

Fish assemblages in a coastal bay adjacent to a network of marine protected areas in southern Brazil

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ABSTRACT

Baía Norte (North Bay) in Santa Catarina State is considered a typical coastal bay and is surrounded by a network of Marine Protected Areas. The objectives of this study were to describe the composition of the demersal fish assemblage, identify seasonal and spatial structures on a fine scale and evaluate the role of habitat descriptors and abiotic variables affecting the fish assemblage structure. Seasonal samplings were conducted in 2005, using bottom trawls in six pre-established areas in Baía Norte in summer, fall, winter and spring. Simultaneously with each trawl, environmental data were collected with a multiparameter probe. Temporal and spatial differences in fish abundance were tested by a PERMANOVA. To illustrate the differences detected graphically we ran a canonical analysis of principal coordinates (CAP). The influence of environmental variables on the fish fauna was evaluated using a Distant Based Linear Model (DistLM) with Akaike's information criterion (AIC). A total of 9,888 specimens, distributed in 27 families and 62 species, were collected. *Citharichthys spilopterus* was the most abundant species. PERMANOVA detected differences for abundance between seasons, areas and interaction among all the factors. The DISTLM selected temperature and pH. The results highlight seasonality as an important factor in the structuring of fish fauna of the study place.

Descriptors: Norte Bay, Ichthyofauna, Santa Catarina Island.

RESUMO

A Baía Norte em Santa Catarina, é considerada como uma típica baía costeira, rodeada por uma rede de Áreas Marinhas Protegidas. Este estudo teve como objetivos descrever a composição e estrutura da comunidade de peixes, testar a influência dos padrões espaciais e sazonais e avaliar a influência das variáveis abióticas nos padrões de abundância. Amostras sazonais foram realizadas por meio de arrasto de fundo em seis áreas predefinidas da Baía Norte no verão, outono, inverno e primavera no ano de 2005. Simultaneamente, foram coletados dados do ambiente com uma sonda multiparâmetro. Diferenças temporais e espaciais na abundância de peixes foram testados por uma análise PERMANOVA. Para visualizar graficamente as diferenças encontradas na PERMANOVA, foi realizada a análise canônica de coordenadas principais (CAP). Para avaliar a influência de variáveis ambientais sobre a fauna de peixes, foi aplicado um DISTLM usando critério de informação de Akaike (AIC). Foram coletados 9.888 espécimes, distribuídos em 27 famílias e 62 espécies. *Citharichthys spilopterus* foi a espécie dominante. A PERMANOVA detectou diferenças na abundância entre estações, áreas e interação entre todos os fatores. O DISTLM selecionou a temperatura e pH. Os resultados enfatizam a sazonalidade como um fator importante para a estruturação da fauna de peixes do local de estudo.

Descritores: Baía Norte, Ictiofauna, Ilha de Santa Catarina.

INTRODUCTION

Fish distribution patterns are shaped on different time scales that range from circadian or nictemeral cycles to interannual variations (MACI; BASSET, 2009), and interfere with ecological processes such as recruitment and reproduction (GARCIA et al., 2001; GREENWOOD; HILL, 2003; JAUREGUIZAR et al., 2004). In spatial terms, fish assemblage composition is organized on hierarchical scales, varying from meters to thousands of kilometers. On a regional scale (hundreds to thousands of kilometers), different factors structure an assemblage and these include the latitudinal temperature gradient, width and length of the estuary, vegetation cover (swamps and marshes), tidal range, rainfall and distance between estuaries and interfere with larval dispersal and species recruitment processes (BLABER, 2000; HARRISON; WHITFIELD, 2006; SHEAVES; JOHNSTON, 2009; VILAR et al., 2013). On a local scale, salinity, dissolved oxygen and transparency are key factors affecting the occurrence of assemblages (BARLETTA et al., 2005; VILAR et al., 2011; 2013).

Human influence also alters spatio-temporal distribution patterns of fish assemblages. In estuarine and lagoon habitats, fish assemblages are potentially impacted by many anthropogenic activities with direct influence on food resources, distribution, diversity, reproduction, abundance, growth, survival and behavior of both resident and migratory species (MCDOWALL, 1988; ELLIOT; QUINTINO, 2007; BREHMER et al., 2013). Estuaries and coastal ecosystems are areas susceptible to the waste dumping and sewage discharge of a growing human population in the coastal zone (KENNISH, 1990), and are, further, still suffering from the effects of overfishing and tourism, as well as urbanization, agriculture, aquaculture and industrial development (RAZ-GUZMA; HUIDOBRO, 2002). Because of their position in the catchment area, these environments are among the most impacted by human activities (CABRAL et al., 2001; LOBRY et al., 2003).

Studies of the composition and structure of fish assemblages and the spatial and temporal variations in estuarine and coastal environments on the Brazilian coast are focused mainly in subtropical and temperate areas (BARLETTA et al., 2005). A recent comparative study of the fish assemblages in five estuaries along the Brazilian coast (Curuçá, Santa Cruz, Piraquê-Açú, Paranaguá and Lagoa dos Patos) found higher variability between estuaries than between the samples within each estuary, and showed that the composition of the assemblages

is structured by both environmental factors (physical, hydrological and geographical characteristics of estuaries) and biological factors (larval recruitment and dispersal ability of species) (VILAR et al., 2013).

In southern Brazil, studies on fish assemblages in coastal environments, particularly estuaries, are more numerous in relation to the coast of the states of Rio Grande do Sul (GARCIA; VIEIRA, 2001a; GARCIA et al., 2001b; RAMOS; VIEIRA, 2001; GARCIA et al., 2003; BURNS et al., 2006) and Paraná (SPACH et al., 2004; OTERO et al., 2006; FALCÃO et al., 2006; SPACH et al., 2006; 2007; CONTENTE et al., 2011). The state of Santa Catarina has a strong fishing vocation but studies on fish assemblages on its coast are less common (MONTEIRO-NETO et al., 1990; RIBEIRO et al., 1997; 1999; BARREIRO et al., 2009, VILAR et al., 2011; RIBEIRO et al., 2014). This study was, therefore, designed to fill the current information gap, as well as to contribute to the understanding of ecological processes involving the fish assemblage in the Baía Norte, a coastal bay adjacent to a network of Marine Protected Areas on the central coast of Santa Catarina State. The main objectives were to: (1) describe the composition of the demersal fish assemblage; (2) identify seasonal and spatial structures on a fine scale; and (3) evaluate the role of habitat descriptors and abiotic variables affecting the fish assemblage structure. Ultimately, this information may provide support for future management plans and/or actions for the adjacent MPAs in the area; and increase ecological knowledge of fish assemblages on tropical and subtropical coasts.

MATERIAL AND METHODS

STUDY AREA

The North Bay (Baía Norte) of the island of Santa Catarina (27°30' S; 48°35' W), southern Brazil (Fig. 1), is considered a typical coastal bay (SORIANO-SIERRA; SIERRA DE LEDO, 1998). It is a protected bay delimited by a mosaic of rocky shores, sandy beaches and mangrove areas. Its oceanographic parameters are similar to those of the adjacent open waters (SIMONASSI et al., 2010). Tidal and drift currents as well as the inflow of freshwater exercise considerable influence on the dynamics of this ecosystem. The bay has a surface area of approximately 200 km², average depth of 5 m and a maximum depth of 21 m. Water temperature varies markedly between seasons (15 - 29° C). Most of the substrate in the inner bay

is silt and mud. The tidal range is of approximately 1 m (SORIANO-SIERRA, 1999).

Our study area is surrounded by three Marine Protected Areas with different degrees of restriction: the Arvoredo Marine Biological Reserve (Arvoredo Reserve), the Anhatomirim Environmental Protection Area (Anhatomirim EPA) and the Carijós Ecological Station (Carijós Station). The Arvoredo Reserve is a no-take reserve created in 1990 (Decree 99142), located in adjacent coastal waters. The Carijós Station (Decree 94656), created in 1987, is also very restrictive to any resource use and visitation, and covers mainly mangrove and estuarine habitats within Baía Norte. The Anhatomirim EPA was created in 1992 (Decree 528) with the main purpose of protecting a resident Guiana dolphin population in North Bay (padronizar North Bay or Baía Norte!). It is a multiple-use protected area, which means that some resource use is permitted inside the MPA, but under specific regulations.

SAMPLING

Seasonal samplings were conducted in 2005. Using a 6-meter boat, bottom trawls were performed for 30 minutes in six pre-established areas in the North Bay (Figure 1) in the four seasons. The central month of each season was chosen as the sampling period, with samples taken on four non-consecutive days (at weekly intervals). Six trawls were performed on each day. Thus, 96 samples were obtained (6 trawls X 4 days X 4 months). Simultaneously with each trawl, salinity, temperature and pH were measured by means of a multiparameter probe. Rainfall data were provided by the Empresa de Pesquisa

Agropecuária e Extensão Rural de Santa Catarina (EPAGRI). Trawl net mesh sizes were 2.5 cm between opposite knots at the codend and 4 cm at the mouth, width of 8.65 m and height of 1.80 meters (15.57 m² opening).

STATISTICAL ANALYSIS

Sampling months were grouped into four seasons: summer (December, January and February); fall (March, April and May); winter (June, July and August); and spring (September, October and November).

For data analysis, the analytical model used was complex: $X = \mu + Sea + Sec + Are (Sec) + Sea * Are (Sec) + e$, where X = dependent variable; μ = mean; Sea = season, Sec = Sector, Are = area; e = error or residue. This model was used to test the differences between environmental parameters and population parameters of fish between seasons (summer, winter, fall and spring), between areas (A, B, C, D, E and F) and sectors (north = areas A, B and C; south = areas D, E and F). The factors season and sector were fixed and the factor area was random, nested within the factor sector.

Temporal and spatial differences in fish abundance were tested by a multivariate analysis of variance using permutations (PERMANOVA - *Permutational multivariate analysis of variance*) (ANDERSON et al., 2008). A pairwise PERMANOVA was applied to a posteriori comparisons between factors showing significant differences in PERMANOVA (p -value < 0.05). For graphical illustration of the differences detected we ran a canonical analysis of principal coordinates (CAP), which generates graphic clusters through permutation (ANDERSON et al., 2008). Within the CAP analysis,

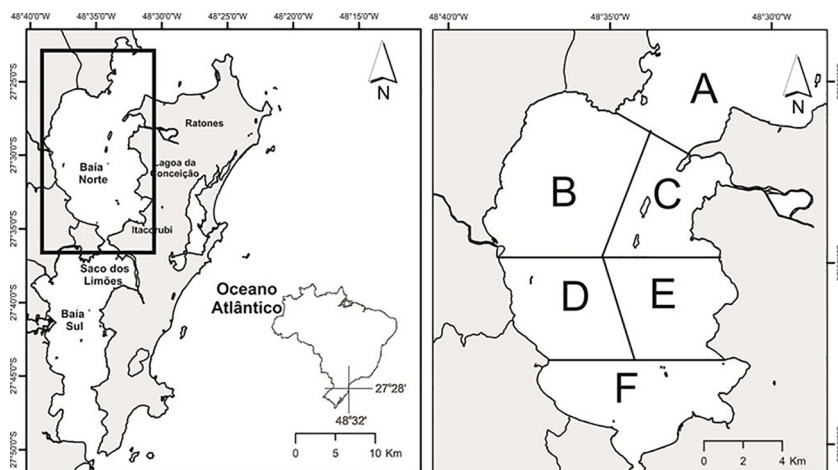


Figure 1. Map of the island of Santa Catarina showing the sampling areas in the North Bay.

correlation Spearman at 0.4 was set to determine which species (vectors) were responsible for the clusters.

The differences in environmental parameters were also tested by a PERMANOVA. To evaluate the influence of environmental variables on the variability of fish data and to select the best explanatory model, we applied a DISTLM (Distance-Based Linear Model) using Akaike's information criterion (AIC) (ANDERSON et al., 2008). A stepwise procedure was adopted to test the importance of the independent variables. Environmental data were log-transformed ($\log(x + 1)$) and biotic data were square root transformed (CLARKE; WARWICK, 1994). Redundancy Analysis (dbRDA - distance-based redundancy analysis) was used to examine the influence of predictor variables on the spatial distribution of samples (ANDERSON et al., 2008). In all analyses, 9999 permutations were made. The similarity index used for abundance data was the Bray-Curtis coefficient. The PERMANOVA for environmental variables was run on the basis of the similarity matrix obtained by Euclidean distance.

To assess the taxonomic differences between seasons in the area and determine the seasons with higher taxonomic complexity, we calculated the indices of Average Taxonomic Distinctness (Delta+ or AvTD) and Variation in Taxonomic Distinctness (Lambda+ or VarTD) with the presence/absence matrix (CLARKE; WARWICK, 1994).

To observe graphically whether the values of Average Taxonomic Distinctness and Variation in Taxonomic Distinctness of the seasons are within the expected taxonomic ranges, we constructed a funnel plot of AvTD and VarTD. We also prepared a biplot graphic display with both indices on each axis of the graph. A 95% probability ellipse of species was superimposed on the biplot graphic display.

Taxonomic differences between the seasons were tested by univariate PERMANOVA, with the species richness, values of AvTD and VarTD as dependent variables and seasons as fixed factor.

RESULTS

ENVIRONMENTAL VARIABLES

The PERMANOVA run individually for each environmental variable (salinity, temperature, pH and rainfall) detected significant differences ($p < 0.05$) among seasons, with no differences among areas and sectors. In the paired comparison by pairwise PERMANOVA, in relation to salinity and pH, except for the summer and

spring, significant differences were detected between the other seasons (Table 1). For rainfall, there were no differences, except between summer and fall, and for temperature, there were differences between the four seasons.

Table 1. Pairwise PERMANOVA on the basis of the Euclidean distance of salinity, temperature and rainfall, log transformed $\log(X + 1)$ and pH, comparing the seasons (summer, winter, fall and spring).

Seasons	Salinity p(perm)	Temperature	pH	Rainfall
Summer, Fall	0.0341*	0.0025**	0.0341*	0.6462
Summer, Winter	0.0078**	0.0017**	0.0078**	0.0001***
Summer, Spring	0.8558	0.0023**	0.8558	0.0001***
Fall, Winter	0.0061**	0.0023**	0.0061**	0.0198*
Fall, Spring	0.0303*	0.0021**	0.0303*	0.0137*
Winter, Spring	0.0106*	0.0021**	0.0106*	0.0001***

$p < 0.05^*$; $p < 0.01^{**}$; $p < 0.0001^{***}$

Higher mean values of salinity were observed in the fall (mean \pm SD, 36.21 ± 1.47), followed by summer (35.25 ± 0.85), spring (35.21 ± 0.88) and winter (32.67 ± 3.24) (Figure 2a). In descending order, higher mean values of temperature were found in summer (25.60 ± 0.62), spring (24.18 ± 1.03), fall (22.48 ± 1.44) and winter (19.4 ± 1.24) (Figure 2b). Regarding the pH, higher mean values were registered in spring (8.56 ± 0.08), winter (8.19 ± 0.08), fall (7.5 ± 0.49) and summer (7.21 ± 0.64) (Figure 2c). Regarding rainfall, higher mean values were verified in winter (212.95 ± 40.6 mm), followed by fall (174.8 ± 84.04 mm), summer (126.3 mm \pm 1.77) and spring (86.2 mm \pm 5.92) (Figure 2d).

FISH ASSEMBLAGE

A total of 9,888 specimens, distributed in 27 families and 62 species (Table 2), were collected in the study period. The richest family was Sciaenidae (13); followed by Tetraodontidae (6); Carangidae (5); Gerreidae (4); Achiridae, Clupeidae, Engraulidae and Paralichthyidae (3 each); and Ariidae, Haemulidae and Mugilidae (2 each) (Table 2). The other families had only a single species. The families with the highest catches (the ten most abundant families) were Paralichthyidae (3,296 individuals),

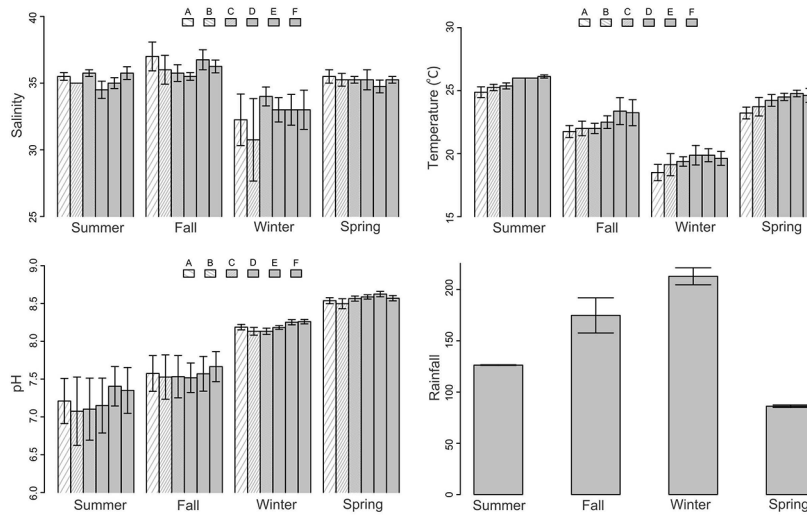


Figure 2. Mean values (standard errors on the bars) for salinity, temperature, pH and rainfall comparing the seasons and the six collection areas (A, B, C, D, E and F) in the North Bay

Sciaenidae (1,820), Carangidae (992), Ariidae (904), Engraulidae (748), Cynoglossidae (639), Achiridae (254), Triglidae (252), Gerreidae (235) and Pristigasteridae (191). As for the weight, the greatest catches (ten dominant families) were found for Paralichthyidae (63,865.2 g), Ariidae (60,739.2 g), Sciaenidae (33,238.9 g), Engraulidae (17,887.5 g), Cynoglossidae (13,476.3 g), Trichiuridae (8,526.24 g), Gerreidae (8,096.39 g), Achiridae (7,951.75 g), Carangidae (7,677.71 g) and Triglidae (5,481.44 g).

In descending order, *Citharichthys spilopterus*, *Genidens genidens*, *Stellifer rastrifer*, *Cetengraulis edentulus*, *Symphurus tessellatus*, *Chloroscombrus chrysurus*, *Micropogonias furnieri*, *Etropus crossotus*, *Selene setapinnis* and *Ctenosciaena gracilicirrhus* were dominant in number of individuals, representing 80% of the total catch (abundance), while the catch of *C. spilopterus* alone corresponded to approximately 30% of the total. *Anchoa spinifer*, *Anchovia clupeioides*, *Macrodon ancylodon*, *Mugil liza*, *Ophichthus gomesii*, *Paralichthys brasiliensis*, *Platanichthys platana*, *Trachinotus carolinus* and *Trinectes paulistanus* were caught only once (Table 2).

The total catch in weight was 254,075.78 g (Table 2). *G. genidens*, *C. spilopterus*, *C. edentulus*, *S. tessellatus*, *M. furnieri*, *S. rastrifer* and *E. crossotus* corresponded, in descending order, to approximately 70% of the total weight. *G. genidens* and *C. spilopterus* amounted to 45% of the total catch in weight.

A total of 29 species were caught in all the seasons and 12 species in only one of the seasons. There was a greater richness in the fall (50 species), followed by the

spring (45 species), winter (43 species) and summer (41 species) (Table 2).

Regarding areas, 25 species occurred in the six areas and 11 species presented exclusive occurrence in a single area. The highest species richness occurred in area C (44 species), followed by areas F (42), E (41), A (40) and B and D (38 species each). Six species occurred exclusively in area A and only two species in area F. In the other areas, there was only one exclusive species (Table 2)

PERMANOVA detected significant differences ($p < 0.05$) for total abundance among seasons, areas and interaction between all factors (seasons, areas and sector), with the higher abundance mean values in areas C and E in the fall and lower means in area A in the winter and area D in the summer (Table 3 and Figure 3). In paired comparisons (pairwise PERMANOVA) within each season, major differences between areas were observed in the spring, followed by winter, fall and summer (Table 4).

Differences in mean values of abundance among seasons by PERMANOVA as well as species that have contributed to such differences can be observed graphically in the canonical analysis of principal coordinates (CAP). The canonical correlation of the two axes obtained by the analysis was $\delta_1 = 0.8052$ and $\delta_2 = 0.7909$. There was a clear separation, along the first axis, between the summer and winter samples and, along axis 2, between the spring and fall (Figure 4). The high abundance of *C. chrysurus*, *E. crossotus* and *S. tyleri* in the winter and fall samples, *S. setapinnis* and *C. microlepidotus* in the fall and summer, *M. furnieri* in the summer and *C. edentulus* in the spring,

Table 2. List of species, number of individuals (n), weight (W), mean, minimum and maximum total length (TL), season and areas (higher abundances to the left) of fish caught in the North Bay.

Family/Species	n	W (g)	Mean TL(mm)	Mín-Máx TL(mm)	Season	Area
Achiridae						
<i>Achirus declivis</i>	16	1273.06	143.44	78-192	su>sp=fa=wi	C>E>D
<i>Achirus lineatus</i>	237	6623	104	64-186	sp>su>fa>wi	F>C>E>D>B>A
<i>Trinectes paulistanus</i>	1	55.69	135	135	fa	A
Ariidae						
<i>Genidens barbuis</i>	6	495.22	207.5	177-285	wi>sp	B>F>C
<i>Genidens genidens</i>	898	60244.10	193.62	55-320	sp>su>wi>fa	E>C>B>D>F>A
Batrachoididae						
<i>Porichthys porosissimus</i>	5	307.52	166.6	39-215	wi>fa=sp=su	A>B=C
Carangidae						
<i>Chloroscombrus chrysurus</i>	575	4487.91	86.81	21-190	wi>fa>su>sp	B>E>F>A>C>D
<i>Oligoplites saurus</i>	6	58.09	114.67	107-126	wi>sp	B>E>D
<i>Selene setapinnis</i>	294	2006.67	78.38	46-180	su>fa>wi>sp	B>E=F>A>C=D
<i>Selene vomer</i>	116	1089.27	65.94	31-209	su>fa>sp>wi	F>D>B>E>A
<i>Trachinotus carolinus</i>	1	35.77	141	141	fa	F
Centropomidae						
<i>Centropomus parallelus</i>	5	551.04	226.2	223-232	wi=fa>sp	C=F>E
Clupeidae						
<i>Harengula clupeola</i>	18	594.29	140.39	90-176	wi>fa=sp	B>C=D=E
<i>Opisthonema oglinum</i>	5	133.55	144.6	130-158	wi>fa	D>B
<i>Platanichthys platana</i>	1	1.61	54	54	sp	
Cynoglossidae						
<i>Symphurus tessellatus</i>	639	13476.31	140.77	90-195	fa>su>wi>sp	B>C>E>F>A>D
Engraulidae						
<i>Anchoa spinifer</i>	1	21.28	150	150	sp	A
<i>Anchovia clupeoides</i>	1	6.71	100	100	fa	A
<i>Cetengraulis edentulus</i>	746	17859.49	132.05	88-174	fa>sp>wi>su	E>D>B>F>C>A
Ephippidae						
<i>Chaetodipterus faber</i>	60	3927.86	112.42	28 - 397	sp>wi>fa>su	C>B>D>F>E>A
Gerreidae						
<i>Diapterus rhombeus</i>	53	2326.97	138.43	105-176	sp>wi>fa	C>E>F>A
<i>Eucinostomus argenteus</i>	70	1156.88	107.44	47-150	fa>wi>su>sp	F>C>D>E>B>A
<i>Eucinostomus gula</i>	44	1145.16	122.84	89-148	wi>su>sp>fa	E>D>F>A>B=C
<i>Eucinostomus melanopterus</i>	68	3467.38	165.54	141-201	wi=fa>sp	F>C>E>D
Gobiidae						
<i>Gobionellus oceanicus</i>	8	213.44	193	160-221	su>fa	F>B=E
Haemulidae						
<i>Orthopristis ruber</i>	72	3156.8	132.75	64-259	sp>su>wi>fa	C>F>E>A
<i>Pomadasys corvinaeformis</i>	14	132.29	87.57	74-117	fa>wi	C>D=F
Monacanthidae						
<i>Stephanolepis hispidus</i>	3	5.56	44.67	39-49	su=fa=wi	C=E=F
Mugilidae						
<i>Mugil curema</i>	3	746.35	286	248-327	su>fa	D>E
<i>Mugil liza</i>	1	677.05	415	415	su	A

Continued Table 2.

Muraenidae						
<i>Gymnothorax ocellatus</i>	3	625.61	489.33	480-498	sp>fa	B>E
Ophichthidae						
<i>Ophichthus gomesii</i>	1	84.27	441	441	su	C
Paralichthyidae						
<i>Citharichthys spilopterus</i>	2955	55281.16	120.41	40-198	wi>fa>sp>su	E>C>B>D>F>A
<i>Etropus crossotus</i>	340	8583.99	94.32	55-132	fa>wi>sp>su	D>C>F>B>E>A
<i>Paralichthys brasiliensis</i>	1	0	482	482	wi	
Pristigasteridae						
<i>Pellona harroweri</i>	191	2814.9	101.86	57-175	fa>sp>su>wi	B>C>A>F>D>E
Rhinobatidae						
<i>Zapteryx brevirostris</i>	2	1073.4	412	360-464	fa=sp	A=C
Sciaenidae						
<i>Ctenosciaena gracilicirrhus</i>	273	4153.93	100.97	62-138	fa>su>sp>wi	E>C>A>F>D>B
<i>Cynoscion jamaicensis</i>	42	520.23	99.52	60-180	fa>su>wi	C>A>B>E>D>F
<i>Cynoscion leiarchus</i>	5	117.24	131.2	113-147	su>fa	D>E
<i>Cynoscion microlepidotus</i>	115	997.06	87.89	41-199	su>fa	E>C>B>D>A>F
<i>Isopisthus parvipinnis</i>	16	551.33	136.88	66-190	fa>su>sp>wi	A>C>B=F
<i>Macrodon ancylodon</i>	1	0.68	55	55		A
<i>Menticirrhus americanus</i>	56	5358.68	186.07	88-408	su>sp=fa=wi	F>C>B>D>E>A
<i>Micropogonias furnieri</i>	448	10278.52	118.53	55-223	su>sp>fa>wi	B>C>D>E>F>A
<i>Odontoscion dentex</i>	2	26.1	98.5	78-119	su	B
<i>Paralonchurus brasiliensis</i>	106	1322.85	111.89	45-194	sp>su>wi>fa	A>B>C=D
<i>Stellifer brasiliensis</i>	5	27.21	84.8	70-97	su=sp>fa	A>B
<i>Stellifer rastrifer</i>	747	9858.69	99.08	33-178	fa>su>sp>wi	C>B>F>A>E>D
<i>Umbrina coroides</i>	3	3.09	46.33	45-47	wi	A
Serranidae						
<i>Diplectrum radiale</i>	31	2458.53	176.84	139-213	wi>fa>sp=su	E>F>C=D>A
Sparidae						
<i>Archosargus rhomboidalis</i>	21	2696.67	192.52	131-245	su>sp=wi>fa	E>C>F
Stromateidae						
<i>Pepilus paru</i>	41	1336.7	98.1	24-220	fa>sp>su>wi	B>A>E>D>C=F
Synodontidae						
<i>Synodus foetens</i>	21	1864.93	231.81	114-309	fa>sp>wi>su	E>C>F>D
Tetraodontidae						
<i>Lagocephalus laevigatus</i>	34	457.26	83.5	47-148	sp>su>wi	B>D>A=C=F>E
<i>Sphoeroides sp.</i>	2	26.45	84	80-88	sp	F
<i>Sphoeroides greeleyi</i>	6	94.83	90.67	56-106	sp	D
<i>Sphoeroides spengleri</i>	34	210.88	64	28-113	sp>fa>su	C>E>F>A=D>B
<i>Sphoeroides testudineus</i>	29	2704	137.38	28-242	sp>fa>su>wi	C>D>E>F>B>A
<i>Sphoeroides tyleri</i>	45	262.58	59.04	31-93	wi>fa>sp	D>B=E>C>A=F
Trichiuridae						
<i>Trichiurus lepturus</i>	93	8526.24	388.4	67-1180	su>sp>fa>wi	C>A>F>B>E>D
Triglidae						
<i>Prionotus punctatus</i>	252	5481.44	109,71	35-187	su>fa>sp>wi	E>B>F>C=D>A
TOTAL	9888	254075.78				

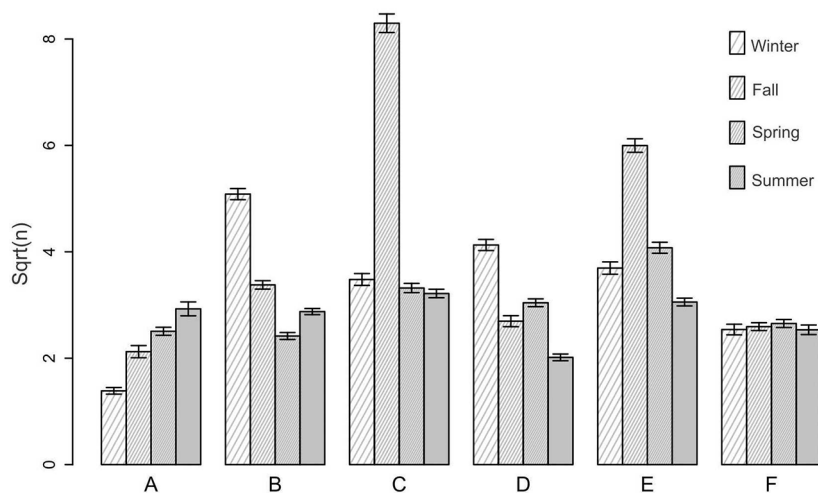
Table 3. PERMANOVA based on Bray-Curtis similarity for total abundance (transformed into square root) of fish caught in the North Bay. Factors: season = Ses, sector = Sec and area = Are (Sec). df = degrees of freedom; MS = sum of mean squares.

Source	df	MS	Pseudo-F	p(perm)
Sea	3	8501.4	3.5741	0.0001
Sec	1	10110	1.8125	0.303
Are(Sec)	4	5578.2	3.9197	0.0001
Sea x Sec	3	2914.2	1.2252	0.2164
Sea x Are(Sec)	12	2378.6	1.6714	0.0001
Res	72	1423.1		

Table 4. Pairwise PERMANOVA comparing areas in each season based on Curtis similarity for total abundance (transformed into square root) of fish caught in the North Bay.

Area	Winter P(perm)	Spring	Fall	Summer
A, B	0.0283*	0.0305*	0.8261	0.0832
A, C	0.0315*	0.0277*	0.082	0.1478
A, D	0.0275*	0.0296*	0.0252*	0.4508
A, E	0.0302*	0.03*	0.0599	0.082
A, F	0.0284*	0.029*	0.1188	0.1661
B, C	0.0306*	0.027*	0.0853	0.0286*
B, D	0.0285*	0.0292*	0.0286*	0.0831
B, E	0.0267*	0.0274*	0.0257*	0.1142
B, F	0.0288*	0.028*	0.0269*	0.374
C, D	0.0287*	0.0847	0.1143	0.3432
C, E	0.0597	0.0307*	0.0596	0.1967
C, F	0.0266*	0.0293*	0.2641	0.0876
D, E	0.1685	0.0871	0.14	0.457
D, F	0.0305*	0.2917	0.0573	0.3632
E, F	0.0615	0.2063	0.2596	0.7462

$p < 0.05^*$.

**Figure 3.** Mean values (standard error on the bars) of the square root of the abundance of fish caught in winter, fall, spring and summer in areas A, B, C, D, E, F of the North Bay.

were responsible for such differences (Figure 4). In relation to the areas, the CAP plot demonstrated a clear separation of samples taken in areas A, B and C and a grouping of areas D, E and F (Figure 5). The high abundance of *E. melanopterus* and *A. lineatus* in these three areas (D, E and F) and of *L. laevigatus* in area B were responsible for the pattern observed (Figure 5). The canonical correlation of the two axes given by the analysis was $\delta_1 = 0.8282$ and $\delta_2 = 0.6727$.

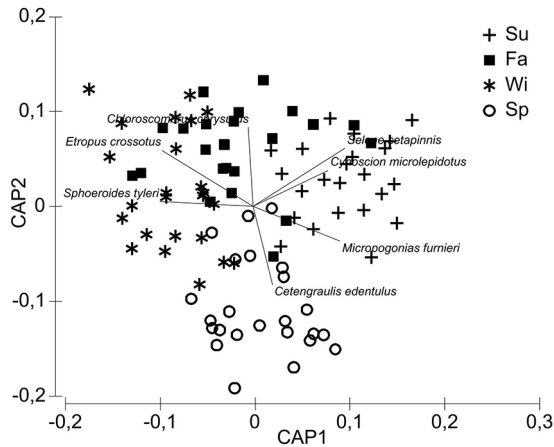


Figure 4. Results of the canonical analysis of principal coordinates (CAP) for the species of the North Bay that contributed to the differences between seasons (Summer = Su; Fall = Fa; Winter = Wi; Spring = Sp). Vector of species based on Spearman correlation values > 0.5.

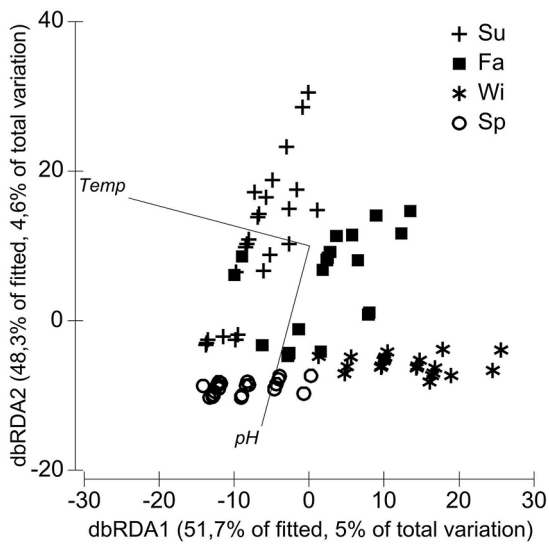


Figure 5. Result of the canonical analysis of principal coordinates (CAP) for the species of the North Bay that contributed to the differences between areas. Vector of species based on Spearman correlation values > 0.5 ($p > 0.5$).

The linear model selected by DISTLM included the temperature and pH as determinants for the variation of numerical abundance. Despite the significance of all the predictor variables in the model, the higher percentages of explanation were observed for the selected variables (Table 6). The graphical response of DISTLM provided by dbRDA pointed to a relationship of temperature with summer and fall samples (axis 1), and of pH with spring samples (axis 2; Figure 6).

Table 5. Result of the DISTLM analysis with p -value of the permutation and the percentage of explanation of variables for the selected model.

Variable	P (Perm)	Proportion
Rainfall	0.0074	2.49E-02
Temperature	0.0002	4.92E-02
pH	0.0001	4.63E-02
Salinity	0.0299	2.21E-02

Table 6. Result of univariate PERANOVA for richness, taxonomic distinctness (AvTD) and variation in taxonomic distinctness (VarTD) for the North Bay, with season as factor.

Source	df	MS	Pseudo-F	p (perm)
Richness	Season	3	106.4	0.73123
	Res	92	145.29	0.5686
AvTD	Season	3	0.64927	0.79938
	Res	92	0.81222	0.7209
VarTD	Season	3	3.8144	0.5753
	Res	92	6.6302	0.6506

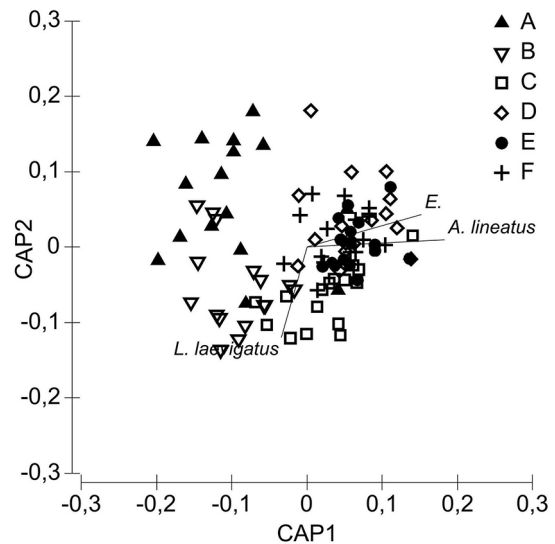


Figure 6. Result of the redundancy analysis based on the linear model (dbRDA) with the predictor variables showing the greatest importance for the linear model. Summer = Su; Fall = Fa; Winter = Wi; Spring = Sp.

Regarding the indices of average taxonomic distinctness (Delta+) and variation in taxonomic distinction (Lambda+), associated with species richness, the PERANOVA indicated no significant differences for any of the variables and a similar taxonomic structure among seasons (Table 6). This is confirmed by the graphic result of the indices Lambda+ and Delta+, whose values were within the 95% confidence interval, calculated in 1000 simulations for each index (Figures 7a and 7b). Nevertheless, for Delta+, we observed that the fall, winter and summer samples were below the values expected (Figure 7a). For Lambda+, winter and summer samples were below the average (Figure 7b). The biplot graph of both indices showed that the Delta+ and Lambda+ of the spring were high (Figure 7c). For this last index, the value is greater than in summer and winter and lower than in fall. The location of the spring samples within the ellipse of 95% probability of occurrence of 60 species ($S = 60$) is a reflection of the high variation in taxonomic distinctness, despite having the highest average taxonomic distinctness, when compared with the other months. On the other hand, winter samples had a lower average taxonomic distinctness, i.e., a lower diversity in taxonomic structure; the variability is lower due to the low variance in the taxonomic distinction.

DISCUSSION

In North Bay, seasonality was pronounced, given the significant differences in salinity, temperature, pH, and rainfall during the sampling year. Regarding rainfall index, an uncommon pattern was observed in 2005, with high levels of rainfall in winter. Despite this, the seasonal pattern expected for the area was maintained, since it is a temperate region with clear distinction between the warm seasons (spring and summer) and cold seasons (fall and winter). Spatially, the environmental parameters showed no significant variation. When evaluating their influence on fish abundance, by means of DistLM, it was observed that all parameters especially temperature and pH significantly influenced the abundance. Temperature is directly related to seasonality and has a direct effect on the metabolic and reproductive processes of fish fauna. In its turn, pH variation is more conditioned by the inflow of freshwater, mainly from mangrove areas, which are rich in humic and fulvic acids, responsible for the acidification of water (DAY; YAÑES-ARANCIBA, 1982; SIMONASSI et al., 2010). This pattern is consistent with the result of dbRDA,

whose positive correlation of pH has been associated with springtime, a period with the lowest indices of rainfall for the year sampled and hence a lower inflow of freshwater into the system.

With respect to the structure of assemblages, the dominance of a few species of demersal fish has also been registered in other studies on the southeastern and southern coasts of Brazil (ROSSI-WONGTSCHOWSKI; PAES, 1993; ARAÚJO et al., 2002; HOSTIM-SILVA et al., 2002; SCHWARZ JR. et al., 2006; AZEVEDO et al., 2007; QUEIROZ et al., 2007; BARLETTA et al., 2008; PINHEIRO et al., 2009; CARTAGENA et al., 2011). The dominance of a few species seems to be an ecological pattern of demersal assemblages or an effect of the selectivity of the fishing gear. The common predominance of the families Ariidae and Sciaenidae was not observed in North Bay. Despite the high occurrence of these families, there were higher abundances of Paralichthyidae and Sciaenidae.

Seasonal differences in the abundance of the demersal fish fauna of the southeastern and southern regions are often observed (ROSSI-WONGTSCHOWSKI; PAES, 1993; HOSTIM-SILVA et al., 2002; ARAÚJO et al., 2002; AZEVEDO et al., 2007; QUEIROZ et al., 2007; BARLETTA et al., 2008; PINHEIRO et al., 2009; CARTAGENA et al., 2011), except for the fish fauna of the Pinheiros Bay, located in the Paranaguá estuarine complex (CEP) (SCHWARZ JR. et al., 2006). However, the lack of statistical seasonal differences in fish abundance in the Pinheiros Bay does not seem to be a pattern for CEP, in view of significant temporal differences on the main axis (east-west) of CEP (BARLETTA et al., 2008). Differences between the spatial scales adopted in these studies seem to have influenced seasonal patterns. In North Bay, high abundances were registered in the fall period and are probably a pattern for fish of the Southeastern and Southern coasts. The reproductive patterns, according to which the main species of the families Sciaenidae and Clupeidae spawn during the spring and summer, while recruiting in shallow areas, but which are still not part of demersal assemblages, might also explain such differences. In autumn and winter, recruited fish have reached maturity and occupy deeper areas of estuaries (PINHEIRO et al., 2009), increasing the probability of capture by trawl.

In the study area, fish species with relative abundance greater than 1%, in descending order of importance, were *G. genidens*, *C. spilopterus*, *C. chrysurus*, *M. furnieri* and *P. punctatus*; the first three had relative

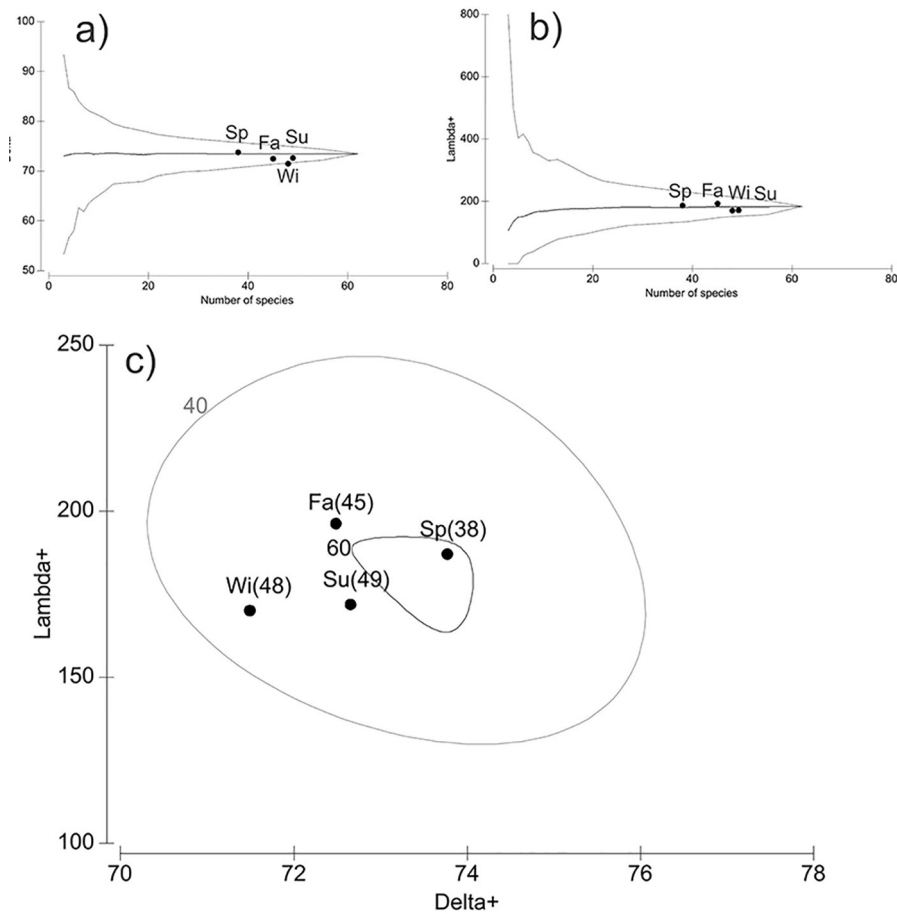


Figure 7. Average taxonomic distinctness (AvTD - DELTA+) and variation in taxonomic distinction (VarTD - LAMBDA+) (b) calculated for the North Bay per season (Summer = Su; Fall = Fa; Winter = Wi; Spring=Sp). For both indices, the expected average represented by the central dotted line and the 95% confidence interval limit is given by the surrounding funnel-shaped solid line. Biplot graphic display of LAMBDA+ and DELTA+ (c). The ellipse represents the value of the 95% confidence interval of the probability of finding 40 and 60 species, respectively.

abundance of approximately 40%. On the southeastern and southern coasts of Brazil, *G. genidens*, *C. chrysurus* and *P. punctatus* are abundant (over 1%) in demersal assemblages (AZEVEDO et al., 2007; QUEIROZ et al., 2007; BARLETTA et al., 2008). However, we registered high abundances of *C. spilopterus* in North Bay (the most abundant species in this area) and a low occurrence of *S. rastrifer*, which is not consistent with these fish surveys. Although *C. spilopterus* is not commonly recorded in the demersal fish fauna of the southeastern and southern coasts of Brazil, it is a shallow-water species, living especially in estuarine areas (FIGUEREDO; MENEZES, 2000; FROSE; PAULY, 2014).

The highest abundance of *C. spilopterus* was found in fall and winter in North Bay. In Guaratuba Bay, this

was observed in the spring and summer, with spawning occurring in mangrove areas, in late spring and early summer (CHAVES; VENDEL, 1997). The high catch of *C. spilopterus* may be associated with the presence of the mangroves of Itacorubi and Ratoes on the bay's shores. This is confirmed by the highest occurrences of this species in areas C and E, which are close to these mangroves.

The high abundance of *G. genidens* is expected in the demersal assemblages of the southern and southeastern coasts of Brazil (HOSTIM-SILVA et al., 2002; QUEIROZ et al., 2007; BARLETTA et al., 2008; CARTAGENA et al., 2011). In a comparison of the fish fauna of five estuaries along the Brazilian coast, there was a predominance of this species on the southern and southeastern coasts (VILAR et al., 2013). In North Bay, high abundances

were registered in all four seasons, mainly in summer and spring. Higher abundances of *G. genidens* occurred in the headwaters of the east-west axis of the Paranaguá Estuarine Complex, in fall and winter (BARLETTA et al., 2008). The numerous presence of *G. genidens* in shallow estuarine areas was also verified in Sepetiba Bay (AZEVEDO et al., 1999; 2007). It is a predominantly estuarine species, inhabiting areas near rivers and displaying the ability to withstand high variations in salinity (FIGUEREDO; MENEZES, 1978; FROESE; PAULY, 2014). The highest abundances occurred in areas B, C and E, associated with the rivers Biguaçu (area B), Ratonés (C, E) and Itacorubi (E). As for the sizes, higher values of total length (TL) were observed in fall and winter, which might coincide with the species' reproductive activity.

C. chrysurus is another species with high abundances in North Bay. It is a pelagic species occurring in estuaries and bays (MENEZES; FIGUEREDO, 1980; FROESE; PAULY, 2014). High abundances were also reported in the Paranaguá Estuarine Complex (BARLETTA et al., 2008) and in inner regions of Sepetiba Bay in spring and summer (ARAÚJO et al., 2002; AZEVEDO et al., 2007). The greatest abundance occurred in the winter in area B. Although differences in abundance between seasons are distinct from those given by other studies, depths were shallow in both areas. The high incidence of pelagic species in shallow areas of Pinheiros Bay (SCHWARZ JR. et al., 2006) has already been observed. Thus, the high prevalence of this species may be related to the shallow depth of the sampled sites.

It may thus be concluded that seasonality has a structuring effect on the fish assemblage in North Bay. However, it remained unclear which is the main regulatory mechanism of assemblages. Although seasonal differences are directly reflected in the physical and chemical parameters of the water column, which, in turn, influence the patterns of distribution and occurrence of demersal assemblages (BLABER; BLABER, 1980; MARSHALL; ELLIOT, 1998; BLABER, 2000; WHITFIELD et al., 2012), in North Bay, environmental gradients were not well-delimited, as is usually observed in estuarine areas. Possibly the ecological processes of reproduction, spawning and recruitment have greater influence on the patterns of dominance, given the high abundance of smaller sized individuals of a few species. The results presented here highlight the importance of North Bay as a nursery of fish of commercial importance and others that may potentially feed the fish stocks of the network of marine protected areas of the state of Santa Catarina.

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