

## Spatial distribution of annelids in the intertidal zone in São Sebastião Channel, Brazil\*

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**SUMMARY:** We studied the spatial distribution of annelids in the intertidal zone of two beaches (Engenho d'Água and São Francisco) in São Sebastião Channel, southeastern Brazil, from August 1995 through July 1996. This region is commonly affected by oil spills and sewage waste. The substratum of the two beaches is composed of a mixture of sand and rock fragments. We established three levels (100 m<sup>2</sup>) in the intertidal zone of each study site: lower, intermediate, and upper. In general, species richness increased from upper towards lower levels. The distribution of species at Engenho d'Água was more homogeneous than at São Francisco. Only some individual spatial patterns were recognised at São Francisco. The most abundant polychaete species at Engenho d'Água (*Nematonereis hebes*, *Timarete filigera*, and *Scyphoproctus djiboutiensis*) occurred in the intermediate and lower levels. The upper level of São Francisco was characterised by a peak of opportunists, with a large number of individuals but few dominant species (*Capitella* sp., *Scolelepis squamata*, *Laeonereis acuta*, and the oligochaete *Tubifex* sp.).

**Key words:** spatial distribution, intertidal zone, sand with rocky fragments beach, annelids, polychaetes, São Sebastião Channel.

### INTRODUCTION

Different aspects of the spatial distribution of the macrofauna in the intertidal zone have been widely studied. Although several authors have attempted to establish a zonation pattern in beaches and tidal flats (e.g. Raffaelli *et al.*, 1991), the vertical gradient of the faunal distribution in beaches is poorly understood. The macrofauna spatial distribution pattern is more evident on hard substrates than in soft bottoms (Wilson, 1988).

In dynamic environments, macrofauna communities are influenced by several biotic and abiotic processes (Rakocinski *et al.*, 1993) such as larval recruitment, competition, predation, heterogeneity

of resources, and sediment characteristics (Thrush *et al.*, 1989). According to Allen and Moore (1987), the patterns of faunal distribution are determined by the degree of immersion, wave energy, and biological control. However, in the view of most authors it is unlikely that a single factor explains the patterns of distribution, since a species can occupy morphologically distinct habitats. Several studies have focused on animal-sediment interaction. For instance, Snelgrove and Butman (1994) believed that infauna distribution depends on characteristics of the sediment. Thrush *et al.* (1989) studied the influence of predators (rays) on the patterns of spatial distribution of communities in the subtidal. Wilson (1988) established a zonation pattern based on interspecific competition in the Bay of Fundy, Nova Scotia. Wendt and McLachlan (1985) divided the

\*Received April 25, 2000. Accepted March 16, 2001.

intertidal zone of River Syndays Beach according to moisture (0-26%), and each region was characterised by a distinct group of species. Dauer and Conner (1980) compared polychaete spatial distribution in two similar habitats affected by organic enrichment, where as the distance from the pollution source increased, the species composition of the communities in those areas changed.

Few studies on the spatial distribution of benthic macrofauna of sandy beaches have been carried out in southern and southeastern Brazil. Omena and Amaral (1997) studied the spatial distribution of polychaetes on five beaches with distinct morphological and textural characteristics, Denadai and Amaral (1999) examined the distribution of the molluscan fauna in the intertidal zone, and Souza and Gianuca (1995) compared zonation patterns observed in Brazilian beaches to the models proposed by Dahl (1952) and Salvat (1964).

This study compared the distribution of polychaetes in the intertidal zone of two beaches in São Sebastião Channel, State of São Paulo, southeastern Brazil, and focused on the morphodynamic characteristics at each site and the variety and abundance of annelids.

## MATERIAL AND METHODS

The beaches of Engenho d'Água and São Francisco are in the northern part of São Sebastião Channel (between 45°21'W, 23°43'S and 45°27'30"W, 23°52'30"S). The channel is frequently affected by sewage discharge and constant oil spills caused by activities in São Sebastião harbour. According to CETESB (1999), the number of faecal coliform bacteria showed that most beaches in São Sebastião Channel were unsuitable for bathing almost year-round over the past decade.

The study sites differ from the other beaches of the channel because their sediment is composed of sand and rocky fragments of different sizes (Rizzo and Amaral, 2000).

At each beach, a 10-meter wide sector was established, its width varying according to the width of the intertidal zone. Based on the degree of moisture, each sector was subdivided into three levels: 1) 'lower level' near the low tide, wettest; 2) 'intermediate level'; and 3) 'upper level' near the high tide, driest. Five randomized samples were taken monthly in a 100 m<sup>2</sup> area within each level, using a cylindrical sampler (0.01 m<sup>2</sup> x 0.02 m), and totalling 15 samples per sector. In total area, 1.8 m<sup>2</sup>

were sampled throughout the study period (August 1995 through July 1996). The environmental variables were characterised by monthly measurements of the sediment temperature and salinity of the interstitial water (three samples/level), and seasonal measurements of slope profile, granulometry, calcium carbonate, and organic matter of the sediment (three samples/level). The sediment samples used for analyses of organic matter content (%) were taken from the surface, at 10 cm, and 10-20 cm deep. Analysis of calcium carbonate and organic matter followed Amoureux (1966), and granulometric analysis followed Suguio (1973). A portable Goldberg T/C refractometer, model 10419, provided data on salinity of interstitial water. Two water samples in each sector were collected in the summer and sent to CETESB (Companhia de Tecnologia e Saneamento Ambiental) for analysis of faecal coliform bacteria.

The samples were washed with seawater over two sieves of 1.0 and 0.5 mm mesh, selective for the macrofauna. The organisms were anaesthetised with magnesium chloride (10%), fixed in 4% formalin, and preserved in 70% alcohol. Whenever possible, the polychaetes were identified to species level. For additional details of the methodology see Rizzo and Amaral (2000).

Data on species composition and abiotic variables were analysed by factorial variance. Data on species were not significantly different. For each level, density (number of individuals/ 0.6 m<sup>2</sup>), species richness (number of species), evenness index ( $E=H/H_{max}$ ), and Shannon-Wiener diversity index ( $H'$ ) (Krebs, 1986) were calculated. To check the similarity of composition of species among the levels within a sector and between the 2 sectors, Jaccard's index of similarity ( $S$ ), was used:  $S = a/(a+b+c)$  where  $a$  = number of species common to both samples,  $b$  = number of species in sample 1, and  $c$  = number of species in sample 2. The Jaccard index ranges from 0 (no similarity) to 1 (complete similarity) (Valentin, 1995). For cluster analysis, Ward's Euclidean distance method was used, with non-transformed data; this method allows graphical observation of the similarity among the levels regarding abiotic variables and species composition. The Principal Component Analysis (PCA) was constructed according to the mean of the main abiotic parameters and number of individuals of the most frequent and/or abundant species in the 3 levels, or in at least one sector.

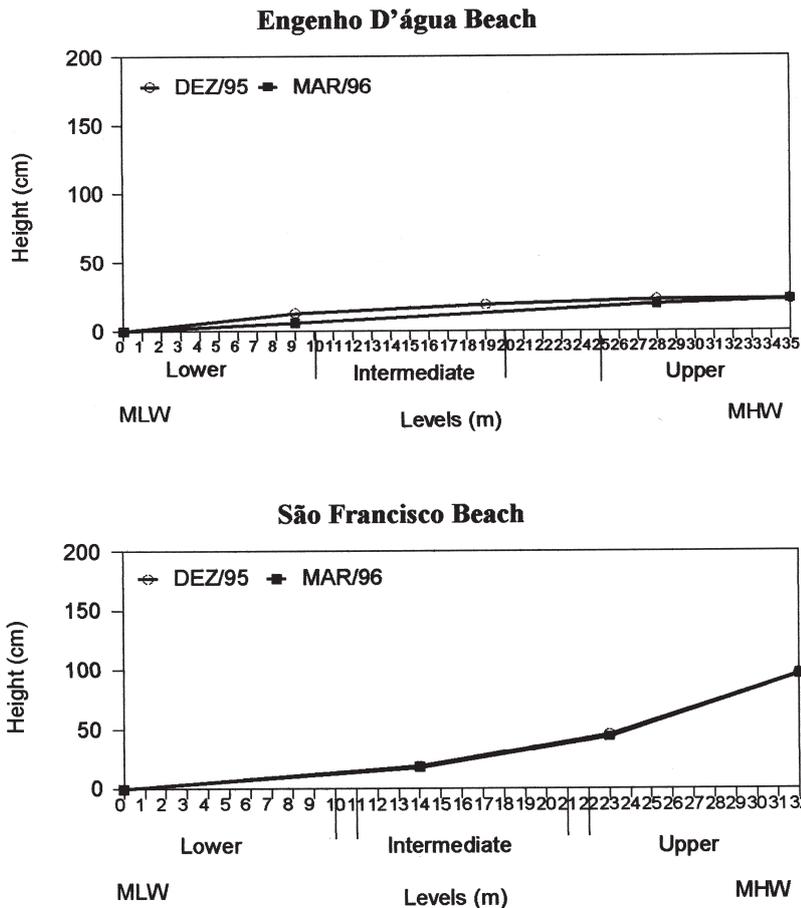


FIG. 1. – Topographic profile of Engenho d'Água and São Francisco Beaches from December 1995 through March 1996. Intervals between levels at Engenho d'Água (20-25 m) and at São Francisco (10-11 and 21-22 m) were not sampled.

## RESULTS

### Environmental variables

According to the classification proposed by McLachlan (1980), both beaches are considered protected within the São Sebastião Channel, and their intertidal slope is slight (Fig. 1). The maximum and minimum values, as well as the mean and standard deviation of the parameters analyzed are shown in Table 1. The sediment of the intermediate and upper levels of Engenho d'Água Beach and the upper level of São Francisco Beach was composed of fine, coarse, and very coarse sand. At the other levels, the sediment varied from medium to very coarse sand besides rocky fragments. During most of the year, the sediment in Engenho d'Água was composed predominantly of medium to coarse sand. At São Francisco, the sediment was mainly coarse to very coarse.

Selection coefficients were higher in the intermediate and upper levels at São Francisco, and the low-

est value was in the lower level of Engenho d'Água. This indicates that the sediment was poorly sorted; and the mean and standard deviation of the selection coefficient indicated homogeneity among the levels. Small quantities of calcium carbonate were found in Engenho d'Água. At São Francisco, calcium carbonate quantities were moderate, with the highest mean value. The standard deviations were proportional to the mean in both sectors. Calcium carbonate values were highest in the intermediate level of São Francisco and lowest in the upper level of Engenho d'Água. The mean organic matter content was similar between the sectors, but the range of variation in the São Francisco sector was higher, with wide standard deviations in three levels. In general, the organic matter content was higher in the first-ten centimeters from the surface, with the values decreasing from the upper towards the lower level, except for the intermediate level of Engenho d'Água.

Salinity was the only variable that differed significantly among levels ( $F = 0.0007$ ;  $p < 0.001$ ). The lowest value was in the upper level of São Francis-

TABLE 1. – Minimum and maximum values, mean and standard deviation of environmental variables in each level of Engenho d'Água and São Francisco Beaches, between August 1995 and July 1996.

Beach Level Parameter	Engenho d'Água			Engenho d'Água Intermediate			Upper		
	Min	Lower Max	M±SD	Min	Max	M±SD	Min	Max	M±SD
Granulometry <sup>1</sup>	VCS	MS		CS	FS		CS	FS	
Mean Grain Size (f)	-0.08	1.82	0.71± 0.21	0.63	2.17	1.24± 0.14	0.07	2.13	1.33± 0.23
Selection Coefficient (S)	0.70	1.59	1.32± 0.06	0.96	1.65	1.38± 0.06	0.81	1.63	1.34± 0.09
Calcium Carbonate (%)	0.94	3.6	2.4± 0.64	1.02	3.54	2.1± 0.75	0.72	3.27	1.69± 0.54
Organic Matter (%) 0-20cm	0.63	2.14	1.18± 0.34	0.90	2.39	1.55± 0.42	1.00	2.71	1.72± 0.55
Organic Matter (%) 0-10cm	0.75	2.14	1.24± 0.37	0.9	2.39	1.67± 0.5	1.04	2.71	1.80± 0.51
Organic Matter (%) 10-20cm	0.63	1.67	1.12± 0.32	1.07	1.96	1.43± 0.31	1.00	2.65	1.64± 0.61
Salinity (psu)	26	34	30.3± 3.3	4	34	30.4± 3.17	27	34	30.8± 2.35
	Min	Max							
Sediment Temperature (°C) <sup>2</sup>	17	28							
Fecal Coliforms (MPN) <sup>2</sup>	2	11							

São Francisco									
Granulometry <sup>1</sup>	Engenho d'Água			Engenho d'Água Intermediate			Upper		
	Min	Lower Max	M±SD	Min	Max	M±SD	Min	Max	M±SD
Granulometry <sup>1</sup>	VCS	MS		VCS	MS		VCS	FS	
Mean Grain Size (f)	-0.67	1.05	-0.4± 0.07	-0.31	1.65	0.33± 1.05	0.51	2.36	0.59± 0.45
Selection Coefficient (S)	0.96	1.79	1.37± 0.73	1.08	1.90	1.49± 0.67	0.72	1.97	1.41± 0.73
Calcium Carbonate (%)	2.34	7.49	4.66± 1.74	1.00	12.01	3.65± 2.03	1.25	6.48	2.97± 2
Organic Matter (%) 0-20cm	0.42	2.66	1.13± 0.66	0.49	5.84	1.30± 1.18	0.23	4.62	1.44± 1.11
Organic Matter (%) 0-10cm	0.57	2.66	1.49± 0.75	0.52	5.84	1.68± 1.54	0.27	4.62	1.51± 1.36
Organic Matter (%) 10-20cm	0.42	1.64	0.80± 0.34	0.49	1.3	0.87± 0.29	0.96	2.73	1.36± 0.79
Salinity (psu)	16	34	29.9± 11.8	10	33	29.2± 13.7	7	30	23.7± 13.5
	Min	Max							
Sediment Temperature (°C) <sup>2</sup>	15	32							
Fecal Coliforms (MPN) <sup>2</sup>	500	800							

<sup>1</sup> VCS = Very Coarse Sand; CS = Coarse Sand; MS = Medium Sand; FS = Fine Sand

<sup>2</sup> MPN = More Probable Number (per 100 ml of water)

co (23.75 psu), and the highest in the upper level of Engenho d'Água (30.85 psu). Temperature in the sediment was similar between the sectors. The mean was 23.62°C at Engenho d'Água and 22.37°C at São Francisco. The maximum and minimum values (32 and 15°C) were measured at São Francisco. The estimated number of faecal coliform bacteria at São Francisco Beach was high and close to the limit considered safe for bathing (1000/100 ml). The water at Engenho d'Água Beach was considered appropriate for bathing.

### Spatial distribution of species

A total of 923 annelids was collected at Engenho d'Água, and 1946 at São Francisco (Table 2). The majority of the individuals was found in the upper level of São Francisco (1456 ind/0.6 m<sup>2</sup>). The smallest number was found in the lower level of São Francisco (229 ind/0.6 m<sup>2</sup>), but this total included most of the species (N=41). Consequently, this level had the highest diversity (4.488 bits/ind.) and evenness (0.838). The lowest values of species richness (18), diversity (2.103 bits/ind.), and evenness (0.504) were found in the upper level of São Fran-

cisco. At Engenho d'Água, the distribution of species and numbers of individuals among levels were homogeneous; while at São Francisco, diversity increased and the number of individuals decreased from the upper towards the lower level.

Sixteen species were common to all levels of Engenho d'Água, and 13 to São Francisco. Seven species were common to all levels of both sectors: *Glycinde multidentis*, *Marphysa sebastiana*, *Naineris setosa*, *Timarete filigera*, *Capitella* sp., *Heteromastus filiformis*, and *Isolda pulchella*. At Engenho d'Água the most abundant species in the lower level were *Nematonereis hebes*, *Timarete filigera*, and *Scyphoproctus djiboutiensis*. In the upper level, *H. filiformis*, *T. filigera*, and *Owenia fusiformis* were the most common; this last species was not found at São Francisco. At São Francisco, the most abundant species were *Capitella* sp., *Scoelelepis squamata*, and *Laeonereis acuta*; *Tubifex* sp. were common, mainly in the upper level.

The highest similarity of species was observed between the intermediate and upper levels of Engenho d'Água (S=0.588), and in São Francisco between the intermediate and upper levels (S=0.448). Comparing the sectors, the highest similarity was

TABLE 2. – Occurrence, density (ind/0.6 m<sup>2</sup>/level), richness, diversity, and evenness of annelids in the three levels (lower, intermediate, and upper) of Engenho d'Água and São Francisco Beaches, from August 1995 through July 1996.

Beach Family/Species	Level	Engenho d'Água			São Francisco		
		Low	Int	Upp	Low	Int	Upp
<b>Polychaeta</b>							
Sigalionidae	<i>Sthenelais boa</i> (Johnston, 1839)	2	2		1		
Amphinomidae	<i>Eurythoe complanata</i> (Pallas, 1766)	4	2		11		
	<i>Pseudeurythoe ambigua</i> Fauvel, 1932				1		
Phyllodocidae	<i>Anaitides cf. madeirensis</i> (Langerhans, 1880)					1	
Hesionidae	<i>Ophiodromus pugettensis</i> (Johnson, 1901)	2		1	2		
Pilargidae	<i>Ansistrosyllis jonesi</i> Pettibone, 1966	1	3	1			
	<i>Parandalia americana</i> (Hartman, 1947)				1		
	<i>Sigambra grubii</i> Müller, 1858			1	7	12	1
Syllidae	<i>Syllis cf. cornuta</i> Rathke, 1843	6		2	6		
Nereididae	Nereididae				1		1
	<i>Laeonereis acuta</i> Treadwell, 1923	3			3	38	102
	<i>Neanthes</i> sp.	1	6	12	1		
	<i>Platynereis dumerilii</i> (A. and M. Edwards, 1834)	1				2	
Goniadidae	<i>Glycinde multidentis</i> Müller, 1858	1	2	6	5	8	1
	<i>Goniada littorea</i> Hartman, 1950		2		5		
Glyceridae	<i>Hemipodus californiensis</i> Hartman, 1938						1
Onuphidae	<i>Diopatra cuprea</i> (Box, 1802)		2	10	1	4	
	<i>Mooreonuphis lineata</i> Lana, 1991				1		
Eunicidae	<i>Marphysa formosa</i> Steiner and Amaral, 2000				1		44
	<i>Marphysa sebastiana</i> Steiner and Amaral, 2000	3	3	4	17	8	2
	<i>Nematonereis hebes</i> Verrill, 1900s	116	32	19	2		1
Lumbrineridae	<i>Lumbrineris tetraura</i> (Shmarda, 1861)	1	1		1	11	2
Dorvilleidae	<i>Dorvillea</i> sp.					1	
Orbiniidae	<i>Naineris setosa</i> (Verrill, 1900)	18	31	6	26	6	3
	<i>Scoloplos (Leodamas) dubia</i> Tebble, 1955				5	1	
	<i>Scoloplos treadwelli</i> Eisig, 1914				10		
Spionidae	Spionidae		1				
	<i>Boccardia redeki</i> sensu Okuda, 1937				1	1	
	<i>Dispio uncinata</i> Hartman, 1951				5		
	<i>Polydora websteri</i> Hartman, 1943				1		
	<i>Prionospio heterobranchia</i> Moore, 1907	8	14	11	2	3	
	<i>Scolelepis squamata</i> (Müller, 1806)	2	1		1	1	464
Magelonidae	<i>Magelona papillicornis</i> Müller, 1858	4	9	3	1	1	
Poecilochaetidae	<i>Poecilochaetus australis</i> Nonato, 1963				3		
Cirratulidae	<i>Cirriformia tentaculata</i> (Montagu, 1808)		7	5	1	1	
	<i>Timarete filigera</i> (delle Chiaje, 1825)	79	79	46	37	23	3
Opheliidae	<i>Armandia agilis</i> Andrews, 1891			1			
Capitellidae	Capitellidae	1			1		
	<i>Capitella</i> sp. (Fabricius, 1780)	2	6	10	4	19	628
	<i>Capitomastus minimus</i> (Langerhans, 1881)	1	1		7	11	43
	<i>Heteromastus filiformis</i> (Claparède, 1869)	2	7	45	15	35	5
	<i>Mediomastus californiensis</i> Hartman, 1944	6	6	3	17	5	
	<i>Notomastus hemipodus</i> Hartman, 1945		3	1			
	<i>Notomastus lobatus</i> Hartman, 1947	19	9	12			
	<i>Notomastus</i> sp.	1					
	<i>Scyphoproctus djiboutiensis</i> Gravier, 1906	80	6	1	6		
Owenidae	<i>Owenia fusiformis</i> Claparède, 1970	3	27	45			
Pectinariidae	<i>Pectinaria laelia</i> Nonato, 1981				3		
Ampharetidae	<i>Isolda pulchella</i> Müller, 1858	2	5	30	9	13	1
Terebellidae	Terebellidae	2			1		
	<i>Loimia medusa</i> (Savigny, 1818)					1	
	<i>Pista corrientis</i> McIntosh, 1885				2		
	<i>Polycirrus plumosus</i> (Wolleback, 1912)	1					
Trichobranchidae	<i>Terebellides anguicomus</i> Müller, 1858				1		
Sabellidae	Sabellidae	1					
	<i>Branchiomma nigromaculata</i> (Baird, 1865)	2					1
	<i>Pseudobranchiomma</i> sp.	1					
	<i>Megalomma bioculatum</i> (Ehlers, 1867)		1				
	<i>Megalomma</i> sp.		1				
<b>Oligochaeta</b>							
Tubificidae	<i>Tubifex</i> sp.		1	1	4	55	153
Number of Individuals (0.6 m <sup>2</sup> )		376	270	277	229	261	1456
Number of Species		32	29	25	41	24	18
Shannon's Diversity (H')		3.086	3.679	3.677	4.488	3.665	2.103
Evenness (E)		0.617	0.757	0.792	0.838	0.799	0.504

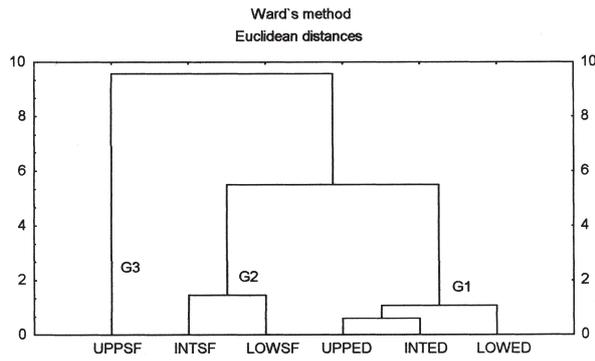


FIG. 2. – Cluster analysis of the environmental variables among the three levels (lower, intermediate, and upper) of Engenho d'Água and São Francisco Beaches.

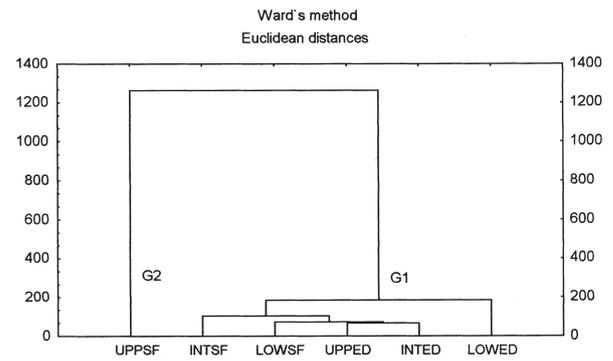


FIG. 3. – Cluster analysis of the species among the three levels (lower, intermediate, and upper) of Engenho d'Água and São Francisco Beaches.

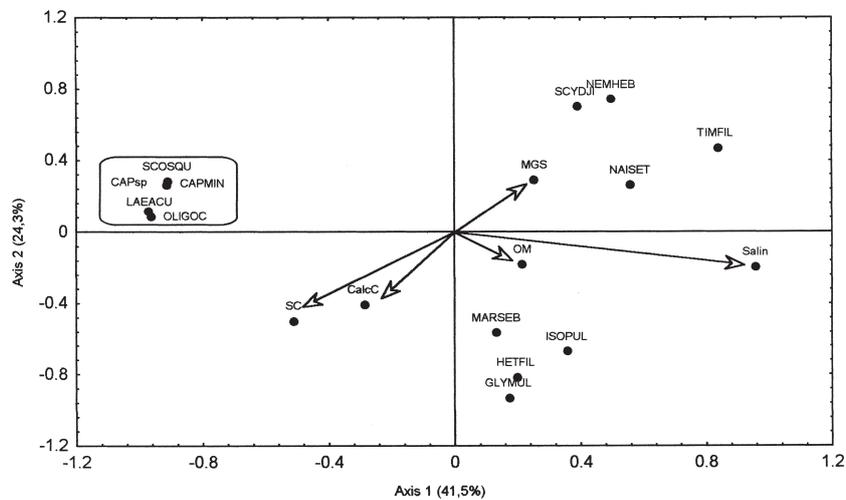


FIG. 4. – Principal Component Analysis of the most frequent and abundant species and main abiotic parameters of Engenho d'Água and São Francisco beaches (for abbreviations see Table 3).

TABLE 3. – Factorial Loading of each component considered in the Principal Component Analysis. The symbol (\*) indicates highly significant values (> 0.7).

Component	Abbreviation	Axis 1	Axis 2	Component	Abbreviation	Axis 1	Axis 2
Mean Grain Size	MGS	0.253	0.291	<i>Naineris setosa</i>	NAISET	0.560	0.260
Selection Coefficient	SC	-0.510	-0.498	<i>Scolecopsis squamata</i>	SCOSQU	-0.907*	0.283
Calcium Carbonate	CalcC	-0.287	-0.408	<i>Timarete filigera</i>	TIMFIL	0.838*	0.468
Organic Matter	OM	0.216	-0.179	<i>Capitella</i> sp.	CAPsp	-0.913*	0.264
Salinity	Salin	0.956*	-0.196	<i>Capitomastus minimus</i>	CAPMIN	-0.970*	0.114
<i>Laeonereis acuta</i>	LAEACU	-0.963*	0.085	<i>Heteromastus filiformis</i>	HETFIL	0.198	-0.816*
<i>Glycinde multidentis</i>	GLYMUL	0.174	-0.931*	<i>Scyphoproctus djiboutiensis</i>	SCYDJI	0.392	0.697
<i>Marphysa sebastiana</i>	MARSEB	0.132	-0.565	<i>Isolda pulchella</i>	ISOPUL	0.358	-0.669
<i>Nematonereis hebes</i>	NEMHEB	0.500	0.738*	Oligochaeta ( <i>Tubifex</i> sp.)	OLIGOC	-0.965	0.072

between the intermediate level of Engenho d'Água and the lowest level of São Francisco (S=0.458), and the lowest similarity was between the upper levels (S=0.273). The cluster analysis of environmental variables created three groups. The highest similarity was among the levels of Engenho d'Água (G1)

and between the intermediate and lower levels of São Francisco (G2); the upper level of São Francisco was isolated (Fig. 2). Two groups of species were recognised: G2 represents the upper level of São Francisco, and G1 the remaining levels of both sectors (Fig. 3).

In the PCA, the first two axes explained 65.8% of total variance (Fig. 4). The Factor Loading of each component is shown in Table 3. Axis 1 was positively and significantly related to *Timarete filigera*, and to salinity. *Capitella* sp., *Scolelepis squamata*, *Capitomastus minimus*, *Laeonereis acuta*, and the oligochaete *Tubifex* sp. were negatively displaced. On axis 2, the most important species in Engenho d'Água were positive: *Nematonereis hebes* and *Scyphoproctus djiboutiensis*. On the other hand, *Glycinde multidentis*, and *Heteromastus filiformis* were negative with high factor loading. Mean grain size (MGS) is positive to both axes, calcium carbonate (CalcC), and selection coefficient (SC) are negative to both axes, but they had low factor loading.

## DISCUSSION

Engenho d'Água and São Francisco Beaches differ from other beaches of the São Sebastião Channel, mainly because the sediment is composed of sand and rocky fragments, allowing the existence of several microhabitats and intensive use by animal species. Moreover, São Francisco is impacted by organic enrichment from sewage, which flows directly onto the beach at the sampling sector, the uppermost level being most affected.

Generally, the number of species increased from the upper towards the lower levels. This pattern was also observed in the estuarine system of Santos in southeastern Brazil (Corbisier, 1991), in the mid- and subtidal zones of Perdido Key, Florida (Rakocinski *et al.*, 1993), and at a sandy beach in southern Brazil (Souza and Gianuca, 1995).

Wendt and McLachlan (1985) believed that the area adjacent to the subtidal is more stable and there are more niches available, because desiccation and temperature variation are less, and feeding activity lasts longer. During low tide, when the upper parts of the beach are exposed, evaporation is more rapid in organisms that do not have a protective cuticle like that of the crustaceans, and the basic physiological necessities are reduced. The distribution of organisms in intertidal communities of rocky coasts is regulated by physiological factors in the upper limits, and by biological interactions in the lower limits (Wilson, 1988). The distribution of the intertidal macrofauna in sandy beaches is not so clearly defined (Wendt and McLachlan, 1985). Physical and biological interactions might act as regulators in soft bottoms, when other factors such as hydrodynamics

and abiotic and human influences are considered.

Dahl (1952) and Salvat (1964) proposed the first zonation models for sandy beaches, which are commonly used in comparative studies of spatial distribution of the macrofauna. These proposals considered the degree of moisture, to distinguish the communities that are typical of non-disturbed sandy beaches. In disturbed areas, such as beaches affected by organic enrichment, the degree of impact on each sampling site was broadly considered.

Based on studies of macrobenthic succession, Pearson and Rosenberg (1978) established three zones, depending on the degree of organic pollution: a) 'peak of opportunists', where there are few species but large numbers of individuals; b) 'ecotone point', where the abundance is low and the number of species tends to increase; and c) 'transition zone', where the population first shows strong fluctuations and subsequent stability, becoming a 'stable community'. The zonation caused by organic enrichment can be used as a parameter in both spatial and temporal gradients.

In the São Francisco sector, there was a peak of opportunists in the upper level, characterised by high densities of *Capitella* sp., *Scolelepis squamata*, *Laeonereis acuta*, and *Tubifex* sp., which together represented 92.5% of the total individuals. These species showed large seasonal fluctuations, being well represented between summer and winter, and decreasing in Oct/95 (spring), when the highest diversity and evenness were observed (Rizzo and Amaral, 2000). This zone corresponds to the highest part of the intertidal described in Dahl (1952) and to the retention zone of Salvat (1964). The intermediate level in São Francisco would be the ecotone point, with 261 ind/0.6 m<sup>2</sup>, 24 species, moderate to high diversity ( $H' = 3.665$  bits/ind), and characterised by species belonging to both upper and lower levels. It corresponds to the central part of the intertidal of Dahl (1952) and to the retention and beginning of the upwelling zone of Salvat (1964). The lower level is equivalent to the upwelling zone, with fewer individuals (229 ind/0.6 m<sup>2</sup>), a high number of species ( $N = 41$ ), high diversity ( $H' = 4.488$  bits/ind), and high evenness ( $E = 0.838$ ). This pattern is similar to that found in communities of natural areas, as at Engenho d'Água Beach.

At Engenho d'Água Beach, zonation was not evident because the species were more evenly distributed, and only a few isolated patterns could be distinguished. It is difficult to recognise any zonation pattern, as there is no moisture gradient, because the

shallow slope and sediment favour the formation of tidal pools that contribute to local homogeneity. Amaral *et al.* (1995) studied the polychaetes in several beaches along the São Sebastião Channel, including Engenho d'Água Beach, and observed that individuals were uniformly distributed among species. These authors verified that a large number of species was found in the upper level of Engenho d'Água, (N = 23), characterised by the presence of *Owenia fusiformis*, *Scolelepis squamata*, and *Timarete tentaculata*; *O. fusiformis* was the single most dominant and frequent species (63%) between May and September, 1990 (Amaral *et al.*, 1995). In our study, it occurred in all levels of Engenho d'Água, mainly the upper level; but no individuals were collected in São Francisco. It reached high density (9136 ind/0.05 m<sup>2</sup>) in the Seine Bay (English Channel), in fine to heterogeneous mud-sand sediments (Dauvin and Gillet, 1991). On the other hand, *Timarete filigera* was abundant in all levels of Engenho d'Água and the intermediate and lower level of São Francisco. *Cirri-formia tentaculata* was found in all levels of Perequê and Engenho d'Água beaches, and over 50% of the individuals were in the lower level, especially in coarse sediment (Amaral *et al.*, 1995).

According to Denadai and Amaral (1999), zonation of the molluscan fauna was evident in São Francisco, whereas its distribution in Engenho d'Água was homogeneous. In the upper level of São Francisco, there were only four species of molluscs and few individuals (21 ind/6.36 m<sup>2</sup>), in contrast to the pattern found for annelids. This might have been caused by the lower resistance of molluscs to waste input (Denadai and Amaral, 1999).

The similarity index isolated the upper level of São Francisco from the others (Fig. 3). This isolation resulted from the presence of a few species with a high number of individuals, and wide variations of the abiotic factors. Granulometric data showed that cyclic alterations occurred in the summer, when heavy rain and strong waves affected the beaches (Rizzo and Amaral, 2000). The lower level of São Francisco had the highest specific diversity and evenness. The homogeneity among the levels of Engenho d'Água resulted from the large number of species in common, and the low species density. *Naineris setosa* and *Timarete filigera* were positive on PCA Axis 1 (Fig. 4, Table 3) and had higher densities in the lower and intermediate levels of Engenho d'Água (Table 2), where the salinity was higher and the sediment was composed of coarse sand. Sediments composed of large quantities of medium

to coarse sand and high salinity usually shelter high numbers of species, but low abundances of polychaetes (Pardal *et al.*, 1993).

Wide variations in salinity, the size of sediment particles, or other limiting factors associated with organic enrichment change the pattern of species distribution (Pearson and Rosenberg, 1978). The opportunistic species (*Capitella* sp., *Capitomastus minimus*, *Laeonereis acuta*, *Scolelepis squamata*, and *Tubifex* sp.) are found in poorly selected sediments with a low percentage of calcium carbonate and wide salinity and organic matter variation. Therefore, PCA Axis 1 summarised the strong effect of waste input on the distribution of species in the intertidal zone. PCA Axis 2 was formed by the positive contribution of two species that are very important in the lower level of Engenho d'Água: *Scyphoproctus djiboutiensis* and *Nematonereis hebes*. The occurrence of the former and the permanence of the latter in Engenho d'Água seemed to be related to the wide variety of habitats and the local hydrodynamics. *Scyphoproctus djiboutiensis* was present in considerable numbers in the lower level of Engenho d'Água and had never before been reported from the Brazilian coast, probably because it was mistaken for a species of *Notomastus*. *Nematonereis hebes* was distributed widely in all levels of Engenho d'Água, according to the results obtained by Amaral *et al.* (1995). The species *Glycinde multidentis*, *Heteromastus filiformis*, *Isolda pulchella*, and *Marphysa sebastiana* were also significant, and fell in the intermediate portion of the factorial plan. In both sectors, these species had moderate numbers of individuals in all levels, and the most frequent species were not always the most abundant; this pattern was also observed by Amaral *et al.* (1995). In the central part, mean grain diameter, calcium carbonate, and organic matter probably were not greatly important in structuring the community, because these factors explained less than 50% of the variation. Dissolved organic matter was not always well quantified by the method employed: it is an important variable in species zonation (Snelgrove and Butman, 1994), but is difficult to measure. However, the occurrence of certain species, indicators of organic pollution, along beaches of the northern coast of the State of São Paulo (Amaral *et al.*, 1998), associated with the faecal coliform bacteria data for São Sebastião Channel beaches (CETESB, 1999), reflected the presence of organic enrichment in sediments of some beaches of the region, including the São Francisco sector.

The high density of one or more species might be related to increased recruitment and fecundity and/or reduction of mortality, but food availability may affect all these factors (Dauer and Conner, 1980). Whereas stable hydrodynamic conditions might guarantee the establishment of a species in an area, human interference (e.g., organic waste input, oil spills, chemical substances) and natural variables (e.g., seasonality, rainfall) can result in increases or decreases in numbers of species and individuals.

## ACKNOWLEDGEMENTS

We thank E. Soares Marinho and A. Máximo Rosa (UNICAMP) and to CEBIMar/USP technicians, who assisted in the fieldwork. We are particularly grateful to the Centro de Biologia Marinha (CEBIMar/USP) for logistical support. This research was supported by grants from the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and from the Fundo de Apoio à Pesquisa (FAEP - UNICAMP). Ms. Ellen Wang and Dr. Janet W. Reid revised the English text.

## REFERENCES

- Allen, P.L. and J.J. Moore. – 1987. Invertebrate macrofauna as potential indicators of sandy beach instability. *Est. Coast. Shelf Sci.* 24: 109-125.
- Amaral, A.C.Z., E.H. Morgado, E.V. Pardo and M.O. Reis. – 1995. Estrutura da comunidade de poliquetos da zona entremarés em praias da Ilha de São Sebastião (SP). *Publ. Esp. Inst. Ocean. S. Paulo.* 11: 229-237.
- Amaral, A.C.Z., E.H. Morgado and L.B. Salvador. – 1998. Poliquetas bioindicadores de poluição orgânica em praias paulistas. *Rev. Bras. Biol.*, 58(2): 307-316.
- Amoureux, L. – 1966. Étude bionomique et écologique de quelques annélides polychètes des sables intertidaux de côtes ouest de la France. *Arch. Zool. Exp. Gen.*, 107: 1-218.
- CETESB. – 1999. *Relatório de balneabilidade das praias paulistas 1998*. Secretaria de Estado do Meio Ambiente, CETESB, São Paulo.
- Corbisier, T.N. – 1991. Benthic macrofauna of sandy intertidal zone at Santos estuarine system, São Paulo, Brazil. *Bolm. Inst. Ocean. S. Paulo*, 3(1): 1-13.
- Dahl, E. – 1952. Some aspects of the ecology and zonation of the fauna on sandy beaches. *Oikos*. 4(1): 1-27.
- Dauer, D.M. and W.G. Conner. – 1980. Effects of moderate sewage input on benthic polychaete population. *Est. Mar. Sci.*, 10: 335-346.
- Dauvin, J.C. and P. Gillet. – 1991. Spatio-temporal variability in population structure of *Owenia fusiformis* delle Chiaje (Annelida: Polychaeta) from de Bay of Seine (eastern English Channel). *J. Exp. Mar. Biol. Ecol.*, 152: 105-122.
- Denadai, M.R. and A.C.Z. Amaral. – 1999. A comparative study of intertidal molluscan communities in sandy beaches, São Sebastião Channel, São Paulo State, Brazil. *Bull. Mar. Sci.*, 65: 91-103.
- Krebs, C.J. – 1986. *Ecologia: análise experimental de la distribución y abundancia*. Pirámide, Madrid. 782 pp.
- McLachlan, A. – 1980. The definition of sandy beaches in relation to exposure: a simple rating system. *S. Afric. Journ. Sci.*, 76: 137-138.
- Omena, E.P. and A.C.Z. Amaral. – 1997. Distribuição espacial de polychaeta (Annelida) em diferentes ambientes entremarés de São Sebastião (SP). *Oecologia Bras.*, 3: 183-196.
- Pardal, M.A., J.C. Marques and G. Bellan. – 1993. Spatial distribution and seasonal variation of subtidal polychaete populations in the Mondego estuary (western Portugal). *Cah. Biol. Mar.*, 34: 497-512.
- Pearson, T.H. and R. Rosenberg. – 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Ocean. Mar. Biol. Ann. Rev.*, 16: 229-311.
- Raffaelli, D., I. Karassakis and A. Galloway. – 1991. Zonation schemes on sandy shores: a multivariate approach. *J. Exp. Mar. Biol. Ecol.*, 148: 241-253.
- Rakocinski, C.F., R.W. Heard, S.E. Lecroy, J.A. McLelland and T. Simons. – 1993. Seaward change and zonation of the sandy-shore macrofauna at Perdido Key, Florida, USA. *Est. Coast. Shelf Sci.*, 36: 81-104.
- Rizzo, A.E. and A.C.Z. Amaral. – 2000. Temporal variation of annelids in the intertidal zone of beaches of the São Sebastião Channel, southern Brazil. *J. Mar. Biol. Ass. U.K.*, 80(6): 1007-1017.
- Salvat, B. – 1964. Les conditions hydrodynamiques interstitielle des sédiments meubles intertidale et la repartition vertical de la genre endoyé. *A.C.R. Acad. Sci. Paris*, 259: 1567-1571.
- Snelgrove, P.V.R. and C.A. Butman. – 1994. Animal-sediment relationships revisited: cause versus effect. *Ocean. Mar. Biol. Ann. Rev.*, 32: 111-177.
- Souza, J.R.B. and Gianuca, N.M. – 1995. Zonation and seasonal variation of the intertidal macrofauna on a sandy beach of Paraná State, Brazil. *Sci. Mar.*, 59(2): 103-111.
- Suguio, K. – 1973. *Introdução à sedimentologia*. Edgard Blucher/EDUSP (ed), São Paulo. 312 pp.
- Thrush, S.F., J.E. Hewitt and R.D. Pridmore. – 1989. Patterns in the spatial arrangements of polychaetes and bivalves in intertidal sandflats. *Mar. Biol.*, 102: 529-535.
- Valentin, J.L. – 1995. Agrupamento e Ordenação. *Oecologia Bras.*, 2: 27-55.
- Wendt, G.E. and A. McLachlan. – 1985. Zonation and biomass of the intertidal macrofauna along a South African study sandy beach. *Cah. Biol. Mar.*, 26: 1-14.
- Wilson, H.W. Jr – 1988. Shifting zones in a Bay of Fundy soft-sediment community: patterns and processes. *Ophelia* 29(3): 227-245.

Scient ed.: T. Kikuchi