

# Structure and dynamics of Gobiidae larvae (Teleostei, Perciformes) in a tropical estuary: seasonal relationships with tidal cycles

EDUARDO A.P. GOMES AND ANA C.T. BONECKER

Universidade Federal do Rio de Janeiro, Instituto de Biologia, Departamento de Zoologia, CCS, Bloco A, Ilha do Fundão, 21941-590, Rio de Janeiro, RJ, Brazil

*This study aims to describe the spatial and temporal distribution patterns of Gobiidae larvae at a tropical estuarine system in south-east Brazil (Macaé). The samples were collected in six stations, through oblique hauls using a bongo net (330 µm mesh size), coupled to a flowmeter, during the night in the ebb and flood tides in March, July and October 2006 and in February 2007. In the Macaé River estuary was collected a total of 1,234 Gobiidae larvae, representing nine taxa. The highest densities occurred in the river mouth during the flood tide in the rainy season. The most abundant groups were: Gobiosoma parri, Gobionellus oceanicus and Ctenogobius boleosoma. Gobiosoma parri was also dominant at the Macaé estuary, which also presented higher densities in the coastal stations during the rainy season (March), both the flood as the ebb tide. Gobionellus oceanicus and Ctenogobius boleosoma were characteristic of the dry season in the mouth and river stations during the flood tide. The abiotic factors chlorophyll-a and temperature were considered biologically significant for Gobiidae larvae distribution. The spatial and seasonal variations together with the tide influence the distribution of the fish larvae Gobiidae family in the Macaé River estuary and its coastal zone.*

**Keywords:** estuary, fish larvae, Gobiidae, tropical

Submitted 9 October 2013; accepted 24 April 2014; first published online 3 June 2014

## INTRODUCTION

The generally small body-sized gobiid fish of the family Gobiidae constitute the most diverse group of marine teleost fish (Burgess *et al.*, 1990). The gobies mainly inhabit coastal waters worldwide: south-western Australia (Neira & Potter, 1992); south Florida (USA; Sponaugle *et al.*, 2003); south-western Europe (Moyano & Hernández-León, 2009); Portugal (Primo *et al.*, 2011); South Africa (Wasserman *et al.*, 2010); and the Persian Gulf (Koochaknejad *et al.*, 2011). Among these, few studies have focused on the larval ecology in Brazilian estuaries. There are more studies about Gobiidae larvae in north-east (e.g. Barletta-Bergan *et al.*, 2002a, b; Barletta *et al.*, 2003; Mafalda Jr *et al.*, 2004, 2008; Bonecker *et al.*, 2007; Sarpedonti *et al.*, 2008) than in south-east Brazil (e.g. Castro *et al.*, 2005; Coser *et al.*, 2007; Spach *et al.*, 2010; Bonecker *et al.*, 2012).

The composition of larval fish assemblages vary spatially and temporally because of the behaviour of larvae (Gray & Miskiewicz, 2000), and due to transport and mixing processes (Muhling *et al.*, 2008). For many marine species, recruitment success requires transport from open ocean to estuarine nursery habitats during early life. Therefore, larvae must adopt strategies to ingress into estuarine nursery grounds (Islam *et al.*, 2007). Selective tidal-stream transport is a common mechanism used by marine and estuarine organisms

for horizontal movement (Forward & Tankersley, 2001). The direction of transport is determined by the tidal type during which the organism migrates up into the water column.

Larvae often use active upward or downward swimming and passive sinking coupled with both circadian and tidal rhythms (Tamaki *et al.*, 2010). Many species rely on both endogenous rhythms and exogenous cues to precisely time vertical migration (Fortier & Leggett, 1983; Sclafani *et al.*, 1993). Therefore, fish larvae can be carried upstream by the flood tide and, on the other hand, are able to remain within the estuary, avoiding the current back to the ocean on the ebb tide (Jager, 1999). This behaviour can be critical to survival since changes in environmental conditions may affect recruitment success of both estuarine and non-estuarine-dependent species (Parrish *et al.*, 1981).

The aim of the present study was to describe the spatial and temporal distribution patterns of Gobiidae larvae at a tropical estuarine system in south-east Brazil. The following were the main points addressed: (1) which is the abiotic factor more related to the density distribution?; (2) does larval density differ among stations?; and (3) what are the dynamics of the larval fish of the family Gobiidae in the Macaé River estuary?

## MATERIALS AND METHODS

### Study area

The Macaé River rises in the Serra de Macaé at Nova Friburgo city and has a drainage basin that covers approximately

Corresponding author:  
E.A.P. Gomes  
Email: eduapg@hotmail.com

1766 km<sup>2</sup>. Its estuary is classified as bar type, and the main channel is relatively narrow and shallow, approximately 3.0 m (Hora *et al.*, 2001). This region has semi-diurnal tides ranging around 1.0 m for spring tides and 0.5 m for neap tides. The region's climate is always humid mesothermal with 1500–2000 mm average annual rainfall. The rainy season (from November to April) is characterized by overflowing rivers and the dry season extends from May to October (Beltrão, 2003).

Since the 1970s, when the exploration of oil and gas in the Campos Basin started, the Macaé population has increased 4.4-fold, from 47,220 in 1970 to 206,728 in 2010 (IBGE, 2012). This growth in a short period of time increased the outflow of nutrients and metals in the Macaé River basin. Anthropogenic sources are responsible for most emissions to the Macaé River (Molisani *et al.*, 2012).

## Field methodology

Sampling was carried out in the rainy (March 2006 and February 2007) and dry seasons (July and October 2006), over two consecutive nights, in the flood and ebb tides. Six sampling stations were positioned in the study area: three located in the adjacent coastal area, one in the estuary mouth and two inside the Macaé River (Figure 1; Table 1).

Plankton samples were obtained by oblique hauls for about five minutes using a bongo net (0.6 m diameter, 2.5 m length, 330 µm mesh-size), according to the technique described by Smith & Richardson (1977). Samples from each net were called R1 and R2. Two flowmeters (General Oceanics®) were used to estimate the volume of water filtered. Geographical location of the sampling stations was provided by a GARMIN 12 XL GPS. Immediately after collection, the samples were fixed in formaldehyde solution diluted to 4% in local water. Surface and bottom temperature and salinity were obtained with a thermosalinometer (LabComp). Surface water samples were obtained for analysis of chlorophyll-*a* using a van Dorn bottle. The precipitation data were

**Table 1.** General data and geographical coordinates of the six sampling stations located in Macaé River estuary and adjacent coastal region.

Station	Region	Latitude	Longitude
1	Coast	22°21'18" S	41°45'21" W
2	Coast	22°21'49" S	41°45'57" W
3	Coast	22°22'33" S	41°45'54" W
4	Mouth	22°22'19" S	41°46'33" W
5	River	22°21'56" S	41°46'40" W
6	River	22°21'21" S	41°46'59" W

provided by the National Water Agency hydrologic system, Brazil and were measured at Gaudinópolis Station (22°22'09" S 42°22'46" W).

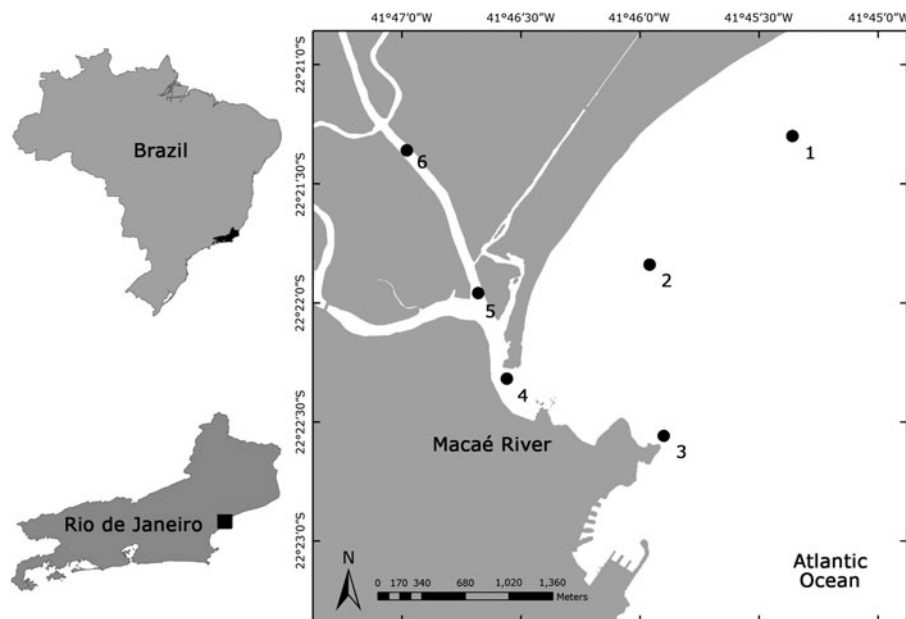
## Laboratory methodology

### LARVAL IDENTIFICATION

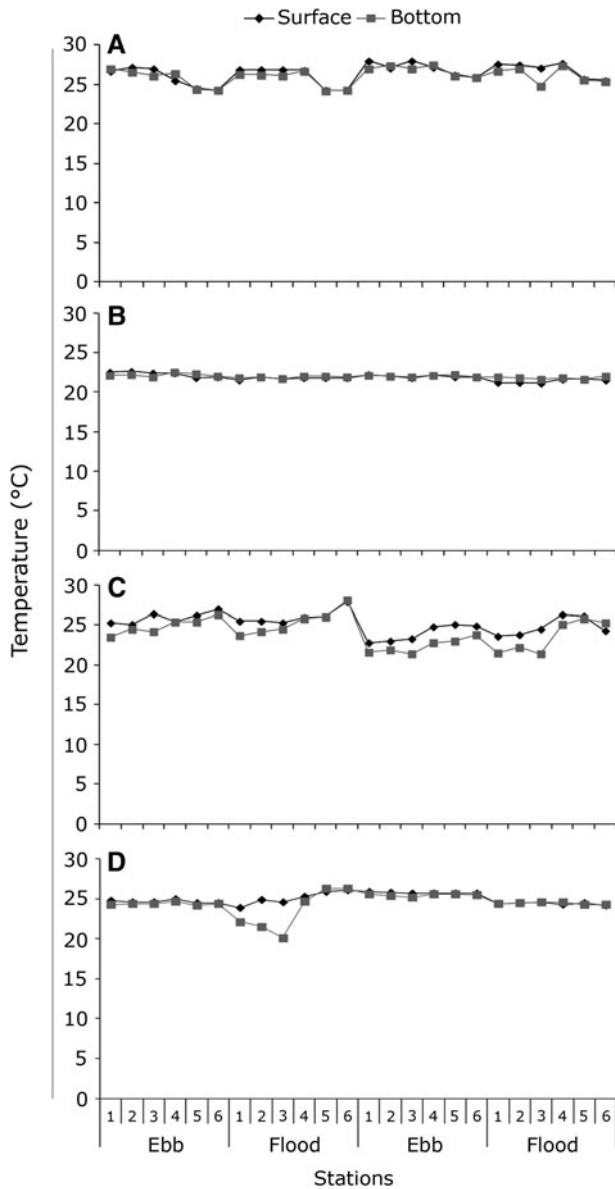
Larvae were sorted from all samples and after the identification were preserved in 70% ethanol. Initially larvae were identified to family level and subsequently to lower taxonomic levels according to the criteria of Wyanski & Targett (2000), Baldwin & Smith (2003), Yeung & Ruple (2006) and Fahay (2007).

### STATISTICAL ANALYSES

The two samples collected with bongo net were considered replicates and we used the mean values and the standard deviations of larval density. Densities were previously transformed to  $\log(x + 1)$  to reduce the heterogeneity of the data (Peters, 1986). Significant differences were considered when  $P < 0.05$ . The normality and homogeneity of variances were tested using the Levene and Shapiro–Wilk tests, respectively, with the statistical program STATISTICA® 6.0. As the Levene test was significant ( $P < 0.05$ ), the spatial variation of larval fish density was analysed with a non-parametric test (Kruskal–Wallis) and tidal and seasonal variations were verified with the Mann–Whitney test.



**Fig. 1.** Macaé River estuary and location of the six sampling stations where goby larvae were collected.



**Fig. 2.** Variation of water temperature on the surface and bottom at sampling stations, ebb and flood tides conducted in March 2006 (A), July 2006 (B), October 2006 (C) and February 2007 (D) in the Macaé River estuary.

To verify the similarity among taxa, we performed a cluster analysis using the program PRIMER 6. Unpaired Weight Group Average was used as the aggregation algorithm on the matrix of pairwise Euclidean distances.

To examine the relationship of taxa with abiotic factors canonical correspondence analysis (CCA) was performed with the program PC-ORD 4.0<sup>®</sup>. The data matrix was generated considering three abiotic variables (temperature, salinity and chlorophyll-*a*) of 68 samples. The null densities of fish larvae were disregarded in this test. The Monte Carlo test (Ter Braak & Smilauer, 2002) was conducted to test the significance of the correlation between taxa and these abiotic variables. Inter-set correlation coefficients were used to assess the importance of the environmental variables, and when inter-set  $\geq |0.4|$ , variables were considered to be biologically important (Rakocinski *et al.*, 1996).

## RESULTS

### Abiotic factors

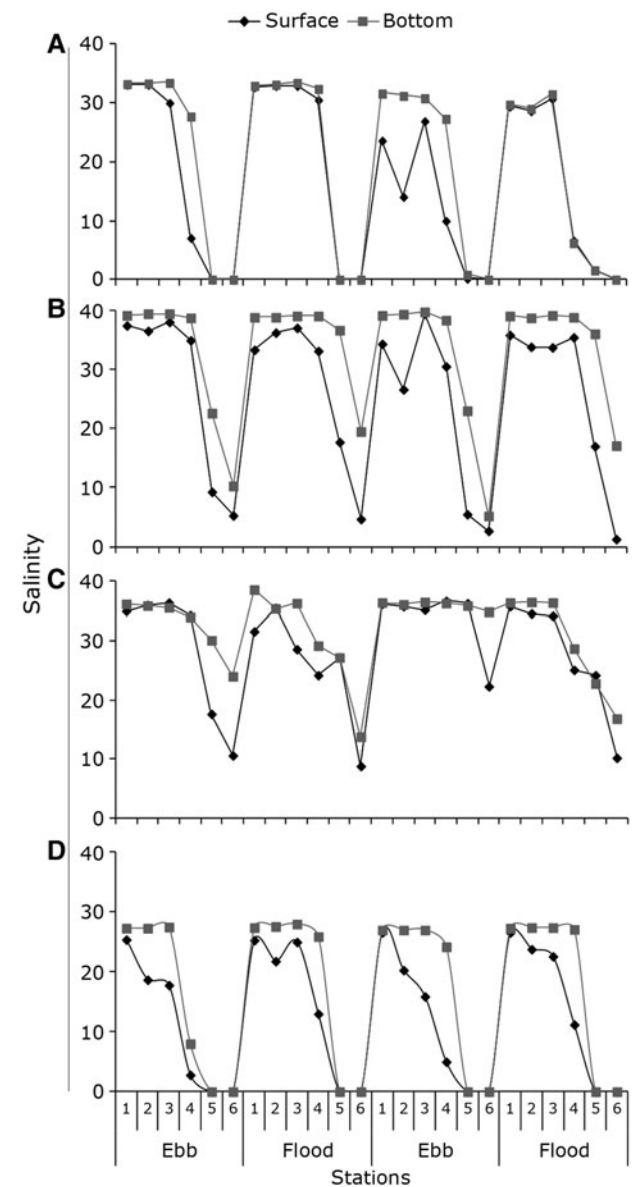
#### TEMPERATURE

In March 2006 the water temperature varied between 24.3°C and 28.0°C at the surface and between 24.2°C and 27.5°C at the bottom (Figure 2A).

During July 2006 temperature values at the surface and bottom varied from 21.1°C to 22.6°C and from 21.6°C to 22.5°C, respectively (Figure 2B).

In October 2006 the surface temperature ranged from 22.8°C to 27.9°C and from 21.4°C to 28.1°C at the bottom (Figure 2C). Vertical stratification was observed in most stations, especially on the adjacent coast, with a difference of 0.8–3.1°C between the surface and the bottom (Figure 2C).

In February 2007 water temperature ranged from 23.9°C to 26.1°C at the surface and from 20.1°C to 26.3°C at the bottom



**Fig. 3.** Variation of salinity at the surface and bottom at sampling stations, ebb and flood tides, conducted in March 2006 (A), July 2006 (B), October 2006 (C) and February 2007 (D) in the Macaé River estuary.

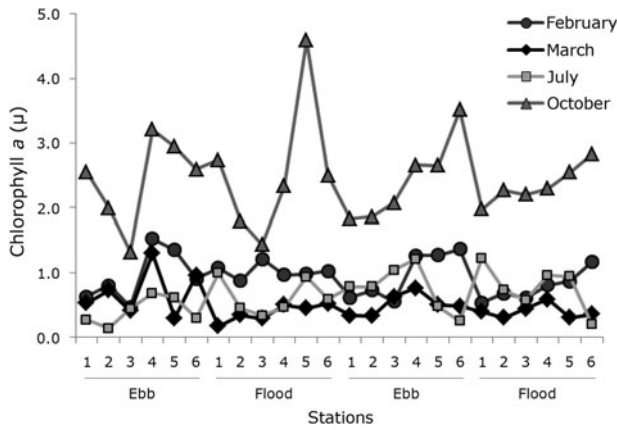


Fig. 4. Variation of chlorophyll-*a* concentrations ( $\mu$ ) at sampling stations, ebb and flood tides, conducted in March, July, October 2006 and February 2007 in the Macaé River estuary.

(Figure 2D). Great variations between surface and bottom were observed in coastal stations during the first flood tide (Figure 2D).

SALINITY

Salinity varied greatly among stations but showed a similar pattern considering all sampling periods. In March, the salinity of stations located inside the river ranged from zero to 1.6 at the surface and at the bottom. In the estuary mouth salinity varied from 6.7 to 30.6 at the surface and from 6.3 to 32.5 at the bottom. Salinity in coastal stations ranged from 14.1 to 33.2 at the surface and from 31.3 to 33.4 at the bottom. The vertical stratification was most pronounced at stations of the coast and the mouth during the ebb tide (Figure 3A).

In July the salinity in the river stations ranged from 1.3 to 17.7 at the surface and from 5.2 to 36.6 at the bottom. At the estuary mouth salinity ranged from 30.5 to 35.4 at the surface and from 38.3 to 39.0 at the bottom. In coastal stations surface salinity ranged from 26.6 to 39.4 at the surface and at the bottom from 39.6 to 39.7. In this period vertical stratification occurred in all collection areas (Figure 3B).

During October 2006 the salinity in the river stations ranged from 9.0 to 36.6 at the surface and from 14.0 to 36.0 at the bottom. In the estuary mouth, the surface salinity ranged from 24.2 to 36.7 and at the bottom from 28.7 to 36.3, and salinity in coastal stations ranged from 28.6 to 36.4 at the surface and from 35.6 to 38.6 at the bottom. Vertical stratification occurred in all regions, but not in all samples (Figure 3C).

In February 2007 at the stations on the river the salinity was zero at both the surface and the bottom in all samples. In the mouth station, salinity ranged from 5.2 to 21.6 at the surface and from 8.0 to 26.0 at the bottom. In coastal stations surface salinity ranged from 16.0 to 26.6 and at the bottom from 27.0 to 28.0. There was a vertical stratification in coastal and estuary mouth stations (Figure 3D).

CHLOROPHYLLA

The highest values of chlorophyll-*a* were recorded in October, with a maximum value of  $4.6 \mu\text{g l}^{-1}$  at the river station during the flood tide and minimum of  $1.3 \mu\text{g l}^{-1}$  at the coastal station during the ebb tide. In March and February the highest values of chlorophyll-*a* were observed in the region of the mouth ( $1.3 \mu\text{g l}^{-1}$  and  $1.5 \mu\text{g l}^{-1}$ ), and lowest in the coastal region ( $0.2 \mu\text{g l}^{-1}$  and  $0.5 \mu\text{g l}^{-1}$ ). In July the minimum ( $0.1 \mu\text{g l}^{-1}$ ) and maximum ( $1.2 \mu\text{g l}^{-1}$ ) values occurred in the coastal region (Figure 4).

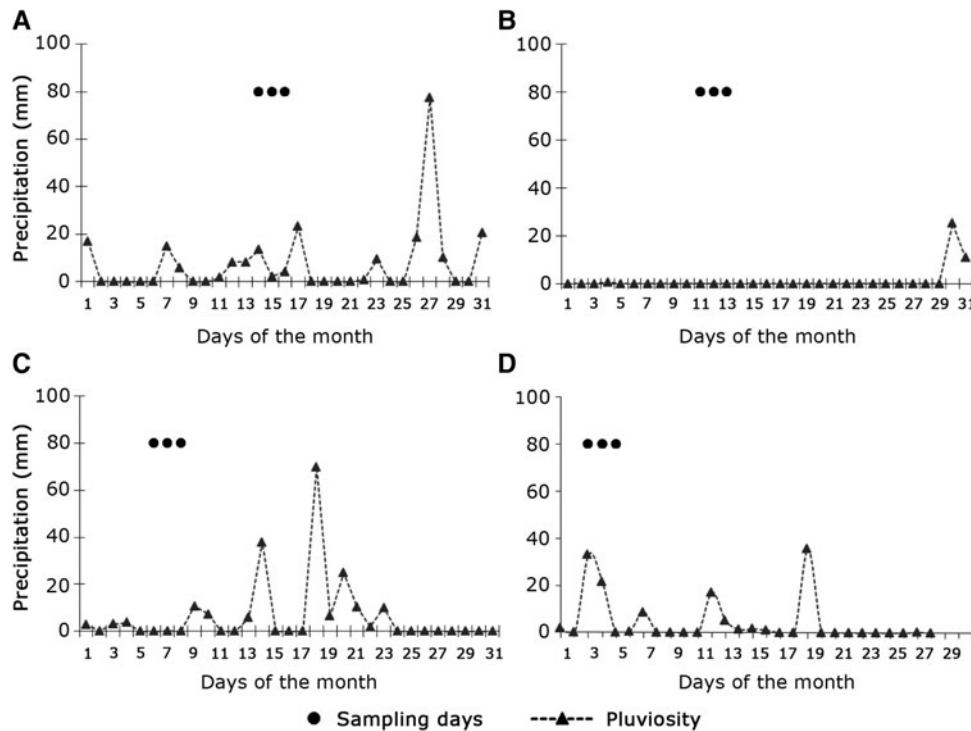


Fig. 5. Daily precipitation values in the campaigns of March 2006 (A), July 2006 (B), October 2006 (C) and February 2007 (D) in Macaé River estuary. The dots indicate the days of sampling.

**Table 2.** Numbers of larvae collected for each taxon and their abundances and frequencies.

Taxon	N	Abundance %	Frequency %
<i>Gobiosoma parri</i>	497	44.35	34.38
<i>Gobionellus oceanicus</i>	463	32.72	41.67
<i>Ctenogobius boleosoma</i>	157	13.22	40.63
Gobiidae n.i.	36	2.30	19.79
<i>Gobiosoma nudum</i>	30	3.05	13.54
Gobiidae sp. 1	26	2.21	9.38
<i>Gobionellus stomatus</i>	9	1.16	7.29
<i>Microgobius meeki</i>	6	0.45	5.21
<i>Bathygobius soporator</i>	7	0.42	6.25
<i>Gobioides broussoneti</i>	3	0.12	3.13

**PRECIPITATION**

The days of maximum precipitation occurred in March (77.6 mm) and October (70 mm; Figures 5A, C). However, in October the days of greatest rainfall occurred after the sampling period (Figure 5C). Thus, the assessment carried out in this period was considered as sampling the dry season. July was the driest month, with maximum precipitation of 2.6 mm and only three days of rain (Figure 5B). In February 2007, the maximum rainfall was 36 mm (Figure 5D).

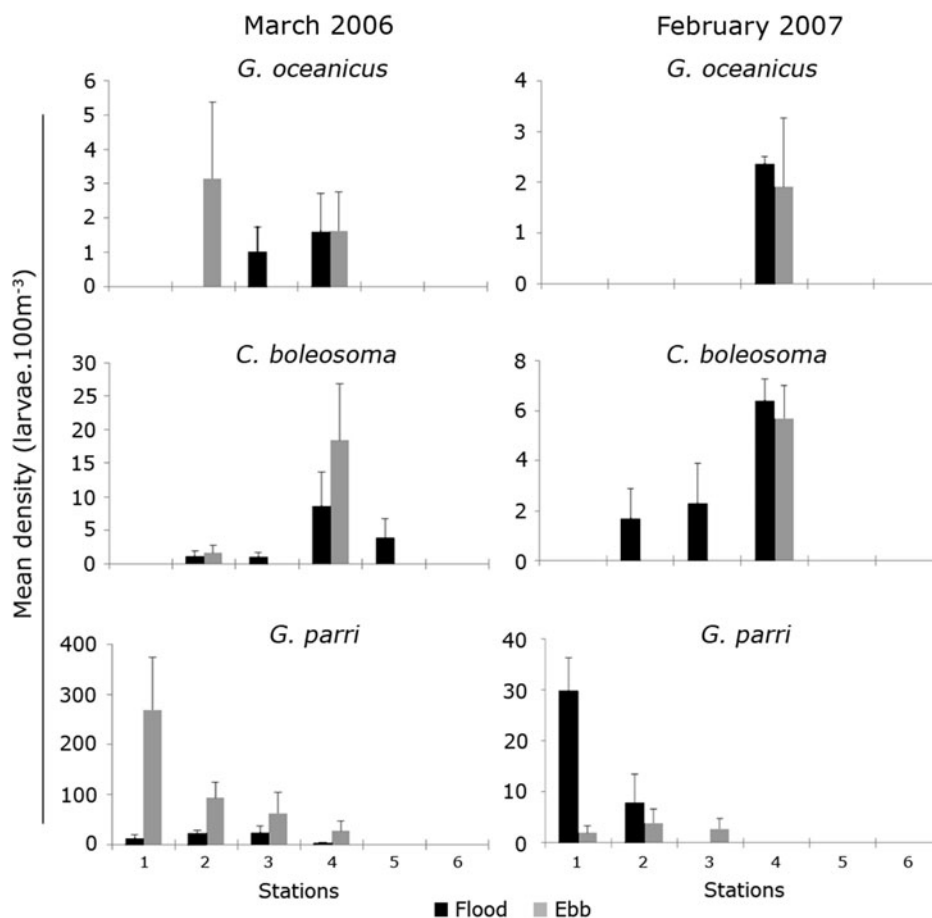
**Taxa composition and density**

A total of 1234 Gobiidae larvae, distributed in eight species and one morphotype, were collected in March, July and October 2006 and February 2007 in the Macaé River estuary (Table 2). Thirty-six larvae were identified to family level because they were in yolk stage or damaged.

The highest density was observed in March ( $24.41 \pm 15.38$  larvae  $100\text{ m}^{-3}$ ) followed by October ( $21.55 \pm 16.40$  larvae  $100\text{ m}^{-3}$ ), July ( $7.93 \pm 7.44$  larvae  $100\text{ m}^{-3}$ ) and February 2007 ( $3.20 \pm 3.00$  larvae  $100\text{ m}^{-3}$ ).

The Macaé River estuary was dominated by three gobiid species comprising 90% of the total abundance (Table 2). The species *Gobiosoma parri* Ginsburg, 1933 was the most abundant comprising 44% of the total caught, followed by *Gobionellus oceanicus* (Pallas, 1770) 33% and *Ctenogobius boleosoma* (Jordan & Gilbert, 1882) 13%. The other taxa were less representative and contributed less than 10% of the total.

In the rainy season (February and March) coastal stations (1, 2 and 3) and the estuary mouth (4) were characterized by having the highest larval densities of the most abundant species (Figure 6). Inside the river (Stations 5 and 6) only *C. boleosoma* larvae were collected. In this season larvae of the species *G. parri* were more representative, especially at Station 1 in March, during the ebb tide (Figure 6). In February larvae of *G. oceanicus* occurred only in the estuary

**Fig. 6.** Mean density of *Gobionellus oceanicus* (Pallas, 1770), *Ctenogobius boleosoma* (Jordan & Gilbert, 1882) and *Gobiosoma parri* Ginsburg, 1933 at sampling stations, on ebb and flood tides, during the rainy season (March 2006 and February 2007) in the Macaé River estuary. Note the different x-axis values.

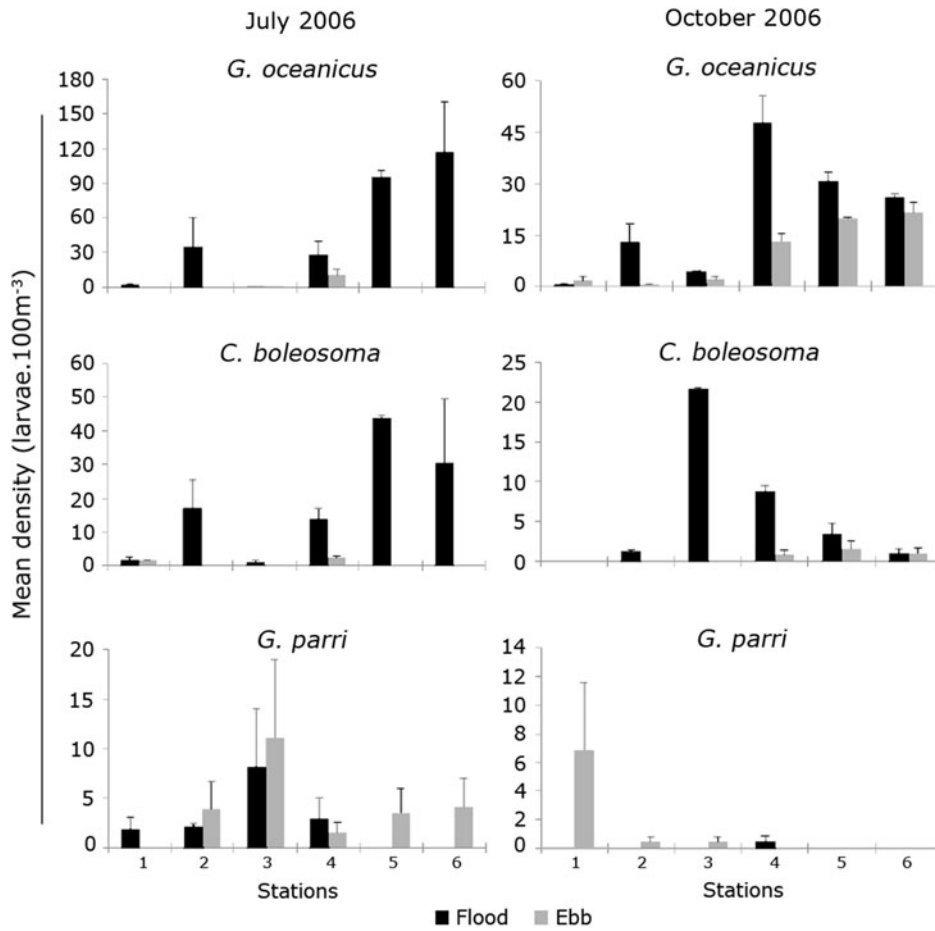


Fig. 7. Mean density of *Gobionellus oceanicus* (Pallas, 1770), *Ctenogobius boleosoma* (Jordan & Gilbert, 1882) and *Gobiosoma parri* Ginsburg, 1933 at sampling stations, on ebb and flood tides during the dry season (July 2006 and October 2007) in the Macaé River estuary. Note the different x-axis values.

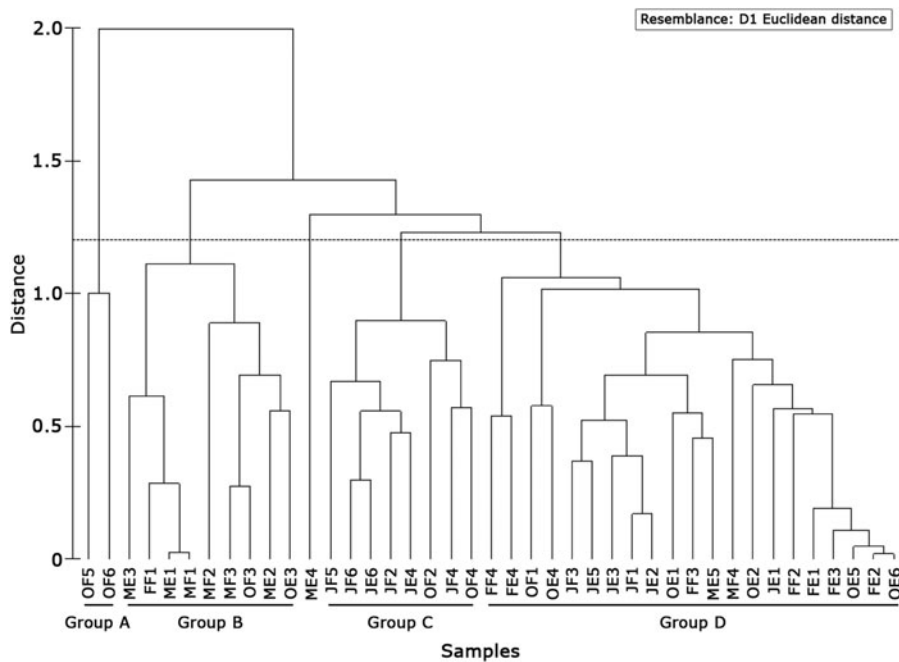


Fig. 8. Similarity between periods and sampling stations, based on relative abundances of species in the Macaé River estuary. O, October; M, March; F, February; J, July, F, flood; E, ebb.

mouth, while in March it also appeared at Stations 2 and 3 (Figure 6). Larvae of *C. boleosoma* showed high densities at Station 4 in February, during the flood tide and March on the ebb tide. Unlike the others, this was the only species that occurred in Station 5 in March (Figure 6).

In the dry months (July and October), stations located inside the river were characterized by high densities (Figure 7), with emphasis on the larvae of the species *G. oceanicus*, dominant in this period. In July, *G. oceanicus* occurred in high densities in the river stations, without any records on the ebb tide (Figure 7). In October, this species had higher densities at the station at the mouth, followed by the stations on the river, always during the flood tide (Figure 7). Larvae of *C. boleosoma* occurred in higher densities at river station 5 during July (Figure 7) and at Station 3 in October (Figure 7), both on the flood tide. Larvae of *G. parri* were recorded in low densities during this period of the year, occurring only at the coastal stations in October (Figure 7). During July and October, they presented their highest densities at coastal stations (3 and 1, respectively) during the ebb tide (Figure 7).

The cluster analysis showed four groups (Figure 8): the first group (A) included only samples collected in Stations 5 and 6 in October during the flood tide. Larval composition was

characterized by absence of *G. parri* (Figure 9). Group B (Figure 8) was formed by coastal stations (1, 2 and 3) during the rainy months. This group showed high abundance of larvae *G. parri* (53%) and low abundance of larvae *G. oceanicus* (7%) and *C. boleosoma* (4%). The Group C was characterized by samples collected during the dry season (Figure 8) when *G. parri* was less abundant than in Groups B and D (Figure 9). Group D showed a greater abundance of the species *G. parri* (27%) compared to the small variation of *C. boleosoma* and *G. oceanicus*, ranging between 23% and 19%, respectively (Figure 9). On the other hand, Station ME4 stood out from the others for being dominated by the species *C. boleosoma* (37%, Figure 9). Using a non-parametric test (Kruskal–Wallis) it was observed that the distribution of larvae differed among stations ( $P < 0.05$ ). Station 4 had the highest average density followed by Station 2, while Stations 5 and 6 had lower average densities (Figure 10). In relation to the tides and the dry and rainy seasons, a Mann–Whitney test showed significant difference between densities obtained between flood and ebb tides and between the rainy and dry periods ( $P < 0.05$ ).

The combined effect of the three variables on the distribution of the CCA axes was significant according to the Monte

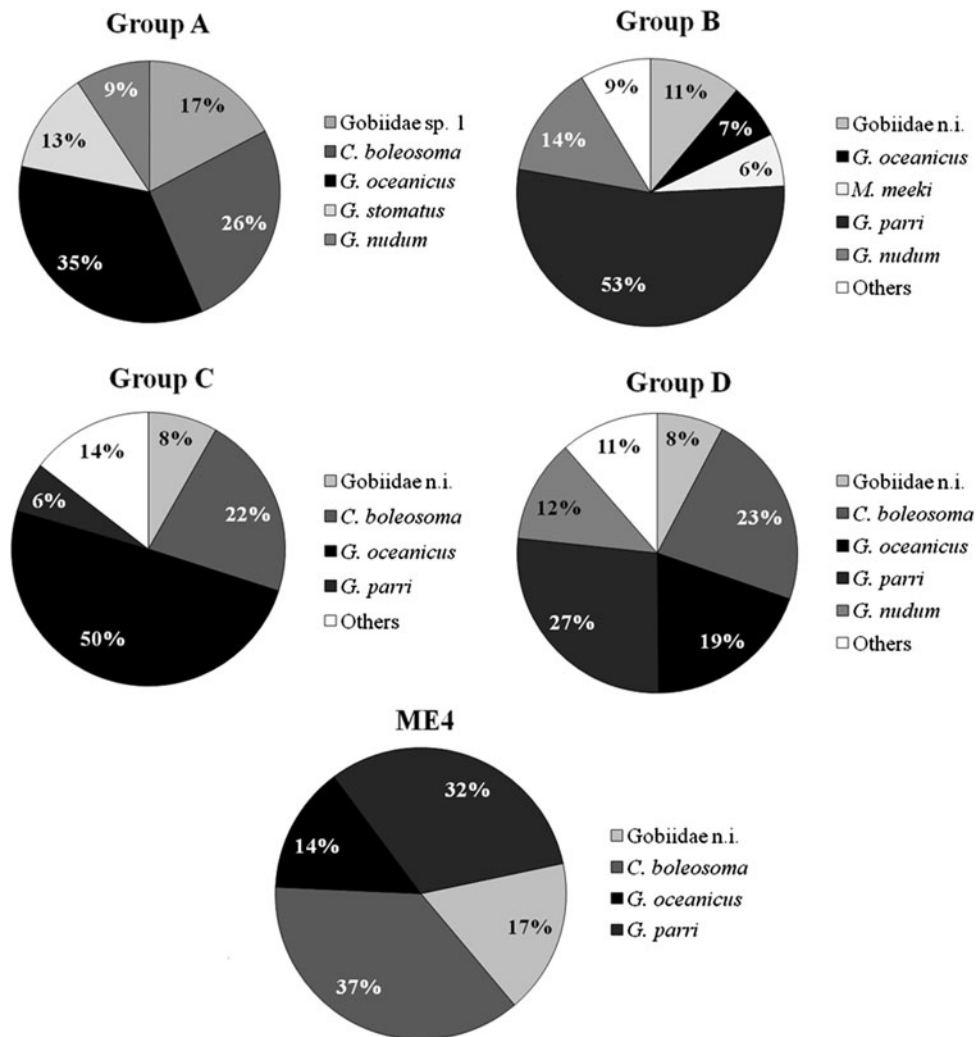


Fig. 9. Relative abundances of the most abundant species in each group formed by cluster analysis in the Macaé River estuary.

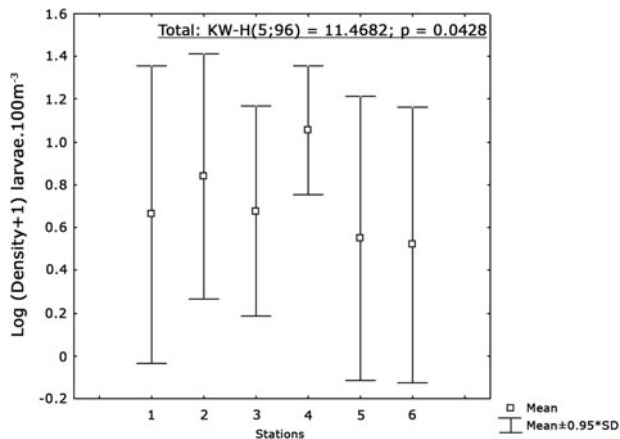


Fig. 10. Differences in the mean densities of Gobiidae larvae between the stations ( $P < 0.05$ ).

Table 3. Inter-set correlations for three variables: salinity, temperature and chlorophyll-*a*. In bold are the values of variables  $\geq |0.4|$ , which are considered biologically important according to Rakocinski *et al.* (1996).

Variable	Axis 1	Axis 2	Axis 3
Salinity	0.247	0.149	0.212
Temperature	<b>0.446</b>	<b>-0.464</b>	-0.008
chlorophyll- <i>a</i>	<b>-0.615</b>	-0.225	-0.107

Carlo permutation test ( $P < 0.05$ ). The axis I (eigenvalue = 0.360) accounted for 38% and axis II (eigenvalue = 0.038) for 4% of the variation in species–environment relationship percentage. According to inter-set correlations, chlorophyll-*a* and temperature factors were considered biologically significant

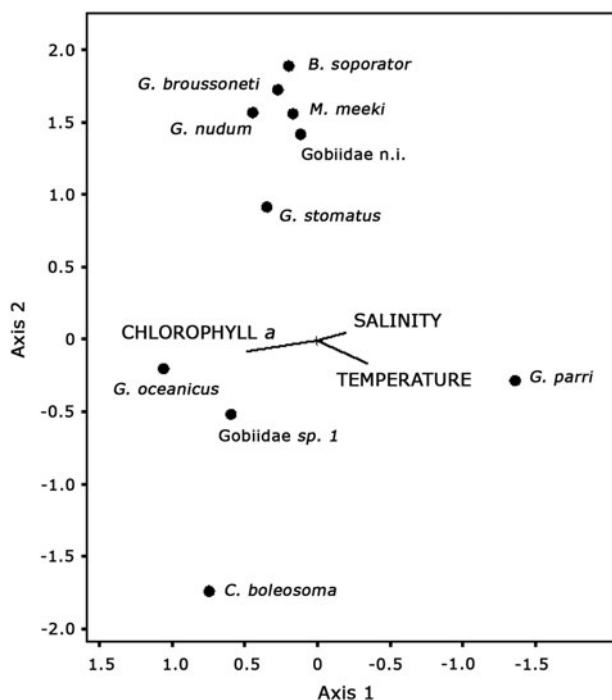


Fig. 11. Gobiidae species and environmental variables in a triplot ordination diagram using the first two canonical correspondence axes.

(Table 3). The chlorophyll-*a* correlated negatively with axis I ( $-0.615$ ). Temperature was positively correlated with axis I (0.446) and negatively with axis II ( $-0.464$ ). Axis I separated the species *G. parri* due to the high temperatures and salinities and low rates of chlorophyll-*a*. The species *G. oceanicus* was associated with higher rates of chlorophyll-*a* and low temperatures and salinities (Figure 11). The species *C. boleosoma* was separated from the others by correlating with high chlorophyll-*a* and temperatures and low salinities. Axis II showed a separation of the species *C. boleosoma* and other species due to their correlation with elevated temperatures (Figure 11).

## DISCUSSION

The water temperature found in the present study reflected the pattern of the humid tropical climate. According to Santos *et al.* (2006) it is characterized by higher temperatures from November to April and cooler temperatures from May to October, with well-defined dry and rainy seasons.

In the Macaé River estuary seasonal variation of rainfall and consequent freshwater discharge directly influence the salt wedge region. The salinity variation in this estuary allows the entry of marine species in the river without suffering drastic adjustments due to variations in salinity.

Miranda *et al.* (2002) characterized this change in regimes of estuaries as common according to the season and tide. In the Mucuri River estuary, located in the north-east of Brazil, during the dry season the salt water penetrates about 3 km, forming a salt wedge in the upper estuary, where during the rainy season salinity is virtually zero (Castro & Bonecker, 1996; Bonecker *et al.*, 2009; Gomes *et al.*, 2014). The Macaé River estuary showed the same pattern. Salinity presented differences between flood and ebb tides. In dry seasons, low river flow leads to an increase in the tidal influence on the estuary resulting in high seawater incursion, mainly during flood tides. The reverse occurs in rainy seasons when the high volume of river flow means the seawater cannot penetrate into the estuary and thus salinity is low.

The values of chlorophyll-*a* observed in the estuary of the Macaé River and adjacent coastal region were very low (maximum  $4.6 \mu\text{g l}^{-1}$ ) when compared with other Brazilian estuaries. In estuarine system of Cananéia chlorophyll concentration ranged between  $1.32$  and  $20.42 \mu\text{g l}^{-1}$  (Ara, 2001) and in the estuary of Camboriú from  $5.1 \mu\text{g l}^{-1}$  to  $22.8 \mu\text{g l}^{-1}$  (Pereira-Filho *et al.*, 2001). According to studies of phytoplankton organisms in estuaries, there is a variation in the concentration of chlorophyll-*a* in different climatic periods during the year (Sin *et al.*, 2000; van der Molen & Pressinotto, 2011). The light availability may limit algal growth during the rainy season (Gameiro *et al.*, 2011) depending on the intensification of land leaching and hence, greater amounts of suspended material will be available in the water column, hindering light penetration (Eskinazi-Leça *et al.*, 2004). This fact may explain the higher rates of chlorophyll-*a* which occurred in the dry season (October) along with results reported for other estuaries of Brazil (Grego *et al.*, 2009; Aquino *et al.*, 2012).

Temperature and chlorophyll-*a* were identified as important regulatory environmental parameters of the occurrence of goby larvae in the Macaé River estuary. In the St Lucia estuary, South Africa, temperature was the most important variable



explaining larval fish distributions and abundances (Harris *et al.*, 1999). Muiño *et al.* (2003) identified temperature as the major environmental factor responsible for temporal variations in sardine larvae abundance along the coast of Northern Spain.

In this study the estuary was used by Gobiidae larvae that were found throughout it and in both dry and rainy seasons. However, there is a general tendency for estuarine fish larvae to peak in abundance during rainy seasons (Harris *et al.*, 1999; Young & Potter, 2003).

In February, the Gobiidae larvae showed a low preference for the Macaé River estuary. This Gobiidae larvae relationship with this month can be linked to the fact that the intense rainfall during the sampling period in February influenced the absence of Gobiidae larvae because the outflow of the river did not allow the larvae to penetrate with the salt wedge. In rainy seasons, there is an increase in river flow and salinity decreases, reducing the density of fish larvae in rivers (Ramos *et al.*, 2006). In March the highest density of fish larvae was reported due to the high density of the species *Gobiosoma parri* in coastal stations. This peak may be a sign that *G. parri* is spawning in this season. According to Tricklebank *et al.* (1992) overall seasonality patterns often directly influence the abundance of dominant taxa, and this happened in this study, with the larvae of *G. parri*. The river discharges by nutrient upload of river plumes lead to the strong positive impact on coastal fisheries (Meynecke *et al.*, 2006).

In this study we found a great number of Gobiidae taxa, with nine identified species, as in other estuaries or coastal zones in the world (Barletta *et al.*, 2005; Borges *et al.*, 2007; Hermosilla *et al.*, 2012; Kundu *et al.*, 2012). In the Mucuri River estuary, in a similar study with the Gobiidae family, a higher number of species was identified, but over a larger sampling period (Gomes *et al.*, 2014). It must be remembered that not all studies of fish fauna have used the same sampling method. Furthermore, variations in the abiotic environment and habitat heterogeneity make it difficult to compare the number of species (Blaber, 1997).

According to this study, *G. parri* was the most abundant species in the Gobiidae assemblage of the Macaé River estuary as well as in the Rio de la Plata River estuary, located between Uruguay and Argentina (Madirolas *et al.*, 1997). This pattern has not been described before for Brazilian estuaries, generally dominated by *Ctenogobius boleosoma* (Coser *et al.*, 2007; Marcolin *et al.*, 2010; Gomes *et al.*, 2014) or *Microgobius meeki* Evermann & Marsh, 1899 (Barletta-Bergan *et al.*, 2002a).

In the Macaé estuarine system the species *G. parri* was dominant in the rainy months and had lower densities in the dry season. Primo *et al.* (2011) reported a similar peak of *Crystallogobius linearis* (Düben, 1845) in a Portuguese temperate estuary. However, Acha (1994), in a temperate estuary in the south-west Atlantic, showed peak abundances from June to August, inferring that the spawning season of *G. parri* occurs from February to April. In Brazil, larvae of this species occurred in the Patos Lagoon estuary during the whole year (Muelbert & Weiss, 1991). They typically use the estuaries to be transported by drift to the nearshore environment (Miller *et al.*, 1984). This explains the high densities in coastal stations of *G. parri* larvae.

*Gobiosoma parri* migrated toward the river only on the ebb in times of drought. However, it remained at shore stations

throughout the year independently of the tide. This larval retention mechanism may be explained by the migration of the larvae to greater depths during low tide (Aceves-Medina *et al.*, 2008) or concentration at the surface during flood tide (Barletta & Barletta-Bergan, 2009).

The larvae of the species *Gobionellus oceanicus* and *C. boleosoma* migrated to the river during dry seasons, benefiting from the rising tide. This may be associated with selective tidal stream transport (STST), which is a strategy for exportation through vertical migrations synchronized with the tide (Boehlert & Mundy, 1988). The species *C. boleosoma*, a marine estuarine-opportunist, does not depend on the estuary as a nursery area, but uses it opportunistically, and *G. oceanicus*, a marine estuarine dependent, requires sheltered estuarine habitats for its development, but also lives along coasts (Gomes *et al.*, 2014). Although this species is found in estuaries, it also inhabits the coastal zone (Camargo & Isaac, 2003). The present data seem to indicate that whenever the salt intrusion was favourable, larvae penetrated into the Macaé River estuary.

The spatial and seasonal variations, together with the tide, influence the distribution of fish larvae of the Gobiidae family in the Macaé River estuary and its coastal zone. The mouth and the coastal region showed the highest densities of fish larvae, as also reported by Faria *et al.* (2006) in an estuary in south-eastern Portugal. Many other studies had similar results to the present study with the greatest densities occurring on flood tides (Neira & Potter, 1992; Sarpedonti *et al.*, 2008; Bonecker *et al.*, 2009; Gomes *et al.*, 2014) during the rainy season (Barletta-Bergan *et al.*, 2002a; Castro *et al.*, 2005; Vendel & Chaves, 2006; Gomes *et al.*, 2014).

## ACKNOWLEDGEMENTS

The authors thank the team of the Zooplankton and Ichthyoplankton Integrated Laboratory of Federal University of Rio de Janeiro who assisted in the field and laboratory work, especially Dr Sérgio Bonecker. The authors would also like to acknowledge Cláudia Namiki for her help with fish larvae identification and Adriana Valente de Araujo for her suggestions in statistical analysis.

## REFERENCES

- Aceves-Medina G., Saldierna-Martínez R., Hinojosa-Medina A., Jiménez-Rosenberg S.P.A., Hernández-Rivas M.E. and Morales-Ávila R. (2008) Vertical structure of larval fish assemblages during diel cycles in summer and winter in the southern part of Bahía de La Paz, México. *Estuarine, Coastal and Shelf Science* 76, 889–901.
- Acha E.M. (1994) Development and occurrence of larvae of the goby, *Gobiosoma parri* (Ginsburg) (Gobiidae), in the estuary of the Rio de la Plata, Argentina. *Scientia Marina* 58, 337–343.
- Aquino E.P., Figueiredo L.G.P., Anjos D.L., Passavante J.Z.O. and Silva-Cunha M.G.G. (2012) Biomassa fitoplanctônica e fatores ambientais em um estuário tropical do Brasil. *Tropical Oceanography* 40, 17–28.
- Ara K. (2001) Temporal variability and production of *Euterpina acutifrons* (Copepoda: Harpacticoida) in the Cananéia Lagoon estuarine system, São Paulo, Brazil. *Hydrobiologia* 453, 177–187.

- Baldwin C.C. and Smith D.G.** (2003) Larval Gobiidae (Teleostei: Perciformes) of Carrie Bow Cay, Belize, Central America. *Bulletin of Marine Science* 72, 639–674.
- Barletta M. and Barletta-Bergan A.** (2009) Endogenous activity rhythms of larval fish assemblages in a mangrove-fringed estuary in North Brazil. *The Open Fish Science Journal* 2, 15–24.
- Barletta-Bergan A., Barletta M. and Saint-Paul U.** (2002a) Structure and seasonal dynamics of larval fish in the Caeté river estuary in North Brazil. *Estuarine, Coastal and Shelf Science* 54, 193–206.
- Barletta-Bergan A., Barletta M. and Saint-Paul U.** (2002b) Community structure and temporal variability of ichthyoplankton in North Brazilian mangrove creeks. *Journal of Fish Biology* 61, 33–51.
- Barletta M., Barletta-Bergan A., Saint-Paul U. and Hubold G.** (2003) Seasonal changes in density, biomass, and diversity of estuarine fishes in tidal mangrove creeks of the lower Caeté Estuary (northern Brazilian coast, east Amazon). *Marine Ecology Progress Series* 256, 217–228.
- Barletta M., Barletta-Bergan A., Saint-Paul U.S.G.H. and Hubold G.** (2005) The role of salinity in structuring the fish assemblages in a tropical estuary. *Journal of Fish Biology* 66, 45–72.
- Beltrão R.** (2003). *Zooplâncton do estuário do rio Macaé (RJ)-Inverno de 2001 e Verão de 2002*. MSc thesis. Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil.
- Boehlert G.W. and Mundy B.C.** (1988) Roles of behavioural and physical factors in larval and juvenile fish recruitment to estuarine nursery areas. *American Fisheries Society Symposium* 3, 51–67.
- Bonecker A.C.T., Castro M.S., Namiki C., Bonecker F.T. and Barros F.B.A.G.** (2007) Larval fish composition of a tropical estuary in northern Brazil ( $2^{\circ}18' - 2^{\circ}47'S/044^{\circ}20' - 044^{\circ}25'W$ ) during the dry season. *Pan-American Journal of Aquatic Sciences* 2, 235–241.
- Bonecker A.C.T., Katsuragawa M., Castro M.S., Gomes E.A.P., Namiki C.A.P. and Zani-Teixeira M.L.** (2012) Larval fish of the Campos Basin, southeastern Brazil. *Check List* 8, 1280–1291.
- Bonecker F.T., Castro M.S. and Bonecker A.C.T.** (2009) Larval fish assemblage in a tropical estuary in relation to tidal cycles, day/night and seasonal variations. *Pan-American Journal of Aquatic Sciences* 4, 238–245.
- Borges R., Ben-Hamadou R., Chicharo M.A., Ré P. and Gonçalves E.J.** (2007) Horizontal spatial and temporal distribution patterns of near-shore larval fish assemblages at a temperate rocky shore. *Estuarine, Coastal and Shelf Science* 71, 412–428.
- Blaber S.J.M.** (1997) *Fish and fisheries of tropical estuaries*. *Fish and Fisheries Series No. 22*. London: Chapman and Hall.
- Burgess W.E., Axelrod H.R. and Hunziker R.E.** (1990) *Atlas of marine aquarium fishes*. 2nd edition. Neptune City, NJ: TFH Publications Inc.
- Camargo M. and Isaac V.** (2003) Ictiofauna estuarine. In Fernandes M.E.B. (ed.) *Os manguezais da costa norte brasileira*. Rio de Janeiro: Fundação Rio Bacanga, pp. 105–142.
- Castro M.S. and Bonecker A.C.T.** (1996) Ocorrência de larvas de peixe no sistema estuarino do Rio Mucuri. *Arquivos de Biologia e Tecnologia* 39, 171–185.
- Castro M.S., Bonecker A.C.T. and Valentin J.L.** (2005) Seasonal variation in fish larvae at the entrance of Guanabara Bay, Brazil. *Brazilian Archives of Biology and Technology* 48, 121–128.
- Coser L.M., Pereira B.B. and Joyeux J.C.** (2007) Descrição da comunidade ictiofítica e sua distribuição espacial no estuário dos rios Piraquê-Açu e Piraquê-Mirim, Aracruz, ES, Brasil. *Interciência* 32, 233–241.
- Eskinazi-Leça E., Koenig M.L. and Silva-Cunha M.G.G.** (2004) Estrutura e dinâmica da comunidade fitoplânctônica. In Eskinazi-Leça E., Newmann-Leitão S. and Costa M.F. (eds) *Oceanografia: um cenário tropical*. Recife: Edições Bagaço, pp. 353–373.
- Fahay M.P.** (2007) *Early stages of fishes in the Western North Atlantic Ocean (Davis Strait, Southern Greenland and Flemish Cap to Cape Hatteras)*. Volume 2. Nova Scotia: Northwest Atlantic Fisheries Organization.
- Faria A., Morais P. and Chicharo M.A.** (2006) Ichthyoplankton dynamics in the Guadiana estuary and adjacent coastal area, South-East Portugal. *Estuarine, Coastal and Shelf Science* 70, 85–97.
- Fortier L. and Leggett W.C.** (1983) Vertical migrations and transport of larval fish in a partially mixed estuary. *Canadian Journal of Fisheries and Aquatic Sciences* 40, 1543–1555.
- Forward R.B. and Tankersley R.A.** (2001) Selective tidal-stream transport of marine animals. *Oceanography and Marine Biology: an Annual Review* 39, 305–353.
- Gameiro C., Zwolinski J. and Brotas V.** (2011) Light control on phytoplankton production in a shallow and turbid estuarine system. *Hydrobiologia* 669, 249–263.
- Gomes E.A.P., Campos P.N. and Bonecker A.C.T.** (2014) Occurrence of Gobiidae larvae in a tropical Brazilian estuary, with particular emphasis on the use of size classes to categorize species guilds. *Journal of Fish Biology* 84, 996–1013.
- Gray C.A. and Miskiewicz A.G.** (2000) Larval fish assemblages in south-east Australian coastal waters: seasonal and spatial structure. *Estuarine, Coastal and Shelf Science* 50, 549–570.
- Grego C.K.S., Feitosa F.A.N., Honorato-da-Silva M., Silva-Cunha M.G.G. and Filho G.A.N.** (2009) Fitoplâncton do ecossistema estuarino do rio Ariquindá (Tamandaré, Pernambuco, Brasil): variáveis ambientais, biomassa e produtividade primária. *Atlântica* 31, 183–198.
- Harris S.A., Cyrus D.P. and Beckley L.E.** (1999) The larval fish assemblage in nearshore coastal waters off the St Lucia estuary, South Africa. *Estuarine, Coastal and Shelf Science* 49, 789–811.
- Hermosilla J.J., Tamura Y., Okazaki D., Hoshino Y., Moteki M. and Kohno H.** (2012) Distribution and community structure of fish in Obitsu-gawa River Estuary of inner Tokyo Bay, Central Japan. *AAAL Bioflux* 5, 197–222.
- Hora A., Massera M.A.G. and Porto M.A.D.** (2001) *Bacias Hidrográficas e Rios Fluminenses—Síntese Informativa por macrorregião ambiental*. Rio de Janeiro: SEMADS/GTAZ (PROJETO PLANÁGUA).
- IBGE** (2012) *Censo demográfico Macaé, Rio de Janeiro 2010*. Available at <http://cidades.ibge.gov.br/xtras/perfil.php?lang=&codmun=330240&search=rio-de-janeiro|macae> (accessed 25 November 2012).
- Islam M.S., Hibino M. and Tanaka M.** (2007) Tidal and diurnal variations in larval fish abundance in an estuarine inlet in Ariake Bay, Japan: implication for selective tidal stream transport. *Ecological Research* 22, 165–171.
- Jager Z.** (1999) Selective tidal stream transport of flounder larvae (*Platichthys flesus* L.) in the Dollard (Ems Estuary). *Estuarine, Coastal and Shelf Science* 49, 347–362.
- Koochaknejad E., Savari A., Dehghan-Madiseh S., Eskandari G. and Sakhaie N.** (2011) Fish larvae assemblage in the Northwestern Coast of the Persian Gulf: Khure Mussa Channel. *Journal of the Persian Gulf* 2, 25–30.
- Kundu N., Chaudhuri A., Mukherjee S., Sen S. and Homechaudhuri S.** (2012) Seasonal fish diversity under tidal influence in the intertidal mudflats of Indian Sundarbans. *Indian Journal of Fisheries* 59, 43–52.

- Madirolas A., Acha E.M., Guerrero R.A. and Lasta C.** (1997) Sources of acoustic scattering near a halocline in an estuarine frontal system. *Scientia Marina* 61, 431–438.
- Mafalda Jr P.O., Sinque C., Muelbert J.H. and Souza C.D.** (2004) Distribuição e abundância do ictioplâncton na costa norte da Bahia, Brasil. *Tropical Oceanography* 32, 69–88.
- Mafalda Jr P.O., Souza C.S. and Velame M.P.B.** (2008) Fish larvae assemblage of a coastal area under influence of petrochemical activities, in Todos os Santos Bay, Bahia, Brazil. *Journal of Aquatic Ecosystem Health and Management* 11, 457–464.
- Marcolin C.R., Conceição B.L., Nogueira M.M., Mafalda Jr P.O. and Johnsson R.** (2010) Mesozooplankton and ichthyoplankton composition in two tropical estuaries of Bahia, Brazil. *Check List* 6, 210–216.
- Meynecke J.O., Lee S.Y., Duke N.C. and Warnken J.** (2006) Effect of rainfall as a component of climate change on estuarine fish production in Queensland, Australia. *Estuarine, Coastal and Shelf Science* 69, 491–504.
- Miller J.M., Reed J.P. and Pietrafesa L.J.** (1984) Patterns, mechanisms and approaches to the study of migrations of estuarine-dependent fish larvae and juveniles. In McCleave J.D., Arnold G.P., Dodson J.J. and Neill W.H. (eds) *Mechanisms of migration in fishes*. New York: Plenum, pp. 209–225.
- Miranda L.B., Castro B.M. and Kjerfve B.** (2002) *Princípios de Oceanografia Física de Estuários*. 1st edition. São Paulo: Universidade de São Paulo.
- Molisani M.M., Esteves F.A., Lacerda L.D. and Rezende C.E.** (2012) Emissões naturais e antrópicas de nitrogênio, fósforo e metais para a bacia do Rio Macaé (Macaé, RJ, Brasil) sob influência das atividades de exploração de petróleo e gás na Bacia de Campos. *Química Nova* 36, 27–33.
- Moyano M. and Hernández-León S.** (2009) Temporal and along-shelf distribution of the larval fish assemblage at Gran Canaria, Canary Islands. *Scientia Marina* 73, 85–96.
- Muelbert J.H. and Weiss G.** (1991) Abundance and distribution of fish larvae in the channel area of the Patos Lagoon estuary, Brazil. In Hoyt R.D. (ed.) *Larval fish recruitment in the Americas. Proceedings of the thirteenth annual fish conference, 21–26 May 1989, Merida, Mexico*. Silver Spring, MD: NOAA, Technical Report NMFS 95, pp. 43–54.
- Muhling B.A., Beckley L.E., Koslow J.A. and Pearce A.F.** (2008) Larval fish assemblages and water mass structure off the oligotrophic south-western Australian coast. *Fisheries Oceanography* 17, 16–31.
- Muiño R., Carrera P. and Iglesias M.** (2003) The characterization of sardine (*Sardina pilchardus* Walbaum) schools off the Spanish-Atlantic coast. *Journal of Marine Science* 60, 1361–1372.
- Neira F.J. and Potter I.C.** (1992) The ichthyoplankton of a seasonally closed estuary in temperate Australia. Does an extended period of opening influence species composition? *Journal of Fish Biology* 41, 935–953.
- Parrish R.H., Nelson C.S. and Bakun A.** (1981) Transport mechanisms and reproductive success of fishes in the California Current. *Biology and Oceanography* 1, 175–203.
- Peters R.K.** (1986) The role of predation in limnology. *Limnology and Oceanography* 31, 1143–1159.
- Pereira-Filho J., Schettini C.A.F., Rörlig L. and Siegle E.** (2001) Intratidal variation and net transport of dissolved inorganic nutrients, POC and chlorophyll a in the Camboriú River estuary, Brazil. *Estuarine, Coastal and Shelf Science* 53, 249–257.
- Primo A.L., Azeiteiro U.M., Marques S.C. and Pardal M.Â.** (2011) Impact of climate variability on ichthyoplankton communities: an example of a small temperate estuary. *Estuarine, Coastal and Shelf Science* 91, 484–491.
- Rakocinski C.F., Lyczkowski-Shultz J. and Richardson S.L.** (1996) Ichthyoplankton assemblage structure in Mississippi Sound as revealed by canonical correspondence analysis. *Estuarine, Coastal and Shelf Science* 43, 237–257.
- Ramos S., Cowen R.K., Ré P. and Bordalo A.A.** (2006) Temporal and spatial distribution of larval fish assemblages in the Lima estuary (Portugal). *Estuarine, Coastal and Shelf Science* 66, 303–314.
- Santos A.M., Amado A.M., Minello M., Farjalla V.F. and Esteves F.A.** (2006) Effects of the sand bar breaching on *Typha domingensis* (PERS) in a tropical coastal lagoon. *Hydrobiologia* 556, 61–68.
- Sarpedonti V.E., Anunciação M.S. and Isaac V.J.N.** (2008) Ichthyoplankton variations in two mangrove creeks of the Curuçá estuary, Pará, Brazil. *Ecotrópicos* 21, 1–12.
- Sclafani M., Taggart C.T. and Thompson K.R.** (1993) Condition, buoyancy and the distribution of larval fish: implications for vertical migration and retention. *Journal of Plankton Research* 15, 413–435.
- Sin Y., Wetzel R.L. and Anderson I.C.** (2000) Seasonal variations of size-fractionated phytoplankton along the salinity gradient in the York river estuary, Virginia (USA). *Journal of Plankton Research* 22, 1945–1960.
- Smith P.E. and Richardson S.L.** (1977) Standard techniques for pelagic fish egg and larvae survey. *FAO, Fisheries Technical Paper* 175, 1–100.
- Spach H.L., Silva A.L.C., Merlyn L. and Santos L.D.O.** (2010) Assembleias de peixes em diferentes ambientes da desembocadura do Rio Sai Guaçu, Sul do Brasil. *Pan-American Journal of Aquatic Sciences* 5, 126–138.
- Sponaugle S., Fortuna J., Grorud K. and Lee T.** (2003) Dynamics of larval fish assemblages over a shallow coral reef in the Florida Keys. *Marine Biology* 143, 175–189.
- Tamaki A., Mandal S., Agata Y., Aoki I., Suzuki T., Kanehara H., Aoshima T., Fukuda Y., Tsukamoto H. and Yanagi T.** (2010) Complex vertical migration of larvae of the ghost shrimp, *Nihonotrypaea harmandi*, in inner shelf waters of western Kyushu, Japan. *Estuarine, Coastal and Shelf Science* 86, 125–136.
- Ter Braak C.J.F. and Smilauer P.** (2002) *Canoco: Reference manual and CanoDraw for Windows. User's Guide: Software form Canonical community ordination (version 4.5)*. New York: Microcomputer Power.
- Tricklebank K.A., Jacoby C.A. and Montgomery J.C.** (1992) Composition, distribution and abundance of neustonic ichthyoplankton off northeastern New Zealand. *Estuarine, Coastal and Shelf Science* 34, 263–275.
- van der Molen J. S. and Perissinotto R.** (2011) Microalgal productivity in an estuarine lake during a drought cycle: the St. Lucia Estuary, South Africa. *Estuarine, Coastal and Shelf Science* 92, 1–9.
- Vendel A.L. and Chaves P.D.T.** (2006) Use of an estuarine environment (Barra do Sai lagoon, Brazil) as nursery by fish. *Revista Brasileira de Zoologia* 23, 1117–1122.
- Wasserman R.J., Strydom N.A. and Wooldridge T.H.** (2010) Larval fish dynamics in the Nxaxo-Ngqusi Estuary Complex in the warm temperate-subtropical transition zone of South Africa. *African Zoology* 45, 63–77.
- Wyanski D.M. and Targett T.E.** (2000) Development of transformation larvae and juveniles of *Ctenogobius boleosoma*, *Ctenogobius shufeldti*, and *Gobionellus oceanicus* (PISCES: GOBIIDAE) from western North Atlantic estuaries, with notes on early life history. *Bulletin of Marine Science* 67, 709–728.
- Yeung C. and Ruple D.** (2006) Gobiidae: gobies. In Richards W.J. (ed.) *Early stages of Atlantic fishes: an identification guide for the western*

*central North Atlantic. Marine Biology Series, Volume 2.* Boca Raton, FL: CRC Press, pp. 2029–2078.

and

**Young G.C. and Potter I.C.** (2003) Do the characteristics of the ichthyoplankton in an artificial and a natural entrance channel of a large estuary differ? *Estuarine, Coastal and Shelf Science* 56, 765–779.

**Correspondence should be addressed to:**

E.A.P. Gomes

Universidade Federal do Rio de Janeiro, Instituto de Biologia  
Departamento de Zoologia, CCS, Bloco A, Ilha do Fundão

21941-590, Rio de Janeiro, RJ, Brazil

email: [eduapg@hotmail.com](mailto:eduapg@hotmail.com)