**Nauplius**
The Journal of The Brazilian Crustacean Society

e-ISSN 2358-2936
www.scielo.br/nau
www.crustacea.org.br

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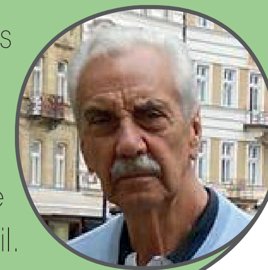

Original Article

# Distribution pattern of juveniles of the pink shrimps *Farfantepenaeus brasiliensis* (Latreille, 1817) and *F. paulensis* (Pérez-Farfante, 1967) on the southeastern Brazilian coast

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SUBMITTED 3 March 2016
ACCEPTED 17 July 2016
PUBLISHED 8 December 2016

Guest Editors
Maria Lúcia Negreiros-Fransozo and Adilson Fransozo

DOI 10.1590/2358-2936e2016024

## Abstract

The spatio-temporal distribution of juveniles of the pink shrimps *Farfantepenaeus brasiliensis* (Latreille, 1817) and *Farfantepenaeus paulensis* (Pérez-Farfante, 1967) in the Ubatuba region (SP) was investigated. Sampling was performed in the bays of Ubatumirim (UBM), Ubatuba (UBA) and Mar Virado (MV). A total of 2,018 *F. brasiliensis* and *F. paulensis* were collected. The largest catch of juveniles of both species occurred in UBA (N = 867), followed by UBM (N = 729) and MV (N= 422). The bottom sediment in MV had the highest silt and clay content, which explains the negative correlation of the substrate with the abundance of both species. Temperature was positively correlated with the abundance of both species. Juveniles were highly abundant in shallower areas in the summer of 1998. The high rainfall in this El Niño period may have lowered the salinity in estuarine waters and led the shrimps to move to coastal areas in search of higher salinities such as in bays. With this unusually early reduction in salinity, individuals migrated to the bay before the closed season began and thus became more exposed to fishing. We confirmed that monitoring environmental variations, especially in El Niño years, is essential for understanding the distribution patterns of juveniles of both species.

## Key words
Abundance, Penaeidae, El Niño, closed season.

## Introduction

The pink shrimps *Farfantepenaeus brasiliensis* (Latreille, 1817) and *Farfantepenaeus paulensis* (Pérez-Farfante, 1967) are among the most important penaeids commercially exploited in the southeastern Brazilian coast (Valentini *et al.*, 1991; D'Incao *et al.*, 2002; Dias-Neto, 2011). The sharp decrease in pink shrimps catches along the Brazilian coast, especially in the southeastern and southern regions, seems to indicate that the fishing effort is dangerously high (Dias-Neto, 1991; Dias-Neto and Dornelles, 1996; Santos *et al.*, 2008). During the 1970s, the harvested biomass averaged over 16,000 t $y^{-1}$, but it declined to < 500 t $y^{-1}$ in the late 1980s and 1990s (D'Incao *et al.*, 2002). Although species of this genus are not included in the Red List of endangered animals of the International Union for Conservation of Nature (IUCN), the Chico Mendes Institute for Biodiversity Conservation (ICM-Bio) classifies *Farfantepenaeus* Burukovsky, 1997 species as having "insufficient data", which means that these species have a priority for evaluations of conservation status (Brasil, 2014). Additionally, no specific information is available on the fishing effort for each species, which precludes a more accurate diagnosis (D'Incao *et al.*, 2002; Santos *et al.*, 2008).

Species of *Farfantepenaeus* have a Type II life cycle, which includes spawning in offshore areas and postlarvae migrating to estuarine regions and remaining there until the juvenile stage is completed (Dall *et al.*, 1990; Costa *et al.*, 2008). After 2–4 months, juveniles migrate down the estuary and pass through the coastal region, moving toward oceanic waters and completing their life cycle (Benfield and Downer, 2001; Pérez-Castañeda and Defeo, 2001). If juveniles migrate in months outside the closed season period, they will be caught in large numbers in the coastal region by artisanal fisheries targeting the seabob shrimp *Xiphopenaeus kroyeri* (Heller, 1862), especially on the southern and southeastern Brazilian coast (Costa *et al.*, 2007). As these individuals have not yet reproduced, such captures may have serious effects on the maintenance of *Farfantepenaeus* populations.

The distribution of juveniles of *Farfantepenaeus* is mainly related to salinity. Most individuals of *F. brasiliensis* are caught at 15–30 (Branco and Verani, 1998a; 1998b), whereas *F. paulensis* is more often caught at lower salinities, primarily below 20 (D'Incao, 1991). Regarding the other variables, penaeid juveniles also prefer finer sediments with higher organic-matter content (Dall *et al.*, 1990) and high temperatures (Costa *et al.*, 2008).

Recent studies have shown that rainfall plays an important role in the distribution of juveniles on Brazilian coast, as it alters mainly the salinity (Santos *et al.*, 2008; Bochini *et al.*, 2014). Also, the El Niño phenomenon, which occurs on inter-annual scales, is the main source of short-term climate variability and can intensify rainfall in southern and southeastern Brazil (Silva, 2000). Bochini *et al.* (2014) recorded earlier juvenile migration of *Litopenaeus schmitti* (Burkenroad, 1936) in years when El Niño was more intense.

Studies of the distribution pattern of a species are essential to develop applicable and effective management measures, especially considering the high commercial value of species of *Farfantepenaeus*. This study investigated the temporal and spatial variation in the catch of juveniles of *F. brasiliensis* and *F. paulensis* in three bays at Ubatuba (Ubatumirim, Ubatuba and Mar Virado), São Paulo, Brazil. We also studied the relationship between environmental parameters (temperature, salinity, rainfall, and sediment organic-matter content and granulometry) and the distributions of these species. Additionally, considering that the closed season period in southern and southeastern Brazil extends from March to May, we evaluated whether the closed season is effective in protecting the two species in the study region.

## Material and Methods

*Shrimp sampling*

Shrimp were collected monthly from January 1998 to December 1999, in the bays of Ubatumirim (UBM) (23°20'15.7338"S 044°53'39.2136"W), Ubatuba (UBA) (23°27'00.0"S 045°03'18.0"W) and Mar Virado (MV) (23°31'43.6548"S 045°12'54.849"W), located in the Ubatuba region, northern coast of São Paulo. In each bay, six stations were sampled monthly at depths up to 20 m. Four stations were located at mean depths of 5 (IV), 10 (III), 15 (II) and 20 m (I); and the other two were adjacent to rocky shores (an exposed and a sheltered shore, stations V at 9 m and VI at 6.5 m, respectively) (Fig. 1).

A shrimp-fishing boat equipped with double-rig nets (mesh size 20 mm and 18 mm in the cod end) was used for trawling. Each trawl was performed over a 30-min period, covering a total area of 18,000 $m^2$.

*Environmental factors*

The salinity and temperature of the bottom water, and the organic-matter content (%) and granulometry (φ) of the sediment were obtained at each sampling station. A Nansen bottle was used for bottom-water samples. Salinity was measured with an optical refractometer and temperature (°C) with a mercury thermometer (0.1°C accuracy). An echo sounder coupled to a GPS (Global Positioning System) was used to provide the depth (m) of each sampling station. The rainfall data were obtained in http://www.ciiagro.org.br.

The values of sediment organic-matter content and granulometry were obtained from samples collected seasonally with a Van Veen grab (area of 0.06 $m^2$) and frozen until the analysis. Detailed descriptions of the methods used to determine the granulometric composition and the organic-matter percentage of the sediment can be found in Costa *et al*. (2007) and Bochini *et al*. (2014).

*Data analysis*

Tests for homoscedasticity (Levene tests) and normality (Shapiro-Wilk tests) were first performed as prerequisites for the statistical test, using an Excel® spreadsheet divided into rows and columns. When necessary, data were transformed with Box-Cox transformation, using the statistical software PAST - PAleontological STatistics - Version 3.02) power transformation in order to select the most appropriate procedure (Sokal and Rohlf, 1995). All data sets were normally distributed, with homogeneous variances.

Shrimp abundance (dependent variable) was compared temporally between years and among seasons (independent variables): summer (January–March), autumn (April–June), winter (July–September) and spring (October–December). Abundance was also compared spatially among bays and collection stations (independent variables) using an analysis of variance model (nested ANOVA, $\alpha = 5\%$) (Statistica 7.0 program), with stations nested within area and seasons nested within years. A post-hoc Tukey test was used to assess differences among seasons, bays and stations.

A redundancy analysis (RDA) (R-project program) was used to assess the amount of variation in faunal densities related to a set of habitat environmental characteristics (Ter Braak, 1996). Previous analysis of the main species showed a linear response in their abundance in relation to the environmental variables used. The use of RDA provides a larger percentage of the variance explained regarding the canonical correspondence analysis (CCA), which is more suitable when there is a unimodal response. The set of environmental variables used in RDA calculations comprised the bottom salinity and bottom temperature, organic-matter content (%) and grain size of sediments (φ) and rainfall.

## Results

*Environmental factors*

The mean values of bottom-water salinity were similar in the two years sampled, with $34.23 \pm 1.43$ in 1998 and $34.08 \pm 1.34$ in 1999. The highest salinity values (> 35) were found during summer and autumn in 1998 and autumn in 1999. The lowest salinity values occurred during early spring (September and October) in 1998 and during winter and spring (except November) in 1999 (Fig. 2). Spatially, despite the lower values recorded at shallower stations and the higher values recorded at deeper stations, the mean salinity did not

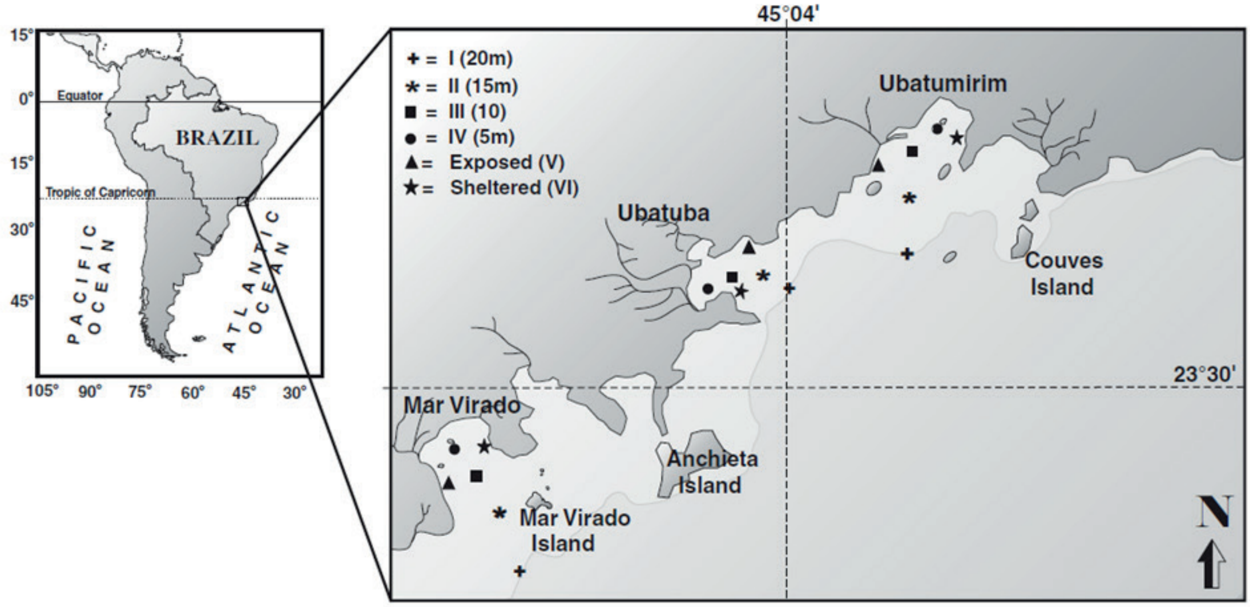


Figure 1. Map of Ubatuba on the coast of São Paulo, showing the three bays and their respective sampling stations.

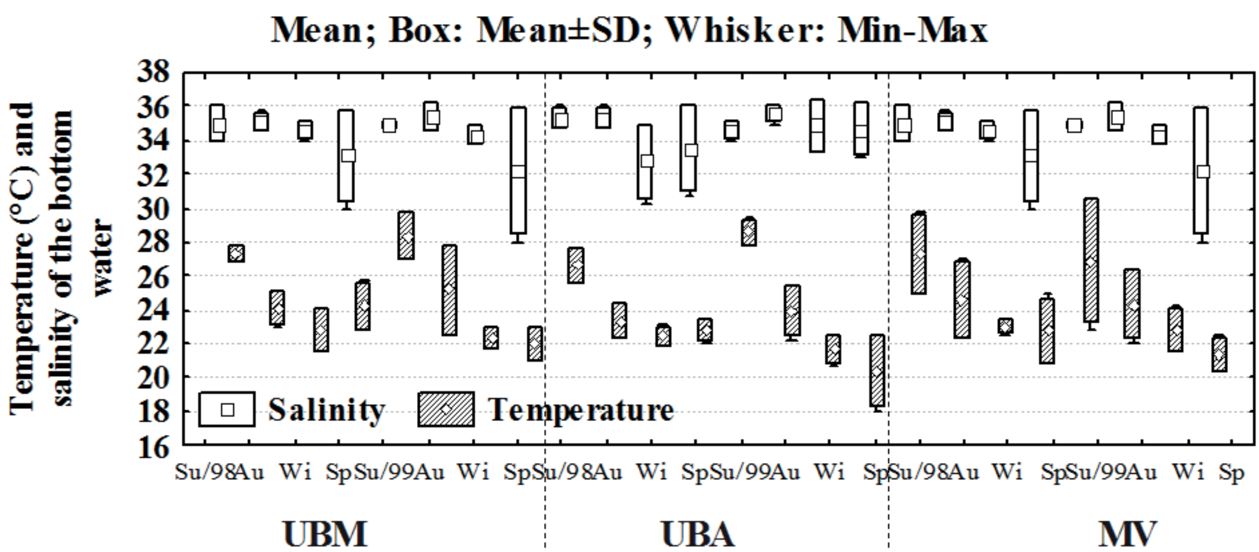


Figure 2. Mean values (minimum and maximum) of salinity and temperature (°C) of the bottom water from January 1998 to December 1999, in each season (Su = summer, Au = autumn, Wi = winter, Sp = spring), in the bays of Ubatumirim (UBM), Ubatuba (UBA) and Mar Virado (MV).

vary significantly among sampling stations (Fig. 3).

The mean values of bottom-water temperature were higher in the first year of sampling in all three bays. The highest mean temperature occurred in the summer of both years and at shallower stations, while lower values were observed in winter 1998 and spring of 1999 and at deeper stations (Figs. 2, 3).

Differences in mean organic-matter content levels were found among the bays, with the deeper stations, located close to the bay mouth (I and II), showing the lowest levels (Tab. 1).

The amount of mud ($\varphi > 4$) in the sediments decreased northward, i.e., from MV to UBM (Tab. 1). In MV, the silt+clay fraction ($\varphi > 4$) predominated at almost all stations. A predominance of fine and very fine sand, associated with silt and clay, was observed

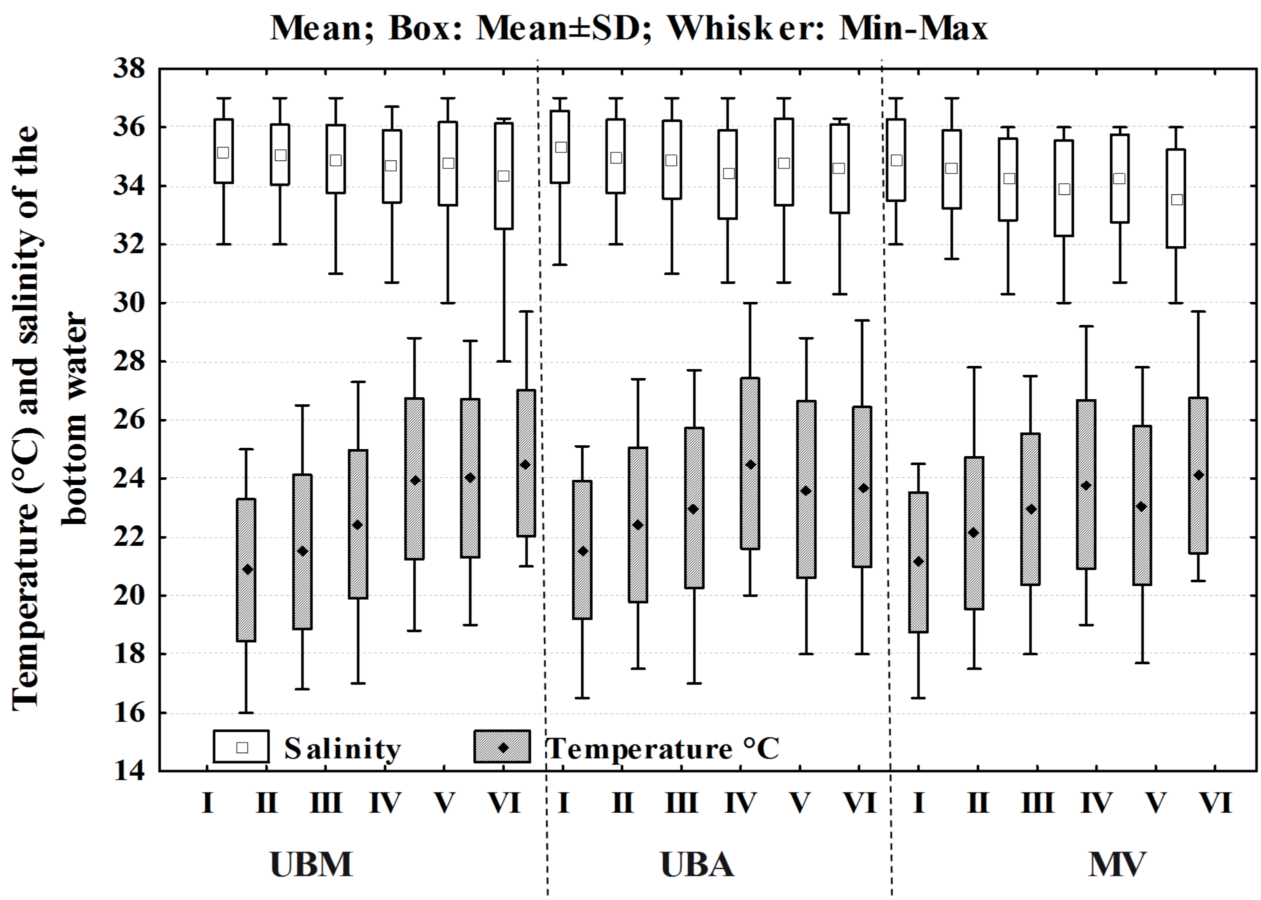


Figure 3. Mean values (minimum and maximum) of salinity and temperature (°C) of bottom water sampled from January 1998 to December 1999, at each sampling station, in the bays of Ubatumirim (UBM), Ubatuba (UBA) and Mar Virado (MV).

in Ubatuba, particularly in UBM, except for stations I and VI in UBA and station I in UBM (Tab. 1).

The mean rainfall was higher during the first year of sampling (249.44 ± 168.20 mm). In the second year, the mean was 195.49 ± 101.64 mm. Rainfall was most intense during spring and summer of both years (Fig. 4).

*Abundance and distribution*

In total, 2,018 juveniles were collected during the study period, with 1,380 individuals of *F. brasiliensis* (900 in 1998 and 480 in 1999) and 638 of *F. paulensis* (422 in 1998 and 216 in 1999). There was no statistically significant difference between the abundance and the sampled years, but there were differences between abundance and seasons (Tab. 2), with larger catches recorded in summer and autumn (Fig. 5). In 1998, the highest abundance was observed in summer, while in 1999 the highest abundance occurred in autumn, especially for *F. brasiliensis*. Over 50% of *F. brasiliensis* individuals sampled in 1999 were captured in April (Figs. 4, 5).

Spatially, the highest abundance of juveniles occurred in UBA, with 867 individuals captured (562 of *F. brasiliensis* and 305 of *F. paulensis),* followed by UBM, with 729 individuals (509 *F. brasiliensis* and 220 *F. paulensis),* and MV, with 422 individuals (309 *F. brasiliensis* and 113 *F. paulensis*). Only the abundance of *F. paulensis* differed among bays, where MV differed from UBM (Nested ANOVA, $p < 0.01$). For both species there were statistically significant differences among the sampling stations (Nested ANOVA, $p < 0.01$) (Tab. 3), with the highest catch of *F. brasiliensis* at stations II and VI in UBM, IV and VI in UBA and I and VI in MV; for *F. paulensis*, the highest catch occurred in V and VI in UBM, IV and VI in UBA and I and VI in MV (Fig. 6). For both species, the highest capture occurred in station VI in the three bays sampled (Fig. 6).

Table 1. Mean values of sediment parameters (φ and % OM) sampled from January 1998 to December 1999, at each sampling station, in the bays of Ubatumirim, Ubatuba and Mar Virado.

| Bays | | Collection stations | | | | | |
|---|---|---|---|---|---|---|---|
| | | I | II | III | IV | V | VI |
| UBATUMIRIM | phi | 4.4 | 4.9 | 4.4 | 4.0 | 3.8 | 1.5 |
| | % OM | 4.2 | 4.2 | 5.2 | 2.4 | 3.4 | 2.1 |
| UBATUBA | phi | 4.8 | 5.7 | 5.3 | 3.6 | 4.0 | 3.2 |
| | % OM | 7.5 | 5.7 | 8.0 | 6.1 | 4.2 | 3.6 |
| MAR VIRADO | phi | 5.4 | 5.9 | 5.8 | 6.2 | 5.7 | 4.3 |
| | % OM | 4.4 | 5.6 | 4.2 | 5.4 | 4.6 | 3.0 |

Phi = sediment diameter, OM = organic matter

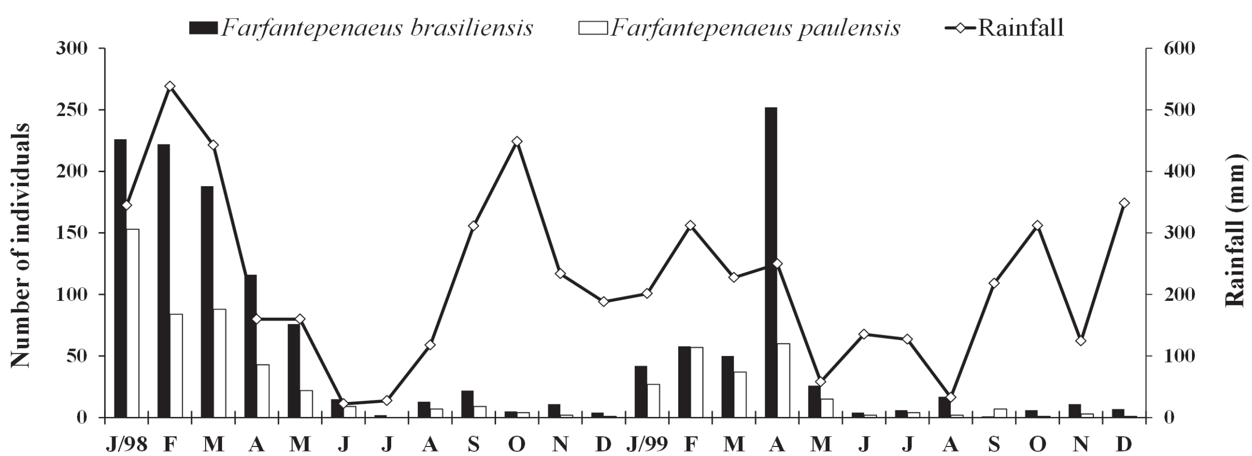


Figure 4. Cumulative values for monthly rainfall (mm) and number of individuals of *Farfantepenaeus brasiliensis* and *F. paulensis* sampled from January 1998 to December 1999 at Ubatuba, São Paulo.

Table 2. Results of nested ANOVA for the number of individuals (log + 1 transformed) of *Farfantepenaeus brasiliensis* and *F. paulensis* collected in three bays of the Ubatuba region, from January 1998 to December 1999.

| Species | Source of variation | df | ms | *F* | *P* |
|---|---|---|---|---|---|
| *F. brasiliensis* | Year | 1 | 0.20498 | 1.3551 | 0.2450 |
| | Season | 6 | 2.81034 | 18.5788 | <0.000 |
| *F. paulensis* | Year | 1 | 0.19731 | 2.0600 | 0.1519 |
| | Season | 6 | 1.43561 | 14.9883 | <0.000 |

df = degrees of freedom, ms = mean square, F = MS factor/MS residual and P = probability of significance; α = 0.05

*The relationship between abundance and environmental factors*

The first and second axes of the redundancy analysis (RDA) represent the relationships between shrimp abundance and environmental factors (Fig. 7A–C). The Monte-Carlo test indicated that these two canonical axes were significant together ($p < 0.005$), but the results are explained by axis 1 in the graph (Tab. 4; Fig. 7A–C).

Environmental variables correlated differently with the abundance of shrimp found in each bay. The bottom-water temperature was the common variable for the three bays, and correlated positively with the abundance of both species. The highest captures occurred in water temperatures above 21°C (Tab. 4; Fig. 7A–C). Rainfall correlated positively in two of the three bays (Tab. 4). The highest rainfall values were recorded during January and February 1998, when the highest abundances of juveniles were found. In 1999, with the decrease in rainfall, especially in January and February, the greatest abundances of juveniles occurred in April (Fig. 4).

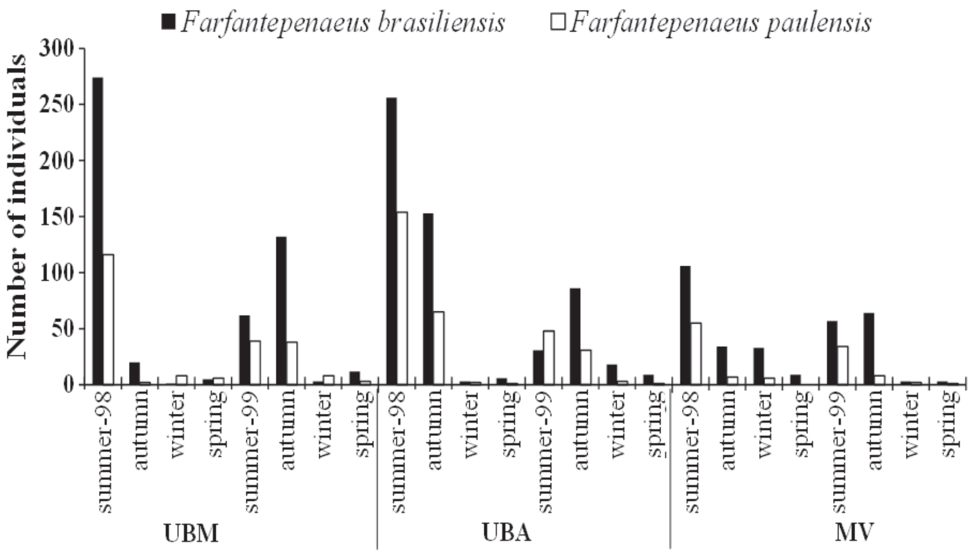


Figure 5. Number of individuals of *Farfantepenaeus brasiliensis* and *F. paulensis* captured seasonally from January 1998 to December 1999 in the bays of Ubatumirim (UBM), Ubatuba (UBA) and Mar Virado (MV).

Table 3. Results of Nested ANOVA for the number of individuals (log + 1 transformed) of *Farfantepenaeus brasiliensis* and *F. paulensis* collected from January 1998 to December 1999 in the bays of Ubatumirim, Ubatuba and Mar Virado.

| Species | Source of variation | df | ms | *F* | *P* |
|---|---|---|---|---|---|
| *F. brasiliensis* | Bays | 2 | 0.10478 | 0.68550 | 0.5043 |
| | Station | 15 | 1.18114 | 7.72780 | <0.000 |
| *F. paulensis* | Bays | 2 | 0.43510 | 4.39043 | 0.0129 |
| | Station | 15 | 0.50155 | 5.06092 | <0.000 |

df = degrees of freedom, ms = mean square, F = MS factor/MS residual and P = probability of significance; α = 5%

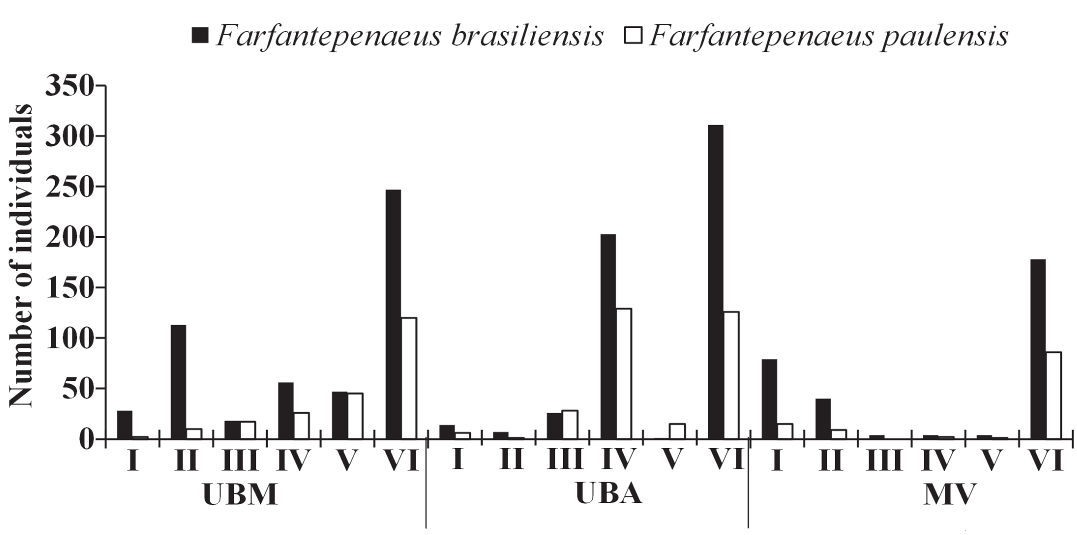


Figure 6. Number of individuals of *Farfantepenaeus brasiliensis* and *F. paulensis* captured at each sampling station in the bays of Ubatumirim (UBM), Ubatuba (UBA) and Mar Virado (MV), from January 1998 to December 1999.

Temperature and rainfall correlated positively with the abundance of both species in UBM (Fig. 7A), while in UBA there was a positive relationship only with temperature (Fig. 7B). In MV, there was a correlation with temperature, rainfall and sediment granulometry (φ) (Fig. 7C). Temperature and rainfall correlated positively with abundance; the largest catches occurred in seasons of higher temperatures and greater precipitation. Granulometry correlated negatively with the number of juveniles; the greatest abundance was observed at the station with the lowest φ value, i.e., with larger-diameter grains (Fig. 7C). However, this sediment is still considered very fine, with a predominance of silt + clay (φ > 4) (Tab. 1).

## Discussion

We observed a seasonal temporal distribution of juveniles of *F. brasiliensis* and *F. paulensis*, i.e., the shrimp migrated from the estuary to the bay between January and May, partially agreeing with the study of Costa *et al.* (2008). These authors recorded the migration to UBA from March to May.

This difference in the months in which juveniles are present is related to rainfall. The high pluviosity in early 1998 was a result of El Niño, which is consequence of the warming waters and heavy rains in southern and southeastern Brazil (Silva, 2000). The El Niño in this period was the strongest in 50 years, which explains the high rainfall values recorded (Glantz, 2001; Berlato *et al.*, 2007; Filgueira *et al.*, 2007; Britto *et al.*, 2008; Pereira and D'Incao, 2012). In 1999, due to the smaller amount of rain, especially in summer, this migration occurred in later months (in autumn and during the closed season period).

Similar results were found by Bochini *et al.* (2014) for the white shrimp *L. schmitti*. For this species, however, the advance of migration from May to April did not result in the capture of recruits by fishing, as this event coincided with the closed season.

The positive association between rainy periods and penaeid juvenile migration, mainly for those with a type II life cycle, was also reported by Garcia and Le Reste (1981) and Dall *et al.* (1990). The high rainfall volumes markedly lowered the salinity values in estuarine waters. As individuals grow, their osmoregulatory capacity decreases, which leads the juveniles to migrate to more favorable areas such as the shallower waters of the bays

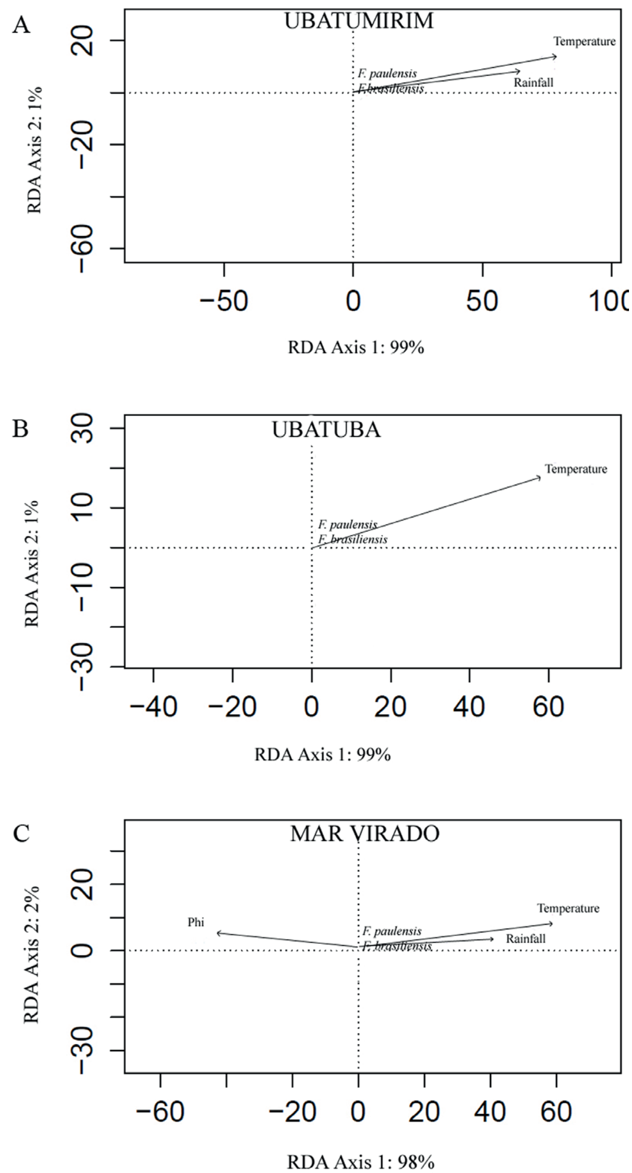


Figure 7. Redundancy analysis showing the relative abundance of *Farfantepenaeus brasiliensis* and *F. paulensis* with environmental factors sampled from January 1998 to December 1999 in the bays of Ubatumirim (A), Ubatuba (B) and Mar Virado (C).

(Dall *et al.*, 1990). This also probably occurred for the species of the present study, as laboratory experiments on postlarvae of *F. paulensis* showed high mortalities in salinities lower than 3 (Tsuzuki *et al.*, 2003). For *F. brasiliensis*, the highest mortality rates occurred in salinities lower than 15 (Brito *et al.*, 2000).

On the other hand, our results completely agree with those of Costa *et al.* (2008) in relation to the positive correlation between abundance and water temperature. Most tropical/subtropical penaeid

Table 4. Redundancy analysis (RDA) of the abundance of *Farfantepenaeus brasiliensis* and *F. paulensis* in relation to environmental variables that best explained the variation of the sampling data in three bays in the Ubatuba region, from January 1998 to December 1999.

| Bays | Axis | Proportion explained | Environmental factors | Explained variance | $r^2$ | P |
|---|---|---|---|---|---|---|
| UBATUMIRIM | RDA 1 | 0.9933 | Temperature | 0.98282 | 0.1685 | 0.001 * |
| | RDA 2 | 0.0067 | Salinity | 0.99465 | 0.0087 | 0.483 |
| | | | Organic matter | -0.97147 | 0.0125 | 0.422 |
| | | | φ | 0.96186 | 0.0275 | 0.115 |
| | | | Rainfall | 0.99353 | 0.1190 | 0.001 * |
| UBATUBA | RDA 1 | 0.9830 | Temperature | 0.96041 | 0.1132 | 0.002 * |
| | RDA 2 | 0.0170 | Salinity | 0.99821 | 0.0032 | 0.802 |
| | | | Organic matter | -0.6544 | 0.0036 | 0.792 |
| | | | φ | 0.72798 | 0.0303 | 0.106 |
| | | | Rainfall | 0.96887 | 0.0237 | 0.216 |
| MAR VIRADO | RDA 1 | 0.9822 | Temperature | 0.99181 | 0.0906 | 0.004 * |
| | RDA 2 | 0.0178 | Salinity | 0.99696 | 0.0166 | 0.303 |
| | | | Organic matter | -0.98372 | 0.0146 | 0.340 |
| | | | φ | -0.99351 | 0.0524 | 0.026 * |
| | | | Rainfall | 0.99702 | 0.0482 | 0.023 * |

* = $P < 0.05$

shrimps prefer higher temperatures, as evidenced by several studies performed with: post-larvae and juveniles of *Fenneropenaeus merguiensis* (De Man, 1888) in two Australian estuaries (Vance *et al.*, 1998); *L. schmitti* in marine and estuarine areas of Santos and Ubatuba Bay, respectively (Santos *et al.*, 2008; Bochini *et al.*, 2014); species of *Farfantepenaeus* in the estuary and adjacent bay of Ubatuba (Costa *et al.*, 2008); and *X. kroyeri* in Ubatuba Bay (Costa *et al.*, 2011).

The temperature is highly important for the distribution of penaeid shrimps. This abiotic factor can significantly affect the metabolism (Dall *et al.*, 1990), mainly the reproductive behavior of some species, as observed for *Rimapenaeus constrictus* (Stimpson, 1874) (Costa and Franzoso, 2004), *Artemesia longinaris* Spence Bate, 1888 (Castilho *et al.*, 2007a; 2007b) and *Pleoticus muelleri* (Spence Bate, 1888) (Castilho *et al.*, 2008b).

In addition to high temperature, the higher incidence of *F. paulensis* and *F. brasiliensis* in UBA and UBM was related to their preference for sediments with larger diameters. Similar results were found by Furlan *et al.* (2013), whose explanation was based on Williams (1958), in which the burying behavior of shrimp is related to their ability to excavate, and to the intrinsic respiratory requirements of each species. Sediment grains with larger diameters are more difficult to move, so individuals require more time and expend more energy to bury in this type of substrate (Ruello, 1973). Pink shrimps, however, buried completely in the sediments with larger diameters, as confirmed by Lopes (2012) under laboratory conditions. In very fine sediments, particles may enter the gills and thus make breathing more difficult. Therefore, species with a preference for fine sediments possess a mechanism that reverses the exhalant water flow, clearing the gills of smaller particles (Ruello, 1973).

For other penaeids such as *X. kroyeri* and *L. schmitti*, also abundant in the region, the largest catches occurred in MV, where the sediment is mostly composed of smaller-diameter grains (silt and clay) (Costa *et al.*, 2007; Bochini *et al.*, 2014). When a species inhabits sediment composed of silt and clay, it does not bury completely, a behavior that facilitates respiration (Freire *et al.*, 2011).

Both pink shrimps were captured in higher abundance at station VI of the three bays, areas protected from wave action. Protected areas have high organic-carbon content (Ameeri and Cruz, 1998), ensuring good environmental conditions with weaker hydrodynamics and larger amounts of food available. Consequently, these areas require less energy for the shrimp to survive in the environment (D'Incao, 1991), which can facilitate the migration process. Unlike adults, juveniles spend more time unburied and foraging, investing energy in growth. Therefore, such environmental conditions favor the establishment of individuals at this stage of a faster growth rate (Dall *et al.*, 1990).

The present study confirmed that monitoring environmental fluctuations is essential for understanding the distribution patterns of juveniles of *F. brasiliensis* and *F. paulensis*. We conclude that variation in rainfall was a key factor in determining the annual presence of juveniles in the marine coastal area. When there is no El Niño, the current shrimp closed season (March to May) is appropriate because it covers the main recruitment of both species of *Farfantepenaeus*. However, in years when the El Niño phenomenon is more intense, the juveniles become vulnerable because these migrate about two months earlier. Our results also showed that the Ubatuba region is extremely important for conservation, establishment and continuity of the life cycle of these important fishery resources.

## Acknowledgements

The authors are grateful to FAPESP for providing financial support (Grant Nos. 94/4878-8, 97/12108-6, 97/12106-3, 97/12107-0, 04/07309-8, 09/54672-4) and to the Brazilian National Council for Scientific and Technological Development (CNPq) (Research Scholarship PQ Nº. 305919/2014-8 awarded to R.C.C.; PQ Nº. 308653/2014-9 awarded to A.L.C. and PQ Nº. 302528/2015-6 awarded to A.F.). We are also thankful to the NEBECC co-workers for their help during fieldwork. All sampling in this study has been conducted in compliance with current applicable state and federal laws in Brazil.

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