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Use of shallow areas by ichthyofauna (Teleostei) on the north-south axis of the Paranaguá Estuarine Complex, State of Paraná, Brazil

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Abstract: Aiming to identify the temporal and spatial patterns of the fish fauna in the tidal zone, monthly samples were taken in the neap tides between August 2010 and July 2011 at 17 sites on the north-south axis of the Paranaguá Estuarine Complex. At each site, in addition to the trawl, we also sampled data for salinity, temperature, chlorophyll, turbidity and sediment. In total, 49056 specimens of 56 taxa were caught with the numerical dominance of *Anchoa tricolor*, *Atherinella brasiliensis*, *Mugil* sp. and *Sphoeroides greeleyi*. Mean values of density and biomass were significantly different among the seasons; the density was different only among the sectors. A greater number of individuals was present in the inner sector and this pattern was also observed for biomass. The mean number of species was significantly higher in the wet season, especially in the inner sector. No statistical difference was detected between the sectors for the Margalef richness and Shannon-Wiener diversity, however they showed differences among the seasons; in turn, the Pielou evenness had no significant variation.

Keywords: spatial variation, temporal variation, estuarine fish, shallow areas, beach seine

Resumo. Utilização de áreas rasas pela ictiofauna no eixo norte-sul do Complexo Estuarino de Paranaguá, Paraná, Brasil. Com o intuito de identificar os padrões temporais e espaciais da ictiofauna na zona entre marés foram realizadas coletas mensais, na maré de quadratura, entre agosto de 2010 e julho de 2011 em 17 pontos do eixo norte-sul do Complexo Estuarino de Paranaguá. Em cada ponto além do arrasto, foram também amostrados dados de salinidade, temperatura, clorofila, turbidez e sedimentos. No total foram capturados 49056 exemplares de 56 taxa, com o domínio numérico de *Anchoa tricolor*, *Atherinella brasiliensis*, *Mugil* sp. e *Sphoeroides greeleyi*. As médias de densidade e biomassa foram significativamente diferentes entre as estações, sendo a densidade diferente somente entre os setores. O maior número de indivíduos esteve presente no setor interno e esse padrão se repetiu para a biomassa. A média do número de espécies foi significativamente maior na estação chuvosa, especialmente no setor interno. Nenhuma diferença estatística foi constatada entre os setores nas médias da riqueza de Margalef e da diversidade de Shannon-Wiener, no entanto houveram diferenças entre as estações; já a equitatividade de Pielou não apresentou diferenças significativas.

Palabras clave: variação espacial, variação temporal, peixes estuarinos, áreas rasas, picaré

Introduction

Fish is the main component of the estuarine macrofauna and several studies have focused on their distribution patterns, which are strongly influenced by the interaction of several factors in estuary (Martino & Able 2003). The environmental variables have a significant effect on the fish fauna structure in an estuarine system, since they originate a high diversity of habitats (Matic-Skoko *et al.* 2005), in which the main ones are: temperature (Rogers & Miller 1996, Larouche *et al.* 1997), water turbidity (Vieira & Castello 1996), dissolved oxygen concentration (Louis *et al.* 1995, Deegan *et al.* 1997), depth (Laegdsgaard & Johnson 1995) and morphological characteristics of the substrate (Jenkins & Wheatley 1998, Garcia-Charton & Perez-Rufala 1998), besides biological interactions (Vieira & Musick 1993).

The coexistence of similar fish in an ecosystem can occur due to the development of life strategies that allow temporal or spatial segregation in the use of the environment. Thus, close species can live in the same area by exploiting different habitats, micro habitats or being active in different periods (Azevedo *et al*. 1999). The spatial distribution of the species guarantees a nonuniformity along the estuary, however there is still the influence of temporal variation, which can have long or short periods. The short-term variations occur mainly due to the tidal cycles, the phases of the moon and the alternation between day and night. The most common and perceptible long-term variations are those caused by the seasons (seasonal variation). Most of the fish fauna found in the estuaries have their migratory and reproductive cycles in synchrony and are partially regulated by long-term variations (Oliveira Neto *et al*. 2004).

Coastal zones are under stress due to human activities that include: overfishing, tourism, urbanization, agriculture and industrial development that cause pollution (Raz-Guzman & Huidobro 2002). Estuarine environments located in the proximities of urban centers have well marked anthropogenic action, leading to a pronounced degradation of these areas (Miranda *et al.* 2002). These alterations in the aquatic environment, originating from anthropic activities, may compromise the maintenance of species in these environments.

It is necessary to identify the structure of fish fauna in estuarine environments to understand how natural or anthropogenic disturbances alter fish distribution, abundance, diversity, reproduction, growth, feeding, survival and behavior patterns of both resident and transient species (Whitfield & Elliot 2002, Vendel *et al*. 2003). Knowledge about the composition of the fish fauna and how it varies both in space and time is essential for making decisions for the sustainable management of species as well as for preservation actions (Kupschus & Tremain 2001). The importance of estuaries is so evident, as they are among the most productive ecosystems in the world and are critical for several species of fish. Therefore, the present study aimed to: describe the use pattern of shallow environments for fish populations in the north-south axis of the estuarine complex of Paranaguá and check the possible relationships between these patterns and environmental variables.

Material and methods

Study area: The Paranaguá Estuarine Complex (PEC) (Fig. 1) is the largest on the coast of the State of Paraná, located at the coordinates 48°25'W and 25°30'S. It comprises the Paranaguá, Antonina, Laranjeiras, Guaraqueçaba and Pinheiros Bays and presents an area of 551.8 km^2 (Noernberg *et al*. 2004).

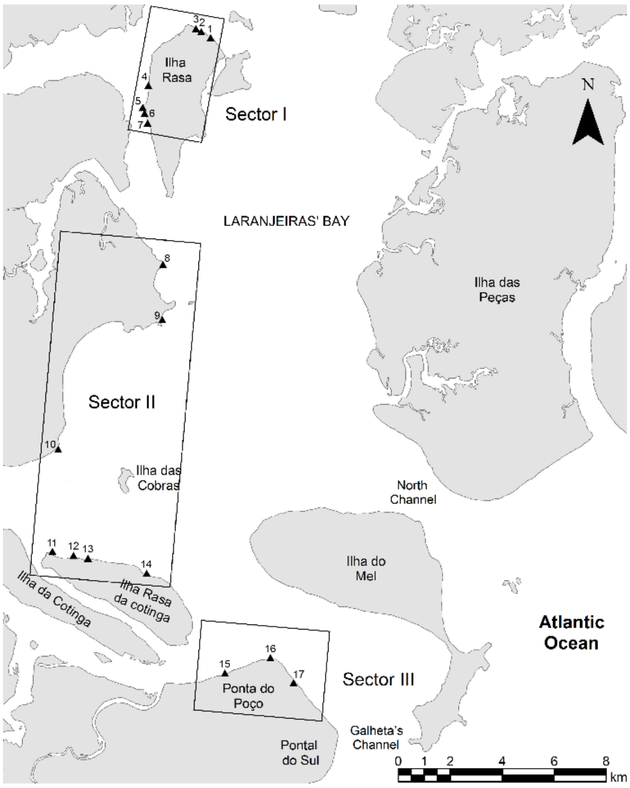

Figure 1. Map showing the sampling sites distributed on the north-south axis of the Paranaguá Estuary Complex.

and 12-29 and in the winter of 18-25°C and 20-34 (Lana *et al.* 2001).

It is a partially mixed estuary, with a moderate vertical gradient of salinity (Knoppers *et al*. 1987), semidiurnal tides with diurnal inequality, circulation and stratification patterns of the estuary varying among seasons and average of temperature and salinity in the summer respectively of 23 -30°C. The climate of the region is subtropical humid, mesothermal with hot summers, there is a tendency of rainfall concentration in the summer months, however there is no well-defined dry season (Lana *et al*. 2001). The average annual rainfall is 2,500 mm and the air humidity is 85%, the climate of the region depends on the displacement of the semi-permanent anti-cyclonic gyre of the South Atlantic and the passage of polar air masses in the winter.

In most cases, the PEC is surrounded by mangrove swamps, composed of *Rhizophora mangle*, *Avicennia schaueriana*, *Laguncularia racemosa* and *Conocarpus erecta* (Lana *et al.* 2001), and marshes of *Spartina alterniflora* (Netto & Lana 1997). The PEC is compound by several fisherman's villages and some cities with consequent anthropic impacts that cause damage to the environment and fauna in some way.

Sampling: Monthly samples were taken between August 2010 and July 2011 at 17 sites located on the north-south axis of the PEC (Fig. 1), always during daylight and neap tides, through a trawl parallel to the coast of 30m per site (approximately 1.5 m deep), with a beach seine net 15 m long, 2 m high, central 2-m long bunt and 2.5 mm (strectched mesh opening) throughout.

The caught specimens were identified at the lowest possible taxonomic level based on specialized literature, measured for total length (to nearest 1 cm) and weighed (to nearest 1 g). At each site on each occasion, salinity, temperature, chlorophyll, turbidity was measured with a multiple sensor (ASTD 687; Alec Eletronics Co., LTda, Kobe, Japan) and depth (cm; measured with ruler).

Data analysis: According to Elliott *et al*. (2007), species were allocated to the following estuarine use: amphidromous (AM; migrate between the sea and freshwater with no migration related to reproduction), anadromous (AN; species that undergo their growth at sea and migrate into rivers to spawn), estuarine species (ES), marine migrants (MM; species that spawn at sea and enter estuaries in large numbers as juveniles; considered euryhaline) and marine stragglers (MS; species that spawn at sea and enter estuaries in low numbers, are considered stenohaline and are found at salinities of approximately 35), Base also in Elliott et al. (2007), species were allocated to the following feeding mode functional groups: detritivore (DV; feeding on detritus and/or microphytobenthos), herbivore (HV; grazing on macroalgae, macrophytes or phytoplankton), opportunistic (OP; feeding on a diverse range of food), piscivore (PV; feeding on finfish and large nektonic invertebrates), zoobenthivore (ZB; feeding on invertebrates that live just above, on or in the sediment) and zooplanktivore (ZP; feeding on zooplankton).

For the definition of the seasons, monthly rainfall data were used for the study period together with a monthly rainfall series of the five years prior to the study (from 2005 to 2009) (Paraná Meteorological System; http://www.simepar.br), and four seasons were defined: early wet (EW - October, November and December of 2010) and late wet (LW - January, February and March of 2011), early dry (ED - April, May and June of 2011) and late dry (LD - July, August and September of 2011) (Fig. 2). For the determination of the sectors, we used distance data between the sampling sites and the entrance of the bay, and the distances of sites 1 to 9 were measured in relation to the North channel and sites 10 to 17 in relation to the Galheta's channel. Then, we calculated the similarity matrix using the Euclidean Distance method and performed a Cluster analysis by the "Single linkage" method. This analysis revealed the existence of three groups (sectors): Sector I (1, 2, 3, 4, 5, 6 and 7), Sector II (8, 9, 10, 11, 12, 13 and 14) and Sector III (15, 16 and 17) (Fig. 3).

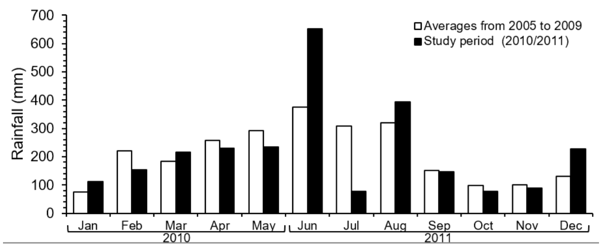

Figure 2. Monthly rainfall averages, in millimeters, for the study period (August 2010 to July 2011) along with rainfall averages from 2005 to 2009.

The salinity variable was replaced with the saline stratification index, which was obtained by subtracting the salinity value obtained at the surface from the value obtained at the greater depth with the multiple sensor. The depth of the trawl was measured at the beginning of each trawl based on the depths, from the margin, at the beginning, middle and end of the net. Both the environmental variables (temperature, salinity stratification index,

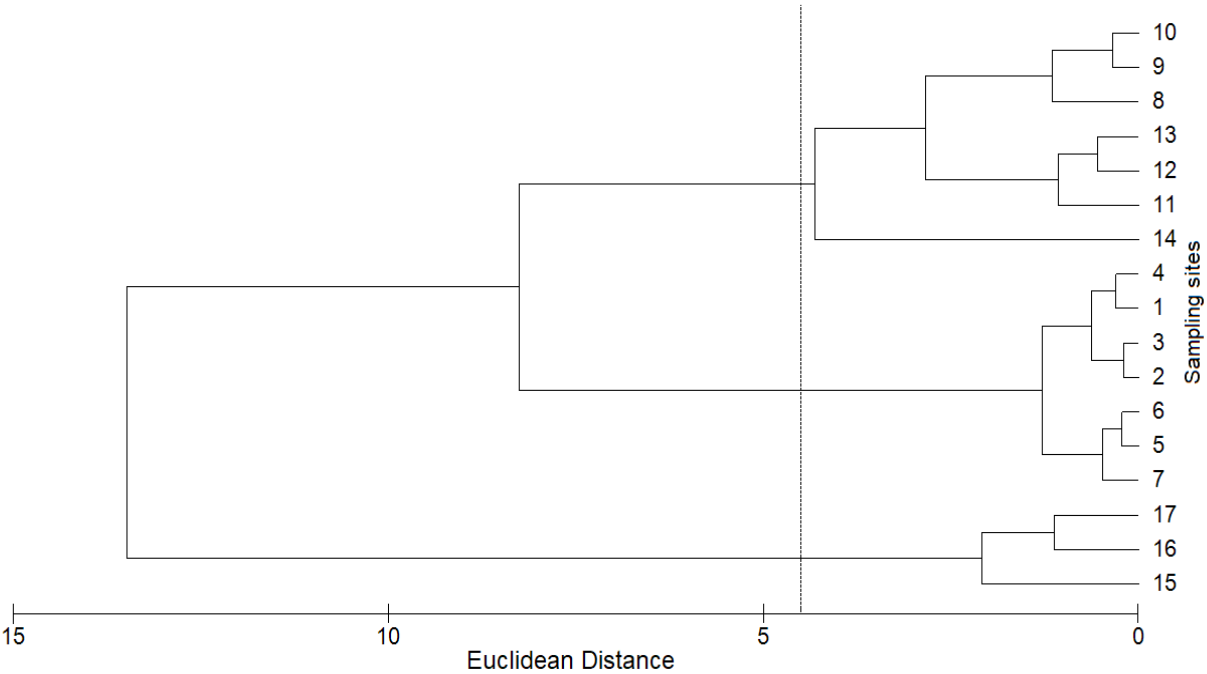

Figure 3. Dendrogram from the cluster analysis for the distances between the sampling sites and the inlets of the Paranaguá Estuarine Complex.

chlorophyll, turbidity and depth of the trawl) and the biological variables (density, biomass, number of individuals, number of species, Margalef richness index, Shannon-Wiener Diversity index and Pielou evenness index) were analyzed in groups formed according to the sectors and sites previously defined.

The size classes were defined for each species following the Sturges formula with the formula: $k = 1+3.322 (\log_{10}n)$, where k is the number of class intervals and n is the number of observations.

Both the environmental variables and the biological variables were tested for variance homogeneity (Bartlett's test) and normality (Shapiro-Wilk test) for the ANOVA test. In cases where the ANOVA assumptions (normality and homoscedasticity) were not met, the non-parametric Kruskal-Wallis test was run. In case of significant differences in the ANOVA test, the Tukey's test was performed a posteriori.

The non-metric multidimensional scaling technique (MDS) was apply to analyze spatial and temporal variations (dry and rainy seasons) in the composition and abundance of all caught species (transformed LogX+1) over the twelve sampling months (Clarke & Warwick 2001). The statistical significance among the groups was evaluated through the analysis of similarity (ANOSIM). Similarity percentage analysis (SIMPER) was used to identify which species were the main responsible for the similarities within each group defined by the MDS and for the dissimilarities among these groups (most discriminant species) (Clarke & Warwick 2001).

To examine the extent to which abiotic data, considered individually and in combination, can explain the pattern of species abundance, we compared the dissimilarity matrices of biotic and abiotic data (BioEnv) using the weighted harmonic Spearman rank correlation coefficient (Clarke & Warwick 2001).

Results

Environmental variables: The temperature in the study period ranged from 16.56ºC to 29.02°C, with significantly higher mean values in the early and late wet seasons compared to the other seasons, however, the means were not statistically different between the sectors (Figure 4a, Table I). The salinity stratification index was between -0.808 and 19.258, with the early and late wet seasons showing values significantly higher than the early and dry seasons only in sector I (Figure 4b, Table I). On average, the salinity stratification index was higher in sector I when compared to sectors II and III (Figure 4b, Table I).

The chlorophyll presented values between 0.925 and 13.040, showing significantly higher mean values in the wet seasons than in the dry seasons and in sector I compared to the other sectors

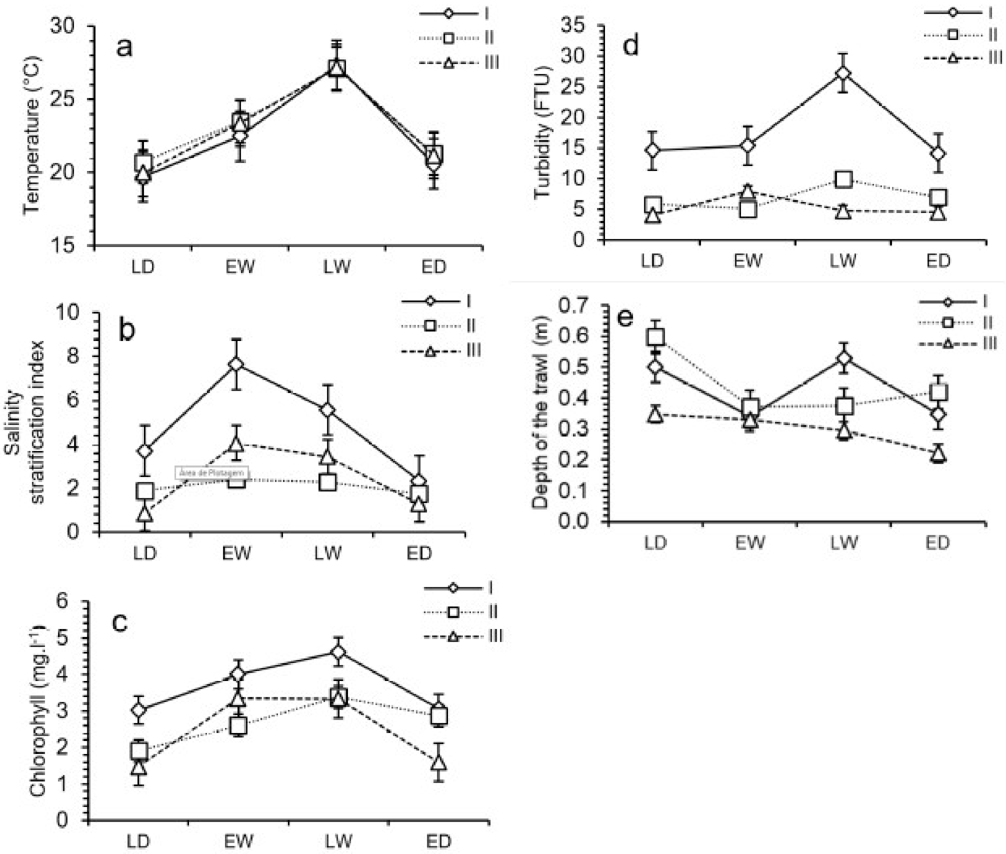

Figure 4. Averages by season (LD, EW, LW and ED) and sectors (I, II and III) of the parameters: temperature (a), salinity stratification index (b), chlorophyll (c), turbidity (d) and depth of the trawl (e). Vertical bars indicate standard error.

Table I. Probability resulting from the statistical tests applied to the parameters of the water column (temperature, salinity stratification index, chlorophyll, turbidity and depth of the trawl). * Significant

	Season				Sector				Tukey HSD		
	H	p	F	p	H	p	F	P	I - II	I - III	II - III
Temperature	110.3239	*<0.01			2.3106	>0.05					
Stratification index	18.9039	*<0.01			27.9001	*<0.01					
Chlorophyll	40.2429	*<0.01			30.9788	*<0.01					
Turbidity	12.8324	*<0.01			51.6825	*<0.01					
Depth of the trawl			1.2442	>0.05			41.208	*<0.01	*<0.01	>0.05	*<0.01

sampled (Figure 4c, Table I). In the sampled areas, the turbidity presented values between 1.418 and 107.968, being on average higher at the late wet season and in sector I (Figure 4d, Table I). The mean depth of the trawls varied between 0.10 m and 1.20 m. On average, the depth of the trawl was not different between the among of the year, however they were higher in sectors II compared to sectors I and III (Figure 4e, Table I).

Fish fauna composition: A total of 49,056 individuals of 56 taxa were collected, 10 of which were not identified to the species level, belonging to 26 families of fish. Few taxa were numerically dominant, with the taxa *Anchoa tricolor* (66.24%), *Atherinella brasiliensis* (21.16%), *Mugil* sp. (6.79%) and *Sphoeroides greeleyi* (1.69%) accounting for 95.88% of the total catch. Each of the other taxa presented relative abundance less than 1% (Table II). The species *A. brasiliensis* (26.48%), *S. greeleyi* (26.29%), *A. tricolor* (25.87%) and *Sphoeroides testudineus* (6.31%) contributed to 84.95% of the total biomass sampled (Table II), with five taxa

Table II. Species composition, absolute and percentage abundance, absolute and percentage biomass, frequency of occurrence, permanence in the estuary (AM = amphidromous, AN = anadromous, ES = estuarine, MM = marine migrant and MS = marine straggler), trophic guild (DV=detritivorous, HV=herbivorous, OP=opportunistic, PV=piscivorous, ZB=zoobenthivorous and ZP=zooplanktivorous), position in the water column (D = demersal and P = pelagic) and commercial importance (N = no, and Y = yes) in the shallow areas of the north-south axis of the Paranaguá Estuarine Complex from August 2010 to July 2011.

	n		biomass (g)						
taxa	total	%	total	%	frequency of occurrence	permanence in the estuary	trophic guild	position in the water column	commercial importance
Trinectes microphthalmus	17	0.035	48.04	0.091	3.92	MM	-	D	N
Albula vulpes	15	0.031	2.07	0.004	4.41	AM	ZB	D	N
Cathorops spixii	6	0.012	179.04	0.340	0.98	ES	ZB	D	Y
Notarius grandicassis	1	0.002	15.99	0.030	0.49	-	-	D	N
Atherinella brasiliensis	10382	21.164	13930.21	26.478	84.31	ES	OP	P	N
Strongylura marina	56	0.114	1449.03	2.754	8.33	MM	PV	P	N
Strongylura sp.	160	0.326	61.36	0.117	20.10	-	-	-	-
Chloroscombrus chrysurus	2	0.004	2.35	0.004	0.49	MS	OP	P	Y
Oligoplites saliens	92	0.188	9.84	0.019	4.90	MM	ZP	P	Y
Oligoplites saurus	132	0.269	75.94	0.144	10.78	MM	PV	P	N
Oligoplites sp.	4	0.008	0.08	0.000	1.47	-	-	-	-
Selene vomer	2	0.004	3.29	0.006	0.98	MM	ZB	D	N
Trachinotus carolinus	36	0.073	63.02	0.120	4.41	MS	ZB	P	Y
Trachinotus falcatus	116	0.236	229.79	0.437	16.67	MS	ZB	P	Y
Centropomus parallelus	2	0.004	28.02	0.053	0.98	ES	ZB	D	Y
Centropomus undecimalis	4	0.008	145.27	0.276	0.98	ES	PV	D	Y
Harengula clupeola	96	0.196	245.69	0.467	2.45	MS	ZP	P	N
Sardinella brasiliensis	58	0.118	13.79	0.026	2.94	MS	ZP	P	Y
Chilomycterus spinosus	47	0.096	369.69	0.703	13.73	ES	ZB	D	N
Guavina guavina	1	0.002	18.98	0.036	0.49	ES	ZB	D	-
Anchoa tricolor	32495	66.241	13612.35	25.873	46.57	ES	ZP	P	N
Cetengraulis edentulus	28	0.057	310.40	0.590	2.45	MM	ZP	P	N
Lycengraulis grossidens	16	0.033	129.66	0.246	2.45	AN	ZP	P	N
Chaetodipterus faber	22	0.045	14.48	0.028	5.39	MS	HV	P	N
Diapterus rhombeus	120	0.245	842.38	1.601	9.80	ES	ZB	D	N
Eucinostomus argenteus	182	0.371	597.61	1.136	17.16	MM	ZB	D	N
Eucinostomus gula	1	0.002	21.20	0.040	0.49	MM	ZB	-	N
Eucinostomus melanopterus	43	0.088	233.36	0.444	11.27	MM	ZB	D	N
Eucinostomus sp.	80	0.163	3.55	0.007	3.94	-	-	-	-
Bathygobius soporator	55	0.112	254.92	0.485	12.75	MM	ZB	D	N
Ctenogobius boleosoma	97	0.198	34.81	0.066	14.22	AM	ZB	D	N
Gobionellus oceanicus	3	0.006	44.42	0.084	1.47	ES	ZB	D	N
Microgobius meeki	1	0.002	0.62	0.001	0.49	MS	ZB	D	N

taxa	n total	n %	biomass (g) total	biomass (g) %	frequency of occurrence	permanence in the estuary	trophic guild	position in the water column	commercial importance
Stephanolepis hispidus	2	0.004	2.32	0.004	0.98	ES	ZB	P	Y
Mugil curema	4	0.008	199.03	0.378	1.47	MM	DV	P	Y
Mugil sp.	3331	6.790	833.59	1.584	46.08	-	-	-	-
Ophichthus gomesii	4	0.008	14.76	0.028	1.47	MS	-	D	N
Citharichthys spilopterus	124	0.253	294.84	0.560	11.76	MS	ZB	D	N
Citharichthys sp.	109	0.222	6.82	0.013	9.31	-	-	-	-
Etropus crossotus	7	0.014	35.02	0.067	2.45	ES	ZB	D	N
Paralichthys orbignyanus	1	0.002	2.69	0.005	0.49	MM	ZB	D	-
Pomatomus saltatrix	2	0.004	6.10	0.012	0.98	MS	PV	P	-
Bairdiella ronchus	54	0.110	981.65	1.866	2.45	ES	ZB	D	Y
Cynoscion sp.	2	0.004	1.00	0.002	0.49	-	-	-	-
Menticirrhus americanus	1	0.002	5.14	0.010	0.49	MM	ZB	D	Y
Menticirrhus sp.	12	0.024	1.76	0.003	3.43	-	-	-	-
Pogonias cromis	1	0.002	7.29	0.014	0.49	MS	ZB	D	Y
Stellifer spp.	2	0.004	0.78	0.001	0.98	-	-	-	-
Sarda sarda	2	0.004	1.36	0.003	0.98	-	PV	P	Y
Sphyraena sp.	2	0.004	2.67	0.005	0.49	-	-	-	-
Hippocampus reidi	1	0.002	2.46	0.005	0.49	ES	ZP	P	Y
Synodus foetens	28	0.057	60.16	0.114	7.35	MS	PV	D	N
Sphoeroides greeleyi	831	1.694	13831.27	26.290	65.69	ES	ZB	D	N
Sphoeroides sp.	17	0.035	0.48	0.001	4.90	-	-	-	-
Sphoeroides testudineus	145	0.296	3321.63	6.314	25.49	ES	ZB	D	N
Prionotus punctatus	2	0.004	7.29	0.014	0.98	MS	ZB	D	Y
Total	49056	100	52611.36	100					

(*Strongylura marina*, *Diapterus rhombeus*, *Eucinostomus argenteus*, *Mugil* sp. and *Bairdiella ronchus*) presenting relative biomass greater than 1%, while the other taxa accounted for less than 1% of the total biomass.

The most frequent species in the samples were *A. brasiliensis* (84.31%), *S. greeleyi* (65.69%), *A. tricolor* (46.57%), *Mugil* sp. (46.08%) and *S. testudineus* (25.49%). Frequencies of occurrence between 10% and 20% were observed in *Oligoplites saurus* (10.78%), *Trachinotus falcatus* (16.67%), *Chilomycterus spinosus* (13.73%), *E. argenteus* (17.16%), *Eucinostomus melanopterus* (11.27%), *Bathygobius soporator* (12.75%), *Ctenogobius boleosoma* (14.22%), *Citharichthys spilopterus* (11.76%). A total of 20 species were present in less than 1% of the samples (Table II).

Regarding the use of the estuary, 15 species are estuarine and accounted for 90% of the sampled specimens. The occurrence of marine migrants (13 species) and marine straggler (13 species) together represented less than 1.5% of the total catch, with only two amphidromous and one anadromous species present in the samples (Table II). Zoobenthivorous individuals (26 species) predominated in the sampled area, but these represented only 3.8% of the total number of individuals captured. Seven zooplanktivorous species (66.7%) and two opportunistic species (21.2%) were most abundant in the region. Piscivorous (6 species), herbivorous (1 species) and detritivorous (1 species) contributed together with about 0.5% of the total catch (Table II).

The number of demersal species (27) was higher in comparison to pelagic species (18); however, pelagic species predominated in number of specimens (89%), with the contribution of *A. brasiliensis* and *A. tricolor* (Table II). A total of 27 species are not economically important in the region, and 16 species present economic importance in the fishing activity of the coast of the State of Paraná, representing less than 1% of the collected specimens. Despite this low abundance, the intertidal environment are nursery areas of species with economic value, present mainly at the juvenile stage.

Spatial and temporal variations: The mean density was significantly different between the seasons (H = 47.582 p <0.01) with higher values in the wet seasons in sectors I and II (Fig. 5). Between sectors, mean densities were also statistically different (H = 7.767 p <0.05), being higher in sector I, followed in decreasing order by sectors II and III (Fig. 5). Although there were differences among the seasonal biomass means (H = 20.335 p <0.01), these differences were only significant in sector I with higher biomass in the wet seasons. Differences in biomass among the three sectors were not significant (H = 1.969 p> 0.05) (Fig. 5).

On average, the number of estuarine species showed no significant variation among the sectors (H = 3.255 p> 0.05, Figure 6a), although it was slightly lower in sector III (Figure 6a). Seasonally, the number of estuarine species was significantly higher in the wet seasons, especially at the late wet season, compared to the dry seasons (H = 41.651 p <0.01, Fig. 6a).

In Sectors II and III, the number of marine stragglers species was higher (H = 7.838 p <0.05, Figure 6b), mainly due to significantly higher mean values at the late wet season and early dry season (H = 36.542 p <0.01, Figure 6b). A higher mean number of marine migrant species was observed in sector I (H = 12.980 p <0.01, Figure 6c) at the late wet season, followed by the early dry season (H = 34.691 p <0.01, Fig. 6c).

As for the descriptors of the fish assemblage, spatial and temporal variations were found. The mean number of species was significantly higher in the wet season (H = 55.139 p <0.01), especially in Sector I, followed by Sector II (H = 7.331 p <0.05, Figure 7a).

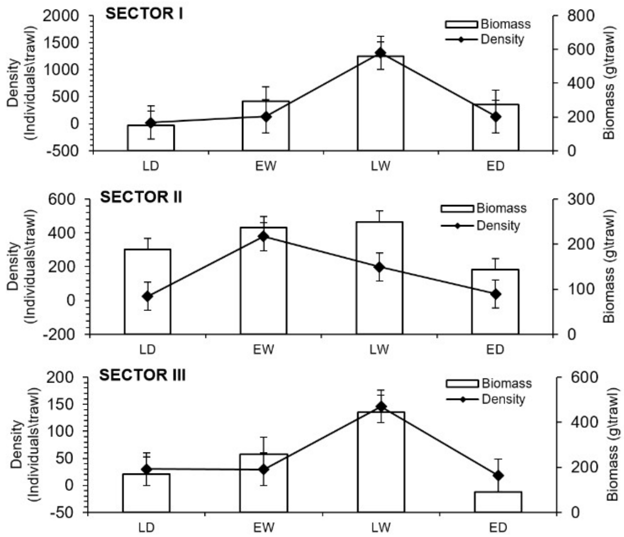

Figure 5. Mean values of density and biomass in each of the sectors of the Paranaguá Estuarine Complex during the study period. Vertical bars indicate the standard error of the mean. Where LD-late dry, EW-early wet, LW- late wet and ED-early dry.

No statistically significant difference was detected among the sectors in the Margalef species richness index (H = 0.065 p> 0.05), but species richness was higher at the late wet season and at the early dry season (H = 10.085 p <0.05, Figure 7b).

The diversity expressed by the Shannon-Wiener index (H'log$_e$) showed no significant difference among the sectors (H = 5.112 p> 0.05), but the mean diversity was higher in the dry seasons, especially at the late dry season (H = 31.954 p<0.01, Figure 7c). Pielou evenness did not vary statistically among the sectors (H = 0.882 p> 0.05) and among the seasons (H = 3.789 p> 0.05, Figure 7d).

Based on the abundance of all taxa collected, the MDS analysis indicated differences among the fish fauna in the different sectors (Figure 8), with the analysis of similarity (ANOSIM) pointing that the separation means were generally weak (overall R = 0.329 P <0.01). There were no differences in fish fauna between sectors I and II (R = 0.098 p> 0.05), with a low separation between sectors II and III (R = 0.253 p <0.01), and groups clearly different, despite the overlap between sectors I and III (R = 0.620 p <0.01). The similarity percentage (SIMPER) analysis showed that the taxa *A. tricolor*, *Mugil* sp., *A. brasiliensis*, *S. testudineus*, *E. argenteus* and *Trachinotus carolinus*, all with higher mean

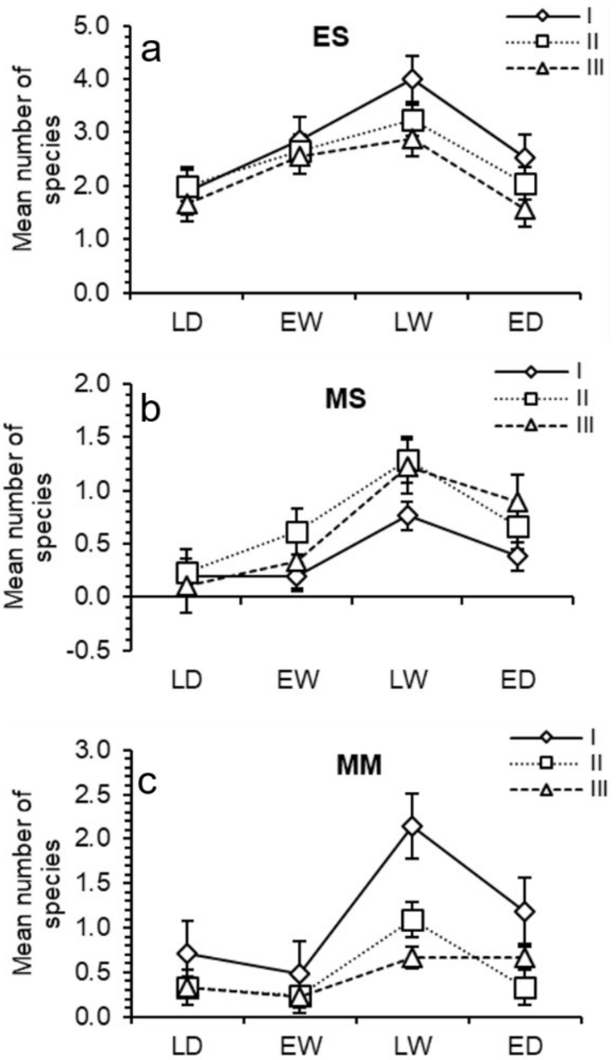

Figure 6. Mean number of estuarine (a), marine straggler (b) and marine migrant (c) species at the late dry season (LD), early wet season (EW), late wet season (LW) and early dry season (ED) in shallow areas on the north-south axis of the Paranaguá Estuarine Complex from August 2010 to July 2011. (ES = Estuarine, MS = Marine Straggler, MM = Marine Migrant).

abundance in sector II, were the main responsible for dissimilarity between sectors II and III. For the dissimilarity between sectors I and III, the greatest contribution came from the taxa *A. tricolor*, *Mugil* sp., *A. brasiliensis*, *Strongylura* sp., *D. rhombeus*, *B. soporator*, *C. boleosoma*, *C. spilopterus* and *C. spinosus* with higher mean abundances of these species in sector I and *S. greeleyi*, most abundant in sector III.

The MDS and ANOSIM applied to the abundance data of the sampled taxa also evidenced differences among the wet and dry seasons (overall R = 0.253 p <0.01, Figure 9). No significant differences were detected in fish fauna caught at the

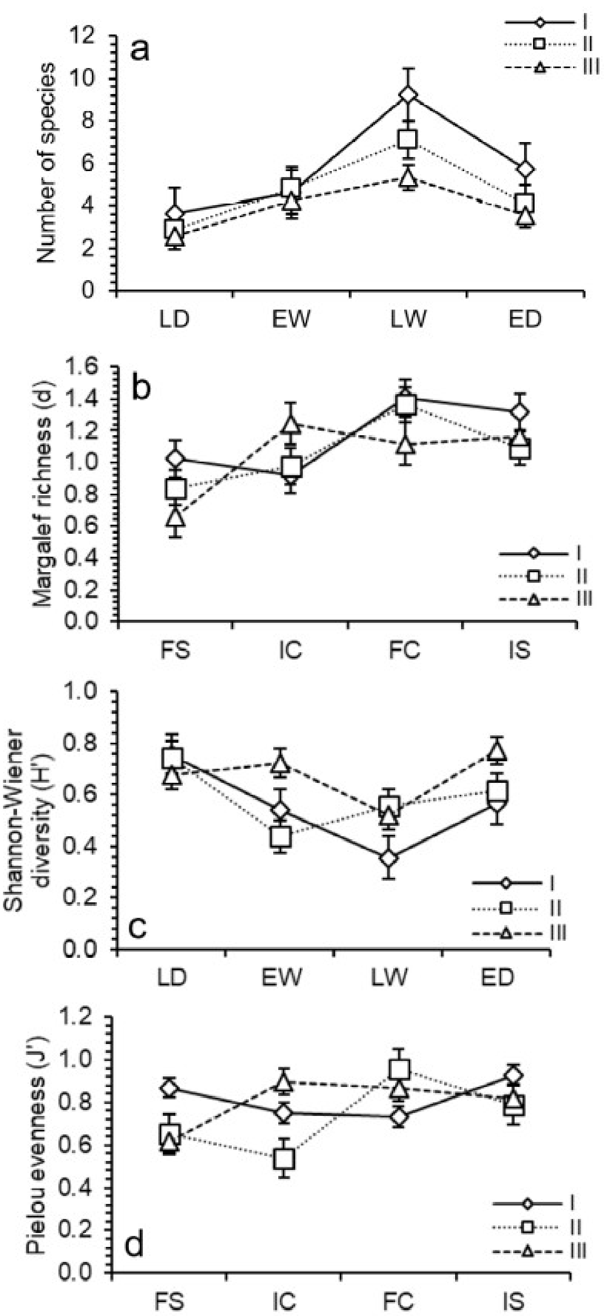

Figure 7. Mean values according to seasons (ED, EW, LW, LD) of the assemblage descriptors: number of species (a), Margalef richness (b), Shannon-Wiener diversity (c), Pielou evenness (d) for fish species collected in shallow areas of the north-south axis of the Paranaguá Estuarine Complex from August 2010 to July 2011. Vertical bars indicate the standard error of the mean.

early wet season compared to the late wet season (R = 0.145 p > 0.05) and early dry season (R = 0.167, p > 0.05), as well as between the late wet season and the early dry season (R = 0.065, p > 0.05). Between the late dry season and the early wet season (R = 0.297, p < 0.01), and between the late dry and early

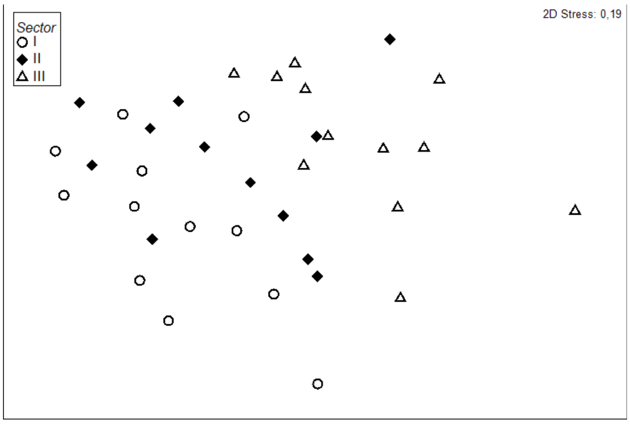

Figure 8. Multidimensional ordination (MDS) according to sectors for the shallow areas of the north-south axis of the Paranaguá Estuarine Complex from August 2010 to July 2011.

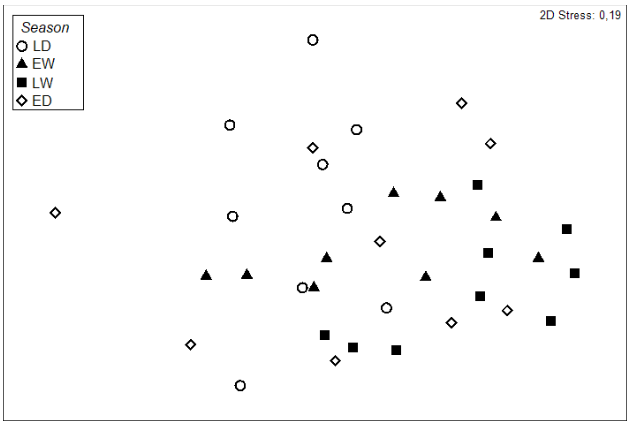

Figure 9. Multidimensional ordination (MDS) according to seasons for the shallow areas of the north-south axis of the Paranaguá Estuarine Complex from August 2010 to July 2011. Where LD-late dry season, EW-early wet season, LW- late wet season and ED- early dry season.

dry seasons ($R = 0.238$ $p < 0.01$), the separation means of the fish fauna sampled were weak. The highest mean abundance of *A. tricolor*, *A. brasiliensis*, *S. greeleyi* and *Strongylura* sp. in the early wet season was responsible for the small difference between this season and the late dry season, whereas between the late dry and the early dry seasons, the difference is mainly due to higher mean abundances of *A. tricolor*, *A. brasiliensis*, *T. falcatus* and *E. argenteus* at the early dry season and *Mugil* sp. and *S. greeleyi* at the late dry season. Despite the overlap, the fish fauna at the late dry season and late wet season are clearly distinct ($R = 0.595$ $p < 0.01$), contributing mainly to this the higher mean abundance of *A. tricolor*, *Mugil* sp., *A. brasiliensis*, *T. falcatus*, *S. testudineus*, *S. greeleyi*, *E. argenteus* and *Strongylura* sp. at the late wet season.

The likely influence of environmental variables on the pattern of species occurrence was investigated using the Spearman correlation coefficient. The results showed low correlations between the abiotic and biotic parameters analyzed (Table III).

Discussion

In the present study, the observed pattern of a greater number of "marine" species and a smaller number of "resident" species is expected for estuarine systems, since these systems are very dynamic (which can generate much stress for the individuals living therein), so only few species are adapted to spend their entire life cycle in their interior. This pattern can be seen in other studies also conducted in shallow estuarine areas (Valesini et al 1997, Lin & Shao 1999, Vidy 2000, Spach *et al.* 2004a, b, Félix *et al.* 2006, Queiroz *et al.* 2006, Félix *et al.* 2007, Ignácio & Spach 2009).

Although the number of marine species was higher, estuarine species accounted for about 90% of the specimens caught during the study, mainly due to the great contribution of *A. tricolor* and *A. brasiliensis*, as also reported by Vilar *et al.* (2011a, b), who found in the Babitonga Bay a numerical predominance of estuarine species. Valesini *et al*. (1997) indicates that there is an inverse relationship in the number of individuals caught in relation to the guilds used in the estuary, in which the guilds with the largest number of (marine) species have the lowest catches and those with lowest number of (resident) species have the highest catches, as seen in the present study.

The most abundant species are usually those belonging to the lowest trophic levels (e.g. primary consumers, such as filter-feeding and planktivorous). This was observed in our study, since more than 65% of the total catch was classified as zooplanktivorous, as well as other studies carried out in the region and in other estuaries (Blaber *et al.* 1984, Ross *et al.* 1987, Chaves *et al.* 2000, Spach *et al.* 2004a, b, Barreiros *et al*. 2005, Félix *et al.* 2006, Félix *et al*. 2007). This pattern is commonly found in other ecological systems, where the trophic levels closest to the base have to be more abundant to sustain higher levels, as there is an energy loss between the levels and the formation of a pyramid which generates balance (Odum 2004).

The highest mean values of density and biomass were recorded in sector I during the wet seasons; this difference among sectors and seasons may have been caused by the combination of the influence of abiotic factors of the region with seasonal factors, creating conditions more favorable for the establishment of some species. Sector I is in the region of lower energy and salinity of the gradient (Lana *et al.* 2001), it was strongly influenced by continental drainage, receiving large inputs of nutrients and other materials mainly in the wet season, as shown by the values found for chlorophyll and water transparency. This condition of low energy, low salinity, high food availability and high turbidity makes these shallow environments (in the wet season) advantageous places for some species, because as verified in other works conducted in periods of higher temperature (wet periods), there is increased number of individuals as well as biomass in shallow environments (Ayvazian *et al.* 1992, Lin & Shao 1999, Spach *et al.* 2004a, b, Vendel & Chaves 2006, Ignácio & Spach 2010, Hackradt *et al.* 2010, Spach *et al.* 2010).

In total number of species, sector I had a higher number of estuarine species followed by marine migrant species and a smaller number of marine straggler (ES> MM> MS). Sector II had the largest number of marine straggler species followed by estuarine and in smaller numbers marine migrant (MS> ES> MM). In Sector III, the number of marine migrant and straggler species was similar, with a smaller number of estuarine species (MS = MM> ES). Vilar *et al.* (2011a), in the Babitonga Bay, also found a difference in the composition of the guilds of use in the estuary in relation to the distance from the estuary entrance, by dividing the estuary into three sectors it was reported that the outermost portion is dominated by marine straggler species and marine migrants (with the presence of estuarine species), while the middle and innermost sectors are dominated by estuarine species (with the presence of marine migrant species). This distribution of species, according to the guild of estuary use, was probably due to differences in environmental parameters in relation to space (sectors), as it is reported by Harris *et al.* (2001), estuarine species correlate positively with turbidity and negatively with salinity while marine species (MS and MM) correlate negatively with turbidity and positively with salinity.

For the descriptors of the assemblage, we found that the number of species was significantly different among sectors and seasons, with higher mean values in sector I and lower in sector III (I> II> III) and higher in the wet season in relation to the others, the same was observed for warmer seasons (wet) in other studies (Ayvazian *et al.* 1992, Spach *et al.* 2004b, Vendel & Chavez 2006, Ignácio & Spach 2010). The higher number of species at the most internal sites would be the result of influence of continental drainage, as discussed previously.

This distribution in the total number of species may have been caused by differences in the energy gradient as seen by Clark (1997), where the areas located in the median wave gradient presented a larger number of species compared to areas located at the extreme ends of the gradient (high and low disturbance). That study, like ours, agrees with the intermediate disturbance hypothesis that states that, in both areas with frequent disturbances and in areas with low frequency of disturbances, few species live, with the greatest number of species occurring in areas with medium frequency of disturbances, since this intermediate disturbance allows greater competition among organisms (Connell, 1978). In areas under constant disturbance, r-strategist species are generally “established”, because for their maintenance in the environment there is a need for rapid growth and high reproduction due to the constant disturbance. In turn, in areas with very low frequency of disturbance, the communities can reach their climax stage where, in general, k-strategists species are established. Nevertheless, in areas under intermediate disturbance, the communities are at a stage of succession where both r- and k-strategist species can be established, which ends up generating environments with greater richness, diversity and lower dominance.

With respect to Margalef richness, the mean values were not different among seasons and sectors with a slight upward trend in the late wet season and early dry season. Lazzari *et al.* (2003) have shown that richness decreases in areas where the dominance of saline water is greater and increases from deeper to shallow areas, which may explain the lack of difference among the areas sampled in our study, since all the samples were taken in shallow environments. The lack of a significant trend was also observed in Sucuriú tidal creek, Paranaguá Bay (Spach *et al.* 2003), while other studies also showed an increase in richness during warmer periods (Lin & Shao 1999, Lazzari *et al.* 2003, Spach *et al.* 2004b, Vendel & Chaves 2006, Ignácio & Spach 2010).

Similarly to Spach *et al.* (2003), in the present study, no significant differences were registered in the Shannon-Wiener diversity, despite an upward trend in the dry (cooler) seasons as reported by Spach *et al*. (2004b). However, other studies point to a different pattern with an increase in diversity indices in warmer months (Lin & Shao 1999, Falcão *et al.* 2006, Félix *et al.* 2007, Ignácio & Spach 2010, Spach *et al.* 2010). It was not possible to observe a spatial pattern for diversity in the present study, but Lazzari *et al.* (2003) suggests that species diversity is lower in the innermost areas of the estuaries, which may be due to the fact that these areas have a greater number of estuarine species and, as previously discussed, few species are adapted to complete their whole life cycle inside estuarine systems, since the outermost areas of the estuary tend to be more diverse, because according to Greenwood *et al.* (2007), they receive juveniles of various species.

The Pielou evenness showed no significant differences among sectors and seasons, with no clear variation as also found by Spach *et al*. (2003). In this way, the Pielou evenness increases in drier (cold) periods, as in these periods there is a trend for low dominance, making the Pielou evenness to increase in cold periods and decrease in hot periods (Spach *et al.* 2004b, Vendel & Chaves 2006, Ignácio & Spach 2010). Nevertheless, some studies demonstrate an inverse pattern, like Felix *et al.* (2007), who found lower values in the dry season (due to the collection of shoals) and Spach *et al.* (2010), who observed higher values in the wet season.

The results pointed out by MDS and ANOSIM (based on species abundances) indicate that no faunal difference between sectors I and II, because the composition of the most abundant species in these sectors is very similar probably due to the similarities of environmental factors between these two sectors. The separation pointed out by the analyses between sectors II and III is weak and occurs mainly due to the greater abundance of several taxa abundant in sector II. The separation between sectors I and III is stronger, since sector I has several abundant estuarine species and sector III has as the most abundant, *S. greeleyi.* For the temporal separation, there is the weak separation of the late dry season (LD) in relation to the early dry season (ED) and the early wet season (EW). These differences were probably caused by differences in food availability among the seasons, as food availability directly influences species abundance (Brandini & Thamn 1994). The difference was stronger between the late dry season (LD) and the late wet season (LW) probably because of the influence of environmental parameters that tend to be more different between these two periods (e.g. turbidity, salinity, chlorophyll) and as seen previously had great influence on the fish fauna.

The low correlations evidenced by the BioEnv analysis do not support the patterns found in the present study. This may have occurred because the sampling sites did not completely capture the spatial gradient of environmental variables, and it is perhaps necessary to further spacing the sites to better capture the environmental gradient and increase the value of the correlations. Meanwhile, Martino & Able (2003) state that the fish fauna structure at scales close to or greater than 10 km is strongly influenced by environmental variables.

Our findings allow to infer that in the shallow areas of the Paranaguá Estuarine Complex the wet (warmer) seasons play a key role in the distribution and abundance of the fish fauna, since it is in the wet season that the best environmental conditions for the fish fauna are found. Information on the distribution and composition of fish fauna are essential both for resource management and for conservation, which can be done with the protection of the shallow areas that are used as nurseries by several species.

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