Larval abundance variation of *Bregmaceros cantori* Milliken & Houde, 1984, related to the El Niño events (1987-1996), southern Gulf of Mexico

Variación de la abundancia de larvas de Bregmaceros cantori Milliken & Houde, 1984, relacionada con los eventos de El Niño (1987-1996), sur del Golfo de México

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Resumen.- Se analiza la influencia de El Niño Oscilación del Sur (ENSO) sobre la variación de la abundancia de las larvas del pez *Bregmaceros cantori* en el sur del Golfo de México. El estudio se desarrolló entre 1987 y 1996, usando 20 cruceros oceanográficos. La abundancia de *B. cantori* fue relacionada con: (1) la anomalía de la temperatura superficial del mar (SSTA) del Océano Pacífico central ecuatorial, (2) la temperatura promedio de la capa superficial de 30 m, de datos de las campañas, (3) las descargas de aguas continentales con datos provenientes de la estación hidrológica mas cercana al área de estudio. Hubo una alta variabilidad de la abundancia de larvas de *B. cantori* a través del tiempo, pero no se registró un patrón estacional. Durante el periodo de estudio ocurrieron tres eventos de El Niño: 1987, 1992 y 1995. Los análisis estadísticos indicaron diferencias significativas en la abundancia de larvas entre los años de El Niño y años normales, sin el evento de El Niño. Se encontraron altas abundancias de *B. cantori* en los periodos de El Niño en comparación con los años normales. Es posible que las mayores abundancias de larvas de *B. cantori* durante años de El Niño estén asociadas con relaciones depredador-presa.

Palabras clave: Larvas de peces, ENSO, influencia medio ambiental

Abstract.- The influence of the El Niño Southern Oscillation (ENSO) on the abundance variation of fish larvae of *Bregmaceros cantori* in the southern Gulf of Mexico was analyzed. The study was conducted between 1987 and 1996, using 20 oceanographic cruises. The larval abundance of *B. cantori* was related to: (1) the sea surface temperature anomaly (SSTA) in the central equatorial Pacific Ocean; (2) the average temperature surface layer, to 30 m, obtained from cruises data; (3) the continental water discharges data from the continental hydrological station nearest to the study area. The variability of *B. cantori* larval abundance was high throughout the sampling period and no seasonal pattern was detected. During the study period, three events of El Niño occurred: in 1987, 1992 and 1995. Statistical analyses indicated significant differences of the larvae abundance of *B. cantori* between El Niño and normal years, i.e, years without El Niño. High abundances of fish larvae were found during El Niño years. Higher abundances of *B. cantori* larvae, during El Niño years, are possibly associated to predator-prey relationships.

Key word: Larval fish, ENSO, environmental influence

Introduction

The ocean-atmosphere interaction in the central Pacific Ocean generates changes on the sea surface temperature (SST) and the movements of warm water masses, over the Ecuador-Peru-Chile coast. This phenomenon is called El Niño (Philander 1990, Chavez *et al*. 1999, Schwing *et al*. 2002), and this event together with the Southern Oscillation is called ENSO. The ENSO signals influence directly physical and biological aspects in the Pacific Ocean, or indirectly in the Atlantic Ocean and Gulf of Mexico by atmospheric teleconnections (Lluch-Cota *et al*. 2004).

Among other effects, El Niño is associated with low fisheries catch in the eastern Pacific coast because this coast is in a zone with direct influence of warm waters during El Niño; for example, in Peru, fisheries decreased 60% during the 1997-1998 El Niño event (Duffy & Bryant 1998). During the same period, in the Mexican Pacific

coast, many fisheries resources from Sinaloa to Baja California also decreased (Lluch-Cota *et al.* 2004). Moreover, El Niño event also produced seasonal changes in the abundance and distribution of fishes and their spawning (Bailey & Incze 1985, Miller *et al.* 1985, Smith 1985, Moser *et al.* 1987, MacCall & Prager 1988); the zooplankton biomass is affected by this event along the California and Oregon coasts (Chelton *et al.* 1982, Roesler & Chelton 1987). In fact, an increased number of equatorial fish larvae has also been recorded in unusual northern zones, while populations of temperate taxa contracted northward during El Niño (Moser *et al.* 1987, Funes-Rodríguez *et al.* 2002).

Mostly, the El Niño effects have been related to the fisheries in the Pacific Ocean; to our knowledge, no studies examining fisheries effects on planktonic organisms in the Gulf of Mexico have been published.

The Bregmacerotidae is among the ten more common and abundant families of organisms collected from plankton samplings, between neritic and oceanic waters, and tropical and subtropical areas (Houde 1984). In the southern Gulf of Mexico, the only genus of this fish family is *Bregmaceros* in which *B. cantori* is generally one of the most abundant species among other groups, such as, clupeids, engraulids, gobids and carangids (Flores-Coto *et al.* 1993, 2000, Espinosa-Fuentes & Flores-Coto 2004).

Fish larvae of bregmacerotids are not commercial species, and because of their high abundance in the southern Gulf of México, they are potential markers of the effects of El Niño events.

Larval abundance variation of *B. cantori* in the Gulf of Mexico has no evident seasonal patterns (Houde 1981, Zavala-García & Flores-Coto 1994), and the abundance variability may be caused by El Niño event. Thus, the objective of this study was to determine if there was a relationship between the larval abundance of *B. cantori* and some environmental factors associated with the El Niño phenomenon.

Material and methods

Data collection

The Bregmacerotidae larvae used in this study were collected during 20 oceanographic cruises. From the winter, between 1992 and 1996, 16 seasonal cruises over 22 sampling stations distributed in four transects on the continental shelf of the southern Gulf of Mexico were performed (Fig. 1). A series of another four cruises were carried out, three in 1987, and one in summer 1988.

During 1987, 1988, 1992, and spring of 1993, Bongo
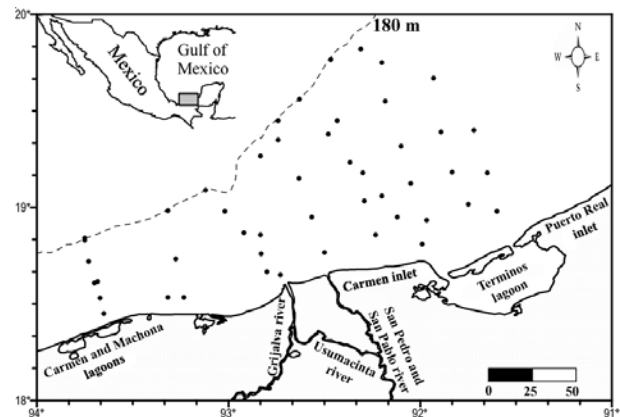
Figure 1

Study area and sampling stations in the southern Gulf of Mexico

Área de estudio y estaciones de muestreo en el sur del Golfo de México

nets with double-oblique tows were used while other cruises used open-close nets with stratified sampling in the water column. In all cases, the mesh size was 505 μm; the samples were preserved in formalin 4% and then transferred to alcohol 70% after 24 h.

Local temperature data were obtained using a conductivity temperature depth (CTD) instrument (except in four cruises) and an average of 30 m surface layer by cruise was considered for this study.

Data analysis

All fish larvae were extracted from the sample and those of the Bregmacerotidae family were selected. Species were identified according to Richards (2006) and their densities were expressed as number of organisms per 100 m^3.

Monthly sea surface temperature anomalies (SSTA) data of the central equatorial Pacific Ocean (Region 3.4) were obtained from the Climate Prediction Center of the National Oceanic and Atmospheric Administration (NOAA) (Table 1).

Continental water discharge data were taken from the hydrological station nearest to the Grijalva-Usumacinta outlet (Table 1).

Monthly mean wind data for the period 1970-2002 were used for the wind field analysis. To estimate the convergence of the wind component along the coast, this quantity was computed along the segments between 21°N and 20°N on the eastern side of the Bay of Campeche as well as between 19N and 20° 30′N on the western side. The difference was evaluated for each month and the

Variables	Period	Source
Sea surface temperature anomalies (SSTA)	1987-1996	Climate Prediction Center http://www.cpc.ncep.noaa.gov/data/indices/
Continental Water Discharges	1987-1996	Banco Nacional de Datos de Aguas Superficiales (BANDAS) CNA-IMTA (México)
Wind Fields Anomalies	1970-2002	http://data.ecmwt.imt/data
Chlorophyll Anomalies	1997-2004	SeaWiFS level 3 Standard Mapped Images Goddard Distributed Active Archive Center at the NASA/Goddard Space Flight Center

anomaly was computed by subtracting the monthly mean of the mentioned period (Table 1).

The monthly anomaly of chlorophyll *a* concentration (as indicator of productivity) was computed by subtracting the corresponding monthly mean of the period to the value of each month. Then, the values of the shelf in the area of study and those of the southern site of the Bay of Campeche were selected for analysis. Montly satellite data used for this study were chlorophyll and climatology data, from September 1997 to December 2004. Eight years of Sea-viewing Wide Field-of-view Sensor (SeaWiFS) ocean color images were also analyzed (Table 1). Further information regarding the calibration methodologies and SeaWiFS data processing can be found in McClain *et al.* (1998).

Statistical analysis

To estimate if there were significant differences among seasonal larval densities, a Kruskal-Wallis multiple comparison test was applied. To obtain the association between the SSTA and larval density, a Spearman correlation test was used, using the larval average density of each season (equals each cruise) and the corresponding SSTA average. The relationships of these variables were calculated and compared between years when El Niño event occurred and for normal years (without El Niño). Finally, the same data were analyzed yearly. Spearman correlations were also used to relate the larval density means to local temperature and continental water discharge. The Chi-square test was used to establish if there was a difference between the annual average larval densities (Zar 1996). The observed values (Ni) of annual catches correspond to the natural logarithm of the annual average density plus one. The expected values (Ei) for each year were obtained using: $Ei = \sum Ni \, (Ai/\sum Ai)$, where Ai = SSTA annual average plus two.

Several environmental factors were identified as likely related to or influenced by El Niño conditions: local water temperature, continental water discharges, wind field anomaly and chlorophyll anomaly (see Table 1 for data sources). The relationships between these environmental variables and SSTA were determined through Pearson correlations. In addition, the relationship between wind field anomaly and chlorophyll anomaly was also tested using a Pearson correlation.

Results

Abundance pattern

Four species, *Bregmaceros cantori* Milliken & Houde, 1984*, B. atlanticus* Good & Bean, 1886, *B. houdei* Saksena & Richards, 1986 and *Bregmaceros* n. sp, have been recorded in the study area; *B. cantori* was the more abundant (98.5%), *B. atlanticus* was scarce (1.37%), while the other two species were rare.

A large variability of larval abundance of *B. cantori* was observed (Table 2, Fig. 2) and no seasonal pattern was detected. Higher and lower larval densities occurred in different seasons and different years. For instance, high densities were recorded during the summer and fall of 1987, or the winter of 1992 and 1995 (Fig. 2). The Kruskal-Wallis test showed no significant differences among seasonal densities (*P*> 0.05) (Table 3).

### El Niño and abundance variability of *Bregmaceros cantori* larvae

The periods of high and low *B. cantori* larval abundance corresponded to El Niño and normal years, respectively (Fig. 2). The Spearman correlation, using the total data as independent of the year or season between SSTA and larval abundance, showed positive relationship although it was not significant (Table 3). The larval abundance

Table 2

Seasonal average density of *Bregmaceros cantori* larvae (in 100 m³) in the southern Gulf of Mexico between 1987 and 1996

Densidad promedio estacional de larvas de *Bregmaceros cantori* (en 100 m³) en el sur del Golfo de México entre 1987 y 1996

Year	Season	*B. cantori*
1987	Winter	4.597
	Summer	57.419
	Fall	28.475
1988	Summer	11.857
1992	Winter	18.124
	Spring	14.470
	Summer	13.880
	Fall	7.955
1993	Winter	2.885
	Spring	4.910
	Summer	8.029
	Fall	2.085
1994	Spring	1.564
	Summer	1.113
	Fall	1.822
1995	Winter	14.756
	Spring	2.719
	Summer	12.244
	Fall	6.435
1996	Winter	9.447
	Σ	224.7858
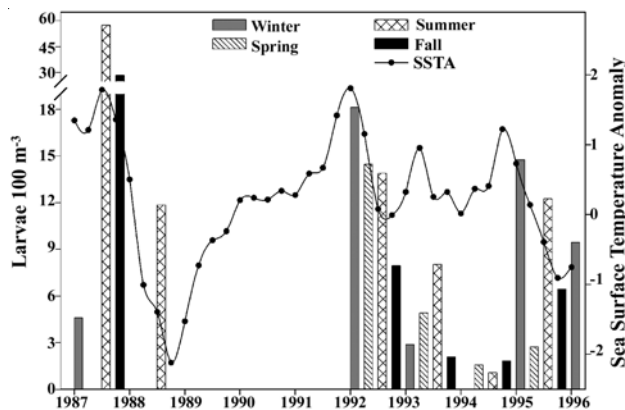
Figure 2

Seasonal variation of *Bregmaceros cantori* larval abundance related to the sea surface temperature anomaly in the central equatorial Pacific, Region Niño 3.4

Variación estacional de la abundancia de las larvas de *Bregmaceros cantori* relacionada con la anomalía de la temperatura superficial del mar en el Océano Pacífico ecuatorial central, Región Niño 3.4

and SSTA showed a positive and significant correlation during El Niño years (1987, 1992, 1995) ($r_s = 0.63$) and a negative but no significant correlation during normal years (1993, 1994) ($r_s = - 0.39$).

Analyses performed by years showed a significant positive correlation for El Niño 1987 and 1992 ($r_s = 1$), and a not significant correlation in 1995 ($r_s = 0.40$); and for normal years, a negative correlation in 1993 ($r_s = - 0.40$) and positive correlation in 1994 ($r_s = 0.5$) (Table 3).

Results of the Chi-square test indicated significant differences among annual average larval density ($\alpha = 0.05$, df = 4) and the residual standard values corroborated a higher larval abundance of *B. cantori* during El Niño

Table 3

Results of statistical analyses applied to different variables

Resultados de los análisis estadísticos aplicados a las diferentes variables

Test	Variables	Test Statistic Value	*P*-value	N
Kruskal Wallis	Larval Density - Season	2.08	0.56	20
Spearman	Larval Density - SSTA (All years)	0.29	0.23	18
Spearman	Larval Density - SSTA (Niño years)	0.63	0.04*	11s
Spearman	Larval Density - SSTA (Non Niño years)	-0.39	0.34	7
Spearman	Larval Density - SSTA (1987)	1.00	0.00*	3
Spearman	Larval Density - SSTA (1992)	1.00	0.00*	4
Spearman	Larval Density - SSTA (1993)	-0.40	0.49	4
Spearman	Larval Density -. SSTA (1994)	0.50	0.48	3
Spearman	Larval Density - SSTA (1995)	0.40	0.49	4
Chi-square	Annual Larval Density and SSTA	1.21	0.05*	5
Spearman	Larval Density - Local Temperature	-0.19	0.45	18
Spearman	Larval Density - Continental Discharge	-0.17	0.50	18
Pearson	SSTA - Local Temperature	-0.07	0.80	17
Pearson	SSTA - Continental Discharge	-0.62	0.02*	13
Pearson	SSTA - Wind Field Anomaly	0.91	0.00*	33
Pearson	Wind Field Anomaly - Chlorophyll Anomaly	-0.14	0.42	33
Pearson	SSTA - Chlorophyll Anomaly	-0.17	0.36	33

* Significant difference

1987, 1992, and 1995 than normal years 1993 and 1994 (Tables 3 and 4).

Environmental factors and larval abundance

Results showed a relationship between the high larval abundance of *B. cantori* and the El Niño years. To investigate what factors were influencing the larval abundance variability, the following factors were considered: local temperature, continental water discharges, chlorophyll (as indicator of productivity).

It was found a negative correlation between larval density and local temperature (r_s = -0.19) and continental water discharges (r_s = -0.17) (Table 3). There was also an inverse relationship between SSTA and local water temperature (Table 3, Fig. 3A) and continental water discharges (Table 3, Fig. 3B). In the latter, the inverse relationship with SSTA was more evident and statistically significant.

There was a high and significant relationship between SSTA and wind fields anomalies (WFA) (r = 0.91). The chlorophyll anomaly also had a negative relationship with WFA (r = -0.14) and SSTA (r = -0.17) (Table 3, Fig. 4).

Table 4

Chi square (χ^2) analysis of the abundance of *Bregmaceros cantori* larvae among years (α = 0.05, df = 4). SSTA = Annual average of the sea surface temperature anomaly on the central equatorial Pacific Ocean (Region 3.4). D = Annual average larval density. Ni = Ln (D + 1). Ei = Expected values. SRi = Standardized residual

Análisis de Chi cuadrado (χ^2) de la abundancia de larvas *Bregmaceros cantori* entre años (α = 0,05, df = 4). SSTA = Promedio anual de la anomalía de la temperatura superficial del mar en el Océano Pacífico ecuatorial central (Región 3.4). D = Promedio anual de la densidad larval. Ni = Ln (D + 1). Ei = Valores esperados. SRi = Valores de residual estandarizado

Year	SSTA+2	D (Org 100m^{-3})	Ni Ln(D+1)	Ei	SRi
87	3.43	31.29	3.47	2.91	0.33
92	2.75	13.60	2.68	2.33	0.23
93	2.47	4.57	1.72	2.10	-0.26
94	2.50	1.51	0.92	2.13	-0.83
95	1.90	8.76	2.28	1.60	0.53
Σ	13.04	59.72	11.07	11.07	
χ^2					1.21*

* Significant difference
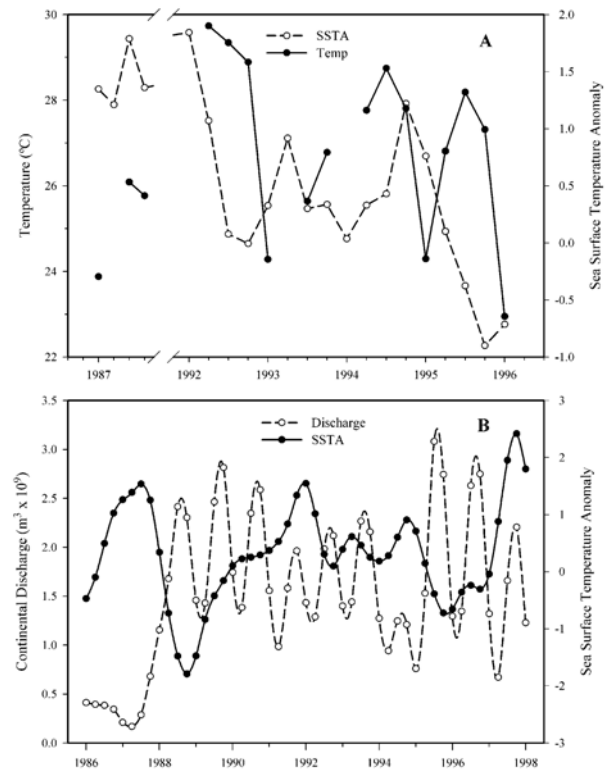
Figure 3

Surface average temperature (30 m depth) of the water column (A) and continental water discharges (B) in the southern Gulf of Mexico related to the sea surface temperature anomaly in the central equatorial Pacific, Region Niño 3.4

Promedio de la temperatura superficial (30 m de profundidad) de la columna de agua (A) y descargas de agua continental (B) en el sur del Golfo de México, relacionados con la anomalía de la temperatura superficial del mar en el Océano Pacífico ecuatorial central, Región Niño 3.4

The above data showed lower values of temperature, discharge, and chlorophyll density and large larval densities of *B. cantori* during El Niño years and an inverse trend during normal years.

Discussion

The largest source of world inter-annual climate variability is El Niño-Southern Oscillation (ENSO) that extends globally through the ability of the atmosphere to bridge oceans basins (Karoly 1989, Wang *et al*. 2004). The manifestations of the changes in the atmospheric circulation in the tropics are detected throughout the global atmosphere by teleconnections (Trenberth *et al*. 1998). At the same time, changes in the atmospheric circulation can influence the oceans and force an
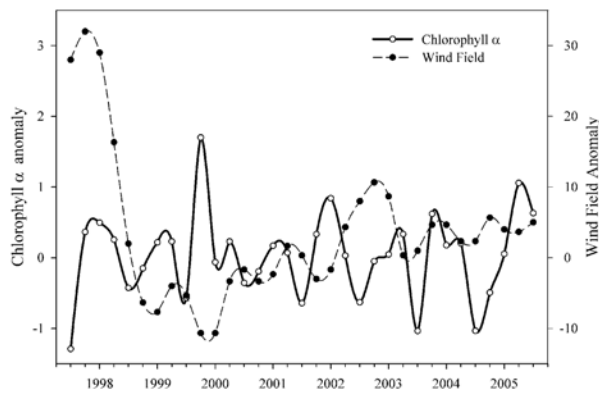
Figure 4

Relationship between wind field and chlorophyll *a* anomalies in the southern Gulf of Mexico

Relación entre las anomalías del campo de vientos y clorofila *a* en el sur del Golfo de México

identifiable signal (Wang *et al*. 2004). ENSO signals in the Gulf of Mexico are small (Mestas-Núñez & Enfield 2005), but they can influence physical and biological aspects of the coast (Escobar-Briones 2002, García *et al*. 2003).

During the study period (1987-1996), there were three El Niño years, 1987, 1992, and 1995. Although some authors did not consider 1995 as an El Niño year, others did. For example, Magaña & Morales (2004) considered that 1991-1995 was the longest El Niño period ever seen. Trenberth & Hoar (1996) referred that the warm event related to El Niño in the tropical Pacific from 1990 to June 1995 was the longest period recorded since 1882; this was never seen in the climate record for the past 113 years. These ten-year data did not show any seasonal variation pattern of abundance for *B. cantori* larvae. High and low densities of this fish larva occurred in different seasons and different years (Fig. 2). High and low values alternated among seasons, except for 1992 when a sequence from high to low values occurred from winter to fall. These differences indicated that abundance variability might be determined by factors acting at time scales longer than one year.

The positive correlation between SSTA and larval abundance was more evident for El Niño years (Table 3). The largest larval densities occurred during El Niño years (1987, 1992, and 1995) and the lowest in the normal years indicated that El Niño events influenced positively the larval abundance, probably as a result of several factors interacting one another each other. Possibly, the influence was indirectly affecting the habitat conditions, particularly the temperature, continental water discharges and primary production, food availability that fish could use.

Low surface temperature in the Atlantic Ocean like those recorded during El Niño 1983 (Philander 1990) was shown in the results of 1987, 1992, and 1995. On the other hand, the low continental water discharges occurring during El Niño years corresponded to its general feature; that is, during El Niño there is less rain in areas which are normally rainy (Magaña & Morales 2004).

The inverse relationship between chlorophyll anomaly in area studied and SSTA indicated that high biological production occurred during the normal years. Probably, there is some nutrients enrichment along with the high continental water discharges in such period. Generally, the largest biotic production in the southern Gulf of Mexico is a consequence of the nutrient enrichment through the continental water discharges, as it occurred in the northern Gulf of Mexico (Govoni *et al*. 1989, Cowan & Shaw 1991, Biggs & Sanchez 1997, Chen *et al*. 1997) and other parts of the world (Bowman & Iverson 1978, Mann & Lazier 1991).

Because larvae of *B. cantori* are first order carnivores that feed on plankton, copepods, and cladocers (Zavala-Gracía & Flores-Coto 1994), high larval density was expected during normal years when larger discharges and high temperatures generated larger biotic production (Vidal & Whiteledge 1982, Davis 1987) from the primary production (high chlorophyll) and zooplankton biomass. As in other ecosystems high primary production is the most important item for larval fish survival (Platt *et al*. 2003). Nevertheless the results were the opposite, consequently the variability of *B. cantor*i larvae must be related indirectly with El Niño events.

According to Bakun & Broad (2003), globally teleconnected climatic trends or shifts might produce globally-coherent population expansions even when local environmental expression may be quite different, as in the case of adult sardine population that increased in the Eastern Pacific during El Niño periods. El Niño has positive and negative effects on different fish populations, such as the decreased population of anchovy (Engraulidae) in Peru, but increased populations of sardine (Clupeidae), jurel (Carangidae), and mackerel (Scombridae). In front of California in 1957-1958 and 1982-1983, El Niño diminished the fish shipments that formed large schools, but increased the capture of species of commercial value such as tunas (Scombridae), dolphins (Coryphaenidae), and barracudas (Sphyrenidae) (Arntz & Fahrbach 1996).

Why did the largest larval densities occur during El Niño years, when the continental water discharges and biotic production are low? The answer could be related to the predator-prey relationship.

It seems logical that abundance of *B. cantori* larvae must be proportional to the adult size population. If there was a large adult population, it probably represented an important food source for large predators' species like Lutjanidae, Scombridae and other pelagic fish. Some fish species, such as *Lutjanus gutatus* (Lutjanidae), *Synodus foetens* (Synodontidae), *Campsodon snyderi* (Campsodontidae), and *Merluccius gayi* (Merlucciidae), prey on Bregmacerotidae (Morohoshi & Sasaki 2003, Rojas *et al.* 2004, Cruz-Escalona *et al.* 2005, Tam *et al.* 2006).

Changes in the diet of some population could occur when the main prey population disappear or decrease. During El Niño 1982-1983, in two locations of the Peruvian coast, the proportion of anchovy (*Engraulis ringens*) abundance in the diet of jack mackerel (*Trachurus murphyi*) was reduced, while the crustacean abundance increased (Arntz & Fahrbach 1996). *Merluccius gayi peruanus* also fed mainly on anchovy and euphausids; however, because of tropicalization during the El Niño in 1997-1998, there was a reduction in anchovy consumption and a significant increase in consumption of other preys such as Myctophidae, and Bregmacerotidae (Tam *et al.* 2006). Thus, any fish population will move toward a more abundant and available prey.

In a normal food chain, during the normal years, where continental water discharges are high and biological productivity is enhanced, large predator fishes must have high food availability and may not need small species like *B. cantori*.

As a result of predator-prey oscillations or low pressure of predation, the stock of *B. cantori* must increase substantially. When the food availability for predators decreases during El Niño, small fish species like Bregmacerotidae become an important prey. Consequently, the adult population decays and the number of larvae decrease for the next generation.

From this study the main conclusions are that in the Southern Gulf of Mexico, the abundance of *B. cantori* larvae do not have a seasonal variation pattern, and that the variability is indirectly related with El Niño through of the habitat parameters as temperature, continental water discharges and food availability. According to the results of this study we propose the following hypothesis: The high and low larval densities of *B. cantori* during El Niño and normal years respectively are controlled by predator-prey relationships.

Acknowledgments

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