BRAZILIAN JOURNAL OF OCEANOGRAPHY, 61(4):251-264, 2013

ANALYSIS OF FISH ASSEMBLAGES IN SECTORS ALONG A SALINITY GRADIENT BASED ON SPECIES, FAMILIES AND FUNCTIONAL GROUPS

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ABSTRACT

Here we test the effects of the east-west salinity gradient in the subtropical Paranaguá Bay Estuarine Complex (PEC) on the structure of shallow water fish fauna, determined according to taxonomic (families and species) and functional composition metrics. A total of 152 species were observed. The families with the largest number of species were the Sciaenidae, Carangidae, Haemulidae and Gobiidae. The most abundant species were *Atherinella brasiliensis*, *Harengula clupeola*, *Anchoa januaria* and *Anchoa tricolor*. Marine stragglers dominated in number of species, followed by marine migrants and estuarine species. Most species were zoobenthivores, followed by piscivores and zooplanktivores. Families and species more frequently associated with estuarine conditions dominated in the mesohaline sector, and those more frequently associated with marine conditions dominated in the euhaline sector. The fish assemblages along the estuarine salinity gradient were found to be better characterized by taxonomic metrics than by functional ones. This is most likely because individuals of all functional groups inhabit all salinity sectors, and thus these metrics are not useful for differentiating assemblages along salinity gradients. Our results differ from those of other studies in tropical and subtropical estuaries, which have emphasized the importance of functional groups in determining fish assemblages along salinity gradients.

RESUMO

Neste trabalho foi testado o efeito do gradiente de salinidade do eixo-leste oeste do sistema subtropical Complexo Estuarino da Baía de Paranaguá na estrutura dos peixes de águas rasas, determinado de acordo com as métricas taxonômica (famílias e espécies) e de composição funcional. Um total de 152 espécies foi registrado. As famílias com maior número de espécies foram Sciaenidae, Carangidae, Haemulidae e Gobiidae. As espécies mais abundantes foram *A. brasiliensis*, *H. clupeola*, *A. januaria* e *A. tricolor*. Os visitantes marinhos dominaram em número de espécies, seguidos pelos migrantes marinhos e estuarinos. A maioria das espécies são zoobentívoras, seguidas pelas piscívoras e zooplanctívoras. As famílias e espécies mais relacionadas com condições estuarinas dominaram no setor mesohalino e aquelas mais relacionadas com condições marinhas dominaram no setor euhalino. A métrica taxonômica foi mais eficiente na caracterização das assembleias de peixes ao longo do gradiente estuarino de salinidade do que a funcional. Isso ocorreu principalmente porque indivíduos de todos os grupos funcionais estiveram presentes ao longo de todos os setores de salinidade, invalidando o emprego dessa métrica na diferenciação das assembleias nos diversos setores. Nosso resultado foi diferente do encontrado em outros estuários tropicais e subtropicais, que enfatizaram a importância dos grupos funcionais na estruturação das assembleias de peixes ao longo de um gradiente de salinidade.

Descriptors: Salinity, Ichthyofauna, Estuarine use, Trophic position, Paranaguá Estuarine Complex.
Descritores: Salinidade, Ictiofauna, Uso do estuário, Posição trófica, Complexo Estuarino de Paranaguá.

INTRODUCTION

Designation of functional groups (FG) is an operational approach used to simplify the structure and dynamics of ecosystems, thus facilitating understanding of complex factors (BLONDEL, 2003). The determination of FG has been widely used to describe the structure of estuarine fish assemblages by grouping fish species according to their trophic level, reproduction strategy and use of the estuary (GARRISON; LINK, 2000; ANGEL; OJEDA, 2001; LOBRY et al., 2003; CHAVES; BOUCHEREAU, 2004; ELLIOTT et al., 2007; FRANCO et al., 2008; SELLESLAGH et al., 2009). Diversity in life cycle, habitat use and trophic position among fishes is expected to affect the functioning of the ecosystem; thus examining these factors is useful for understanding how an ecosystem functions. (ELLIOTT et al., 2007). Using a traditional taxonomic approach, along with an analysis of FG, represents a holistic approach to describing the structure of fish fauna (FRANCO et al., 2008). Moreover, because functional aspects provide important cues regarding ecosystem health, this approach may help in decision-making processes related to the management of estuarine areas (MATHIESON et al., 2000).

Tropical and subtropical estuaries are more complex than temperate ones, primarily due to their great biodiversity, coupled with biological productivity, high habitat diversity and multiple complex interactions among biotic and highly variable abiotic factors (SHEAVES, 2006). Despite these important biodiversity attributes, tropical estuaries are under increased human pressure because most tropical estuaries are in developing countries that have experienced accelerated coastal development in recent decades. Thus, an understanding of the functional traits of fish assemblages is critical for fully understanding ecosystem function (BLABER, 2008).

The Paranaguá Estuarine Complex (PEC), situated on the coast of Paraná state (southern Brazil), constitutes the southern sector of the large subtropical Iguape-Cananéia-Paranaguá estuarine system, which is part of the southern sector of Brazil's Atlantic Forest Biosphere Reserve, a global biodiversity hotspot (Fig. 1). PEC harbors a rich fish fauna of 213 species that represent a mixture between tropical Brazilian coastal fauna and temperate Argentinian and Uruguayan species (PASSOS et al., 2012). This richness is higher than, or comparable to, those of other systems located in species-rich, tropical biogeographical zones around the world, which emphasizes the importance of PEC for global biodiversity conservation (PASSOS et al., 2012). Despite this conservation status, PEC has suffered from the impact of three ports (Paranaguá, Antonina and Ponta do Félix), dredging, discharge of domestic and industrial effluents, introduction of exotic species (VITULE et al. 2006; CAIRES et al., 2007; CONTENTE et al., 2011b), and growing urbanization (LANA et al., 2001).

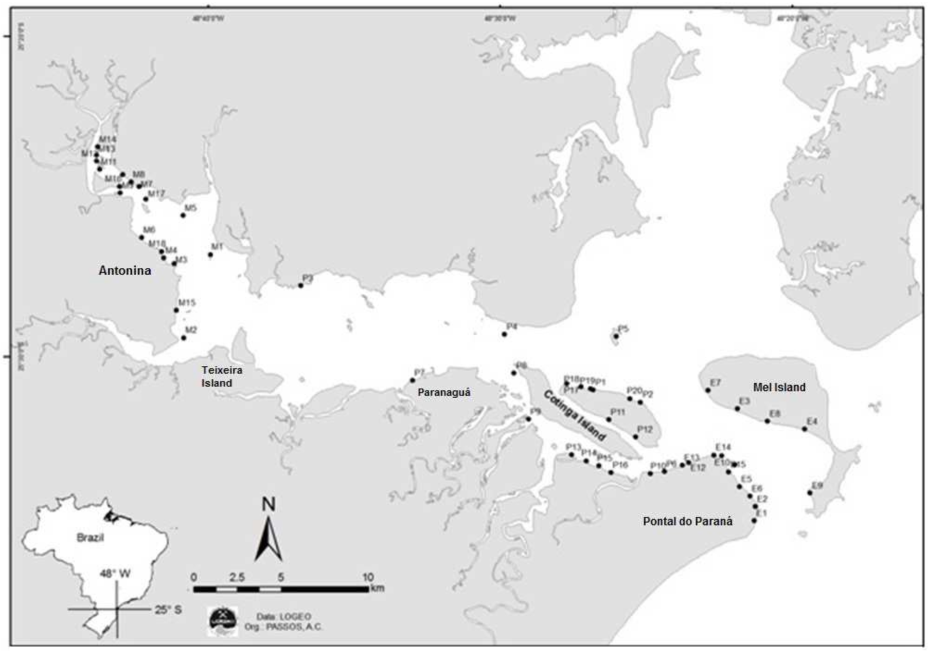

Fig. 1. Location of the sampling sites in the euhaline (E1-E15), polyhaline (P1-P20) and mesohaline (M1-M18) sectors of the east-west axis of the Paranaguá Estuarine Complex.

The structure and composition of the fish assemblages along the east-west salinity gradient of the PEC, and their relationship to the abiotic factors of beaches (GODEFROID et al., 1997; FÉLIX et al., 2006; FÉLIX et al., 2007a, b; HACKRADT et al., 2011), rivers (CONTENTE et al., 2011a), tidal creeks (SPACH et al., 2003; SPACH et al., 2004a, b; IGNÁCIO; SPACH, 2009) and tidal flats (FALCÃO et al., 2006; FALCÃO et al., 2008; GODEFROID et al., 2003) has been widely studied, primarily using taxonomic metrics. Despite the varied studies, there is no integrated approach taking into account the spatial distribution across this gradient using taxonomic (families and species) and functional terms. Therefore, we here tested the effect of the east-west salinity gradient of the PEC on the structure of shallow water fish fauna by determining the fish taxonomic (families and species) and functional composition.

Material and Methods

Study Area

The PEC is connected to the ocean by two channels, has an east-west axis with a maximum length of 56 km and a maximum width of 7 km and a north-south axis with a maximum length of 40 km and a maximum width of 13 km. The system possesses a moderate vertical salinity gradient, with semidiurnal tides with diurnal inequality, of which the maximum variation is 2.7 m, and a consistent seasonality in circulation and stratification (KNOPPERS et al., 1987; MARONE et al., 2005). The climate of the region is transitional tropical (mean annual rainfall = 2500 mm)(LANA et al., 2001), with distinctive seasonality (rainy summers and dry winters) (MARONE et al., 2005).

The east-west axis of the PEC can be divided into three salinity sectors: mesohaline (salinity between 5 and 15; Antonina region); polyhaline (salinity between 15 and 25; Teixeira Island to the eastern tip of Cotinga Island); and euhaline (salinity greater than 25; eastern part of Cotinga Island to Mel Island) (NETTO; LANA, 1996). The system is bordered by mangroves (*Rhizophora mangle*, *Avicennia schaueriana*, *Laguncularia racemosa* and *Conocarpus erectus*) (LANA et al., 2001) and salt marsh beds (*Spartina alterniflora*) (NETTO; LANA, 1997). For each sector, salinity, sampling sites, sampling periods and gear are provided in Table 1.

Data Collection

Unpublished data from the Fish Ecology Laboratory of the Center of Marine Studies of the Federal University of Paraná and data from published studies conducted in tidal flats on the east-west axis of the PEC were compiled. Details of the surveys can be found in the following papers: Godefroid et al. (1997), Spach et al. (2003), Godefroid et al. (2003), Spach et al. (2004a, b), Falcão et al. (2006), Félix et al. (2006), Félix et al. (2007a, b), Falcão et al. (2008), Ignácio and Spach (2009), Contente et al. (2011a), and Hackradt et al. (2011). A total of 52 sites (18 in the mesohaline, 31 in the polyhaline and 22 in the euhaline zone) were considered (Fig. 1).

Fish species nomenclature was confirmed by comparison with information from Craig and Hastings (2007), Sheaves and Craig (2007), Eschmeyer (2010), Carvalho-Filho et al. (2010) and Figueiredo et al. (2010). *Mugil* sp. was used for the species usually identified under the invalid name *Mugil gaimardianus* (MENEZES et al., 2003). Species were allocated to the following estuarine use of FG according to Elliott et al. (2007): 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), marine migrants (MM; species that spawn at sea and enter estuaries in large numbers as juveniles; considered euryhaline), estuarine species (ES), anadromous (AN; species that undergo their growth at sea and migrate into rivers to spawn), catradomous (CA; species that live in freshwater and migrate to marine environments to spawn), amphidromous (AM; migrate between the sea and freshwater with neither migration related to reproduction) and freshwater migrants (FM; found in moderate numbers in estuaries; considered oligohalines). Species were allocated to the following feeding mode functional groups (ELLIOTT et al. 2007): zooplanktivore (ZP; feeding on zooplankton), detritivore (DV; feeding on detritus and/or microphytobenthos), herbivore (HV; grazing on macroalgae, macrophytes or phytoplankton), omnivore (OV; feeding on filamentous algae, macrophytes, peryphyton, epifauna and infauna), piscivore (PV; feeding on finfish and large nektonic invertebrates), zoobenthivore (ZB; feeding on invertebrates that live just above, on or in the sediment) and opportunist (OP; feeding on a diverse range of food).

Data Analysis

Because our descriptive distribution models were spatial, individuals from all the surveys for each species were grouped first by sampling point; then the percentage of species within a family, the frequency of occurrence per species, the percentage of individuals per species, and the percentage of species and individuals per functional group were calculated for each sampling point. We expressed the number of individuals as a percentage in order to standardize the scale of the abundance estimates, which were inherently biased due to the different sampling protocols.

Table 1. Sampling sites in each salinity sector, with the respective salinity ranges, periods and sampling methods, as well as the number of families, species and individuals. Codes for sampling nets are as follows: (1) = seine (15 m x 2.6 m, 2 m bag and 0.5 mesh), (2) = seine (15 m x 2.6 m, 2 m bag and 1 cm mesh), (3) = seine (30 m x 2 m, 2 m bag and 0.5 cm mesh), (4) = seine (15 m x 2 m and 1 cm mesh), (5) = capéchade with barrier (20 m x 2.0 m, 13 mm mesh and 3 minnow traps, with 13.0 to 6.0 mm mesh), (6) = seine (9 m x 2.5 m, wings with 13 mm mesh and bag with 5 mm mesh), (7) = seine (15 m x 1.60 m, wings with 13 mm mesh and bag with 5 mm mesh), (8) = seine (15 m x 2 m, 2.5 cm mesh), (9) = seine (30 m x 3 m and 0.5 cm mesh), (10) = seine (18 m x 2 m and 1 to 2 mm mesh), (11) = seine (30 m x 2 m, 2 m bag and 0.5 cm mesh).

Sector	Site	Salinity	Sampling period	Sampling method	No. of families	No. of species	No. of individuals
Mesohaline	M1	9.0 - 27.0	Oct/2005 - Sep/2006	(1) and (2)	3	3	3
Mesohaline	M2	10.0 - 27.0	Oct/2005 - Sep/2006	(1) and (2)	12	18	190
Mesohaline	M3	12.0 - 27.0	Oct/2005 - Sep/2006	(1) and (2)	13	23	907
Mesohaline	M4	10.0 - 26.0	Oct/2005 - Sep/2006	(1) and (2)	13	20	385
Mesohaline	M5	4.0 - 25.5	Oct/2005 - Sep/2006	(1) and (2)	11	18	784
Mesohaline	M6	0.0 - 23.0	Oct/2005 - Sep/2006	(1) and (2)	15	18	1068
Mesohaline	M7	0.0 - 25.0	Oct/2005 - Sep/2006	(1) and (2)	9	10	168
Mesohaline	M8	0.0. - 20.5	Oct/2005 - Sep/2006	(1) and (2)	11	13	246
Mesohaline	M9	2.0 - 21.0	Oct/2005 - Sep/2006	(1) and (2)	12	16	471
Mesohaline	M10	0.0 - 19.0	Oct/2005 - Sep/2006	(1) and (2)	13	22	597
Mesohaline	M11	0.0 - 20.0	Oct/2005 - Sep/2006	(1) and (2)	16	20	1044
Mesohaline	M12	0.0 -19.0	Oct/2005 - Sep/2006	(1) and (2)	13	22	662
Mesohaline	M13	0.0 - 18.0	Oct/2005 - Sep/2006	(1) and (2)	14	22	354
Mesohaline	M14	0.0 - 15.0	Oct/2005 - Sep/2006	(1) and (2)	15	24	417
Mesohaline	M15	0.0 - 15.0	Oct/2005 - Sep/2006	(1) and (2)	14	22	1715
Mesohaline	M16	0.0 - 8.0	Apr/2000 - Mar/2001	(3)	29	34	22867
Mesohaline	M17	2.0 - 10.0	Apr/2000 - Mar/2001	(3)	22	32	5830
Mesohaline	M18	12.0 - 24.0	Apr/2000 - Mar/2001	(3)	21	32	3967
Polihaline	P1	25.0 - 34.0	Mar/2006 - Mar/2007	(4)	25	50	2155
Polihaline	P2	25.0 - 34.0	Mar/2006 - Mar/2007	(4)	23	48	3968
Polihaline	P3	17.0 - 29.0	Jun/2005 - May/2006	(1)	15	34	3649
Polihaline	P4	20.0 - 32.0	Jun/2005 - May/2006	(1)	16	38	4225
Polihaline	P5	23.0 - 33.0	Jun/2005 - May/2006	(1)	31	58	2949
Polihaline	P6	20.0 - 34.0	Jul/2006 - Jun/2007	(5)	31	66	39709
Polihaline	P7	20.0 - 28.0	Aug/2003 - Jun/2004	(6) and (7)	9	14	614
Polihaline	P8	16.0 - 27.0	Aug/2003 - Jun/2004	(6) and (7)	14	22	2431
Polihaline	P9	17.0 - 28.0	Aug/2003 - Jun/2004	(6) and (7)	14	20	1284
Polihaline	P10	23.0 - 29.0	Aug/2003 - Jun/2004	(6) and (7)	13	21	1566
Polihaline	P11	24.0 - 33.0	Apr/2000 - Mar/2001	(3)	23	35	7949
Polihaline	P12	25.0 - 33.0	Apr/2000 - Mar/2001	(3)	27	39	15328
Polihaline	P13	15.0 - 30.0	Jul/2005 - Dec/2006	(7)	11	15	648
Polihaline	P14	17.5 - 33.0	Jul/2005 - Dec/2006	(7)	15	24	931
Polihaline	P15	18.0 - 33.0	Jul/2005 - Dec/2006	(7)	15	24	504
Polihaline	P16	17.0 - 34.0	Jul/2005 - Dec/2006	(7)	7	11	527
Polihaline	P17	19.8 - 28.3	Aug/2010 - Apr/2011	(8)	10	12	854
Polihaline	P18	19.6 - 27.1	Aug/2010 - Apr/2011	(8)	14	17	685
Polihaline	P19	20.8 - 27.2	Aug/2010 - Apr/2011	(8)	12	15	2143
Polihaline	P20	23.8 - 28.0	Aug/2010 - Apr/2011	(8)	14	21	2925
Euhaline	E1	33.0 - 36.0	Jun/2004 - May/2006	(1)	22	55	23645
Euhaline	E2	25.0 - 34.0	Jun/2004 - May/2005	(1)	23	47	8847
Euhaline	E3	25.0 - 35.0	May/2000 - Apr/2001	(9)	23	49	9243
Euhaline	E4	25.0 - 35.0	May/2000 - Apr/2001	(9)	23	49	2822
Euhaline	E5	19.0 - 35.0	Apr/2000 - May/2001	(3)	19	30	3069
Euhaline	E6	28.0 - 36.0	Apr/2000 - May/2001	(3)	19	31	2557
Euhaline	E7	23.0 - 34.0	Jun/2005 - May/2006	(1)	16	37	1985
Euhaline	E8	24.0 - 35.0	Jun/2005 - May/2006	(1)	17	31	1082
Euhaline	E9	25.5 - 33.0	Jun/2005 - May/2006	(1)	15	28	2551
Euhaline	E10	27.1 - 34.8	May/1993 - Apr/1994	(10)	21	51	1713
Euhaline	E11	19.0 - 35.0	May/1993 - Apr/1994	(10)	32	71	13106
Euhaline	E12	11.0- 35.0	Aug/1998 - Jul/1999	(11)	49	118	63165
Euhaline	E13	20.6 - 30.1	Aug/2010 - Apr/2011	(8)	9	12	464
Euhaline	E14	22.9 - 31.1	Aug/2010 - Apr/2011	(8)	7	12	1126
	E15	11.6 - 32.1	Aug/2010 - Apr/2011	(8)	10	12	242

Non-metric multidimensional scaling (nMDS) analyses were used to assess the effect of the salinity sectors on fish taxonomic composition and functional groups. The difference in taxonomic composition and FG among salinity sectors were tested by analysis of similarity (ANOSIM). In addition to the significance level, an R value is calculated for the ANOSIM, which indicates the magnitude of the separation between groups. *R*-values, which range from 0 to 1, indicate that groups are clearly distinct if R> 0.75. If R> 0.5, the groups overlap but can be differentiated, and if R< 0.25, groups are typically indistinguishable (CLARKE; GORLEY, 2006). Analysis of similarity of percentages (SIMPER) was applied to identify the families, species and guilds responsible for such differences (CLARKE; WARWICK, 2001).

RESULTS

Taxonomic Distribution and Functional Groups

A total of 152 species (149 Actinopterygii and 3 Elasmobranchii), distributed in 19 orders and 51 families, were recorded along the east-west axis of the PEC. Most individuals were captured in the euhaline sector (50% - 131 species), while the polyhaline and mesohaline sectors accounted for 35% (109 species) and 15% (70 species) of individuals, respectively. A total of 55 species were ubiquitous along the east-west PEC axis and 36, 7 and 6 were found exclusively in the euhaline, polyhaline, and mesohaline sectors, respectively (Table 2).

Most of the families had a small number of species (1 to 5 species), with *c.* 43% represented by a single species. The families with the largest number of species were Sciaenidae (19), followed by Carangidae (15), Haemulidae (8) and Gobiidae (8), which represented 33% of the species total. The most abundant species throughout the east-west axis were *A. brasiliensis* (16.6%), *H. clupeola* (15.9%), *A. januaria* (10.3%) and *A. tricolor* (10.2%). In the mesohaline sector, the most abundant species were *A. januaria* (58%), *A. brasiliensis* (10.0%), *D. rhombeus* (7%) and *C. schufeldti* (6.6%), while in the polyhaline sector, *A. brasiliensis* (30%), *H. clupeola* (15.3%) and *A. lyolepis* (13.1%) were abundant, and in the euhaline sector, *H. clupeola* (21.1%), *A. tricolor* (17.8%), *A. brasiliensis* (8.8%) and *A. surinamensis* (8.1%) were the most abundant.

Marine stragglers dominated in number of species (41%), followed by marine migrants (25%) and estuarine species (3%, 35 species). Each of the other functional groups (i.e., amphidromous, anadromous, catadromous, estuarine migrant, estuarine resident, and freshwater migrant) accounted for less than 2% of the species. The estuarine species dominated in number of individuals (50%), followed by marine stragglers (30%) and marine migrants (15%). The zoobenthivores had the greatest percentage of species per trophic functional group (50%), followed by piscivores (18%) and zooplanktivores (16%). Each of the other functional groups (i.e., detritivores, herbivores, omnivores, and opportunists) represented less than 4% of the taxa. The zooplanktivores had the most individuals per trophic group (40%), followed by the opportunists (28%) and zoobenthivores (21%).

A total of 16 species were not assigned to any functional group due to a complete lack of information about their feeding habits and estuarine habitat use patterns.

The Effect of Salinity Sector on Fish Fauna

The ordination of sampling points based on presence/absence of families (Fig. 2), and corresponding ANOSIM (R-Global = 0.326, $P < 0.01$), showed that the polyhaline and euhaline sectors almost completely overlapped ($R = 0.152$; $P < 0.01$) and the polyhaline and mesohaline sectors strongly overlapped ($R = 0.259$; $P < 0.01$). There was a large difference in the families present between the mesohaline and euhaline sectors ($R = 0.596$; $P < 0.01$). Families with species more suited to estuarine conditions (e.g., Atherinopsidae, Engraulidae, and Gerreidae) dominated in the mesohaline sector and those with species more suited to marine conditions (e.g., Carangidae, Clupeidae, and Tetraodontidae) dominated in the euhaline sector (Table 3).

The ordination of sampling points based on the presence/absence of species (Fig. 3), and associated ANOSIM, revealed consistent separation among salinity sectors (R-Global = 0.502; $P < 0.01$). The greatest differences occurred between the mesohaline and euhaline sectors ($R = 0.813$; $P < 0.01$), followed by those between the mesohaline and polyhaline sectors ($R = 0.548$; $P < 0.01$). The polyhaline and euhaline sectors were indistinguishable ($R = 0.131$; $P < 0.05$). The species most responsible for the differentiation of the mesohaline and euhaline sectors were *Trachinotus falcatus, Harengula clupeola* and *Trachinotus carolinus* (Table 4). Those most responsible for the differentiation of the mesohaline and polyhaline sectors were *Anchoa tricolor, Sphoeroides greeleyi* and *Ctenogobius shufeldti*.

The ordination of sampling points based on the percentage of individuals per species (Fig. 4), and associated ANOSIM, revealed that each salinity sector differed significantly, although with some overlap (R-Global = 0.437; $P < 0.01$). The paired comparisons indicated significant differences between the mesohaline and euhaline sectors ($R = 0.622$; $P < 0.01$), overlap, but distinction, between the mesohaline and polyhaline sectors ($R = 0.479$; $P < 0.01$) and no distinction between the polyhaline and euhaline sectors ($R = 0.205$; $P < 0.01$). Following the same tendency observed in the family analysis, there was a progressive increase in the occurrence of species more suited to estuarine conditions (i.e., *A. brasiliensis, A. januaria,* and *D. rhombeus*) in the mesohaline sector and an increase in species more suited to marine conditions (i.e., *A. tricolor*, *H. clupeola* and *T. falcatus*) in the euhaline sector (Table 5).

Table 2. Species and their respective families in alphabetical order, as well as abundance in each of the sectors, estuarine use and trophic guilds and the references used to classify each species. Estuarine use: AN = anadromous, AM = amphidromous, CA = catadromous, EM = estuarine migrant, ER = estuarine resident, ES = estuarine, FM = freshwater migrant, MM = marine migrant, MS = marine straggler and SC = semi-catadromous. Trophic guilds: ZP = zooplanktivorous, DV = detritivorous, HV = herbivorous, OV = omnivorous, PV = piscivorous, ZB = zoobenthic, OP = opportunistic. Estuarine use references: *a* – Reis Filho *et al.* (2010); *b* - Barletta & Blaber (2007); *c* - Barletta *et al*. (2008); *d* – Froese & Pauly (2010); *e* – Vilar *et al.* (2011); *f* - Garcia & Vieira (2001). Trophic guild references: *1* - Froese & Pauly (2010); *2* - Alves & Filho (1996); *3* - Barletta & Blaber (2007); *4* - Guedes & Araujo (2008); *5* - Araujo (1984); *6* – Contente *et al.* (2011); *7* - Piedras & Pouey (2005); *8* - Cassemiro *et al*. (2003); *9* - Randall (1967); *10* - Stefanoni (2008); *11*- Chaves & Bouchereau (2004); *12* - Zahorcsak *et al*. (2000); *13* - Contente *et al.* (2009); *14* - Teixeira (1997); *15* - Figueiredo & Menezes (1978); *16* - Sacardo & Rossi-Wongtschowski (1991); *17* - Guedes & Araujo (2008); *18* - Sergipense et al. (1999); *19* - Bortoluzzi *et al*. (2006); *20* - Hayse (1990); *21* - Hiatt & Strasburg (1960); *22* - Chaves & Otto (1998); *23* - Contente (2008); *24* - Corrêa & Uieda (2007); *25* - Gegg & Fleeger (1997); *26* - Vieira (1991); *27* - Nagelkerken et al. (2001); *28* - Castillo-Rivera et al. (2000); *29* - Elliot et al. (2007); *30* - Figueiredo (1977); *31* - Vendel & Chaves (1998); *32* - Chaves & Umbria (2003); *33* - Soares & Vazzoler (2001); *34* - Chaves & Vendel (1998); *35* - Teixeira & Haimovici (1989); *36* - Cervigón (1994).

Families	**Species**	**Mesohaline sector**	**Polihaline Sector**	**Euhaline Sector**	**Guilds**	
					Estuarine use	**Tropic**
Achiridae	*Achirus declivis*	1	6	0	ES[a]	ZB[1]
	Achirus lineatus	41	92	4	ES[a,b,c]	ZB[2,3,4]
	Trinectes microphthalmus	0	0	1	MM[a]	
	Trinectes paulistanus	19	2	1	ES[a]	ZB[1,2]
Albulidae	*Albula vulpes*	0	121	310	AM[a,d]	ZB[1]
Argentinidae	*Glossanodon pygmaeus*	0	0	3	ES[d]	ZB[1]
Ariidae	*Cathorops spixii*	10	129	237	ES[b,c]	ZB[2,3]
	Genidens genidens	478	51	994	MM[d,e]	ZB[1,5]
Atherinopsidae	*Atherinella brasiliensis*	4182	28883	11957	ES[a,d,e,f,]	OP[1,6]
	Membras dissimilis	0	0	72		
	Odontesthes bonariensis	0	0	2001	FM[e]	ZP [1,7,8]
Batrachoididae	*Opsanus beta*	1	2	0	ES[d]	
Belonidae	*Strongylura marina*	5	79	260	MM[a,e]	PV[1,9]
	Strongylura timucu	15	85	171	MM[a,b]	PV[3]
Blennidae	*Parablennius pilicornis*	1	0	0	MS	ZB[1]
Carangidae	*Caranx hippos*	0	1	0	MS[a,c,e]	PV[1,2,9]
	Caranx latus	2	3	29	MM[a,c]	ZB[2,3]
	Caranx ruber	0	0	53	MS	PV[1]
	Chloroscombrus chrysurus	2	111	209	$MS_{a,c,e}$	OP[1,10]
	Oligoplites palometa	0	8	3	MM[a,e]	PV[1,2]
	Oligoplites saliens	16	42	943	MM	ZP[1,10]
	Oligoplites saurus	135	80	2271	MM[a,e]	PV[1,2,9]
	Selene setapinnis	0	0	45	MS[a]	PV[1]
	Selene vomer	3	45	116	MM[a,b,c,e]	ZB[2,3,11]
	Seriola lalandi	0	0	8	MS	PV[1]
	Trachinotus carolinus	0	201	5573	MS[e]	ZB[1,10,12]
	Trachinotus falcatus	11	335	2418	MS[a,e]	ZB[2,10,12]
	Trachonotus goodei	0	0	266	MS	ZB[1,12]
	Trachinotus marginatus	0	0	27	MS	
	Uraspis secunda	0	1	1	MS	
Centropomidae	*Centropomus parallelus*	461	50	20	ES[a]	ZB[2,13]
	Centropomus undecimalis	1	18	2	ES[a,e]	PV[2,14]
Clinidae	*Ribeiroclinus eingenmanni*	0	0	9	MS	
Clupeidae	*Brevoortia sp.*	0	0	1		ZP
	Chirocentrodon bleekerianus	0	0	8	MS	ZP
	Harangula clupeola	14	14602	28562	MS[a,e]	ZP[1,10,15]
	Harengula jaguana	0	0	29	MS	ZP[1]
	Opistonema oglinum	11	1097	3927	MS[a,e]	ZP[1,2,9]
	Platanichthys platana	96	4	9	ES[d]	ZP[1,2]
	Sardinella brasiliensis	0	985	7433	MS[e]	ZP[1,16]
Cynoglossidae	*Symphurus tesselatus*	24	3	2	MM[c,e]	ZB[1,17]
Dactylopteridae	*Dactylopterus volitans*	0	1	7	MS[a,e]	ZB[1,9]
Diodontidae	*Chilomycterus spinosus*	42	83	34	ES[a]	ZB[1,2,11]
Eleotridae	*Guavina guavina*	1	2	0	ES[b,d]	ZB[1,3]
Elopidae	*Elops saurus*	0	2	21	AM[d]	PV[1,2]
Engraulidae	*Anchoa filifera*	0	0	1	ES[d]	ZP
	Anchoa januaria	24157	2733	1106	ES[a,d,e]	ZP[10]
	Anchoa lyolepis	13	12415	4082	ES[a]	ZP[1]
	Anchoa tricolor	507	3252	24127	ES[e]	ZP[1]
	Cetengraulis edentulus	144	2585	901	MM[a,b,e]	ZP[3,11,18]
	Engraulis anchoita	0	39	0	MS[d]	ZP[1]

	Lycengraulis grossidens	12	114	3273	AN[a,d,e]	ZP[2,19]
Ephippidae	*Chaetodipterus faber*	8	73	321	MS[a,b,e]	HV[2,3,20]
Fistularidae	*Fistularia petimba*	0	4	9	ES[e]	PV[21]
	Fistularia tabacaria	0	3	60	MM[a,d]	ZP
Gerreidae	*Diapterus auratus*	0	93	0	EM[a,d]	ZB[1]
	Diapterus rhombeus	2924	1804	109	ES[e]	ZB[1,2,22]
	Eucinostomus argenteus	54	2461	6177	MM[a,e]	ZB[2,23]
	Eucinostomus gula	0	383	415	MM[a,d,e]	ZB[1,12]
	Eucinostomus melanopterus	2322	3321	240	MM[a,e]	ZB[1,23]
	Eugerres brasilianus	4	11	0	MM[a]	ZB[1,2]
	Ulaema lefroyi	0	102	693	ES[d]	ZP[1]
Gobiesocidae	*Gobiesox strumosus*	0	0	1	ES[d]	
Gobiidae	*Bathygobius soporator*	83	186	17	MM[a,e]	ZB[1,2,24]
	Ctenogobius boleosoma	4	19	1	AM[a,d,e]	ZB[1,25]
	Ctenogobius shufeldti	2764	42	0	ER	ZB
	Ctenogobius smaragdus	16	6	2	ES[a,b]	ZB[2,3]
	Ctenogobius stigmaticus	1	3	0	ES[a,b,c,e]	ZB[3]
	Gobioides broussonnetii	2	0	0	EM[d]	
	Gobionellus oceanicus	16	2	1	ES[a,b,e]	ZB[2,3]
	Microgobius meeki	78	22	5	MS[a,e]	ZB[1]
Haemulidae	*Anisotremus surinamensis*	0	1	11008	MS[a]	ZB[1]
	Boridia grossidens	3	0	0		
	Conodon nobilis	0	0	899	MM[b]	ZB[3]
	Genyatremus luteus	6	0	24	MS[a,b,c]	ZB[2,3]
	Haemulon steindachneri	0	0	9	MM[a]	ZB[1,2]
	Orthopristis ruber	0	33	295	MS	ZB[1,12]
	Pomadasys corvinaeformis	0	6430	652	MM[a,e]	ZB[1,2,10]
	Pomadasys ramosus	0	2	6	MM	
Hemirhamphidae	*Hemiramphus brasiliensis*	0	18	209	MM[d]	PV[1]
	Hyporhamphus robertii	2	0	0	MS	
	Hyporhamphus unifasciatus	203	47	1501	MS[a,e]	OV[1,2]
Lobotidae	*Lobotes surinamensis*	0	6	1	MS[a,d]	ZB[1]
Lutjanidae	*Lutjanus analis*	0	4	19	MM[d]	PV[1]
Monacanthidae	*Stephanolepis hispidus*	13	69	96	ES[c]	ZB[1]
Mugilidae	*Mugil curema*	5	476	512	MM[a,e,f]	DV[2,26,27]
	Mugil curvidens	0	2	6	ES[d]	DV[1]
	Mugil incilis	0	0	7	EM[d]	DV[1]
	Mugil liza	2	365	563	CA[a,d]	DV[1]
	Mugil sp.	219	181	528	MM[a,e]	DV
Narcinidae	*Narcine brasiliensis*	0	0	9	MS[a]	ZB[1]
Ophichthidae	*Ophichthus gomesii*	1	10	0	MS	
Paralichthyidae	*Citharichthys arenaceus*	350	102	124	MS[c,e]	ZB[1,10]
	Citharichthys macrops	0	0	1	MS	ZB[1]
	Citharicthys spilopterus	1	230	77	MS[a,c,e]	ZB[2,23,28]
	Etropus crossotus	6	131	743	ES[a,c]	ZB[1,10]
	Paralichthys brasiliensis	0	0	3	MM[a]	ZB[2]
	Paralichthys orbignyanus	8	5	5	MM[e]	ZB[1]
	Syacium papillosum	0	0	1	MS	PV[1]
Pleuronectidae	*Oncopterus darwinii*	0	0	12	MS	ZB[1]
Poeciliidae	*Poecilia vivipara*	0	299	16	FM[d]	ZP[1]
Polynemidae	*Polydactylus oligodon*	0	0	1	MS	ZB
	Polidactylus virginicus	0	11	82	MM[a,b,e]	ZB[1,2,3]
Pomatomidae	*Pomatomus saltatrix*	0	2	241	MS[e]	PV[1,29]
Pristigasteridae	*Pellona harroweri*	0	0	16	MS[a]	ZP[15]
Rhinobatidae	*Rhinobatos horkelii*	0	0	2	MS[a,c]	ZB[1]
	Rhinobatos percellens	0	3	0	MS	ZB[1,30]
Sciaenidae	*Bairdiella ronchus*	201	692	57	ES[c]	ZB[1,2,31]
	Ctenosciaena gracilicirrhus	0	56	32	MS	ZB[1]
	Cynoscion acoupa	1	0	0	MM[a,b]	ZB[3]
	Cynoscion leiarchus	0	8	49	MS[a,c,e]	PV[1,2,32]
	Cynoscion microlepidotus	0	0	4	ES[a]	
	Cynoscion striatus	0	3	0	MS[d]	ZB[1]
	Isopisthus parvipinnis	0	1	15	MM[a]	ZB[1,33]
	Larimus breviceps	0	0	66	ES[a]	ZB[1,2,33]
	Menticirrhus americanus	2	117	1521	MM[a,c,d,e]	ZB[1,10,32]
	Menticirrhus littoralis	0	18	1888	MM	ZB[2,10,12]
	Micropogonias furnieri	67	22	389	MM[a,c,e]	ZB[2,32,33]
	Ophioscion punctatissimus	0	0	22	MS	ZB[1,12]
	Paralonchurus brasiliensis	0	0	1	MS	ZB[1,33]
	Pogonias cromis	7	1	0	MS	ZB[1]
	Stellifer brasiliensis	5	3	3	MM	ZB
	Stellifer rastrifer	19	137	1945	MM[a,b,c,e]	ZB[3,34]
	Stellifer stellifer	4	17	3	ES[a]	ZB

	Umbrina canosai	0	2	7	MS	ZB[1]
	Umbrina coroides	0	1	481	MS	ZB[1,12]
Scombridae	*Sarda sarda*	0	1	0		PV
	Scomberomorus brasiliensis	0	6	14	MS[a]	PV[1]
Scorpaenidae	*Scorpaena isthmensis*	0	1	0	MS	PV
Serranidae	*Diplectrum radiale*	5	47	167	MS[a,c,e]	PV[1,2,15]
	Hyporthodus nigritus	0	0	1	MS[d]	ZB[1]
	Mycteroperca bonaci	0	0	1	MS	PV[1,2]
	Mycteroperca rubra	0	0	6	MS	ZB[1]
	Rypticus randalli	0	119	8	MS[a]	PV[9]
Sparidae	*Archosargus probatocephalus*	1	0	0	MS	ZB[1,2]
	Archosargus rhomboidalis	0	21	3	MM[a]	ZB[1,27]
Sphyraenidae	*Sphyraena tome*	0	1	2	MM	PV
Stromateidae	*Peprilus paru*	0	0	25	MS	OV[1]
Syngnathidae	*Bryx dunckeri*	0	0	7	ES[d]	ZP
	Cosmocampus elucens	0	1	3	MS[e]	ZP
	Hippocampus reidi	1	2	9	ES[a,c]	ZP
	Syngnathus folletti	0	5	27	ES[e]	ZP
	Syngnathus pelagicus	12	14	70	MS[e]	ZP
Synodontidae	*Synodus foetens*	3	75	284	MS[a,c,e]	PV[1,9,15]
Tetraodontidae	*Lagocephalus laevigatus*	0	9	16	MM[d,e]	ZB[1,2]
	Sphoeroides greeleyi	9	2575	494	ES[a,d,e]	ZB[1,9]
	Sphoeroides testudineus	1838	5849	433	ES[a,c,d,e]	ZB[1,2,11]
Trichiuridae	*Trichiurus lepturus*	0	1	9	MS[a,b]	PV[3]
Triglidae	*Prionotus nudigula*	0	3	24	MS	PV[1]
	Prionotus punctatus	0	10	206	MS[a,c,e]	ZB[1,2,35]
Uranoscopidae	*Astrocopus sexspinosus*	0	0	5		PV
	Astrocopus u-graecum	0	2	49	MS[e]	PV[1,36]

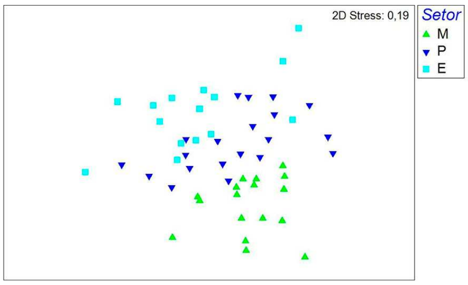

Fig. 2. Multidimensional ordination (MDS) based on the presence/absence of families between three salinity sectors (E = euhaline; P = polyhaline; M = mesohaline).

Table 3. SIMPER results based on presence/absence of families within salinity sectors. Families most responsible for the mean similarity within each group and the dissimilarity between groups are shown in non-shaded and shaded boxes, respectively.

Sectors	**Mesohaline**	**Euhaline**
Mesohaline	Atherinopsidae Engraulidae Gerreidae Gobiidae	
Euhaline	Albulidae Gobiidae Ephippidae Achiridae	Carangidae Clupeidae Engraulidae Tetraodontidae

The ordination of the sampling points based on the percentage of the estuarine use functional groups (Fig. 5), and respective ANOSIM, did not show clear separation between salinity sectors (*R*-Global = 0.183; *P*< 0.01). Substantial overlap was observed between the mesohaline and euhaline sectors (*R* = 0.306; *P*< 0.01), and even greater overlap was observed between the polyhaline and euhaline sectors (*R* = 0.236; *P*< 0.01). There was no significant difference (*P* > 0.05) between the mesohaline and polyhaline sectors.

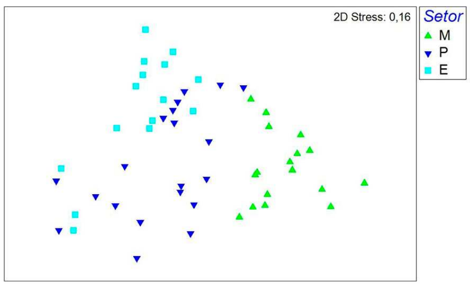

Fig. 3. Multidimensional ordination (MDS) based on the presence/absence of species between three salinity sectors (E = euhaline; P = polyhaline; M = mesohaline).

In the trophic functional composition percentage analysis (Fig. 6), the sectors sampled were not well defined in the nMDS; this lack of differentiation was confirmed by ANOSIM (*R*-Global = 0.107; *P*< 0.05). There were no significant differences among sectors in paired comparisons.

Table 4. SIMPER results based on presence/absence of species within salinity sectors. Species most responsible for the mean similarity within each group and the dissimilarity between groups are shown in non-shaded and shaded boxes, respectively.

Sectors	**Mesohaline**	**Polyhaline**	**Euhaline**
Mesohaline	*Anchoa januaria* *Atherinella brasiliensis* *Diapterus rhombeus*		
Polyhaline	*Anchoa tricolor* *Sphoeroides greeleyi* *Ctenogobius shufeldti*	*Atherinella brasiliensis* *Sphoeroides testudineus* *Anchoa tricolor*	
Euhaline	*Trachinotus falcatus* *Harengula clupeola* *Trachinotus carolinus*	*Albula vulpes* *Trachinotus carolinus* *Selene vomer*	*Anchoa tricolor* *Harengula clupeola* *Trachinotus falcatus*

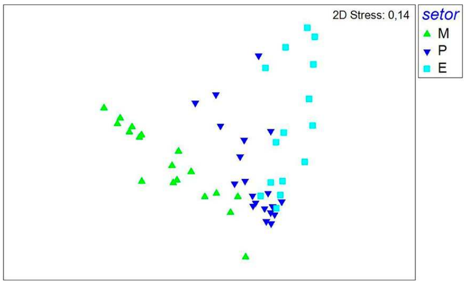

Fig. 4. Multidimensional ordination (MDS) based on the quantitative similarity of fish species between three salinity sectors (E = euhaline; P = polyhaline; M = mesohaline).

Table 5. SIMPER results based on the percentage of individuals within a species in each salinity sector. Species most responsible for the mean similarity within each group and the dissimilarity between groups are shown in non-shaded and shaded boxes, respectively.

Sectors	**Mesohaline**	**Polyhaline**	**Euhaline**
Mesohaline	*Anchoa januaria* *Atherinella brasiliensis* *Diapterus rhombeus*		
Polyhaline	*Atherinella brasiliensis* *Anchoa januaria* *Diapterus rhombeus*	*Atherinella brasiliensis* *Sphoeroides greeleyi* *Anchoa tricolor*	
Euhaline	*Anchoa januaria* *Atherinella brasiliensis* *Harengula clupeola*	*Atherinella brasiliensis* *Harengula clupeola* *Anchoa tricolor*	*Atherinella brasiliensis* *Harengula clupeola* *Anchoa tricolor*

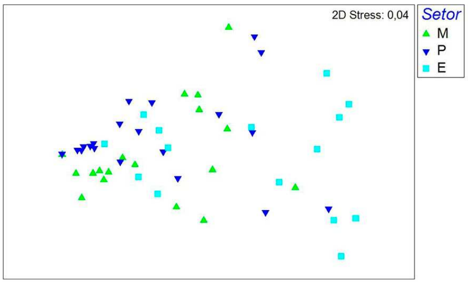

Fig. 5. Multidimensional ordination (MDS) based on the percentage of fish within estuarine use guilds between three salinity sectors (E = euhaline; P = polyhaline; M = mesohaline).

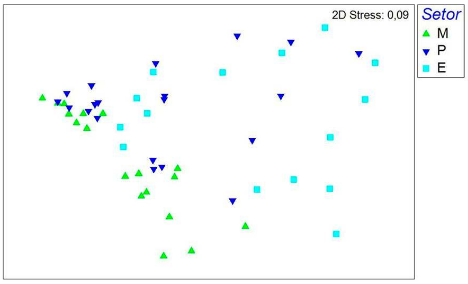

Fig. 6. Multidimensional ordination (MDS) based on the percentage of fish within trophic guilds between three salinity sectors (E = euhaline; P = polyhaline; M = mesohaline).

Discussion

In this study we tested the effect of the east-west salinity gradient of the PEC on the structure of shallow water fish fauna, described in taxonomic (families and species) and functional terms. We found that the taxonomic metrics were better able to characterize fish assemblages along the estuarine salinity gradient than were functional metrics. In other words, the osmoregulatory abilities of the various species played a greater role in determining the spatial distribution of an assemblage than did their functional traits. We used a mean spatial model that represented an individual's salinity affinity well. However, individuals of all functional groups occurred in all salinity sectors and, thus, this metric was not useful for differentiating assemblages along the salinity gradient using a mean model. Our results differed from those of other studies, which emphasized the importance of functional groups in determining fish assemblages along salinity gradients (ELLIOTT; DEWAILLY, 1995; MATHIESON et al., 2000; CHAVES; BOUCHEREAU, 2004; HARRISON; WHITFIELD, 2012).

Among the taxonomic metrics employed here, presence/absence of families was less efficient than species in discriminating assemblages across sectors. In fact, each family may contain many species, each with a different capacity for reaching their optima in different salinity zones (ELLIOTT et al., 2007, BLABER, 2008). For example, *E. melanopterus* and *E. argenteus* were two of the most important species in the PEC mesohaline and polyhaline zones, respectively (SANTOS et al., 2002; VENDEL et al., 2002, 2003; SPACH et al., 2006; FALCÃO et al., 2006; FÉLIX et al., 2006; OLIVEIRA-NETO et al., 2008, CONTENTE et al., 2011a).

Atherinella brasiliensis, *Anchoa januaria*, *Diapterus rhombeus* and *Harengula clupeola* were the most abundant species, both along the entire east-west axis of the PEC and within each of the sectors individually. *A. brasiliensis* was the most abundant fish throughout the entire east-west axis, but showed a tendency for larger abundance within inner estuarine zones. These fish are generalists and opportunistic estuarine omnivores, tolerant of any estuarine environmental conditions (CONTENTE et al., 2011b). The wide range and dominance of this species in the PEC, as well as in other southern Brazilian estuaries, are primarily due to these plastic trophic features and a fast growing, short-lived life cycle (CONTENTE et al., 2011a). The species generally inhabits shallow bays and estuaries and can form large populations [as also in other subtropical estuaries, e.g., Lagoa do Patos Estuary; (GARCIA et al., 2001)], thus comprising a key component of the trophic web (CONTENTE et al., 2011b). *A. januaria* and *D. rhombeus* were more characteristic of the mesohaline sector of the PEC. *A. januaria* forms large schools and is associated with the internal areas of bays and estuaries; it is influenced by continental drainage and less saline waters. Juveniles of *D. rhombeus* prefer shallow mesohaline areas, such as beaches and mangrove channels, to grow and store somatic reserves during the reproductive period (MENEZES; FIGUEIREDO, 1980; CHAVES; OTTO, 1998). *H. clupeola* (zooplanktivorous marine straggler) and *A. tricolor* (zooplanktivorous estuarine species) were more abundant in the euhaline sector - a finding was not in accord with observations from other estuaries (FALCÃO et al., 2006; FÉLIX et al., 2006; OLIVEIRA-NETO et al., 2008; CONTENTE et al., 2011a). Differences in sector usage by *A. januaria*, *D. rhombeus* and *H. clupeola* most likely occur due to differences in the salinity tolerances of these species. Despite being euryhaline, estuarine species generally reach their optima within specific salinity ranges (PAPERNO et al., 2001; PAPERNO; BRODIE, 2004; CONTENTE et al., 2011a) due to strong species-specific physiological responses to the estuarine salinity gradient (BLABER, 2008).

There were some differences in sampling effort and net mesh size given in the studies from which data were drawn for the assemblage analyses. Nevertheless, samples were representative of the spatial pattern of shallow water fish fauna, because the predominance of seine nets reduced potential bias (ELLIOTT; DEWAILLY, 1995). Analyses were limited to the fauna captured with seine and capéchades nets; thus our conclusions were limited to shallow water fish fauna consisting of individuals with mean total lengths of less than 100 mm. Our conclusions must be tested using other components of the PEC fish fauna (e.g., larger fishes from the main channel and open water environments). Another potential source of error is that the same species could fit into different guilds according to the site and region due to differences in the availability of resources and environmental conditions (ELLIOTT et al., 2007; BARLETTA; BLABER, 2007). For example, in our study *D. rhombeus* was classified as an estuarine species, while in Vilar et al. (2011) it was considered a marine migrant. Similarly, *G. luteus* was classified here as a marine straggler, while Barletta and Blaber (2007) considered it to be an estuarine species. These discrepancies highlight the need for more comprehensive information on the ecology and biology of the species inhabiting SW Atlantic estuaries (BARLETTA et al., 2010) to resolve such ambiguities.

Although many studies of Brazilian estuaries have classified species into functional guilds (VIEIRA; MUSICK, 1993; GARCIA; VIEIRA, 2001; CHAVES; BOUCHEREAU, 2004; ANDRADE-TUBINO et al., 2008; REIS-FILHO et al., 2010; VILAR et al., 2011), they have not tested the effect of the estuarine salinity gradient on the functional traits of the assemblages. We found that traditional taxonomic metrics were a better indicator of structural changes than were trophic groups or membership in categories of estuarine use. We have demonstrated that the salinity gradient has a key impact on the taxonomic structure of PEC fish assemblages because of the consistent link between estuarine fish fauna along a longitudinal gradient and the longitudinal salinity gradient of the estuary; this type of impact is a general feature among estuaries worldwide (BULGER et al., 1993; JAUREGUIZAR et al., 2004; AKIN et al., 2005; CHAGAS et al., 2006; BARLETTA; BLABER, 2007; BARLETTA et al., 2008; VILAR et al., 2011).

We suggest that future studies consider environments on a smaller spatial scale along the east-west axis of the PEC. The similar results for the polyhaline and euhaline sectors may have been due to their proximity to the Cotinga sub-estuary (located between the euhaline and polyhaline sectors) which possesses different morphological and hydrological characteristics (primarily related to the tides and the energy in the drainage area) from the east-west axis of the PEC (NOERNBERG et al., 2006). This environment is composed of winding rivers and extensive floodplains, which can form unvegetated sandbanks and confer unique characteristics to this area. In addition, this sub-estuary is near the mixing zone of the estuary. We had expected that these habitat features would have had a greater influence on the trophic features of the fish fauna than the long salinity gradient examined in this study. A similar relationship might be expected for the Nhundiaquara and Cachoeira sub-estuaries in the mesohaline sector.

ACKNOWLEDGMENTS

We would like to thank the CEM Geological Oceanography Laboratory for the map data base and Pâmela Emanuelly Cattani for her valuable help with the map. We would like to thank the "Fundação Grupo Boticário de Proteção à Natureza" for financial support. Funding was provided by the CAPES foundation through a master's grant to Ana Carolina dos Passos.

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(Manuscript received 22 February 2013; revised 30 November 2013; accepted 06 December 2013)

ERRATA

ANALYSIS OF FISH ASSEMBLAGES IN SECTORS ALONG A SALINITY GRADIENT BASED ON SPECIES, FAMILIES AND FUNCTIONAL GROUPS

Na pág. 252
Onde se lê:
Fig. 1. Multidimensional ordination (MDS) based on the presence/absence of families between three salinity sectors (E = euhaline; P = polyhaline; M = mesohaline).

Leia-se:
Fig. 1. Location of the sampling sites in the euhaline (E1-E15), polyhaline (P1-P20) and mesohaline (M1-M18) sectors of the east-west axis of the Paranaguá Estuarine Complex.