaé (east limit—22°34′08″S and 41°40′28″W). Samples were collected with bottom trawls by the artisanal fleet in Guanabara Bay with a net mesh of 20 mm and 16 mm at the bagger and by the industrial fleet offshore with a net mesh of 90 mm and 45 mm at the bagger. At Araruama Lagoon trawling was operated manually (80 m long with a net mesh of 10 mm).

The specimens that were analysed from Guanabara Bay and Araruama Lagoon corresponded to the whole sample from a single monthly trawling, in each of these areas. Whereas that from offshore, captured by the industrial fleet, corresponded only to the first thirty kilos of pink shrimp individuals, acquired from one or more trawling, depending on the amount of each sample. There were no samples in March and April 2009, because of the closed season.

In laboratory all specimens were classified according to sex, weighed to nearest 0.1 g and measured (total length (TL) and carapace length (CL)) to nearest 0.1 mm. To analyse the reproductive parameters only gonads of females were used due to their bigger size and easier macroscopic observation (Dumont & D'Incao, 2004). Sixty females of both species from each sample were dissected out for gonad weighing and observation of their coloration. The maturation stage was classified according to a gonadal colour table for *Farfantepenaeus paulensis* based on histological procedures (Dumont *et al.*, 2007). According to the colour table the gonads were classified as immature, maturing, ripe and spent.

In order to avoid an overestimation of the L_{50} due to the difficulty to discriminate macroscopically the gonads of the immature stage from the spent or recovering stage (Cha *et al.*, 2002; Peixoto *et al.*, 2005) a histogram of frequencies of occurrence by CL classes of individuals presenting gonads staining relative to the immature stage was analysed. The latest mode of the histogram was considered to separate immature from spent/recovering stage. Therefore, for *F. brasiliensis* all individuals up to 46 mm of CL were considered as spent/recovering (Figure 2). For *F. paulensis* all individuals up to 50 mm of CL were considered as spent/recovering (Figure 3).

Size at first maturation (L_{50}) was estimated by fitting the frequency of mature females to a logistic model calculated by the expression: $P = 1/1 + e^{(-r.(Cl-Lm))}$, where P is the relative frequency of occurrence of ripe females, r is the slope of the curve and Lm is the size at first maturation.

The reproductive period was based on the frequency analysis of mature females, employing only the data collected offshore by the industrial fleet; there are no females at that stage within the breeding areas (Guanabara Bay and Araruama Lagoon). The analysis of gonadosomatic index (GSI) was used to corroborate the reproductive period: GSI = GW/CW * 100; CW = TW – GW, where GW is the gonadal weight, TW is the total weight, and CW is the body weight. Even varying a little from the conventional GSI formula, applying this form of calculus it is possible to highlight deep variations on the physiology of the ovaries (Vazzoler, 1996). To verify if there was significant difference between the GSI along the study period one-way analysis of variance and a Tukey *a posteriori* test were used. All seasonal analyses were grouped bimonthly, so the months of closed

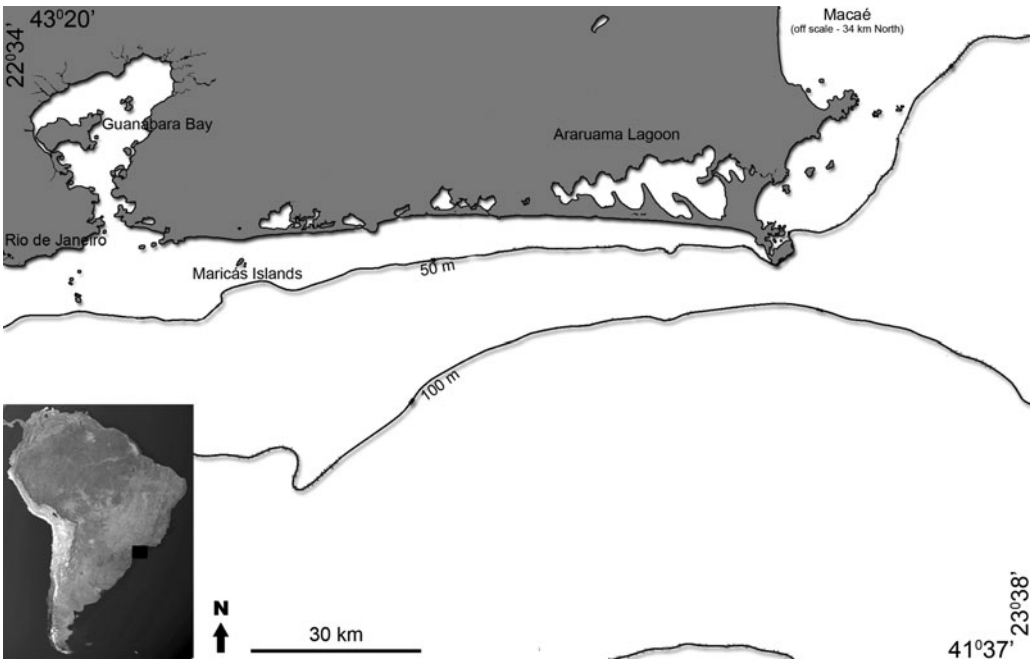

Fig. 1. Location of the sampling areas offshore along Rio de Janeiro State and at the fishing grounds including Guanabara Bay and Araruama Lagoon.

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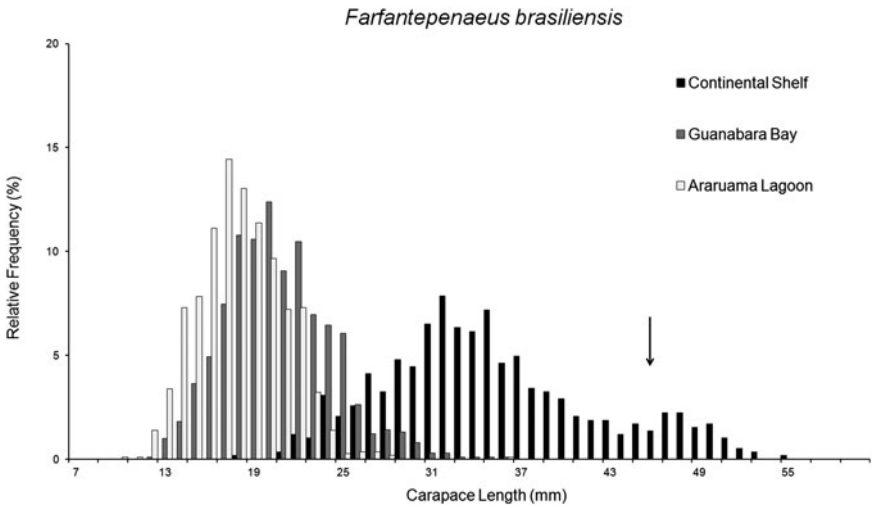

Fig. 2. Individuals with gonads referring to the immature stage of *Farfantepenaeus brasiliensis*. The arrow indicates the size-class (carapace length, mm) where the individuals began to be considered at the stage spent/recovering.

season could be grouped together and the seasonal sexual proportion was verified by a Chi-square test (Zar, 1999).

RESULTS

Farfantepenaeus brasiliensis was the most captured penaeid species in this work (Table 1), with 13.433 specimens representing 55.48% of the total catch, while *Farfantepenaeus paulensis* represented 44.52%, with 10.779 specimens. The same occurred considering the samples from Guanabara Bay and Araurama Lagoon, where *F. brasiliensis* represented 86.27% and 72.13% of the total captured, respectively. Considering only the industrial fleet collection offshore, the contribution of *F. paulensis* was higher than *F. brasiliensis* with 63.49% of the production and 8.139 individuals. *Farfantepenaeus brasiliensis* contributed with 4.680 individuals (36.51%) in this site.

The Chi-square test demonstrated that the sex-ratio of the pink shrimp during the period of this study was favourable to the number of females (*F. brasiliensis*—$\chi^2 = 60.34$; *F. paulensis*—$\chi^2 = 118.01$; $P < 0.05$), however there was a variation between the months (Figures 4 & 5).

As expected, females with reproductive activity begun were verified only offshore, as well as ripe females. Table 2 shows the percentage of mature females from the mentioned area for each period of study. The relation of the values of GSI in each stage was well set for the two species, with the lowest values of GSI related to immature and spent/recovery stages and the highest values to the ripe stage (Figures 6 & 7). With this information was estimated the females' size at first maturity (L_{50}) for *F. brasiliensis* in 37.90 mm of CL and for *F. paulensis* in 41.95 mm of CL. Offshore 60.85% of the *F. brasiliensis* females and 29.37% of *F. paulensis* females caught by the industrial fleet were smaller than the calculated L_{50}. At Guanabara Bay and Araruama Lagoon, for both species, all females caught were below this body length.

The frequency of occurrence of ripe females (Figures 8 & 9) demonstrated that during all the studied period the pink shrimp presented reproductive females. The GSI analysis demonstrated periods of greatest gonad activity as an

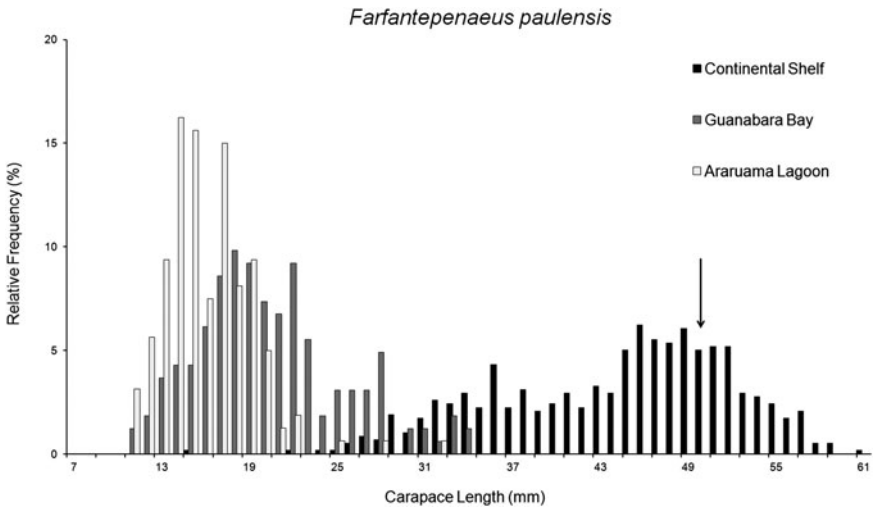

Fig. 3. Individuals with gonads referring to the immature stage of *Farfantepenaeus paulensis*. The arrow indicates the size-class (carapace length, mm) where the individuals began to be considered at the stage spent/recovering.

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Table 1. Total of captured individuals per bi-month and sample area.

	Araruama Lagoon		Guanabara Bay		Continental Shelf	
	Farfantepenaeus brasiliensis	*Farfantepenaeus paulensis*	*F. brasiliensis*	*F. paulensis*	*F. brasiliensis*	*F. paulensis*
Sep/Oct 2007	161	512	98	77	648	1008
Nov/Dec 2007	190	253	105	34	179	840
Jan/Feb 2008	276	151	146	17	436	913
Mar/Apr 2008	215	104	120	11	7	200
May/Jun 2008	1694	681	216	40	1015	520
Jul/Aug 2008	364	170	432	24	693	543
Sep/Oct 2008	344	64	469	71	479	583
Nov/Dec 2008	455	18	447	145	805	842
Jan/Feb 2009	69	0	346	25	182	978
Mar/Apr 2009	561	43	280	46	0	0
May/Jun 2009	572	89	461	11	235	472
Jul/Aug 2009	546	21	147	19	2	1238
Total	5447	2106	3267	520	4681	8137

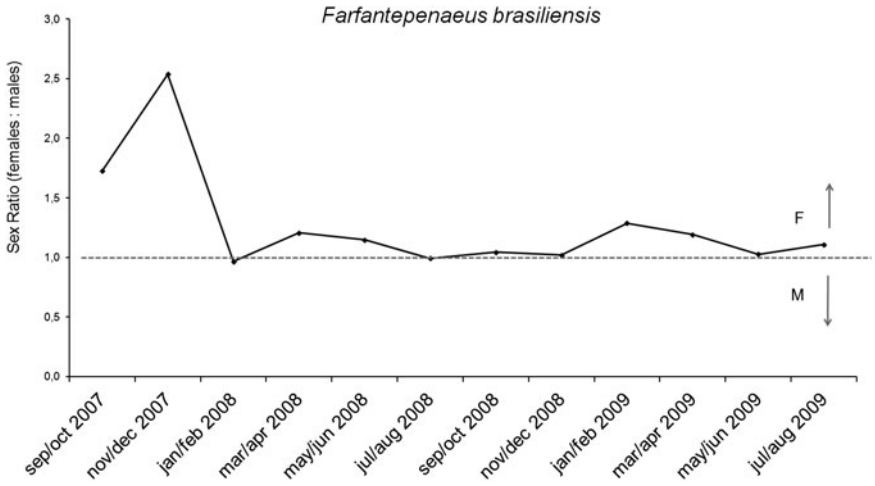

Fig. 4. Bimonthly variation of the sex-ratio of *Farfantepenaeus brasiliensis*. Dotted lines indicate a ratio of 1:1 (female: male).

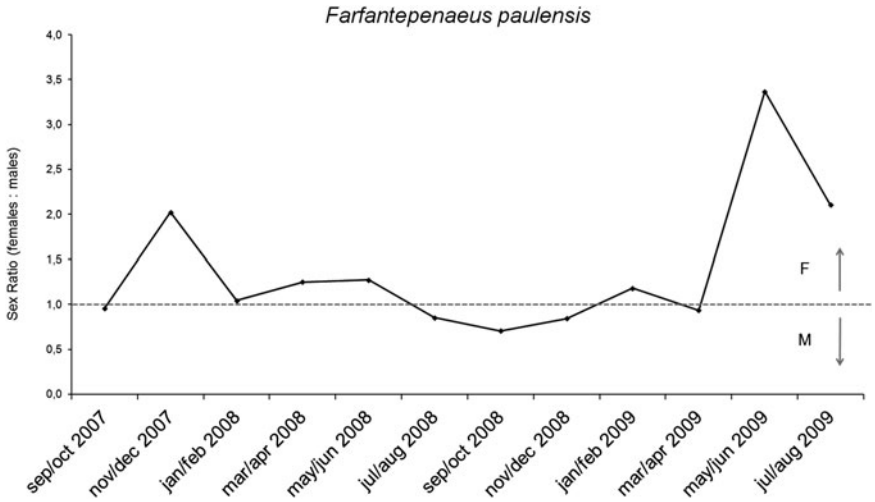

Fig. 5. Bimonthly variation of the sex-ratio of *Farfantepenaeus paulensis*. Dotted lines indicate a ratio of 1:1 (female: male).

indicator of spawning season (Table 3). For *F. brasiliensis* these spawning peaks occurred from November 2007 to February 2008 and again in November/December 2008. For *F. paulensis* the reproductive peaks were featured in March/April 2008, January/February 2009 and between May and August 2009.

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Table 2. Total number (N) and percentage (%) of mature females collected by the industrial fleet at continental shelf area.

	Farfantepenaeus brasiliensis		*Farfantepenaeus paulensis*	
	N	%	N	%
Sep/Oct 2007	60	9.26	323	32.04
Nov/Dec 2007	86	48.04	588	70.00
Jan/Feb 2008	162	37.16	181	19.82
Mar/Apr 2008	0	0.00	118	59.00
May/Jun 2008	263	25.91	229	43.95
Jul/Aug 2008	191	27.60	239	44.01
Sep/Oct 2008	50	10.44	152	26.07
Nov/Dec 2008	185	22.98	115	13.66
Jan/Feb 2009	28	15.38	411	42.02
Mar/Apr 2009	0		0	
May/Jun 2009	13	5.53	324	68.64
Jul/Aug 2009	2	100.00	760	61.42

DISCUSSION

The sex-ratio of the pink shrimp in this study was favourable to the number of females as generally observed for penaeids (Cha *et al.*, 2002; Peixoto *et al.*, 2005). It has already been suggested that this difference is a strategy to guarantee the reproduction (Peixoto *et al.*, 2005) and may be related to the dimorphism in growth of males and females of this family (Branco & Verani, 1998a, b; López-Martínez *et al.*, 2005; Yamada *et al.*, 2007). Males have higher constant growth (k) reaching their asymptotic lengths earlier than females (Garcia & Le Reste, 1986; Albertoni *et al.*, 2003) driving dissimilarities in mortality rates. Such disparities are common in decapods and can be related to differences in behaviour and migration between regions (Fernandes-Góes *et al.*, 2005; Keunecke *et al.*, 2009).

The values of GSI observed for pink shrimp proved to be associated with maturation stages, with some overlap between them. The same pattern was verified by Yamada *et al.* (2007) for *Trachysalambria curvirostris* and by Peixoto *et al.* (2003) for *Farfantepenaeus paulensis*, both species of the family Penaeidae. Moreover, this analysis was sensitive to distinguish which size-class should be considered the spent/recovery stage from immature stages (Dumont *et al.*, 2007).

From the frequency of occurrence of ripe females and monthly GSI analysis the reproductive period of pink shrimp in two main peaks over a year was verified. Although this work has dealt with individuals collected during two years, only one of the major peaks of spawning was corroborated in the second year for both species, due to the lack of individuals collected because of the closed season from March to May.

Farfantepenaeus brasiliensis presented higher spawning frequencies in the summer and winter months, while *F. paulensis* presented higher spawning frequencies in the autumn and summer months. Both sets of results agree with studies which verified a continuous spawning for many penaeid species throughout a year with two periods of higher importance (Isaac *et al.*, 1992; Crocos *et al.*, 2001; Dumont *et al.*, 2007). The reproduction occurs in response to environmental factors such as the rainfall and temperature, which modify the percentage of ripe females in the population (Dall *et al.*, 1990; Dumont & D'Incao, 2004) that may vary between years and species (Crocos *et al.*, 2001; Cha *et al.*, 2002; Peixoto *et al.*, 2002, 2003; López-Martínez *et al.*, 2005; Dumont *et al.*, 2007). Such environmental oscillations could influence deeply the differential behaviour between *F. brasiliensis* and *F. paulensis*, which will respond in its own way to these changes. Besides which, the continental shelf along Rio de Janeiro State is not the main reproduction and spawning area for *F. paulensis* (D'Incao *et al.*, 2002).

Pérez-Farfante (1969) defined in 25 mm of carapace length (CL) the minimum size of adults of *Farfantepenaeus* and Branco & Verani (1998a, b) defined in 105 mm of total length (TL), around 23.7 mm of CL, the size of adults of *F. brasiliensis* and in 115 mm of TL, corresponding to 25.5 mm of CL, the size of *F. paulensis*. These estimates are lower than those found in this study of 37.9 mm of CL for *F. brasiliensis* and 41.9 mm of CL for *F. paulensis*. Pérez-Farfante (1969) and Branco & Verani (1998a, b) took into account only the morphology of the organisms to classify them as adults or not, but usually the morphological maturity

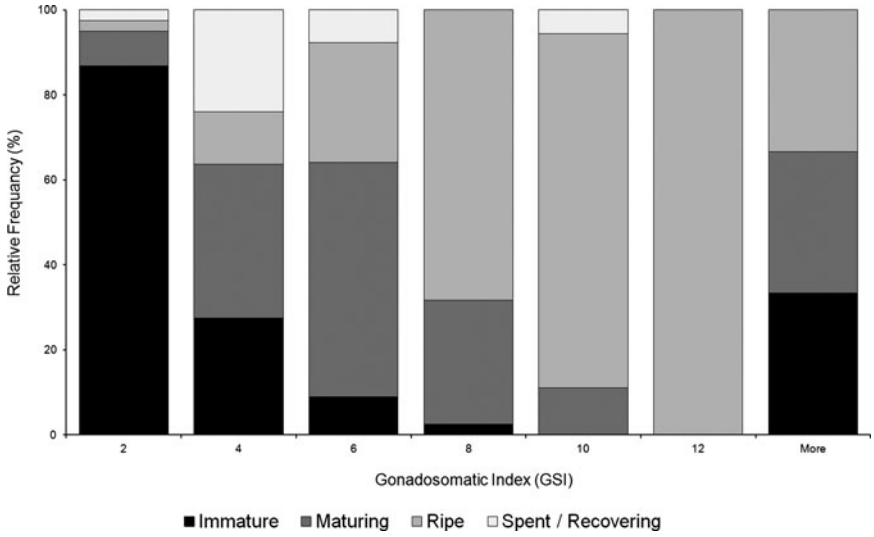

Fig. 6. Relative frequency of occurrence of the gonadosomatic index values of *Farfantepenaeus brasiliensis* in each stage of gonadal maturation.

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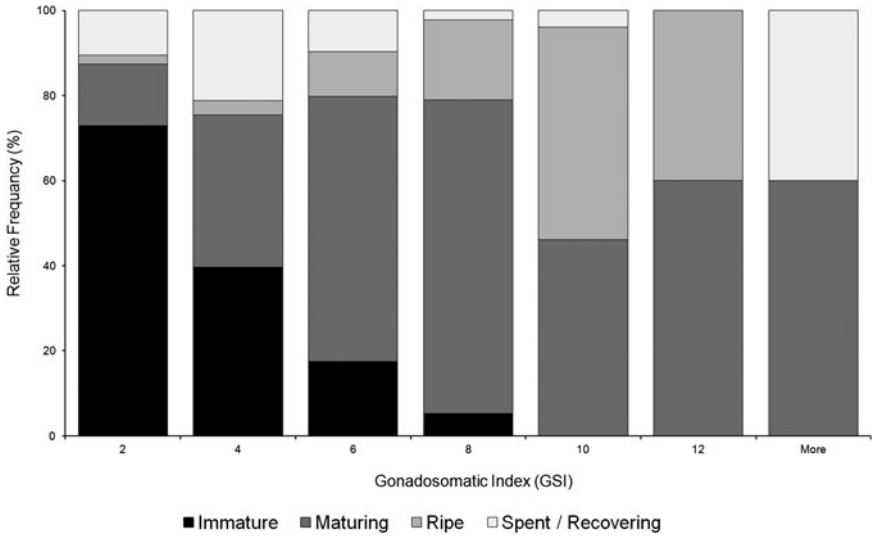

Fig. 7. Relative frequency of occurrence of the gonadosomatic index values of *Farfantepenaeus paulensis* in each stage of gonadal maturation.

of crustaceans does not occur synchronously with the gonadal maturity, so individuals considered morphologically mature can be functionally immature (Mantelatto & Fransozo, 1996). The different sampling sites may also have influenced these results, since the L_{50} can possibly vary with latitude and water temperature, as observed for several species of this family and genus by other authors (Dall *et al.*, 1990; Crocos *et al.*, 2001).

The size at first maturation is usually used as the minimum landing size of commercially exploited species (Vazzoler, 1996). However, the minimum landing size for this resource, according to Brazilian law (Enforced Law 55—SUDEPE, December 20, 1984), is 90 mm of TL. However, this has no scientific basis and was defined in order to meet the requirements of the productive sector and to ensure that there were no losses of market values (Dr Fernando D'Incao, personal communication). In addition, as observed in this study, this ordination is not being respected by the artisanal fisheries in estuaries that focused only on individuals below the L_{50}. Even the industrial fleet captures a lot of young individuals; during two years of sampling, 86.19% of the total sample of *F. brasiliensis* females was below the size at first maturity. In the case of *F. paulensis*, the representation of young females was less pronounced, with 29.24% of the catch (which may be related to species distribution, south-eastern Brazil being its geographical boundary (Pérez-Farfante & Kensley, 1997)), so the smaller individuals may be found more often on the south Brazilian coast.

Froese (2004) believes that the minimum landing size should be even larger than the size at first maturation; it increases the population resilience with females being larger and thus more fruitful, since the number of eggs increases exponentially with the growth in several species. Besides, specimens that can reach older ages are a sign of wellbeing and donors of good genes. The extension of the reproductive phase increases the guarantee against a bad recruitment.

Nevertheless, the social factor must have to be taken into account for an appropriate management (Gillet, 2008), and because the artisanal fisheries only capture young individuals, as shown in this work, the use of the size at first maturation as minimum landing size for pink shrimp is questionable, since it would represent the end of these kind of fisheries. Moreover, these two species have different L_{50}, and therefore should be treated in a different way by the legislation, for example

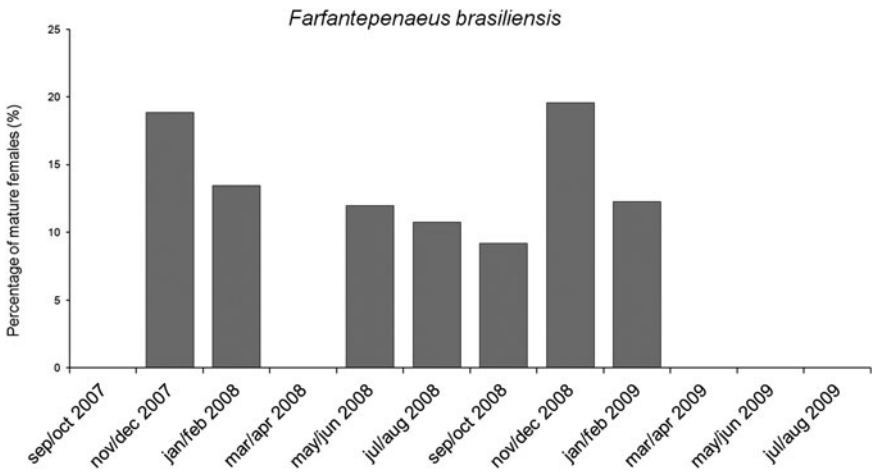

Fig. 8. Bimonthly variation of the frequency of occurrence of mature females of *Farfantepenaeus brasiliensis*.

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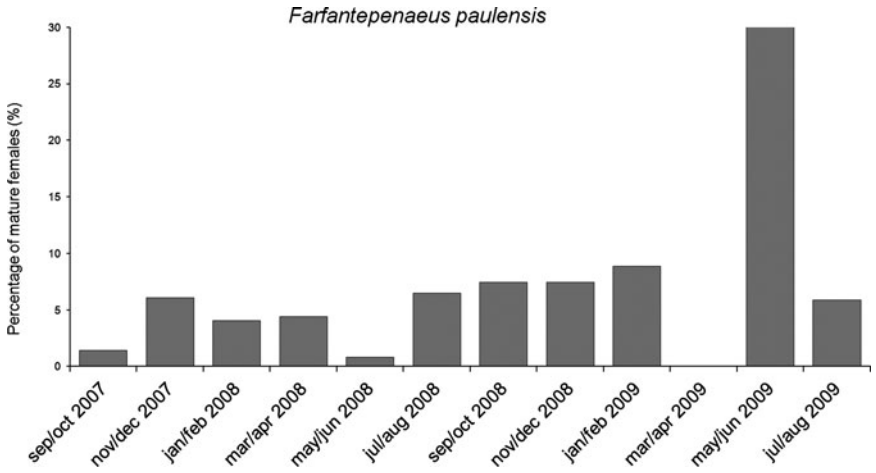

Fig. 9. Bimonthly variation of the frequency of occurrence of mature females of *Farfantepenaeus paulensis*.

Table 3. Values of gonadosomatic index (GSI) for *Farfantepenaeus brasiliensis* and *Farfantepenaeus paulensis* captured offshore along the period of study (CL, confidence limits; 95%).

	Farfantepenaeus paulensis		*Farfantepenaeus brasiliensis*	
	GSI	**CL**	**GSI**	**CL**
Sep/Oct 2007	3.89	0.50	1.67	0.40
Nov/Dec 2007	4.00	0.45	4.61	0.66
Jan/Feb 2008	3.63	0.56	4.02	0.54
Mar/Apr 2008	4.96	1.00	–	–
May/Jun 2008	3.37	0.57	2.50	0.43
Jul/Aug 2008	3.89	0.38	3.18	0.46
Sep/Oct 2008	4.26	0.50	3.86	0.90
Nov/Dec 2008	4.55	0.62	3.44	0.51
Jan/Feb 2009	4.03	0.37	2.92	0.58
May/Jun 2009	6.03	0.67	0.47	0.36

with a specific ordination for each species. This would be important, since it was demonstrated that *F. paulensis* has only 29.24% of its capture below its size at first maturation, whereas for *F. brasiliensis* this proportion is more representative (86.19%), which would justify the implementation of a minimum land size for this species. However, this possibility is not feasible, because these two species are sympatric and syntopic in great part of their range, including the south-eastern Brazilian coast. Usually, they are captured together and their morphological distinction is complex.

All these facts reinforce the idea that other biological aspects of pink shrimp must be studied in south-eastern Brazil, such as recruitment, for instance, in order to develop further restrictive measures, ensuring the maintenance of pink shrimp stocks.

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