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Habitat use by *Atherinella brasiliensis* (Quoy & Gaimard, 1825) in intertidal zones of a subtropical estuary, Brazil

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ABSTRACT. Habitat use is different along the ontogenetic development of some species and may be influenced by environmental parameters. This study described the interaction of *Atherinella brasiliensis* caught in intertidal areas of the Paranaguá Estuarine Complex with environmental parameters. We caught 10024 individuals between August 2010 and July 2011, with total mean length of 44.32 mm (SD ± 25.37 mm), variation range between 12 and 142 mm, and weight between 0.01 and 73 g, averaging 1.35 g (SD ± 2.66 g) and ages estimated between < 1 and 22 months. Significant differences were detected between sectors and periods for number of individuals and weight at capture, with higher mean values in the mean sector during the rainy period. The spatial and temporal distribution of ages was statistically different, individuals between < 1 and 3 months were more abundant in the sector 2 during the rainy period, and individuals older than 7 months were evenly distributed throughout the sampling area, and with higher mean abundance at the beginning and end of the dry period. Environmental variables that most influenced the distribution of age classes were temperature and salinity.

Keywords: Atheriniformes, distribution, age, environmental parameters.

Uso do habitat por *Atherinella brasiliensis* (Quoy & Gaimard, 1825) nas regiões intertidais de um estuário subtropical, Brasil

RESUMO. O uso do habitat é diferenciado ao longo do desenvolvimento ontogenético em algumas espécies, podendo ser influenciado pelos parâmetros ambientais. O presente estudo descreve a interação da *Atherinella brasiliensis* capturada nas regiões intertidais do Complexo Estuarino de Paranaguá (CEP) com os parâmetros ambientais deste ambiente. Foram capturados 10024 indivíduos entre agosto de 2010 e julho de 2011, com comprimento total médio de 44,32 mm (DP = ± 25,37 mm), amplitude de variação entre 12 e 142 mm, e pesos entre 0,01 e 73 g, com média de 1,35g (DP = ± 2,66 g) e idades estimadas entre < 1 e 22 meses. Foram evidenciadas diferenças significativas entre setores e estações do ano no número de indivíduos e peso da captura, com maiores médias no setor mediano e na estação chuvosa. Diferenças estatísticas foram observadas na distribuição espaço-temporal das idades, com os indivíduos entre < 1 e 3 meses em média mais abundantes no setor 2 e período chuvoso, e os com indivíduos com idades acima de 7 meses igualmente distribuídos em toda a área amostral e com maior abundância média no início e final da seca. As variáveis ambientais que mais influenciaram na distribuição das classes etárias foram a temperatura e a salinidade.

Palavras-chave: Atheriniformes, distribuição, idade, parâmetros ambientais.

Introduction

Studies on population dynamics depend on the description of the migrations performed by species during the ontogenetic development, for proper management of these populations (GILLANDERS, 2002). The diversification of habitat use along the ontogenetic development is directly related to the physiological changes imposed by the growth of the species, thus larvae, juveniles and adults do not use the same environment, in most species of fish (KIMIREI et al., 2010; GREEN et al., 2012).

The Brazilian estuarine fish fauna has been described in several works (BARLETTA et al., 2005, 2010; CONTENTE et al., 2011; VILAR et al., 2011; PASSOS et al., 2012), but few of them have addressed the shift of habitat during the ontogenetic development of fish (BECK et al., 2003; DANTAS et al., 2010, 2012; MOURA et al., 2011).

The target species of this study is *Atherinella brasiliensis* (Atherinopsidae) (Quoy and Gaimard, 1824), a benthic-pelagic species abundant in the intertidal zone of the Estuarine Complex of Paranaguá (VENDEL et al., 2003; SPACH et al., 2004;

IGNÁCIO; SPACH 2009; CONTENTE et al., 2011), which has adhesive benthic eggs and direct larval development (DEL RIO et al., 2005). The length at first maturity of females ranges from 7.6 and 9.1 cm in the studied environments, with recruitment during October and January with multiple spawning (BERVIAN; FONTOURA, 1997; FÁVARO et al., 2003). It has opportunistic, generalist feeding habit (CHAVES; VENDEL (2008); VENDEL; CHAVES (2006); CONTENTE et al., 2011), being a food item for piscivorous animals (BORDIGNON, 2006; BUGONI; VOOREN, 2004) and its distribution is influenced by oceanographic parameters in the estuaries (FÁVARO et al., 2007).

Given the ecological importance and the lack of studies describing the shift along the development in the habitat use by *Atherinella brasiliensis* in the Estuarine Complex of Paranaguá Bay, this study sought to evaluate the spatial use of the area using the age as a population parameter, essential for understanding the patterns of species distribution and interactions between organisms and environmental conditions.

Material and methods

Collections of *A. brasiliensis* were conducted between August 2010 and July 2011, at 17 sites in the north-south axis of the Paranaguá Estuarine Complex (PEC), Paraná State (25º 15' - 25° 35' S and 48° 20' - 48° 45' W) (Figure 1). CTD profiling was carried out every month to measure the environmental parameters of salinity, chlorophyll (μg L^{-1}), pH and water temperature (°C) in the sampling sites. At each month and sampling site, a paralel trawling 30 m long was carried out using a beach seine net 5 m long, 2 m high and 2.5 mm between opposite knots, dragged by two people. After collection, fish were cooled, identified (MENEZES; FIGUEIREDO, 2000), measured for total length (LT in mm) and weighed (W in g).

Ages were estimated according to Froese (2006). For analysis, sampling sites were pooled into sectors and months into periods. In order to determine the sectors, we used data of distance between sampling sites and mouths of the PEC. The distances of the sites 1 - 9 were measured in relation to the northern channel, and sites 10 -17, in relation to the Galheta Channel. Thus, the similarity matrix was calculated on the basis of the Euclidean distance, and then a Cluster analysis was performed using the single linkage method (CLARK; WARWICK, 2001). The months sampled were grouped into four periods: late dry period (LD: July, August and September), early rainy period (ER: October, November and December), late rainy period (LR: January, February and March) and early dry period (ED: April, May and June).

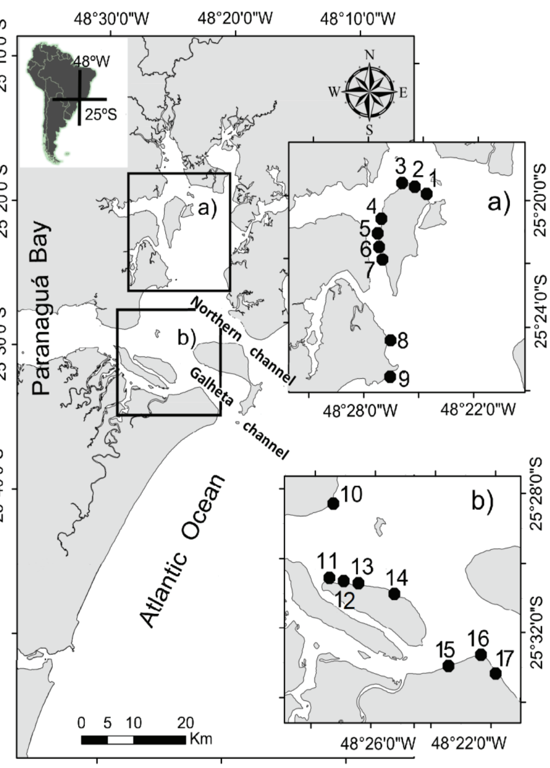

Figure 1. Map of the Paranaguá Estuarine Complex showing the sampling sites.

Taking sectors and periods as fixed factors, we used a permutational analysis of variance (PERMANOVA) with 9999 permutations, using raw data and the similarity matrix calculated by the Bray-Curtis index to test the variations and interactions of the catch by trawl of the number and weight and age of individuals. The same analysis was applied to evaluate differences between sectors and periods for normalized environmental parameters, with the similarity calculated by the Euclidean distance. When rejected the null hypothesis, the comparison between the means of groups was performed using the permutation t test (ANDERSON et al., 2008).

A Canonical Analysis of Principal coordinates (CAP) was run to evaluate the pattern of occurrence of ages between sectors and periods on a multivariate space, using a Spearman correlation of 0.3. Using the Akaike Information Criterion (AIC) and the stepwise procedure, with raw biotic data and normalized environmental data, the Distance-based

Linear regression model (DistLM) checked for a significant correlation between environmental variables and ages in the sectors and periods. The visualization of the models was carried out by the distance-based redundancy analysis (dbRDA) (ANDERSON et al., 2008).

Results

Three sectors were set in the study area by the cluster analysis based on the distance between the sampling sites, and the mouths of the PEC: Sector 1 (sites 1, 2, 3, 4, 5, 6 and 7), Section 2 (sites 8, 9, 10, 11, 12, 13 and 14) and sector 3 (sites 15, 16 and 17) (Figure 2).

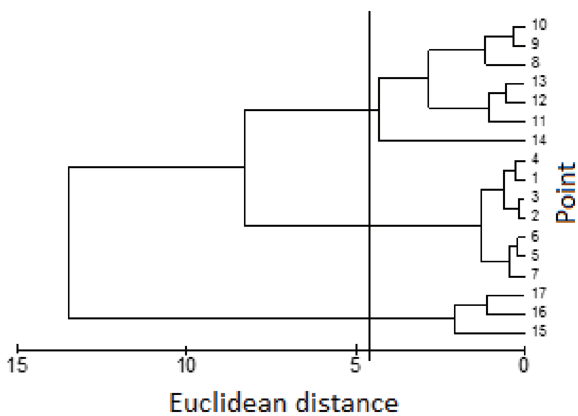

Figure 2. Dendrogram of the cluster analysis for distances between sampling sites and mouths of the Paranaguá Estuarine Complex.

Environmental differences were significant between sectors (PERMANOVA, pseudo-F = 6.08, $p < 0.001$). The paired t-test revealed statistical differences between sectors 1 and 2 ($t = 2.96$, $p < 0.001$), 1 and 3 ($t = 2.77$, $p < 0.001$) but not between sectors 2 and 3 ($t = 0.79$, $p > 0.05$). The sectors showed variations in environmental parameters: the salinity was higher in the sector 3 (25.32 ± 3.68 ups) and lower in the sector 1 (22.70 ± 4.97 ups), similarly to water temperature (sector 3 = 24.11 ± 3.02°C; sector 1 = 23.09 ± 2.80°C). A higher mean pH was registered in the sector 2 (7.92 ± 0.52), and a lower mean pH in the sector 1 (7.79 ± 0.39). The mean chlorophyll was greater in the sector 1 (2.97 ± 1.06 $\mu g\ L^{-1}$) and lower in the sector 3 (2.35 ± 0.85 $\mu g\ L^{-1}$).

Environmental variables were significantly different between periods (PERMANOVA: pseudo-F = 25.17, $p < 0.001$). The paired t-test revealed significant differences ($p < 0.001$) between all periods, except for the early and late dry periods ($t = 1.61$, $p > 0.05$). Regarding the periods, the mean salinity was higher in the early dry period (26.77 ± 3.56 ups) and lower at the end rainy period (20.22 ± 4.79 ups), with a mean temperature higher in the late rainy period (27.57 ± 1.36°C), and the smaller mean temperature was measured in the late dry period (20.86 ± 1.65°C). The pH values were higher in the early dry period (8.13 ± 0.56) and lower in the early rainy period (7.63 ± 0.31). The mean chlorophyll concentration was lower in the late dry period (2.22 ± 0.93 $\mu g\ L^{-1}$), and higher in the late rainy period (3.25 ± 0.96 $\mu g\ L^{-1}$).

We caught 10024 individuals of *A. brasiliensis* with mean total length of 44.32 mm (SD ± 25.37 mm), variation range between 12 and 142 mm, and weight between 0.01 and 73 g, averaging 1.35 g (SD ± 2.66 g). Significant differences between sectors were detected for the number of individuals (PERMANOVA: pseudo-F = 3.56, $p < 0.01$), with higher values in the sector 2 compared to sector 1 ($t = 2.63$, $p < 0.01$), but not different between sectors 1 and 3 ($t = 0.73$, $p > 0.05$) and 2 and 3 ($t = 1.20$, $p > 0.05$). Biomass was also different between sectors (PERMANOVA: pseudo-F = 2.84, $p < 0.01$), with weight at capture higher in the sector 2, compared to the sector 3 ($t = 2.15$, $p < 0.01$), but not significantly different between sectors 1 and 2 ($t = 1.39$, $p > 0.05$) and 1 and 3 ($t = 1.49$, $p > 0.05$). Between periods, the variation in the number of individuals (PERMANOVA: pseudo-F = 6.24, $p < 0.001$) exhibited greater values in the early ($t = 2.08$, $p < 0.01$) and late rainy periods ($t = 3.98$, $p < 0.01$) compared to the late dry period, which was also verified between the late rainy and early dry periods ($t = 3.12$, $p < 0.01$). The weight at capture varied between periods (PERMANOVA: pseudo-F = 2.15, $p < 0.05$), with a statistically greater mean value in the late rainy period in relation to the late dry ($t = 1.94$, $p < 0.05$) and early dry ($t = 2.16$, $p < 0.01$) periods, without significant differences between mean values of the other periods (LDxER: $t = 0.87$, $p > 0.05$; LDxED, $t = 0.64$, $p > 0.05$; ERxLR: $t = 1.39$, $p > 0.05$; ERxLD: $t = 1.01$, $p > 0.05$). Both for the number of individuals (PERMANOVA: pseudo-F = 1.33, $p > 0.05$) and weight at capture (PERMANOVA: pseudo-F = 0.85, $p > 0.05$), no significant interactions were found between sectors and periods.

Between sampled sectors, significant differences were registered for the abundance of individuals per age (PERMANOVA: pseudo-F = 2.77, $p < 0.001$). The paired PERMANOVA evidenced differences in frequencies of ages between sectors 1 and 2 ($t = 1.58$, $p < 0.01$), 1 and 3 ($t = 1.68$, $p < 0.01$) and 2 and 3 ($t = 1.75$, $p < 0.001$). The Canonical Analysis of Principal coordinates (CAP: δ_1 = 0.5493 and δ_2 = 0.4536) demonstrated that individuals with < 1 month, 1, 2, and 3 months of age were more abundant in sectors 1 and 2, especially in the sector 2, while individuals with age from 7 and 16 months were distributed throughout the sampling area, with greater abundance in sectors 1 and 2 (Figure 3).

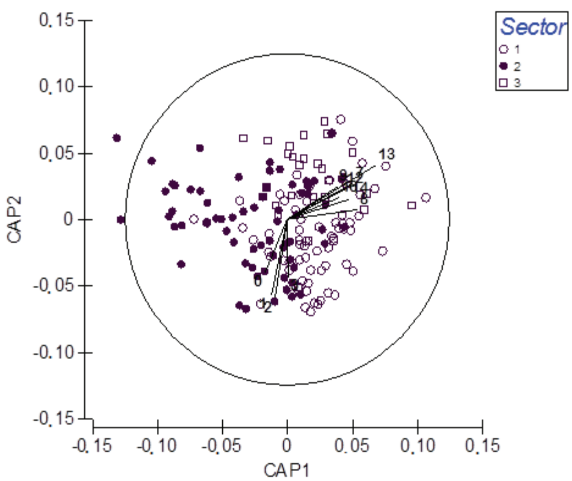

Figure 3. Results of the Canonical Analysis of Principal Coordinates (CAP) with the ages that contributed for differences between sectors. Vectors of ages on the basis of Spearman correlation of 0.3 (1 = sector 1, 2= sector 2 and 3 = sector 3).

The Distance-based Linear regression model (DistLM) showed the relationship between the spatial distribution pattern of age structure and the set of predictor variables: temperature (AIC = 1380.5), salinity (AIC = 1379.3), chlorophyll (AIC = 1378.9) and pH (AIC = 1378.6), with 61.82 and 19.94% of the variance explained by the first and second axes, respectively. The visualization of the linear model with four predictor variables through the distance-based redundancy analysis (dbRDA) demonstrated a better explanation by the variables temperature and salinity, more associated with the variation along the axis 1, with younger individuals predominantly associated with colder and less saline waters in the inner areas of the study region (Figure 4).

The permutational analysis of variance evidenced significant differences in the temporal pattern of occurrence of individuals of different ages (PERMANOVA: pseudo-F = 4.76; $p < 0.001$). The paired permutation test indicated significant differences in the age structure between late dry and early rainy periods ($t = 1.53$, $p < 0.01$), late dry and rainy periods ($t = 2.94$, $p < 0.001$), early and late dry periods ($t = 1.78$, $p < 0.001$), early and late rainy periods ($t = 2.46$, $p < 0.001$), early rainy and early dry periods ($t = 1.84$, $p < 0.001$) and late rainy and early dry periods ($t = 2.17$, $p < 0.001$).

The Canonical Analysis of Principal coordinates (CAP: δ_1 = 0.7047 and δ_2 = 0.5062) pointed out that, proportionally, individuals aged between 1 and 7 months are more abundant mainly in the late rainy period, and to a lesser extent in the early dry period, with greater proportional frequencies of older individuals (10, 11, 12, 13 and 14 months of age) at the late dry period and early rainy period (Figure 5).

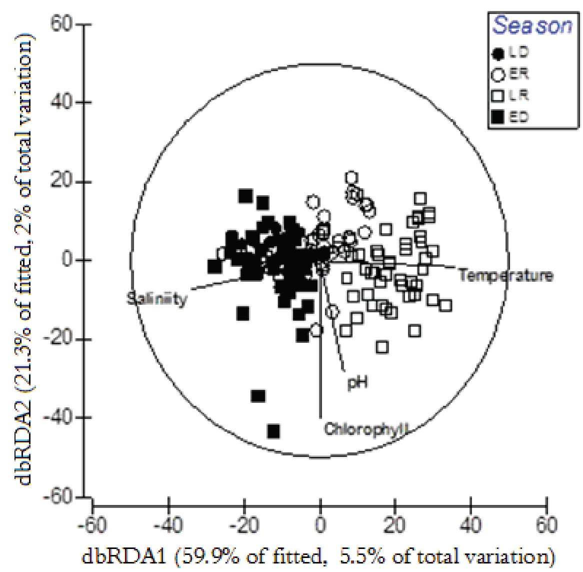

Figure 4. Results of the distance-based redundancy analysis (dbRDA) with predictor variables selected by the linear model (1 = sector 1, 2 = sector 2 and 3 = sector 3).

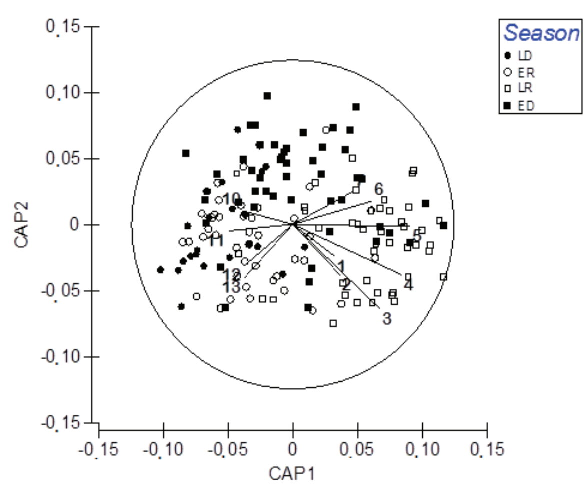

Figure 5. Results of the Canonical Analysis of Principal Coordinates (CAP) with the ages that contributed to the differences between periods. Vectors of ages on the basis of Spearman correlation of 0.3. (LD = late dry, ER = early rainy, LR = late rainy and ED = early dry).

The best set of predictor variables explaining the relationship between the ages of individuals and the periods were: temperature (AIC = 1380.5), salinity

(AIC = 1379.3), chlorophyll (AIC = 1378.9) and pH (AIC = 1378.6), with 59.87 and 21.32% of the variance explained by the first and second axis, respectively. Regarding the dbRDA (Figure 6), there was a satisfactory correlation between the temporal pattern of occurrence of the ages of individuals with salinity and temperature, with younger individuals mostly associated with lower salinity and higher temperature at the end of the rainy period; proportionally, older individuals were more abundant at lower temperature and higher salinity at the early and late dry periods.

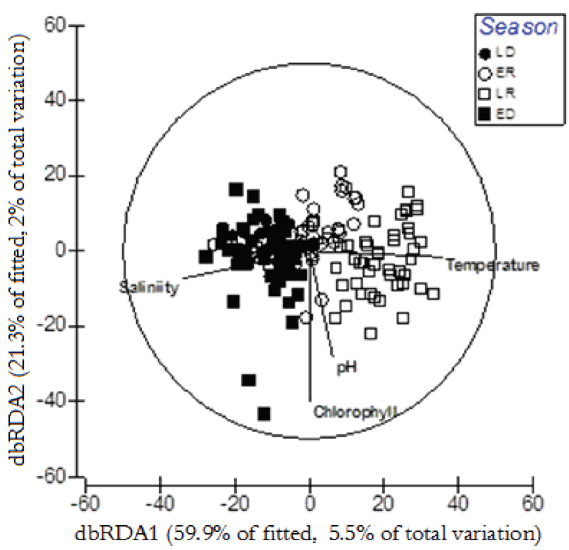

Figure 6. Results of the distance-based redundancy analysis (dbRDA) with predictor variables selected by the linear model (LD = late dry, ER = early rainy, LR = late rainy and ED = early dry).

Discussion

The abundance and biomass were significantly greater in the rainy period, resulting from the formation of reproductive aggregates and increased recruitment in the rainy period (warmer). The increased recruitment and/or aggregation of reproducing individuals of *A. brasiliensis* in the warmer period was also found in other studies. Hostim-Silva et al. (1995) observed increased catch during warmer periods in the Conceição Lagoon (Santa Catarina State). In turn, Fávaro et al. (2007) reported a reduction in the total length of individuals collected in the summer (input of recruits) for the PEC, and related this result to the reproductive success in the spring, when larger individuals were caught. Félix et al. (2006) correlated the increased catch in the intertidal zones of the PEC in the summer with increased primary productivity, which favored the approximation of shoals of this species.

Despite its occurrence in all sectors of the intertidal zone of PEC, in this study, individuals of *A. brasiliensis* were more abundant in less saline intertidal areas, less hydrodynamic and more structured (higher presence of marshes and mangroves), which had already been described for intertidal zones of PEC by Fávaro et al. (2007). An interaction of this species with more saline regions was found in the mangrove of Guaratiba (Rio de Janeiro State) by Neves et al. (2006), but some studies have demonstrated the preference of *A. brasiliensis* for mesohaline regions in the Manducaba River (Rio de Janeiro State) (NEVES et al., 2010) and in the PEC (PASSOS et al., 2013). In the Conceição Lagoon (Santa Catarina State), this fish species preferred environments with reduced salinity (HOSTIM-SILVA et al., 1995) and in the Sepetiba Bay (Rio de Janeiro State), *A. brasiliensis* showed no preference for oligo- or mesohaline habitats, once it was distributed throughout the sampling area (PESSANHA; ARAÚJO, 2003). The lack of a clear pattern of spatial distribution of *A. brasiliensis* related to salinity in the different south-southeast regions of Brazil may be explained by the high osmoregulatory capacity of estuarine fish (SOUZA-BASTOS; FREIRE, 2011).

Moreover, in this study we registered a correlation between the age distribution pattern of *A. brasiliensis* with salinity and temperature. Younger individuals were mostly associated with colder and less saline waters in inner regions of the PEC, preferentially in the sector 2. Other characteristics that may have influenced this pattern include the presence of mangroves and marshes, and a reduced energy of waves in these inner areas. Likewise, Spach et al. (2004) mentioned a greater abundance of this species in marginal environments with high environmental structure, while Hackradt et al. (2009) observed larger individuals in highly structured marginal environments, and smaller individuals in inner areas of the PEC. In the Barra do Sai (Santa Catarina State), Spach et al. (2010) suggested that *A. brasiliensis* prefers the tidal creek to lagoons or the bed of the adjacent river, possibly because of intermediate salinity and greater environmental structure of the tidal creek. All the studies cited above seem to explain the reduced catch in the outer area in the present study, where there are higher salinity and hydrodynamics and lower environmental structuring.

Migratory processes of *A. brasiliensis* were reported by Hostim-Silva et al. (1995), who supposed that the species migrates to the ocean during the winter. Long distance migratory species show morphological adaptations in sagitta otoliths, greater development of the rostrum, which aids in the equilibrium of the species during the migratory process in the water column (POPPER; LU, 2000). *A. brasiliensis* does not have such well-developed structure (CARVALHO; CORRÊA, 2014), which indicates that this species perform short migrations, consequently, we suppose little migration between sectors in this study. The combination of reduced potential for migration (displacement) with adhesive benthic eggs and direct larval development (DEL RIO et al., 2005) seem to indicate that differences in the distribution patterns are mainly determined by local driving forces, with less influence of exchange of individuals between sectors.

Shifts in habitat use by age classes of *A. brasiliensis* exhibited a marked pattern with younger individuals (< 1,1,2,3 months) being abundant in sectors 1 and 2, especially the sector 2, and individuals with more than 7 months of age distributed throughout the sampled area, mainly in the inner sectors 1 and 2. Among the factors that affect the spatial distribution of age classes of *A. brasiliensis*, stand out feeding, protection against predation and higher influence of waves. According to Contente et al. (2010) *A. brasiliensis* changes the feeding habits as it grows, initially it feeds on centric diatoms, and when reaches 7 cm, it begins to feed on larger items. The sector 2 shows a higher concentration of chlorophyll, which justify the greater presence of younger individuals in this environment, using the sector for feeding and growth. On the other hand, as the other age classes have low feeding specificity they can be distributed across all sectors studied. Another factor explaining the distribution pattern of age classes is that the sector 2 is closer to the maximum turbidity zone of the PEC (MACHADO, 2011), which promotes a greater protection against piscivores compared to the sector 3, most influenced by marine waters with low turbidity.

The temporal distribution of age classes of *A. brasiliensis* showed a variation along the sampling period, assisting in determining the life cycle of the species. At the late dry period, individuals of different ages were caught, mostly older than 7 months of age, possibly members of cohorts from the reproductive process in previous years, described by Fávaro et al. (2003) as being more intense in October, with multiple spawning. As the species has adhesive benthic eggs, adults (with length above 7 cm) would aggregate in shallower areas of the PEC for spawning and fertilization, and this would probably occur at the end of the dry period.

The predominance of younger individuals (< 1, 1, 2, 3 months) at the end of the rainy period is explained by the development of this species and mesh size of the net. Due to multiple spawning of the species, the reproductive aggregate demonstrated by the abundance of adults in the late dry period would have led to the finding of younger individuals of different ages during the rainy period. In laboratory, Del Rio et al. (2005) described the embryonic development of *A. brasiliensis*, and registered that spawning and hatching take 6 days, the larvae hatch out with average total length of 5.04 mm (± 1.22 mm), reaching 13 mm total length after 40 days. When interpreting the results of temporal distribution, it is important to note the possible influence of the sampler, given the high probability of escape of individuals smaller than 15 mm through the net mesh and of larger individuals because of the low trawling speed.

Conclusion

Our results evidenced that all age classes of *A. brasiliensis* are present in shallow areas. This species shows different habitat use between age classes, which is caused by changes in feeding habits, higher availability of favorable environments, higher turbidity of water, and lower local hydrodynamics, besides specific characteristics.

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