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Research Article

How marine upwelling influences the distribution of *Artemesia longinaris* (Decapoda: Penaeoidea)?

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ABSTRACT. Upwelling events can occur in most of the oceans altering the water physical, chemical and sediment conditions and consequently the species communities dwelling the areas. For better understanding the behavior of populations inhabiting upwelling regions, the spatial and temporal distribution of a Penaeoidea shrimp was studied correlating it with the abiotic factors that vary during upwelling and non-upwelling periods in an area under influence of Cabo Frio upwelling. Bottom salinity and temperature, organic matter and sediment type from each station were sampled from March 2008 to February 2010, in six stations located between 5 and 45 m depth. The lowest temperatures were recorded during spring and summer for both years with temperature values lower than 19°C. A total of 26,466 *Artemesia longinaris* shrimps were captured mainly in 10-35 m depth. Upwelling periods showed significant differences in abundance in relation to non-upwelling periods. The spatial distribution among stations varied according to the temperature with higher abundance in stations with values between 19 and 21°C. The highest abundance of *A. longinaris* was recorded in spring and summer when intrusions of the cold waters of South Atlantic Central Waters (SACW) were frequent. Thus, the effect of cold water of SACW boosted by the upwelling was a determinant factor in the spatial and temporal distribution of *A. longinaris* in the studied region.

Keywords: *Artemesia longinaris*, Penaeoidea, distribution, environmental factors, SACW, Brazil, South Atlantic Ocean.

¿Cómo influye la surgencia marina en la distribución de *Artemesia longinaris* (Decapoda: Penaeoidea)?

RESUMEN. Los eventos de surgencia pueden ocurrir en la mayoría de los océanos alterando las condiciones físicas y químicas del agua y del sedimento, y por consiguiente a las comunidades de especies que viven en la zona. Para una mejor comprensión del comportamiento de las poblaciones que habitan en las regiones de surgencia, se estudió la distribución espacial y temporal de un camarón peneido y se correlacionó con los factores abióticos que varían durante los períodos de surgencia y sin surgencia, en una zona bajo la influencia de la surgencia de Cabo Frío. La salinidad y temperatura del fondo, materia orgánica y el tipo de sedimento de cada estación fueron muestreados entre marzo 2008 y febrero 2010, en seis estaciones ubicadas entre 5 y 45 m de profundidad. Las temperaturas más bajas se registraron durante primavera y verano para ambos años, cuando los valores de temperatura fueron inferiores a 19°C. Un total de 26.466 camarones de *Artemesia longinaris* se capturó principalmente entre 10 y 35 m. Los períodos de surgencia mostraron diferencias significativas en la abundancia en relación con los períodos sin surgencia. La distribución espacial entre estaciones varió según la temperatura con las mayores abundancias en las estaciones con valores entre 19 y 21°C. La mayor abundancia de *A. longinaris* se registró en primavera y verano, cuando las intrusiones de las frías aguas del Agua Central del Atlántico Sur (SACW) fueron frecuentes. Por lo tanto, el efecto del agua fría del SACW impulsada por la surgencia fue un factor determinante en la distribución espacial y temporal de *A. longinaris* en la región estudiada.

Palabras clave: *Artemesia longinaris*, Penaeoidea, distribución, factores ambientales, SACW, Brasil, Océano Atlántico Sur.

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INTRODUCTION

The tropical continental shelf ecosystem is little known due to its great extension and there is scarce information about the distributional models of organisms and the factors influencing this distribution. A vast variety of environmental processes (luminous intensity, salinity, temperature, oxygen concentration, and others) contributes to the marine communities pattern of response to the environment that they dwell (Bertness *et al*., 2001). Therefore, the study of the interaction of these factors with the populations leads to a greater understanding about the dynamic of marine communities.

Thus, benthic ecosystems are influenced by complex interactions among oceanographic process, organic input and its use by populations, and hydrological and sediment conditions (Barry & Dayton, 1991), which may influence juveniles recruitment, growth, survival, and fecundity of benthic species (Peterson, 1979; Ambrose, 1991). The spatial and temporal distribution of shrimps, as well as the onset at sexual maturity, growth, longevity, and spawning are affected by temperature, salinity, food availability, sediment structure and intrinsic factors (Bauer 1992; Castilho *et al*., 2007a, 2007b; Castro *et al*., 2005; Costa *et al*., 2005a, 2005b, 2007; Simões *et al*., 2010).

Artemesia longinaris Bate, 1888 is a species endemic to the western area of the South Atlantic occurring from Atafona (21°S) (Rio de Janeiro, Brazil), to the Province of Chubut (43°S) (Argentina) (Boschi, 1969a). This shrimp is commonly found in shallow waters up to 30 m of depth (Boschi, 1997; Costa *et al*., 2003). Boschi (1963, 1969a) stated that this species is typical of colder regions, occurring in a temperature range from 15 to 21°C and salinity above 33. The density of *A. longinaris* increases with latitude from the Rio de Janeiro coast to the South (Magalhães, 1944; Boschi, 1969b). This pattern has also been confirmed in other studies, given that the species is occasionally detected in minor amounts on the coast of Rio de Janeiro (Iwai, 1973) and São Paulo States (Mistakidis & Neiva, 1964; Iwai, 1973; Costa *et al*., 2005b). However, from the coast of Rio Grande do Sul State to Argentina (Boschi, 1969b; Nascimento, 1983), this species is caught all year long. It lives exclusively in the marine environment throughout its life cycle, without any period linked to continental brackish waters (Boschi, 1997; Branco, 2005; Costa *et al*., 2005b).

The southeast region of Brazil is influenced by the oceanic currents of Brazil (T > 20°C, S > 36) and Malvinas (T < 15°C, S < 34). Due to the confluence of both currents between latitudes 25°S and 45°S of the western South Atlantic observed in certain periods of the year, there is the formation of water masses like the South Atlantic Central Water (SACW; T < 20ºC, S < 36.4), accounting for part of the convergence of the subtropical gyre and giving rise to the Cabo Frio upwelling, which extends between 23°S and 29°S (Castro-Filho *et al*., 1987; Campos *et al*., 1996, 2000; Silveira *et al*., 2000; Acha *et al*., 2004). This upwelling is enhanced by coastal winds and by the break in the continental shelf (approximately 50 km from the coast) driven by the meandering pattern and eddy of the Brazil Current (Castro & Miranda, 1998; Campos *et al*., 2000). The combination of these effects results in a strong mechanism capable of carrying cold and nitrate-rich SACW waters to the coast (Acha *et al*., 2004), altering the physical conditions and also enhancing water nutrient concentrations (Valentin, 1984). Consequently, the primary productivity of the Brazilian Southeast Bight increases, particularly in Cabo Frio, Rio de Janeiro (23°S) (De Léo & Pires-Vanin, 2006).

The upwelling in Cabo Frio area is an uncommon case. Most of the coastal upwelling regions in the world are located on the west coast of the oceans, like in Peru, Equator, California and Oregon (Pacific coast), and the Northeast of South Africa and Bengal in the Atlantic Ocean. On the other hand, Cabo Frio upwelling occurs on the west coast of the Atlantic Ocean, which is very important for biological enrichment and consequently for fishing activities in the area (Franchito *et al*., 2007). Generally, physical processes can affect the primary productivity in a time and space scales, causing variations in food availability affecting the growth and survival of organisms (Scheltema, 1986; Morgan *et al*., 2001).

The distinctive environmental characteristics, caused by the inflow of SACW, found in Cabo Frio region and adjacent areas may provide different results about spatial and temporal abundance of *A. longinaris* when compared to results from other localities, especially where its occurrence is seasonal such as in São Paulo State coast (Costa *et al.*, 2005b; Castilho *et al.*, 2008a).

Thus, the aim of this study was to analyze the spatial and temporal distribution of the shrimp *Artemesia longinaris* correlating abiotic factors that vary in periods with and without influence of Cabo Frio upwelling.

MATERIALS AND METHODS

Sampled shrimps

Shrimps were collected monthly from March 2008 to February 2010 (Autumn: March-May; and so on) at six stations located in the Inside Area (5, 10 and 15 m deep) and the Outside Area (25, 35 and 45 m deep), in Macaé northern coast of Rio de Janeiro State (22^{o}22'33"S, 41^{o}46'30"W) (Fig. 1). The inside area and outside area terms were used only to characterize less and larger depths of the stations, respectively. A shrimp fishing boat equipped with otter-trawl nets (3.5 m mouth width, mesh size 20 and 15 mm in the cod end) was used for trawling. The stations were trawled over a 15 min period at a constant speed of 2.1 knots through a 1 kilometer distance per trawl.

Sampling and abiotic environmental data collection

Salinity and temperature (°C) were measured on surface and bottom-water samples, obtained monthly in each station using a Van Dorn bottle. In the laboratory, the salinity was verified with a manual salinometer calibrated with distilled water. The water temperature was verified with a mercury thermometer immediately after sampling in a thermic isolated container in the shade. An ecobathymeter coupled with a GPS (Global Positioning System) was used to record depth at sampling sites. Sediment samples were collected in each season with a 0.06 m^2 Van Veen grab. Grain-size categories followed the American standard, and sample sediments were sieved at 2.0 mm (gravel), 1.0 mm (very coarse sand), 0.5 mm (coarse sand), 0.25 mm (intermediate sand), 0.125 mm (fine sand), 0.0625 mm (very fine sand) and smaller particles, which were classified as silt-clay. Grain-size fractions were expressed on the phi (Φ) scale, accounting for the central tendency of sediment samples. Procedures for sediment analysis followed Hákanson & Jansson (1983) and Tucker (1988).

The organic matter content (%) was obtained by ash weighing: three aliquots of 10 g each per station, placed in porcelain crucibles for 3 h at 500°C, and the samples were weighed one more time (see Mantelatto & Fransozo, 1999).

Data analysis

Water masses and periods under upwelling influence were identified through Temperature-Salinity diagram (T-S) and monthly difference between the highest surface temperature and the lowest bottom temperature.

Coastal Water (CW) shows high temperature and low salinity (T > 20ºC, S < 36.4), Tropical Water (TW) shows both high temperature and salinity (T > 20ºC, S > 36.4), and South Atlantic Central Water (SACW) shows both low temperature and salinity (T < 20ºC, S < 36.4) (Mascarenhas *et al*., 1971; Campos *et al*., 1996; 2000; Castro-Filho & Miranda, 1998; Silveira *et al*., 2000).

The abundance of shrimps was compared among stations and between upwelling and non-upwelling periods using analysis of variance (TWO-WAY ANOVA), and the *post-hoc* Tukey's test was used to indicate the difference between stations. The differences of shrimp abundance in each class of environmental factor were tested by ANOVA and *post-hoc* Tukey's. Homoscedasticity and normality of the data set were evaluated and found satisfactory after data logarithmic transformation (Zar, 1999).

RESULTS

Environmental factors analysis

Three water masses were identified in the studied region, *i.e.*, Coastal Water (CW), Tropical Water (TW) and South Atlantic Central Water (SACW). The influence of SACW was evident in spring-summer months in both years, and in autumn (March-April) of the second year (Figs. 2, 3).

The environmental factors varied in spatial-temporal gradients. In bottom salinity, the smallest mean value was detected during March 2009, mainly in Inside Area (27.0 ± 1.00), when compared to Outside Area (31.7 ± 3.21). Contrarily, the greater values were verified in October 2009 (37.0 ± 1.00) in Inside Area, and April 2009 and Mach 2008 (37.7 ± 0.58 e 37.3 ± 0.58) in Outside Area (Fig. 4).

In both years, smaller mean values of bottom temperature were registered in spring and summer seasons, mainly in January 2010 and November 2009 in Inside and Outside Area, respectively. The opposite was observed in winter with greater mean bottom temperature values (Fig. 5).

The stations distributed in the Inside Area showed sediment composed mainly of medium and fine sand, and a low percentage of organic matter. In Outside Area the sediment was composed mainly of silt and clay and a greater content of organic matter (Fig. 6).

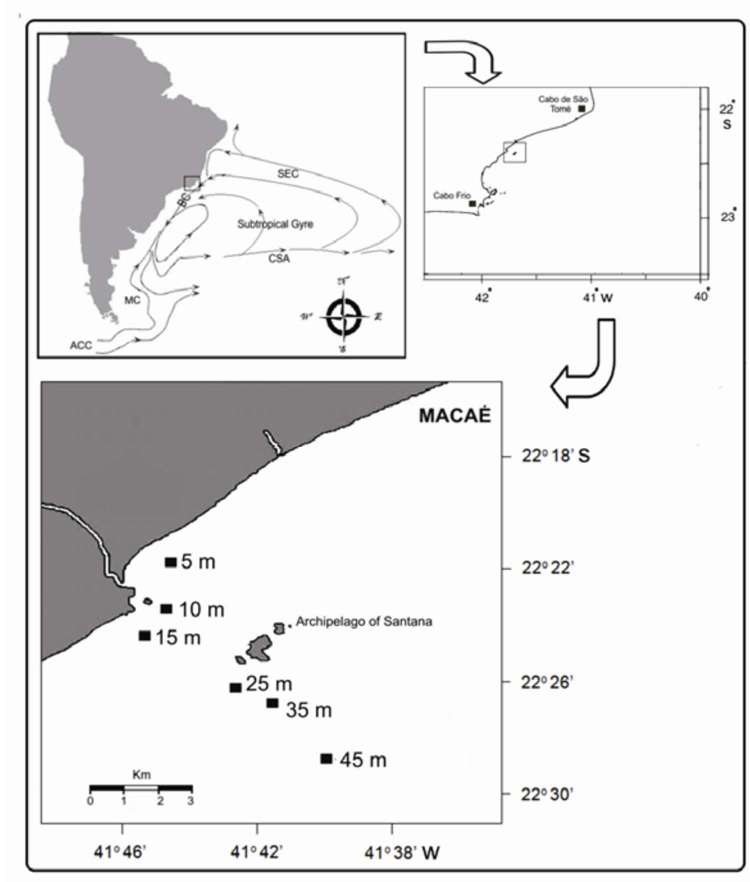

Figure 1. Study area evidencing the upwelling region and the sampling area. Location of stations (5-45 m of depth) and major ocean currents of the South Atlantic. AC: Antarctic Circumpolar Current, MC: Malvinas Current, SAC: South Atlantic Current, SEC: South Equatorial Current, BC: Brazilian Current (Modified from Peterson & Stramma, 1991).

Spatial-temporal distribution

A total of 26,466 *A. longinaris* specimens were captured in all stations sampled in Inside and Outside Area, with greater amount of shrimps between depths 10 to 35 m. The greatest captures occurred during summer months in both years (2,907 and 6,779, respectively). In spring of YEAR I (2008) the smallest captures (611) were obtained. Contrarily, the spring of YEAR II (2010) was the second season with the greatest number of shrimps (Table 1). The analysis of variance showed a significant difference only between stations (ANOVA, F = 10.32; $P = 0.000$) and between upwelling and non-upwelling periods (ANOVA, F = 6.85; $P = 0.009$).

For all environmental factors, ANOVA analysis indicated significant difference with abundance of individuals (Table 2). The greatest concentration of individuals in sites and/or months occurred in the temperature classes 19 and 21°C, salinity higher than 31, and granulometry composed of medium sand ($1 \leq$ phi ≥ 2). It can be noticed a lower abundance of *A. longinaris* in intermediate values (3 and 9%) of organic matter in the sediment, however it was not found a pattern for differences among classes. In this study water samples for salinity between 28.5 and 31 were not recorded (Fig. 7).

DISCUSSION

The distribution of megabenthonic community in the study area is closely connected to seasonality of the thermic front of SACW and upwelling. The deepest area (100 m) is influenced by high sedimentation, while shallower regions are more influenced by cold water (De Léo & Pires-Vanin, 2006). According to Pires-Vanin *et al*. (2013) changes on water temperature and salinity affect the distribution pattern of the macrofauna of benthonic invertebrates. Additionally, Dall *et al*. (1990) and Costa & Fransozo (2004) affirm that the temperature is considered one of the main determinant parameters in the temporal distribution of organisms, mainly for penaeid shrimps.

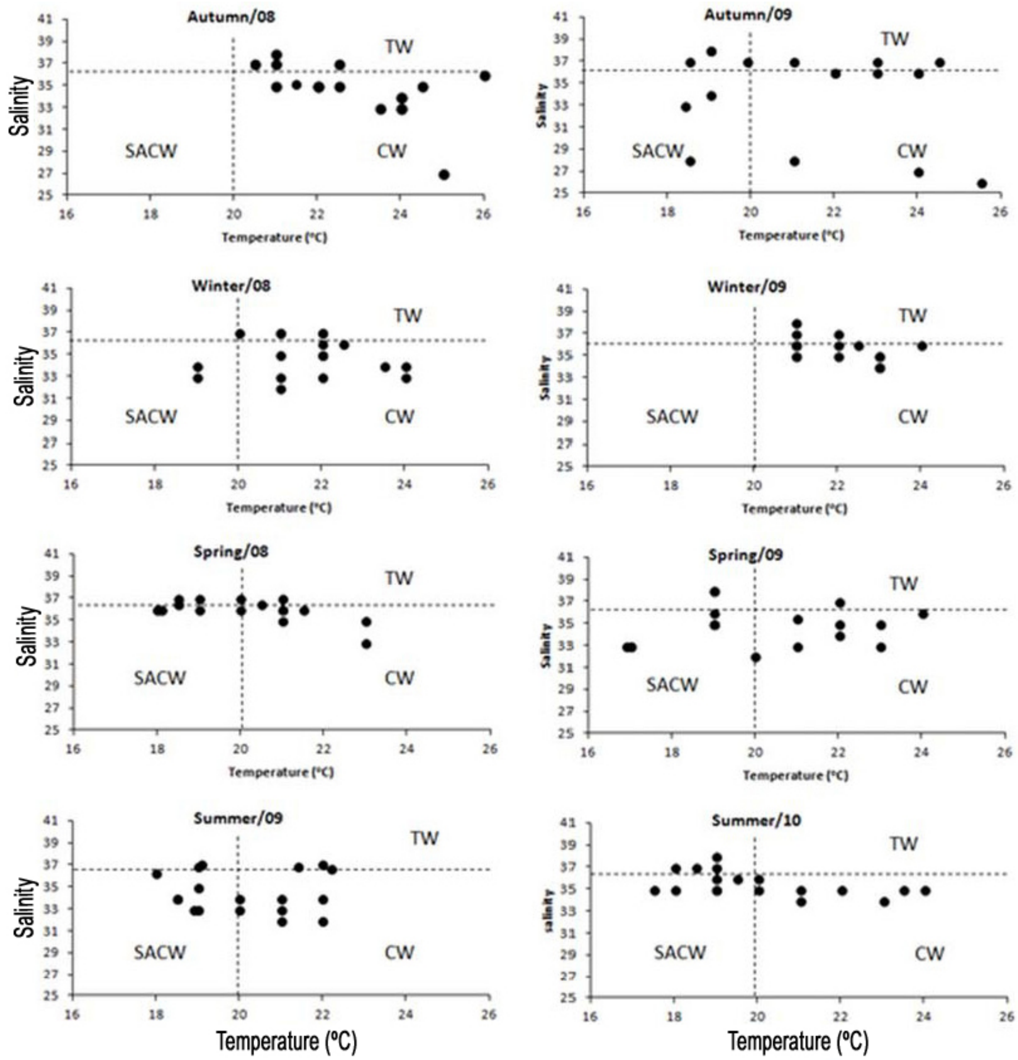

Figure 2. T-S Diagram showing the seasonal variation of water temperature and salinity during the sampling period at upwelling area studied, southeastern coast of Brazil. CW: Coastal Water, TW: Tropical Water, SACW: South Atlantic Central Water. Autumn: March-May, winter: June-August, spring: September-November and summer: mean December-February.

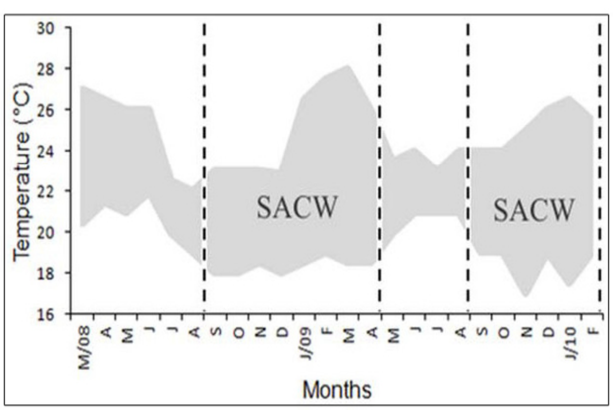

Figure 3. Highest surface and lowest bottom temperatures, showing the upwelling periods (SACW) in the study area.

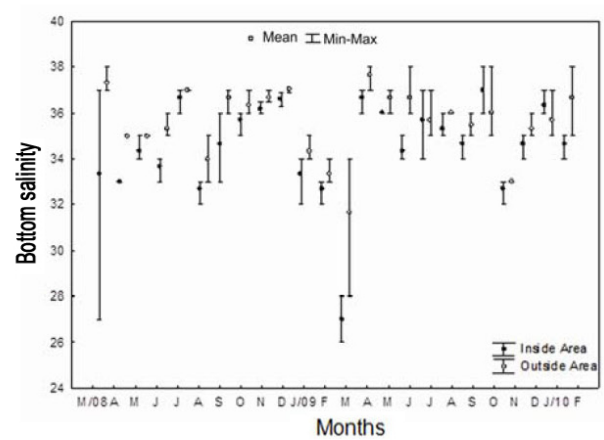

Figure 4. Mean, maximum and minimum salinity values for each month in "Inside area" and "Outside area", sampled from March 2008 to February 2010.

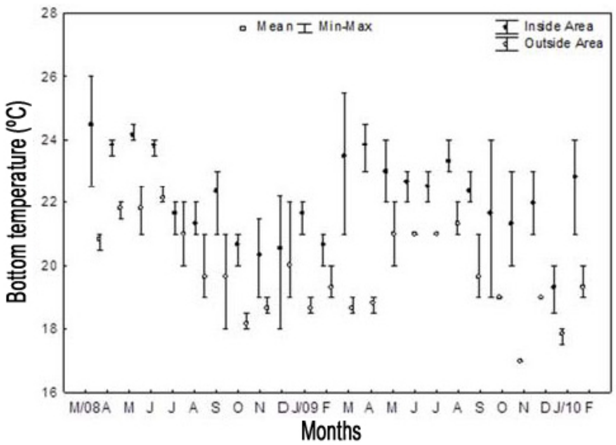

Figure 5. Mean, maximum and minimum temperature (°C) values for each month in "Inside area" and "Outside area" sampled from March 2008 to February 2010.

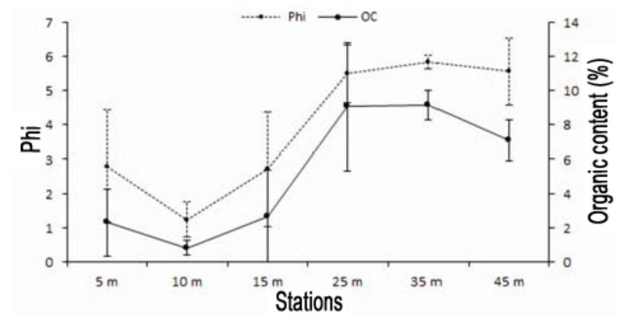

Figure 6. Mean values and standard deviation of phi and organic matter content, recorded in each station, sampled from March 2008 to February 2010.

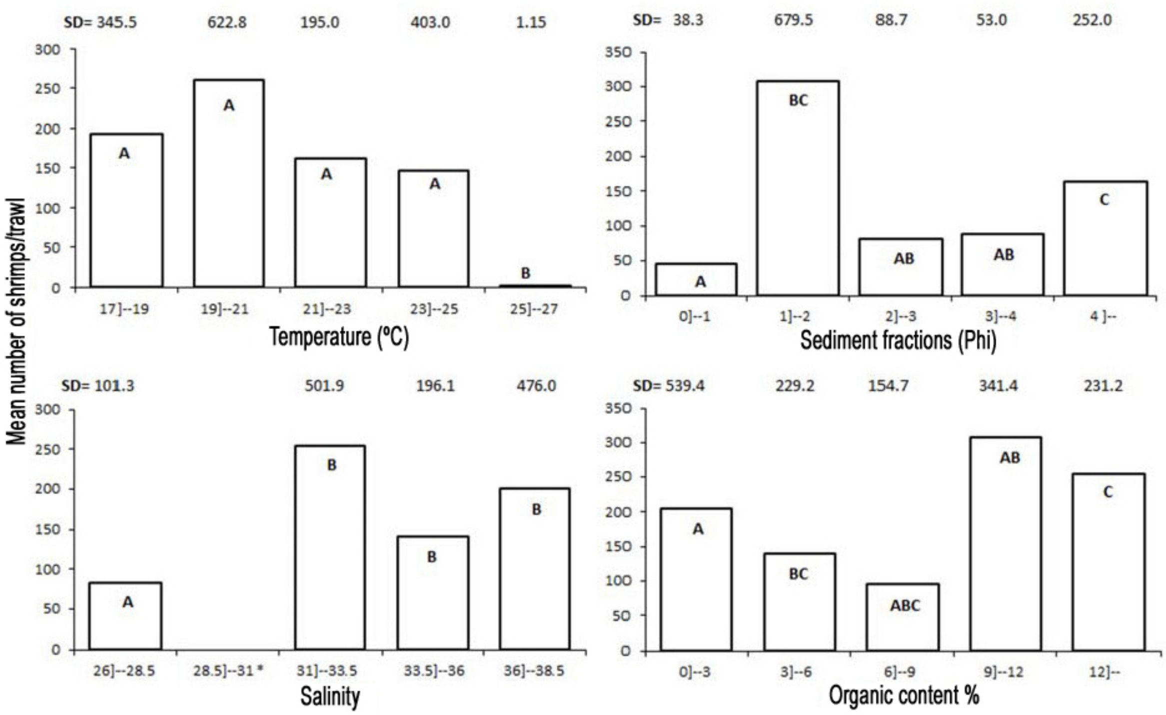

Figure 7. Distribution of mean number of shrimp per trawl and standard deviation (SD) for each class of environmental variable, along with variance analysis results indicating results of Tukey test ($P > 0.05$). Different letters indicate statistical significant difference. (*) No samples were collected with this particular salinity value in this class.

Even though factors like migration, predation and food availability may influence the distribution and abundance of *A. longinaris*, the presence of the SACW, propelled by Cabo Frio upwelling, and could be a very strong modulating factor in the region, despite the influence of salinity and sediment composition. This is supported by the fact that the species shows evolutionary origin linked to cold waters of temperate regions.

In this study, salinity values higher than 31 positively influenced the increase of *A. longinaris* abundance. This pattern suggests that *A. longinaris* presents a life cycle of type III (proposed by Dall *et al.*, 1990) in this studied region. Within this category, individuals complete their life cycle in coastal marine regions, where post-larvae settle in protected areas near the coast, which does not include estuaries or low salinity areas.

Table 1. Number of individuals in each month and station sampled from March 2008 to February 2010, indicating the results of the Tukey test (*Results of the Tukey test. Different letters indicate statistical significant difference ($P > 0.05$)). Dashed boxes indicate upwelling periods.

Season	Month	Inside area			Outside area			Total	
Year I		5 m	10 m	15 m	25 m	35 m	45 m	Month	Season
	Mar/08	2	0	77	233	350	0	661	
Autumn I	Apr/08	33	90	86	184	157	4	554	2574
	May/08	15	155	577	583	0	28	1359	
	Jun/08	71	90	66	807	259	142	1435	
Winter I	Jul/08	86	132	134	494	165	19	1030	2673
	Aug/08	26	0	72	24	86	0	208	
	Sep/08	19	46	54	26	71	9	225	
Spring I	Oct/08	0	0	43	170	0	0	213	611
	Nov/08	0	0	81	64	28	0	173	
	Dec/08	12	0	23	1001	33	0	1069	
Summer I	Jan/09	31	18	519	26	20	0	614	2906
	Feb/09	243	412	567	2	0	0	1223	
Total Year I		538	943	2299	3614	1168	202	8765	
Year II		5 m	10 m	15 m	25 m	35 m	45 m		
	Mar/09	0	81	82	249	233	1	646	
Autumn II	Apr/09	1	37	67	16	1150	2	1273	3321
	May/09	32	70	85	636	520	59	1402	
	Jun/09	31	22	101	488	325	447	1413	
Winter II	Jul/09	37	116	73	205	195	5	631	2276
	Aug/09	19	55	56	70	10	22	232	
	Sep/09	0	80	41	34	151	40	346	
Spring II	Oct/09	40	73	146	517	473	57	1306	5326
	Nov/09	5	2161	1126	368	14	0	3674	
	Dec/09	287	413	268	94	79	0	1141	
Summer II	Jan/10	28	3474	624	955	0	0	5081	6779
	Feb/10	9	14	77	457	0	0	557	
Total Year II		490	6596	2746	4088	3149	633	17703	
Total		1028	7539	5045	7702	4317	835	26466	
Tukey test		(bc)*	(ab)	(a)	(a)	(ab)	(c)		

The organic matter did not influence the distribution of *A. longinaris* once it occurred in all value classes. For Penaeoidea, the grain particle size may be more important in shrimp distribution than the amount of organic matter available in the substrate (Ruello, 1973; Costa & Fransozo, 2004; Costa *et al*., 2004). This may be due to the fact that shrimp are generalist and they do not feed only on organic matter dissolved in the sediment.

Feeding diversification showed by Penaeoidea shrimps may explain the preference of *A. longinaris* for sediment composed by medium sand in which the content of organic matter is lower. Boschi (1969a, 1969b), Fransozo *et al*. (2004) and Costa *et al*. (2005b) observed preference for sediment composed of very fine sand. This preference for fine sediment is common in most of the peneid species like *Penaeus esculentus* Haswell, 1879, *Metapenaeus endeavouri* (Schmitt, 1926) (Gribble *et al*., 2007), *Sicyonia dorsalis* Kingsley, 1878 (Castilho *et al*., 2008b) and *A. longinaris* (Costa *et al*., 2005b). Very fine sand enables the shrimp's strategy of burying themselves to protect against predators and thus to decrease their energetic expenditure (Ameeri & Cruz, 1998; Simões *et al*., 2010).

The results obtained regarding sediment allow proposing that *A. longinaris* individuals do not totally bury themselves and their greater abundance in sediment with medium sand is due to the influence of environmental factors.

According to Fenucci (1988), *Artemesia longinaris* rests on the substrate and they do not bury themselves. Such information may be reinforced once *A. longinaris* are translucent when alive, evidencing in

Table 2. Results of the analysis of variance (ANOVA) of the number of shrimp per trawl for each class of environmental variable. Different letters indicate statistical significant difference ($P > 0.05$).

Source	df	MS	F	P
Temperature	4	4.0159	8.4642	0.0000
Sediment fractions	4	3.7843	6.9142	0.0003
Salinity	4	5.4891	15.3820	0.0000
Organic content	4	3.6092	5.9543	0.0009

their body only brownish spots that resemble sand grains enabling them to be unnoticed by a potential predator.

The results found for organic matter content and sediment texture reinforce the greater effect of temperature in spatial distribution of *A. longinaris*. The variation of temperature made the individuals move to areas with less than 15 m of depth when the temperature was colder, however as the temperature increased, the individuals moved to deeper areas regardless the sediment type. *Artemesia longinaris* displaced specially between depths of 10 to 35 m, following the water temperature variation. In periods when the temperature decreased (<20°C) due to the SACW intrusion and the upwelling phenomena in the region (mainly in spring and summer), most of the individuals were collected in depths of less than 14 m. While in winter, when the retraction of the SACW happened and temperature values were higher than 22°C, individuals were collected in greater amounts in depths of more than 25 m.

The pronounced thermocline verified in the upwelling months, together with an abrupt drop of bottom temperature values (<20°C), triggered a substantial increase of *A. longinaris* during these periods. Similar results were obtained by Fransozo *et al*. (2004) and Costa *et al*. (2005b) on the North coast of São Paulo State. According to Costa *et al*. (2005a), the species is considered migratory following the cold water mass SACW.

According to the results obtained, the studied region refutes the theory that the abundance of *A. longinaris* increases towards higher latitude (Magalhães, 1944; Boschi, 1969b; Iwai, 1973). The favorable conditions, especially low temperatures, found in Cabo Frio/RJ region and adjacent areas provide the continuous establishment of *A. longinaris*, differing from seasonal captures described by Fransozo *et al*. (2004) and Costa *et al.* (2005b) in Ubatuba region (23°S), Sao Paulo State coast.

Stramma & England (1999) and Silveira *et al*. (2000) proposed a flow of ACAS from north to south in the Southwestern Atlantic Ocean. These authors stated that the Subtropical Gyre originates the SACW and part of it flows toward south along Brazilian coast from Cabo de São Tomé (22°S). This study propose the hypothesis that possibly there is an established population on the north coast of the State of Rio de Janeiro due to favorable conditions with low temperature, and this population migrates with the SACW to lower latitudes, and it may populate the coast of Sao Paulo State. Therefore, the species success in the studied region is related to local physical conditions responsible for creating an environmental scenario similar to the cold waters of a cold temperate region, such as the Argentine coast.

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