

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 Frio. 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.

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°22'33"S, 41°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 m² 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 Håkanson & 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 ($T > 20^{\circ}\text{C}$, $S < 36.4$), Tropical Water (TW) shows both high temperature and salinity ($T > 20^{\circ}\text{C}$, $S > 36.4$), and South Atlantic Central Water (SACW) shows both low temperature and salinity ($T < 20^{\circ}\text{C}$, $S < 36.4$) (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 March 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).

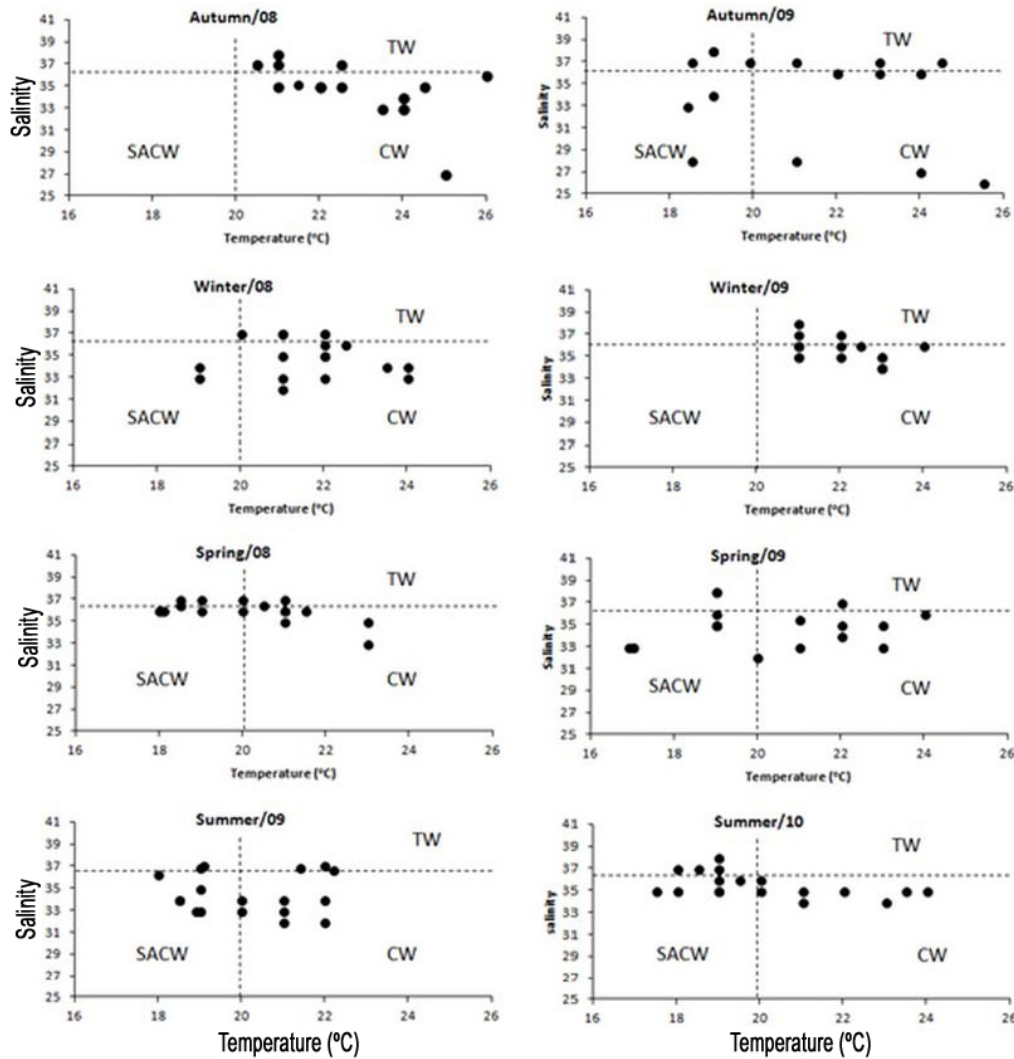


Figure 2. T-S Diagram showing the seasonal variation of water temperature and salinity during the sampling period at upwelling area studied, southeastern coast of Brazil. CW: Coastal Water, TW: Tropical Water, SACW: South Atlantic Central Water. Autumn: March-May, winter: June-August, spring: September-November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

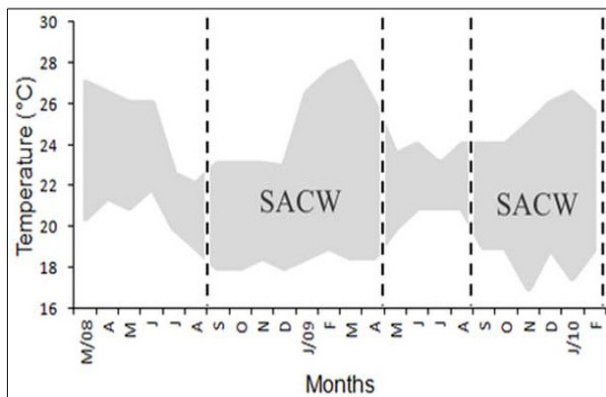


Figure 3. Highest surface and lowest bottom temperatures, showing the upwelling periods (SACW) in the study area.

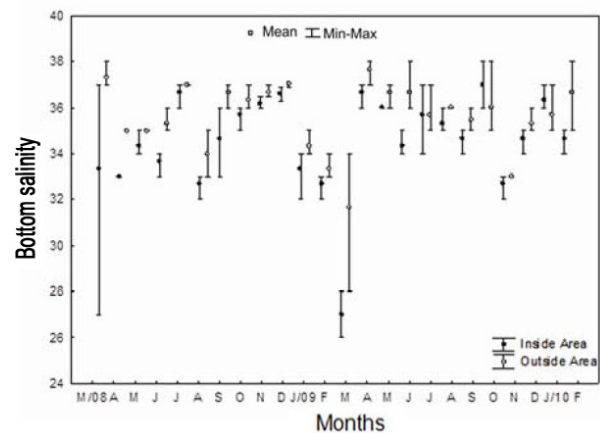


Figure 4. Mean, maximum and minimum salinity values for each month in "Inside area" and "Outside area", sampled from March 2008 to February 2010.

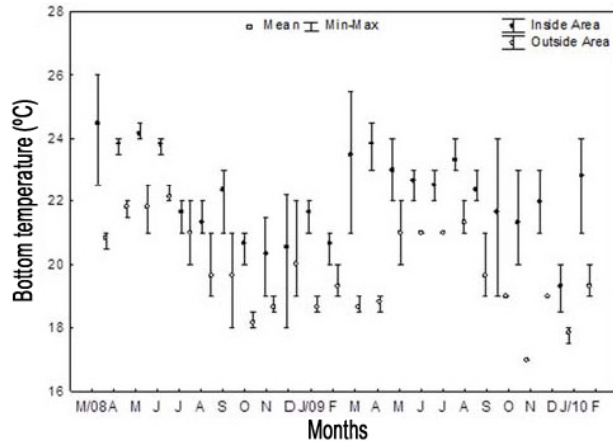


Figure 5. Mean, maximum and minimum temperature (°C) values for each month in "Inside area" and "Outside area" sampled from March 2008 to February 2010.

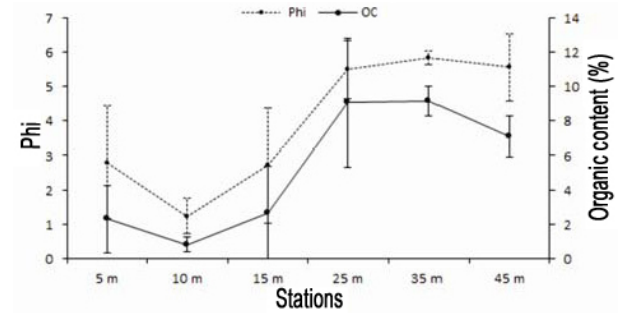


Figure 6. Mean values and standard deviation of phi and organic matter content, recorded in each station, sampled from March 2008 to February 2010.

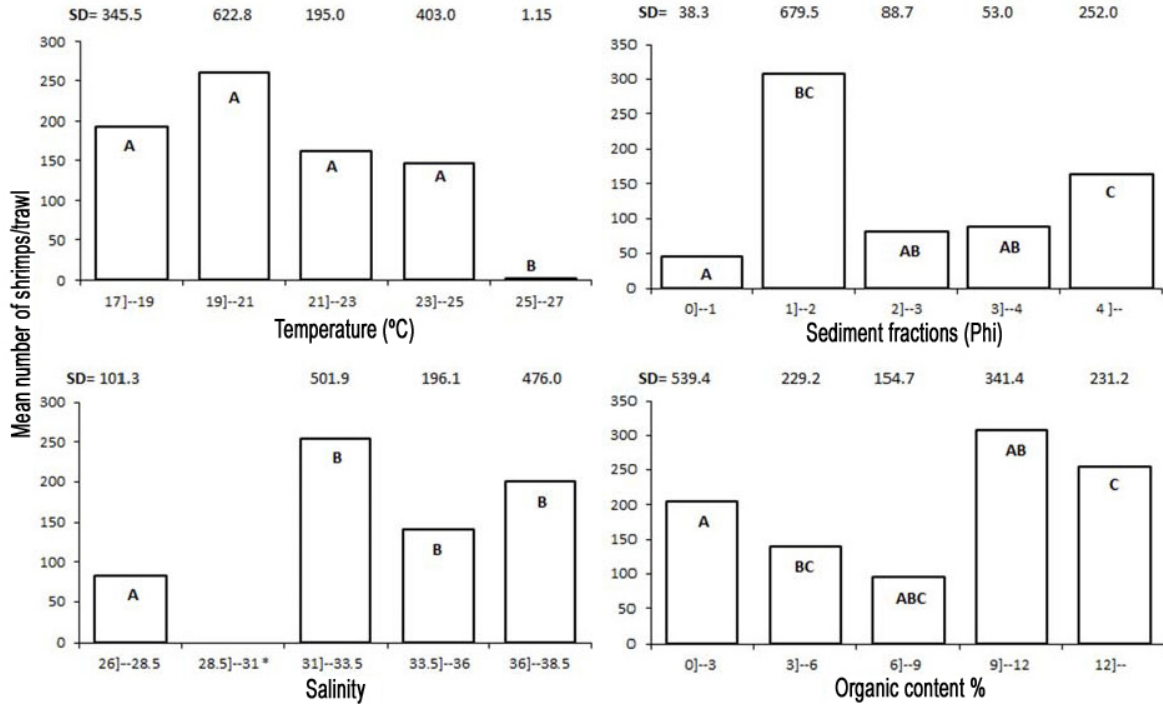


Figure 7. Distribution of mean number of shrimp per trawl and standard deviation (SD) for each class of environmental variable, along with variance analysis results indicating results of Tukey test ($P > 0.05$). Different letters indicate statistical significant difference. (*) No samples were collected 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	
		5 m	10 m	15 m	25 m	35 m	45 m	Month	Season
Year I									
Autumn I	Mar/08	2	0	77	233	350	0	661	
	Apr/08	33	90	86	184	157	4	554	2574
	May/08	15	155	577	583	0	28	1359	
Winter I	Jun/08	71	90	66	807	259	142	1435	
	Jul/08	86	132	134	494	165	19	1030	2673
	Aug/08	26	0	72	24	86	0	208	
Spring I	Sep/08	19	46	54	26	71	9	225	
	Oct/08	0	0	43	170	0	0	213	611
	Nov/08	0	0	81	64	28	0	173	
Summer I	Dec/08	12	0	23	1001	33	0	1069	
	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		
Autumn II	Mar/09	0	81	82	249	233	1	646	
	Apr/09	1	37	67	16	1150	2	1273	3321
	May/09	32	70	85	636	520	59	1402	
Winter II	Jun/09	31	22	101	488	325	447	1413	
	Jul/09	37	116	73	205	195	5	631	2276
	Aug/09	19	55	56	70	10	22	232	
Spring II	Sep/09	0	80	41	34	151	40	346	
	Oct/09	40	73	146	517	473	57	1306	5326
	Nov/09	5	2161	1126	368	14	0	3674	
Summer II	Dec/09	287	413	268	94	79	0	1141	
	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 penaeid 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 ($<20^{\circ}\text{C}$) 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 ($<20^{\circ}\text{C}$), 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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