Ecological distribution of the shrimp *Pleoticus muelleri* (Bate, 1888) and *Artemesia longinaris* Bate, 1888 (Decapoda, Penaeoidea) in the southeastern Brazilian littoral

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Abstract

The relationship between species abundance and environmental factors such as the bottom water temperature and salinity, the texture and organic matter content of the sediment and the distribution of *Pleoticus muelleri* and *Artemesia longinaris* were investigated. Specimens and samples of abiotic factors were collected monthly from May 2008 to April 2010 at 4 locations in Santos Bay on the southern coast of the State of São Paulo. A shrimp boat equipped with an otter-trawl net with an 8 m mouth aperture and a mesh size of 20 mm tapering to 18 mm at the cod end was used for sampling. Shrimp abundances were compared with an analysis of variance (ANOVA). However, when the data did not follow a normal distribution, we used the Kruskal-Wallis test. The relationship between environmental factors and the abundance of individuals was assessed with a Pearson's correlation. The largest catches of individuals of both species occurred in the late spring of 2008. The greatest abundance occurred at the outer part of the bay (collection point 4). The greatest abundance of *P. muelleri* was associated with lower temperatures and sediments with higher clay and organic matter content, whereas for *A. longinaris,* there was no significant correlation with any of the abiotic factors recorded. However, the occurrence of both species was related to lower bottom temperatures associated with the intrusion of the South Atlantic Central Water in the region.

Key words: Abundance, Dendrobranchiata, environmental factors, SACW.

Introduction

Among the biogeographical provinces of Argentina and Brazil, there is a transition region (23º to 35ºS) where a mixing of water bodies occurs and both euryhaline and eurythermal species are found. Within this latitudinal range, there are a number of species found along the coasts of both Argentina and Brazil, including *Artemesia longinaris* Bate, 1888 and *Pleoticus muelleri* (Bate, 1888) (Boschi, 2000; Costa *et al.*, 2000). *Artemesia longinaris* is distributed between Atafona, Rio de Janeiro (21°37'S), Brazil, and Rawson, Argentina (43°00'S). The northern distributional limit of *P. muelleri* is similar, but this species extends farther south, reaching the Santa Cruz Province of Argentina (50°00'S) (D'Incao, 1999).

The shrimp fisheries of southeastern Brazil target the most profitable species, such as the pink shrimp *Farfantepenaeus brasiliensis* (Latreille, 1817) and *F. paulensis* (Pérez Farfante, 1967), the white shrimp *Litopenaeus schmitti* (Burkenroad, 1936) and the Atlantic seabob shrimp *Xiphopenaeus kroyeri* (Heller, 1862). However, declines in these stocks have caused an increase in demand for other, less commercially attractive species, including *A. longinaris* and *P. muelleri* (D'Incao *et al.*, 2002; Castilho *et al.*, 2008a).

Several studies have investigated the ways in which distributions of the penaeid shrimps are modulated by changes in ecological parameters. The types of sediment, depth, bottom salinity and temperature of the water have been identified as the most important modulators (Fransozo *et al.*, 2004; Costa *et al.*, 2005; Fernandez *et al.*, 2011).

There have been few studies on *P. muelleri* and *A. longinaris* populations along the Brazilian coast. Ecological studies have been conducted along the northern coast of São Paulo, for example, Fransozo *et al.* (2004), Costa *et al.* (2004, 2005) and Castilho *et al.* (2007a, b, 2008a) studied the reproductive patterns and juvenile recruitment of both species. Other studies on the abundance, composition and associated fauna of shrimp species have also included these species (Nakagaki *et al.*, 1995; D'Incao, 1998 and 1999; Boschi, 2000; Costa *et al.*, 2000 and 2003; Robert *et al.*, 2007; Severino-Rodrigues *et al.*, 2007; Castilho *et al.*, 2008b).

The aim of the present study was to investigate the spatio-temporal abundance of *P. muelleri* and *A. longinaris* and the influence of environmental factors such as bottom temperature and salinity, sediment texture and organic matter content on the distribution of these species in Santos Bay, along the southern coast of São Paulo, Brazil.

Materials and Methods

The sampling area used in this study is in Santos Bay on the southern coast of the State of São Paulo between 23°55' – 24°00'S and 46°20' – 46°25'W (Fig. 1). The site is located in Baixada Santista, an area named in reference to the landscape with mangroves between the two main islands of the region, Santo Amaro and São Vicente, and outcrops of the Serra do Mar (Ab'Saber, 2003).

Specimens of *P. muelleri* and *A. longinaris* were caught monthly from May 2008 to April 2009 (Year 1) and May 2009 to April 2010 (Year 2) in Santos Bay, São Paulo. Sampling was conducted at 4 points (P1, P2, P3 and P4) with the aid of a shrimp boat equipped with an otter-trawl net with the following dimensions: an 8 m mouth aperture, a total length of 10 m and a mesh size of 20 mm tapering to 18 mm in the cod end. Hauls were conducted for 30 minutes at each collection point at an average speed of 2 knots, covering a distance of approximately 2 km and an area of 16,000 m^2 (Fig. 1).

Bottom water temperature (°C) and salinity were measured in bottom-water samples collected monthly on each point using a Nansen bottle. An ecobathymeter coupled with a GPS was used to record the depths at the points. Sediment samples were collected monthly with a Van Veen grab, sampling an area of 0.06 m^2. 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 and Jansson (1983) and Tucker (1988).

All shrimp specimens collected were identified following Pérez Farfante and Kensley (1997) and Costa *et al.* (2003) and quantified monthly by point. Shrimp abundances were

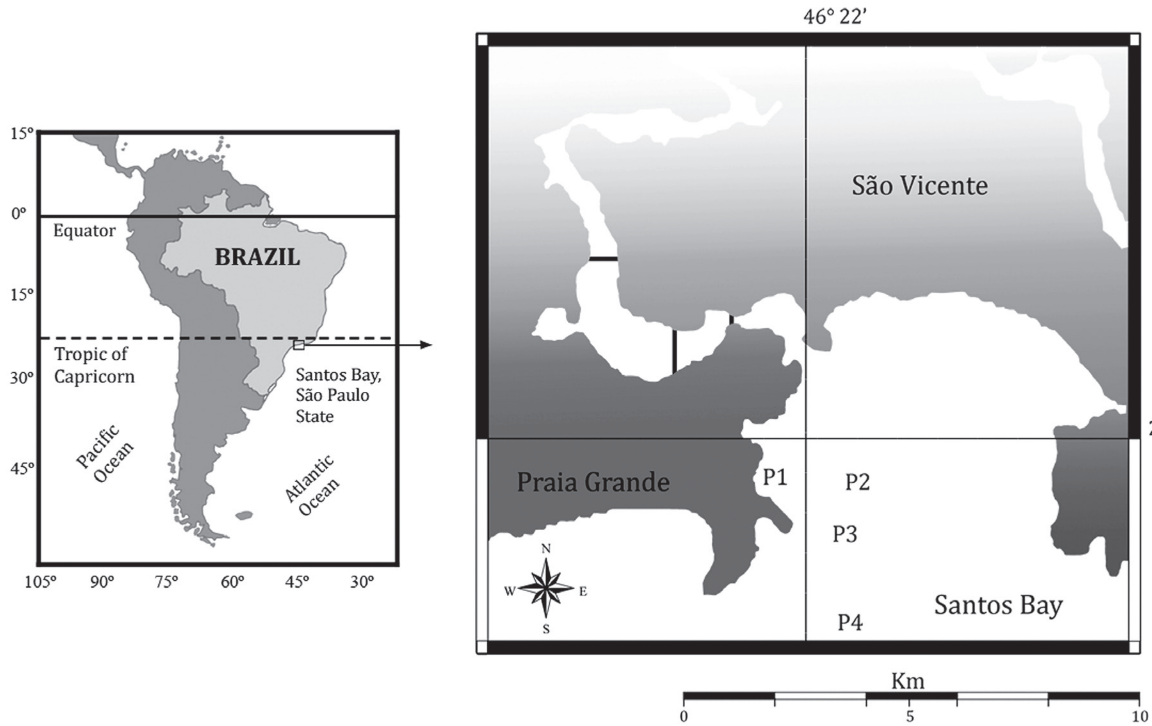

Figure 1. Map of the study region indicating collection locations.

compared between the seasons, grouping months for each site during the two survey years and between sites with an analysis of variance (ANOVA). However, when the data did not follow a normal distribution, we used the Kruskal-Wallis test. The relationship between environmental factors and the abundance of individuals was assessed with a Pearson's correlation. The data were transformed by natural logarithm for the purpose of satisfying analytic premises. All statistical procedures followed Zar (1999), and the significance level adopted was $p < 0.05$.

Therefore, the data for the abiotic factors were associated against the presence of *A. longinaris* and *P. muelleri* in each point sampled. Such relationships consisted of distributing the obtained total results of these factors in classes, determining the number of captured specimens and the frequency of repetitions of the values for each class of the factors, with the obtaining of the individuals' relative frequency by collection.

Results

The depth ranged from 5.8 to 17.0 m, and the average depths at each point were as follows: P1 = 7.24 m, P2 = 8.58 m, P3 = 10.37 and P4 = 13.50 m (Fig. 2). The minimum and maximum amplitudes for the

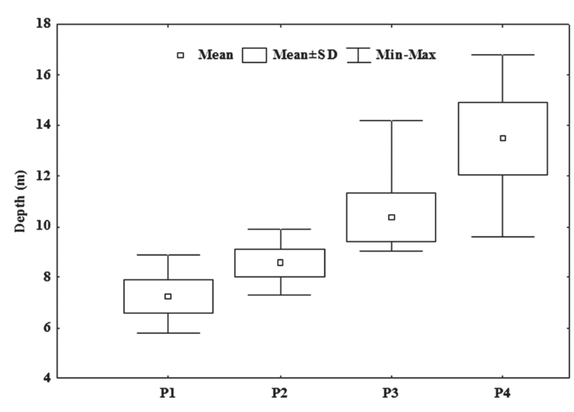

Figure 2. The mean, standard deviation and minimum and maximum depths at each point recorded from May 2008 to April 2010 in Santos Bay.

bottom temperature were 17.5 and 30.0°C. The highest monthly averages were recorded in February 2009 and March 2010 and the lowest in November and December 2008. Bottom salinity values ranged between 30 (P1) in April 2010 and 40 (P1 and P4) in 2008 (Fig. 3).

The sediment texture remained at approximately 3.5 (Φ) for the entire period analyzed, i.e., consisting predominantly of very fine sand. In 2009, sediment texture values between 4 and 5 (silt and clay) were recorded at P1 in July, P2 in January, P3 in August and September and P4 in September. During June and July of the same year at P4, the value of this factor was equal to 6 (Fig. 3).

The organic matter content of the sediment ranged from 0.87% in May 2008 at P2 to 15.6% in April 2010 at P1. However, organic matter content was close to 2% at the majority of sites and in the majority of months sampled (Fig. 3).

We collected 630 individuals of *P. muelleri,* of which 253 were captured in December 2008 and 167 in January 2009. A total of 156 *A. longinaris* specimens were collected and the greatest abundances occurred at the same times as for *P. muelleri*, i.e., in December 2008 and January 2009, with 52 and 29 individuals, respectively. There was no significant difference in abundance among seasons for either species, and only for *P. muelleri* were captures significantly higher during the first year of collection than the second year (Kruskal-Wallis, $p < 0.05$) (Tab. 1).

There was a significant difference in

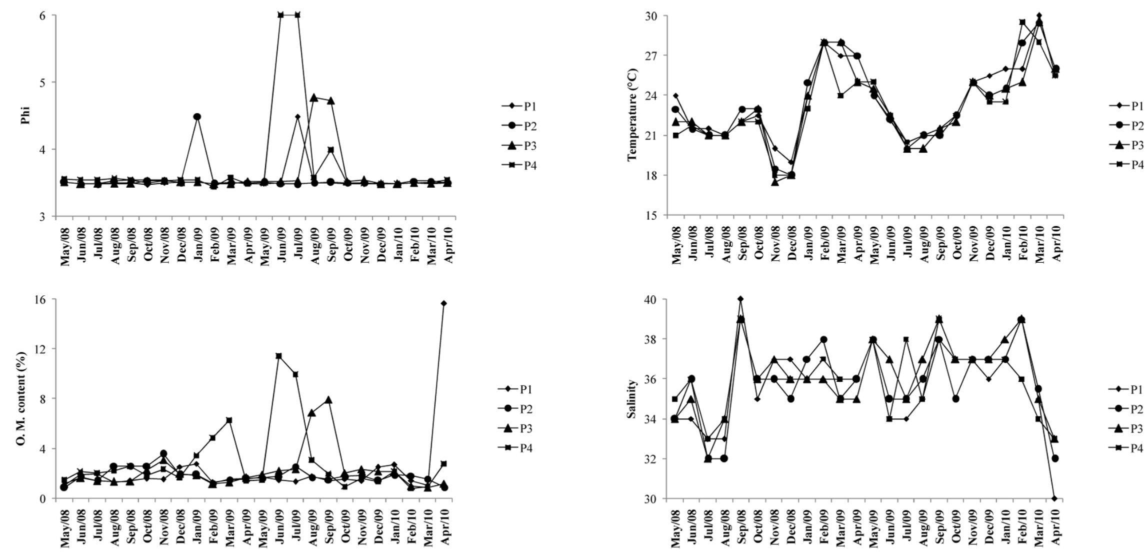

Figure 3. Monthly values of bottom water temperature (°C) and salinity, phi and organic matter content of the sediment (%) at each point from May 2008 to April 2010 in Santos bay.

Table 1. The monthly abundances by point of *Artemesia longinaris* in Santos bay from May 2008 to April 2010. Different letters indicate significant differences (Kruskal-Wallis, p< 0.05).

	Season	Months	P1	P2	P3	P4	Total
Year 1	Autumn	May/08	-	-	-	26	26
		Jun/08	-	-	-	-	-
	Winter	Jul/08	-	-	-	-	-
		Aug/08	-	-	-	3	3
		Sep/08	-	-	-	-	-
	Spring	Oct/08	-	-	-	4	4
		Nov/08	-	-	-	1	1
		Dec/08	-	-	2	50	52
	Summer	Jan/09	-	-	1	28	29
		Feb/09	-	-	-	3	3
		Mar/09	-	-	-	5	5
Year 2	Autumn	Apr/09	-	-	2	-	2
		May/09	-	2	2	8	12
		Jun/09	-	2	-	12	14
	Winter	Jul/09	-	-	-	-	-
		Aug/09	-	-	-	2	2
		Sep/09	-	-	-	1	1
	Spring	Oct/09	-	-	-	-	-
		Nov/09	-	-	-	1	1
		Dec/09	-	-	-	-	-
	Summer	Jan/10	-	-	1	-	1
		Feb/10	-	-	-	-	-
		Mar/10	-	-	-	-	-
	Autunm	Apr/10	-	-	-	-	-
	Total		-	4A	8A	144B	156

Table 2. The monthly abundances by point of *Pleoticus muelleri* in Santos Bay from May 2008 to April 2010. Different letters indicate significant differences (Kruskal-Wallis, p < 0.05).

	Season	Months	P1	P2	P3	P4	Total
Year 1^{A}	Autumn	May/08	-	-	-	15	15
		Jun/08	-	-	-	5	5
	Winter	Jul/08	-	-	5	8	13
		Aug/08	-	1	12	28	41
		Sep/08	-	1	8	7	16
	Spring	Oct/08	-	-	-	3	3
		Nov/08	-	1	1	23	25
		Dec/08	6	9	36	202	253
	Summer	Jan/09	1	17	39	110	167
		Feb/09	-	-	-	-	-
		Mar/09	-	-	4	-	4
Year 2^{B}	Autumn	Apr/09	-	-	1	1	2
		May/09	-	-	2	8	10
		Jun/09	-	1	2	1	4
	Winter	Jul/09	-	-	6	35	41
		Aug/09	-	-	3	4	7
		Sep/09	-	-	9	15	24
	Spring	Oct/09	-	-	-	-	-
		Nov/09	-	-	-	-	-
		Dec/09	-	-	-	-	-
	Summer	Jan/10	-	-	-	-	-
		Feb/10	-	-	-	-	-
		Mar/10	-	-	-	-	-
	Autumn	Apr/10	-	-	-	-	-
	Total		7^{A}	30^{AB}	128^{BC}	465^{C}	630

abundances among the sample points analyzed (Kruskal-Wallis, p < 0.05). The biggest catch of shrimp (465 *P. muelleri* and 144 *A. longinaris)* was obtained at P4, and at P1, only 7 *P. muelleri* and 0 *A. longinaris* specimens were collected (Tabs. 1, 2).

The abundance of *P. muelleri* was negatively correlated with bottom water temperature (Pearson, p < 0.05), i.e., the highest catch rates were correlated with a decrease in the temperature (Fig. 4). For this species, we also observed a correlation between abundance and values of phi greater than 4 (silt and clay) and the highest levels of organic matter in the sediment (Pearson, p < 0.05) (Tab. 3).

For *A. longinaris,* we observed an increase in the capture rate of individuals with decreasing values of bottom temperature, salinity values between 34 and 36 and phi values between 5 and 6 (Fig. 4). However, there was no statistically significant correlation between the abundance of this species and any of the abiotic factors investigated (Pearson, p > 0.05) (Tab. 3).

Table 3. Test results of Pearson correlations between the abundances of *Pleoticus muelleri* and *Artemesia longinaris* in Santos Bay and the following abiotic factors: bottom water temperature and salinity, organic matter content of the sediment and phi.

Pleoticus muelleri				
Abiotic Factors	Temp.	Sal.	O.M.	Phi
Test value	-0,547	-0,137	0,232	0,259
P value	8,2E-09	0,182	0,023	0,011
Artemesia longinaris				
Abiotic Factors	Temp.	Sal.	O.M.	Phi
Test value	-0,141	0,019	0,190	0,127
P value	0,172	0,855	0,064	0,218

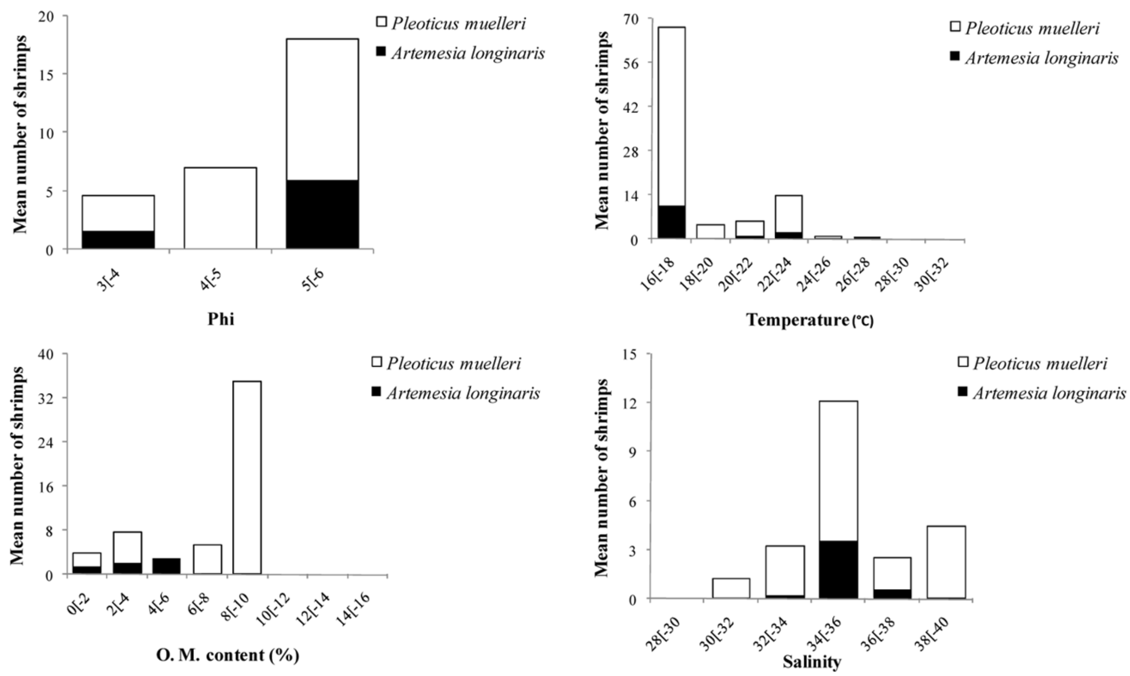

Figure 4. The average number of *Pleoticus muelleri* and *Artemesia longinaris* individuals captured by trawling from May 2008 to April 2010 in Santos Bay for each class of values for bottom water temperature and salinity, sediment organic matter content and phi.

Discussion

In this study, temperature was the main factor influencing the abundances of both species in the Santos Bay: lower bottom water temperatures resulted in increased abundances. These results corroborate those of Castilho *et al.* (2008a) and Costa *et al.* (2005), who considered these shrimp species as indicators of the intrusion of cold water along the northern coast of São Paulo State.

According to Campos *et al.* (1995, 1999), the body of water known as the South Atlantic Central Water (SACW) typically approaches the southeastern coast of Brazil during the spring and summer months, driven by the winds out of the northeast that predominate at this time of year. This water mass is characterized by temperatures below 20°C and salinities less than 36.4 (Castro-Filho and Miranda, 1998). This temperature and salinity pattern was observed mainly during the first year of the present study.

In Argentinean waters, *A. longinaris* and *P. muelleri* are caught at depths of 2-30 m and 3-100 m, respectively (Boschi, 1969; Bertuche *et al.*, 2000). However, in the present study, these species were caught at the deepest and outermost points in the Santos Bay, which were most influenced by the presence of the SACW. Costa *et al.* (2005) suggested that *A. longinaris* is more eurythermal than *P. muelleri.* The results of the present study support that assertion; *A. longinaris* was represented in samples collected at higher temperatures than *P. muelleri,* and there was a smaller increase in the abundance of *A. longinaris* than of *P. muelleri* during the period of intrusion of the SACW.

Studies conducted at Ubatuba found that the sediments composed of greater proportions of silt and clay were more favorable to the establishment of *P. muelleri* (Costa *et al.*, 2004), whereas *A. longinaris* was found in sediments predominantly composed of very fine sand (Costa *et al.*, 2005). In the present study, only *P. muelleri* followed this trend, as the highest catch rate recorded for both species occurred in hauls made in sediments with phi values of between 5 and 6, i.e., high proportions of silt and clay. However, these phi values were recorded at P4 (where the greatest abundances of both species occurred during the study period) during months of low temperatures (June and July 2009), which likely explains the higher catches in these hauls.

Costa *et al.* (2004) and Fransozo *et al.* (2004) found no correlation between organic matter content and the presence of either species in Ubatuba region, northern coast of São Paulo State. However, Fernández *et al.* (2007) found a relationship between *P. muelleri* juveniles, which were distributed in shallow waters, with total organic carbon in sediments, in São Jorge Gulf, Argentina. In the present study, although the majority of individuals of both species were adults, only *P. muelleri* individuals were collected in shallow waters in Santos Bay, which probably contributed for a significant relation between abundance of this species with this environmental factor.

During the study period, the values of phi and organic matter in the region varied little between the collection points. The sharp increase recorded for the values of these abiotic factors, especially during the second half of 2009, was likely anthropogenic, as Santos Bay regularly receives the deposition of dredged sediments from estuarine areas (Souza *et al.*, 2007).

According to Dall *et al.* (1990), salinity is a determining factor in the distribution of shrimp, however, there was no significant correlation between this factor and the distribution of the study species. An increase in abundance was only found with salinity values of between 34 and 36, followed by a slight drop in the following classes. Costa *et al.* (2005) also recorded higher catch rates for *A. longinaris* within this salinity range, whereas Costa *et al.* (2004) reported an increase in the capture rates of *P. muelleri* in hauls performed at higher salinity classes along the northern coast of São Paulo State.

During the second collection year, we observed both high salinity and high temperature values, indicating that the region was likely under the influence of tropical water, hindering the establishment of these species in the region. Santos Bay is affected by strong estuarine influences, which may have contributed to both species being found at sites of greater depth, as *P. muelleri* and *A. longinaris* have life cycles that are completely disconnected from the estuarine environment (Boschi, 1969; Boschi, 1989; Costa *et al.*, 2004). According to Odum (1988), certain environmental conditions are more likely to be critical for a given organism because they have larger amplitudes than the tolerance range of the species, limiting these species' distributions in relation to other, less variable factors. The present study shows that in Santos Bay, the distribution of *P. muelleri* and *A. longinaris* is limited by temperature and that these species can be considered to be indicators of SACW intrusion in the region.

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