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RESEARCH ARTICLE

Diversity and space-time dynamics of fish assemblages in a coastal lagoon, western Atlantic

Diversidade e Dinâmica Espaço-Temporal das Assembleias de Peixes em uma Lagoa Costeira, Atlântico Ocidental

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Abstract

The knowledge of the temporal and spatial dynamics in the composition of fish fauna makes it possible to identify patterns of occupation of ecosystems, providing a basis for evaluation and preservation of the local biodiversity. Monthly samplings were carried out at seven sites in a coastal lagoon, using

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a casting net, dip net and beach seine. A total of 4,110 individuals were collected, distributed in 23 families and 49 taxa of fish, with a predominance of *Mugil liza*, *M. curema*, *Atherinella brasiliensis*, *Micropogonias furnieri* and *Eucinostomus argenteus*, corresponding to more than 80% total weight of all individuals caught. Regarding seasonality, greater abundances were recorded in fall, influenced by the high abundance of *A. brasiliensis* in this period. In addition to fall, this species was also abundant in summer. However, this pattern of dominance was different for the families Mugilidae and Gerreidae, with higher abundances in spring and summer, respectively. The highest abundances were found in the southern section of the lagoon, which are related to the high abundance of *A. brasiliensis*, *M. liza* and *M. curema*. In relation to the indices of average taxonomic distinctness and variation in the taxonomic distinctness, no significant differences were detected between the seasons of the year. Thus, the patterns of distribution and occurrence of fish in the lagoon were consistent with the patterns observed in Brazilian coastal lagoons and estuaries, as well as to the coastal shallow areas of the southeastern and southern regions.

Resumo

O conhecimento da dinâmica temporal e espacial na composição da ictiofauna permite identificar padrões de ocupação dos ecossistemas, base de avaliação e preservação da biodiversidade local. Amostragens mensais foram realizadas em sete locais da lagoa costeira, utilizando tarrafas, puças e arrasto de praia. Um total de 4110 indivíduos foi coletado, distribuído em 23 famílias e 49 táxons de peixes, com predomínio de *Mugil liza*, *M. curema*, *Atherinella brasiliensis*, *Micropogonias furnieri* e *Eucinostomus argenteus*, correspondendo a mais de 80% do peso total de todos os indivíduos capturados. Em relação à sazonalidade, maiores abundâncias foram registradas no outono, influenciadas pela alta abundância de *A. brasiliensis* neste período. Além do outono, esta espécie também foi abundante no verão. No entanto, este padrão de dominância foi diferente para as famílias Mugilidae e Gerreidae, com maiores abundâncias na primavera e no verão, respectivamente. As maiores abundâncias foram encontradas no trecho sul da lagoa, relacionadas à alta abundância de *A. brasiliensis*, *M. liza* e *M. curema*. Em relação aos índices de diferenciação taxonômica média e variação na distinção taxonômica, não foram detectadas diferenças significativas entre as estações do ano. Assim, os padrões de distribuição e ocorrência de peixes na lagoa foram consistentes com os padrões observados nas lagoas e estuários costeiros brasileiros, bem como nas áreas costeiras rasas das regiões sudeste e sul.

Keywords

coastal area, fish fauna, south Brazil, taxonomic structure

Palavras-chave

área costeira, estrutura taxonômica, fauna de peixes, sul do Brasil

Introduction

According to Yáñez-Arancibia and Nugent (1977), fish are considered regulators of the ecosystem. The ecological role of fish in the energy chain is of paramount importance, especially for fish from coastal lagoons, as they participate in different trophic levels, exchanging or storing energy with neighboring ecosystems, or storing energy through juvenile fish. In South America, about 12.2% of the coastline is in the form of lagoons (Cromwell 1971). Coastal lagoons present physical and chemical gradients influenced by marine and continental environments (Kjervfe

1994; Suzuki et al. 1998). These ecosystems, like estuaries, are highly productive and dynamic environments of fundamental importance in the ecological processes of the coastal biota, especially for fish (Day Jr. and Yáñez-Arancibia 1982). They are also commercially important environments and home to some species of fish such as mojarra (*Eugerres* spp), fat snook (*Centropomus parallelus*) (Aguierre-León et al. 2014) and mullet (*Mugil* spp.) (Embarek et al. 2017).

Among studies on the fish fauna of coastal lagoons, the following stand out: Mariani (2001), Verdiell-Cubedo et al. (2006), Pérez-Ruzafa et al. (2006) and Embarek et al. (2017) in the Mediterranean Sea; Pombo et al. (2005) on the Portuguese coast; as well as Onuf and Quammen (1983) and Amezcua and Amezcua-Linares (2014) in the Gulf of California. In the Western Atlantic, the following stand out: Andreata et al. (1989), Barbien et al. (1991) and Aguiaro and Caramaschi (1995), tropical region; and Borgo et al. (2015) in the Conceição Lagoon (subtropical region). These studies address spatial and temporal distributions of abundance, biomass, richness, diversity, and the relationships of these aspects to environmental variables.

The Conceição Lagoon, located in the subtropical western Atlantic, is the target of intense environmental impacts because it is a hub for leisure activities, culture, tourism and recreation (Sierra de Ledo et al. 1985). In the 1980s, this lagoon was already considered eutrophic (Odebrecht and Caruso Jr 1987) and in the 1990s, the number of inhabitants in its surroundings tripled (IBGE 2000), increasing nutrient and organic matter intake in this ecosystem. In general, the highest concentrations of nutrients were recorded after rainy periods, near river mouths and in the vicinity of domestic effluent discharge points (Souza Sierra et al. 1999; Dias et al. 2014), also interfering directly in the decrease of the salinity of these environments.

Another impact to this Lagoon was the opening of a channel that connects the lagoon to the sea in 1982 (Lisboa et al. 2008), which caused an even greater homogenization in its physical and chemical parameters (Silva et al. 2017). These impacts vary seasonally and spatially, also influencing the distribution of fish fauna (Pazete de Oliveira and Tejerina-Garro 2010). According to Barbosa (2003), in a survey of the fishery data made between 1964 and 1998 in Conceição Lagoon, the catch in the fishery had a linear decrease, decreasing from 326 tons to 5 tons of fish and crustaceans in the course of these years. In the same period, the Conceição Lagoon suffered major changes in water quality due to the eutrophication process (Fonseca 2004), which may lead to impacts such as anoxia, hypoxia, toxic algal blooms, fish mortalities and reduction of the biodiversity of these systems (Silva et al. 2017).

Variations in the number of species, biomass and species richness between the seasons and areas of the Conceição Lagoon were studied by Borgo et al. (2015) and reinforce their ecological importance as a nursery and feeding grounds, since most of their species are in the recruitment phase. In addition to the composition and structure of the fish fauna, the present study evaluates the occurrence of seasonal and spatial variations in the taxonomic structure of the Conceição Lagoon. Studies involving taxonomic diversity contribute to basic knowledge, since they help to understand the strategies developed by the organisms in adaptation to the environmental conditions and in the understanding of the distribution patterns of the species (Pouilly et al. 2006), mainly in environments such as Conceição Lagoon, the target of intense environmental impacts.

Material and methods

Study area

Located in the center-east region of Santa Catarina Island, in southern Brazil, at 27°34'S, 48°34'W latitude, with a total length of 13.5 km (north-south axis), the Conceição Lagoon (Fig. 1) has 19.2 km^2 area, width between 2.5 and 0.15 km and depth ranging from 0.5 m in the sand banks to 8.8 m in the channels (Muehe and Gomes Jr 1999; Lisboa et al. 2008). The Conceição Lagoon maintains a connection with the sea through the Barra Channel, which since 1982 has been permanently open, directly influencing the salinity of the water (Lisboa et al. 2008).

Sampling

Daytime monthly samplings were carried out in 1988 at seven sampling sites (Fig. 1), data that could allow a current evaluation of the local fish fauna. The Conceição Lagoon was divided into three sectors (Knoppers et al. 1984; Odebrecht and Caruso Jr 1987) based on physical and chemical characteristics. Sites 1, 2 and 3 correspond to the northern sector, with greater influence of the river and water supply from precipitation, being the place with lower salinity, corresponding to the average of 11 ups. Site 5, with mean salinity of 18.5 ups, and site 7, with salinity close to 35 ups, form the central area. In the south sector, there were sites 4 and 6 with mean salinity of 6.7 ups. At each sampling site and month, fish were sampled with 10 throws of a 12.0-meter perimeter cast net with 10.0 and 30.0 mm mesh sizes; 10 sifted off a dip net with 30.0 cm in diameter and 5.0 mm mesh; and 3 deployments of a beach seine with 1.0-meter-high, 9.0 meters long, 7.0 mm mesh size in the central portion and 10.0 mm on the sides. The specimens were packed in identified bags, according to the site and date of collection, and transported to the laboratory in iceboxes. In the laboratory, fish were identified up to the species level whenever possible. Then, fish were quantified, measured for total length (mm) and weighed (g). All specimens were deposited in the fish collection of the Núcleo de Estudos do Mar-NEMAR, Universidade Federal de Santa Catarina, Florianópolis, Brazil.

Data analysis

In the evaluation of spatio-temporal differences in fish abundance, the permutational multivariate analysis of variance (PERMANOVA) was applied considering together the three fishing gears, with the seasons of the year (summer, fall, spring and winter) and the sectors (north, south and central) as fixed and orthogonal factors (Anderson et al. 2008).

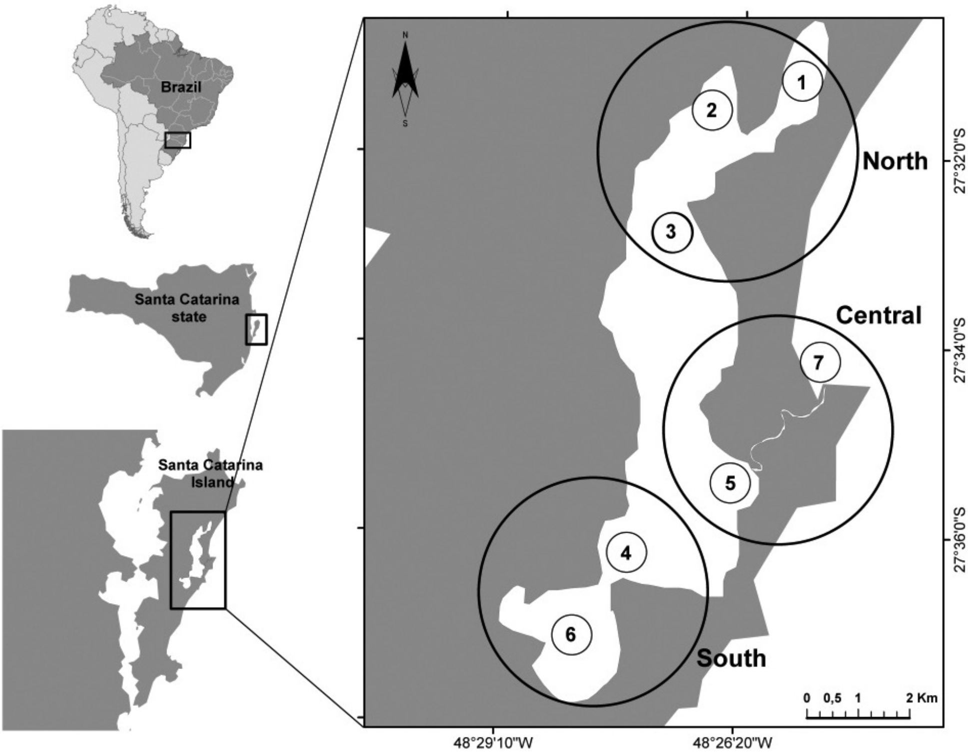

Figure 1. Location of the seven sampling sites in the Conceição Lagoon, Santa Catarina Island, southern Brazil.

In the case of rejection of the null hypothesis by PERMANOVA, a pairwise PERMANOVA was applied, which is a test similar to a post-hoc analysis, to perform a posteriori comparison between factors that had significant differences (p-value <0.05). In order to visualize the differences detected by PERMANOVA, we performed the canonical analysis of principal coordinates (CAP), which generates graphical groupings through permutation (Anderson et al. 2008). In these groupings, Spearman correlations at 0.4 were used to determine which species (vectors) were responsible for each junction.

In addition to the analysis of the whole assemblage, the size structure (total length-TL) of the most abundant species was also tested for spatio-temporal differences. In this case, PERANOVA was used. Unlike PERMANOVA, which analyzes the significance of factors through a multivariate matrix (abundances of all species), PERANOVA is a univariate analysis. In all analyzes, 9999 permutations were made.

In order to evaluate the taxonomic differences between the seasons at each site and to verify which seasons had the highest taxonomic complexity, we calculated the Average Taxonomic Distinctness (Delta+ or AvTD) and Variation in the Taxonomic Distinctness (Lambda+ or VarTD) with the presence/absence matrices (Clarke and Warwick 1994). To visualize graphically if the values of Average Taxonomic Distinctness and Variation in the Taxonomic Distinctness of the seasons of the year are within the taxonomic patterns expected for each location, AvTD and VarTD funnel graphs were elaborated. The taxonomic differences between the seasons of the year were tested by one-way PERANOVA, in which dependent variables were the species richness, and the values of AvTD and VarTD and the fixed factor was the seasons of the year.

Results

A total of 4,110 specimens were caught, distributed in 23 families and 49 species (Table 1). The families with the highest number of taxa were Gerreidae (S=6), Carangidae and Sciaenidae (S=5, each), Clupeidae and Gobiidae (S=4, each), Mugilidae (S=3), Atherinopsidae, Engraulidae, Haemulidae, Hemiramphidae, Paralichthyidae and Sparidae (S=2, each) (Table 1). The other families had only one taxon.

The five families most abundant in their number of individuals were Mugilidae (2,040 individuals), Atherinopsidae (772), Gerreidae (696), Sciaenidae (111) and Carangidae (103) (Table 1). In weight, the largest catches (five most abundant families) were Mugilidae (21.2 kg), Gerreidae (2.8 kg), Atherinopsidae (1.7 kg), Sciaenidae (1.5 kg) and Belonidae (0.5 kg) (Table 1).

In decreasing order, the taxa *Atherinella brasiliensis* (N=770), *Mugil* spp. (N=748), *Mugil liza* (N=712), *Mugil curema* (N=580), *Eucinostomus lefroyi* (N=226), *Eucinostomus argenteus* (N=208), *Eucinostomus gula* (N=111) and *Poecilia* sp. (N=92) were more abundant, accounting for more than 80% of the total catch, and *A. brasiliensis* and *Mugil* spp. corresponded to approximately 35% of the total. Six species, namely *Bregmaceros atlanticus*, *Dactylopterus volitans*, *Ophichthus gomesii*, *Paralichthys* sp., *Stellifer rastrifer* and *Stephanolepis hispidus*, were caught only once (Table 1).

The total catch in weight was 30 kg (Table 1). The species *M. liza* and *M. curema* accounted for approximately 70% of the total catch in weight, and in addition to *A. brasiliensis*, *Micropogonias furnieri* and *E. argenteus* corresponded to more than 80% of the total weight.

In relation to the occurrence of the species in the seasons, 13 species were caught in all seasons of the year and twelve species in only one of the seasons. There was greater richness in summer and fall (36 species each), followed by winter (26) and spring (23) (Table 1). In relation to the sectors (North, Center and South), 15 species occurred in the three sectors and 21 species occurred exclusively in only one sector. The largest number of species occurred in the central sector (42), followed by the southern (29) and northern (21) sectors (Table 1).

In the comparison between the means of total length of the most abundant fish species, PERANOVA detected significant differences for the interaction between season and sector for *A. brasiliensis* and *M. liza* and for season of the year for the three most abundant taxa (*A. brasiliensis*, *Mugil* spp. and *M. liza*) (Table 2). In relation to *A. brasiliensis*, pairwise PERANOVA detected significant differences between the central and south sectors ($t = 3.8561$, p-pera = 0.0001) and between south

Table 1. List of taxa, number of individuals (N), weight (W), mean, minimum and maximum total length (TL), season (fall = F, spring = S, summer = Su and winter = W) and sector (central = C, north = N and south = S) (greater abundance on the left) of fish caught in the Conceição Lagoon, Santa Catarina Island, southern Brazil.

Family / Species	N	W (g)	Mean TL (mm)	Min-Max TL (mm)	Season	Sector
Achiridae						
Achirus lineatus (Linnaeus, 1758)	3	22.9	71	68–74	W>SU	S
Ariidae						
Genidens genidens (Cuvier, 1829)	23	136.25	68.96	51–207	F>W	N>C=S
Atherinopsidae						
Atherinella brasiliensis (Quoy & Gaimard, 1825)	770	1661.61	57.14	15–130	F>SU>S>W	S>N>C
Odontesthes argentinensis (Valenciennes, 1835)	2	34002E77	134.5	132–137	W=S	C
Belonidae						
Strongylura marina (Walbaum, 1792)	12	463.46	255.5	68–460	SU=F>S	N>S>C
Bregmacerotidae						
Bregmaceros atlanticus Goode & Bean, 1886	1	0.72	48	48–48	S	C
Carangidae						
Caranx hippos (Linnaeus, 1766)	2	3.94	50.5	50–51	F	C
Caranx latus Agassiz, 1831	10	81.95	74.5	57–129	SU>F	C
Oligoplites saurus (Bloch & Schneider, 1801)	6	42.28	98.33	35–135	W>F	N
Trachinotus falcatus (Linnaeus, 1758)	14	17.31	38.36	21–44	F>SU	C>N=S
Trachinotus marginatus Cuvier, 1832	71	88.01	40.51	28–81	F	C
Cichlidae						
Geophagus brasiliensis (Quoy & Gaimard, 1824)	3	50.58	94	79–106	SU>W	S>N
Clupeidae						
Brevoortia pectinata (Jenyns, 1842)	3	14.59	82	73–93	F	S>C
Harengula clupeola (Cuvier, 1829)	7	47.13	85.43	75–101	W>SU	S
Opisthonema oglinum (Lesueur, 1818)	4	51.81	104	86–150	F>SU	N>C
Sardinella brasiliensis (Steindachner, 1879)	18	78.72	75	38–104	F	C>S
Dactylopteridae						
Dactylopterus volitans (Linnaeus, 1758)	1	8.48	107	107–107	SU	C
Engraulidae						
Anchoa tricolor (Spix & Agassiz, 1829)	15	39.05	73.27	53–104	F>SU=S	C>N
Cetengraulis edentulus (Cuvier, 1829)	34	153.17	83.74	71–103	F>W>SU	S>C>N
Gerreidae						
Diapterus rhombeus (Cuvier, 1829)	8	4.27	38	31–43	F	C
Eucinostomus argenteus Baird & Girard, 1855	208	1029.11	71.01	33–130	SU>F>S>W	S>C>N
Eucinostomus gula (Quoy & Gaimard, 1824)	111	837.49	79.93	42–137	F>SU>W=S	S>N=C
Eucinostomus lefroyi (Goode, 1874)	226	154.27	37.77	17–92	W>F=S>SU	C>S>N
Eucinostomus melanopterus (Bleeker, 1863)	78	597.17	77.04	48–223	SU>F>W>S	S>C>N
Eugerres brasilianus (Cuvier, 1830)	65	176.75	59.8	40–120	F>W>S>SU	S>N>C
Gobiidae						
Bathygobius soporator (Valenciennes, 1837)	27	254.18	84.78	37–115	SU>F>S>W	C>S
Ctenogobius boleosoma (Jordan & Gilbert, 1882)	24	59.91	54.54	22–112	SU>F>S>W	C
Ctenogobius shufeldti (Jordan & Eigenmann, 1887)	14	18.24	53.79	22–64	S>W=SU	C
Ctenogobius stigmaticus (Poey, 1860)	5	6.03	58	55–63	S>SU	C
Haemulidae						
Haemulon steindachneri (Jordan & Gilbert, 1882)	13	274.51	100	48–195	SU>F	N>S
Orthopristis ruber (Cuvier, 1830)	29	50.12	45.93	30–96	SU>F>W	C
Hemiramphidae						
Hemiramphus brasiliensis (Linnaeus, 1758)	2	63.59	197	181–213	F	C
Hyporhamphus unifasciatus (Ranzani, 1841)	4	74.03	141	77–272	F>SU	S>C

Family / Species	N	W (g)	Mean TL (mm)	Min-Max TL (mm)	Season	Sector
Monacanthidae						
Stephanolepis hispidus (Linnaeus, 1766)	1	5.26	103	103–103	SU	C
Mugilidae						
Mugil curema Valenciennes, 1836	580	7512.72	62.65	24–298	F>S>W>SU	S>C>N
Mugil liza Valenciennes, 1836	712	13513.45	50.32	28–402	S>W>SU>F	S>C>N
Mugil spp.	748	212.34	27.33	22–81	W>S>F>SU	C>S>N
Ophichthidae						
Ophichthus gomesii (Castelnau, 1855)	1	86.31	453	453–453	SU	C
Paralichthyidae						
Citharichthys spilopterus Günther, 1862	7	135.76	114.86	72–147	S>F>SU	C>S
Paralichthys sp.	1	7.43	89	89–89	SU	
Poeciliidae						
Poecilia sp.	92	114.86	41.19	12–73	SU>F>S>W	C>S>N
Pomatomidae						
Pomatomus saltatrix (Linnaeus, 1766)	22	206.46	98.32	68–152	F>SU=W=S	C>S
Sciaenidae						
Menticirrhus littoralis (Holbrook, 1847)	72	165.53	74.67	29–188	F>SU>W	C
Micropogonias furnieri (Desmarest, 1823)	33	1278.99	96.26	51–144	SU>W>F	S>C
Stellifer rastrifer (Jordan, 1889)	1	7.85	92	92–92	S	S
Umbrina coroides Cuvier, 1830	4	13.2	63	55–70	F>S	C
Sparidae						
Archosargus rhomboidalis (Linnaeus, 1758)	9	80.37	78.89	66–103	F>W>S	N>C>S
Diplodus argenteus (Valenciennes, 1830)	11	28.59	50.91	33–76	SU	C
Synodontidae						
Synodus foetens (Linnaeus, 1766)	3	69.1	140	110–198	SU>F	S>N
TOTAL	**4110**	**30034.61**				

Table 2. Peranova based on the Bray-Curtis similarity of the total length (square root transformed) of *A. brasiliensis*, *Mugil* spp. and *M. liza* caught in the Conceição Lagoon, Santa Catarina Island, southern Brazil. Factors: season = S and sector = Se. Test parameters: d.f. = degrees of freedom; MS = sum of mean squares.

Atherinella brasiliensis				
Source of Variation	**d.f**	**MS**	**Pseudo-F**	**p(pera)**
S	3	1669.8	15.894	**0.0001**
Se	2	21.147	0.20129	0.8445
SxSe	3	586.42	5.5819	**0.0001**
Res	670	105.06		
***Mugil* spp.**				
Source of Variation	**d.f**	**MS**	**Pseudo-F**	**p(pera)**
S	3	91.601	22.71	**0.0006**
Se	2	2.7338	0.67779	0.3725
SxSe	6	4.277	1.0604	0.318
Res	735	4.0335		
Mugil liza				
Source of Variation	**d.f**	**MS**	**Pseudo-F**	**p(pera)**
S	3	921.04	7.5138	**0.0002**
Se	2	635.29	5.1826	0.0157
EsxSe	5	1131.1	9.2272	**0.0001**
Res	700	122.58		

and north (t = 4.2582, p-pera = 0.0001) in the summer. Higher mean values were found in winter in the central (TL = 9.8 mm) and north (TL = 9.7 mm) sectors; in spring in northern (TL = 8.4 mm) sector and in summer in southern (TL = 7.5 mm) sector, and lower mean values occurred in summer in the central (TL = 5.7 mm) and northern (TL = 6.3 mm) sectors (Fig. 2).

For *Mugil* spp., whose significant differences occurred only between seasons (Table 2), according to PERANOVA pairwise results, fall was significantly different from summer (t = 1.9062, p-pera = 0.0009), winter (t = 6.2243, p-pera = 0.0001) and spring (t = 8.2312, p-pear = 0.0001). Higher mean TL were observed in winter (TL = 5.25 mm) and spring (TL = 5.2 mm) in the central sector and in spring and winter in the southern sector with averages of total length of 5.18 mm, and lower values were verified in fall, in southern (TL = 4.9 mm), central (TL = 5.0 mm) and northern (TL = 5.05 mm) sectors and in summer in the central (TL = 5.15 mm) sector (Fig. 2).

For *M. liza*, pairwise PERANOVA detected significant differences between the southern and central sectors in the summer (t = 3.9543, p-pera = 0.0001), winter (t = 8.6419, p-pera = 0, 0001) and in the spring (t = 5.2852; p-pera = 0.0001) (Table 2). There were also significant differences between the central and northern sectors in winter (t = 2.6783, p-pera = 0.0008) and south and north in spring (t = 3.5397, p-pear = 0.0001). Higher mean values were observed in fall (TL = 11 mm), summer (TL = 8.05 mm), and spring (TL = 7.2 mm) in the southern sector and in the fall in the central sector (TL = 7.8 mm), and lower mean values occurred in the spring in the central sector (TL = 5.3 mm); in winter in the northern

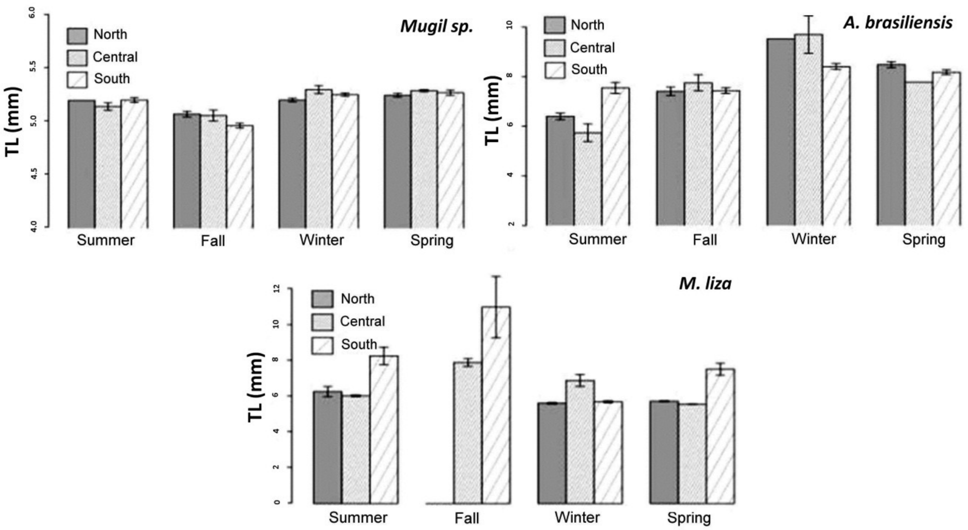

Figure 2. Mean values (standard error in vertical bars) of total length (TL) of *Mugil* spp., *Atherinella brasiliensis* and *M. liza* in the seasons of the year and sectors of the Conceição Lagoon, Santa Catarina Island, southern Brazil.

and southern sectors with averages of total length of 5.4 mm, and in fall, in the northern sector (Fig. 2).

In the comparison of the means of abundance between the seasons and sectors, PERMANOVA detected significant differences for both isolated factors (Table 3). In the paired comparisons (pairwise PERMANOVA), for the seasons, only winter and spring were not significantly different (Table 4) and for the sectors, only between the north and the south no statistical differences were found (Table 4). Higher mean values of abundance occurred in the fall in the central and southern sectors; in the spring, central sector and in winter, southern sector and lower values were observed in winter and fall in the northern sector; in winter, in the central sector and in summer, in the northern sector (Fig. 3).

In relation to the species responsible for the graphic groupings elaborated by the canonical analysis of principal coordinates (CAP), it can be observed that, for the season of the year, there was a clear separation of the fall samples in relation to the other samples associated to the first axis, with the species *A. rhomboidalis*, *M. curema* and *E. gula* correlated positively with these samples, and *A. brasiliensis* and *E. argenteus* were correlated with the summer samples (Fig. 4A). There was also an overlap of winter and spring samples correlated with *Mugil* spp. and *Mugil liza* (Fig. 4A).

With respect to sectors, the canonical analysis of principal coordinates (CAP) clearly showed a separation between the three sectors, with the species *O. ruber*,

Table 3. Permanova based on the Bray-Curtis similarity of abundance (square root transformed) of fish caught in the lagoon. Factors: season = S and sector = Se. Test parameters: d.f.= degrees of freedom; MS = sum of mean squares.

Source of Variation	d.f	MS	Pseudo-F	p(perm)
S	3	6072.7	2.7508	**0.0001**
Se	2	4884.2	2.2124	**0.0008**
SxSe	6	1718.2	0.7783	0.9073
Res	32	2207.6		

Table 4. Pairwise Permanova based on the Bray-Curtis similarity of abundance (square root transformed) comparing the seasons of the year and sectors for fish caught in the Conceição Lagoon, Santa Catarina Island. Bold values are significant (p-value<0.05).

Groups	t	p(perm)
Summer x Fall	1.7224	**0.0019**
Summer x Winter	1.99	**0.0006**
Summer x Spring	1.5724	**0.0094**
Fall x Winter	1.734	**0.0035**
Fall x Spring	1.7355	**0.0015**
Winter x Spring	1.0403	0.3865
North x South	1.2334	0.1346
North x Central	1.5603	**0.0067**
South x Central	1.5803	**0.0055**

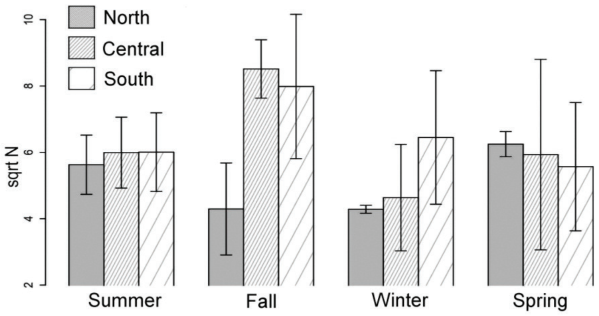

Figure 3. Mean values (standard error in vertical bars) of abundance (N) of fish caught in the seasons of the year and sectors of the Conceição Lagoon, Santa Catarina Island, southern Brazil.

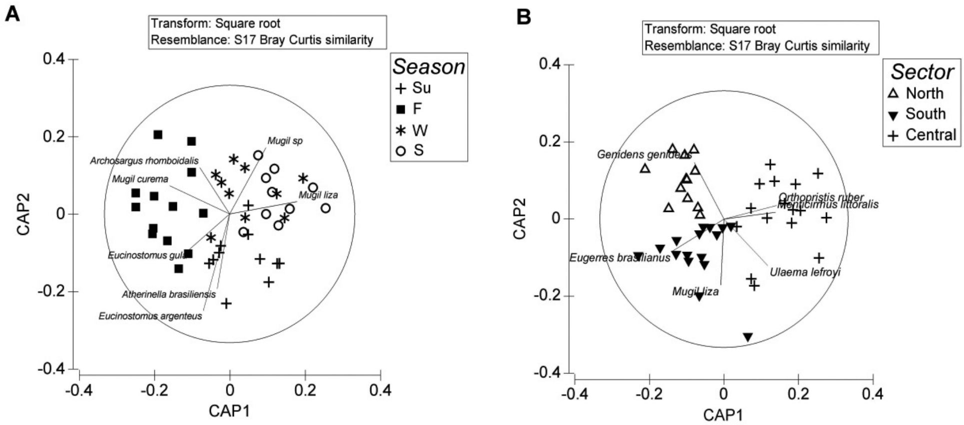

Figure 4. Results of the canonical analysis of principal coordinates (CAP) of fish caught in the Conceição Lagoon, Santa Catarina Island, southern Brazil: (A) with the taxa that contributed to the differences between the seasons of the year ; (B) with the taxa that contributed to the differences between the sectors (North, South and Central). Vectors of the species based on the Spearman correlation above 0.4 ($p > 0.4$). The canonical correlations of the two axes obtained by the analysis were $\delta_1 = 0.8623$ and $\delta_2 = 0.6642$ (A) and $\delta_1 = 0.8782$ and $\delta_2 = 0.6999$ (B). F: fall; S: spring; Su: summer; W: winter.

M. littoralis and *E. lefroyi* correlated with the samples from the central sector, the species *E. brasilianus* and *M. liza* correlated with the samples from the southern sector and *G. genidens* correlated with the samples from the northern sector (Fig. 4B).

Regarding the indices of average taxonomic distinctness (Delta+) and variation in the taxonomic distinctness (Lambda+), associated with species richness, PERANOVA did not detect significant differences for any of the variables, between the seasons (Table 5). As for the Delta+ index, the values for each season of the year were within the confidence interval, with the summer in the average and the other seasons below the average (Fig. 5A). However, for Lambda+, the value for spring was out of the confidence interval, and winter and fall values were within the confidence interval (Fig. 5B). Only the summer showed value within the average. In

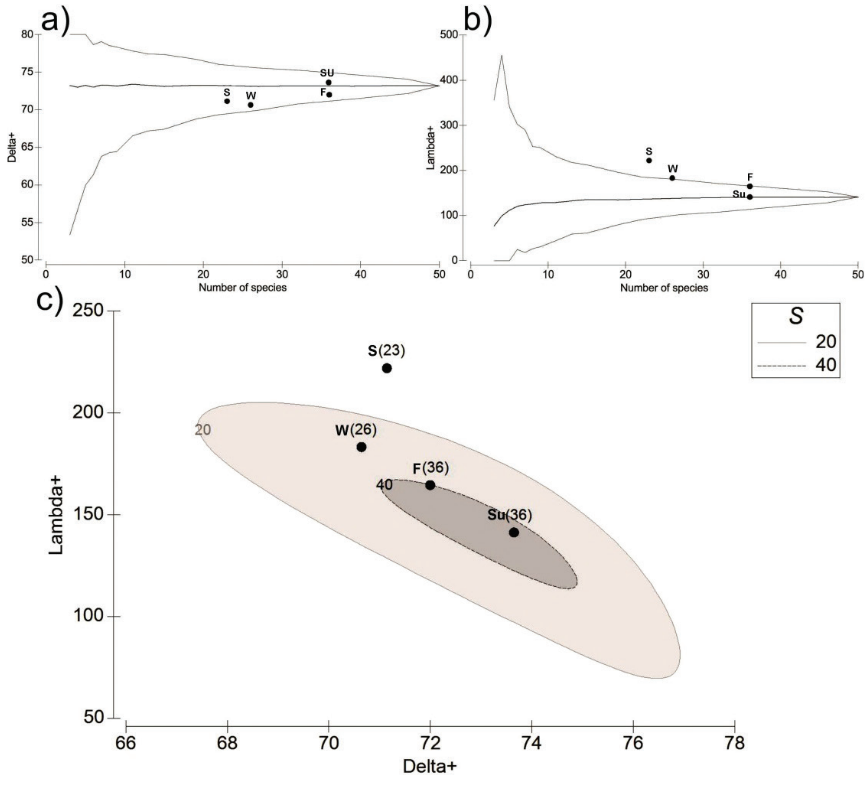

Figure 5. Average taxonomic distinctness (AvTD – Delta⁺) (A), variation in the taxonomic distinctness (VarTD – Lambda⁺) (B) and Lambda⁺ and Delta⁺ biplots (C) calculated per season of the year for the Conceição Lagoon, Santa Catarina Island, southern Brazil. A-B: the expected mean is represented by the center dashed line and the 95% confidence interval limit is given by the solid, funnel-shaped line; C: the ellipse represents the value of the 95% confidence interval of 20 and 40 species, respectively. F: fall; S: spring; Su: summer; W: winter.

Table 5. Result of PERANOVA for richness, average taxonomic distinctness (AvTD) and variation in taxonomic distinctness (VarTD) for the lagoon, with the season of the year as the factor.

Source of Variation		d.f	MS	Pseudo-F	p(perm)
Riches	Season	3	292.99	1.7732	0.1449
	Res	40	165.23		
AvTD	Season	3	0.08681	0.85882	0.4882
	Res	39	0.10116		
VarTD	Season	3	29.713	1.7217	0.185
	Res	36	17.257		

descending order, higher Lambda+ values were verified in spring, winter, fall and summer (Fig. 5B). In the biplot, the fall and summer values were observed within the ellipse of 95% probability of occurrence of 40 species; the winter value was within the ellipse of 95% probability of occurrence of 20 species and the value of spring was out of both ellipses (Fig. 5C).

Discussion

The predominance of the families Atherinopsidae, Mugilidae and Gerreidae is a common pattern to the lagoons and coastal lagoons located in the South and Southeast regions of Brazil (Chao et al. 1982; Andreata et al. 1990; Monteiro-Neto et al. 1990; Barbien et al. 1991; Sierra de Ledo et al. 1993; Ramos and Vieira 2001; Hollanda-Carvalho et al. 2003; Loebmann and Vieira 2005; Lisboa et al. 2008; Spach et al. 2010; Moura et al. 2012). In the Conceição Lagoon, the high abundance of mugilids is also highlighted (Sierra de Ledo et al. 1993; Ribeiro et al. 1999; Borgo et al. 2015). This pattern of dominance can be influenced by the contribution of freshwater to the lagoon system, even though it represents a small contribution, it promotes the presence of areas with great availability of food in the lagoon due to the high primary productivity and the greater quantity of organic matter that is carried with this fresh water intake in the system, a direct reflection of the increase of urbanization in the hydrographic basin (Rios 2017). According to Vieira (1991), these characteristics are important to influence the distribution of the juvenile individuals of Mugilidae. In the Laguna region, approximately 120 km to the south of the study area, there was a greater dominance of the families Anablepidae (represented by *Jenynsia lineata*, which predominates in freshwater) and Mugilidae (Monteiro-Neto et al. 1990).

In the Conceição Lagoon, we observed the occurrence of species of *Poecilia*, the eighth most abundant in this study, with predominance in the sector with greater marine influence (point 5, in the central sector). Although predominantly freshwater (Mendonça and Andreata 2001), this species is the most tolerant of intermediate and high salt stress among anablepids (Rosen and Bailley 1963), being considered in this context an euryhaline species. Corroborating with our results, in faunal surveys conducted in coastal lagoons on the north coast of Rio de Janeiro, the species *Poecilia vivipara* was also found in areas considered hypersaline, with salinity up to 36 ups (Hollanda-Carvalho et al. 2003; Correia 2015).

In the case of Conceição Lagoon, the composition of the fish fauna is predominantly estuarine and marine, and it is observed that the freshwater contribution has little influence on the distribution patterns of the assemblages. However, this contribution of freshwater from the rivers, with great attenuation in precipitation events, brings with it a lot of organic matter and contributes directly to the eutrophication of this system, creating recruitment environments for species more resistant and resilient to these physicochemical alterations locations. The high marine influence in the Conceição Lagoon was intensified after 1982, with the artificial stabilization of the Barra Channel, which kept the mouth permanently open, and drastically altered the aquatic biota (Lisboa et al. 2008). Due to channel stabilization, the salinity of the central sector remains above 28 ups, between 24 and 27 ups in the northern sector and close to 24 ups in the southern sector (Odreski 2012).

Similarly to our results, greater abundances of Mugilidae followed by Atherinopsidae were recorded in a coastal lagoon with high marine influence, located near the mouth of the Saí Guaçu river, a border of the states of Paraná and Santa Catarina

(Spach et al. 2010). In the Peixe Lagoon, located in the coastal zone of the state of Rio Grande do Sul, there was a greater abundance of *M. liza*, comprising approximately 76% of the fish caught, and *A. brasiliensis* had an occurrence close to 1% (Loebmann and Vieira 2005). The same pattern is observed in the Patos Lagoon (Chao et al. 1982, Garcia et al. 2001; Ramos and Vieira 2001; Moura et al. 2012). In the coastal lagoons of Rio de Janeiro, mugilids are more abundant (Andreata et al. 1990; Barbien et al. 1991). Therefore, since there are differences in patterns of species diversity and abundance associated with latitudinal variations (Vieira and Musick 1994), these alternating patterns of dominance among the fish of the families Atherinopsidae and Mugilidae may be associated with these latitudinal differences, with Mugilidae predominating to the south and the Atherinopsidae further to the north.

In relation to seasonality, different from Borgo et al. (2015), which carried out a study contemplating three years of sampling in this same area, of which the Mugilidae family was dominant in abundance mainly in the fall season, in this work the overall abundance peaked also in the fall, but influenced by *A. brasiliensis* during this period, an explanation for the occurrence is that this species spends most of its life cycle in marginal areas associated with marshes (Garcia and Vieira 1997; Spach et al. 2004). *Atherinella brasiliensis* is considered a typical estuarine species (Barbien et al. 1991; Pessanha and Araújo 2001). Since its life cycle and niche are associated directly with estuarine and marginal areas, a high catch of this species is expected in all seasons of the year. However, the fall, which constitutes the post-reproductive and recruiting (spring and summer) period, was the period of greatest catchability of the individuals of this species, probably due to the type and mesh sizes of the fishing gear used and their high abundance. In addition to fall, this species was also abundant in the summer, corroborating the results reported by Pessanha and Araújo (2001) in Sepetiba Bay, Rio de Janeiro and by Neves et al. (2006) in the mangrove of Guaratiba, Rio de Janeiro. However, this pattern of dominance was different for fish from the families Mugilidae and Gerreidae, with higher abundances in spring and summer, respectively. Among the mugilids, *M. curema* was more abundant in the fall while *M. liza*, in the spring.

In the state of Rio Grande do Sul, differences were also found for the dominance of mugilids, with higher abundances of *M. curema* in summer and *M. liza*, in winter (Ramos and Vieira 2001). In the same study, the occurrence of *A. brasiliensis* and *Odontesthes argentinensis* was observed throughout the year for the family Atherinopsidae, with higher abundances in summer and winter, respectively. In the Patos Lagoon, Chao et al. (1982) also reported the alternation between dominance peaks of *A. brasiliensis* in summer and *O. argentinensis* in winter. In Rio de Janeiro, significant differences were also detected between the seasons, with higher dominance of *A. brasiliensis* in the hot periods (Andreata et al. 1990; Barbien et al. 1991).

Regarding the differences between the sectors of the Conceição Lagoon, the highest abundances were recorded in the southern sector, which were related to high abundances of *A. brasiliensis*, *M. liza* and *M. curema*. This high catchability recorded may be associated with the types of reproduction of r-strategists and for forming shoals, which is expected for subtropical estuarine regions (Haedrich 1983; Chaves et al. 2000). Fish that occupy lower levels in the trophic chain, such as *A. brasiliensis* (the most abundant species in this study), are the dominant species in numbers of individuals in biological communities (Blaber et al. 1984). *Mugil* spp. were more abundant in the central sector, where there is a strong marine influence and a higher salinity. However, in a study by Sierra de Ledo et al. (1993), with juveniles of Mugilidae from Conceição Lagoon, there was greater abundance of *M. liza* in the central sector, and a homogeneous distribution of *M. curema* in the northern and southern sectors.

Thus, in Conceição Lagoon, we can infer that the pattern of distribution and occurrence of fish may have been caused by the influence of anthropic actions, such as eutrophication, changes in the inflow, fragmentation of the landscape and geomorphological modification (De Jonge and De Jong 2002). However, they were in agreement with the observed patterns for the coastal and estuarine lagoons, as well as for the shallow areas of the southeastern and southern regions of Brazil. With respect to taxonomic diversity, we can observe in the biplot chart that the seasons of spring and winter presented greater taxonomic complexity in relation to the seasons of fall and summer. An explanation for the low complexity in the last two seasons is given by the fact that some genera and families are represented by only one species, whereas in the other two seasons, the higher taxa are relatively rich in species, thus increasing their taxonomic complexity.

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