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Environmental variables and intertidal beach annelids of São Sebastião Channel (State of São Paulo, Brazil)

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Abstract: Benthic annelid communities were studied during a one-year period (August/95 to July/96) in two sectors of the beaches Engenho d'Água and São Francisco, São Sebastião Channel (São Paulo, Brazil), where the substrate is composed by a mixture of sand and rock fragments. Abiotic parameters such as salinity of interstitial water and sediment properties were used to characterize the environment. The polychaetes were well represented in the two sectors and their distribution was related with sediment type. The density of individuals and the number of taxa was higher at São Francisco, while the diversity and the evenness were higher at Engenho d'Água. This difference can be a consequence of organic enrichment caused by domestic input, and of the lower and more variable salinity at São Francisco. Due to these factors, the high density of opportunistic species, like *Capitella capitata* ssp., *Scolelepis squamata, Laeonereis acuta* and several oligochaetes, represented 75.5% of total abundance at this sector.

Key words: Sand with rock fragments beach, intertidal zone, annelids, polychaetes, São Sebastião Channel, Brazil.

Sandy beaches, as important coastal ecosystems, shelter a high diversity of taxonomic groups that form considerable links in the marine food web (Feder and Jewett 1981). The species diversity, abundances and dominance of sandy beach communities is often associated with environmental conditions such as salinity, temperature, dissolved oxygen, tide variations, wave action, topography, and granulometry (Snelgrove and Butman 1994, McLachlan 1996). Interactions between these factors are responsible for the stability of the system, and alterations caused directly or indirectly by humans may disrupt the system and it may take a long time for recovery (Pearson and Rosenberg 1978).

Polychaetes are important representatives of the marine benthic macrofauna and have often been utilized in environmental monitoring programs as their diversity and relative abundances may be an indication of environmental disturbance (Choi and Koh 1984, Pocklington and Wells 1992). In sheltered beaches macrofauna from the intertidal zones may dominate and the polychaetes are usually the more abundant group (Brown and McLachlan 1990, Amaral *et al.* 1995).

Opportunistic species have been receiving great attention in studies of organically enriched areas because they can be used to characterize the degree of impact that has affected a certain locality (Grassle and Grassle 1974). The capitelid polychaetes, specially the *Capitella capitata* "complex", are classified as r-strategists, having the ability to colonize new habitats quickly (Tsutsumi 1990). In undisturbed conditions these r-strategist species are replaced by k-strategist species (Pianka 1970, Gray 1981) which, with rare exceptions, dominate numerically in the community.

The aims of this study were to evaluate the influence of environmental variables in the density, frequency, diversity and evenness of annelids in an intertidal environment at two beaches of São Sebastião Channel (Engenho d'Água and São Francisco) and to compare to results obtained in previous studies. The data of spatial and temporal distribution were analysed in Rizzo and Amaral (in press).

MATERIALS AND METHODS

The beaches at Engenho d'Água and São Francisco are located in the northern part of São Sebastião Channel (between 45°21'W, 23°43'S and 45°27'30"W, 23°52'30"S). São Francisco Beach is more densely populated then Engenho d'Água Beach due to the intense flow of tourists in the summer and by harbor activities, due the presence of the largest oil terminal in the country "Dutos e Terminais Centro Sul" (DTCS – Central and Southern Ducts and Terminals). The substrate found at the studied localities is composed by a mixture of sand and rock fragments, presenting a high environmental complexity (Rizzo and Amaral 2000).

Between August 1995 and July 1996, samples were collected in the intertidal zone at the beaches Engenho d'Água (180 samples) and São Francisco (180 samples). At each beach, a 10 m-wide sector was established with an amplitude corresponding to the extension of the intertidal zone. These sectors were defined using visual markers. The samples were taken during the syzygy tides using a cylindrical sampler with an area of 0.01 m^2 which was inserted in the sediment to a depth of 20 cm.

In order to characterize the system, granulometry and organic matter in the sediment (36 samples/sector) were sampled seasonally. Sediment temperature and salinity of the interstitial water (108 samples/sector) were sampled monthly.

Biological samples were washed with sea water and sieved using 1.0 mm and 0.5 mm mesh screens and the organisms anesthetized with magnesium chloride, fixed in 4 % formaldehyde, and later preserved in 70 % ethanol.

The salinity of the interstitial water was evaluated using a portable Goldberg T/C refractometer, model 10419. Samples of water were collected and sent to CETESB (Companhia de Tecnologia e Saneamento Ambiental) for the analysis of fecal coliforms. According to the resolution of CONAMA Nr. 20/1986, beaches with fecal coliform counts greater than 1 000/100 ml of water are considered inappropriate for resorts. The organic matter content was analyzed according to Amoureux (1966) while granulometric analysis was accomplished using the technique proposed by Suguio (1973). A program developed at the sedimentology laboratory of the Institute of Geosciences, University of São Paulo, was used to obtain the statistical parameters of Folk and Ward (1957).

The environmental variables were submitted to the analysis of factorial variance to test the inequalities between the two sectors. The salinity of the interstitial water and the temperature of the sediment were tested using the factorial type model elaborated with beach and month factors while the model used for the sedimentary parameters (mean grain size, selection coefficient and organic matter) utilized beach and season (SAS program v. 6.0).

Species diversity and evenness were assessed using the Shannon-Wiener index (H') (Krebs 1986). In many of the samples each species was represented by only a few individuals, and consequently there were few numerically dominant species. To express the results in a better way, graphs of absolute abundance were elaborated (Fig. 1).The binary index of Jaccard was used to compare the similarity between the communities of the two sectors. The Jaccard index ranges from 0 (no similarity) to 1 (total similarity) and was calculated using the KREBS Program (Valentin 1995).

RESULTS

Environmental variables: The maximum and minimum values, as well as the mean and standard deviation of the main parameters analyzed, are shown in Table 1. The granulometry of the sediment, both in the Engenho d'Água sector and at São Francisco, showed a typical sandy constitution with very coarse and fine sand occurring in both sectors. The largest range in grain size was found at São Francisco (-0.67 – 2.36 phi), suggesting an accentuated heterogeneity. During most of the year, medium (54.2 %) and coarse (40.2 %) sand predominated at Engenho d'Água and coarse (54.9 %) and very coarse (32.4 %) sand at São Francisco. The medium diameter of the grain differed statistically in the analysis of variance ($F = 0.0019$; $p < 0.001$) undertaken to test the inequalities between the two sectors.

The values of the selection coefficient varied from 0.70 (Engenho d'Água) to 1.97 (São Francisco) and they are moderately to poorly selected. For this parameter, the means observed in the two sectors were very close, while the standard deviation was larger at São Francisco (0.67).

The concentration of organic matter had a larger amplitude of variation at São Francisco (0.04 to 5.84 %) which is located close to the exit of a domestic sewer. At Engenho d'Água organic matter values were more homogeneous (0.63 to 2.65 %), however, significant statistical differences were not verified between the two sectors.

The means of the sediment temperature were the same at the two sectors, although the standard deviation was larger at São Francisco (4.4) due to the extreme values caused by seasonal variations.

The salinity also showed a wide variation in both sectors, reaching a minimum value of 4‰ at Engenho d'Água and a maximum value of 34 ‰ at São Francisco. The more extreme variations occurred at São Francisco which had a mean value of 26.35 ‰ and a standard deviation of 5.35 ‰, showing a significant difference ($F = 0.0001$; $p < 0.001$) between the two environments.

The analysis of fecal coliforms in the São Francisco sector revealed a water quality index (800 NMP) that was very close to the tolerable limit for resorts, while Engenho d'Água can be considered as having an excellent water quality (11 NMP).

Species composition: Table 2 presents the occurrence, density, diversity and evenness values for the species of annelids found during the sample period at Engenho d'Água and São Francisco sectors. A total of 2 869 individuals were collected, distributed among 60 taxa belonging to 26 polychaete families and one oligochaete family. At Engenho d'Água, *Timarete filigera* (22.1 %), *Nematonereis hebes* (18.1 %), *Scyphoproctus djiboutiensis* (9.4 %) and *Owenia fusiformis* (8.1 %) were the most abundant species amounting to 57.7 % of the individuals collected in this sector. São Francisco had the largest number of individuals sampled (67.8 %) with only four species, *C. capitata* ssp. (33.4 %), *Scolelepis squamata* (23.9 %), *Laeonereis*

TABLE 1

Variation in the environmental parameters between August 1995 and July 1996

	Engenho d'Água		São Francisco	
Parameter	Min./Max.	Mean/S.D.	Min./Max.	Mean/S.D.
Granulometry*	VCS-FS	-	VCS-FS	-
Mean grain size (f)	-0.08-2.17	1.09 ± 0.34	-0.67-2.36	0.17 ± 0.68
Selection coefficient (S)	0.70-1.65	1.35 ± 0.07	0.72-1.97	1.42 ± 0.67
Organic matter (%)	0.63-2.65	1.48 ± 0.39	0.04-5.84	1.25 ± 0.68
Salinity (‰)	4-33	30.43 ± 3.39	7-34	26.35 ± 5.35
Sediment temperature (ºC)	17.25-28	23.2 ± 3.1	15.5-32	23.2 ± 4.4
Fecal coliforms (MPN)**	2-11	-	500-800	-

* VCS = Very coarse sandy; FS = Fine sandy; ** MPN = More probable number (per 100 ml of water).

Table 2
Occurrence, density (ind/1.8 m^2), diversity and evenness of the species at Engenho d'Água and São Francisco sectors between August 1995 and July 1996

Family	Species	Engenho d'Água	São Francisco
Polychaeta			
Sigalionidae	*Sthenelais boa* (Johnston, 1839)	4	1
Amphinomidae	*Eurythoe complanata* (Pallas, 1766)	6	11
	Pseudoeurythoe ambigua Fauvel, 1932		1
Phyllodocidae	*Anaitides madeirensis* (Langerhans, 1880)		1
Hesionidae	*Ophiodromus pugettensis* (Johnson, 1901)	3	2
Pilargidae	*Ansistrosyllis jonesi* Pettibone, 1966	5	
	Parandalia americana (Hartman, 1947)		1
	Sigambra grubii Müller, 1858	1	20
Syllidae	*Langerhansia cornuta* (Rathke, 1843)	8	6
Nereididae	Nereididae Undetermined		2
	Laeonereis acuta Treadwell, 1923	3	143
	Neanthes sp.	19	1
	Platynereis dumerilii (A. and M. Edwards, 1834)	1	2
Goniadidae	*Glycinde multidens* Müller, 1858	9	14
	Goniada littorea Hartman, 1950	2	5
Glyceridae	*Hemipodus californiensis* Hartman, 1938		1
Onuphidae	*Diopatra cuprea* (Box, 1802)	12	5
	Mooreonuphis lineata Lana, 1991		1
Eunicidae	*Marphysa formosa* Steiner and Amaral, 2000		45
	Marphysa sebastiana Steiner and Amaral, 2000	10	27
	Nematonereis hebes Verril, 1900	167	3
Lumbrineridae	*Lumbrineris tetraura* (Shmarda, 1861)	2	14
Dorvilleidae	*Dorvillea* sp.		1
Orbiniidae	*Naineris setosa* (Verril, 1900)	55	35
	Scoloplos (Leodamas) dubia Tebble, 1955		6
	Scoloplos treadwelli Eisig, 1914		10
Spionidae	Spionidae Undetermined	1	
	Boccardia redeki Okuda, 1937		2
	Dispio uncinata Hartman, 1951		5
	Polydora websteri Hartman, 1943		1
	Prionospio heterobranchia Moore, 1907	33	5
	Scolelepis squamata (Müller, 1806)	3	466
Magelonidae	*Magelona papillicornis* Müller, 1858	16	2
Poecilochaetidae	*Poecilochaetus australis* Nonato, 1963		3
Cirratulidae	*Timarete filigera* (Delle Chiaje, 1825)	204	63
	Cirriformia tentaculata (Montagu, 1808)	12	2
Opheliidae	*Armandia agilis* Andrews, 1891	1	
Capitellidae	Capitellidae Undetermined	2	
	Capitella capitata ssp.	18	651
	Capitomastus minimus (Langerhans, 1881)	2	61
	Heteromastus filiformis (Claparède, 1869)	54	55
	Mediomastus californiensis Hartman, 1944	15	22
	Notomastus hemipodus Hartman, 1945	4	
	Notomastus lobatus Hartman, 1947	40	
	Notomastus sp.	1	
	Scyphoproctus djiboutiensis Gravier, 1906	87	6
Oweniidae	*Owenia fusiformis* Claparède, 1970	75	
Pectinariidae	*Pectinaria laelia* Nonato, 1981		3

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Ampharetidae	*Isolda pulchella* Müller, 1858	37	23
Terebellidae	Terebellidae Undetermined	2	1
	Loimia medusa (Savigny, 1818)		1
	Pista corrientis McIntosh, 1885		2
	Polycirrus plumosus (Wolleback, 1912)	1	
Trichobranchidae	*Terebellides anguicomus* Müller, 1858		1
Sabellidae	Sabellidae Undetermined	1	
	Branchiomma nigromaculata (Baird, 1865)	2	1
	Pseudobranchiomma sp.	1	
	Megalomma bioculatum (Ehlers, 1867)	1	
	Megalomma sp.	1	
Oligochaeta			
Tubificidae	*Tubifex* sp.	2	212
Number of Individuals (1.8 m^2)		923	1946
Number of Species		42	47
Shannon's Diversity (H')		3.839	3.179
Evenness (E)		0.712	0.572

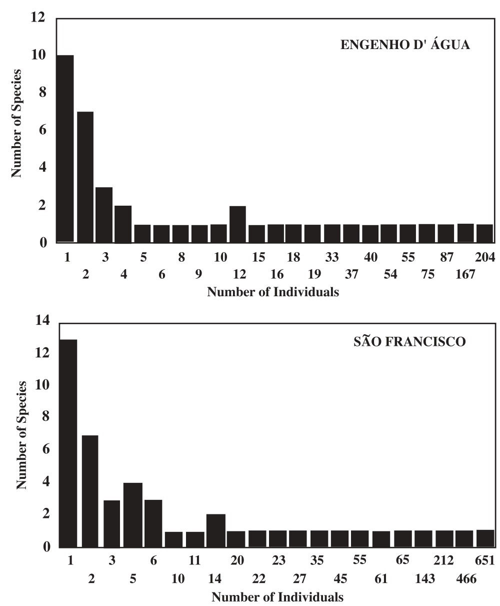

Fig. 1. Absolute abundance of species obtained between August 1995 and July 1996 at Engenho d'Água and São Francisco sectors (the bars on the left indicate the occasional species).

acuta (7.3 %) and the oligochaete Tubificidae (10.9 %) making up 75.6 % of the total number of individuals.

Of the 47 species that occurred at São Francisco and of the 42 species that occurred at Engenho d'Água, 29 were common to both sectors. Eighteen were exclusive to São Francisco and 13 to Engenho d'Água. Comparing the two sectors, the Jaccard index of similarity was 0.659 indicating a 66 % similarity between the two annelid communities.

Although the number of species found at São Francisco is larger than at Engenho d'Água, the indexes of Shannon-Wiener (H') showed that the diversity (3.839 bits/ind.) and the evenness (0.712) were higher at Engenho d'Água than at São Francisco (H' = 3.179; E = 0.572) due to a lower level of numerical dominance by a few species. Fig. 1 shows how these species behave when plotted in an absolute abundance graph.

DISCUSSION

The number of species of polychaetes found at Engenho d'Água and São Francisco sectors are probably related to the substrate which is a mixture of fine to very coarse sand and rock fragments at both sites, presumably providing a wide variety of niches and, consequently, minimizing the interspecific interactions. A study in the Bay of Kwangyang (Korea) showed that the community of polychaetes had a larger density in sand-mud sediment and a tendency to decrease in abundance in finer sediment (Choi and Koh 1984). Even so, these authors concluded that the mixture of sediments can be more advantageous for an increase in the diversity and abundance.

Although the studied beaches do not appropriately fit in to the classification established by

Wright and Short (1984) they can be characterized as protected due to contrasting characteristics such as minimum wave action and little slope besides they are sheltered inside São Sebastião Channel. Such beaches composed by sand with rock fragments are commonly denominated in the literature as mixed rock and sand beach (Brown *et al.* 1991).

For Dexter (1988) the degree of exposure can be a decisive factor for the establishment of macrofauna at sand beaches. The macrofauna of sheltered beaches is characterized by higher density and diversity than that of exposed beaches (Allen and Moore 1987). This was supported by Amaral *et al.* (1995) and Denadai and Amaral (1999) who studied some aspects of the intertidal zone macrofauna of beaches of São Sebastião Channel and found a higher species diversity and density specific of a lower energy beach. However, the stability of the São Francisco Sector has been disturbed by the effects of domestic sewage on sediment, altering the salinity and organic matter values and consequently the faunistic composition.

In terms of granulometric composition, the predominance of coarse and very coarse sand at São Francisco is related to the rains and intense winds that caused strong breakers in the summer, mixing the sediments and depositing larger particles in the lower levels of the intertidal zone. According to Fontes (1996), the circulation of currents in the summer occurs in two layers: the superficial layers flow predominantly in a south-westerly direction by the predominating winds while the deep currents flow towards the NE, probably under the influence of intrusions that occur near the southern insular margin of channel. That process can partly explain the significant difference between the medium diameter of the grains observed at each sector.

The São Francisco Sector, located a few meters away from an exit of a domestic sewage, revealed a water quality index very close to the limit tolerated for bathing. Although significant differences were not observed between organic matter at Engenho d'Água and São Francisco, the organic content in the sediment is considered a source of constant food for detritivores and suspension feeders (Snelgrove and Butman 1994), but not always is well quantified and depend of the method employed. The organic particulate material can be of autochthonous (plant fragments, feces) or allochthonous (transported by oceanic currents, fluvial channels or wind) origin. At Engenho d'Água, the concentration of organic matter may be a result of the decomposition of algae remains, or of the angiosperm *Halodule*, which is abundant in the area (Amaral *et al.* 1995). At São Francisco, besides the decomposition of animal and plant remains, untreated waters of domestic origin, may have contributed to the maximum value of organic matter (5.84 %).

Some organisms tolerate some degree of pollution. According to Pearson and Rosenberg (1978), species or group of species associated with organic enrichment tended to be ubiquitous, but the behavior of these species in relation to the organic enrichment is similar, independent of their geographical location. Associations between one or more species of capitelid, spionid, nereid polychaetes and/or species of oligochaetes are common in studies of stressed environments. This may be the case for *C. capitata* ssp., *S. squamata* and of the oligochaetes which contribute with 68.3 % of the total of individuals sampled at São Francisco.

In studies accomplished at São Sebastião Channel, like those of Amaral *et al.* (1990) another association was observed, *Heteromastus filiformis*, *Tubifex* sp. and *Kalliapseudes schubarti*. This tanaidacean occurs in large numbers in the Araçá region (São Sebastião) and is considered an r-strategist and opportunist (Leite 1989).

In this study, *C. capitata* ssp. was the dominant species reaching 651 ind/1.8 m^2 in the most eutrophic sector (São Francisco). The other capitelids, *Capitomastus minimus*, *H. filiformis*, *Mediomastus californiensis*, *Notomastus hemipodus*, *N. lobatus* and *Scyphoproctus djiboutiensis* constituted 12 % of all the collected individuals. The *C. capitata* "complex" tolerates a wide variation in salinity and depth, occurring from estuaries to the deep sea. The biological activities of *Capitella*, such as feeding and bioturbation can aid in the decomposition of organic matter and in the oxidation of sulfites in the sediment (Chareonpanich *et al.* 1994).

The second most common species, *S. squamata*, is commonly found in the intertidal zone of beaches in São Paulo State (Amaral 1979, Amaral *et al.* 1990, Corbisier 1991, Shimizu 1995) and Paraná State (Souza and Gianuca 1995). It is a generalist species, ingesting sand particles of several sizes, and can also be predacious and/or coprophagous (Dauer 1983). It preferentially inhabits fine sand sediments (Shimizu 1995) with low amounts of silt and clay (Corbisier 1991). It adapts easily to different environmental pressures, such as great salinity oscillations (Amaral 1979), biological contamination and oil spills (Shimizu 1995). In São Francisco, the high density of *S. squamata* does not seem to be associated directly to the type of sediment, but to the local hydrodynamism and organic enrichment.

Laeonereis acuta occurred at a high density at Enseada Beach, was abundant at São Francisco (7.3 % of the total number) and was also frequently found at the beaches studied by Omena and Amaral (1997) in São Sebastião, SP. This species tolerates great salinity variations, being common in estuaries. In Bahia Blanca, Argentina, the highest recorded abundance of *L. acuta* (1 024 ind/m^2) was at the greatest salinity gradient 31.9 ‰ (Elias and Ieno 1993). On the other hand, the occurrence of *L. acuta* and *S. squamata* in the estuarine system of Santos (SP), was related to the low salinity of the interstitial water (Corbisier 1991). At São Francisco, *L. acuta* reached its largest densities (29 to 47 ind/0.15m^2) when the salinity was between 16 and 31 ‰.

Compared to the São Francisco Sector, Engenho d'Água had a reduced number of species and individuals. The most abundant species at Engenho d'Água were *Timarete filigera, Nematonereis hebes, Scyphoproctus djiboutiensis* and *Owenia fusiformis*. Amaral *et al.* (1995) registered low densities and number of species at Engenho d'Água, with *O. fusiformis* the only dominant. In this study, *O. fusiformis* is also one of the dominant species with 75 ind/1.8 m^2. These values are relatively low when compared to those obtained at the Seine Bay (English Channel), that reached densities superior to 4 000 ind/m^2 mainly due to recruitment (Ménard *et al.* 1989).

Although the density and the number of species were smaller at Engenho d'Água, the diversity and evenness indexes were higher once more as the equal distribution among species may increase diversity using the Shannon-Wiener function (Krebs 1986). The absolute abundance was lower because the number of species represented by a single individual is very high at São Francisco and at Engenho d'Água.

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RESUMEN

Se estudiaron las comunidades bénticas de anélidos durante un periodo de un año (de agosto/95 a julio/96) en dos sectores de las playas Engenho d'Água y São Francisco, Canal de São Sebastião, donde el sustrato está compuesto por una mezcla de arena y fragmentos de roca. Se usaron parámetros abióticos como salinidad del agua intersticial y propiedades del sedimento para caracterizar el ambiente. Los poliquetos estuvieron bien representados en los dos sectores y su distribución fue relacionada con el tipo de sedimento. La densidad de los individuos y el número de táxones fueron mayores en São Francisco, mientras que la diversidad y la equidad fueron mayores en Engenho d'Água. Esta diferencia puede ser una consecuencia de un enriquecimiento orgánico causado por una entrada doméstica y de la salinidad más baja y variable en São Francisco. Debido a estos factores, la alta densidad de especies

oportunistas como *Capitella capitata* ssp., *Scolelepis squamata*, *Laeonereis acuta* y varios oligoquetos representó 75.5 % de la abundancia local en ese sector.

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