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Research Article

Spatial pattern of benthic macrofauna in a sub-tropical shelf, São Sebastião Channel, southeastern Brazil

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ABSTRACT. Diversity and community organization of the benthic macrofauna were investigated along the São Sebastião Channel, northern coast of São Paulo State, Brazil, and related to sedimentary variables and organic load. These important outstanding soft bottom benthic habitats are characterized by their close proximity to sources of human impact. Sampling was undertaken seasonally, using a Van Veen grab (0.1 m^2) in 15 oceanographic stations, from November 1993 to August 1994. A total of 392 species were recorded and polychaetes completed nearly 50% of the fauna. Twenty three species were most numerous and frequent and comprised the baseline pool for the area. Sites were classified with respect to sediments in three site-groupings according to Arasaki *et al.* (2004). The finest-sediment site-group had significantly fewer species than coarser site-groups. The stations locate at the south opening and in the axis of the channel presented sediments with organic matter predominantly of marine origin, indicating the flow of open sea waters across the channel. These places showed also higher values of diversity and species richness. The site-group located along the insular side and in the channel north mouth, stood out for the significantly higher density. Although its relative small area the channel presented species richness similar to that found in the adjacent inner continental shelf. Comparisons between channel and adjacent shelf habitats are addressed in the light of ecological data.

Keywords: diversity, macrofauna, continental shelf, São Sebastião Channel, Brazil, South Atlantic Ocean.

Aspectos ecológicos de la macrofauna bentónica del Canal de São Sebastião, sudeste de Brasil

RESUMEN. Se estudió la organización y diversidad de la comunidad macrobentónica de fondos blandos del canal de São Sebastião, costa norte del Estado de São Paulo, Brazil, relacionándolo con variables sedimentológicas y carga orgánica del sedimento. Estos fondos marinos importantes para especies bentónicas se caracterizan por encontrarse próximos a fuentes de impacto antrópico. El muestreo se desarrolló estacionalmente a lo largo de un año, en 15 estaciones oceanográficas, con una draga Van Veen (0.1 m^2), desde noviembre de 1993 hasta agosto de 1994. Se identificó un total de 392 especies, correspondiendo los poliquetos aprox. al 50% de la fauna. De este total, 23 especies fueron las más abundantes y frecuentes. Las estaciones fueron clasificadas según el sedimento en tres grupos de acuerdo con Arasaki *et al.* (2004). El grupo de estaciones caracterizado por sedimentos finos presentó significativamente menos especies que los otros dos grupos. Las estaciones localizadas en el extremo sur del canal y en su eje longitudinal presentaron sedimentos con materia orgánica predominantemente de origen marino, reflejando el flujo de aguas del océano abierto a través del canal. Estas estaciones mostraron también mayores valores de diversidad y riqueza de especies. Por otro lado, el grupo de estaciones localizado del lado insular y en la boca norte del canal presentó mayores densidades. A pesar de ser un área relativamente pequeña, el ecosistema del canal de São Sebastião presentó una riqueza de especies semejante a la registrada en la plataforma continental interna adyacente. La comparación de ambos ecosistemas se discute considerando los datos ecológicos disponibles.

Palabras clave: diversidad, macrofauna, plataforma continental, Canal de São Sebastião, Brasil, océano Atlántico Sur.

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INTRODUCTION

The study of marine communities has been contributed to the understanding of coastal areas dynamics. The knowledge of community organization in function of space and time is an important tool for analyzing ecological aspects of the ecosystem, including the maintenance of species diversity, stability (Koenig, 1999; Gray & Elliot, 2009), functional diversity (Hewitt *et al.*, 2008) and biological niche invasion (Shea & Chesson, 2002). Environmental conditioning factors (such as sediment texture, oceanographic conditions and seasonal variation) can be frequently mixed up with sources of pollution (*e.g.* sewage discharges, oil pollution) being difficult to distinguish the effects of natural variation from anthropic effects on the faunal responses (Hyland *et al.*, 2005; Spellerberg, 2005).

The São Sebastião Channel is a peculiar area in the northern São Paulo State coast due the physical geography and oceanographic complexity (Furtado *et al.*, 2008). It separates the main coast from the large São Sebastião Island and acts as a tunnel for winds, since changes in direction and velocity of the marine currents and in patterns of sedimentation has been frequently observed (Castro, 1990). The oceanographic regime and eutrophic condition differ seasonally. In early spring near the bottom layer starts the intrusion of the South Atlantic Central Water (SACW), cold, saline and nutrient rich (Castro & Miranda, 1998) from the continental slope to the coast, which promotes pulses of eutrophication at mid depths (Braga, 1999). In the winter SACW retreats to the shelf break and inner shelf is filled with the warm, low saline Coastal Water (Silveira *et al.*, 2000). Besides, the area is affected by multiple human impacts. It houses the commercial port of São Sebastião, the oil terminal DTCS, which processes up to 55% of the Brazil's oil (Zanardi *et al.*, 1999a) and two sewage discharges. In spite of that, little is known about how the benthic fauna is structured or how diversity behaves in relation to species richness.

Few investigations dealt with composition and spatial patterns of macrofaunal species in the São Sebastião Channel (Flynn *et al.*, 1999; Muniz & Pires-Vanin, 2000), and with trophic relationships (Muniz & Pires, 1999). A functional analysis carried out recently using the AZTI's Marine Biotic Index highlighted the relationship between faunal abundance and human activity in the area (Arasaki *et al.*, 2004). However, a study about species diversity and distribution patterns of the assemblages is still lacking.

The present paper investigates the community structure of the benthic macrofauna from São Sebastião Channel on a spatial scale. We hypothesize that the macrofauna structure will differ along the channel due to changes associated with sediment type, organic matter variation and the oceanographic regime. Given the facts, we expect changes in the structure of the macrofauna assemblages in those sites where high amounts of organic matter are present and the SACW signal is stronger.

MATERIALS AND METHODS

Study area

The São Sebastião Channel is located on the northern coast of São Paulo State (23º41´-23º53.5´S, 45º19´-45º30´W), Brazil (Fig. 1). It is situated parallel to the coast and separates the continent from the São Sebastião Island. The channel is approximately 25 km long with two relatively large openings (6-7 km wide), and a nearly 2 km narrow central part. The distribution of sediments is heterogeneous, patchy, and reflects the complex hydrological regime of the area (Furtado, 1995). A wide fine and well sorted sand "plateau" is situated to the south and contrasts with the northern shallow coarse sand bank. Also in the north, a counter-clockwise vortex is responsible for the transport of fine grains to the south, promoting deposition of fine sediments at the continental margin (Castro, 1990). The central area is the deepest and narrowest part of the channel (about 40-45 m depth), and coarse grains found there mixed with mud are the consequence of the current speed increase due to the narrowing of the channel (Furtado, 1995).

According to Castro (1990), in the channel the current flow is highly variable through the year, both in direction and speed, and always moving toward the NE, except in summer, when a two-layer water structure appears, the surface one to the SW and the deeper directed to the NE. This bottom current is associated with the penetration of the low temperature (<20°C) and high salinity (>35.4) water mass – the South Atlantic Central Water (SACW) (Miranda,

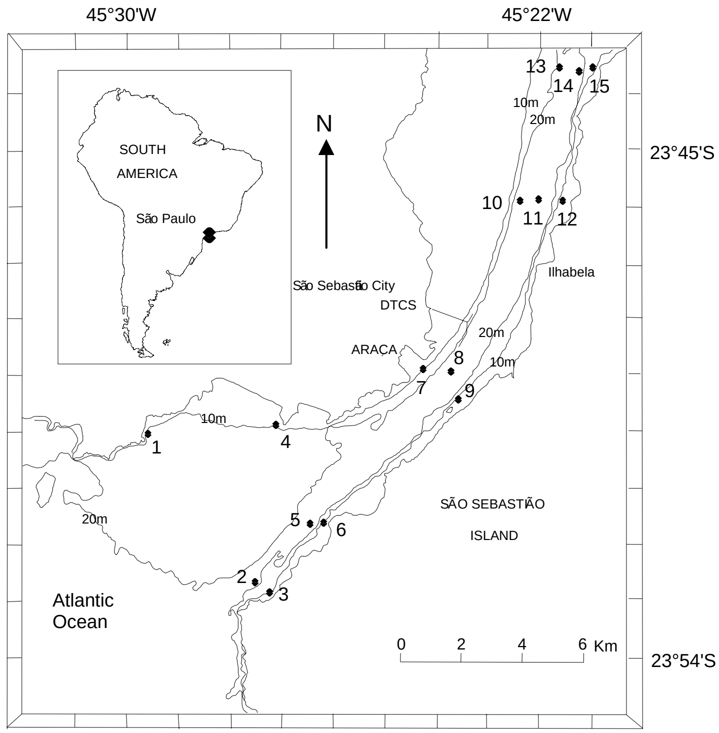

Figure 1. Study area with location of the 15 sampling stations. The isobaths corresponding to 10 and 20 m are indicated.

1985). The Coastal Water mass (CW) dominated in the other periods. The CW is associated with high temperatures (>24°C) and low salinities (<35), and is the result of mixing waters of small and medium-size estuaries from the south (Castro & Miranda, 1998).

The channel area is influenced by human activities as well, originated by frequent oil spills from the petroleum terminal DTCS - Duto e Terminais Centro Sul, a domestic sewage discharge of the sea outfall from Ponta do Araçá, and a commercial harbor (Zanardi, 1999a, 1999b).

Data collection

Four surveys were carried out at 15 oceanographic stations distributed in five radials perpendicular to the axis of the channel (Fig. 1), in November 1993, February, May and August 1994 on board of the boats "Veliger II" and "Albacora" from the University of São Paulo Oceanographic Institute. Stations were located with a GPS Garmin 128 and depths were measured by sounding with "Fish-Finder". Nansen bottles with digital thermometers were used to sample hydrographic data at each sampling station in three depth intervals of the water column (surface, mid-depth and bottom). The practical salinity scale (psu) was used to determine salinity; dissolved oxygen concentration was obtained by the Winkler titration method (Strickland & Parsons, 1968).

Sediment samples were obtained with a 0.1 m^2 Van Veen grab, in duplicate, at each sampling station situated between 8 and 45 m depth (Table 1). Nearly 200 g of the surface sediment was separated for granulometry, according to the standard dry-sieve and pipette method described in Suguio (1973). Folk and Ward's parameters were obtained and used for sediment type classification (Folk & Ward, 1957). Organic carbon and total nitrogen were determined using about 500 mg of freeze-dried and weighed sediment, decarbonated with 1M solution of hydrochloric acid, washed three times with deionized water, freeze-dried again and then analyzed in a LECO CNS 2000 analyzer. These values were also used to calculate C/N ratios of sedimentary organic matter. C/N ratios have often been used to distinguish between algal and land-plant origins of sedimentary organic matter (*e.g.*, Premuzic *et al.*, 1982; Jasper & Gagosian, 1990; Stein, 1991). This distinction arises from the absence of cellulose in algae and its abundance in vascular plants. Algae typically have C/N ratios between 4 and 10, whereas vascular land plants have C/N ratios of 20 and greater (Meyers, 1994).

For biological analysis the sediment was washed through 0.5 mm mesh sieve, and the material retained was preserved in 70% ethanol. The elutriation technique (Santos *et al.*, 1996) was applied before

Table 1. Abiotic variables from the sampling stations of São Sebastião Channel in the four seasons. S: salinity (psu); T: temperature; O_2 (%): percent saturation of oxygen; MS medium sand; FS: fine sand; C: organic carbon; Diam: mean diameter of the sediment.

Station	Depth (m)	S	T (ºC)	O_2 (mL L^{-1})	O_2 (%)	MS (%)	FS (%)	Silt (%)	Clay (%)	C (%)	C/N	Diam (φ)	Class
Spring													
1	15	33.59	20.71	3.85	74.9	11.7	85.46	0.23	0.00	0.07	7.00	2.98	Fine sand
2	26	34.18	20.42	3.72	72.2	0.25	12.42	59.07	28.25	1.92	16.00	6.35	Fine silt
3	10	32.53	21.64	4.70	92.4	21.24	14.63	0.52	0.00	0.71	14.20	0.72	Coarse sand
4	10	31.45	23.61	4.82	97.6	0.00	95.35	2.51	2.08	0.17	8.50	3.47	Very fine sand
5	23	34.79	19.69	3.08	59.2	2.12	79.37	10.45	6.96	0.61	12.20	3.44	Very fine sand
6	10	31.4	23.51	5.01	101.2	7.07	37.1	32.43	16.21	1.51	18.88	4.68	Coarse silt
7	10	31.6	23.1	4.65	93.4	0.37	32.23	49.85	17.45	1.69	21.13	5.64	Medium sand
8	45	35.57	16.81	3.84	70.2	8.13	18.23	38.53	14.62	1.20	13.33	4.25	Coarse silt
9	10	32.01	22.7	4.91	98.1	41.81	33.07	0.16	0.00	0.20	10.00	1.53	Medium sand
10	10	32.14	22.39	4.99	99.2	0.18	29.19	53.62	17.00	1.42	10.14	5.61	Medium silt
11	28	33.86	20.21	3.87	74.7	25.39	6.33	0.19	0.00	0.07	3.50	0.35	Coarse sand
12	9	31.42	22.36	5.09	100.7	10.78	50.91	23.65	9.46	0.88	17.60	3.85	Very fine sand
13	11	33,00	21.29	4.37	85.6	4.15	34.11	41.76	17.51	1.49	16.56	5.2	Medium silt
14	26	34.19	19.69	3.95	75.7	26.36	12.72	4.94	3.25	0.29	9.67	1.06	Medium sand
15	8	32.55	22,00	4.47	88.5	9.36	49.65	8,00	2.67	0.18	6.00	2.17	Fine sand
Summer													
1	15	34.97	29.85	4.25	101.1	1.05	90.14	8.65	0.00	0.19	9.50	3.47	Very fine sand
2	26	34.87	27.5	4.87	98.7	0.42	37.42	41.17	20.59	1.66	15.09	5.55	Medium silt
3	10	34.95	26.83	---	---	48.41	24.45	3.94	0,00	0.20	6.67	1.56	Medium sand
4	10	35.01	27.35	---	---	0.19	93.84	4.6	1.06	0.33	11.00	3.45	Very fine sand
5	23	35.34	24.58	---	---	0.49	89.48	8.56	1.07	0.63	21.00	3.25	Very fine sand
6	10	34.88	27.33	4.52	99.4	9.8	65.08	16.25	4.64	0.84	16.80	3.49	Very fine sand
7	10	34.76	27.9	4.65	103.1	0.36	37.57	44.87	16.98	1.26	9.69	5.51	Medium silt
8	45	35.31	22.86	3.95	80.7	6.54	14.65	49.22	18.62	1.38	5.52	5,00	Medium silt
9	10	34.76	27.97	4.71	104.6	38.9	35.07	0.00	0.00	0.08	4.00	1.55	Medium sand
10	10	35.07	28.27	4.87	108.9	0.09	29.5	55.48	14.94	1.51	7.95	5.42	Medium silt
11	28	35.15	23.21	4.25	87.3	38.56	19.45	4.25	1.06	0.17	5.67	1.35	Medium sand
12	9	34.84	26.89	4.59	106.7	12.38	15.97	11.02	18.73	0.47	11.75	3.18	Very fine sand
13	11	34.98	26.95	4.64	101.4	8.87	48.48	6.19	1.25	0.17	8.50	1.97	Medium sand
14	26	35.15	25.74	4.09	87.7	21.6	16.41	5.85	1.08	0.23	7.66	0.91	Coarse sand
15	8	35.35	26.29	4.36	94.5	0.63	38.03	46.28	14.72	1.53	12.75	5.31	Medium silt
Autumn													
1	15	34.79	24.49	3.31	69.3	0.14	94.01	5.8	0.00	0.12	6.00	3.47	Very fine sand
2	26	35.78	24.11	3.72	77.9	0.3	25.75	50.02	23.92	1.91	19.10	5.92	Medium silt
3	10	33.91	26.01	4.35	93.1	33.07	35.67	1.34	0,00	0.19	6.33	1.55	Medium sand
4	10	33.73	25.06	5.10	107.3	0.15	98.16	1.6	0,00	0.19	6.33	3.41	Very fine sand
5	23	35.29	24.16	3.49	72.9	0.48	71.16	19.2	9.04	0.69	8.63	4.2	Coarse silt
6	10	34.02	25.82	4.04	86.2	7.27	67.93	17.31	4.33	0.67	11.17	3.72	Very fine sand
7	10	33.95	25.21	4.52	95.4	0.26	20.92	61.16	17.47	1.81	18.10	5.91	Medium silt
8	45	35.50	23.16	4.04	83.0	13.14	18.58	25.71	11.57	1.05	15.00	3.24	Very fine sand
9	10	34.16	25.26	4.27	90.3	42.77	31.43	0.005	0.00	0.12	4.00	1.51	Medium sand
10	10	34.25	24.95	4.40	92.6	0.33	20.63	62.7	16.26	1.49	16.56	5.76	Medium silt
11	28	34.92	24.3	3.95	82.5	24.11	8.46	2.34	0.00	0.15	7.50	0.5	Coarse sand
12	9	34.56	24.25	4.32	90.0	6.1	49.34	31.71	9.76	1.24	17.71	4.22	Coarse silt
13	11	34.35	25.02	4.17	87.9	8.07	54.43	17.1	3.95	0.31	10.33	3.1	Very fine sand
14	26	34.76	24.31	4.78	99.8	16.81	12.65	8.26	1.18	0.29	9.67	0.83	Coarse sand
15	8	34.71	24.70	4.10	86.2	40.1	22.82	2.91	0.00	0.11	3.67	1.41	Medium sand
Winter													
1	15	33.16	20.41	4.14	80.0	9.82	85.42	1.93	0.00	0.05	2.50	3.08	Very fine sand
2	26	33.76	20.23	4.77	92.0	0.36	31.84	40.98	26.64	1.65	12.67	5.87	Medium silt

Station	Depth (m)	S	T (ºC)	O_2 (mL L^{-1})	O_2 (%)	MS (%)	FS (%)	Silt (%)	Clay (%)	C (%)	C/N	Diam (φ)	Class
3	10	33.24	20.40	4.92	95.1	7.39	80.14	11.51	0.00	0.43	8.60	3.04	Very fine sand
4	10	33.19	20.39	4.34	83.8	0.28	91.72	4.40	3.3	0.38	7.60	3.48	Very fine sand
5	23	33.16	20.39	4.86	93.8	1.22	86.23	8.86	3.32	0.50	8.33	3.13	Very fine sand
6	10	33.25	20.58	4.78	92.7	5.36	69.51	20.63	2.06	0.69	11.50	3.84	Very fine sand
7	10	33.60	20.71	4.93	95.9	0.21	17.8	58.80	23.1	1.70	14.16	6.15	Fine silt
8	45	33.84	20.68	5.11	99.7	9.63	19.48	39.75	15.46	0.82	11.71	4.52	Coarse silt
9	10	33.39	20.65	5.06	98.3	40.78	36.42	0.27	0.00	0.17	8.50	1.61	Medium sand
10	10	33.29	20.58	5.13	99.4	0.12	31,00	56.32	12.52	1.48	14.80	5.4	Medium silt
11	28	34.22	20.70	4.65	90.8	29.94	10.5	2.51	0,00	0.11	5.50	0.62	Coarse sand
12	9	33.78	20.53	4.73	91.9	17.82	44.5	14.11	4.03	0.52	10.40	2.54	Fine sand
13	11	33.74	20.60	5.15	100.2	8.16	68.82	7.46	1.24	0.51	12.75	2.72	Fine sand
14	26	34.10	20.64	5.12	96.1	26.51	14.28	9.09	3.41	0.3	7.50	1.22	Medium sand
15	8	34.05	20.66	5.16	100.5	32.75	19.94	9.28	5.3	0.41	10.25	1.86	Medium sand

sorting. To estimate biomass, species were pooled by taxonomic group and weighted (wet weight) with an analytical balance (0.001 g).

Data analysis

Density and biomass are expressed, respectively, in mean number of individuals and in g m^{-2}. Species richness (S), Shannon-Weaver diversity (H_e') and evenness (J') indexes were also calculated. Natural logarithm was used for calculating diversity in order to compare present data with those of previous works carried out in the adjacent continental shelf (such as Pires-Vanin, 1993, 2008). Species abundance data were pooled in three groups of stations, as reported in Arasaki *et al.* (2004) for São Sebastião Channel (SSC). According to these authors the bottom of the SSC may be divided in three different areas based on granulometry and sedimentary organic matter content: central area with muddy sediment and high levels of total organic matter (Group I); south and north areas characterized by mixed sediments and medium values of organic matter (Group II); coarse sandy area with low organic matter content situated along the São Sebastião Island side (Group III).

In the present paper, stations 2, 7, and 10 correspond to Group I, stations 1, 4, 5, 6 and 12 to Group II, and stations 3, 9, 11, 13, 14 and 15 to Group III. The ANOVA analysis was employed for testing differences of the biological parameters among the four cruises. Multiple Linear Regression models were used for identifying the relationships between biological and environmental variables (BioEstat 5.0, Ayres *et al.*, 2007), considering the significance level of 0.05.

RESULTS

The environment

Bottom water showed temperature near or higher than 20ºC along the channel and salinity varied between 31 and 35 psu. A seasonal pattern was detected, with large variation in spring (16.8 to 23.5ºC for temperature and 31.4 to 35 psu for salinity) and high homogeneity in winter (temperatures varying between 20.2 and 20.7ºC and salinities between 33.1 and 33.8 psu) (Table 1). In summer temperature was always high, reaching 29.85ºC at 15 m depth (station 1). The deepest station (station 8), located in the central area of the channel, presented the extreme values for both variables.

Temperature and salinity distributions indicate that Coastal Water (CW) filled the channel during the study period, except in spring when the cold and saline South Atlantic Central Water (SACW) occurred in the deepest part (station 8).

Oxygen saturation was generally high and values below 75% were found in few stations, at the south area of the channel, in spring and fall (Table 1). Sediments showed high heterogeneity along the channel with deposition of finer sands in the south entrance and coarse grains both in the north and insular side. The continental side and central area were dominated by pelitic fractions (silt and clay) associated with high values of organic carbon and nitrogen.

The highest values of organic carbon and total nitrogen were frequently found at stations 2, 7 and 10. Results of C/N ratio indicated the predominance of organic matter of marine origin at stations 1 and 11, during the four samplings, and also in the whole axis of the channel in summer. Conversely, organic matter of continental origin predominated at stations 7, 5 and 2 in spring, summer and fall, respectively, with values higher than 20 (Table 1).

Community analyses

A total of 23,456 individuals were obtained, of which 81% were identified at the species level (392 species). The remainder material was composed of juvenile specimens of various phyla that could not be identified. The fauna showed large variability in density, biomass and species richness considering the channel as a whole area in a temporal scale as can be seen by the large standard deviation of the means, especially in spring and winter (Fig. 2). This variability can be associated to the patchy sediment found in the channel bottom (Furtado *et al*., 2008) and/or to low sampling efficiency. Analysis of variance applied to the data showed no significant differences among data obtained in the four seasons, except for species richness (F = 3.09; *P* = 0.03). Richness was higher in the winter survey, and in summer and spring the values were smaller and similar.

In general, higher values of total abundance were recorded in winter (a total of 9,862 individuals, being 4,746 polychaetes) (Fig. 3) and lower in fall (2,601 individuals). Both summer and spring presented more similar numbers (4,640 and 6,152 respectively) (Table 2).

Considering all samples, the most abundant species in the study area were *Exogone arenosa* (71 ind m^{-2}), *Chone insularis* (44 ind m^{-2}), *Aricidea (Acmira) taylori* (33 ind m^{-2}), Lumbrineris *tetraura* (26 ind m^{-2}) and *Cirrophorus americanus* (23 ind m^{-2}). The first four species were most abundant in winter, whereas *C. americanus* and *Neanthes bruaca* were dominant in summer (17 and 10 ind m^{-2}, respectively). In spite of mollusks that were present in all seasons, the species showed noticeable spatial variation in distribution. For instance, all mollusks were absent in winter at station 2 and in fall at station 7, but in spring *Caecum striatum* and *C. pulchellum* were highly abundant and dominant at station 9 (352 and 192 ind m^{-2}, respectively), values higher than those of the most abundant polychaetes species.

Peracarida were the dominant crustaceans found in the samples, particularly the tanaid *Saltipedes paulensis* (18 ind m^{-2}), the amphipods *Phoxocephalopsis zimmeri* (12 ind m^{-2}) and *Ampelisciphotis podophthalma* (12 ind m^{-2}) and the isopod *Apanthura* sp. (8 ind m^{-2}). The tanaid were most numerous at stations 5 and 8 with moderate to high organic carbon content (groups I and II of stations) and the higher densities were exhibited by amphipods at places with fine sand and moderate content of organic carbon (Group III of stations). Each species peaked in a different season starting with *P. zimmeri* in spring, *M. cornutus* in summer and *A. podophthalma* in autumn. Decapoda were present in low abundance and species richness, standing out *Hexapanopeus paulensis* in summer and *H. schmitti* in winter (Table 3).

Ophiuroids were noticeable in winter, especially at station 8, where *Hemipholis elongata* dominated with a number of 296 ind m^{-2}. Other important but less numerous species were *Amphiodia atra, Ophioderma januarii* and *Ophiactis lymani* (Table 3).

The anthozoan *Edwardsia* sp. and the sipunculid *Aspidosiphon gosnoldi* were quite abundant in stations of Group III, the first species in those stations situated at the north mouth of the channel (13, 14 and 15), and the second species at station 9 in summer (84 individuals) and winter (100 individuals).

Density was similar among the surveys (F = 6.29, *P* = 0.09) with the highest mean value recorded in winter (658.87 ± 711.51 ind m^{-2}) and the lowest in fall (173.40 ± 171.13 ind m^{-2}) (Table 2, Fig. 2). The high numbers found at stations 8, 9, 14 and 15 were accounted mainly by polychaetes: *Exogone arenosa*, *Chone insularis* and *Cirrophorus americanus* (approximately 350, 300 and 250 ind m^{-2} respectively). On the other hand, lower values appeared generally at stations 2, 7 and 10 (between 25 and 96 ind m^{-2}), places dominated by subsurface deposit-feeders, such as the amphipod *Microphoxus cornutus*, and the ophiuroids *Amphipholis subtilis*, *A. squamata* and species of Alpheidae.

Biomass was also variable spatially but not temporally (F = 2.47, *P* = 0.48). Inversely to density, biomass dominance was shared among other groups besides Polychaeta (27%), as Mollusca (39%), Echinodermata (22%), Sipuncula (8%) and Crustacea (4%). In winter the highest value was due to the presence of the polychaete *Spirographis spallanzani* (with approximately 50 g each individual) and numerous and/or large ophiuroids as *Hemipholis elongata*, *Amphiodia atra* and *Ophioderma januarii*. The presence of bivalve species (Veneridae and Corbulidae) with their thick shells, besides the high abundance of the gastropods *Caecum pulchellum* and *C. striatum* increased the biomass values in spring (Fig. 3).

Species richness was high in the studied area, 392 species, but varied among stations (Table 2) and seasons (F = 3.09, *P* = 0.03). It ranged between 9 species at station 11 in fall and 72 species at station 13 in winter. Respecting species diversity, although

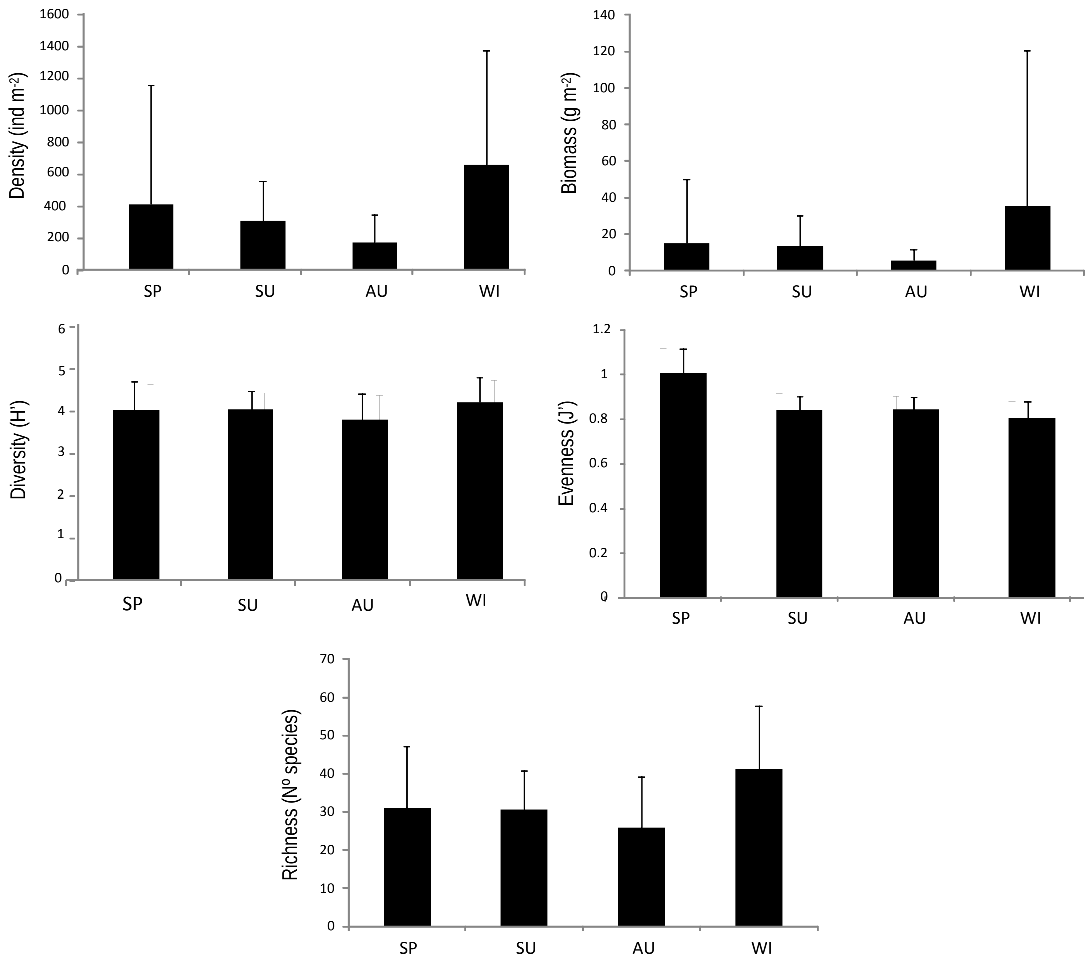

Figure 2. Mean values and standard deviation of density (nº ind m^{-2}), biomass (g m^{-2}), diversity (H'), eveness (J') and species richness for each sampling period. SP: Spring; SU: Summer; AU: Autumn; WI: Winter.

almost constant seasonally (F = 1.14, P = 0.34) it varied spatially, since the northern part of the channel showed the highest values (Table 2).

Evenness varied between 0.59 and 0.98 and in general followed the same trend of diversity. The lowest values were found at station 9 in spring and summer (Table 2) and are indicative of high dominance of few species. Seasonally, considering all the stations pooled, evenness was homogeneous (F = 0.66, P = 0.58) with low values of standard deviations (Fig. 2).

Multiple linear regressions applied to biological and environmental data showed that the model for richness fitted best and explained 55% of the variation in the data (Table 4). Diversity and species richness presented similar behavior, showing positive correlation with bottom water salinity, dissolved oxygen and sedimentary C/N, and negative correlation with bottom water temperature and organic carbon content in the sediments. The positive correlations point out places in the north area of the channel, such as stations 13 and 14 plus station 4 in summer. Unsuitable places, with low diversity and species richness, are linked to the negative correlations and in all sampled periods, and were represented by station 2, situated in the south axis of the channel. Density was positively correlated with bottom water dissolved oxygen and negatively correlated with temperature, which points out, respectively, the high number of individuals present in the northern stations and the depleted area at station 7. Regarding biomass, silt was in positive correlation and organic carbon in negative correlation, which reflects the high biomass of few large polychaetes present at the pelitic station 8, in winter, and the low biomass found in the sandy station 1. At this last station, a low number of tiny organisms, such amphipods, juveniles of carideans and gastropods, were found in the poorly enriched sediments.

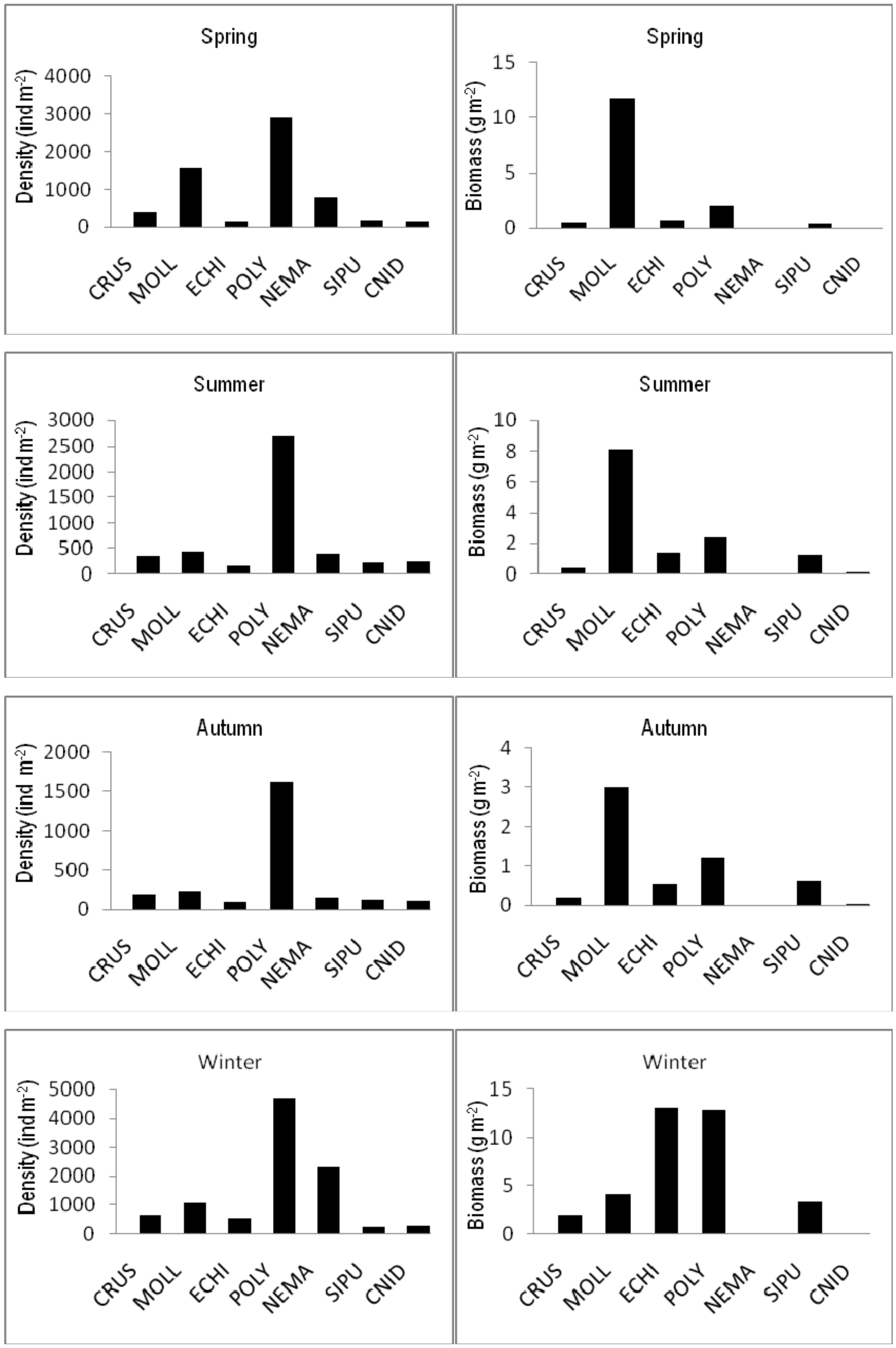

Figure 3. Density (ind m^{-2}) and biomass (g m^{-2}) of the main groups of macrofauna obtained in each sampling period. CRUS: Crustacea, MOLL: Mollusca, ECHI: Echinodermata, POLY: Polychaeta, NEMA: Nematoda, SIPU: Sipuncula, CNID: Cnidaria.

DISCUSSION

The present results showed that despite the existence of a major pattern in the sediment distribution on the São Sebastião Channel (Furtado, 1995), some temporal variation can occur, changing the bottom texture. Sediments are frequently suspended and settled by the wind driven marine currents, the Coastal

Table 2. Density (nº ind m^{-2}), biomass (g m^{-2}), species richness (R), diversity (H') and eveness (J') mean values of the stations and periods sampled in 1993-1994.

	Density	Biomass	R	H'	J'
Spring					
1	111	0.12	27	4.09	0.86
2	37	0.87	11	2.4	0.69
3	254	1.52	34	4.61	0.90
4	202	2.75	32	4.15	0.83
5	60	4.11	25	4.34	0.93
6	144	7.77	26	3.79	0.81
7	34	1.73	19	3.93	0.93
8	305	5.27	53	4.27	0.71
9	2944	15.45	64	3.59	0.59
10	25	1.09	12	3.5	0.98
11	208	137.07	10	3.12	0.94
12	151	0.35	21	3.03	0.69
13	104	1.23	42	4.97	0.92
14	1011	40.82	46	4.69	0.85
15	562	12.26	46	4.6	0.83
Summer					
1	173	2.39	28	3.7	0.77
2	96	1.34	22	3.62	0.81
3	653	37.81	28	3.98	0.83
4	252	5.13	44	4.02	0.74
5	174	1.49	42	4.25	0.79
6	266	22.47	28	4.18	0.86
7	53	3.3	19	3.81	0.90
8	174	2.37	20	3.73	0.88
9	606	29.98	30	3.14	0.64
10	55	4.89	23	4.31	0.95
11	801	56.83	50	4.74	0.84
12	252	3.96	38	4.8	0.92
13	466	20.71	37	4.43	0.85
14	580	9.6	36	4.35	0.84
15	39	0.46	15	3.42	0.88
Autumn					
1	92	2.99	33	4.13	0.83
2	51	4.49	14	2.67	0.70
3	196	7.1	16	3.39	0.85
4	229	7.13	50	4.54	0.80
5	65	0.98	21	3.48	0.79
6	68	2.78	23	3.93	0.87
7	24	0.78	14	3.55	0.93
8	89	1.55	19	3.13	0.74
9	190	4.68	19	3.61	0.85
10	46	2.07	19	3.72	0.88
11	60	0.84	9	2.87	0.90
12	93	17.39	26	4.09	0.87
13	322	5.47	44	4.72	0.87
14	604	22.59	50	4.77	0.84
15	472	4.05	32	4.24	0.85
Winter					
1	111	1.29	24	3.15	0.69
2	86	3.01	19	3.13	0.77
3	550	2.57	40	4.43	0.83
4	183	1.04	36	3.99	0.77
5	279	3.49	45	4.02	0.73
6	537	36.39	57	5.07	0.83
7	35	1.75	18	3.88	0.93
8	1689	332.94	58	4.34	0.74
9	2554	80.19	43	3.87	0.72
10	61	3.33	26	4.4	0.94
11	866	3.26	29	3.67	0.75
12	129	5.21	38	4.71	0.90
13	689	12.43	72	4.86	0.79
14	1159	16.54	53	4.48	0.78
15	955	30.31	61	4.84	0.82

Water and the South Atlantic Central Water, as consequence of the constant changes in wind direction and intensity (Castro, 1990; Furtado *et al.*, 2008). So, fine particles are deposited where the prevailing current strength permits, fact that modifies the nature of benthic assemblages in a scale of meters.

The role of fluid dynamics in benthic environment is well known, since it influences the type and size of substrate, the spatial configuration of habitat patches, the distribution of resources and the structure of biotic communities as well (Loreau, 2000; Austern *et al.*, 2002). There have been many studies dealing with the importance of physical processes on the disturbance of benthic systems, such as velocity and intensity of marine currents (Pastor de Ward, 2000; De Leo *et al.*, 2006) and storms (Posey *et al.*, 1996). In the southern Atlantic region, depth, temperature, water movement patterns and sediment type are considered the primary factors controlling species composition (Pires, 1992; Pires-Vanin, 1993; Absalão *et al.*, 2006). Sediment mobility, organic carbon and chlorophyll-*a* contents have also been implicated as influential factors at the regional scale (Sumida *et al.*, 2005; De Leo & Pires-Vanin, 2006; Venturini *et al.*, 2011). In the São Sebastião Channel the chemical alteration in part of the sea bed should be added due to the activities of the petroleum industry (Zanardi *et al.*, 1999a; Da Silva & Bicego, 2010), which increases the disturbance and complexity of the communities relationships. So, the heterogeneity of the fauna is probably maintained by a great variety of local physical disturbances that might be allied to alteration or loss of certain ecosystem processes such as flow of energy and the cycling of nutrients and carbon (Covich *et al.*, 2004; Kinzig *et al.*, 2002).

In the central-continental zone of the channel the prevalence of silt and clay fractions together with high content of organic carbon is a result of a north counter-clockwise vortex that transports fine grains to the south and deposits the finer sediment at the continental margin, region submitted to low hydrodynamics (Castro, 1990; Furtado, 1995). Due to the complex pattern of deposition found in the channel area, with sand banks in the south and north and mud bottom in the middle, it is expected that the variables linked to sediment be the most evident constraints of the faunal structure. The stations west of the channel, in the insular margin, especially stations 3, 9, 14, exhibited always the highest density values and relative high diversity values. Sandy sediments with organic matter, mainly of marine origin, were dominant in these places and, as usually occur on heterogeneous mixed bottoms, the diverse size and proportion of particles offer a variety of microhabitats

Table 3. Abundance of the main species found at each station group and sampling season in the São Sebastião Channel. G I corresponds to stations 2, 7, 10; G II to stations 1, 4, 5, 6, 12; G III to stations 3, 9, 11, 13, 14, 15 (groups are after Arasaki *et al.*, 2004).

	Spring			Summer			Autumn			Winter		
	GI	GII	GIII	GI	G II	GIII	GI	GII	GIII	GI	GII	GIII
Polychaeta												
Chone insularis			351			22			34		16	144
Exogone arenosa	1		316	2	3	205	3	11	51		21	664
Aricidea taylori	9	10	142	3		115	2	10	12	2	60	237
Neanthes bruaca	12	78	32	12		16	9		18		24	48
Magelona posterenlongata		27			75		3	28	18	12	56	
Lumbrinereis tetraura		24			96		1	20	187	1	2	105
Cirrophorus americanus	36			32	135		26		2	48	21	8
Mollusca												
Caecum striatum			601			8						192
Caecum pulchellum			462			8						
Corbula caribea	2		78	8	75	131	2	2	70	4	13	67
Sipuncula												
Aspidosiphon gosnoldi			42			84			50			100
Crustacea												
Microphoxus cornutus		13		1	30			7				
Phoxocephalopsis zimmeri	1		33	11	1				24			
Ampelisciphotis podophthalma								1	69			4
Apanthura sp.	1		50			24			6	1	2	1
Saltipedis paulensis	4	6	2	29	31	6		8	9	131	85	2
Hexapanopeus paulensis						21			4			
Hexapanopeus schimitti												18
Echinodermata												
Hemipholis elongata	1		32			10	1		4		6	
Ophiactis lymani			2			52						54
Amphiodia atra	3	4	20		47	12	2	8	6		14	46
Ophioderma januari			4			4			4			24
Edwarsia sp.	6		124		10	224			96	6		223
Chordata												
Branchiostoma platae			90			23		6	49		10	74
Total	76	162	2381	98	503	965	49	101	713	205	330	2011

and niches that favors the establishment and maintenance of many benthic species (Wood, 1987; Pastor de Ward, 2000).

During the study, the influence of temperature and salinity changes could be detected in the distributional patterns of the São Sebastião Channel macrofauna. Despite that the warm and less saline Coastal Water (CW) had filled the area, in almost all the occasions, in springtime at station 8, the central and deepest station, the signal of the South Atlantic Central Water (SACW) could be found. Correlation of diversity and richness with temperature and salinity data, most probably address the seasonal intrusion of the SACW. The spatial and temporal predominance of CW in the

Table 4. Multiple regression results for macrobenthic community parameters in the São Sebastião Channel. Signals of the partial regression coefficients of the significative variables and the respective *P* value are given. D: depth; S: salinity; T: temperature; O_2 (%): percent saturation of oxygen; CS: coarse sand; MS: medium sand; FS: fine sand; C: organic carbon. In bold are indicate the significant values.

	Density		Diversity		Evenness		Richness		Biomass	
F regression	4.37		3.72		2.14		9.22		3.94	
P value	0.001		0.003		0.06		0.0001		0.002	
R^2	0.37		0.33				0.55		0.35	
Variables	b	*P*-value	b	*P*-value	b	*P*-value	b	*P*-value	b	*P*-value
D	+	0.82	**-**	**0.04**			+	0.901	**+**	**0.0009**
S	+	0.14	**+**	**0.02**			**+**	**0.02**	-	0.51
T	**-**	**0.03**	**-**	**0.002**			**-**	**0.0001**	-	0.48
O_2	**+**	**0.001**	**+**	**0.01**			**+**	**0.0001**	+	0.03
CS	+	0.11	+	0.09			+	0.08	+	0.07
MS	+	0.18	+	0.22			+	0.21	+	0.12
FS	-	0.23	+	0.18			+	0.09	-	0.21
Silt	+	0.65	+	0.21			+	0.57	**+**	**0.01**
Clay	+	0.22	+	0.12			+	0.09	+	0.11
C	-	0.08	**-**	**0.02**			**-**	**0.008**	**-**	**0.005**
C/N	+	0.15	**+**	**0.01**			**+**	**0.0004**	+	0.11

area, conversely, could explain the lack of remarkable differences on density, diversity and richness of the fauna in the temporal approach. The negative correlation of those variables with temperature, and the positive correlation with oxygen content points out the low numbers of species and individuals found in the shallow group 1 of stations. However, the significant positive correlation of salinity, dissolved bottom oxygen and C/N, with diversity and species richness seems to differentiate the northern stations (12 to 15) from the rest of the area. At this part of the channel the counter clock-wise water circulation frequently occurs with the inflow from the south (Castro, 1990). As result, the periodical local disturbance of the sandy bottom, the organic matter may be constantly recycled and returned to the macrofauna disposal, fact that affects the ecosystem functioning (Loreau, 2000; Orians, 2000) as discussed earlier.

Despite the lack of statistical difference among the medium abundance values for each season, very low numbers were detected in places along the channel axis in autumn. This fact matches with the occurrence of dense populations of penaeid shrimps (*Litopenaeus schimitti* and *Xiphopenaeus kroyeri)* in the area, as pointed earlier for the Brazilian southern coast (Pires-Vanin *et al.*, 1997). Macrofaunal control of benthic community structure is well known (Bell & Coull, 1978; Nelson, 1981). Low abundance and low species richness of soft bottom macrobenthos were previously reported for the Brazilian shelf, and the evoked explanation was predation by *Xiphopenaeus kroyeri* (Pires-Vanin, 1993) and fish species (Rocha *et al.*, 2007; Soares *et al.*, 2008). In fact, nearly 83% of the demersal fishes (flaunders, gerreid and scienid spp.) found in the SSC, fed upon tubicolous crustaceans, penaeid shrimps and sub-surface polychaetes (Soares *et al.*, 2008) and predation was considered to be the mandatory factor for structuring benthic assemblages in these occasions (Muniz & Pires-Vanin, 2000).

Interaction among species can result in an increase or decrease in biodiversity (Orians, 2000). According to Ambrose Jr. (1993) the high density of ophiuroids can affect local species diversity, due to the effect of predation and bioturbation. The role of ophiuroids on infaunal abundance is not well established yet, although high densities were associated with low abundance of sedentary tubicolous polychaetes in the Arctic and deep-sea communities (Brenchley, 1981). In the present study this possible interaction seems not to occur because tubicolous polychaete and ophiuroids presented high densities at the same time, especially at station 8. A possible explanation could be linked to the lack of competition among them, since they explore the environment differently. In fact, *Spirographis spallanzani* is a suspension feeder, whereas the species of ophiuroids, *Amphiodia atra* and *Ophiactis lymani*, are deposit consumers (Arasaki *et al.*, 2004; Muniz & Pires, 1999).

Recently Muniz *et al.* (2005) classified the São Sebastião Channel as an undisturbed area in its major part, with few sites at the centre slightly disturbed by human impacts. The behavior of the structural variables studied herein indirectly attest the contamination of stations 7 and 10 submitted to effects of the Araçá sewage pipe and the DTCS oil terminal (Zanardi *et al.*, 1999b). Despite species richness and density appeared to be low on these places, the deposit feeders are large and represented by of one or two species of subsurface deposit-feeders. It is possible that chronic local contribution of petroleum hydrocarbons and domestic sewage may induce the enhanced growth of bacterial and diatom populations, a constant food source for subsurface deposit-feeders (Montagna *et al.*, 1987). Experimental studies and bioassays carried out with algal species in the area of the Araçá sewage pipe showed that algal growth improved several times in the vicinity of the submarine outfall (Lima, 1998). Also, *in situ* algal bioassays pointed out that the greater the quantity of sewage added the higher phytoplankton growth was (Lima, 1998). Benthic responses to variable organic loads are well established (*e.g*. Gray *et al.*, 2002; Hyland *et al*., 2005). However, sometimes the quality of food instead of quantity may limit distribution and metabolism of macrofauna (Pearson, 2001; Sumida *et al.*, 2005). Venturini *et al.* (2011) showed the organic enrichment and the prevalence of refractory material in sediments on the central area of the São Sebastião Channel and related the vertical distribution, abundance and functional structure of polychaete assemblages to those differences.

Recent modeling studies about dispersion of the Araçá submarine outfall indicated that the effluent is not efficient enough to comply with environmental standard, in accordance of CONAMA (Brazilian Environmental Council) resolution number 20 (Marcellino & Ortiz, 2001). Araçá sewer is stayed in an area with low values of current speed, making difficult the dispersion of the effluent. Furthermore, studies carried out in the area (Weber & Bicego, 1991; Ehrhardt *et al.*, 1995) have shown that the muddy region of the São Sebastião Channel receive an important amount of organic input from the sewage pipe and its sediments always present hydrocarbons derived from petroleum, probably from the DTCS oil terminal activities (Zanardi *et al.*, 1999a). The low density and diversity found at station 2 is probably linked to the presence of hydrocarbons. Zanardi *et al.* (1999b) reported that concentration of petroleum hydrocarbons was always high on the southern island margin (the present station 2 area) and addressed this finding to clandestine washing of oil tanks, frequent in that region.

In spite of the relative small area, when compared with the adjacent inner shelf, the channel presented high number of species, similar to that found in the adjacent São Sebastião shelf. Here, a total of 398 species were found in summer1994, and 352 spp. in early spring of 1997 (Pires-Vanin, 2008), considering the same depth range and sediment types sampled in the channel area. Both places, however, contrast in number of main species, 60 in the CSS and 98 in the shelf (Muniz & Pires, 2000; Arasaki *et al.*, 2004). Dominance and low number of species in common are contrasting as well (Pires-Vanin, 2008). The areas have been considered alike not only relative to the macrofauna and megafauna components (Pires-Vanin, 2008) but also in relation to the benthic fish composition and population structure. Rossi-Wongtschowski *et al.* (2008) showed that the channel presented Gerreidae and Hemulidae species associated with rocky substrates instead of the shelf dominant Scienidae, besides a major proportion of the adult stratum.

In conclusion, the benthic communities of the south and northern area of the São Sebastião Channel present high density and species diversity that contrasts with the unbalanced communities found at the central area. Here, the shallow or deep places are characterized by very few species and this finding confirms the hypothesis rose in this paper. The stations located at the south channel mouth and in the deep channel axis present sediments with organic matter predominantly of marine origin, indicating the path of the major flux of waters across the channel. Although in a relative small area, the channel presented high values of species richness. This discovery probably reflects the highly heterogeneous patchy surperficial sediments that increase the numbers of niches potentially open to the macrofauna (Loreau, 2000; Pastor de Ward, 2000; Austern *et al.*, 2002). However, the biological parameters evaluated did not present a striking seasonal variation and indicated that the communities were relatively stable through the year.

The present study pointed out that community structure and ecological relationships are favored both by the complexity and heterogeneity of the substratum and the marine current circulation, but may be disfavored by the anthropogenic activities developed in the central area.

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REFERENCES

Absalão, R.S., J. Moreira & J.S. Troncoso. 2006. Common environmental descriptors of two benthic amphi-atlantic mollusc assemblages. Braz. J. Oceanogr., 54(1): 65-73.

Ambrose Jr., W.G. 1993. Effects of predation and disturbance by ophiuroids on soft-bottom community structure in Oslo fjord: results of a mesocosm study. Mar. Ecol. Prog. Ser., 97: 225-236.

Arasaki, E., P. Muniz & A.M.S. Pires-Vanin. 2004. A functional analysis of the benthic macrofauna of the São Sebastião Channel (southeastern Brazil). P.S.Z.N.I. Mar. Ecol., 25: 249-263.

Austern, M.C., J. Lambshead, P. Hutchins, G. Boucher, C. Heip, G. King, I. Koike, C.R. Smith & P.V.R. Snelgrove. 2002. Biodiversity links above and below the marine sediment-water interface that may influence community stability. Biodivers. Conserv., 11: 113-136.

Ayres, M., M. Ayres Jr., D.L. Ayres & A.S. Santos. 2007. BioEstat 5.0. Aplicações estatísticas nas áreas das ciências biológicas e médicas. Instituto de Desenvolvimiento Sustententável Mamirauá, Belém, 364 pp.

Bell, S.S. & B.C. Coull. 1978. Field evidence that shrimp predation regulates meiofauna. Oecologia, 35(2): 141-148.

Braga, E.S. 1999. Seasonal variation of atmospheric and terrestrial nutrients and their influence on primary production in an oligotrophic coastal system-southeastern Brazil. Braz. J. Oceanogr., 47(1): 47-57.

Brenchley, G.A. 1981. Disturbance and community structure: an experimental study of bioturbation in marine soft-bottom environments. J. Mar. Res., 39: 767-790.

Castro, B.M. 1990. Wind driven currents in the channel of São Sebastião: winter. Bol. Inst. Oceanogr. São Paulo, 38(2): 111-132.

Castro, B.M. & L.B. Miranda. 1998. Physical oceanography of the western Atlantic continental shelf located between 4°N and 34°S coastal segment (4, W). In: A.R. Robinson & K.H. Brink (eds.). The sea. John Wiley, New York, pp. 209-251.

Covich, A.P., M.C. Austen, F. Barlocher, E. Chauvet, B.J. Cardinale, C.L. Bile, P. Inchausti, O. Dangles, M. Solan, M.O. Gessner, B. Statzner & B. Moss. 2004. The role of biodiversity in the functioning of freshwater and marine benthic ecosystems. BioScience, 54(8): 767-775.

Da Silva, D.A.M. & M.C. Bícego. 2010. Polycyclic aromatic hydrocarbons and petroleum biomarkers in São Sebastião Channel, Brazil: assessment of petroleum contamination. Mar. Environ. Res., 69: 277-286.

De Leo, F.C. & A.M.S. Pires-Vanin. 2006. Benthic megafauna communities under influence of the SACW (South Atlantic Central Water) intrusion onto the Brazilian southeastern shelf: a comparison between an under upwelling and a non-upwelling ecosystem. J. Mar. Syst., 60: 268-284.

Ehrhardt, M., R.R. Weber & M.C. Bicego. 1995. Caracterização da fração orgânica dissolvida nas águas do porto de São Sebastião e Praia do Segredo (CEBIMAR-USP), Canal de São Sebastião, São Sebastião, São Paulo, Brasil. Publção Esp. Inst. Oceanogr., São Paulo, 11: 81-86.

Flynn, M.N., M.T. Valério-Berardo, Y. Wakabara & V.K. Miyagi. 1999. Preliminary study of the spatial distribution of the benthic macrofauna of the São Sebastião Channel, southeastern Brazil. Oceánides, 14(2): 97-111.

Folk, R.L. & W.C. Ward. 1957. Brazos River bar: a study of the significance of grain size parameters. J. Sedim. Petrol., 27(1): 3-27.

Furtado, V.V. 1995. Sedimentação quaternária no Canal de São Sebastião. Publção Esp. Inst. Oceanogr., São Paulo, 11: 27-35.

Furtado, V.V., R.L. Barcellos, L.A. Conti, M. Rodrigues & M.M. Mahiques. 2008. Sedimentação. In: A.M.S. Pires-Vanin (org.). Oceanografia de um ecossistema subtropical, plataforma de São Sebastião, SP. EDUSP, São Paulo, pp. 141-180.

Gray, J.S. & M. Elliot. 2009. Ecology of marine sediments. Oxford University Press, New York, 225 pp.

Gray, J.S., R.S. Wu & Y.Y. Or. 2002. Effects of hypoxia and organic enrichment on the coastal marine environment. Mar. Ecol. Prog. Ser., 238: 249-279.

Hewitt, J.E., S.F. Thrush & P.D. Dayton. 2008. Habitat variation, species diversity and ecological functioning in a marine system. J. Exp. Mar. Biol. Ecol., 366: 116-122.

Hyland, J., L. Balthis, I. Karakassis, P. Magni, A. Petrov, J. Shine, O. Vestergaard & R. Warwick. 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. Mar. Ecol. Prog. Ser., 295: 91-103.

Jasper, J.P. & R.B. Gagosian. 1990. The sources and deposition of organic matter in the Late Quaternary Pygmy Basin, Gulf of Mexico. Geochim. Cosmochim. Acta, 54: 117-132.

Kinzig, A.P., S.W. Pacala & D. Tilman. 2002. The functional consequences of biodiversity: empirical progress and theoretical extensions. Princeton (NJ): Princeton University Press, 365 pp.

Koenig, W.D. 1999. Spatial autocorrelation of ecological phenomena. Trends Ecol. Evol., 14: 22-26.

Lima, G.M.S.S.B. 1998. Efeitos do efluente doméstico do emissário submarino de São Sebastião (SP), sobre o fitoplâncton marinho: estudos de campo e laboratório. PhD Thesis, Universidade de São Paulo, São Paulo, 160 pp.

Loreau, M. 2000. Biodiversity and ecosystem functioning: recent theoretical advances. Oikos, 91: 3-17.

Marcellino, E.B. & J.P. Ortiz. 2001. Sistematização dos projetos de emissários submarinos da sabesp e avaliação de desempenho através do modelo computacional CORMIX. Bol. Téc., EPUSP, São Paulo, 79: 1-20.

Meyers, P.A. 1994. Preservation of elemental and isotopic source identification of sedimentary organic matter. Chem. Geol., 114: 289-302.

Miranda, L.B. 1985. Forma de correlação T-S de massas de água das regiões costeira e oceânica entre o Cabo de São Tomé (RJ) e a Ilha de São Sebastião (SP), Brasil. Bolm. Inst. Oceanogr. São Paulo, 33: 105-119.

Montagna, P.A., J.E. Bauer, J. Toal, D. Hardin & R.B. Spies. 1987. Temporal variability and the relationship between benthic meiofaunal and microbial populations of a natural coastal petroleum seep. J. Mar. Res., 45(3): 761-789.

Muniz, P. & A.M.S. Pires. 1999. Trophic structure of polychaetes in the São Sebastião Channel (Southeastern Brazil). Mar. Biol., 134: 517-528.

Muniz, P. & A.M.S. Pires-Vanin. 2000. Polychaete associations in a subtropical environment (São Sebastião Channel, Brazil): a structural analysis. P.S.Z.N.I. Mar. Ecol., 21(2): 145-160.

Muniz, P., N. Venturini, A.M.S Pires-Vanin, L.R. Tommasi & A. Borja. 2005. Testing the appicability of a Marine Biotic Index (AMBI) to assessing the ecological quality of soft-bottom benthic communities in South America Atlantic region. Mar. Pollut. Bull., 50: 624-637.

Nelson, W.G. 1981. Experimental studies of decapod and fish predation on seagrass macrobenthos. Mar. Ecol. Prog. Ser., 5: 141-149.

Orians, G.H. 2000. Biodiversity and ecosystem processes in tropical ecosystems. Rev. Biol. Trop., 48(2/3): 297-303.

Pastor de Ward, C.T. 2000. Polychaete assemblages in the San José Gulf (Chubut, Argentina) in relation to abiotic and biotic factors. P.S.Z.N.I. Mar. Ecol., 21: 175-190.

Pearson, T.H., 2001. Functional group ecology in soft-sediment marine benthos: the role of bioturbation. Oceanogr. Mar. Biol. Annu. Rev., 39: 233-267.

Pires, A.M.S. 1992. Structure and dynamics of the benthic megafauna from the continental shelf offshore of Ubatuba, southeastern Brazil. Mar. Ecol. Prog. Ser., 86: 63-76.

Pires-Vanin, A.M.S. 1993. A macrofauna bêntica da plataforma continental ao largo de Ubatuba, São Paulo, Brasil. Publção Esp. Inst. Oceanogr., São Paulo, 10: 137-158.

Pires-Vanin, A.M.S. 2001. Identyfing the temporal component of biological variation in a marine benthic megafauna. Rev. Bras. Oceanogr., 49(1/2): 29-38.

Pires-Vanin, A.M.S. 2008. Megafauna e macrofauna. In: A.M.S. Pires-Vanin (org.). Oceanografia de um ecossistema subtropical, plataforma de São Sebastião, SP. EDUSP, São Paulo, pp. 311-349.

Pires-Vanin, A.M.S., T.N. Corbisier, E. Arasaki & A.M. Moellmann. 1997. Composição e distribuição espaço-temporal da fauna bêntica no Canal de São Sebastião. Relat. Téc. Inst. Oceanogr., 41: 29-46.

Posey, M., W. Lindberg, A. Troy & F. Vose. 1996. Influence of storm disturbance on an offshore benthic community. Bull. Mar. Sci., 59(3): 523-529.

Premuzic, E.T., C.M. Benkovitz, J.S. Gaffney & J.J. Walsh. 1982. The nature and distribution of organic matter in the surface sediments of world oceans and seas. Org. Geochem., 4(2): 63-77.

Rocha, G.R.A., C.L.B. Rossi-Wongtschowski, A.M.S. Pires-Vanin & L.S. Soares. 2007. Trophic models of São Sebastião Channel and continental shelf systems, SE Brazil. PANANJAS, 2(2): 149-162.

Rossi-Wongtschowski, C.L.B., L.S. Soares & E.Y. Muto. 2008. Ictiofauna. In: A.M.S. Pires-Vanin (org.). Oceanografia de um ecossistema subtropical, plataforma de São Sebastião, SP. EDUSP, São Paulo, pp. 381-403.

Santos, M.F.L., A.M.S. Pires & P. Muniz. 1996. A simple and efficient device for sorting large marine benthic samples. Rev. Bras. Oceanogr., 44(1): 57-60.

Shea, K. & P. Chesson. 2002. Community ecology theory as a framework for biological invasions. Trends Ecol. Evol., 17(4): 170-176.

Silveira, I.C.A., A.C.K., Schmidt, E.J.D. Campos, S.S. Godoi & Y. Ikeda. 2000. A corrente do Brasil ao Largo da Costa Leste Brasileira. Braz. J. Oceanogr., 48: 171-183.

Soares, L.S., E.Y. Muto, M.R. Gasparro & C.L.B. Rossi-Wongtschowski. 2008. Organização trófica dos peixes. In: A.M.S. Pires-Vanin (org.). Oceanografia de um ecossistema subtropical, plataforma de São Sebastião, SP. EDUSP, São Paulo, pp. 405-425.

Spellerberg, I.F. 2005. Monitoring ecological changes. Cambridge University Press, Cambridge, 399 pp.

Stein, R. 1991. Accumulation of organic carbon in marine sediments. Results from the deep-sea drilling project/ocean drilling program. Lecture Notes in Earth Sciences, Springer-Verlag, Berlin, 34: 217.

Strickland, J.D.H. & T.R. Parsons. 1968. A practical handbook of sea water analysis. Bull. Fish. Res. Bd. Can., 167: 1-311.

Suguio, K. 1973. Introdução à sedimentologia. Edgard Blücher/EDUSP, São Paulo, 317 pp.

Sumida, P.Y.G., M.Y.Yoshinaga, A.M. Ciotti & S.A. Gaeta. 2005. Benthic response to upwelling events off the SE Brazilian coast. Mar. Ecol. Prog. Ser., 291: 35-42.

Venturini, N., A.M.S. Pires-Vanin, M. Salhi, M. Bessonart & P. Muniz. 2011. Polychaete response to fresh food supply at organically enriched coastal sites: Repercussion on bioturbation potential and trophic structure. J. Mar. Syst., 88: 526-541.

Weber, R.R. & M.C. Bicego. 1991. Survey of petroleum aromatic hydrocarbons in the São Sebastião Channel, SP, Brazil, November 1985 to August 1986. Bolm. Inst. Oceanogr., São Paulo, 39(2): 117-121.

Wood, E. 1987. Subtidal ecology. Edward Arnold, London, 124 pp.

Zanardi, E., M.C. Bicego & R.R. Weber. 1999a. Dissolved/dispersed petroleum aromatic hydrocarbons in the São Sebastião Channel, São Paulo, Brazil. Mar. Pollut. Bull., 38(5): 410-413.

Zanardi, E., M.C. Bicego, L.B. Miranda & R.R. Weber. 1999b. Distribution and origin of hydrocarbons in water and sediment in São Sebastião, SP, Brazil. Mar. Pollut. Bull., 38(4): 261-267.

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