SPATIO-TEMPORAL VARIATION OF THE DENSITY OF SHRIMPS *Farfantepenaeus subtilis*, *Litopenaeus schmitti* AND *Xiphopenaeus kroyeri* (CRUSTACEA; DECAPODA) IN THE CURUÇÁ ESTUARY, NORTH OF BRAZIL*

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ABSTRACT

The shrimps Penaeidae represent one of the most frequent and exploited fishery resources in coastal regions worldwide. In the estuaries of the north coast of Brazil they are caught, even when juveniles, by artisanal fisheries and mostly serving local markets. The objective of this study was to determine the composition, abundance and spatio-temporal distribution of species of Penaeidae shrimp caught in the Curuçá estuary, State of Pará, north coast of Brazil. The samples were collected every two months from July 2003 to July 2004 in eight sampling sites using an otter trawl net when the tide was ebbing. Two profiles were selected to study this area: Muriá tidal creek and the Curuçá River, with four sampling points in each site. A total of 6,158 Penaeidae shrimps, belonging to three species, were obtained. *Farfantepenaeus subtilis* was the dominant species with 78.5% of the total of shrimps, followed by *Litopenaeus schmitti* and *Xiphopenaeus kroyeri* that corresponded to 11.5 and 9.8%, respectively. The highest density of *F. subtilis* and *X. kroyeri* was obtained during the rainy season ($p < 0.05$), with a density of 197.4 ind./1,000 m^2 and 23.7 ind./1,000 m^2 respectively, both in March/04. The white shrimp (*L. schmitti)* was more abundant in the dry season and had two peaks of larger density in July 2003 (10.4 individuals/1,000 m^2), dry season and one second peak in March (16.5 individuals/1,000 m^2), rainy season. These results show the importance of the Curuçá estuary for the life cycle and maintenance of coastal stocks of these species.

Keywords: Amazon; density; Penaeidae.

VARIAÇÃO ESPAÇO-TEMPORAL DA DENSIDADE DE CAMARÕES *Farfantepenaeus subtilis*, *Litopenaeus schmitti* E *Xiphopenaeus kroyeri* (CRUSTACEA; DECAPODA) NO ESTUÁRIO DE CURUÇÁ, NORTE DO BRASIL

RESUMO

Os camarões Penaeidae representam um dos recursos pesqueiros mais freqüentes e explorados nas regiões costeiras de todo o mundo. Nos estuários da costa norte do Brasil eles são pescados, ainda quando jovens, de forma artesanal e abastecem principalmente os mercados locais. O objetivo deste trabalho foi determinar a composição, a abundância e a distribuição espacial e temporal das espécies de camarões Penaeidae capturadas no estuário de Curuçá, Estado do Pará, costa norte do Brasil. Coletas bimestrais de julho/03 a julho/04 foram realizadas em oito locais de coleta, distribuídos em dois perfis desse estuário (Rio Curuçá e Furo Muriá) usando uma rede de arrasto otter trawl durante a maré vazante diurna. Dois perfis foram selecionados para o estudo nesta área: o canal-de-maré Muriá e o Rio Curuçá, com quatro coletas em cada local. Um total de 6.158 camarões Penaeidae pertencentes a três espécies foram obtidos. *Farfantepenaeus subtilis* foi a espécie dominante, com 78,5% do total de camarões, seguido por *Litopenaeus schmitti* e *Xiphopenaeus kroyeri* que corresponderam a 11,5 e 9,8%, respectivamente. A maior densidade do camarão-rosa (*F. subtilis*) e do camarão-sete-barbas (*X. kroyeri*) foi registrada durante o período chuvoso ($p<0,05$), com densidade de 197,4 ind./1000 m^2 e 23,7 ind./1000 m^2, respectivamente, ambas em março/2004. O camarão-branco (*L. schmitti*) foi significativamente mais abundante no período seco ($p < 0,05$), e suas maiores densidades ocorreram em julho/03 (10,4 ind./1000m^2), período seco, e um segundo pico em março/04 (16,5 ind./1000m^2), período chuvoso. Estes resultados demonstram a importância do estuário de Curuçá para o ciclo de vida e manutenção dos estoques costeiros destas espécies, bem como auxiliam nas discussões sobre o período de defeso.

Palavras-chave: Amazônia; densidade; Penaeidae.

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INTRODUCTION

The northern coast of Brazil has a large and diverse area composed by islands, bays and estuaries, where wide ranges of dense mangrove forests are found (HERZ, 1991). Mangroves are highly productive environments (ROBERTSON and ALONGI, 1992) and play an important role in nutrient cycling of coastal and marine ecosystems (ALONGI, 1990). They serve as nurseries for many marine species (MIRANDA *et al.*, 2002) and are essential to the life cycle of many species of Penaeidae shrimps that migrate from the sea to calmer and richer estuarine waters in search for food and protection during post-larval stage (ROBERTSON and DUKE, 1987; CHONG *et al.*, 1990; VANCE *et al.*, 1990; D'INCAO, 1991). The family Penaeidae represents most of the catches of shrimps in the world, constituting one of the most frequent and exploited fish stocks in coastal regions (D'INCAO, 1999; RÖNNBÄCK, 1999).

In the tidal channels of estuaries on the north coast of Brazil, shrimps are caught by small-scale fishers using traditional methods and serve as a basis for livelihood for many local families (ESPÍRITO SANTO *et al.*, 2005). Most research on shrimp in estuaries is limited to the study of a single species. In Brazil's North Shore Amazon, prawn *Macrobrachium amazonicum* (Heller, 1862) has been the most studied species (Silva *et al.*, 2002; Lucena-Frédou *et al.*, 2010; Bentes *et al.*, 2011; Cavalcante *et al.*, 2012, among others). Among the Penaeidae, *L. schmitti*, *F. subtilis* and *X. kroyeri* are most often studied the Brazilian coast. The ecological distribution of the shrimp *L. schmitti* in Ubatuba Bay (São Paulo, Brazil) was studied by Capparelli et al. (2012) and the stages of gonadal development and mean length at first maturity of females of this wild white shrimp in southern Brazil was studied by MACHADO *et al.* (2009). *Farfantepenaeus subtilis* has been the subject of studies on the northeast coast and southeast Brazil (Silva *et al.*, 2010; Silva *et al.*, 2015). The seabob-shrimp *X. kroyeri* was the most studied species on the morphometric variation in the shape of the cephalothorax (BISSARO *et al.*, 2013), sex ratio (LOPES *et al.*, 2010), population biology (LOPES *et al.*, 2014) an diel variation in abundance and size (SIMÕES *et al.*, 2010). CASTILHO *et al.* (2008) were the only ones who searched an assemblage of shrimp due to the environmental variation in south-eastern coast of Brazil and NÓBREGA *et al.* (2013) in non-vegetated areas of two river islands in the Brazilian Amazon estuary.

The aim of this study was to determine the spatio-temporal distribution of density of species of Penaeidae shrimps caught in the estuary of Curuçá, Pará, Brazilian Amazon.

MATERIAL AND METHODS

The Curuçá estuary is located in the northeast of the State of Pará, in northern Brazil. It has equatorial climate, characterized by high temperatures (average of 27 °C), small thermal range and abundant rainfall, exceeding 2,000 mm annually. The months of highest rainfall are December to June, when the rain is intensive in the region (MORAES *et al.*, 2005).

Field collections were held from July 2003 to July 2004. Samples were taken every two months in two profiles of the estuary: one in the Muriá creek and the other in the Curuçá River (Pará, Brazil). In each profile, we took samples from four collection sites, regularly spaced at distances of approximately two kilometers (Figure 1). Collections were carried out during ebbing tides, during the last quarter moon and at daytime.

For the collection of shrimps, we used a wing trawl model net dragged by a trawler with 15 to 50 HP engine and two trawls were performed in each collection site. In each operation of fishing, trawling lasted for five minutes, counting from the total release of the head rope. Temperature and salinity of the water were measured with a conductivimeter and pH through a potentiometer (Hanna), immediately after the collection of samples. For calculation of dissolved oxygen and suspended particulate matter (SPM) we collected 300 mL of water and stored it in ice for subsequent analysis in the laboratory.

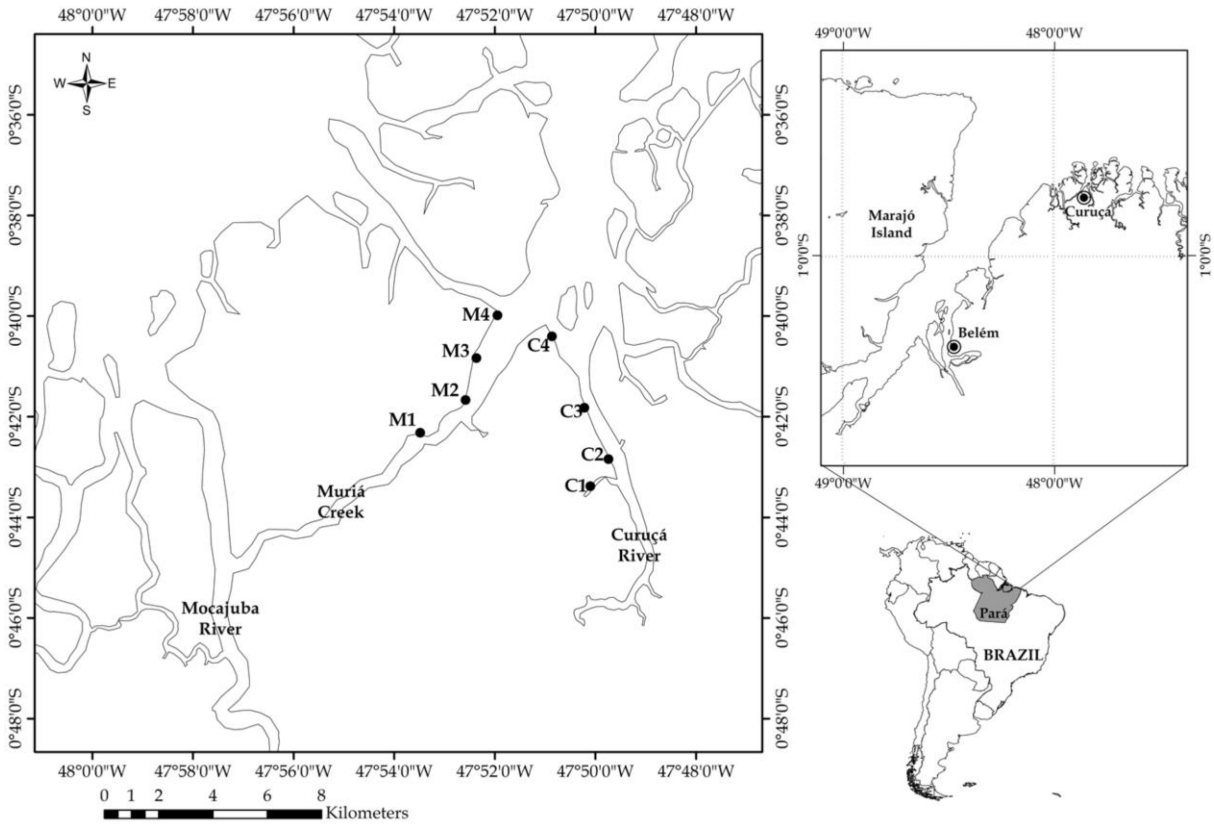


Figure 1. Study area in the estuary on the Curuçá River, indicating the eight collection sites (M for Muriá creek and C for Curuçá River).

Dissolved oxygen was assessed according to Winkler and modified with the addition of sodium azide, and the gathering of SPM, dissolved oxygen and biochemical oxygen demand (BOD) followed the procedures published by the Institute of the Millennium Project (BARROSO et al., 2007). SPM and dissolved oxygen analyses were performed at the Hydro-chemical Laboratory of the Geosciences Center, at the Universidade Federal do Pará (UFPA). Shrimps collected were identified according to CERVIGÓN et al. (1992) and PÉREZ-FARFANTE and KENSLEY (1997)

Population density was estimated as a function of the density of each species of shrimps collected and expressed as individuals per 1,000 square meters (ind./1,000 m^2). The area sampled was calculated by multiplying the width of the net (m) by the distance trawled (m). A Global Positioning System (GPS) was used to calculate the distance trawled. One-way analysis of variance (ANOVA) followed by the Tukey's test were performed to assess significant differences in the density of shrimp species between the two profiles with respect to the different months and periods of the year. We used Kruskal-Wallis test for the species that showed no normal distribution in the density values.

Cluster analyses were used to assess the spatial (collection sites) and temporal (dry and rainy seasons) variations in the density of the each Penaeidae species, in which the transformation of data by the fourth root and the similarity coefficient of Bray-Curtis were used for the creation of the similarity matrix. The species that contributed substantially to the average similarity within each group were identified through analysis of similarity of percentages (SIMPER) using the PRIMER® 6.0 program (CLARKE and WARWICK, 1994). The relative frequency of Penaeidae species density in each period (dry and rainy seasons) was used for identify the groups formed by cluster analysis. Normality and homogeneity of samples variances were tested with D'Agostino-Pearson and Cochran C, Bartley, Bartlett, respectively, and transformed to Log (X+1) for standardization of data.

RESULTS

The average temperature of water was 26 ± 1.59 °C, with a maximum of 31 °C in July 2003 and a minimum of 20.6 °C in January 2004, which showed significant differences ($p < 0.05$) with respect to all other months (Figure 2a). Salinity varied from a minimum of 6.1 in March 2004 to a maximum of 40.8 in November 2003, with an average of 18.6 ± 3.16, being higher in the dry season (July to November). Unlike salinity, SPM showed higher averages during the months of highest rainfall intensity (Table 1).

pH showed small range, with major averages in the dry period: minimum of 6.8 in March 2004, maximum of 8.1 in November 2003 and an average of 7.5 ± 0.04. The major averages of dissolved oxygen (7.5 ± 0.2 and 6.7 ± 0.1 mg/L) were recorded in July 2003 and July 2004, respectively, showing significant differences ($p < 0.05$) compared to the other months. The total range of variation was between 3.4 and 8.4 mg/L, with an average value of 5.6 ± 0.1 mg/L (Table 1). BOD showed a minimum of 0.5 mg/L in July 2003 and a maximum of 3.1 mg/L in January 2004, with an average of 2.2 ± 0.1 mg/L (Table 1). Abiotic factors did not show significant differences between collecting sites (Table 1).

Table 1. Mean and standard error of abiotic factors recorded bimonthly at each collection site in the Curuçá estuary, from July 2003 to July 2004. There was not significant difference in abiotic factors among locals.

Samples	Temperature (°C)	Salinity	pH	SPM (mg/L)	O_2 (mg/L)	BOD (mg/L)
M1	25.6 ± 0.92	19.9 ± 11.35	7.6 ± 0.35	44.2 ± 29.64	5.2 ± 1.08	2.4 ± 0.70
M2	26.0 ± 0.88	18.8 ± 11.26	7.7 ± 0.33	41.8 ± 28.58	5.3 ± 0.93	2.4 ± 0.66
M3	25.8 ± 0.94	19.2 ± 10.41	7.7 ± 0.28	36.3 ± 21.44	5.9 ± 0.96	2.1 ± 0.75
M4	25.5 ± 0.96	19.1 ± 10.53	7.7 ± 0.36	36.2 ± 18.62	5.9 ± 1.17	2.1 ± 0.85
C1	26.7 ± 1.19	14.8 ± 8.54	7.2 ± 0.30	38.5 ± 19.91	5.3 ± 1.08	2.4 ± 0.68
C2	26.6 ± 1.15	17.9 ± 11.32	7.5 ± 0.40	41.4 ± 28.75	5.9 ± 1.44	2.1 ± 0.95
C3	26.2 ± 1.07	19.2 ± 10.77	7.5 ± 0.38	36.6 ± 24.99	6.0 ± 1.33	2.1 ± 0.91
C4	26.1 ± 1.07	20.6 ± 11.28	7.6 ± 0.37	40.3 ± 27.07	5.9 ± 1.35	2.1 ± 0.92

A total of 6,158 Penaeidae shrimps were caught. The following species were identified: *Farfantepenaeus subtilis* (Pérez-Farfante, 1967), *Litopenaeus schmitti* (Burkenroad, 1936) and *Xiphopenaeus kroyeri* (Heller, 1862). The species *F. subtilis* had the largest frequency, representing 78.5%, followed by *L. schmitti* and *X. kroyeri*, which corresponded to 11.5 and 9.8%, respectively.

The pink shrimp *(F. subtilis)* was the most common in the region, showing the highest average density (197.4 ind/1,000m^2), with significant differences ($p < 0.05$) in relation to September 2003, November 2003, January 2004 and May 2004 (Figure 2a).

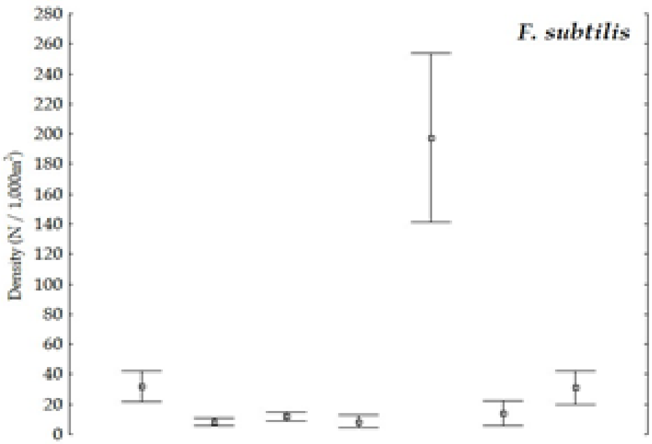
The species *L. schmitti* (white shrimp) was presented the second highest density in the Curuçá estuary, showing two peaks of highest average densities (16.5 and 10.4 ind/1,000m^2 in July 2003 and March 2004, respectively). From July 2003, the density gradually decreased until January 2004, increasing later in March 2004 and falling again until July 2004. However, no significant differences were found ($p = 0.37$) in density between the months (Figure 2b).

The Atlantic seabob shrimp (*X. kroyeri*) had the highest average density in March 2004, with 23.7 ind/1,000m². *Xiphopenaeus kroyeri* was not captured in November 2003 (Figure 2c). All species of Penaeidae caught were more abundant in the Curuçá River, when compared to those from the Muriá creek. *F. subtilis* and *L. schmitti* had significant differences (p< 0.05) between these profiles (Figure 3). The density of the species collected in the Curuçá estuary was significantly different with respect to seasonality. Farfantepenaeus subtilis and X. kroyeri were more frequent during the rainy season (p< 0.01 and p= 0.03, respectively) and L. schmitti were more abundant in the dry period (p= 0.03), as can be seen in Figure 4. Farfantepenaeus subtilis were over 60% more frequent in all collection sites, with the exception of M3, in which X. kroyeri corresponded to 80.5% of the relative frequency in this season. Atlantic seabob shrimps showed a decreasing trend in their spatial distribution as they move away from the coastline and up the estuary. M1 and C1 sites had only 1.0 and 0.6% of the relative frequency of the species in these sites, respectively (Figure 5).

Three groups (A, B and C) were identified by cluster analysis to the level of 82% significance (Figure 6), considering the every two months density of Penaeidae with respect to seasonality and collection sites.

Group A was comprised of species found in M1 and C1 during the dry and rainy seasons, respectively, and located in the innermost portion of the estuary. This group was characterized by the absence of X. kroyeri. Group B featured mainly the densities of the three species in the dry period. Group C was characterized mainly by the species that occurred during the rainy season.

From the SIMPER analysis, we found an average similarity of 53.17% in Group A, in which the species F. subtilis had a strong contribution (92.57%). Group B had an average similarity of 60.63%, in which the contribution of F. subtilis was 82.22% and that of X. kroyeri was 9.4%. In Group C (average similarity of 56.58%), the contribution of F. subtilis and L. schmitti were 81.68% and 10.41%, respectively.



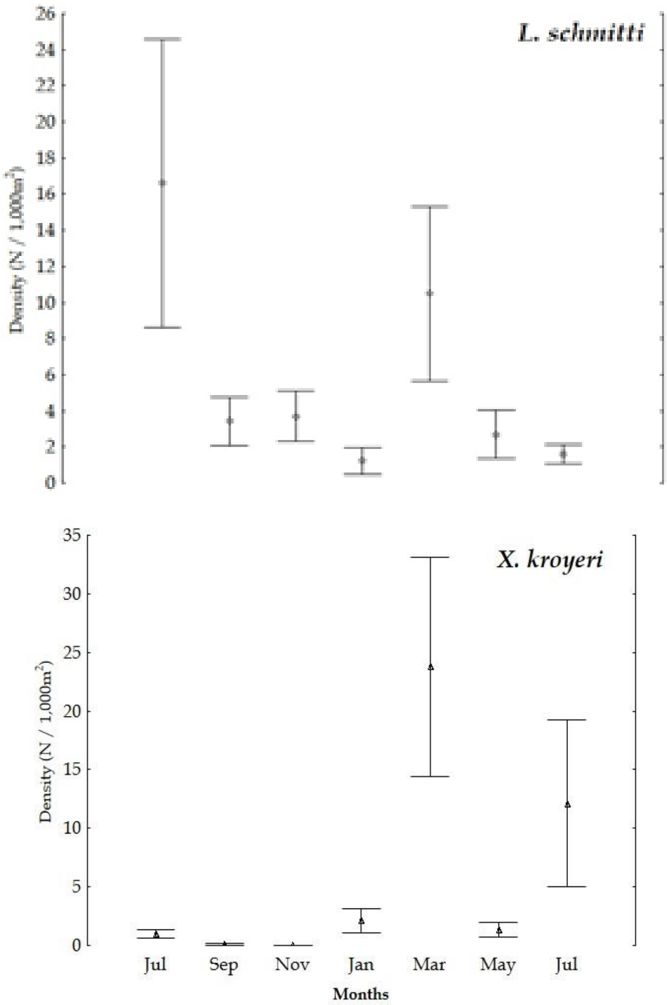


Figure 2. Density of *F. subtilis* (a), *L. schmitti* (b) and *X. kroyeri* (c), caught every two months from July 2003 to July 2004 in the Curuçá estuary. Whiskers (mean ± standard error).

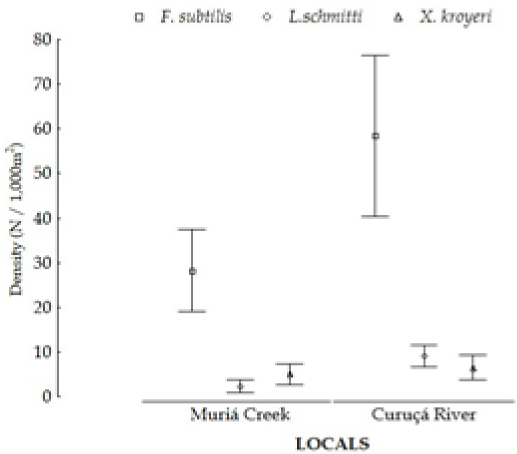


Figure 3. Density of species of Penaeidae, between profiles (Muriá creek and Curuçá River), caught every two months in the Curuçá estuary, from July 2003 to July 2004. Whiskers (mean ± standard error).

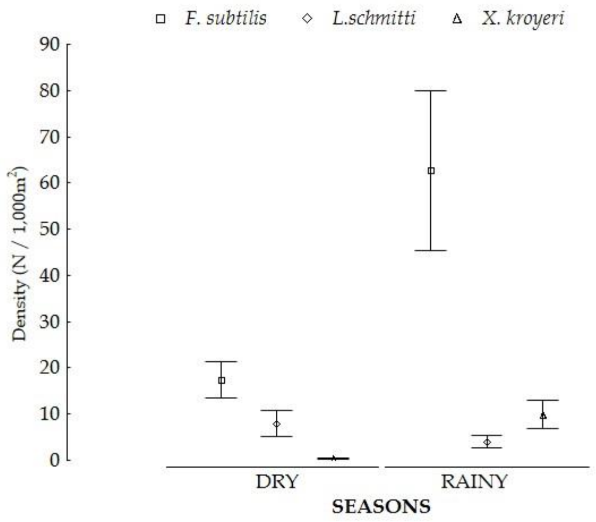


Figure 4. Density of species of Penaeidae, between dry and rainy seasons, caught bimonthly in the Curuçá estuary, from July 2003 to July 2004. Whiskers (mean ± standard error).

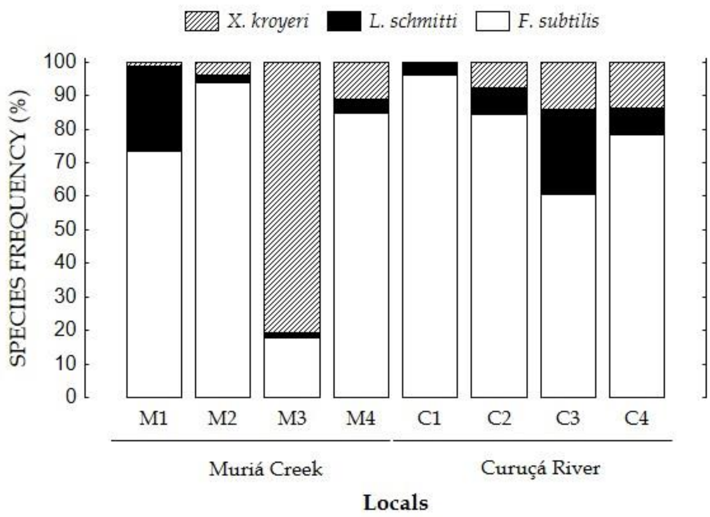


Figure 5. Relative ration of the density of each Penaeidae species, in the Curuçá estuary from July 2003 to July 2004.

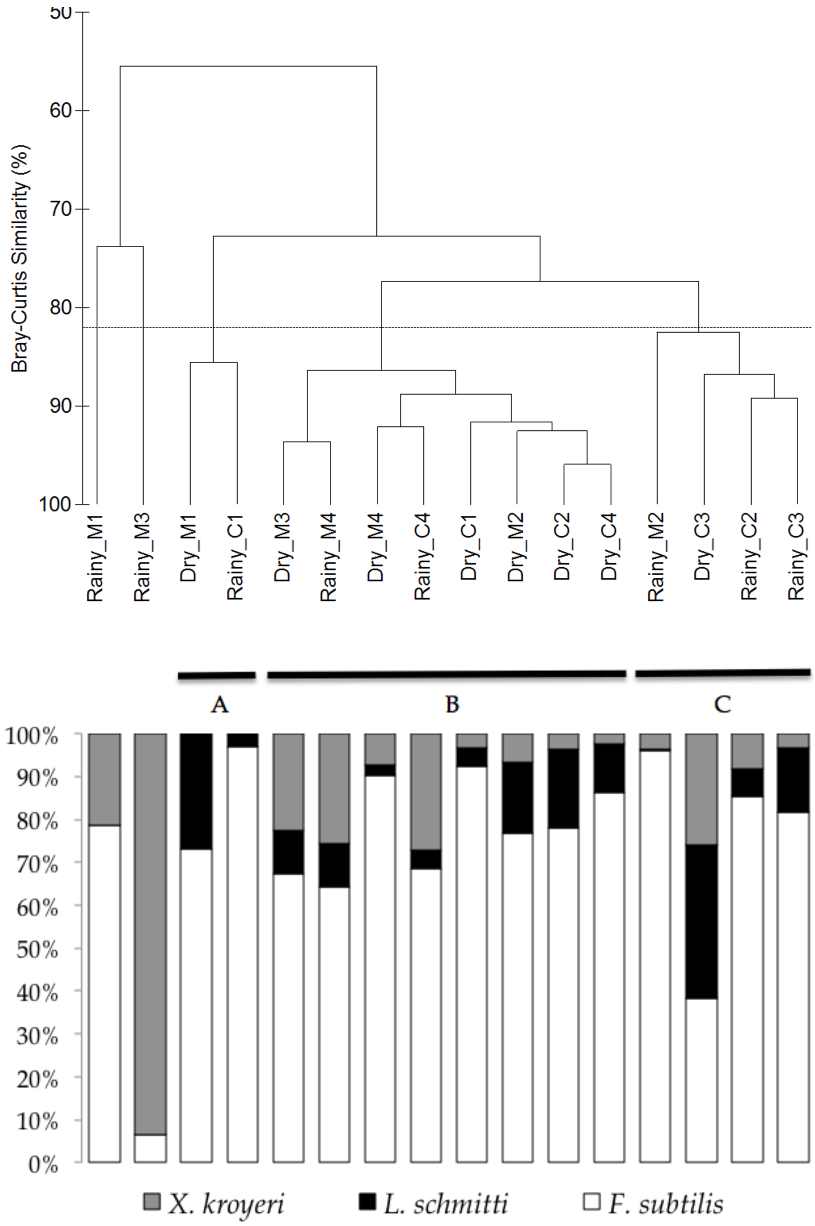


Figure 6. Dendrogram (upper) and percentage (lower) of cluster analysis based on Penaeidae species density in each period (dry and rainy seasons) and collection sites in the Curuçá estuary, from July 2003 to July 2004.

DISCUSSION

Salinity appears to be the most important abiotic factor that acts as regulator of the distribution and abundance of macro-crustaceans in estuarine environments (ABREU, 1980; NEVIS *et al.*, 2009; SILVA *et al.*, 2010; OLIVEIRA *et al.*, 2012). In the Curuçá estuary, salinity showed a great variation between the rainy and dry periods. Strong decrease in salinity averages in January 2004, March 2004 and May 2004 is justified due to the strong intensity of the local rains during this period, which according to MORAES *et al.* (2005), covers the months from December to June as the highest rainfall period in the region. High rainfall increases the continental drainage of rivers, causing the flow of river waters to push the masses of sea water out of the estuarine complex, leading to decreased salinity in the system

(ESPÍRITO SANTO *et al.,* 2005). During this period, the minimum salinity of water in C1 was 6.1 in March 2004. The same site had much higher salinity in the dry period, reaching to 29.6 in November 2003.

When compared to other estuaries of the coastal region of Pará, the salinity range in the Curuçá estuary (6.1 to 40.8) was well above that in Vigia estuary (north coast of Brazil), which was described as oligohaline by SILVA *et al.* (2002), with a range of 0 to 28; approaching Caeté estuary (north coast of Brazil) – where MARTINELLI (2005) observed a range of 6 to 36 – and Ubatuba Bay (southeastern Brazil) with a range of 5 to 35 approximately (CAPPARELLI *et al*., 2012). These results corroborate those already found in other Amazonian estuaries such as Mosqueiro oligohaline estuary (NÓBREGA *et al*., 2013) and the tide pools of beach Areauá (SAMPAIO and MARTINELLI-LEMOS, 2014), both on the northeast coast of Pará. According to NÓBREGA *et al*. (2013), *F. subtilis* was found for the first time in oligohaline environments (0-8 salinity) and exclusively juveniles composed the population. *F. subtilis* was most abundant in months and locations when and where salinity is higher. There is a direct relationship between the abundance of this species and rain cycles, as also reported by NAGELKERKEN *et al.* (2008).

Temperature and pH of the water were the most important environmental descriptors that significantly affected the density and biomass of shrimps on tide pools (rocky outcrops, mangrove and salt marhes). Among the abiotic factors studied (temperature, salinity, pH, area and volume of tide pools), the pH showed significant negative correlation with the density and biomass of *F. subtilis* on Areuá Beach (Amazon littoral). (SAMPAIO and MARTINELLI-LEMOS, 2014). The temperature correlated significantly and positively with the biomass of *F. subtilis* in the pools of the rocky outcrop. Salinity was the only physico-chemical factor that did not correlate significantly with the abundance of shrimp species (SAMPAIO and MARTINELLI-LEMOS, 2014).

On the northern coast of Brazil, fishing of shrimps is based on pink shrimp *(F. subtilis)*, where catches are performed in one of the most important shrimp fishing grounds of the world, which extends from Tutóia, in the State of Maranhão, to the border between Brazil and French Guiana (ISAAC *et al.,* 1992). The high density of *F. subtilis* caught in the Curuçá estuary shows the important role that this estuary plays for the recruitment of juveniles (CARVALHO *et al*., 2015) and for the maintenance of the population stock of this species and other species of minor economic importance for the region (*L. schmitti* and *X. kroyeri*).

The peak in density of *F. subtilis* observed in March 2004 can be associated with the period of most intense spawning of this species that, according to ISAAC *et al.* (1992), occurs continuously and during a longer period of time, apparently coinciding with periods of increased rainfall in the northern region of Brazil. VIEIRA *et al.* (1997) and CINTRA *et al.* (2004) also found a large production of small specimens caught from January to March and December to March, respectively, in this region.

Bimodal variation in the density of *L. schmitti* over the months suggests two important periods of recruitment of juveniles in the Curuçá estuary, one at the beginning of the dry season (July) and the other in March, during the rainy season. The largest catches of white shrimps in July 2003 indicate that the species shows a pattern similar to that found by MARTINELLI (2005) in the Caeté estuary, northeastern Pará, north coast of Brazil. This also agrees with CAPPARELLI *et al*. (2012), who claim that the main recruitment period for *L. schmitti* occurs during the warmer months in coastal southeastern Brazil.

According to SANTOS and FREITAS (2004), the season of greatest production of white shrimp in the northeastern coast of Brazil seems to follow the peak of the rainiest season of the year, which can also be observed in this work.

The pink shrimp was the least abundant in the Curuçá estuary. Its spatial distribution pattern within the estuary shows that it has more coastal habit, being found in greater abundance in the most downstream location of the estuary. This coastal habit is confirmed by MARTINELLI (2005) in the Caeté estuary and by CASTILHO *et al*. (2008) on the southeastern coast of Brazil.

According to NAKAGAKI *et al.* (1995), *X. kroyeri* is found throughout the year, but with a decreased density within the estuarine in summer. This can be explained in terms of the migration of these shrimps to deeper regions at the time of spawning (unpublished data). There was no positive correlation between number of *X. kroyeri* juveniles and temperature, salinity, depth, and sediment organic matter content (CASTRO *et al.*, 2005). In the Brazilian southeast-south coast, capturing individuals of all demographic categories suggests that *X. kroyeri* has life cycle with no differential segregation between juveniles and adults, with individuals sharing the same habitat at all stages of life (BRANCO *et al.*, 1999; BRANCO, 2005; CASTRO *et al*., 2005; HECKLER *et al*., 2013; BRANCO *et al.,* 2013). This pattern is not the same presented by *X. kroyeri* inhabitant of Amazonian coastal waters, where there is a clear stock segregates, which is present in the open sea and the juvenile stock that enters estuaries throughout the year (NÓBREGA *et al*., 2013; SAMPAIO and MARTINELLI-LEMOS, 2014), confirmed by this work. The explanation for this would be a great production of organic material in this environment, associated with macrotidal with strong influence of ocean currents, allowing the occurrence of shrimp including *F. subtilis* reported for the first time in oligohaline environments (0-8) by NÓBREGA *et al.* (2013).

It can be inferred that the highest density for the three species of shrimps in the Curuçá River – compared to Muriá creek – can be related to hydrodynamic differences between profiles, since there were no significant differences of abiotic factors between them.

This way, we highlight that the Curuçá estuary has favorable characteristics for the development of young marine shrimps, being an important area of post-larvae migration and, consequently, essential in the maintenance of the stocks of these species in the north coast of Brazil.

This study is an important contribution to the knowledge on the ecology of shrimps in this estuary in northern Brazil. Still, more studies in this region are necessary, due to its socioeconomic and ecological importance.

CONCLUSIONS

The high density of Penaeidae shrimps caught in the Curuçá estuary shows the important role that this estuary plays for the recruitment of juveniles and for the maintenance of the stocks of these species (*F. subtilis, L. schmitti* and *X. kroyeri*) and other species of minor economic importance for the region.

The species composition of shrimps differs between the two periods of the year and also between locations nearby as well, suggesting the inclusion of diverse areas for the management of the species.

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