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The influence of abiotic and biotic factors on the composition of Tetraodontiforms larvae (Teleostei) along the Brazilian Northeast Exclusive Economic Zone (1ºN - 14ºS)

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Abstract. The aim of the present study was to verify the composition of the Tetraodontiforms larvae and to analyze the influence of abiotic factors (temperature and salinity) and biotic factors (phytoplanktonic and zooplanktonic biomass), on the spatial and temporal distribution of larvae. Ichthyoplankton was collected during Period: 1 (August – October 1995), 2 (January – April 1997), 3 (April – July 1998) and 4 (September – December 2000), realized in the Brazilian Northeast Exclusive Economic Zone (BNEEZ). We examined 1230 Bongo-net (300 and 500 µm) samples units that contained 51 Tetraodontiforms larvae from six families: Balistidae (*Balistes capriscus*), Monacanthidae (*Stephanolepis hispidus*), Ostracidae (*Lactophrys trigonus*), Tetraodontidae (*Sphoeroides* sp.1 and *Sphoeroides* sp.2), Diodontidae (*Diodon hystrix)* and Molidae *(Ranzania laevis*). *Sphoeroides* sp.1 was the species highest relative abundance (36%), with higher value during the Period 3 (20%), while the Period 1 was recorded low relative abundance (2%). *B capriscus* was the second species with highest relative abundance (18%), with higher values during the period 2 and 3. The results demonstrated that abiotic and biotic factors influence the distribution and abundance of Tetraodontifomes larvae in the BNEEZ leading each species to occur in a period and place more favourable to spawn.

Key words: ichthyoplankton, oceanographic factors, distribution, abundance

Resumo. Influência de fatores abióticos e bióticos na composição de larvas de Tetraodontiformes (Teleostei) ao longo da Zona Econômica Exclusiva do Brasil (1ºN – 14ºS). Este trabalho teve como objetivo estudar a composição das larvas de Tetraodontiformes e analisar a influência de fatores abióticos (temperatura e salinidade) e bióticos (biomassa fitoplanctônica e zooplanctônica), sobre a distribuição espacial e temporal dessas larvas. O ictioplâncton foi coletado nos Períodos: 1 (Agosto – Outubro 1995), 2 (Janeiro – Abril 1997), 3 (Abril – Julho 1998) e 4 (Setembro – Dezembro 2000), na Zona Econômica Exclusiva do Nordeste Brasileiro (ZEENB). Foram analisadas 1230 unidades amostras coletadas com rede Bongo (300 e 500 µm) que continham 51 larvas de Tetraodontiformes pertencentes a 6 famílias: Balistidae (*Balistes capriscus*), Monacanthidae (*Stephanolepis hispidus*), Ostracidae (*Lactophrys trigonus*), Tetraodontidae (*Sphoeroides* sp.1 e *Sphoeroides* sp.2), Diodontidae (*Diodon hystrix)* and Molidae *(Ranzania laevis*). *Sphoeroides* sp.1 foi a espécie com maior abundância relativa (36%), com maior valor observado no Período 3 (20%) e a menor no Período 1 (2%). *B. capriscus* foi a segunda espécie com maiores valores de abundância relativa (18%), registrados nos Períodos 2 e 3. Os resultados demonstraram que os fatores abióticos e bióticos tendem a influenciar a distribuição e abundância de larvas de peixes Tetraodontifomes na ZEENB fazendo com que cada espécie tenha um período e um local mais favorável para desovar.

Palavras chave: ictioplâncton, fatores oceanográficos, distribuição, abundância

Introduction

The fishes of the Tetraodontiforms Order inhabit pelagic and demersal environments in tropical and subtropical regions (Richards 2006). The Tetraodontiforms fishes have extended pelagic juvenile stages (Leis 1993) and they are popularly called "puffers", "boxfishes", "triggerfishes", "porcupinefishes" and "molas" (Nelson 2006).

In Brazilian waters this order is represented by 6 families with 40 species (Menezes *et al.* 2003): Balistidae (6 species), Monacanthidae (8 species), Ostracidae (5 species), Tetraodontidae (11 species), Diodontidae (7 species) and Molidae (3 species). However, few is know about larval abundance and distribution patterns of Tetraodontiforms in Brazil (Matsuura & Katsuragawa 1981, Lessa *et al*. 1999, Nonaka *et al*. 2000, Bonecker *et al*. 2007a, 2007b, Mafalda Jr. *et al*. 2008, Bonecker *et al*. 2009, Costa & Souza-Conceição 2009, Mafalda Jr. & Souza 2009).

According to Lessa *et al.* (1999) more westerly stations in the Fernando de Noronha were dominated by species of the Tetraodontidae family, which made up 75 to 100% of the larvae found at all stations. In Todos os Santos Bay, *Sphoeroides* sp. larvae was found in coastal area under influence of petrochemical activities (Mafalda Jr. *et al*. 2008). Recent studies in Exclusive Economic Zone (EEZ) also present information about the occurrence of Tetraodontiforms fishes in the Northeast (Nobrega *et al.* 2009, Mafalda Jr. & Souza 2009), and Central region (Bonecker *et al*. 2009).

Distribution patterns of fish larvae in any region of the ocean are related to the reproductive activity of the adult population and to topographic and hydrographical features that affect the dispersal of the larvae (Nonaka *et al*. 2000). So, the occurrence of fish larvae should be a seasonal sequence depending upon the distribution of each species and its spawning period, which are faith know for most of Tetraodontiforms species.

The present work analyzed the occurrence of the Tetraodontiformes larvae, spatial and temporal distribution patterns of the most abundant species and evaluated the influence of abiotic factors (temperature and salinity) and biotic factors (phytoplanktonic and zooplanktonic biomass) along the Brazilian Northeast EEZ.

Study Area

The study area is limited by the estuary of the Parnaíba river (Piauí), and Todos os Santos bay, in Salvador (Bahia) (Fig. 1), includes the Archipelagos of Fernando de Noronha and Saint Peter and Saint Paul. This is tropical oceanic region, constituted of a oligothrophic system, that it possess a complex alimentary web, however with low biological productivity (Ekau & Knoppers 1999). The South Equatorial Current (SEC) reaches the NE Brazilian shelf between 11 and 15º S (Peterson & Stramma 1991). The SEC comprises a broad westward flow with a mean velocity of 10 to 15 $cm.s^{-1}$ and along the equator there is a much swifter current with a mean velocity of 30 $cm.s^{-1}$ (Tchernia 1980). The North Brazil Current follows at a mean velocity of 75 $cm.s^{-1}$ with superficial temperature between 28 and 30 ºC, and superficial salinity between 35 and 37 (Medeiros *et al*. 1999). The Brazil Current flows at a mean velocity of 10 to 15 $cm.s^{-1}$ with mean superficial temperature of 26 ºC and salinity above of 35 (Tchernia 1980).

Materials and methods

Sampling

A total of 1230 samples units were collected during four REVIZEE expeditions realized between 1995 and 2000 (Fig. 1). The expeditions were made on August – October 1995 (Period 1 - winter), January – April 1997 (Period 2 - summer), April – July 1998 (Period 3 - spring) and September – December 2000 (Period 4 - autumn). Ichthyoplankton sampling was made with Bongo nets (50 cm of diameter mouth, 300 and 500 µm meshes). The nets were equipped with two flowmeters independent to estimate the water volume filtered.

The sampling method used followed Smith & Richardson (1977). Sampling was done through oblique hauls from the maximum depth of 200 m to the surface. The duration of the tow was 10 minutes. The samples obtained were preserved in 4% buffered formalin – seawater. All Tetraodontiforms larvae were removed from each sample and stored in 70% alcohol.

Tetraodontiforms larvae were identified to the lowest taxonomic level according to the morphological characters of each group (Lyczkowski-Shultz 2006a, Lyczkowski-Shultz 2006b, Lyczkowski-Shultz & Ingram 2006, Lyczkowski-Shultz *et al*. 2006a, Lyczkowski-Shultz *et al*. 2006b). Standard densities of individual taxa were expressed as the number per 100 m^3 of filtered water for each collection. All larvae identified were deposited in the larval fish collection of the Plankton Laboratory of the Federal University of Bahia, Salvador, Brazil.

Water temperature and salinity were measured at each station using a CTD. Water samples for determination of phytoplanktonic biomass (chlorophyll *a*) in 1% of light were obtained using a fluorescence sonde. The determination of the zooplanktonic biomass (dry weight) was carried through according to methodology of Omori & Ikeda (1984).

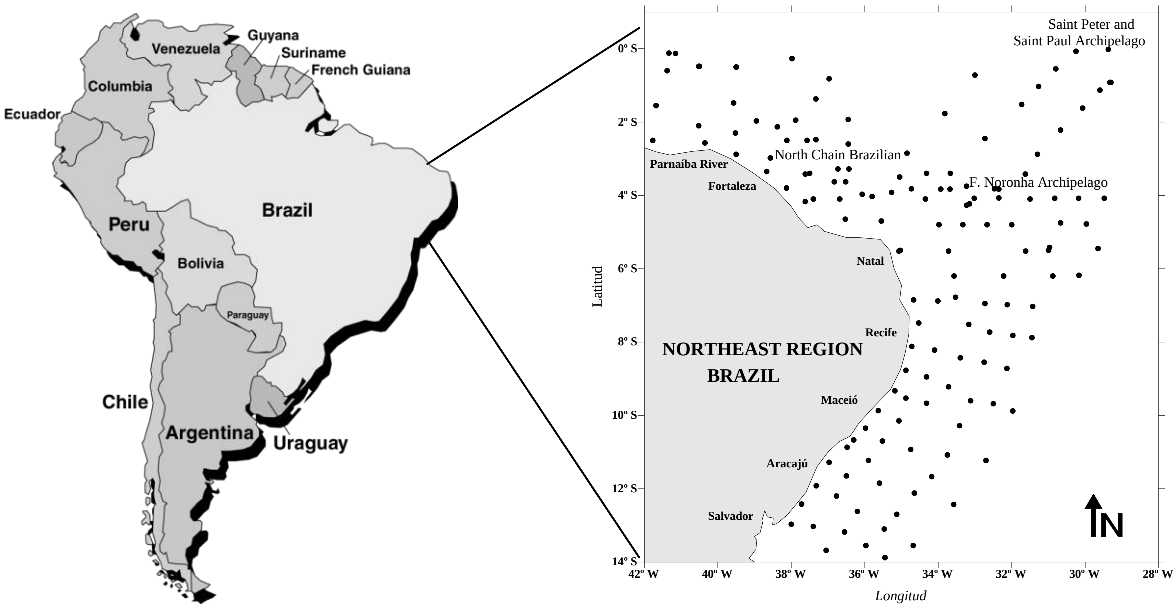

Figure 1. Study area showing the sampling stations along the Brazilian Northeast Exclusive Economic Zone.

Data analysis

In order to determine the statistical significance of the temporal variables on biotic and abiotic factors were used non-parametric Kruskal-Wallis test and Dunn's multiple comparisons test (Zar 1984). The Detrended Canonical Correspondence Analysis (DCCA) was performed with all oceanographic variables to investigate the gradient length. Since the gradient was below 3 the Redundancy Analysis (RDA) was employed (Ter Braak & Smilauer 1998) to verify the Tetraodontiforms pattern of variation associated to the oceanographic variables (temperature, salinity, phytoplanktonic biomass and zooplanktonic biomass). Prior to analysis, logarithmic transformation Ln(x+1) of larval density (x) was performed to homogenize the variance. The matrix created with the oceanographic data was submitted to a square root transformation to reduce the effect of different scales.

Results

Oceanographic characteristics

The distribution patterns of the oceanographic factors were based on values measured at surface (Table I). In terms of temperature was observed variations up to 1.5ºC between periods 1 and 2. There were significant differences in temperature between the four analyzed periods (Kruskal-Wallis, $p < 0.0001$). The test of multiple comparisons of Dunn verified that the periods 1 and 4 differ from periods 2 and 3. The salinity was too significantly different among periods (Kruskal-Wallis, $p < 0.0001$). The test of multiple comparisons of Dunn showed that the periods 1 and 2 differ from periods 3 and 4. The values of salinity and temperature registered in all the periods, indicated the presence of Superficial Equatorial Water (SEW), which had a salinity > 35 and temperature > 26º C, and Coastal Water (CW), with salinity around 35.

Table I. Results of Kruskal-Wallis test, amplitude and mean of abiotic factors (temperature and salinity), biotic factors (phytoplanktonic and zooplanktonic biomass) and Tetraodontifoms larvae (abundance and relative percentual abundance) along the Brazilian Northeast Exclusive Economic Zone.

	Temperature (?C)	**Salinity**	**Phytoplanktonic biomass (µg.L-1)**	**Zooplanktonic biomass (g.100m-3)**	**Tetraodontifoms larvae (%)**
Period 1	26.1 - 27.8 (26.6)	35.5 - 37.3 (36.1)	0.03 - 0.2 (0.15)	0.02 - 1.6 (0.5)	3 (6)
Period 2	26.2 - 29.4 (28.9)	34.8 - 37.2 (36.2)	0.2 - 3.9 (1.2)	0.03 - 11.3 (1.0)	22 (43)
Period 3	25.8 - 28.6 (27.1)	34.5 - 37.4 (36.4)	0.1 - 5.1 (1.7)	0.07 - 4.1 (1.0)	17 (33)
Period 4	25.7 - 28.4 (26.8)	35.2 - 37.2 (36.3)	0.2 - 5.9 (1.8)	0.2 - 2.4 (1.5)	9 (18)
KW Test	p < 0.0001	p < 0.0001	p < 0.0001	p < 0.0001	51 (100)

Phytoplanktonic and Zooplanktonic Biomass

The phytoplanktonic and zooplanktonic biomass (Table I) were significantly different among periods (Kruskal-Wallis test, $p < 0.0001$). The lowest primary biomass was founded in period 1 and the highest values were observed in periods 3 and 4 (Dunn test, $p < 0.05$). The dry weight also presented lowest values during Period 1 but the highest were found in the Period 2 (Dunn test, $p < 0.05$).

Larval fish composition

A total of 51 larvae were identified in the Brazilian Northeast EEZ, represented by: Balistidae (*Balistes capriscus*) (Gmelin, 1789), Monacanthidae (*Stephanolepis hispidus*) (Linnaeus, 1766), Ostracidae (*Lactophrys trigonus*) (Linnaeus, 1758), Diodontidae (*Diodon hystrix*) (Linnaeus, 1758), Molidae (*Ranzania laevis*) (Pennant, 1776) and two species of Tetraodontidae (*Sphoeroides* sp1 and *Sphoeroides* sp2). Among the total of Teleostei fish larvae, the Tetraodontiforms had low relative abundance (0.26%) and frequency of occurrence (6.7%).

Dominant species comprised 66% of total relative abundance. They were *Sphoeroides* sp.1 (36%), *B. capriscus* (18%) *and R. laevis* (12%) (Fig. 2). *Sphoeroides* sp.1 showed the highest abundance during the Period 3 that corresponding 20% of the total of larvae identified (Fig. 2), while the period 1 was the period of low abundance, with 2% of the total (Fig. 2). *B. capriscus* was the second species in abundance representing 18% of the total of Tetraodontiforms. This species had greatest abundance during the period 2 and the period 3 (Fig. 2). The third species in abundance was *R. laevis* that corresponded to 12% of the Tetraodontiforms larvae. *S. hispidus*, *L. trigonus*, *D. hystrix* and *Sphoeroides* sp.2 were less abundant, contributing 34% of total larvae (Fig. 2).

Spatial and temporal distribution

Tetraodontiforms larvae were collected more frequently within the oceanic zone of the Northeast Brazilian. *Sphoeroides* sp.1 presented large distribution occurring in neritic and oceanic region and were collected in all periods with the maximum density during period 3 in the Fernando de Noronha Archipelago (Fig. 3). *B. capriscus* were found predominantly in neritic stations and the higher density occurred near the Parnaíba river mouth, during period 2. This species did not occur during period 4 (Fig. 3). *R. laevis* occurred mainly in oceanic stations, between Maceió and Aracaju, during period 2 and in front off Salvador during period 4 (Fig. 3). *Stephanolepis hispidus* larvae were found in neritic and oceanic stations, and *Lactophrys trigonus*, *Diodon hystrix* and *Sphoeroides* sp.2 were found only in oceanic region (Fig. 3).

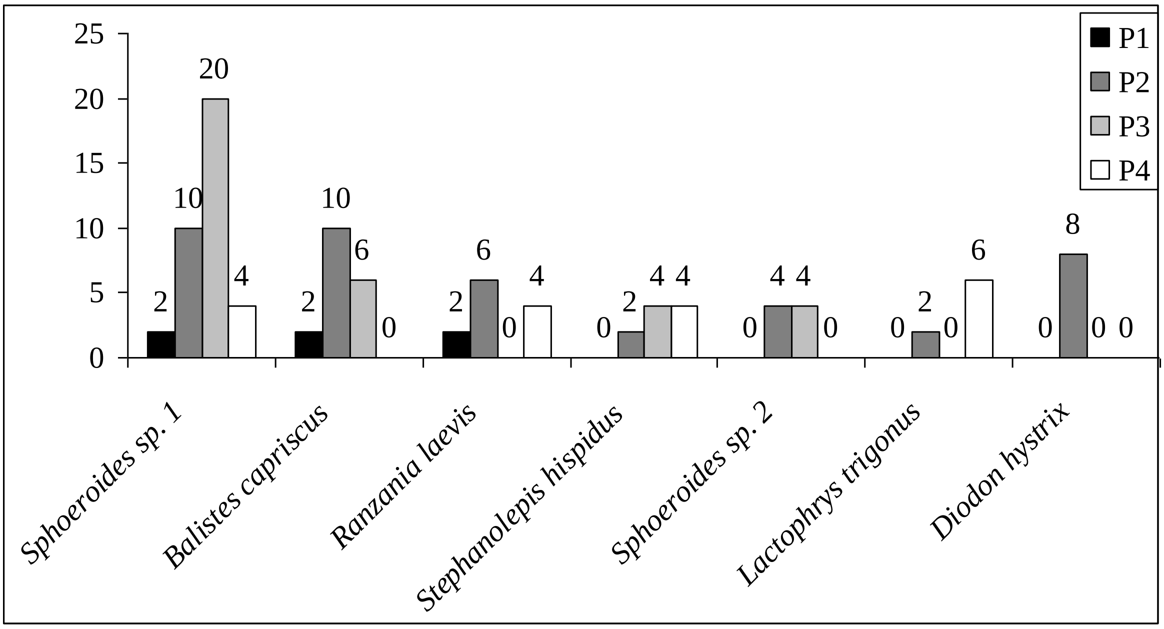

Figure 2. Relative percentual abundance of Tetraodontiforms larvae along the Brazilian Northeast Exclusive Economic Zone in periods of collection (P – Period).

Data analysis

The Redundancy Analysis based on a reduced set of four environmental variables (temperature, salinity, phytoplanktonic biomass and zooplanktonic biomass) was performed to verify the existence of an ordination between species and respective samples. Eigenvalues, measures of importance for RDA axes that may vary between zero and one, ranged from 0.071 for RDA 1 to 0.003 for RDA 4 (Table II). Species-environment correlations were high for the two first RDA axes, ranging from 0.637 to for RDA 1 to 0.556 for RDA 2. The cumulative percentage of species variance (CPSV) accounted for the RDA in a total of 14.1% for the first four RDA axes. Furthermore, the first two RDA axes explained 77.1% of the cumulative percentage of the species-environment (CPSE). Because the first two RDA axes explained 14.1% of the CPSV and 77.1% of the CPSE, the latter two RDA axes were not further interpreted.

The low multiple regression coefficients of environmental variables indicated that there were not collinear variables. This result is important because multicolinear variables must be deleted from the analysis, since collinear variables can influence the canonical coefficients (Ter Braak, 1986). The plot of RDA sample and species scores illustrates their dispersion pattern, and the plot of environmental variables vectors illustrates the directions and strengths of environmental relationships within the first two dimensions of the RDA ordination (Fig. 4).

The environmental gradients were important correlates with the abundance of Tetraodontiforms larvae in the RDA. The temperature, salinity and zooplaktonic biomass were correlated with the RDA axis 1 and the phytoplanktonic biomass correlated with the RDA axis 2. These environmental gradients also reflected the spatial and temporal changes in the species density. *B. capriscus* and *D. hystrix* were negatively correlated with the first and second RDA axes. *Sphoeroides* sp.1, *Sphoeroides* sp.2 and *R. laevis* were positively correlated with the first and second RDA axes. *S. hispidus* and *L. trigonus* were negatively correlated with the first axis and positively correlated with the second RDA axis.

This implies that *Stephanolepis hispidus, Lactophrys trigonus, Balistes capriscus* and *Diodon hystrix* occurred mainly at high water temperature and zooplanktonic biomass during Periods 2 (summer) and 3 (spring). *Ranzania laevis, Sphoeroides* sp.1 and *Sphoeroides* sp.2, appeared preferentially during periods 2 (summer) and 4 (autumn) at high phytoplanktonic biomass and salinity (Fig. 4).

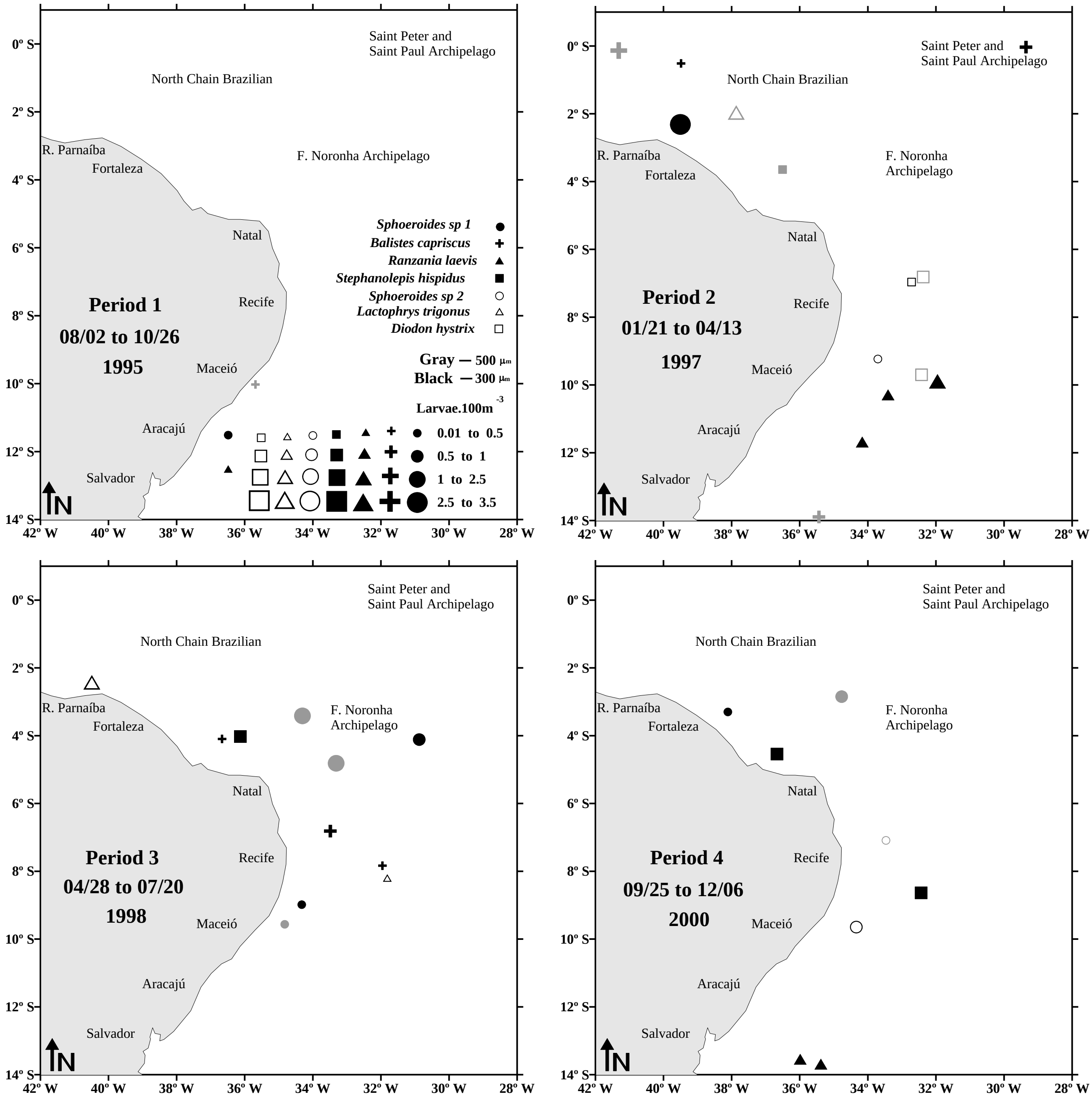

Figure 3. Temporal and spatial distribution of Tetraodontiforms larvae along the Brazilian Northeast Exclusive Economic Zone.

Most of stations with Tetraodontiforms larvae (Table I) was concentrated in periods 2 (summer), 3 (spring) and 4 (autumn), characterized by higher temperature values, as well as primary and secondary biomass. The period 1 (winter), that was characterized by low values of temperature, primary and secondary biomass, showed a low occurrence of Tetraodontiforms larvae (6%).

Discussion

Based upon temperature and salinity results the study area presented typical characteristics of tropical regions, with high salinity and temperature. The water masses indicated the presence of Superficial Equatorial Water and Coastal Water where the Tetraodontiformes fish larvae were captured during this study. Consequently this area is known to be oligotrophic with a low concentration of nutrients, phytoplanktonic and zooplanktonic biomass (Ekau and Knoppers 1999, Medeiros *et al.* 1999, Neumann-Leitão *et al.* 1999). Such characteristics may be explained by the existence of a warm surface layer above a colder and denser sub-surface layer, which creates a permanent thermocline. This tends to inhibit the upward flow nutrient of rich deeper layers, restricting primary production in surface waters (Travassos *et al*. 1999).

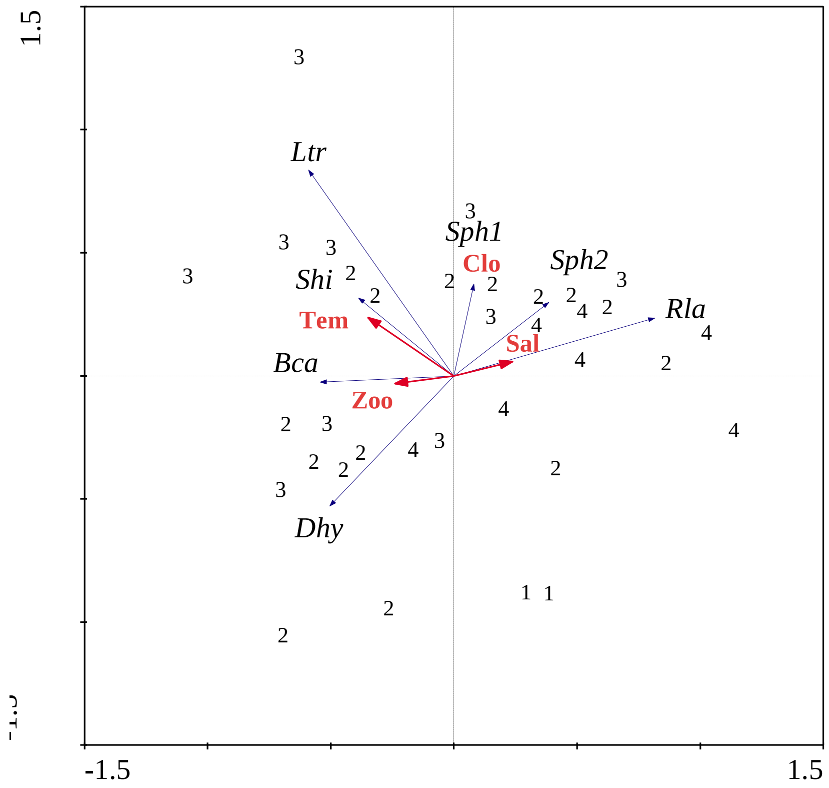

Figure 4. Ordination diagram of the Redundancy Analysis (RDA) (1: Period 1; 2: Period 2; 3: Period 3; 4: Period 4; Clo: phytoplanktonic biomass; Tem: temperature; Sal: salinity; Zoo: zooplanktonic biomass; Bca: *Balistes. capriscus*; Shi: *Stephanolepsis. hispidus*; Ltr: *Lactophrys. trigonus*; Sph1: *Sphoeroides* sp1; Sph2: Sphoeroides sp2; Dhy: *Diodon. hystrix;* Rla: *Ranzania. laevis*).

Table II. Results from Redundancy Analysis (RDA) of abiotic factors, biotic factors and Tetraodontifoms larvae along the Brazilian Northeast Exclusive Economic Zone.

	Axes				
	1	2	3	4	Total variance
Eigenvalues	0.071	0.038	0.030	0.003	1.000
Species-environment correlations	0.637	0.556	0.470	0.133	
Cumulative percentage variance					
of species data	7.1	10.9	13.9	14.1	
of species-environment relation	50.3	77.1	98.0	100.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.141

In the Brazilian Northeast Exclusive Economic Zone, there are three areas where submarine relief and local current may facilitate the upwelling process. These include the Saint Peter and Saint Paul Archipelago, Fernando de Noronha Chain and North Brazilian Chain. At one seamount in the North Brazilian Chain, a pronounced upwelling cone was found, suggesting the formation of a Taylor column that presented the greatest potential for enrichment of the surface layers, but there was no evidence to show that any of the upwelling extended to the surface (Travassos *et al*. 1999).

According to Medeiros *et al.* (1999) mangrove export, via river discharge and shelf break upwelling, could be the mechanisms contributing to the phytoplanktonic productivity of Northeast Brazilian waters. In the four investigated periods, the values of macrozooplankton trended to increase in the adjacent areas to North Brazilian Chain, Saint Peter and Saint Paul Archipelago and Fernando de Noronha Chain, possibly owing the topographic upwelling. The *Sphoeroides* sp.1 larvae were collected with the maximum density during period 3 in the Fernando de Noronha Archipelago.

The low abundances of mesozooplankton generally correspond to oligotrophic water masses and differences were locally affected by mangroves inshore or by topographic upwelling offshore (Neumann-Leitão *et al*. 1999). In period 1 was recorded the lowest values for occurrence and density of ichthyoplankton (Fig. 3), this is may happen because the oligotrophic water conditions in the period represented by the low values of phytoplankton biomass (0.15 $\mu g.L^{-1}$) compared to others periods (Table I).

The Tetraodontiformes fish larvae in the Brazil Northeast EEZ were composed by a diverse collection of coral-reef-associated and epipelagic fish (*R. laevis*) represented by 6 families, 1 genus (with two morphotypes) and 5 species. Tetraodontiformes are an order composed by 9 families (Nelson 2006), six of them identified in the present study. The high richness of 7 morphotypes is characteristic of the tropical marine ecosystem and similar taxonomic richness of larval fish found in the Brazil Central EEZ where were identified 6 families, 2 genus and 9 species (Barros *et al.* 2006).

Bonecker *et al*. (2009) found in Brazilian Central ZEE four families of Tetraodontiformes all of them found in the present study, but only two species match with species found in the Brazilian Northeast ZEE (*Balistes capriscus* and *Ranzania laevis*). Most species found in their study occurred in spring, period with highest values of *S. hispidus*, *Sphoeroides* sp.1 and *Balistes capriscus* in Brazilian Northeast ZEE (Fig. 3). The occurrence of Tetraodontiforms fish larvae should be a temporal sequence depending upon the distribution of each species and its spawning period, which are faith know for most of the species.

Three Tetraodontiforms species predominated in the surveyed area: *Sphoeroides* sp.1 (35%), *Balistes capriscus* (18%) and *Ranzania laevis* (14%). Different species of *Sphoeroides* are also more abundant in other areas of the western Atlantic (Bonecker *et al.* 2007b, Mafalda *et al.* 2008, Bonecker *et al.* 2009, Costa & Souza-Conceição 2009).

Tetraodontiforms larvae distribution in Brazilian Northeast EEZ varied over time and among sampling locations. The wide larval distribution of this taxa at open ocean stations might be a consequence of a high larval drift from the seamounts and coral-reef area where massive spawning occurs. Studies that interpret ichthyoplankton structure in terms of adult characteristics often find spatially heterogeneous distribution of larvae that are attributable to adult characteristics (Gaughan *et al.* 1990, Yoklavich *et al.* 1992).

Variation on hydrographic structure seems to have an important influence on spawning season and area as well as on the distribution pattern and abundance of fish larvae (Olivar & Shelton 1993, Thorrold & McWilliams 1996, Mafalda Jr. & Rubín 2006, Sabatés *et al*. 2001). Hence, the environmental influence revealed by multivariate analysis, with higher density of fish larvae during the periods 2 (summer), 3 (spring) and 4 (autumn) (higher salinity and temperature), might be due to the preference of Tetraodontifomes fishes to spawn in optimal conditions of salinity and temperature.

The group formed in these periods presented higher secondary productivity also showing a helpful larval habitat with high food availability (Heath 1992). In the Gulf of Mexico (Flores-Coto *et al.* 1989) and Mediterranean Sea (Sabatés 1990) highest spawning period occurs in summer. In Gulf of Cádiz the high abundance of fish larvae suggest that summer too coincides with the onset of the reproductive season of many fishes (Mafalda Jr. & Rubín 2006).

Favorable larval habitats have been defined by their biological (e.g. high abundance of phytoplankton and zooplankton and low abundance of predators) and physical (e.g. circulation patterns promoting retention or transport to nursery area) characteristics (Heath 1992). However, the environmental conditions at the time of fish eggs and larvae development may differ from year to year, due to variation in the environmental characteristics, changes in the timing of emergence of fish eggs and larvae or a combination of both (Page and Frank 1989).

Examining spatial and temporal patterns in distribution and abundance of ichthyoplankton in relation to abiotic conditions may provide insight into the adaptation of spawning strategies to the prevailing physical and biological processes as well as into the effect of the variability in these processes on year – class strength (Somarakis *et al.* 2002). What supports our results, that demonstrated the influence of abiotic factors (temperature and salinity) and biotic factors (phytoplanktonic and zooplanktonic biomass) on the distribution and abundance of Tetraodontifomes fish larvae in Brazilian Northeast EEZ.

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