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ECOLOGY

Temporal variation in composition, abundance and biomass of the fish fauna after impact on subtropical transitional water

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ABSTRACT. Transitional waters are characterized by large variations in salinity, temperature, turbidity, among other factors, such as tidal cycle, wind action and rainfall, that are constantly changing over time. The distribution of biota in these environments is regulated by these natural variations and also by human activities, such as pollution, overexploitation of resources, acceleration of urbanization, suppression of habitats and changes in hydrological dynamics. The objective of this study was to analyze the temporal dynamics of the fish fauna of the Saco dos Limões Cove, state of Santa Catarina, Brazil, after the construction of a highway. Fish community was evaluated over five years by annual and monthly variation in species richness, abundance and biomass. A total of 17,993 individuals were collected, distributed in 33 families, 59 genera and 79 species. The evaluated years were similar to each other in species composition. Community descriptors varied over time but did not show seasonal trends. In all years, abundance was higher than biomass, indicating both the disturbance and the ecosystem function as a nursery in the studied area. This was corroborated by the large number of juveniles of dominant species (*Genidens genidens, Eucinostomus gula* and *Eucinostomus argenteus*).

Keywords: ichthyofauna; diversity; coastal environment; ecotone; anthropic impact.

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Introduction

Coastal environments, such as estuaries, deltas, bays, mangroves and coastal lagoons, are marine-freshwater transitional systems characterized by dynamic environmental factors (McLusky & Elliott, 2004; Elliott et al., 2007; Basset et al., 2013). These ecosystems are highly productive and recognized as nurseries and breeding grounds for species of commercial interest (Pihl, Isaksson, Wennhage, & Moksnes, 1995; McLusky & Elliott, 2004; Sheaves, Baker, Nagelkerken, & Connolly, 2014). In addition to fishing resources, coastal environments deliver several other ecosystem services, such as coast protection, filtering and detoxification services provided by filtering organisms and submerged vegetation, as well as places for tourism (McLusky & Elliott, 2004; Worm et al., 2006; Lee et al., 2006; Elliott & Whitfield, 2011; Barbier et al., 2011). Despite this, these environments are under increasing human threat, due to pollution, overexploitation of resources, acceleration of urbanization, suppression of habitats and changes in hydrological dynamics and in the distribution of organisms in space and time (Lee et al., 2006; Lotze et al., 2006; Worm et al., 2006; Hughes, Williams, Duarte, Heck, & Waycott, 2009; Bevilacqua, Plicanti, Sandulli, & Terlizzi, 2012; Basset et al., 2013).

The distribution of biota in these ecosystems is determined by the dynamics of environmental conditions, which vary in short time scales (such as tidal cycle and wind action) or long scales (such as the rainfall of a season), which affects the distribution and composition of the fish fauna. Relationships of fish assemblages with environmental conditions in coastal ecosystems have been investigated in several studies (Whitfield & Elliott, 2002; McLusky & Elliott, 2004; Barletta & Blaber, 2007; Carvalho, Cardoso, & Gomes, 2012; Potter, Tweedley, Elliott, & Whitfield, 2015). Human actions on estuarine habitats can have a direct influence on the distribution, food resources, diversity, reproduction, abundance, growth, survival and behavior of both resident and migratory fish species. The direct and indirect relationship between fish communities and human impacts in estuaries reinforce the choice of this taxonomic group as a biological indicator that can help formulate environmental and ecological quality objectives (Whitfield & Elliott, 2002; Asha, Cleetus, Suson, & Nandan, 2015).

When studying the characteristics that shape the occupation of ecosystems, it is essential to consider the temporal scale in community description. Studies on fish fauna in coastal environments in Brazil usually address spatial and temporal variations in relation to environmental heterogeneity (Andrade-Tubino, Ribeiro, & Viana, 2008). Dredging and landfilling in Saco dos Limões caused changes in the hydrodynamics of the cove, which underwent important physical changes, such as decreasing its area and increasing the average depth, leading to a greater circulation of the adjacent marine water (Veado & Resgalla, 2005). Such anthropic impacts have altered environmental characteristics, which play a key role in structuring fish assemblages. We hypothesized that after the construction of the highway the fish community of the Saco dos Limões Cove experiences negative changes in its structure and composition along the years. We predict that (i) fish abundance decreases; (ii) fish richness decreases and (iii) fish biomass decreases.

Material and methods

Study area

The study area (Figure 1) is a shallow cove (2-8 m) called Saco dos Limões, located between Santa Catarina Island and the mainland, on the east bank of the South Bay. This environment is characterized by low hydrodynamic energy, sandy-muddy bottom and high biological productivity, due to the continental input of the Tavares River (Souza-Conceição, & Schwingel, 2011). In the period from August 1996 to February 1997, the bank of the cove was grounded for the construction of a highway (Veado & Resgalla, 2005). For landfilling, sediment was dredged from the cove. As part of the environmental licensing of the work, an environmental monitoring of the area was carried out at six sampling sites (Figure 1) (Veado & Resgalla, 2005), generating the data used for this study.

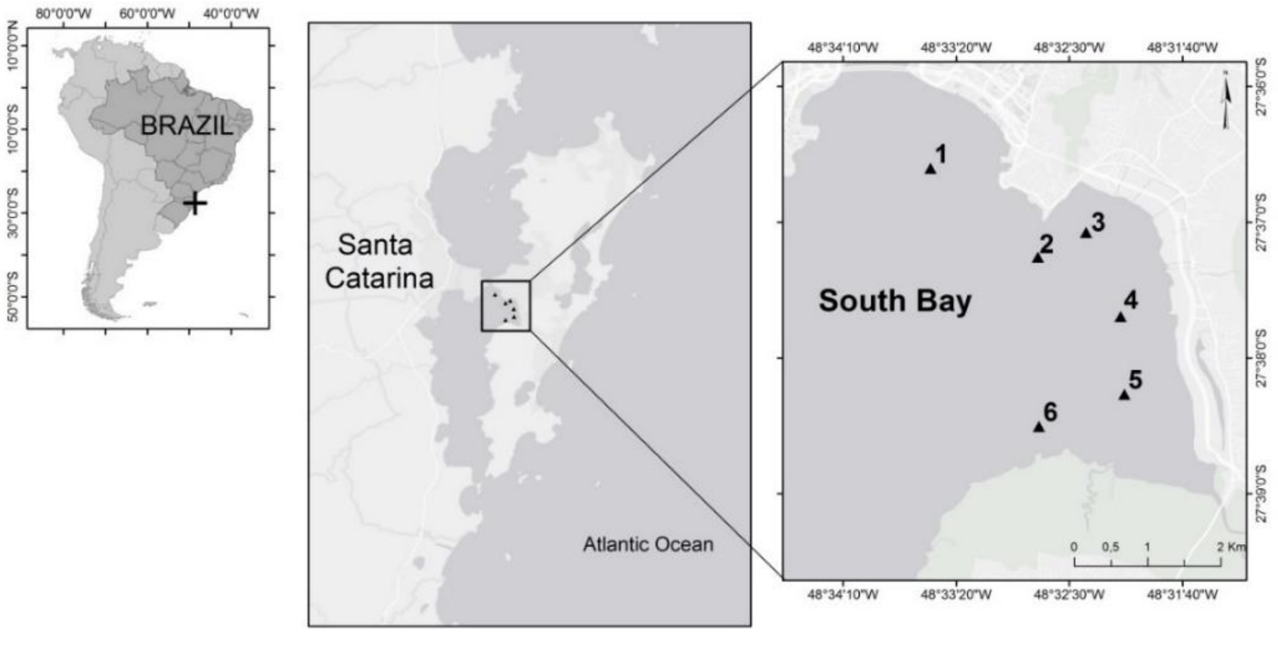

Figure 1. Location of sampling sites (1 to 6) in Saco dos Limões Cove – South Bay (Santa Catarina, Brazil).

Data collection

Fish sampling was carried out in February, April, June, August, October and December of 1997, 2000, 2001, 2002, 2003, at six sampling sites (1 to 6) (Figure 1). Fish were collected using two identical otter trawls with a length of 4.5 m, 7.5 m headline and 9 m footrope, mesh size of 14 mm in the top and bottom panel, and 12 mm in the cod-end, with fishing effort standardized to 10 minutes, operating simultaneously. The material of the two nets was considered a single sample. Specimens caught were identified based on the taxonomic keys of Figueiredo and Menezes (1978, 1980), Fischer (1978) and Menezes and Figueiredo (1980, 1985) and measured in its total length (in millimeters) and weighed (in grams). Taxonomic classification and nomenclature of fish species was confirmed by comparison with information from Marceniuk, Caires, Siccha-Ramirez and Oliveira (2016), Marceniuk (2018) and Eschmeyer (2021).

Data analysis

To assess the sampling sufficiency of the fish community, cumulative species curves were constructed for each sampled year. The observed richness curves were compared to modeled curves, calculated based on the first order Jackknife index (Magurran, 1988).

To check for differences in the fish community structure over the five years of sampling, a complex linear model was defined, which consists of a linear equation, $y = ax + b$, in which y is the dependent or response variable (species richness, abundance and biomass), and x, independent variables (year and month). The model is complex because it includes fixed factors (year) and random factors (month).

To check for differences in abundance, richness and biomass over the sampled months and years, a Permutational multivariate analysis of variance (Permanova) (Anderson, Gorley, & Clarke, 2008) was applied through permutations. Permanova was run with multivariate data for each dependent variable, transformed into $log\ (x + 1)$. Analyses were run based on the similarity matrix calculated by the Bray-Curtis index. In addition to the evaluation of the level of significance (p-value <0.05) for each factor analyzed, the proportion of components of variance estimates was also used to determine which factor was the most important for any significant differences detected.

When significant differences in factors were found, a pairwise Permanova was applied, which is an analysis similar to an *a posteriori* test. Due to the nested linear model, when significant differences were detected for the month, the comparisons compared months of the same year, with no comparisons of months from different years (Anderson et al., 2008).

To visualize the differences found in Permanova with quantitative data of abundance and biomass, a Principal Coordinates Analysis (PCO) was used. This analysis arranges spatially the samples in a biplot by means of permutation (Anderson et al., 2008). In PCO analysis, Spearman correlations ($\rho > 0.45$) were used to determine which species (vectors) were responsible for the clusters in relation to the factors analyzed.

The same analysis routine was performed with data on abundance (number of individuals) and size (total length) of the three most abundant species in the environment throughout the sampling period. Variations in abundance distribution, richness and biomass data per month and year of the collected fish fauna were evaluated using boxplot graphs.

To estimate possible disturbances in the community, k-dominance curves with abundance data were designed to compare the patterns of relative species abundances (Clarke & Warwick, 1994). Unlike multivariate methods, k-dominance curves can extract universal characteristics from the community structure and represent levels of biological stress (Clarke, Warwick, 1994). Abundance and biomass were used to quantify environmental stress according to the ABC method (Abundance-Biomass Curves) and the W stress index (biomass/abundance ratio), whose values vary between -1 and 1, where values approaching -1 indicate great impact, close to 1 indicate little impact, and close to 0, moderate impact (Clarke & Warwick, 1994). In theory, in disturbed communities, opportunistic species predominate, with a short life cycle and reduced body size, while, without disturbance, there is a significant occurrence of conservative species, with a long-life cycle and large body size (Clarke & Warwick, 1994).

All statistical analyses were run in the PRIMER 6 software (Clarke & Gorley, 2006), with Permanova package, and the graphics were prepared in R software (R Core Team, 2018), using the ggplot package (Wickham, 2016).

Results

Fish assemblage composition

In the Saco dos Limões Cove, 17,993 specimens of 78 species of fish were caught, distributed in 33 families and 59 genera. Most species were present in more than a year, with 22 species caught in only one year. Higher species richness was found in the families Sciaenidae (13 species), Carangidae (7 species), Epinephelidae (6 species) and Tetraodontidae (5 species) (supplementary material).

Genidens genidens, *Eucinostomus gula*, *Eucinostomus argenteus*, *Cetengraulis edentulus* and *Citharichthys spilopterus* (supplementary material) prevailed in number and biomass. In each year, these species were also among those contributing most in number and biomass of catches. *Micropogonias furnieri* (in 2001), *Diapterus* *rhombeus* (2002), *Chloroscombrus chysurus* (2003) and on biomass of *Mugil curema* (1997), *Archosagus rhomboidalis* (2000, 2001, 2002 and 2003), *Micropogonias furnieri* (2000 and 2001), *Diapterus rhombeus* (2002) and *Sphoeroides testudineus* (2003) were also numerically important (Table 1).

Temporal variation of fish assemblages

Among the sampled years, the greatest abundance was recorded in 2001 (n = 6,166), followed by 1997 (n = 3,378), 2000 (n = 3,004), 2003 (n = 2,760) and 2002 (n = 2,685). As for species richness (s), higher absolute values were recorded in 2001, 2002 and 2003 (s = 50 each), followed by 1997 and 2000 (s = 46). Regarding biomass (b), the highest value occurred in 2001 (b = 114.90 kg), followed by 2000 (b=81.94 kg), 2002 (b = 57.61 kg), 2003 (b=55.20 kg) and 1997 (b = 54.16 kg) (supplementary material; Table 1).

Table 1. Descriptive synthesis of total and mean (μ) abundance (a), richness (s) and biomass (b) ± standard deviation (SD) of the fish fauna collected in 1997, 2000, 2001, 2002 and 2003 in February, April, June, August, October and December in Saco dos Limões Cove, state of Santa Catarina, Brazil.

Year	Month	a Total	a (μ ± SD)	s Total	s (μ ± SD)	b (Kg) Total	b (g) (μ ± SD)
1997	Feb	301	50.17 ± 27.37	24	11.67 ± 1.97	5.85	19.43 ± 18.6
	Apr	388	77.6 ± 62.76	28	10.6 ± 3.05	3.23	8.33 ± 11.99
	Jun	1292	215.33 ± 156.95	31	12.83 ± 5.46	25.15	19.48 ± 38.1
	Aug	766	127.67 ± 52.98	23	10.5 ± 3.45	11.75	15.35 ± 25.49
	Oct	437	145.67 ± 67.01	14	10	4.02	9.21 ± 10.19
	Dec	194	32.33 ± 14.83	16	6.5 ± 2.07	4.16	21.43 ± 26.98
2000	Feb	368	61.33 ± 39.33	26	10.5 ± 3.94	9.48	25.77 ± 33.6
	Apr	788	131.33 ± 78.14	31	13.83 ± 6.64	17.47	22.20 ± 85.24
	Jun	680	113.33 ± 80.34	25	11.83 ± 2.64	19.25	28.30 ± 52.53
	Aug	445	74.16 ± 25.37	22	10.5 ± 2.17	16.10	36.17 ± 39.62
	Oct	287	47.83 ± 23.83	24	10.5 ± 1.05	9.48	33.02 ± 56.39
	Dec	436	72.67 ± 35.58	19	8.83 ± 2.79	10.17	23.32 ± 22.44
2001	Feb	1184	197.33 ± 94.86	32	14.83 ± 6.43	16.67	14.09 ± 62.47
	Apr	893	148.83 ± 82.78	33	16.5 ± 3.15	19.61	21.98 ± 40.52
	Jun	1696	282.67 ± 198.44	36	18 ± 3.95	25.63	15.11 ± 19.41
	Aug	1044	174 ± 116.07	33	15.5 ± 3.02	23.37	22.39 ± 61.07
	Oct	713	118.83 ± 71.63	28	13.33 ± 2.73	15.10	21.18 ± 28.31
	Dec	636	106 ± 64.23	26	12.83 ± 0.75	14.52	22.82 ± 27.65
2002	Feb	148	24.67 ± 8.31	21	8.33 ± 2.66	5.30	35.79 ± 44.03
	Apr	514	85.67 ± 60.01	32	12.5 ± 5.54	5.99	11.66 ± 32.5
	Jun	385	64.17 ± 57.06	26	10.5 ± 5.75	7.21	18.72 ± 30.47
	Aug	461	76.83 ± 45.56	29	14.5 ± 1.38	11.44	24.82 ± 33.7
	Oct	942	157 ± 111.48	40	17.33 ± 4.03	21.38	22.70 ± 33.22
	Dec	235	39.17±25.55	22	8.5±2.26	6.29	26.75±29.42
2003	Feb	576	96 ± 37	27	14.17 ± 1.6	7.52	13.05 ± 19.86
	Apr	413	68.83 ± 55.46	22	10.17 ± 3.6	7.51	18.18 ± 32.58
	Jun	377	62.83 ± 48.67	29	11.67 ± 4.89	8.53	22.63 ± 23.59
	Aug	301	50.17 ± 39.2	28	9.67 ± 3.39	4.70	15.65 ± 16.92
	Oct	810	135 ± 79.71	33	14.67 ± 5.47	20.57	25.39 ± 141.24
	Dec	283	47.17 ± 42.82	22	7.17 ± 6.27	6.37	22.52 ± 38.11

In relation to the months within each year, greater abundances were recorded in June 1997, April 2000, June 2001, October 2002, and October 2003 (Table 1). For richness, higher values were found in June 1997, April 2000, June 2001 and in October 2002 and 2003 (supplementary material). As for biomass, higher total values were found in June 1997, 2000 and 2001 and in October 2002 and 2003 (Table 1).

Regarding temporal patterns in fish fauna, Permanova evidenced significant differences for abundance, richness and biomass between years and months, with a larger variation (component of variance) of month for the three variables (Table 2). Although the results of the Permanova Pairwise analysis indicated significant differences in the factors of abundance, richness and biomass between the months of each year, patterns were not detected. The distribution of abundance, richness and biomass data for each month of collection are illustrated in Figures 2, 3 and 4 respectively.

Table 2. Permanova results for abundance, species richness and biomass between factors year and month. CV=component of variance estimated in the analysis.

Factor	Abundance (a)		Richness (s)		Biomass (b)	
	Pseudo-F	CV	Pseudo-F	CV	Pseudo-F	CV
Year	2.32***	7.67%	2.08***	5.65%	2.27***	7.17%
Month (Year)	2.90***	22.65%	2.39***	18.11%	2.78***	21.69%

*p < 0.05; **p < 0.01; ***p < 0.001

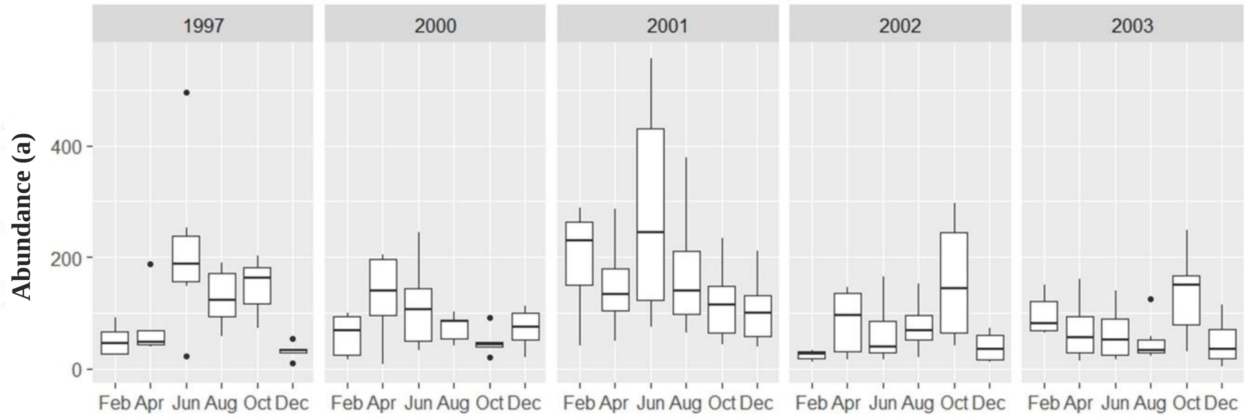

Figure 2. *Boxplot* representing the distribution of mean abundance data (a) of the fish fauna collected at the sampling sites in 1997, 2000, 2001, 2002 and 2003 in the months of February, April, June, August, October and December in the Saco dos Limões Cove, state of Santa Catarina, Brazil. Median is represented by the black horizontal line within the rectangles. Bases of the rectangles indicate the first quartile and the tops indicate the third quartile. Vertical rods below and above the rectangles indicate the minimum and maximum values of the distribution, respectively. Black circles indicate the outliers.

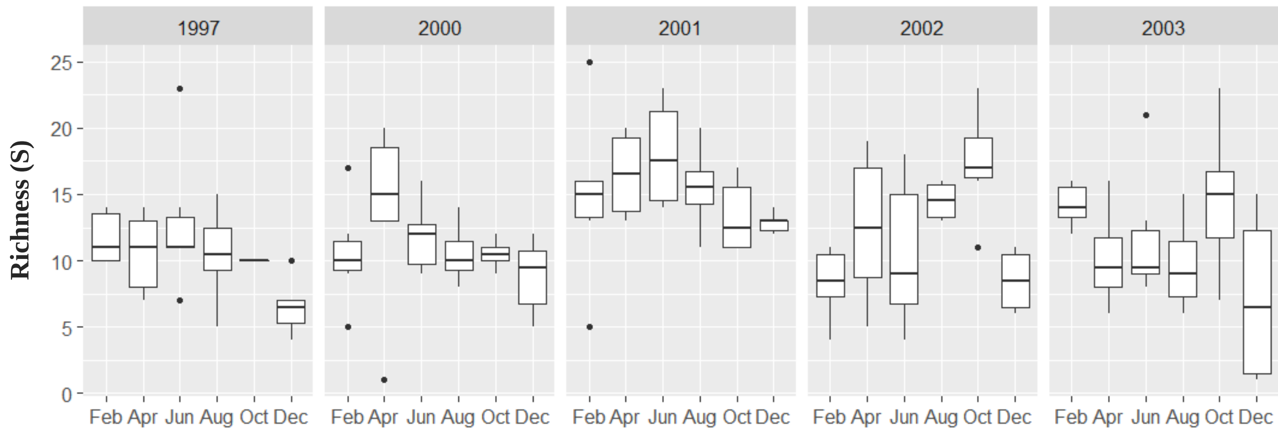

Figure 3. *Boxplot* representing the distribution of the fish fauna richness (s) data collected at the sampling sites in 1997, 2000, 2001, 2002 and 2003 in the months of February, April, June, August, October and December in the Saco dos Limões Cove, state of Santa Catarina, Brazil. Median is represented by the black horizontal line within the rectangles. Bases of the rectangles indicate the first quartile and the tops indicate the third quartile. Vertical rods below and above the rectangles indicate the minimum and maximum values of the distribution, respectively. Black circles indicate the outliers.

Permanova results evidenced significant differences in mean abundance between years and months, but there was no evident separation of the samples, both for the year factor (Figure 5a) and for the month factor (Figure 5b), observed in the canonical analysis of principal coordinates (CAP). However, when comparing the collection years, some samples from 1997 and 2001 differed from the cluster at the center. As for the species correlation, the 1997 samples were correlated with *C. edentulus* (*C.ede*), the 2001 samples with *C. spilopterus* (*C.spi*), *G. genidens* (*G.gen*), *Isopisthus parvipinnis* (*I.par*), *M. furnieri* (*M. fur*) and *Selene vomer* (*S.vom*), the 2002 samples with *Synodus foetens* (*S.foe*) and the 2002 and 2003 samples with *Chaetodipterus faber* (*C.fab*), *Etropus crossotus* (*E.cro*) and *S. testudineus* (*S.tes*). Considering the months as a factor, there was a separation of the samples from the months of December and April in relation to the others, with the species *C. spilopterus* (*C.spi*) and *C. faber* (*C.fab*) correlated with the samples from June, August and October and *Selene setapinnis* (*S.set*) with samples from February and April.

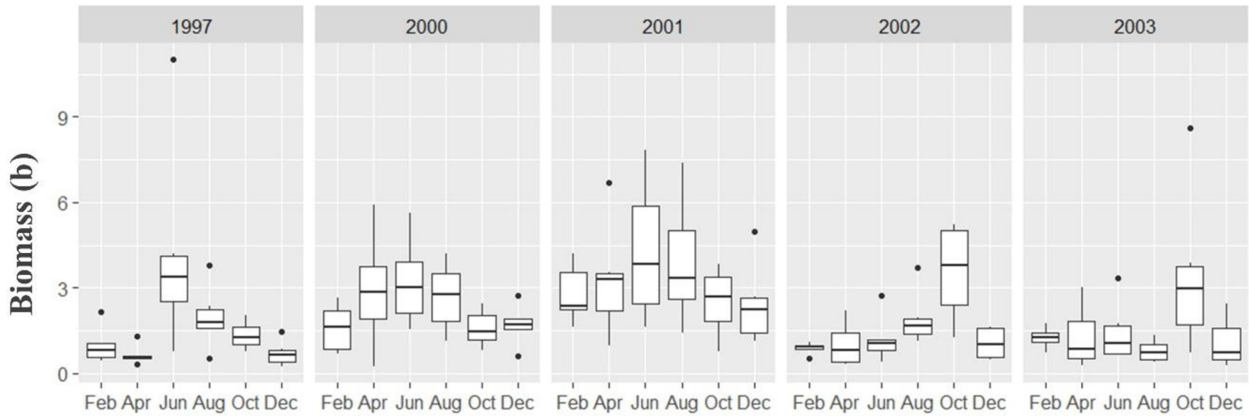

Figure 4. *Boxplot* representing the distribution of the fish fauna biomass (b) data of the fish fauna collected at the sampling sites in 1997, 2000, 2001, 2002 and 2003 in the months of February, April, June, August, October and December in the Saco dos Limões Cove, state of Santa Catarina, Brazil. Median is represented by the black horizontal line within the rectangles. Bases of the rectangles indicate the first quartile and the tops indicate the third quartile. Vertical rods below and above the rectangles indicate the minimum and maximum values of the distribution, respectively. Black circles indicate the outliers.

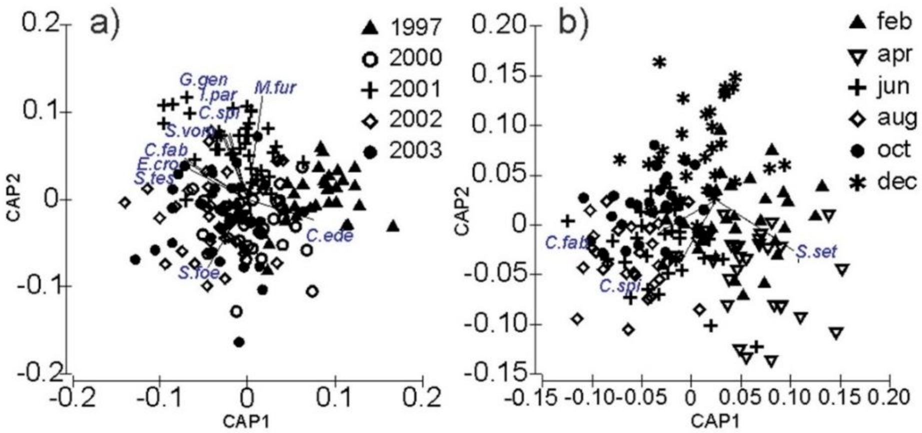

Figure 5. Result of the canonical analysis of principal coordinates (CAP) with the abundance data, with the species that were correlated with the samples, considering the year (a) and month (b). Species vectors based on Spearman correlation above 0.5 ($\rho > 0.45$).

In the evaluation of species dominance using k-dominance curves, greater dominance (lower richness) was observed in 1997 and lower dominance, in 2001 (greater richness) (Figure 6). The years 2000, 2002 and 2003 showed intermediate dominance. The result of ABC curves for total and partial cumulative dominance demonstrates that, in all years, the abundance curve was above the biomass curve and the value of the W statistic was close to zero, which indicates a condition of moderate impact (Figure 7).

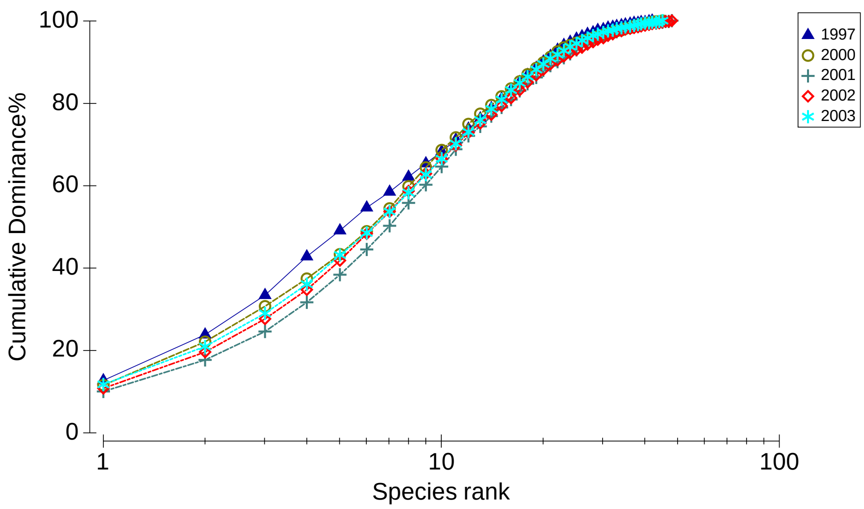

Figure 6. K-dominance curve constructed with abundance data for the five years of collection.

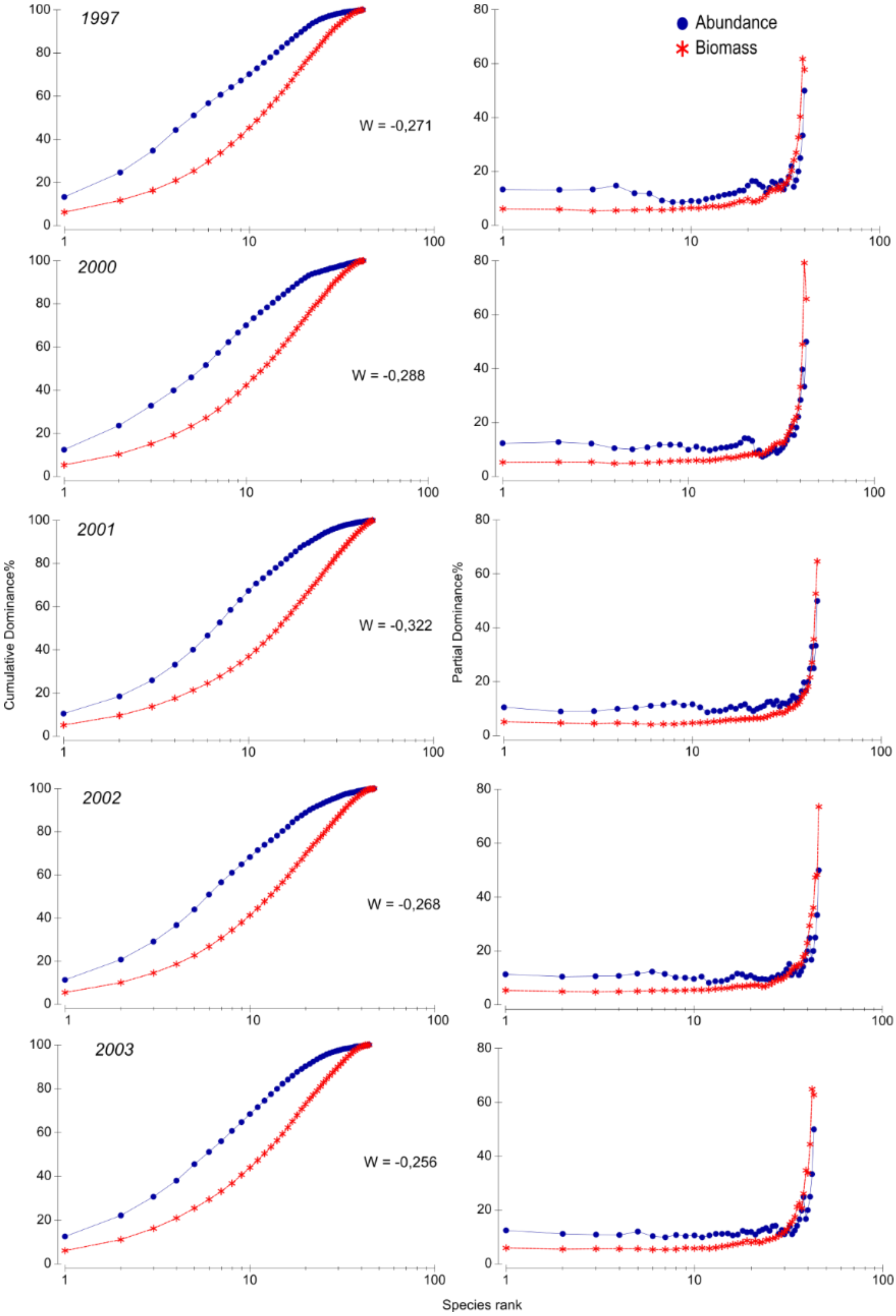

Figure 7. ABC (A) and partial ABC (B) curves for abundance (white circles) and biomass (black squares) and W index values for the fish fauna from the Saco dos Limões Cove, state of Santa Catarina, Brazil. Negative W values suggest environmentally stressed ecosystems (Clarke & Warwick, 1994).

Discussion

Our results demonstrate that the years evaluated are very similar to each other in terms of composition. Although there was no temporal pattern of abundance, richness and biomass, significant differences were detected between years and months. The observed fluctuations can be attributed to the migration of oceanic species to the cove for breeding, feeding and growth, similar to that reported by Falcão et al. (2008) at the

Paranaguá Estuarine Complex, in the state of Paraná. In fact, the oscillating environmental conditions of transition waters represent an environmental filter for the occupation of species. In these environments, few species are able to enter and/or live in such variable conditions (Basset et al., 2013). In this perspective, it is possible that species composition will not change over time. The alternation in dominance between fish populations at different times of the year was observed among environments of bay, mangrove, beach and lagoon of the Santa Catarina Island (Cattani et al., 2016).

The richness of the family Sciaenidae registered in the Saco dos Limões Cove is characteristic in tropical and subtropical transition environments in the Atlantic Ocean (Blaber, 2002). Other studies using bottom trawling in southern Brazil also point to greater richness for the family Sciaenidae (Kotas, 1998; Chaves, Cova-Grando, & Calluf, 2003; Godefroid, Spach, Santos, MacLaren, & Schwarz Junior, 2004; Branco & Verani, 2006). However, the most abundant species in number and biomass in the Saco dos Limões Cove were *Genidens genidens, Eucinostomus gula* and *E. argenteus*, which do not belong to the family Sciaenidae. The discrepancy observed can be ascribed to abiotic characteristics at the sampling site, such as depth, salinity and substrate type, since these are factors that influence the structure of fish communities in coastal environments (Monteiro-Neto, 1990; Schwarz Junior et al., 2018).

Genidens genidens had a predominance in abundance and frequency in the environment, and is one of the most frequent species in coastal environments in southeastern-southern Brazil (Araújo et al., 2002; Spach, Godefroid, Santos, Schwarz Junior, & Queiroz, 2004; Azevedo, Araujo, Paula, & Guedes, 2007; Cattani et al., 2016). This high abundance can be justified by feeding habits of the species that predates upon benthic organisms (Rabitto & Abilhoa, 1999), and thus may give preference to the studied region due to characteristics of the sandy-muddy bottom. In addition, fishing activities on Carib pointed-venus (*Anomalocardia brasiliana*) in the area, using hook (Pezzuto & Silva, 2015) can stir the bottom and make crustaceans and polychaetes available, the main food items of *G. genidens* (Chaves & Vendel, 1996; Rabitto & Abilhoa, 1999).

As for *E. gula*, abundance was constant over time. This species is also abundant in other transition environments of the south and southeastern Brazilian coast, such as in the Guaratuba Bay, state of Paraná (Chaves & Otto, 1999), in the Palmas Bay, in the north coast of São Paulo (Rocha, Fernandez, & Paiva Filho, 2010) and Mambucaba estuary, in Rio de Janeiro (Franco, Neves, Teixeira, & Araújo, 2012). Results similar to those of *E. gula* were obtained for *E. argenteus*. Abundance data did not differ between years or months. *E. argenteus* was also among the most caught species in the studies by Godefroid, Hofstaetter and Spach (1997) and Spach, Santos and Godefroid (2003), with a predominance of catches in summer and fall. The high abundance of *E. argenteus* in the Saco dos Limões Cove can also be associated with characteristics of the substrate and fishing activities on Carib pointed-venus, as the species feeds on benthic animals and detritus (Branco, Aguiaro, Esteves, & Caramaschi, 1997). Physical characteristics of the cove may also justify the occurrence, as individuals of *E. gula* and *E. argenteus* occur in places with low hydrodynamic energy (Godefroid, Santos, Hofstaetter, & Spach, 2001).

As for the temporal assessment of environmental impacts in the region, when comparing the years regarding species dominance using k-dominance curves, greater dominance is observed in 1997. This result represents low species diversity, which may be related to dredging activities that occurred between 1995 and 1997 in the Saco dos Limões Cove. This has already been reported for the Paranaguá Estuary, state of Paraná, when the number of collected fish species decreased during the dredging process to maintain the channel of access to the region ports (Barletta, Cysneiros, & Lima, 2016).

The stress condition of the studied fish fauna is also supported by the curves between biomass and abundance (ABC). In all years, the abundance curve was above the biomass curve, and the value of the W statistics showed a negative value, but close to zero. These results indicate a situation of moderate environmental impact in all years evaluated (Clarke &Warwick, 1994).

Conclusion

The present study found no relevant impact caused by dredging on the fish fauna. Despite the results obtained, determination of richness, abundance and biomass, in addition to registering aspects of the community in an impacted transitional environment, allowed to analyze the temporal behavior of the community after the construction of a highway, which can be a reference for similar work projects, as well as for establishing management and conservation plans in coastal environments.

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