Modulating factors over the abundance and distribution of *Achelous spinimanus* (Latreille, 1819) (Decapoda, Portunoidea): a fishery resource in the Southeastern Brazilian littoral

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ABSTRACT

This study analyzes the association of environmental factors (bottom water temperature and salinity, and sediment texture and associated organic matter content) and the spatiotemporal distribution of the swimming crab *Achelous spinimanus*. We collected the swimming crabs from January 1998 through December 1999 by trawling with a shrimp-fishing boat outfitted with double-rig nets. The sampled localities were the following bays: Ubatumirim (UBM), Ubatuba (UBA) and Mar Virado (MV), which present distinct physiographic features, in the northern littoral from São Paulo State (Brazil). We sampled 1.911 crabs (UBM = 351; UBA = 1.509; MV = 51), with significant differences among their abundances, which were observed in each bay and trawl sites. The specimens' distribution was primarily associated with the sediment features, since the higher abundance of swimming crabs was registered in sites in which sediment was composed mainly of~~by~~ sand grains, i.~~-~~e., classified in the higher classes of granulometry (gravel, very coarse sand and intermediate sand). ~~However, it is noteworthy that the sampling site, in which w~~We registered the highest abundance of *A. spinimanus* in a naturally excluded fishing site composed of heterogeneous sediment grains ~~is a naturally excluded fishing area, besides, it is composed by heterogeneous sediment grains~~. Hence, ~~one may consider that~~ the sediment heterogeneity allied to other biotic and abiotic factors are probably the most effective~~s~~ modulators acting over the abundance and distribution of *A. spinimanus* throughout the sampling stations.

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INTRODUCTION

The abundance and distribution of organisms in the environment, as a rule, are modified according to the variation of the environmental resources (*Organista et al., 2005*). In this sense, those authors assumed that individuals may be adapted to a wide variation of a given environmental factor (~~=~~eurytopic) or not (~~=~~stenotopic). Moreover, the relationship of predator-prey and the intra- ~~and/~~or interspecific competition may alter the seasonal occurrence of the studied species (*Pinheiro, Fransozo & Negreiros-Fransozo, 1996*). Even slight variations in the environmental conditions might lead individuals to display different behavioral, morphological and physiological responses (*Thompson, 1991*).

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The studies on distribution of benthic organisms have evidenced the effects of environmental factors such as temperature, salinity, ~~and~~ sediment texture, and associated organic matter on~~ver~~ the distribution of marine organisms. Thus, this ~~issue has become of importance for scientists; and it~~topic has been widely studied for most~~ of the~~ marine taxa~~on~~, in virtually all ~~the~~ oceans (*Abelló, Valladares & Castellón, 1988*; *Fariña, Freire & González-*

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Gurriarán, 1997; *Cartes et al., 2007*; *Bertini, Fransozo & Negreiros-Fransozo, 2010*; *Fransozo et al., 2016*; *Costa et al., 2016*).

According to Mahiques (*1995*), the Southeastern Brazilian littoral (especially within~~the~~ northern São Paulo State~~ one~~) is characterized by a great deal of bays and ~~a~~ sinuous land, which~~at~~ makes its internal borders very irregular~~, mainly~~ due to the close proximity of~~ness to~~ the Serra do Mar mountains complex. ~~Such aspects allow the shaping of environments that are~~These topographic qualities are favorable to the establishment and development of marine organisms~~; and, consequently,~~and may lead to ~~a~~ higher regional biodiversity ~~in such areas~~ (*Negreiros-Fransozo et al., 1991*).

Due to its high productivity, the Ubatuba region is commonly exploited by the shrimp-fishing industry~~fleet~~ (*Mantelatto et al., 2016*)~~,~~ that harvests ~~especially aims to capture~~ *Farfantepenaeus brasiliensis* (Latreille, 1817), *F. paulensis* (Pérez-Farfante, 1967) and *Xiphopenaeus kroyeri* (Heller, 1862) (*D'incao, Valentini & Rodrigues, 2002*). ~~Taking into account that trawling fishery uses a predatory fishing gear in its activities, and causes a great disturbance in the~~ Trawling disturbs benthic communities and diminishes fishing stocks (*Branco & Fracasso, 2004*)~~, the fishing stocks tend to diminishing~~. It especially holds true when considering the more profitable species, what led to an essential search for alternative resources. Thus, *Achelous spinimanus* (Latreille, 1819) has become a new target to the fishing fleet (*Santos, Negreiros-Fransozo & Padovani, 1995*; *Branco, Lunardon-Branco & Souto, 2002*; *Ripoli et al., 2007*), given its body size and particular taste, both suitable for the human consumption.

Besides its economic potential, *A. spinimanus*, together to other swimming crab species, plays a fundamental role in the trophic web from the coastal ecosystems, acting as predators for various invertebrate groups (*Branco & Verani, 1997*). In the Northern littoral of São Paulo State, the representatives of Portunoidea are abundant and present one of the highest species richness values when compared to other brachyuran (*Braga et al., 2005*; *Bertini, Fransozo & Negreiros-Fransozo, 2010*). In the same region, several studies addressing crustaceans, which belong to this taxon, were accomplished, namely: *Santos, Negreiros-Fransozo & Fransozo*, (*1994*), *Pinheiro, Fransozo & Negreiros-Fransozo* (*1996*), *Pinheiro, Fransozo & Negreiros-Fransozo*, (*1997*), *Santos* (*2000*), *Chacur & Negreiros-Fransozo* (*2001*), *Andrade et al.* (*2013*), *Andrade et al.* (*2014*), *Lima et al.* (*2014*), *Martins et al.* (*2014*) and *Antunes et al.* (*2015*). In such studies, the importance of environmental factors on those species biology has been responsible for their distribution patterns.

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Even though, *Santos*, *Negreiros-Fransozo & Fransozo*, (*1994*) and *Santos* (*2000*) have previously studied *A. spinimanus* achieving the environmental factors that can exert any influence over their distribution patterns, such studies focused only on one bay in the Northern São Paulo State littoral (Fortaleza Bay, Ubatuba, SP). Therefore, there are no comparative studies addressing the distribution pattern of *A. spinimanus* in different locations, with different environmental features, within the same time gap.

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Thus, this study aimed to compare the distribution of *A. spinimanus* in three bays (Ubatuba, Ubatumirim and Mar Virado) located in the Northern São Paulo State littoral. Furthermore, our goal was determin~~ing~~e possible relationships between the target species' spatiotemporal distribution and the following environmental factors: bottom water temperature and salinity; sediment texture; and organic matter content, in these bays with distinct physiographical features.

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MATERIAL & METHODS

Study area

Ubatuba is located at the northern coast of the São Paulo State littoral. Such region has its geological conformation, particularly known by presenting a very sinuous littoral (*Ab'saber*, *1955*). This region is affected by the influence of three water masses: Coastal Water (CW: temperature >20ºC; salinity <36), Tropical Water (TW: temperature >20ºC; salinity >36) and South Atlantic Central Water (SACW: temperature <18ºC; salinity <36) (*Castro-Filho, Miranda & Myao, 1987*).

We choose three bays at Ubatuba for this study: Ubatumirim (UBM), Ubatuba (UBA) and Mar Virado (MV) (Fig. 1). They present distinct physiographical features considering both their shape and outfall direction. The UBM bay presents an outfall heading Southwest, with many islands and marine rock banks (Prumirim and Porcos Pequenos Islands facing its entrance, and Couves Island (*Bertini, Fransozo & Negreiros-Fransozo, 2010*). The UBA outfall faces East and shows a seaward constriction formed by rocky projections, thus delimiting a shallower inner area and an outer and deeper area (>10 m deep) (*Mahiques, 1995*). Four rivers influence the organic matter content of the sediment in this bay (*Cetesb, 1996*), especially during rainy seasons, when greater amounts of sewer, originally from the city of Ubatuba, outflow into the area. The MV bay shows a large outflow that faces Southwest, with the Mar Virado Island on the left side of the bay entrance. The predominant substratum verified in this area comes from the sediment of two rivers, namely: Lagoinha and Maranduba (*Mahiques, 1995*).

Sampling

We collected the swimming crabs monthly, from January 1998 through December 1999, in six sampling stations in each bay. Three sampling sites were located in areas sheltered from the force of waves (5, 7.5 and 10 m deep), while three were located in exposed sites (10, 15 and 20 m deep) (Fig. 1). We used for trawls a commercial shrimp-fishing boat outfitted with double-rig nets. Trawls lasted for 30 minutes each, totalizing an 18,000-m² sampled area. Individuals were identified to species level (*Melo, 1996*), and sorted by sex, based on the morphological features of the abdomen (male = triangular-shaped abdomen; female = round-shaped abdomen) and number of pleopods (males = two pairs; females = four pairs).

For each sampling station, we sampled sea water using a Nansen bottle, from which we measured salinity (‰) and temperature (ºC), using an optical refractometer and a mercury thermometer, respectively. After that, we measured the water temperature (for both bottom and surface samples) and salinity (bottom). Sediment samples were taken using a Van Veen grab, from which we obtained sediment texture and its organic matter content. Depth was assessed using an echometer connected to a Global Positioning System (GPS). Shortly after collection, we put each sediment sample into labelled plastic bags. After that, they were frozen to minimize the organic matter decomposition until the laboratory analysis.

Sediment analysis procedures followed the ones proposed by Hakanson & Jansson (1983) and Tucker (*1988*). Two 50-g subsamples were taken, to which we added 250 ml of a NaOH (0.2 N) solution, aiming to lift up the silt+clay. Afterward, we washed the subsamples using a sieve (mesh = 0.063 mm), washing away the silt+clay. The remaining sediment was dried and then submitted to a differential sieving, classifying the sediment grains according to the *Wentworth* (*1922*)'s scale.

Phi (φ) values were calculated based on the equation $phi = -log_2 d$, where d= grain diameter (mm), thus obtaining the following classes: -1|—0 (very coarse sand), 0|—1 (coarse sand), 1|—2 (intermediate sand), 2|—3 (fine sand), 3|—4 (very fine sand) e > 4 (silt+clay). Based on the obtained values, we calculated the central trend measurements, determining the most frequent granulometric fractions in the sediment. We calculated these values based on data graphically taken from cumulative sediment samples frequency distribution curves. We used values corresponding to the 16th, 50th and 84th percentages to determine the average diameter (AD), using the equation $AD= (\varphi_{16} + \varphi_{50} + \varphi_{84}/3)$ (*Suguio, 1973*).

In order to determine the percentage of the organic matter content of the sediment, we put the 10-g subsamples in porcelain containers, previously labelled and weighed. After that,

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we put them into an oven (500ºC for 3 hours) and weighed them again. The difference between the initial and final weight indicated the organic matter content of the substratum in each sampling station, what was later converted into percentage values.

Data analysis

Prior to analyses, we tested the data concerning their normality (Shapiro-Wilk test) and homoscedasticity (Levene's test) (*Zar, 1999*). Environmental factors (BT= bottom water temperature; ST= surface water temperature; BS= bottom water salinity; %OM= percentage of associated organic matter content; and Phi= sediment texture) were compared between years using a Mann-Whitney test (significance level = 5%). We compared BT, ST, BS, %OM and Phi values among bays, sampling stations and seasons of the year (Summer: January to March, and so on) by means a Kruskal-Wallis test, followed by a post-hoc Dunn test.

Comparisons of the total abundance of specimens among the studied bays, and sampling stations were carried out using a Kruskal-Wallis test, followed by a post-hoc Dunn test (significance level= 5%).

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We run a Redundancy Analysis (RDA) to detect possible relationships between the abundance of *A. spinimanus* and the environmental variables, which requires the existence of, at least, two dependent variables, reason why we grouped our biological data into males (M) and females (F). The RDA produces final coordination scores that summarize the linear relation between the explanatory and answering variables, in which only environmental variables with scores higher than 0.4 and lower than -0.4 are considered as biologically significant (*Rakocinski, Lyczkowski-Shultz & Richardson*, 1996). Such analysis was performed by means "Vegan" package in the statistical software "R" (*R Development Core Team, 2013*).

RESULTS

In general terms, according to previous analysis (*Bertini, Fransozo & Costa, 2001; Costa et al., 2007; Almeida et al., 2012*), the mean bottom and surface water temperature values did not significantly differ among the analyzed bays. However, significant differences in the ST, BT and BS were observed when comparing the studied years (Table 1).

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Furthermore, the highest variation on the BT and ST values, in all the bays, were recorded in the summer and spring 1998/1999. Concerning the sampling stations belonging to the exposed area (10, 15 and 20 m deep), we observed a clear difference between the mean values of ST and BT (thermocline), especially in spring 1999. During autumn and winter, neither ST nor BT values varied as depth increased.

Temporally, the highest BS values were recorded in summer and autumn 1998, while in 1999, its highest means were observed only in the autumn. The highest BS values were recorded in the 20-m deep sampling station; significant variations in this parameter were recorded only in 1999.

Based on data from the BS and BT diagram, the presence of three water masses is noticeable and is typically observed in the studied region. From them, CW was prevalent, during both years, in all the bays; while the SACW and TW influences were noted only in 1999 (Fig. 2 and 3).

The sediment features (both grain diameter and organic matter content) differed among bays and sampling sites (Fig. 4). There was a gradual increase in phi values from north through south, with mean phi values of 3.8, 4.4 and 5.5 in UBM, UBA and MV, respectively. The highest %OM was recorded in UBA (5.9%), followed by MV (4.5%) and UBM (3.6%). The 20-m deep sampling site, in all studied bays, in both studied years, was the one with the lowest %OM average value (3.3%) ($p < 0.05$) (phi = 3.0). With respect to the 10-m deep sampling sites, we observed the highest %OM (6.2%) and phi (5.3) average value, i.e., we observed a trend of increasing %OM as the sediment grain size decreased.

We sampled 1.911 individuals (1.255 in 1998, and 656 in 1999). The highest abundance of *A. spinimanus* was recorded in UBA (1.509), followed by UBM (351) and MV (51). We observed a variation in the abundance of individuals throughout the seasons of the year, with higher occurrences recorded mainly in the fall and spring 1998, in UBA (Table 2). When comparing the abundance of individuals among bays, we observed that MV has significantly lower abundance ($p < 0.01$). In UBM, the highest abundance registered in 1998 was in the 20-m deep sampling station, while in 1999, it was in the 15-m one. In UBA, the highest abundance observed for both 1998 and 1999 was registered in the 7.5-m deep sampling station. In MV, even though we did not observe significant differences in the abundance of swimming crabs among the sampling stations ($p > 0.05$), individuals were sampled only in two sampling sites (7.5 and 20-m deep) (Fig. 5).

When analyzing the results obtained with the RDA, we observed the axis 1 (which explained 92.3% of the variation in our data), the sediment features (%OM and Phi) were the ones that mostly modulated the individuals' distribution in all studied bays, for both the years (Table 3). Based on this analysis, one may attest that the sediment grain size is inversely proportional to the abundance of *A. spinimanus*, since the highest swimming crab abundances were registered in sampling stations with sediment mainly composed by low and intermediate

Phi values. It characterizes a heterogeneous sediment, mainly composed by higher granulometric classes such as gravel, very coarse sand, coarse sand and medium sand.

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DISCUSSION

Based on the water temperature and salinity values obtained in this study, we infer that the Coastal Water current prevailed in the three studied bays. This water mass is characterized by salinity values under 36 and temperature higher than 20ºC (*Castro-Filho, Miranda & Myao, 1987*). The effects of the South Atlantic Central Waters and Tropical Water masses could only be noticed in the second studied year. *Pires* (*1992*) consider that the SACW is a cold water mass, with temperatures under 18ºC and salinity lower than 36, reaching the deepest layers of the coastal water column, generating a thermocline. In this study, this thermocline was more evident in the sampling sites with depth from 10 to 20 m, especially considering the seasonal water temperature variation, with considerable SACW effects in the spring 1999.

Several studies indicate the influence that the physicochemical characteristics of the SACW exert in the temporal abundance of decapod crustaceans along the southeastern Brazilian coast (*Furlan et al., 2013*; *Bochini et al., 2014*; *Andrade et al., 2014*; *Castilho et al., 2015*). In this study, we could notice the negative influence of this water mass over the abundance of *A. spinimanus*, once its decreases in summer and spring 1999 in UBA. UBA bay seems to be more vulnerable when compared to UBM and MV bays with respect to the effects of oceanic currents as it has no physical protection, such as islands nearby. As a consequence, the effects of the SACW in the UBA bay are greater; in such a way that in 1999, in the UBA bay, there was occurred migration of *A. spinimanus* towards shelter areas. *Mantelatto & Fransozo* (*2000*), studying the same bay, evidenced that, from September 1995 through August 1996, individuals of *A. spinimanus* were grouped in a more sheltered sampling site, in the inner portion of the UBA bay (which was not addressed in this study).

Temperature is widely accepted as a limiting factor to the distribution of organisms (*Lewis & Roer, 1988*), since many metabolic and physiological processes in crustaceans (such as the molting and growth process, and oocytes maturation in females) depend on this variable (*Sastry, 1983*). Previous studies (*Santos, Negreiros-Fransozo & Fransozo, 1994*; *Santos, 2000*; *Bertini & Fransozo, 2004*; *Lima et al., 2014*), carried out in the same area as the present one, have also evidenced the bottom water temperature influence over *A. spinimanus* biological parameters.

In the UBM bay, the sampling sites with depth from 15 up to 20 m were the only ones showing sediment composed by higher granulometric fractions, even though being exposed to the effects of water masses, making these areas favorable to the establishment of *A. spinimanus*. Besides that, according to *Antunes et al.* (2015), in the same bay, during the same studied occasion of this study, it was possible noticing greater abundance of *Callinectes danae* Smith, 1869 in the shallower sampling sites. According to *Shinozaki-Mendes, Manghi & Lessa* (*2012*), *C. danae* shows agonistic and territoriality behaviors, what could difficult the establishment of *A. spinimanus* in the same area. The abundance of one species in a certain place may be considered an ecological answer to the species' adaptations to both the environmental factors and the intra- and interspecific interactive processes (*Shinozaki-Mendes, Manghi & Lessa, 2012*).

This study reveals the texture of the sediment as the main modulating factor acting over the distribution of *A. spinimanus*. In all the covered bays, the sampling sites composed mainly by a heterogeneous sediment were the ones with higher abundance of *A. spinimanus*. This may be explained by the foraging and refuge options as made possible by the heterogeneous sediments, once the chances of the species to prevail is higher in places where there is a great variety of microhabitats (*Bertini, Fransozo & Melo 2004*). Previous studies (*Santos, Negreiros-Fransozo & Fransozo, 1994*; *Bertini & Fransozo, 2004*; *Furlan et al., 2013*, for instance) have described the higher abundance of *A. spinimanus* in areas where the sediment texture is more heterogeneous.

The higher abundance of *A. spinimanus* was recorded in UBA (78.9% from the total number of individuals), in the 7.5-m deep sampling site. It may be associated to the presence of heterogeneous texture of the sediment and a greater percentage of organic matter content in this sampling site. According to *Moore* (*1958*), areas with sediment composed mainly by finer grains may present a higher percentage of organic matter content, when compared to the ones with thicker grains. However, we observed an association between the higher granulometric fractions and the organic matter content levels, even though this last one was also positively associated with the silt+clay fraction. The higher organic matter amount observed in the 7.5-m deep sampling site is related to gravel-composed sediments, which are of biogenic nature, constituted by remains of mollusk shells, crustacean carapaces and echinoderms.

Lima et al. (*2014*) studying *A. spinimanus* in the UBA, during 2000, sampled less *A. spinimanus* (402 individuals) than in any year addressed in the present study. This fact is probably due to those authors did not collected in the 7.5-m deep sampling station. One may thus, assume that sheltered and heterogeneous-composed sediments areas may provide a favorable habitat to the establishment of *A. spinimanus*. It is noteworthy that the sampling station mentioned above is a part of a naturally excluded fishing area, that could contributed to the higher abundance of individuals there; locals that undergo a lower fishing impact maintaing the habitats' complexity, favoring the establishment of individuals (*Kaiser et al*., *2002*; *Fransozo et al., 2016*). Furthermore, *Fransozo et al.* (*2016*) describes the fishing activity as predatory and destabilizing to benthic communities, since it does not select the fishery target and jumbles the seafloor, displacing or removing many other organisms from its natural environment.

The low abundance observed in MV can be related to the sediment features observed in that bay. This site shows sediment composed mainly by silt+clay, generated by the influence of the continent, as well as a consequence of the physical barriers formed mainly by the São Sebastião channel, together to the Anchieta and Vitória islands. Corroborating with such statement, *Santos, Negreiros-Fransozo & Fransozo et al.* (*1994*) sampled 126 specimens of *A. spinimanus* in the Fortaleza bay (November 1998 through October 1989), while *Hiroki* (*2012*), in the same bay, 20 years later (November 2008 through October 2009), and adopting the same sampling procedure, collected only 5 individuals. It is noteworthy that, besides observing a lower abundance of individuals, *Hiroki* (*2012*) also observed a decrease in the higher granulometric fractions (grave, very coarse sand, coarse sand and intermediate sand).

Based on our investigation, we highlight the role that environmental factors such as the sediment texture play over the modulation of the establishment and development of *A. spinimanus*. According to *McNaughton & Wolf* (*1970*), the prevailing of certain species in a given habitat may be explained mainly by two opposite hypotheses. Firstly, the dominant species are generalists, and are adapted to several environmental conditions, in a way that, usually, they are not limited by environmental factors. Secondly, the dominant species are specialists and are well adapted to one or some aspects of their habitat. In the study carried out by *Bertini, Fransozo & Negreiros-Fransozo* (*2010*), some species seemed to be generalists, and they were not restricted to a certain type of substrate [*Callinectes ornatus* Ordway, 1968 and *Hepatus pudibundus* (Herbst, 1785) for instance], while others were frequently associated to specific sediment types (e.g. *Libinia ferreirae* Brito Capello, 1871 and *A. spinimanus*). In this study, *A. spinimanus* showed a specialist-portunid pattern, probably due to their tolerance to higher granulometric fractions (i.e., a stenotopic species).

CONCLUSION

Overall, this study broadens the knowledge about the most appropriate sediment features to the establishment and development of *A. spinimanus*, and collaborates to future improvements on the management measurements and in the sustainable fisheries, such as the creation of marine fishery exclusion.

ACKNOWLEDGEMENTS

We thank the NEBECC co-workers for their help during the fieldwork and Dr. Maria Lucia Negreiros-Fransozo for her constructive comments and valuable grammar review of this manuscript.

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