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Original Article

# Distribution patterns of the protandric simultaneous hermaphrodite, the spine-shrimp *Exhippolysmata oplophoroides* (Holthuis, 1948), in the Cananéia-Iguape system on the southern coast of the state of São Paulo, Brazil

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## Abstract

The aim of this study was to investigate the spatial and temporal distribution of *Exhippolysmata oplophoroides* and relate its abundance to various environmental variables (bottom water temperature and salinity, texture of sediment and percentage of dissolved organic matter). The sampling of shrimp and abiotic factors was carried out monthly from July 2012 to June 2014, in seven trawling stations (S1–S7), four of them in the marine area and three in the estuary (southern coast of the state of São Paulo, Brazil). The distribution of individuals showed significant differences between stations and between the two years of study (ANOVA, $p < 0.05$), but not among seasons ($p > 0.05$). A total of 2005 shrimp were collected, with the highest abundance being found in S4 (n= 937). Bottom salinity and sediment texture were the environmental factors with significant influence on the distribution of the species in the studied region. The low salinity values at S6 and S7, and the low capacity for osmoregulation of *E. oplophoroides* limit its distribution in the marine environment. High concentrations of silt+clay found at S4 contributed to the accumulation of organic matter, which influenced the high abundance of shrimp there. The information gathered in our study provides valuable results for the knowledge of this species in its area of distribution and contributes to a better understanding of the life history.

## Keywords

Abundance, Cananéia, Caridea, ecological distribution, environmental variables

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## Introduction

The spine-shrimp *Exhippolysmata oplophoroides* (Holthuis, 1948), also known as the "redleg humpback shrimp" (McLaughlin *et al.*, 2005), is a caridean of the family Lysmatidae (De Grave *et al.*, 2014) distributed in shallow marine waters from North Carolina (USA) to Uruguay (Christoffersen, 2016), occurring in soft-bottom areas and depths between 5 and 45 meters (Baeza *et al.*, 2010).

The spine-shrimp is one of the most abundant caridean species in shallow marine waters of the states of Rio de Janeiro, São Paulo and Paraná, Brazil (Severino-Rodrigues *et al.*, 2002; Fransozo *et al.*, 2005; Robert *et al.*, 2007; Mantelatto *et al.*, 2016; Herrera *et al.*, 2017), and is commonly taken as by-catch in penaeid shrimp fisheries of high economic interest in Brazil, especially the sea-bob shrimp *Xiphopenaeus kroyeri* (Heller, 1862) and the white shrimp *Litopenaeus schmitti* (Burkenroad, 1936) (Costa *et al.*, 2000; Pantaleão *et al.*, 2016; Bochini *et al.*, 2019). These two economically important species sometimes occupy the same habitats as the spine-shrimp (Mantelatto *et al.*, 2016).

As the majority of the shrimp catch in Brazil is obtained using non-selective trawls as fishing gear, the extraction of *E. oplophoroides* is accidental (Stanski *et al.*, 2018) and therefore the spine-shrimp is subject to the same impacts as the economically exploited species (Christoffersen, 2016).

The importance of studying the distributional patterns of these species is clear, and although the spine-shrimp is not a commercially exploited species, due to its small body size, it has great ecological importance; acting as a detritivore, recycling the nutrients back into the food chain (Dumont and D'Incao, 2011). It is integrated into the marine food web, playing a vital role at intermediate trophic levels (Bilgin *et al.*, 2008), serving as a prey item for various invertebrate and fish species (Stanski *et al.*, 2018).

The relationship between biotic and abiotic factors and the distribution and abundance have previously been reported in various species of shrimps like *X. kroyeri*, *Artemesia longinaris* Spence Bate, 1888, *Pleoticus muelleri* (Spence Bate, 1888), *Acetes americanus* Ortmann, 1893 and *Peisos petrunkevitchi* Burkenroad, 1945, among others (Dall *et al.*, 1990; Bauer, 1992; Castilho *et al.*, 2008a; Simões *et al.*, 2013). Water temperature, salinity and sediment composition are some of the abiotic conditions that can influence the abundance of benthic organisms (Castilho *et al.*, 2008a; Herrera *et al.*, 2017; Garcia *et al.*, 2018).

However, there are few studies addressing the biology of *E. oplophoroides* and most of them were carried out in the Ubatuba region, on the northern coast of the state of São Paulo, Brazil. For example, Chacur and Negreiros-Fransozo (1998) estimated the fecundity; Negreiros-Fransozo *et al.* (2002) described the first larval stage; Fransozo *et al.* (2005) investigated the population biology, and Stanski *et al.* (2018) analyzed the reproductive characteristics at three locations. Also, Herrera *et al.* (2017) and Pescinelli *et al.* (2018) investigated the ecological distribution of two caridean species and the population dynamics, respectively, under the influence of the upwelling in Macaé, Rio de Janeiro State, Brazil.

Despite their wide distribution, the present study is a first attempt to describe the distribution and abundance of *E. oplophoroides* in areas with different environmental features like the region of Cananéia, on the southern coast of the state of São Paulo, Brazil. The Cananéia-Iguape system is a unique spot on the Brazilian coastline, due to the formation of an estuarine-lagoon complex, driven by several rivers, causing a mixture of fresh and oceanic waters and seasonal fluctuations in salinity (Mishima *et al.*, 1985). In addition, this region has great ecological importance because it presents highly diversified environments, faunal and floral biodiversity, and experiences significant preservation of the biota (Diegues, 1987; Garcia *et al.*, 2018).

The question of which factors determine species distributions could reveal differences in the population dynamics of a species in a determined region, which is essential information for knowing the life history of an organism. Thus, studies in different regions, particularly in locations with local environmental variation, could reveal differences in the distribution of a species. Moreover, information on the abundance and distribution is necessary to identify strategies that can improve the capture and management of the species (Bochini *et al.*, 2019). It is, therefore, important to explore distribution patterns of the biota and their determinants which can elucidate future ecological changes.

Given the importance of this region and the relevance of these organisms to the environment, studies on the variation in the distribution patterns of this species in relation to environmental fluctuation are relevant to understanding the biology of *E. oplophoroides;* as well as the function of this species in the local biota. In this study, the spatial and temporal distribution of *E. oplophoroides* were analyzed in the Cananéia region. We investigated the influence of environmental variables, such as bottom water characteristics, sediment grain size and organic matter content, in relation to the abundance of this species.

## Materials and Methods

*Study area*

On the south coast of São Paulo State, Brazil, there are lots of natural environments protected by law, with great ecological relevance due to their importance as nursery areas to many marine and estuarine species (Garcia *et al.*, 2018). The estuarine-lagoon system of Cananéia-Iguape is located in one of these protected areas – The Federal Environmental Protection Area of Cananéia, Iguape, Peruíbe (APA - CIP) – on the Southeastern Brazilian coast (25°S 48°W).

This estuarine-lagoon system is formed by the continental waters of the Ribeira de Iguape River, and its many smaller rivers (Besnard, 1950). The system is separated from the Atlantic Ocean by Comprida Island and is connected to the Atlantic Ocean in the southern portion through the Cananéia Strait and in the northern portion by the Icapara Strait (Mendonça and Katsuragawa, 2001). In the northeastern portion of the system, the Mar Pequeno channel exists separating the continent from Comprida Island (Garcia *et al.*, 2018).

The Brazilian coast is influenced by a number of major oceanic water masses, which can alter abiotic conditions near the shore, such as Tropical Water (TW), with both high temperatures and salinities (T>20°C; S>36 ppm); Coastal Water (CW), with high temperatures and low salinities (T>20°C; S<36 ppm); and the South Atlantic Central Water (SACW), with both low temperature and salinity (T<20°C; S<36 ppm) (Miranda, 1985; Silveira *et al.*, 2000; Barioto *et al.*, 2017). The presence of either one of these water masses can be better detected in the northern part of the system because, according to Garcia *et al.* (2018), the direct influence of tides and oceanic currents in this portion of the system is stronger than in other areas of the lagoon system.

*Sample processing*

The target species of this study was collected monthly, during the daylight, from July 2012 to June 2014 (except March 2013 and February 2014, due to bad weather conditions that did not allow us to reach the sampling areas), using a shrimp fishery boat equipped with double-rig nets (4 m mouth opening, 10 m long, 20 mm mesh size and 18 mm cod-end). Each sampling station was trawled for 30 minutes (2.0 knots), covering a total area of approximately 16,000 m$^2$. After each trawl, shrimps were placed in labeled plastic bags and packed in coolers with crushed ice. Seven sampling stations were delimited using a Global Positioning System (GPS), four stations were located in the adjacent coastal area of the Cananéia region: S1, S2 and S3, were located in the 10–15m isobaths, and S4, was located in the 5–10 m isobaths. The other three sampling stations were located in the Mar Pequeno estuarine area (S5, S6 and S7) in the 5–10 m isobaths (Fig. 1).

*Environmental variables*

Bottom water temperature (°C) and salinity (ppm) were recorded monthly at all sampling stations, using a multiparameter probe. The sediment samples were obtained using a Van Veen grab (0.063 m$^2$ area) to determine the mean grain size and the organic matter content (OM).

In the laboratory, sediment samples were oven-dried at 70°C for 72 hours. To analyze the grain sizes, a 100 g subsample was taken from each station and treated with 250 ml of a NaOH solution (0.2 N) in order to separate silt and clay particles. After an hour in this solution, the subsamples were rinsed on a 0.063 mm mesh sieve. Sediments were sieved through different mesh sizes to determine the grain size: >2 mm sieve (gravel); 2–1 mm (very coarse sand); 1–0.5 mm (coarse sand); 0.5–0.25 mm (medium sand); 0.25–0.125 mm (fine sand) and 0.125–0.063 mm (very fine sand) (Wentworth, 1922).

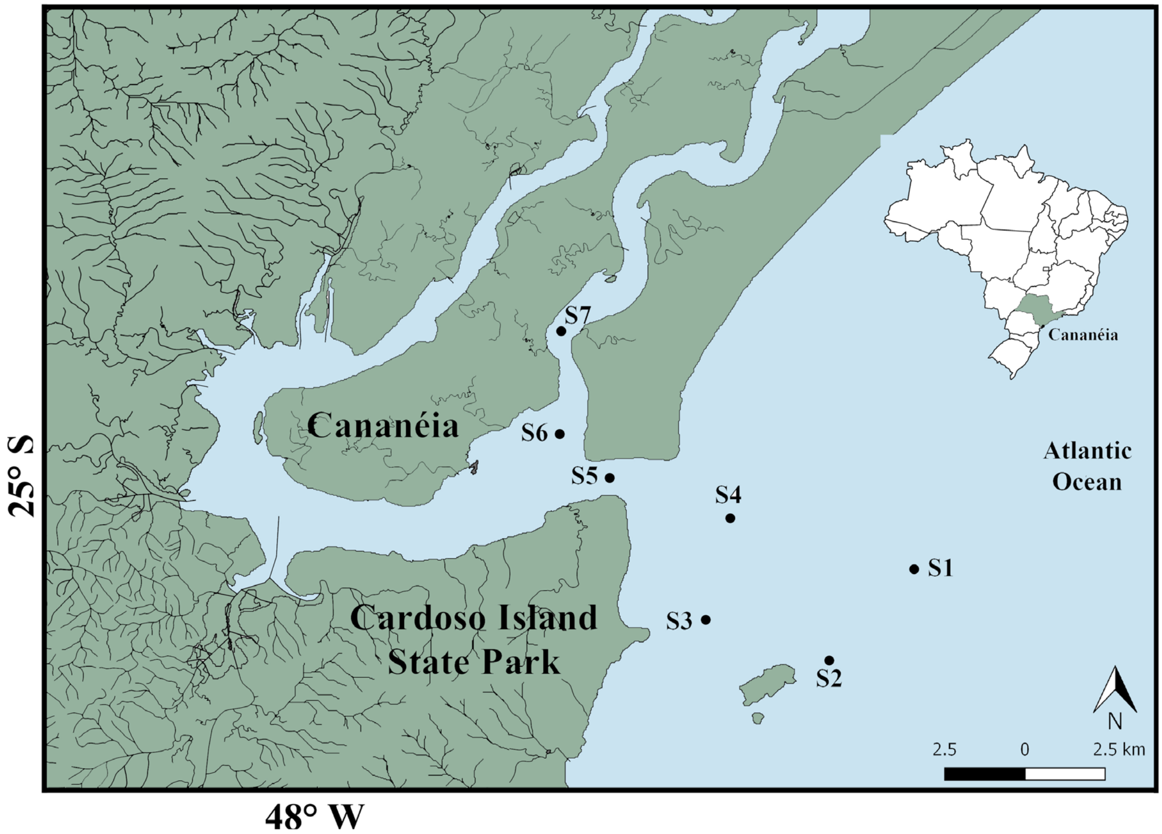


**Figure 1.** Map of the study area, highlighting the sampling stations in the adjacent coastal area (S1, S2, S3 and S4) and in the estuarine-lagoon system in Mar Pequeno (S5, S6 and S7) of Cananéia region.

The sediment grain size categories follow the American standard (Wentworth, 1922) and fractions were expressed on the *phi* scale (ϕ) to estimate the central tendency of sediment samples, using cumulative curves according to the formula: $Md = (\phi_{16} + \phi_{50} + \phi_{84})/3$. The *phi* classes were then converted into granulometric fractions using $\phi = -\log_2 d$, where $d$ is the grain diameter (mm), from which we obtained the following classification: -1=ϕ <0 (gravel); 0 = ϕ <1 (coarse sand); 1 = ϕ < 2 (medium sand); 2 = ϕ < 3 (fine sand); 3 = ϕ < 4 (very fine sand) and ϕ ≥ 4 (silt + clay) (Tucker, 1988).

To determine the OM content, a 10 g subsample was taken from each of the oven-dried samples, placed into porcelain crucibles, and heated in an oven at 500°C for 3 hours. The percentage of organic matter was estimated as the difference between the initial and final crucible weights (Mantelatto and Fransozo, 1999).

*Data Analysis*

Normal distribution was checked by the Shapiro-Wilk test, whereas homoscedasticity was checked by the Levene test, as pre-requisites for the statistical analysis, and in the absence of these premises, the data was $\log_{10}$ transformed (Zar, 2010).

To assess temporal and spatial distribution, the Analysis of Variance (ANOVA) was applied with a *post-hoc* Tukey test (α = 5%) in order to differentiate abundance spatially (in the stations) and through time (seasons and years) (summer: January – March; autumn: April – June; winter: July – September; spring: October – December. First year: July/2012 to June/2013; second year: July/2013 to June/2014).

The influence of the environmental variables (water temperature and salinity, sediment grain size and organic matter content) in the distribution and abundance of the individuals was assessed through the Multiple Linear Regression test (Levene *et al.*, 2000). The statistical tests were performed using the software R® (R Development Core Team, 2018).

## Results

### *Environmental variables*

The mean value of bottom water temperature found was 23.2°C (± 3.10), ranging from 17.2°C in July/2013 to 29.8°C in January/2014, with mean values of 23.4°C (± 2.58) for the first year of study and 23.1°C (± 3.58) for the second year. The surface water temperature ranged from 17.5°C in July/2013 to 30.6°C in January/2014, with a mean value of 24.7°C (± 1.18) (Fig. 2). In spatial terms, the highest bottom temperature (29.8°C) was registered at stations S6 and S7, within the estuary, and the highest surface temperature (30.6°C) was also at station S7. The lowest bottom temperature (17.2°C) was registered at station S1 and the lowest surface temperature (17.5°C) was at station S2 (Fig. 3).

Bottom water salinity ranged from 16.9 ppm in December/2013 to 38.0 ppm in October/2012 (mean: 31.4 ppm ± 4.91), whereas surface salinity values ranged from 10.0 ppm in July/2012 to 37.0 ppm in October/2012 (mean: 30.3 ppm ± 4.50) (Fig. 4). Spatially, the lowest bottom salinity value was registered at S5 (16.9 ppm), in the Cananéia strait, and the highest (38.0 ppm) at S3; while the lowest surface salinity value (above) was registered in S7 and the highest in S6 (Fig. 5).

The highest *phi* value (6.43) was found in April, May and June/14 (during autumn), while the lowest value (1.56) was found in January and February/13 (during the summer) (Fig. 6). Spatially, the sediment composition was classified as "very fine sand" (3 = $\phi$ < 4) in all of the collecting stations, except for S4, where "silt+clay" ($\phi \geq 4$) was obtained, and S6, where we obtained "fine sand" (2 = $\phi$ < 3) (Fig. 7).

The organic matter content ranged from 0.49% in the winter of 2013 to 16.62% in the spring of 2012, with a mean value of 3.95% in the first year and 3.38% in the second year, with 3.67% as the mean of the entire study (Fig. 6). Spatially, the highest and lowest values of organic matter were registered at stations S4 and S7, respectively (Fig. 7).

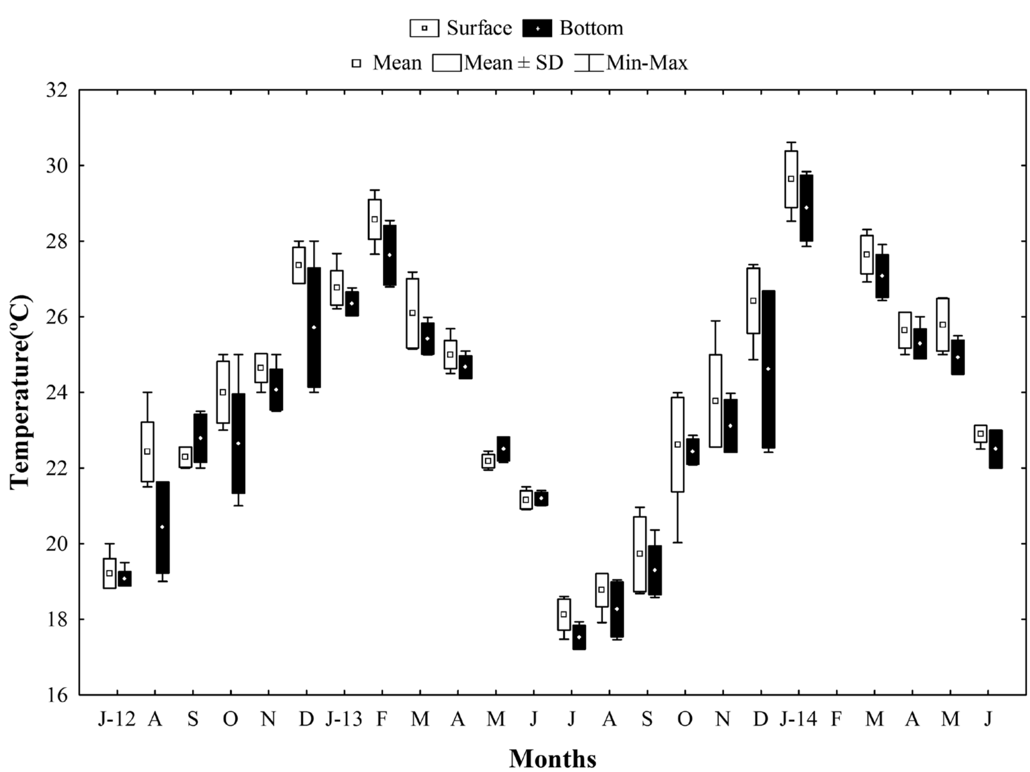


**Figure 2.** Temporal variation of temperature of surface and bottom water, from July/2012 to June/2014, in Cananéia region, Brazil (Mean; SD = standard deviation; Min = minimum; Max = Maximum).

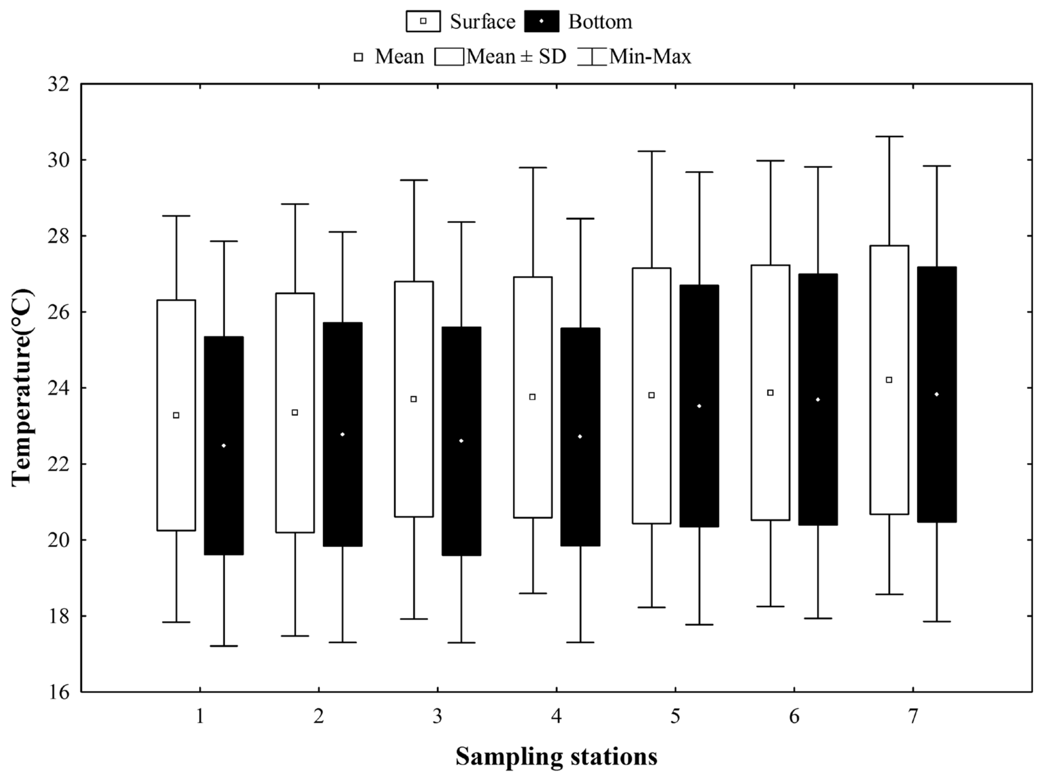


Figure 3. Spatial variation of temperature of surface and bottom water, from July/2012 to June/2014, in Cananéia region, Brazil (Mean; SD = standard deviation; Min = minimum; Max = Maximum).

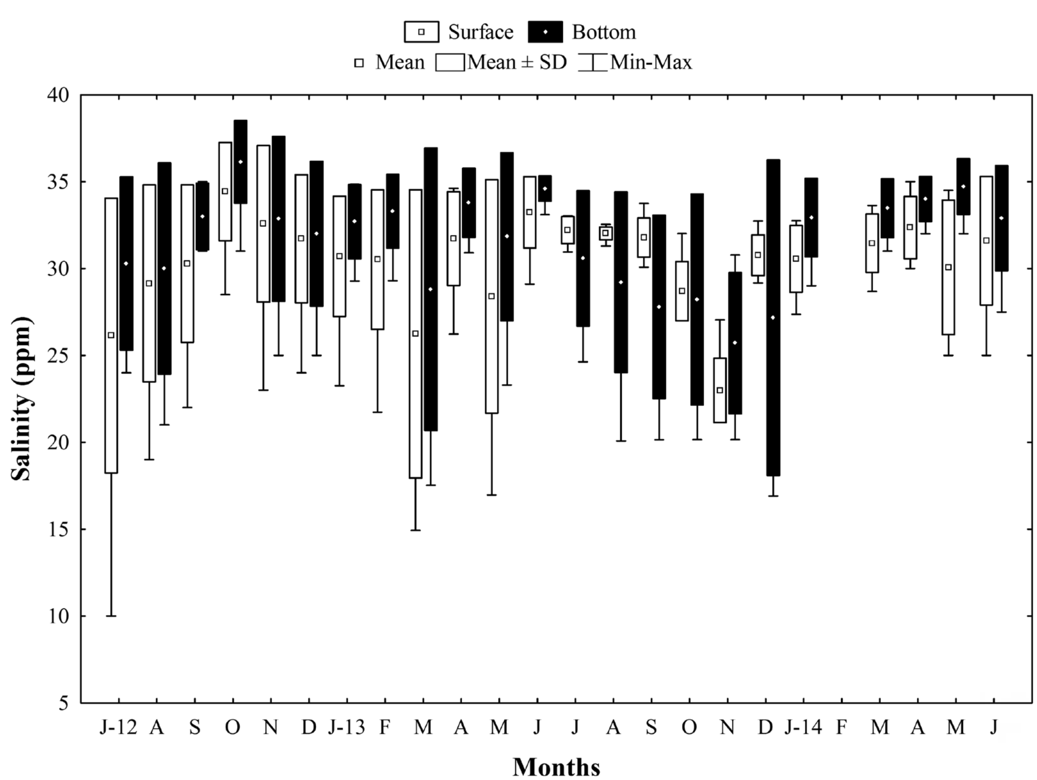


Figure 4. Temporal variation of salinity values of bottom and surface water, from July/2012 to June/2014, in Cananéia region, Brazil. (Mean; SD = standard deviation; Min = minimum; Max = maximum).

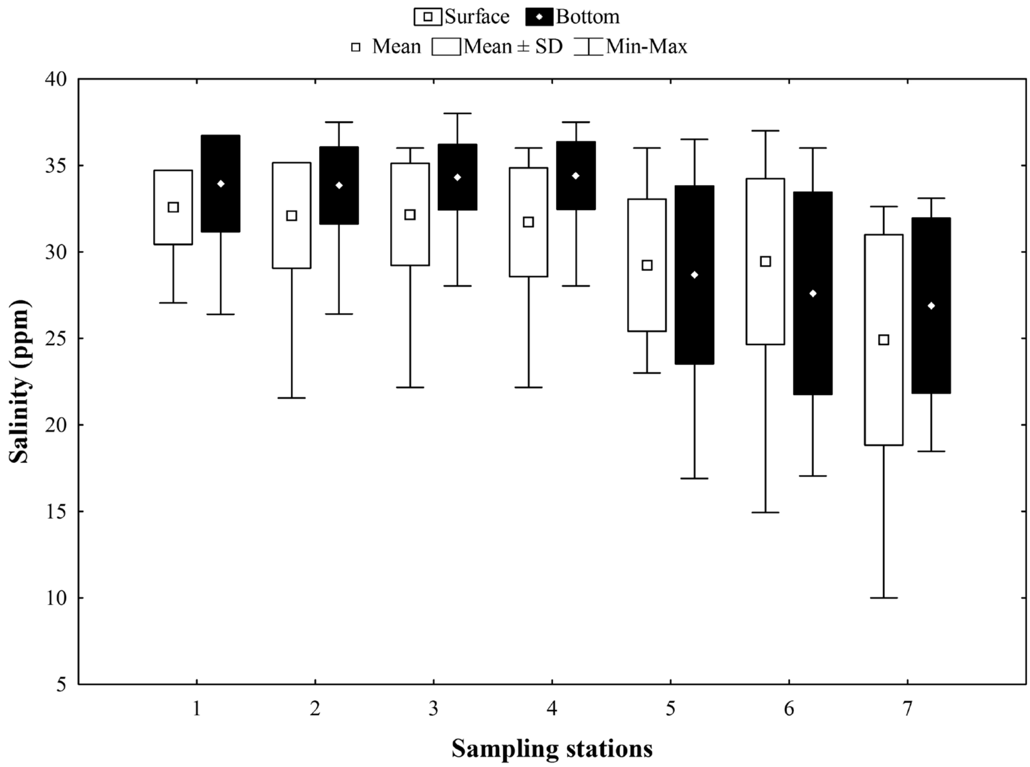


Figure 5. Spatial variation of salinity values of bottom and surface water, from July/2012 to June/2014, in Cananéia region, Brazil. (Mean; SD = standard deviation; Min = minimum; Max = maximum).

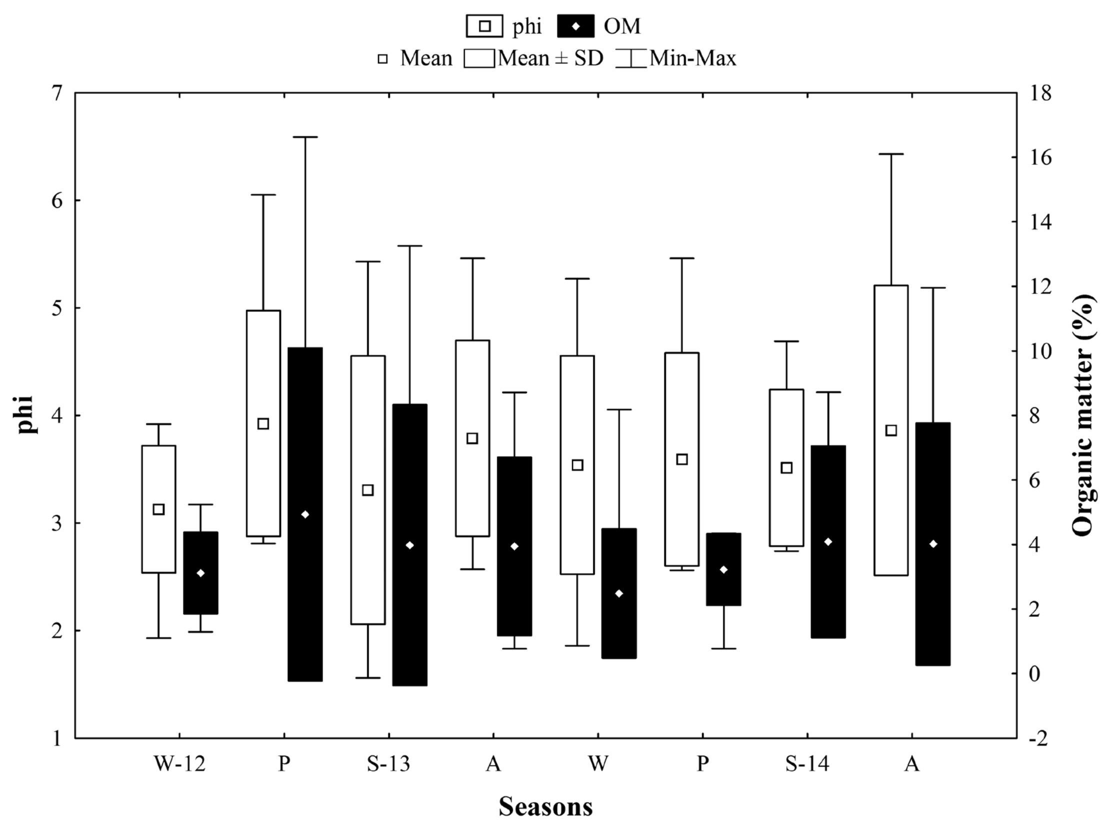


Figure 6. Seasonal variation of organic matter (OM) and the sediment composition (*phi*) from July/2012 to June/2014, in Cananéia region, Brazil (Mean; SD = standard deviation; Min = minimum; Max = maximum).

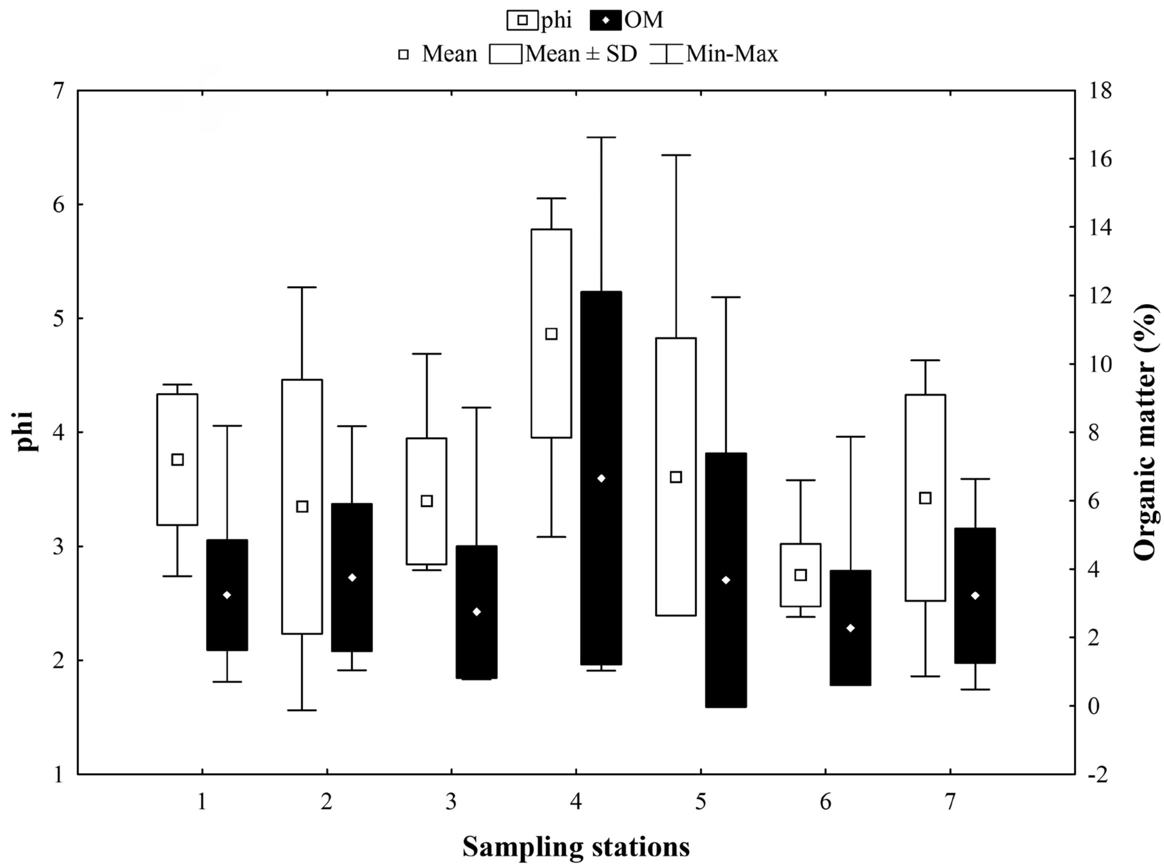


**Figure 7.** Spatial variation of organic matter (OM) and the sediment composition (*phi*) from July/2012 to June/2014, in Cananéia region, Brazil (Mean; SD = standard deviation; Min = minimum; Max = maximum).

*Temporal and spatial distribution*

A total of 2005 individuals of *E. oplophoroides* were captured throughout the study, 1141 (57%) of them during the first year of sampling and 864 (43%) during the second year, showing a significant difference between the two years (ANOVA, $p = 0.018$).

The highest abundance of shrimp was registered in the autumn of 2013 (n = 800; 39.9%) and the lowest, in the winter of 2012 (n = 17; 8%). However, there was no significant difference in the abundance of the species between seasons (ANOVA, $p > 0.05$) (Tab. 1).

Spatially, station S4 had the highest number of shrimp captured (n = 937; 46.7%), followed by stations S3 (n = 544) and S1 (n = 510). At stations S2 and S5, only seven individuals were collected in each location, and at stations S6 and S7, no specimens were found (Fig. 8). The abundance of *E. oplophoroides* showed a significant difference between stations (ANOVA, $p = 0.000$).

The Linear Multiple Regression analysis showed that the bottom water salinity and the sediment grain size were significantly correlated with the abundance of the shrimp (Linear Multiple Regression, $p < 0.05$) (Tab. 2).

**Table 1.** Abundance of *Exhippolysmata oplophoroides* in each month and each season, from July/2012 to June/2014, in Cananéia, Brazil. The sign (-) indicates months when there was no sampling due to bad weather conditions.

| Year | Month | Season | N/month | N/season | Total |
|---|---|---|---|---|---|
| 1st year (July/12 - June/13) | July/12 | Winter | 7 | 17 | 1141 |
| | Aug/12 | | 5 | | |
| | Sept/12 | | 5 | | |
| | Oct/12 | Spring | 186 | 217 | |
| | Nov/12 | | 30 | | |
| | Dec/12 | | 1 | | |
| | Jan/13 | Summer | 10 | 107 | |
| | Feb/13 | | 97 | | |
| | Mar/13 | | - | | |
| | Apr/13 | Autumn | 354 | 800 | |
| | May/13 | | 413 | | |
| | June/13 | | 33 | | |
| 2nd year (July/13 - June/14) | July/13 | Winter | 17 | 74 | 864 |
| | Aug/13 | | 45 | | |
| | Sept/13 | | 12 | | |
| | Oct/13 | Spring | 0 | 104 | |
| | Nov/13 | | 15 | | |
| | Dec/13 | | 89 | | |
| | Jan/14 | Summer | 9 | 610 | |
| | Feb/14 | | - | | |
| | Mar/14 | | 601 | | |
| | Apr/14 | Autumn | 76 | 76 | |
| | May/14 | | 0 | | |
| | June/14 | | 0 | | |

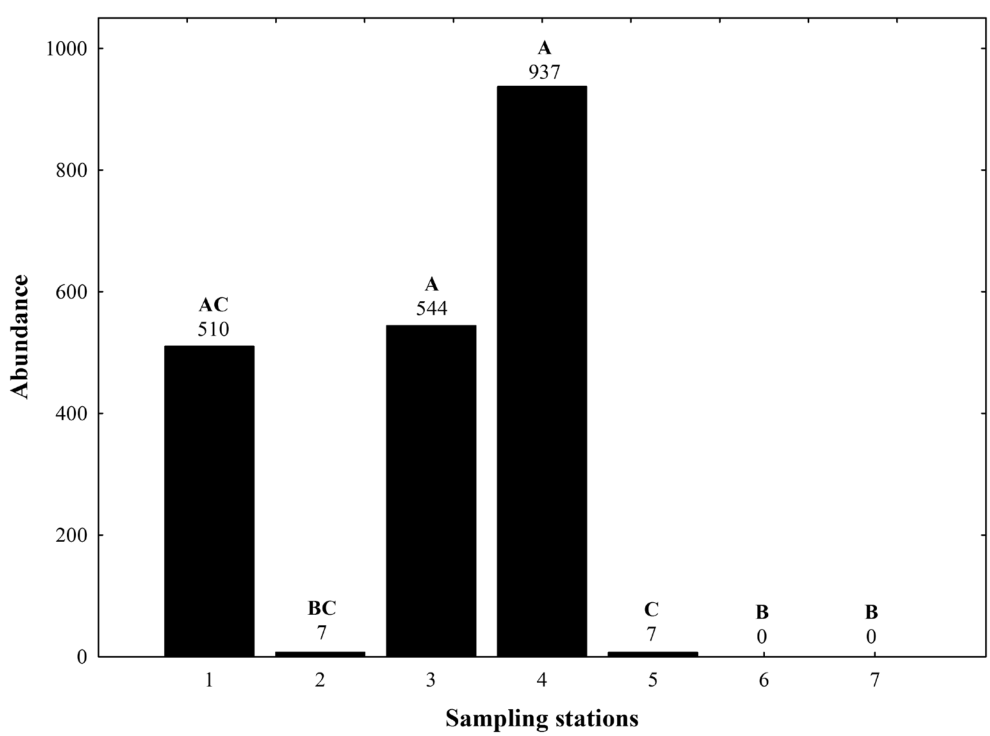


**Figure 8.** Spatial distribution of *Exhippolysmata oplophoroides* in the Cananéia region, Brazil. At least one different letter above the bars indicates significant difference between those stations (ANOVA, $p < 0.05$).

**Table 2.** Results of the Multiple Linear Regression test, highlighting the environmental variables with a significant influence (*) on the abundance of *Exhippolysmata oplophoroides*, from July/2012 to June/2014, in Cananéia region, Brazil.

| Coefficient | SD | t value | p value |
|---|---|---|---|
| Temperature | 0.82339 | - 0.288 | 0.77366 |
| Salinity | 0.64691 | 3.023 | 0.00295 * |
| Granulometry | 0.60530 | 2.139 | 0.03409 * |
| Organic Matter | 0.20790 | 0.050 | 0.96043 |

SD = standard deviation; *p < 0.05

## Discussion

The present study provides the first insights into the distribution patterns of *E. oplophoroides* on the Cananéia region. Our results show that water salinity and sediment texture were key determinants of the spine-shrimp's distribution.

In Cananéia, the temperature records show a pattern expected for a subtropical region, with higher water temperatures in spring and summer, and lower in autumn and winter, also seen by Garcia *et al.* (2018). In other regions where the spine-shrimp has been studied, such as Ubatuba and Macaé, this pattern was not always found due to the high influence of the SACW during spring and summer, which decreases the water temperature (Castilho *et al.*, 2008b; Silva *et al.*, 2016). Herrera *et al.* (2017) observed seasonal fluctuations in the distribution of the spine-shrimp in Macaé resulting from variation in bottom temperature due to the influence of the SACW, which was not observed in the present study.

Because of this subtropical pattern, spring and summer are the seasons with the highest primary productivity in Cananéia, which increases the food availability for planktotrophic larvae creating favorable conditions for reproduction. This was verified by Stanski *et al.* (2018) during the summer, the reproductive season for *E. oplophoroides* in Cananéia. Stanski *et al.* (2018) observed distinct reproductive patterns in the *E. oplophoroides* populations which are directly related to the environmental features of the region, more specifically, to seasonal variation in food supply for larval development.

Grego *et al.* (2004) and Melo-Magalhães *et al.* (2004) reported higher concentrations of chlorophyll-*a* during the rainy season, which is directly linked to primary productivity. In Cananéia, the summer of the first year was the season with the highest rainfall (Miazaki *et al.*, 2019; Perroca *et al.*, 2019), which influenced food availability for the larvae, contributing to the high abundance in that year. The rainfall during the following summer was lower (CIIAGRO, http://www.ciiagro.sp.gov.br); therefore, conditions for reproduction were not as favorable as they were in the first year of our study. This may help to explain the lower abundance in the second year.

Another possible explanation for the higher number of shrimp caught in the first year of sampling may be the closed fishing season that occurs annually from March 1 to May 31 (IBAMA, 2008), which forbids trawl fishing of the target penaeid species in Southern and Southeastern Brazil. The closed fishing season overlaps with the end of the summer (reproductive period of the spine-shrimp in Cananéia) and early autumn, when recruitment takes place, increasing the population of adult prawns.

A combination of environmental conditions that enables reproduction of this species in the summer, such as rainfall and food availability and the annual closed fishing season, should explain the difference in abundance between the two years of our study.

According to Garcia *et al.* (2018), the tides may play a major role in the daily salinity fluctuations within the estuary, since the Cananéia strait, in the southern portion of the system, has no natural barriers to the influx of oceanic waters during high tides, therefore, salinity at station S5 rises during high tides. In the Icapara strait, in the northern portion of the system, on the other hand, there are two main barriers to the entrance of ocean water into the estuary: the silting of the strait and the delta of the Ribeira de Iguape River. When the oceanic water enters the system through the Icapara strait, all of the fresh water of the Ribeira de Iguape River is directed to the Mar Pequeno area, creating a low salinity zone at stations S6 and S7.

The intolerance of *E. oplophoroides* to low salinities justifies its restriction to the oceanic region and its complete absence at Mar Pequeno (S6 and S7). Spargaaren (1972) stated that stenohalinity and the low capacity of osmoregulation are common features in non-migrating marine species, such as the spine-shrimp, because in their natural conditions, they are not exposed to high variations in salinity. Fransozo *et al.* (2016) and Mantelatto *et al.* (2016), investigating the composition of by-catch fauna in two different bays in the Ubatuba region, did not find any specimens of *E. oplophoroides* at trawling stations with low salinity values, close to river mouths.

Station S4 was the only one mainly composed of silt+clay, and this was the station with the highest abundance of the spine-shrimp. This is probably due to the fact that sediments in the lower granulometric diameters, like silt and clay, retain more organic matter particles in the substrate (Herrera *et al.*, 2017; Garcia *et al.*, 2018).

Considering that organic matter is an important resource for the survival of many benthic invertebrates, and it is the main food source for detritivores, such as *E. oplophoroides* (Dumont and D'Incao, 2011), one can understand the increased abundance of these individuals in stations with higher OM concentrations, as observed in our study. A similar result was observed by Herrera *et al.* (2017) in Macaé, with higher abundance of *E. oplophoroides* in stations with higher concentrations of organic matter and muddier substrate.

Penaeoid shrimp, such as *X. kroyeri,* also tend to occupy habitats with fine sediment, like very fine sand or silt+clay, because it facilitates their burrowing habits and hiding from predators (Costa *et al.*, 2007; Silva *et al.*, 2014). According to Pettijohn (1975), the accumulation of organic matter in sediments is strongly dependent on the amount of clay deposited, due to the adsorption process. The organic content, thus, can be directly correlated to the average diameter and, mainly, to the percentage of clay in the sediment.

The relationship of *E. oplophoroides* to finer sediments may be associated with the concentration of organic matter, both for food availability (Herrera *et al.*, 2017) and for a sheltered environment that allows establishment and maintenance of the population (Fransozo *et al.*, 2005).

Fransozo *et al.* (2005), studying the population biology of the spine-shrimp in Ubatuba, suggested that the deposition of terrestrially-derived bio-detritus and plant fragments may be another factor that favors the accumulation of organic matter on the bottom of the sea, creating favorable conditions for this species to occupy and maintain its populations. This kind of material would reach the ocean through the input of the surrounding rivers that drain into the bay (Fransozo *et al.*, 2005; 2009; Silva *et al.*, 2014).

In our study, the amount of plant material was not quantified, but station S4 is located right in front of the Cananéia Strait, which, during low tides, receives most of the input of the lagoon-estuarine system, contributing to the accumulation of OM at that station, and consequently, perhaps to the higher number of captures at this station.

With the information collected in our study, we conclude that bottom water salinity is a limiting abiotic variable for the spine-shrimp's distribution, and the high percentage of OM associated with higher *phi* classes (silt+clay) is a resource of preference for *E. oplophoroides*, as a food source or, even as a habitat that provides protection against potential predators.

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