Regional Studies in Marine Science 43 (2021) 101695

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Role of the habitat condition in shaping of epifaunal macroinvertebrate bycatch associated with small-scale shrimp fisheries on the Southern Brazilian Coast

Germano Henrique Costa Barrilli [a,*], Jorge Luiz Rodrigues Filho [b,c], Julia Gomes do Vale [a], Dagoberto Port [d], José Roberto Verani [a,e], Joaquim Olinto Branco [a,d]

[a] Postgraduate Program in Ecology and Natural Resources, Universidade Federal de São Carlos (UFSCar), Highway: Washington Luis, Km 235, Postal Code 676, São Carlos SP, Brazil

[b] Universidade Estado de Santa Catarina (UDESC), Ecology Laboratory, Street: Cel. Fernandes Martins, Progresso, CEP: 88.790-000270, SC, Brazil

[c] Postgraduate Program in Territorial Planning and Socio-Environmental Development (PPGPLAN)/UDESC/FAED), Avenue Madre Benvenuta, 2007, CEP: 88.035-001, Florianópolis, SC, Brazil

[d] Universidade do Vale do Itajaí (Univali) School of the Sea, Science and Technology, Street: Uruguai, 458, CP 360, Itajaí, SC, Brazil

[e] Universidade Federal de São Carlos (UFSCar), Department of Hydrobiology, São Carlos SP, Brazil

A R T I C L E   I N F O

Article history:
Received 17 September 2020
Received in revised form 14 February 2021
Accepted 20 February 2021
Available online 23 February 2021

Keywords:
Trawl
Conservation
Shrimp
Bycatch
Bioindicators
Ecology

A B S T R A C T

Shrimp captures have reached a record in Southern Brazil, and some populations show signs of over-exploitation. One shrimp species in particular, *Xyphopenaeus kroyeri*, abundant in Brazilian landings, is caught by bottom trawl. Trawl fishery is recognized by the impacts it causes on the seabed and on organisms that live in or on the substrate. The present study was conducted in traditional fishing areas on the southern Brazilian coast to assess the conditions of the habitat and the ecological aspects of the marine macroinvertebrate community at 3 areas (Barra do Sul, Penha and Porto Belo) in the Central and Northern Coast of the state of Santa Catarina (southern Brazil). Bottom water and sediment data were used to analyze the differences between the sites. Macroinvertebrate captures were used to analyze ecological aspects of the communities such as composition, diversity and patterns associated with the abiotic variables and habitat conditions. We used a trawling vessel for samplings. The results showed a homogeneous water mass between the areas. However, the sediment characteristic differentiates the areas and contributes to the species composition's heterogeneity between the samples. The ABC and species-ranking curves results suggest moderate disturbances in the three areas, but with a better structure for the Porto Belo communities. In this context, Barra do Sul was characterized by an environment relatively poor in sediment structure, the abundance and biomass of species. In contrast, Porto Belo and Penha were the opposite. Since trawling changes the sediment's characteristics are strongly correlated with the diversity and the permanence of sensitive species, we suggest that increased small-scale trawling activities might contribute to the substrate's homogenization and reduce species diversity in these areas. Therefore, constant surveys to monitor the physical structure and the community and its dynamics in trawling areas are indispensable for the conservation of species and fisheries' sustainability.

1. Introduction

In the last decades, shrimps have gradually become an important item in the international fish trade according to the world's records of production (FAO, 2016). As a result, some stocks show signs of over-exploitation (D'Incao et al., 2002; Ferreira and Medley, 2005; Leite and Petrere, 2006; Arreguin-Sanchez et al., 2008; Rajakumaran and Vaseeharan, 2014), generating a demand for studies and actions that assist in the management of shrimp fisheries around the world.

In Brazil, shrimp fishing mostly exploits the species of the Penaeoidea superfamily. Penaeid shrimps are widely distributed along the continental shelf and are more abundant in shallow areas and near the coast (Gillett, 2008). The fact that it is relatively easy to access and to catch this valuable resource makes it an easy target for both artisanal and industrial fisheries (D'Incao et al., 2002). Among Penaeidae shrimps, the seabob shrimp *Xyphopenaeus kroyeri* (Heller, 1862) is one of the most abundant resources in Brazilian landings. It is commonly caught by artisanal fleets in shallow areas (below 20 m) and fine sediment cover,

* Corresponding author.
E-mail address: germanohcb@msn.com (G.H.C. Barrilli).

https://doi.org/10.1016/j.rsma.2021.101695
2352-4855/

where there are greater aggregations of this species (Costa et al., 2007; Kolling and Ávila-da Silva, 2014).

Small-scale fisheries target the Atlantic seabob shrimp along the Brazilian coastline, particularly in the Southern region (D'Incao et al., 2002), yielding considerable production (Gillett, 2008). More specifically, in the Central and Northern Coast (CNC) of the state of Santa Catarina (southern Brazil), there are several localities that have historically relied on this type of fishing (Pezzuto et al., 2008; Serafini et al., 2014), where shrimp fisheries have important social and economic roles (Branco, 2005).

The oceanographic conditions are characterized by a coastal waterbody rich in nutrients and organic matter (Schettini et al., 2005). Seasonality is well defined, and there is an influence of a platform waterbody, which is derived from the mixture of waters (Coastal, Tropical and Central waters of the South Atlantic) that arrive at the southeastern and southern Brazilian coast (Emilson, 1961; Pereira et al., 2009). There is little information about the substrate of the CNC of Santa Catarina, but since the area maintains dense shrimp populations, it is assumed that the substrate may be composed of fine sand and mud, similar to other places where these crustaceans usually aggregate (Costa et al., 2007; Freire et al., 2011). However, even though oceanographic conditions are shared among fishery sites on this stretch of the coast, there is considerable heterogeneity in the composition of the catches (Branco et al., 2015), indicating that local factors may influence these ecosystems.

In general, artisanal trawlers in the CNC of Santa Catarina are equipped with double trawls (Branco et al., 2015), which are known to impact the seabed and the benthic organisms living inside or on the surface of the substrate (Blanchard et al., 2004). Bottom trawls generate significant physical changes in the substrate (*e.g.* bottom abrasion and sediment resuspension), interfering directly and indirectly with the composition of benthic communities and matter and energy transfer in coastal ecosystems (Bellido et al., 2011; Keledjian et al., 2014; Pusceddu et al., 2014). Another important way shrimp fishery impacts the local fauna is the catch of non-target organisms, due to the low selectivity of the net (Davies et al., 2009).

The direct and indirect impacts of fishing extend across different levels of the ecosystem (Madrid-Vera et al., 2007). Among the impacts related to trawling, the capture of "non-target" species, called "bycatch", is one of the biggest current problems in fisheries management, which is due to the low selectivity of nets in this type of fishery (Alverson et al., 1994; Kelleher, 2005). The impact of the seabob shrimp fishing on this region's fauna takes on worrying dimensions, whether due to the high number of species with no economic value or caught juveniles, forcing the fisherman to return to the sea, usually dead, the surplus of the catches (Branco and Verani, 2006).

In general, benthic communities disturbed by trawling show an increase in the numbers of fast-growing species, and decreased species diversity (Lockwood, 2000; Blanchard et al., 2004). The impact of trawling on the dynamics of ecosystems (Magnússon, 1995) depends on the frequency and intensity of the trawling activities (Jennings et al., 2002; Blanchard et al., 2004).

In view of what was discussed above, studies on the conditions of the habitats and communities of species affected by bottom trawling become very important (Duplisea and Blanchard, 2005; Hiddink et al., 2017). In this way, we studied invertebrate macrofauna in three important penaeid shrimp fishing areas on the southern coast of Brazil. We aim to provide ecologically-based information for fisheries management in this region and answer the following questions: There are differences in the community's composition captured in the three fishing areas? If so, are these related to abiotic factors, such as water mass and sediment variables?

The bottom water and sediment data were used to verify if there is variation in the environmental conditions among the fishing sites analyzed. The data on the benthic macroinvertebrates obtained at the trawling sites were used to: (1) analyze the structure of the epifaunal macroinvertebrates bycatch and the dissimilarity in species' composition between them; (2) ascertain if there is a relationship between species' distributions and abiotic variables on the fishing grounds; (3) assess the abundance–biomass curves at each fishing areas; and (4) compare the bycatch diversity between areas exploited by fisheries.

2. Material and methods

The study area is located in the northern portion of the coast of central Santa Catarina, including the limits of the municipalities of Balneário Barra do Sul, Penha and Porto Belo (Fig. 1), where artisanal fishing of the shrimp *Xyphopenaeus kroyeri* is significant in coastal areas (Branco, 2005). The predominant winds in the study areas are southwest in the winter, and northeast during other times of the year (Araújo et al., 2006). The water mass of these areas is characterized by coastal waters, which receive a large riverine supply of nutrients from the rivers of the state of Santa Catarina. Other masses of water that occur in these areas are tropical waters, coming from the Brazilian current (summer and fall) and, eventually, the South Atlantic Central Water (SACW), in the summer, in the lower layers of the water column (Resgalla and Schettini, 2006).

Barra do Sul (Area I) is located in the north of Santa Catarina state and has 110.62 km^2 with 86 km of coastal extension. It is located between parallels 26°27'20"S and 48°36'43"W, surrounded by Atlantic forest and mangroves and bounded by the Serra do Mar mountain range. Penha (Area II) is surrounded by hills, sheltered from the southern quadrant winds, and exposed to the prevailing winds from the northern quadrant that operate with moderate intensity. It has an area of 60.3 km^2 and 70 km of coastal extension. In this region, the area studied is between "Praia de Armação" and the district of "Armação do Itapocoroy", between the coordinates 26°40'–26°47'S and 48°36'–48°38'W. Porto Belo (Area III) is located in the state's central-north portion with an area of 92.76 km^2 and 81 km of coastal extension, between parallels 27°09'28"S and 48°33'11"W. Its main feature is the Porto Belo peninsula, composed of sandy–rocky beaches but mainly muddy sediments from the Tijucas River. The three areas studied are traditional in small-scale artisanal fisheries and range from 10 to 25 meters in depth (Branco, 2005).

2.1. Samplings

Experimental trawls were carried out in the fishing areas, following the common work routine of small-scale fishermen in the region, and using similar vessels. In the small-scale fishing communities in these places, only shrimp are used. The other species are discarded. Sampling was carried out between 2009 and 2010, totalizing 36 trawls between areas (12 per area) and under SISBIO's license # 324642. Each sample is the result of three random 20-minute trawls (totaling a sampled hour), which were grouped according to the current season. A singled boat (double rigged) for bottom trawling was used, with a diamond net meshes of 30 mm between opposing nodes (at the net entrance) and 20 mm in the collecting codend, trawled at two knots' mean speed. Before each trawl, the bottom water was collected with a vertical van Dorn bottle, and the bottom temperature and salinity were measured with a thermometer (0.1 °C) and an optical refractometer (0.5%), respectively. In addition, a sediment sample was collected with a van Veen sampler prior to the start of the trawling.

The shrimps and other invertebrates were separated, kept in refrigerated coolers and taken to the laboratory (Zoology lab — Univali) for identification, quantification and biometrics.

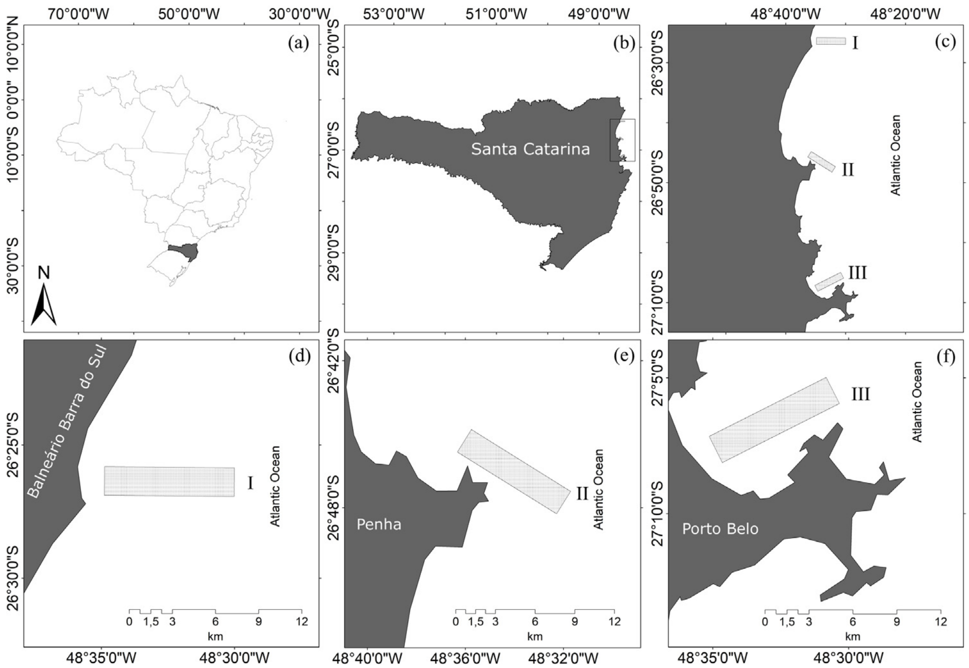

Fig. 1. Study area with the indication of the three regions sampled. Legends: (a) Brazil; (b) Santa Catarina state; (c) Santa Catarina coast and sampling areas; (d) I — Barra do Sul trawling area; (e) II — Penha trawling area; (f) III — Porto Belo trawling area.

2.2. Data analysis

Data on the replicates were considered, and the average result was categorized in the current season at the time of collection. Seven parameters of water samples were analyzed: bottom temperature and Salinity, silicon dioxide (SiO_2), ammonia (NH_4^+), nitrite (NO_2^-), phosphate ($PO^{3-}{}_4$) according to APHA (1998), and chlorophyll — a according to Mantoura et al. (1997).

Sediments were analyzed using the screening and pipetting methods (Suguio, 1973), where the particle size followed the parameters of Folk and Ward (1957) and the texture classification proposed by Shepard (1954). The gravimetric method was used to quantify calcium carbonate and organic matter (Suguio, 1973). To quantify the carbonate content, 100 g of sample were exposed to a solution of hydrochloric acid (HCl — 10%). The organic matter content was determined by loss on ignition (8 h at 800 °C).

2.3. Statistical analysis

2.3.1. Environmental variables

To verify differences in environmental conditions across areas, seasonal water and sediment data were separately tested through a multivariate variance permutation analysis (two-way — PERMANOVA) (Anderson, 2001), by the Euclidean distance method, to establish which of the parameter data sets (Water or sediment variables) are significantly responsible for local and seasonal differences. After determining which of the data sets (water or sediment variables) responsible for the differences among the areas, we test each variable independently to detect which ones are responsible for the differences found. For this, we submitted each variable to the Kolmogorov Smirnov's normality test and an ANOVA, followed by Tukey's post hoc test (Zar, 2010)

2.3.2. Species composition

In order to evaluate species' composition at the sites, the abundance matrix, containing the total abundance and biomass of the current season, was square root transformed to downweight the role of dominant taxa in order to improve the understanding of the obtained pattern (Clarke et al., 2006). Then, ANOSIM (Clarke, 1993), using the Bray–Curtis index, was used to verify differences in species composition among the areas and seasons. When statistical differences were detected, the SIMPER was used to determine the dissimilarity (%) among fishing sites and to highlight the species that contributed the most to the recorded changes (Clarke and Warwick, 1994). The value of 80% of cumulative contribution was used as a cut-off to define the most representative species in the results (Moscatello and Belmonte, 2009).

For comparison among the trawling areas, the alpha diversity descriptors among the sampled sites were calculated by species richness (S), Pielou's equitability (J′), Simpson's index (D), Shannon's index (H′) as described in Magurran (2004). These descriptors calculations, together with PERMANOVA, SIMPER, and ANOSIM, were performed using the PAST statistical package v.3.16 (Hammer et al., 2001).

2.3.3. Relationship between species and environmental variable

To find significant associations between environmental and faunal data, the species retained in the SIMPER analysis and the abiotic variables retained in PERMANOVA were used for a redundancy analysis — RDA (Legendre and Legendre, 1998). The RDA, followed by the Monte Carlo significance axis test ($p < 0.05$), was generated using the software Canoco 4.5 (Ter Braak and Smilauer, 2002).

2.3.4. Abundance–biomass curves in the trawl areas

The communities of the different areas were evaluated for their integrity through the abundance and biomass curves (ABC). The ABC represents the accumulated numerical abundance and biomass of all populations present in a community and the relationship between the curves is used to make inferences about the degree of environmental disturbance (Warwick, 1986). Clarke (1990) developed an index (W index) to mitigate the visual interpretation effect. The W index is obtained from the expression: $W = \sigma$ (Bi–Ai)/ [50 (S-1)], where Bi is the biomass value of each species (i); Ai is the abundance value of each sequence of species (i) and S is the number of species. Positive values indicate an undisturbed environment, negative values suggest disturbed communities, and values close to zero indicate moderate disturbances, ranging from −1 to 1 (Clarke, 1990; Magurran, 2004).

To evaluate if the disturbance degrees differ between areas, W values was subjected to analysis of variance (ANOVA) with a significance level of 95% ($p < 0.05$).

2.3.5. Species abundance distribution and descriptors of diversity (community structure)

Species Abundance Distribution Models were adjusted to analyze the patterns that structure the marine macroinvertebrate communities in the different areas and then evaluated and compared with the following theoretical models: Broken-Stick, Preemption, Lognormal, Zipf and Zipf–Mandelbrot (Magurran, 2004; McGill et al., 2007). The Broken-Stick model brings evidence that an environmental variable is being stochastically divided similarly between species. It is used as a null hypothesis against which other niche division patterns can be tested. The Preemption model assumes that each species exhausts more than half of the existing niche space, describes less uniform ecological communities and degraded conditions (Odum, 1988). The lognormal model is usually associated with good-quality environments with habitat heterogeneity and high species diversity (Krebs, 2009; Magurran, 2004). The Zipf and Zipf–Mandelbrot models are interpreted as a successional process in which late species (species that appear late in the succession) have more specific environmental needs and, therefore, are rarer than the species present in the beginning of the colonization process (Magurran, 2004). The best fit was defined by the maximum likelihood estimation, which compares the models using the lower Akaike (AIC), Bayesian (BIC) and Deviance criteria value for the best adjusted ecological model (Oksanen et al., 2010). The models were processed using the vegan package v1.17.9 (Oksanen et al., 2010) of software R v3.2.2 (R Core Team, 2016).

3. Results

3.1. Environmental variables

Considering the average values of the water and sediment variables (Supplementary material 1), the PERMANOVA analysis (Table 1) did not reveal significant local and seasonal differences in water composition (water mass). Only sediment composition, except for gravel ($F_{2-33} = 1.78$, $p = 0.18$), was responsible for significant differences among sites. Thus, grain size ($F_{2-33} = 10.96$), carbonate fractions ($F_{2-33} = 8.31$), organic matter ($F_{2-33} = 3.38$), sand ($F_{2-33} = 9.19$), silt ($F_{2-33} = 12.42$) and clay ($F_{2-33} = 7.30$) in the sediment, which were significant for the differences between the areas ($p < 0.05$), were selected for the Redundancy analysis (RDA).

In general, the significant differences in carbonate, organic matter, silt and clay fractions were, on average, lower in Barra do Sul when compared to Porto Belo samples (Fig. 2). On the other hand, the sand fraction and grain size were higher in Barra do Sul; and the clay fraction was higher in Porto Belo ($p < 0.05$). However, carbonate, organic matter, silt sand and average grain size did not differ ($p > 0.05$) between samples from Penha and Porto Belo. Similarly, Barra do Sul and Penha were not significantly different concerning to carbonate, organic matter and clay fractions.

Thus, in the sediment fractions, sand predominated in Barra do Sul; silt and sand predominated in Penha; whereas a more equitable distribution among sand, clay and silt fractions characterized the bottom of Porto Belo. Consequently, the classification of the seabed resulted in sandy for Barra do Sul, sandy silt for Penha and sandy–silty–clay for Porto Belo.

Table 1
Results of the multivariate analysis of variance (PERMANOVA — two-way) of the water and sediment parameters between the areas and seasons sampled.

Water characteristics					
Source	Sum of squares	df	Mean square	F	P
Areas	3507.8	2	1753.9	1.2469	0.3051
Seasonal	6705.2	3	2235.1	1.589	0.1694
Interaction	15806	6	2634.3	1.8728	0.0717
Residual	33758	24	1406.6		
Total	59777	35			
Sediment characteristics					
Source	Sum of squares	df	Mean square	F	P
Areas	19845	2	9922.5	7.8512	0.0009*
Seasonal	561.48	3	187.16	0.14809	0.9648
Interaction	3100.3	6	516.72	0.40886	0.8866
Residual	30331	24	1263.8		
Total	53838	35			

*Significant ($p < 0.05$).

3.2. Species composition

The samplings contributed 41 species of epifaunal macroinvertebrates distributed in 25 families, totaling 34686 individuals collected in the trawling areas of Barra do Sul, Penha and Porto Belo (Supplementary material 2). The Arthropoda (Crustacea) represented 63.41% of the all species, followed by Cnidaria (14.63%), Mollusca (12.20%) and Echinodermata (9.76%).

A total of 4797 individuals distributed in 28 taxa were identified in the collections of Barra do Sul, and the Arthropoda (Crustacea) accounted for 60.71% of the species collected, followed by Mollusca (17.86%), Cnidaria (17.86%) and Echinodermata (3.57%). The species *Xiphopenaeus kroyeri*, *Olivancillaria urceus*, *Callinectes ornatus* and *Lolliguncula (Lolliguncula) brevis* were the most representative in the number of individuals in this area, occurring in all samples and contributing with 95.60% of the macroinvertebrates sampled. The biomass ratios between discharges (bycatch) and the target species varied between the spring (1.53:1), summer (0.56:1), autumn (1.87:1) and winter (1.01:1) seasons, obtaining an average ratio of 1.24:1 per year.

In Penha, a total of 13752 individuals distributed in 31 taxa were collected, where the Arthropoda (Crustacea) contributed 70.97% of the species, followed by Mollusca (16.13%), Cnidaria (6.45%) and Echinodermata (6.45%). The most abundant species in this area were *X. kroyeri, Penaeus brasiliensis, Pleoticus muelleri, C. ornatus, Renilla muelleri, L. brevis* and *Astropecten marginatus*, collectively contributing 94.6% of the invertebrates sampled. The biomass ratios between bycatch and the target species varied between the spring (3.95:1), summer (0.31:1), autumn (2.06:1) and winter (4.68:1) seasons, obtaining an average ratio of 2.75:1 per year.

In Porto Belo, a total of 16137 individuals, distributed in 39 species, were registered. The most representative groups were Arthropoda (66.67%), Mollusca (12.82%), Cnidaria (10.26%) and Echinodermata (10.26%). The species *X. kroyeri*, *A. marginatus*, *P. muelleri*, *Loxopagurus loxochelis*, *Buccinanops cochlidium*, *Acetes americanus*, *Porcellana sayana* and *Sicyonia dorsalis*, together contributed with 93.4% of the macroinvertebrates sampled. The biomass ratios between bycatch and the target species varied between the spring (8.81:1), summer (0.58:1), autumn (0.57:1) and winter (5.55:1) seasons, obtaining an average ratio of 3.88:1 per year.

Significant differences ($R = 0.43$ and $p < 0.01$) were found by ANOSIM in species' composition between Porto Belo and Barra do Sul ($p = 0.03$), the former contributing to the greater species dissimilarity in this study. The composition of species at Penha did not differ statistically from Barra do Sul ($p = 0.06$) and Porto

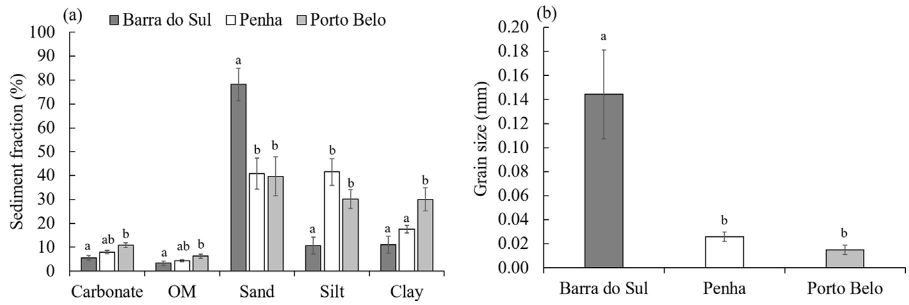

Fig. 2. Mean values and standard error of the sedimentary composition of the bottoms (a) and average grain size (b) of Barra do Sul, Penha and Barra do Sul — trawling areas. Legend: Equal letters above the bars — no significant differences between the environments by Tukey's multiple comparison test ($p > 0.05$).

Table 2
Similarity percentage analysis (SIMPER) of the community of marine macroinvertebrates between the studied areas.

Species	ID	Average dissimilarity	Contribution %	Accumulated %	Mean (B)	Mean (A)	Mean (P)
Xiphopenaeus kroyeri	Xkr	11.59	18.91	18.91	30.20	38.9	40.0
Astropecten marginatus	Ama	5.63	9.18	28.09	0.35	5.53	22.30
Pleoticus muelleri	Pmu	5.09	8.31	36.40	1.25	7.10	17.50
Penaeus brasiliensis	Fbr	3.37	5.50	41.90	0.60	12.90	1.12
Renilla muelleri	Rmu	3.11	5.07	46.97	1.80	8.48	10.90
Loxopagurus loxochelis	Llo	2.55	4.17	51.14	0.75	0.35	8.40
Callinectes ornatus	Cor	2.38	3.88	55.02	4.88	9.14	4.58
Olivancillaria urceus	Our	1.90	3.09	58.11	7.63	3.99	1.37
Buccinanops gradatum	Bgr	1.89	3.08	61.19	1.74	5.04	8.36
Sicyonia dorsalis	Sdo	1.88	3.07	64.26	0.60	0.96	7.15
Hepatus pudibundus	Hpu	1.60	2.61	66.87	1.76	4.50	4.31
Acetes americanus	Aam	1.46	2.38	69.25	0	1.48	5.63
Lolliguncula brevis	Lbr	1.43	2.34	71.59	4.33	6.00	4.23
Doryteuthis sanpaulensis	Lsa	1.39	2.27	73.86	0.25	3.01	2.47
Persephona lichtensteinii	Pli	1.27	2.08	75.94	0	0.50	5.16
Callinectes danae	Cda	1.20	1.97	77.92	0.50	2.78	3.39
Exhippolysmata oploforoides	Eop	1.17	1.91	79.82	0.90	2.44	1.91

Barra do Sul (B), Penha (A), Porto Belo (P) and species code (ID).

Belo ($p = 0.11$). However, no significant differences ($R = 0.12$ and $p = 0.20$) were found between the seasons.

The total dissimilarity between sites compositions, determined by the SIMPER analysis (Table 2), resulted in 61.29%. *X. kroyeri*, *A. marginatus*, *P. muelleri*, *P. brasiliensis*, *R. muelleri*, *L. loxochelis*, *C. ornatus*, *O. urceus*, *B. cochlidium* were responsible for 61.19% of the cumulative difference, while the *S. dorsalis, Hepatus pudibundus, A. americanus, L. brevis, Doryteuthis sanpaulensis, Persephona lichtensteinii*, *C. danae, Exhippolysmata oploforoides* species contributed 18.63% more, closing the cut of 80% of the most influential species in the SIMPER analysis.

3.3. Relationship between species and environmental variables

The redundancy analysis (Table 3) resulted in 84.3% of the total explainability of the relationship between environmental variables and species, with axis 1 accounting for 70.0% and axis 2 accounting for 14.3% of the contribution. The Monte Carlo test indicates that both axes contribute significantly (F ratio = 2.41, $p = 0.01$).

The RDA generated from the sediment data and species composition (Fig. 3) showed strong positive association between sand fraction and grain size with the following species: *X. kroyeri* (Xkr), *O. urceus* (Our), *C. ornatus* (Cor). In addition, the sand fraction and the species *H. pudibundus* (Hpu) and *L. brevis* (Lbr) were positively correlated.

On the other hand, *B. cochlidium* (Bgr), *R. muelleri* (Rmu), *P. mulleri* (Pmu), *E. oploforoides* (Eop), *P. lichtensteinii* (Pli), *P. brasiliensis* (Fbr), *D. sanpaulensis* (Lsa), *S.dorsalis* and *A. marginatus* (Ama), were associated positively with silt, organic matter and clay fractions, being negatively associated with large fractions of sand and to the larger grain size in the sediment. The species *L. loxochelis* (Llo), *A. americanus* (Aam) and *C. danae* (Cda) were positively associated with higher carbonate values, being negatively associated with the larger grain size and the sand fraction.

Table 3
RDA matrix of species–environment correlation.

	Axis 1	Axis2
Carbonate	−0.60	−0.36
Organic Matter	−0.55	0.05
Sand	0.78	0.00
Silt	−0.58	0.01
Clay	−0.80	−0.02
Grain Size	0.77	0.32
Eigenvalues	0.47	0.10
Species–environment correlations	0.97	0.84
Cumulative percentage variance of species data	46.70	56.30
Cumulative percentage of species–environment relation:	70.0	84.3
Summary of Monte Carlo test	F - ratio	p-value
Test of significance of first canonical axis	5.26	0.002
Test of significance of all canonical axis	2.41	0.01

3.4. Degree of disturbance in trawl areas

The negative values of W for the calculations of the abundance–biomass curves showed that all areas have suffered a certain degree of disturbance. The highest negative value was recorded for Penha in the winter (Fig. 4). The lowest negative value was registered in the summer in Porto Belo. However, no significant differences were detected ($F_{2-14} = 1.92$; $p = 0.30$) in the disturbance index (W) between the areas.

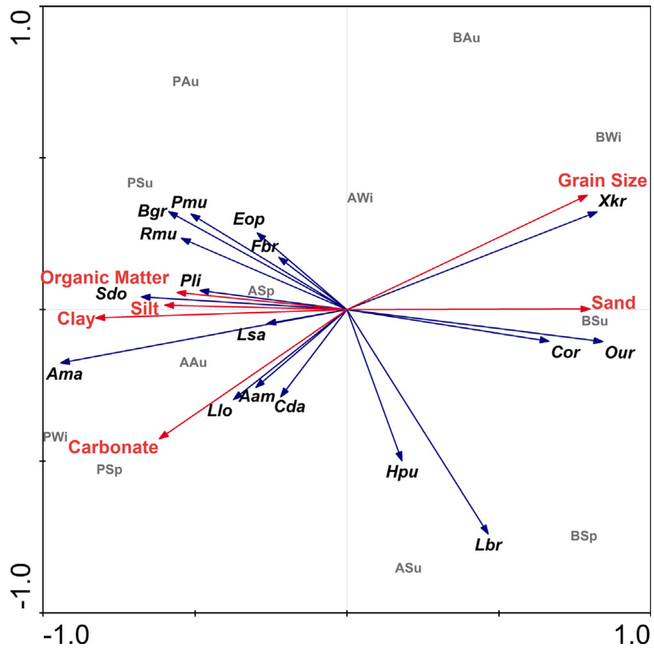

Fig. 3. Redundancy analysis (RDA) between the species and environments variables (Sand, Silt, Clay, Carbonate and Organic Matter — MO and Grain size) responsible for the differences between the trawling areas. Legend sampling: spring (Sp), summer (Su), autumn (Au) and winter (Wi) in the localities of Barra do Sul (B), Penha (A) and Porto Belo (P). Legend of the species according to "ID" –(see Table 2).

3.5. *Macroinvertebrates structure*

Considering the total abundances of each area, the Zipf and Lognormal models were selected by the lowest values for AIC, BIC and Deviance criteria (Supplementary material 3). Thus, the log-normal model was the one that best fit the Porto Belo community, and the Zipf model, which presented the best fit for the Barra do Sul and Penha communities (Fig. 5)

Concerning to the diversity metrics (Table 4), species richness (S) ranged from 14 to 17 in Barra do Sul, 17 to 21 in Penha and 17 to 30 in Porto Belo. The Shannon index (H′) ranged from 0.56 to 1.08 in Barra do Sul, from 0.54 to 1.93 in Penha and 0.90 to 2.26 in Porto Belo samplings. The Pielou's index (J′) presented a variation of 0.21 to 0.39 in the Barra do Sul samples, 0.19 to 0.63 in Penha and 0.29 to 0.66 in Porto Belo. In addition, the variation of the Simpson's dominance index (D′) was 0.57 to 0.81 in Barra do Sul, 0.23 to 0.80 in Penha and 0.24 to 0.65 in Porto Belo samples.

In total, the Porto Belo community was the one with the highest richness (S = 39), diversity (H′ = 1,90), equitability (J′ = 0.51) and species abundance (N = 16678), followed by Penha (S = 31, H′ = 1.31, J′ = 0.38 and N = 13752). On the other hand, the community at Barra do Sul presented lower values of species abundance (N = 4797), richness (S = 28), diversity (H′ = 0.74) and equitability (J′ = 0.22). Pertaining species dominance, the highest values were recorded for Barra do Sul (D = 0.73), followed by Penha (D′ = 0.46) and Porto Belo (D′ = 0.29).

4. Discussion

The water parameter obtained revealed a similar pattern among the study sites, which indicates that the water mass was relatively homogeneous among the sample areas, corroborating the studies of Pereira et al. (2009), Bernardes Júnior et al. (2011) and Sedrez et al. (2013), which indicates that the water characteristics in this region do not very different.

Table 4
Richness (S), Shannon diversity (H′), equitability (J′), dominance (D) and number of individuals (n) values for total and seasonal samplings in study areas.

	S	H′	J′	D′	n
BSp	16	1.08	0.39	0.57	656
BSu	14	0.56	0.21	0.77	2642
BAu	15	0.57	0.21	0.81	785
BWi	17	0.83	0.29	0.67	714
B total	28	0.74	0.22	0.73	4797
ASp	21	1.93	0.63	0.23	508
ASu	18	0.54	0.19	0.80	7048
AAu	17	1.10	0.39	0.42	5080
AWi	21	1.65	0.54	0.29	1116
A total	31	1.31	0.38	0.46	13752
PSp	30	2.26	0.66	0.21	3621
PSu	17	1.27	0.45	0.43	6034
PAu	22	0.90	0.29	0.65	5167
PWi	19	1.91	0.66	0.22	1846
P total	39	1.90	0.51	0.29	16678

Spring (Sp), summer (Su), Autumn (Au), Winter (Wi) Barra do Sul (B), Penha (A) and Porto Belo (P).

In contrast, sediment data varied significantly among sites suggesting that notable differences in the composition of the substrate are responsible for the differences among sites. The sediment of the trawling areas of Barra do Sul are sandy, while larger proportions of silt and clay are present in Penha and Porto Belo. According to some studies, sites where the proportion of silt and clay are greater than the proportion of sand are more suitable to accumulate organic matter, a key compound for the maintenance of the benthic fauna (Kenyon et al., 1995; Pusceddu et al., 2014). In contrast, areas of sandy sediment can be detrimental to the benthic fauna and may indicate that erosive processes of anthropic origin (e.g. bottom trawling) contribute to a simplification of the ocean floor (Pusceddu et al., 2014).

The catch's composition varies considerably according to the nature of the stock, the type and selectivity of fishing equipment used, trawl duration, target species, the economic importance of the species, depth of capture, and time of year (Rochet et al., 2002; Rodrigues-Filho et al., 2015). The discard rate (by-catch:target species) ranged between 0.38:1 to 8.81: 1 considering all areas' sampling, resulting in higher discharge averages in Porto Belo (3.88:1) and lower in Barra do Sul (1.24:1). This result is similar to previous studies, which recorded discard rates ranging from 0.57:1 to 8:1 for southern Brazil (Branco and Verani, 2006; Cattani et al., 2011; Rodrigues-Filho et al., 2015).

Small-scale shrimp trawling in southern Brazil demonstrates a wide variety of fish and invertebrates in the catch's composition, resulting from low selectivity and its incisive impact on marine biota. Besides, sampling using this methodology has effectively represented fish and invertebrate species in this region (Sedrez et al., 2013; Branco et al., 2015; Rodrigues Filho et al., 2016). Among the species recorded, Arthropoda (Crustacea) predominated in samples from all environments, followed by Mollusca, Cnidaria and Echinodermata. This is a recurring pattern in trawl fishery samples from Santa Catarina (Branco and Verani, 2006; Sedrez et al., 2013; Branco et al., 2015; Rodrigues Filho et al., 2016). The variety of Crustaceans is probably due to a large amount of nutrients and organic matter present in these areas, which are sources of resources that favor this group's abundance and diversity (Melo, 1996; Schettini et al., 2005; Branco et al., 2015).

The redundancy analysis indicates that *X. kroyeri, C. ornatus*, *H. pudibundus*, *O. urceus*, and *L. brevis* are associated with sandy environments. Previous studies on the biology and ecology of these species indicate that they are flexible when it comes to

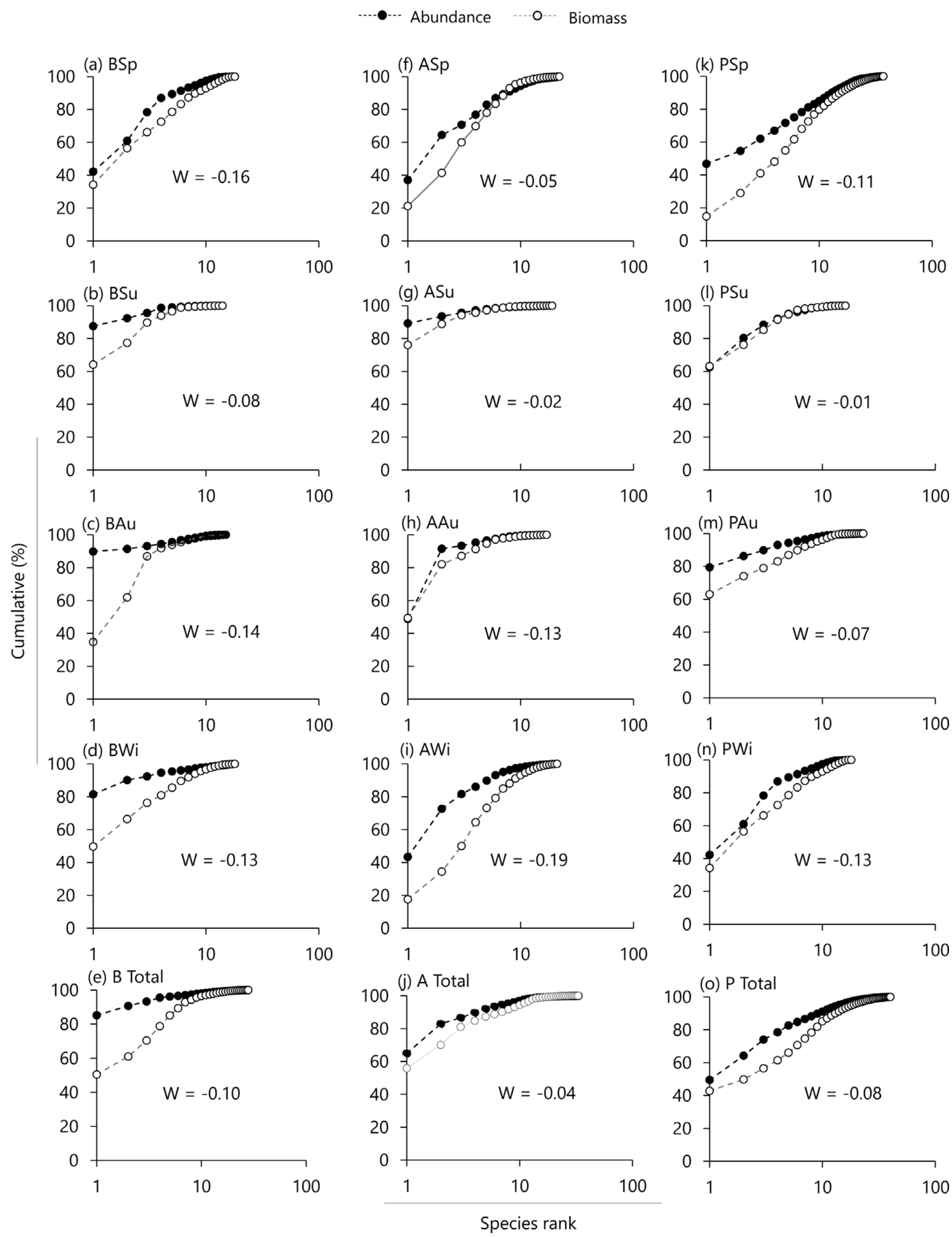

Fig. 4. Abundance and Biomass Curves (ABC) for the seasonal and total samples of Barra do Sul (B; a–e), Penha (A; f–j) and Porto Belo (P; k–o). Legends: Spring (Sp), Summer (Su), Autumn (Au), Winter (Wi) and Disturbance index (W).

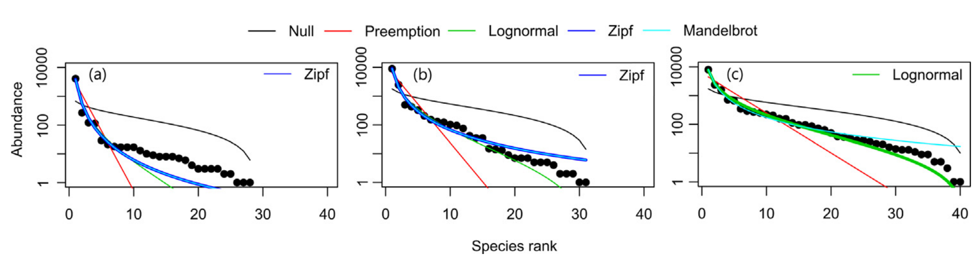

Fig. 5. Species-Abundance distribution models for samples of Barra do Sul (a), Penha (b) and Porto Belo (c).

sediment structure and occur from sand to clay substrates (Melo, 1996; Teso et al., 2011; Branco et al., 2015; Santos et al., 2016).

Conversely, *A. marginatus* and *P. muelleri* were strongly associated with a more complex sediment with fine fractions of silt, clay and organic matter. The abundance of *P. muelleri* has been associated with environments that have greater amounts of clay and organic matter (Batista et al., 2011), suggesting that homogenization of the substrate may be a limiting factor for the permanence of this species in the environment. In the same way, as pointed out by Blanchard et al. (2004) and Vergón and Blanchard (2006), *Astropecten* starfish are sensitive to environmental degradation and need a better background habitat structure to establish themselves. Thus, the high abundance recorded for these species in Porto Belo samples may indicate the better background quality of this environment when compared to the others.

Similarly, our data found a negative correlation between *A. americanus*, *L. loxochelis*, *P. lichtensteinii*, *C. danae*, *S. dorsalis*, *B. cochlidium*, *R. muelleri*, *E. oploforoides*, *D. sanpaulensis*, and *F. brasiliensis* and sandy substrates and a positive correlation with the other soil fractions, indicating a preference for less simplified substrates. This trend is due to the fact that the heterogeneous sediment properties represent important resources for the marine fauna, since they are involved in food processes and serve as shelter for most benthic species (van Oevelen et al., 2011; Mayor et al., 2012; Pusceddu et al., 2014).

The results generated by the abundance–biomass curves suggest that all areas are under frequent disturbances. The trawling impacts caused in these environments can change the dominance relationships in a community, favoring the r-strategist species and harming those that need more time to establish themselves in the system. However, even if we do not have a controlled environment (without or with few disturbances), this method was applied to record the curves at that given moment and verify their behavior in future monitoring studies. On the other hand, the curves' results also infer that biota is composed of organisms with high numerical abundance but with less biomass. The proximity of the study areas to the surf area may well increase this result, because these areas are critical habitat for factors related to the recruitment and development of many fish and invertebrates species (Rodrigues-Filho et al., 2015). In this context, the dominance of *X. kroyeri* in all areas may reflect the great reproductive potential, rapid development and a short life cycle of this species (Branco, 2005; Lopes, 2008).

The results of the rank abundance distribution models were largely in accordance with the ABC, indicating that the communities of Barra do Sul and Penha are moderately disturbed. The Zipf model is interpreted as reflecting a successional process. The species that need better conditions (physical and ecological) to stabilize in the environment are rarer than the resistant and more adapted species (e.g. pioneer species) (Frontier, 1985; Magurran, 2004). In this context, the most adapted species prevail over those that require that the environmental conditions are more pristine. Consequently, the differences in the relative abundance of species are a result of competition and other ecological interactions (Wilson, 1991; Magurran, 2004).

The lognormal model was obtained for Porto Belo. This model represents an environment of high diversity and better-quality habitats, implying a community with high diversity of species (Krebs, 2009; Magurran, 2004). This is consistent with the data on the Porto Belo background, where the sediment structure is better, and the diversity of species is greater than other areas. In this case, the greater diversity of species results from many independent factors and may be associated with the high capacity of species to occupy habitats and use the many existing resources of this environment, making the lognormal the most representative model of heterogeneous and balanced tropical communities (May, 1975; Sugihara, 1980; Wilson, 1991). In addition, even with the perturbations indicated by the abundance–biomass curves, the data from Porto Belo suggests that these disturbances that occur there change the dynamics of the environment, decreasing the dominance, balancing and, consequently, increasing the diversity of species in the environment (Connell, 1978; Wilson, 1991; Peterson et al., 1998).

The Shannon index values (H′) recorded for the Barra do Sul samples are similar to those found in areas West of the Atlantic Coast of France by Blanchard et al. (2004), where the values ranged from 0.68 to 0.89 under conditions of strong exploitation. In moderately exploited areas reported in the same work, the Shannon index ranged from 0.97 to 1.15, resulting in the biomass curve above abundance (no disturbance). However, our results reveal a negative disturbance, with the biomass curve below the abundance curve, even when the diversity is higher than found by Blanchard et al. (2004), as in samples from Penha and Porto Belo. Among these sites (Penha and Porto Belo), the gradual improvement in the sedimentary structure in relation to the composition of the substrate of Barra do Sul may explain the greater richness, diversity and species abundance in both sites.

Pusceddu et al. (2014), argued that the effects of trawling on the sedimentary structure and benthic diversity are similar to the negative impacts caused by soil erosion and can transform the environments into large faunal deserts and degraded seas. In this context, the substrate of environments under frequent trawling is characterized by an increase in the sandy fraction and a decrease in the organic matter, essential compound for the feeding and consequent maintenance of the bottom biota (Witte et al., 2003; van Oevelen et al., 2011; Pusceddu et al., 2014), which is similar to the Barra do Sul characteristics.

Also, fishing performance can function as a top-down control controlling dominant organisms, altering competitive interactions and contributing to an increase in species diversity (Levine, 1976; Vandermeer, 1980; Blanchard et al., 2004; van Denderen et al., 2013). It seems to be what happens in Porto Belo. However, the increase in trawling can contribute to the homogenization of areas, contributing to the disappearance of k-strategist species and leaving only species with lesser environmental requirements, which become dominant and make the environment less diverse (Engel and Kvitek, 1998; Blanchard et al., 2004).

According to our results, the seabed of Barra do Sul is relatively simplified compared to other areas. The lower diversity can confirm this factor in terms of species and sediment characteristics, predominantly sandy. Its lower abundance and the lower biomass of individuals contributed to the lowest bycatch rate among the areas, which can give a false impression that it is the location where there are the lowest rates of discharges. Conversely, Porto Belo detained the most significant representation of marine macroinvertebrates and the best seabed condition of the northern and central north of Santa Catarina, followed by Penha.

The lack of a controlled environment (without the effect of shrimp trawling) and past data from these areas does not allow us to say whether the results interpreted by the abundance and biomass curves are natural consequences or the impact of shrimp trawling. However, a first result using this methodology is recorded here for these areas, in order to contribute to the monitoring of this region. Since trawling changes the sediment's characteristics are strongly correlated with the diversity and the permanence of sensitive species, the results suggest that increased small-scale trawling activities might contribute to the substrate's homogenization and reduce species diversity in these areas.

Constant surveys to monitor the physical structure and the community and its dynamics in trawling areas are indispensable. Besides, monitoring areas under the influence of trawling is essential to keep up-to-date information on this practice's effect on the seabed habitats, the problems related to bycatch and the conservation of species impacted by fishing practices.

CRediT authorship contribution statement

Germano Henrique Costa Barrilli: Conceptualization, Software, Formal analysis, Investigation, Data curation, Writing - original draft, Validation, Writing - review & editing. **Jorge Luiz Rodrigues Filho:** Conceptualization, Writing - review & editing. **Julia Gomes do Vale:** Methodology, Writing - review &

editing. **Dagoberto Port:** Software, Writing - review & editing. **José Roberto Verani:** Conceptualization, Review, Project administration, Supervision. **Joaquim Olinto Branco:** Conceptualization, Writing - review & editing, Project administration, Supervision, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We thank the Coordination of Improvement of Higher Education Personnel (CAPES), Brazil for the financial support (process n°1422783); the Zoology Laboratory School of the Sea, Science and Technology of the University of Vale do Itajaí -SC, Brazil, and the postgraduate program in Ecology and Natural Resources of the Federal University of São Carlos (PPGERN- UFSCar), Brazil.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2021.101695.

References

Alverson, D.L., Freeberg, M.H., Pope, J.G., Murawski, S.A., 1994. A Global Assessment of Fisheries Bycatch and Discards. FAO Fisheries Technical Paper 339, Food and Agriculture Organization of the United Nations, Rome, 233p.

Anderson, M.J., 2001. A new method for non-parametric multivariate analysis of variance. Austral. Ecol. 26, 32–46. http://dx.doi.org/10.1111/j.1442-9993.2001.01070.pp.x.

APHA, 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Water Works Association, Water environmental association, 20th Washington, DC, USA.

Araújo, A.S., Haymussi, H., Reis, F.H., Silva, F.E., 2006. Caracterização climatológica do município de Penha. SC, pp. 11–28, Branco, J.O e Marenzi, A.W.C. (Org.). Bases ecológicas para um desenvolvimento sustentável: estudo de caso em Penha, SC. Editora da UNIVALI, Itajaí, SC.

Arreguin-Sanchez, F., Zetina-Rejón, M., Ramírez-Rodríguez, M., 2008. Exploring ecosystem-based harvesting strategies to recover the collapsed pink shrimp (*Farfantepenaeus duorarum*) fishery in the Southern Gulf of Mexico. Ecol. Model. 214, 83–94. http://dx.doi.org/10.1016/j.ecolmodel.2007.11.021.

Batista, A.C., Simões, S.M., Lopes, M., Costa, R.C., 2011. Ecological distribution of the shrimp *Pleoticus muelleri* (Bate, 1888) and *Artemesia longinaris* Bate, 1888 (Decapoda, Penaeoidea) in the southeastern Brazilian littoral. Nauplius 19, 135–143. http://dx.doi.org/10.1590/S0104-64972011000200005.

Bellido, J.M., Santos, M.B., Pennino, M.G., Valeiras, X., Pierce, G.J., 2011. Fishery discards and bycatch: solutions for an ecosystem approach to fisheries management? Hydrobiologia 670, 317–333. http://dx.doi.org/10.1007/s10750-011-0721-5.

Bernardes Júnior, J.J., Rodrigues Filho, J.L., Branco, J.O., Verani, J.R., 2011. Spatiotemporal variations of the ichthyofauna structure accompanying the seabob shrimp *Xiphopenaeus kroyeri* (Crustacea: Penaeidae) fishery, in important fisheries areas of the Santa Catarina shore, Brazil. Zoo 28, 151–164. http://dx.doi.org/10.1590/S1984-46702011000200002.

Blanchard, F., LeLoc'k, F., Hily, C., Boucher, J., 2004. Fishing effects on diversity, size and community structure of the benthic invertebrate and fish megafauna on the Bay of Biscay coast of France. Mar. Ecol. Prog. Ser. 280, 249–260. http://dx.doi.org/10.3354/meps280249.

Branco, J.O., 2005. Biologia e pesca do camarão sete-barbas *Xiphopenaeus kroyeri* (Heller) (Crustacea, Penaeidae), na Armação do Itapocoroy, Penha, Santa Catarina. Brasil. Rev. Bras. Zoo 22, 1050–1062. http://dx.doi.org/10.1590/S0101-81752005000400034.

Branco, J.O., Freitas Júnior, F., Christoffersen, M.L., 2015. Bycatch fauna of seabob shrimp trawl fisheries from santa catarina state. southern Brazil. Biota Neotrop. 15, 1–14. http://dx.doi.org/10.1590/1676-06032015014314.

Branco, J.O., Verani, J.R., 2006. Análise quali-quantitativa da ictiofauna acompanhante na pesca do camarão sete-barbas, na Armação do Itapocoroy, Penha, Santa Catarina. Rev. Bras. Zoo 23, 381–391. http://dx.doi.org/10.1590/S0101-81752006000200011.

Cattani, A.P., Santos, L.O., Spach, H.L., Budel, B., Guanais, J.H.D.G., 2011. Avaliação da ictiofauna da fauna acompanhante da pesca do camarão sete-barbas do município de Pontal do Paraná, litoral do Paraná. Bol. Inst. Pesca 37, 247–260.

Clarke, K.R., 1990. Comparisons of dominance curves. J. Exp. Mar. Biol. Ecol. 138, 143–157. http://dx.doi.org/10.1016/0022-0981(90)90181-B.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Austral. Ecol. 18, 117–143. http://dx.doi.org/10.1111/j.1442-9993.1993.tb00438.x.

Clarke, K.R., Chapman, M.G., Somerfield, P.J., Needham, H.R., 2006. Dispersion-based weighting of species counts in assemblage analyses. Mar. Ecol. Prog. Ser. 320, 11–27. http://dx.doi.org/10.3354/meps320011.

Clarke, K.R., Warwick, R.M., 1994. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. PML, Plymouth, United Kingdom, 144p.

Connell, J.H., 1978. Diversity in tropical rain forests and coral reefs. Science 199, 1302–1310. http://dx.doi.org/10.1126/science.199.4335.1302.

Costa, R.C., Fransozo, A., Freire, F.A.M., Castilho, A.L., 2007. Abundance and Ecological distribution of the Sete-Barbas Shrimp *Xiphopenaeus kroyeri* (Heller, 1862) (Decapoda: Penaeoidea) in three bays of the Ubatuba Region. Southeastern Brazil. Gulf Caribb. Res. 19, 33–41. http://dx.doi.org/10.1590/1519-6984.01814.

Davies, R.W.D., Cripps, S.J., Nickson, A., Porter, G., 2009. Defining and estimating global marine fisheries bycatch. J. Mar. Pol. 33, 661–672. http://dx.doi.org/10.1016/j.marpol.2009.01.003.

D'Incao, F., Valentini, H., Rodrigues, L.F., 2002. Avaliação da pesca de camarões nas regiões Sudeste e Sul do Brasil. Atlântica, Rio Grande 24 (2), 103–116.

Duplisea, D., Blanchard, F., 2005. Relating species and community dynamics in anheavily exploited marine fish community. Ecosystems 8, 899–910. http://dx.doi.org/10.1007/s10021-005-0011-z.

Emilson, I., 1961. The shelf and coastal waters off southern Brazil. Bol. Inst. Ocean. São Paulo 11, 101–112. http://dx.doi.org/10.1590/S0373-55241961000100004.

Engel, J., Kvitek, R., 1998. Effects of otter trawling on a benthic community in Monterey Bay National Marine Sanctuary. Conserv. Biol. 12, 1204–1214.

FAO, 2016. The State of World Fisheries and Aquaculture: Opportunities and Challenges. FAO, Rome.

Ferreira, L., Medley, P., 2005. The southern pink shrimp (*Farfantepenaeus notialis*) and Atlantic seabob (*Xiphopenaeus kroyeri*) fisheries of the Trinidad and Tobago trawl fishery. In: CRFM Fishery Report. Caribb. Reg. Fish. Mech. 11, 63–88.

Folk, R.L., Ward, W.C., 1957. Brazos river bar: A study in the significance of grain size parameters. J. Sediment. Petrol 27, 3–27. http://dx.doi.org/10.1306/74D70646-2B21-11D7-8648000102C1865D.

Freire, F.A., Luchiari, A.C., Fransozo, V., 2011. Environmental substrate selection and daily habitual activity in *Xiphopenaeus kroyeri* shrimp (Heller, 1862) (Crustacea: Penaeioidea). Indian J. Mar. Sci. 40, 325–330.

Frontier, S., 1985. Diversity and structure in aquatic ecosystems. Oceanogr. Mar. Biol. Ann. Rev. 23, 253–312.

Gillett, R., 2008. Global Study of Shrimp Fisheries. FAO Fisheries Technical Paper 475, FAO, Rome, p. 331.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontol. Electron. 25, https://palaeo-electronica.org/2001_1/past/issue1_01.html. (Accessed 05 January 2020).

Hiddink, J.G., Jennings, S., Sciberras, M., Szostek, C.L., Hughes, K.M., Ellis, N., Rijnsdorp, A.D., McConnaughey, R.A., Tessa, M., Hilborn, R., Collie, J.S., Pitcher, C.R., Amoroso, R.O., Parma, A.M., Suuronen, P., Kaiser, M.J., 2017. Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. Proc. Natl. Acad. Sci. 114, 8301–8306. http://dx.doi.org/10.1073/pnas.1618858114.

Jennings, S., Nicholson, M.D., Dinmore, T.A., Lancaster, J.E., 2002. Effects of chronic trawling disturbance on the production of infaunal communities. Mar. Ecol. Prog. Ser. 243, 251–260. http://dx.doi.org/10.3354/meps243251.

Keledjian, A., Brogan, G., Lowell, B., Warrenchuk, J., Enticknap, B., Shester, G., ..., Cano-Stocco, D., 2014. Wasted catch: Unsolved problems in US fisheries. Oceana https://oceana.org/sites/default/files/reports/Bycatch_Report_FINAL.pdf. (Accessed 13 march 2020).

Kelleher, K., 2005. Discards in the World's Marine Fisheries: An Update. Food and Agriculture Organization of the United Nations, Rome, 131p.

Kenyon, R.A., Loneragan, N.R., Hughs, J.M., 1995. Habitat type and light affect sheltering behavior of juvenile tiger prawns (*Penaeusesculentus Haswell*) and success rates of their fish predators. J. Exp. Mar. Biol. Ecol. 192, 87–105. http://dx.doi.org/10.1016/0022-0981(95)00064-X.

Kolling, J.A., Ávila-da Silva, A.O., 2014. Evaluation of determinants of *Xiphopenaeus kroyeri* (Heller, 1862) catch abundance along a southwest Atlantic subtropical shelf. ICES J. Mar. Sci. 71, 1793–1804. http://dx.doi.org/10.1093/icesjms/fst225.

Krebs, C.J., 2009. Ecology: The Experimental Analysis of Distribution and Abundance, sixth ed. Benjamin Cummings, San Francisco, 655 pp.

Legendre, P., Legendre, L., 1998. Numerical Ecology. In: Developments in Environmental Modelling, vol. 20, Elsevier Science, Amsterdam.

Leite, Jr., N.O., Petrere, Jr., M., 2006. Stock assessment and fishery management of the pink shrimp *Farfantepenaeus brasiliensis* Latreille, 1970 and *F. paulensis* Pérez-Farfante, 1967 in Southeastern Brazil (23° to 28°S). Braz. J. Biol. 66, 263–277. http://dx.doi.org/10.1590/S1519-69842006000200009.
Levine, S.H., 1976. Competitive interactions in ecosystems. Am. Nat. 110, 903–910. http://dx.doi.org/10.1086/283116.
Lockwood, S.J., 2000. The Effects of Fishing on Marine Ecosystems and Communities (Fish Biology and Aquatic Resources Series 1), by Stephen J. Hall. Blackwell Science, Oxford, 1999, 274. Aquat. Conserv.: Mar. Fresh. Ecosyst. 10, 226–227. http://dx.doi.org/10.1002/1099-0755(200005/06)10:3<226::AID-AQC411>3.0.CO;2-9.
Lopes, P.F.M., 2008. Extracted and farmed shrimp fisheries in Brazil: economic, environmental and social consequences of exploitation. Environ. Dev. Sustain. 10, 639. http://dx.doi.org/10.1007/s10668-008-9148-1.
Madrid-Vera, J.F., Amezcua, F., Morales-Bojórquez, E., 2007. An assessment approach to estimate biomass of fish communities from bycatch data in a tropical shrimp-trawl fishery. Fish. Res. 83, 81–89. http://dx.doi.org/10.1016/j.fishres.2006.08.026.
Magnússon, K.G., 1995. An overview of the multispecies VPA – theory and applications. Rev. Fish Biol. Fish 5, 195–212. http://dx.doi.org/10.1007/BF00179756.
Magurran, A.E., 2004. Measuring Biological Diversity. Blackwell Science, Oxford, 256p.
Mantoura, F.A., Jeffrey, S.W., Llewellyn, C.A., Claustre, H., Morales, C.E., 1997. Comparison between spectrophotometric, fluorometric and HPLC methods for chlorophyll analysis. In: Jeffrey, S.W., Mantoura, R.F.C., Wright, S.W. (Eds.), Phytoplankton Pigments in Oceanography. UNESCO, Paris, pp. 361–380.
May, R.M., 1975. Patterns of species abundance and diversity. In: Cody, M.L., Diamond, J.M. (Eds.), Ecology and Evolution of Communities. Harvard University Press, Cambridge, MA, pp. 81–120, chapter 4.
Mayor, D.J., Thornton, B., Hay, S., Zuur, A.F., Nicol, G.W., McWilliam, J.M., Witte, U.F., 2012. Resource quality affects carbon cycling in deep-sea sediments. ISME J. 6, 1740–1748. http://dx.doi.org/10.1038/ismej.2012.14.
McGill, B.J., Etienne, R.S., Gray, J.S., Alonso, D., Anderson, M.J., Benecha, H.K., Dornelas, M., Enquist, B.J., Green, J.L., He, F., Hurlbert, A.H., Magurran, A.E., Marquet, P.A., Maurer, B.A., Ostling, A., Soykan, C.U., Ugland, K.I., White, E.P., 2007. Species abundance distributions: moving beyond single prediction theories to integration within an ecological framework. Ecol. Lett. 10, 995–1015. http://dx.doi.org/10.1111/j.1461-0248.2007.01094.x.
Melo, G.A.S., 1996. Manual de identificação de Brachyura (caranguejos e siris) do litoral brasileiro. FAPESP, São Paulo, Plêiade, 604p.
Moscatello, S., Belmonte, G., 2009. Egg banks in hypersaline lakes of South-East Europe. Saline Syst. 5, 123–127. http://dx.doi.org/10.1186/1746-1448-5-3.
Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., O'Hara, R.G., Simpson, G.L., ..., Wagner, H., 2010. Vegan: Community Ecology Package. R Package. Version 1.18-2/R1135.
Pereira, M., Schettini, C.A.F., Omachi, C.Y., 2009. Caracterização de feições oceanográficas na plataforma de Santa Catarina através de imagens orbitais. Ver. Bras. Geof 27, 81–93. http://dx.doi.org/10.1590/S0102-261X2009000100007.
Peterson, G., Allen, C.R., Holling, C.S., 1998. Ecological resiliense, biodiversity and scale. Ecosystem 1, 6–18. http://dx.doi.org/10.1007/s100219900002.
Pezzuto, P.R., Alvarez-Perez, J.A., Wahrlich, R., 2008. The use of the swept area method for assessing the seabob shrimp *Xiphopenaeuskroyeri* (Heller, 1862) biomass and removal rates based on artisanal fishery-derived data in southern Brazil: using depletion models to reduce uncertainty. Lat. Am. J. Aquat. 36, 245–257.
Pusceddu, A., Bianchelli, S., Martín, J., Puig, P., Palanques, A., Masqué, P., Danovaro, R., 2014. Chronic and intensive bottom trawling impairs deep-sea biodiversity and ecosystem functioning. Proc. Natl. Acad. Sci. 111, 8861–8866. http://dx.doi.org/10.1073/pnas.1405454111.
R Core Team, 2016. R Core Team 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Rajakumaran, P., Vaseeharan, B., 2014. Survey on penaeidae shrimp diversity and exploitation in South East Coast of India. Fish, Aquac. J. http://dx.doi.org/10.4172/2150-3508.1000103.
Resgalla, J.R.C., Schettini, C.A.F., 2006. Características e variação do seston da enseada da Armação do Itapocoroy. SC, Penha, pp. 107–120, Joaquim Olinto Branco e Adriano W.C. Marenzi (Org.). Bases ecológicas para um desenvolvimento sustentável: estudo de caso em Penha, SC. Editora da UNIVALI, Itajaí, SC.
Rochet, M.-J., Peronnet, I., Trenkel, V.M., 2002. An analysis of discards from the French trawler fleet in the Celtic Sea. ICES J. Mar. Sci. 59 (3), 538–552.
Rodrigues-Filho, J.L., Branco, J.O., Monteiro, H.S., Verani, J.R., Barreiros, J.P., 2015. Seasonality of ichthyofauna bycatch in shrimp trawls from different depth strata in the southern Brazilian coast. J. Coast. Res. 31 (2), 378–389, Coconut Creek (Florida).
Rodrigues Filho, J.L., Couto, E.C.G., E., Barbieri., Branco, J.O., 2016. Ciclos sazonais da carcinofauna capturada na pesca do camarão–sete-barbas, *Xiphopenaeus kroyeri* no litoral de Santa Catarina. Bol. Inst. Pesca 42 (3), 648–661. http://dx.doi.org/10.20950/1678-2305.2016v42n3p611.
Santos, M.C.F., Port, D., Fisch, F., Barbieri, E., Branco, J.O., 2016. Biologia populacional de *Callinectes ornatus* associada à pesca do camarão-sete-barbas, Rio São Francisco (Alagoas e Sergipe, Brasil). Bol. Inst. Pesca 42, 449–456. http://dx.doi.org/10.20950/1678-2305.2016v42n2p449.
Schettini, C.A.F., Resgalla, Jr., C., Filho, J.Pereira., Silva, M.A.C., Truccolo, E.C., Rörig, L.R., 2005. Variabilidade temporal das características oceanográficas e ecológicas da região de influência fluvial do rio Itajaí-açu. Braz. J. Aquat. Sci. Technol. 9, 93–102. http://dx.doi.org/10.14210/bjast.v9n2.p93-102.
Sedrez, M.C., Branco, J.O., Freitas Júnior, F., H.S., Monteiro, Barbieri, E., 2013. Ictiofauna acompanhante na pesca artesanal do camarão sete-barbas (*Xiphopenaeus kroyeri*) no litoral sul do Brasil. Biota. Neotrop. 13, 165–175. http://dx.doi.org/10.20950/1678-2305.2016v42n4p816.
Serafini, T.Z., Andriguetto-Filho, J.M., Pierri, N., 2014. Subsídios para a gestão compartilhada da pesca na baía da Babitonga (SC, Brasil). Braz. J. Aquat. Sci. Technol. 18, 99–111. http://dx.doi.org/10.14210/bjast.v18n1.p99-111.
Shepard, F.P., 1954. Nomenclature based on sand-silt-clay ratios. J. Sedim. Petrology 24, 151–158.
Sugihara, G., 1980. Minimal community structure: an explanation of species abundance patterns. Am. Nat. 116, 770–787. http://dx.doi.org/10.1086/283669.
Suguio, K., 1973. Introdução à sedimentologia. Ed. USP, São Paulo, Edgard Bliicher, 317 p.
Ter Braak, C.J.F., Smilauer, P., 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5). Microcomputer Power, Ithaca, 500p.
Teso, V., Signorelli, J., Pastorino, G., 2011. Shell phenotypic variation in the south-western Atlantic gastropod *Olivancillaria carcellesi* (Mollusca: Olividae). J. Mar. Biolog. Assoc. UK 91, 1089–1094. http://dx.doi.org/10.1017/S0025315410001475.
van Denderen, P.D., van Kooten, T., Rijnsdorp, A.D., 2013. When does fishing lead to more fish? Community consequences of bottom trawl fisheries in demersal food webs. Proc. Royal Soc. B 280, 20131883. http://dx.doi.org/10.1098/rspb.2013.1883.
van Oevelen, D., Soetaert, K., Garcia, R., de Stigter, H.C., Cunha, M.R., Pusceddu, A., Danovaro, R., 2011. Canyon conditions impact carbon flows in food webs of three sections of the Nazaré canyon. Deep Sea Res. Part II Top. Stud. Oceanogr 58, 2461–2476. http://dx.doi.org/10.1016/j.dsr2.2011.04.009.
Vandermeer, J.H., 1980. Indirect mutualism: variations on a theme by Stephen Levine. Am. Nat 116, 441–448.
Vergón, R., Blanchard, F., 2006. Evaluation of trawling disturbance on macrobenthic invertebrate communities in the Bay of Biscay, France: Abundance Biomass Comparison (ABC method). Aquatic Living Resour. 19 (3), 219–228. http://dx.doi.org/10.1051/alr:2006022.
Warwick, R.M., 1986. A new method for detecting pollution effects on marine macrobenthic communities. Mari. Biol. 92, 557–562. http://dx.doi.org/10.1007/BF00392515.
Wilson, W.H., 1991. Competition and predation in marine soft-sediment communities. Ann. Rev. Ecol. Syst. Palo Alto 21, 221–241.
Witte, U., Wenzhöfer, F., Sommer, S., Boetius, A., Heinz, P., Aberle, N., ..., Pfannkuche, O., 2003. In situ experimental evidence of the fate of a phytodetritus pulse at the abyssal sea floor. Nature 424, 763–766. http://dx.doi.org/10.1038/nature01799.
Zar, J.H., 2010. Biostatistical Analysis, fifth ed. Pearson Prentice Hall, Upper Saddle River, New Jersey, 944p.