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Management

Foraminifera zonation and water renewal in transects along Bertioga Channel, SP, Brazil

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ABSTRACT The purpose of this research is to correlate modern distribution of foraminifera with environmental parameters in transects to evaluate microhabitats and geohabitats along and across Bertioga channel. We show zonation of foraminiferal species to salinity changes, temperature, currents and sedimentological characteristics correlating with renewal capacity of its estuarine waters. The western mouth that receives polluted water from the Santos Bay, shows signs of environmental degradation because their renewal rate is average, on the other hand, the south inner part is in more problematic situation, as its waters have low efficiency rate of renew.

KEYWORDS : Zirconia, Fixed dental prostheses, connector , chipping , opacity

1. Introduction

Estuaries, estuarine channels and mangroves, transition regions between sea and river, are the most productive environments in the world where the natural dynamics is very important for the balance and sustainability of coastal ecosystems. They are highly variable and pose a challenge to assess their environmental quality since it depends on having the widest possible range of information on the environment. Only from a cooperative effort between different areas of knowledge, it is possible to obtain a broad spectrum of information essential to effective knowledge and environmental management (Tommasi & Griesinger, 1983; Pires Filho & Cycon, 1987; Weber, 1992). Within this aspect, research covering the study of circulation, mixing, transport and deposition related to biological aspects and biomarkers provide a broader view of the processes occurring in this environment.

It is necessary to use a biomarker in a simple and inexpensive management, able to synthesize the general characteristics of the environment, highlighting the environmental changes in short periods. This marker must be sensitive enough to react quickly to changes in the environment and the effects of pollution. In this regard, foraminifera are widely used because they respond to these criteria. Using foraminiferal associations as indicators is often possible to detect and map different characteristics of estuarine circulation and distribution of salinity (Scott et al., 1980).

The purpose of this research is to correlate modern distribution of foraminiferal species with salinity changes, temperature, currents and sedimentological characteristics in the Bertioga Channel (BC) (São Paulo, Brazil).

2. Study area

The BC is located on the southern coast of São Paulo, divided into bodies of water, mountains, mangroves and urban areas (Tommasi, 1979) is considered as a secondary connection to the ocean for the estuarine complex of Santos (Miranda et al., 1998). The eastern mouth is located near the city of Bertioga and the western mouth is near Santos channel, which flows into the Santos Bay (Figure 1). The penetration of tidal wave inside the channel is through its mouths, Bertioga bar and Santos Channel. There is a "meeting of waters" in Largo do Candinho, where the tidal waves penetrate in opposite directions from both ends of BC have zero speeds and is characterized as depositional site.

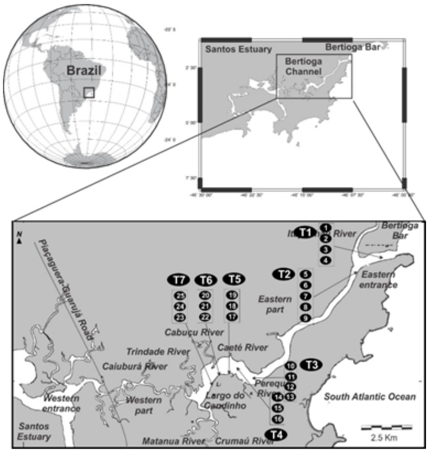

Figure 1: Location of the study area.

3. Material and Methods

Sampling in Bertioga estuarine channel were done on board of research vessels and 25 biological and sediment samples from 7 transects (T1: 1-4; T2: 5-9; T3: 10-13; T4: 14-16; T5: 17-19; T6: 20-22; T7: 23-25) were collected perpendicular to the channel. The location of samples and transects are show in Figure 2.

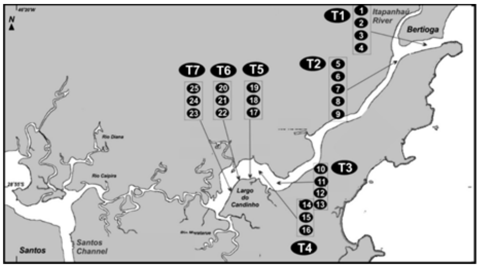

Figure 2: Location of samples (1 to 25) in transects (T1 to T6) in Bertioga channel.

Sedimentological and hydrological data were plotted in contour maps in Surfer program (Golden Software, 1995). The hydrographic data were obtained at the time of sample collection. Sediment sampling was done with Van Veen grab sampler.

For each sample, 50 cc of sediment was removed from the first cm of collected sediment, sieved in 0.500 and 0.062 mm sieves, washed to remove silt and clay, and dried at 60 °C. Fractions were floated in Carbon Tetrachloride (CCl_4). The identification of foraminifera was based primarily on Cushman (1950), Loeblich & Tapan (1964.1988), and Boltovskoy et al. (1980). The absolute frequency is the number of individuals per 50 cm3. From the absolute frequency table, it was calculated the relative percentage of species. Species considered dominant in the transects were photographed in a scanning electron microscope.

3.1. Confinement Index (CI):

CI is influenced by marine intrusion of water (Debenay, 1990). It uses foraminifera species to differentiate mixohaline and marine environments. This ratio is determined from the relative frequency of three groups of species susceptible to saline confinement. Its formula is:

* $CI = C / (B + C) - A / (A + B) + 1$, where:

A: Association of relative frequency of *Elphidium fichtelianum, Pararotalia sp, Bolivina striatula and Rosalina* spp. (typical species of coastal marine environments).

B: Association of relative frequency of *Eggerelloides scabrum, poyeana Quinqueloculina, Quinqueloculina seminula, Haynesina germanica, Elphidium gunteri, E. limosum, Bolivina variabilis and Ammonia tepida* (typical species of moderately confined marine environments).

C: Association relative frequency of *Ammobaculites exigus, Ammotium salsum, Arenoparrella mexicana, Gaudryina exilis, Haplophragmoides wilberti, Miliamina sp, Trochamina sp., and Siphotrochammina lobata* (typical species of environments under strong confinement). Results may vary between 0 and 1 according to the degree of marine influence. The values 0 to 0.4 indicate marine environments, the values of 0.4 to 0.7 indicate some restricted environments, values of 0.7 to 0.9 indicate restricted environments and values of 0.9 to 1 indicate totally confined environments.

3.2. Sedimentological analyses

Particle size analysis of samples was performed by Suguio (1973), and classification of fractions is given by Wentworth (1922). Sediment collected for determination of organic sediment components (carbon, sulfur and nitrogen) were analyzed by CNS-2000 analyzer Leco.

Total organic matter, carbon / nitrogen ratios (C/N), and carbon/sulfur (C/S) were studied to infer whether there is a predominance of terrestrial sources or marine and the condition of oxidation-reduction in sediment. Lower values of C / N ratio (less than 6, according to Mahiques, 1998) are related to high contribution from the total N content, indicating marine origin. Values above 20, according to the same author, indicate a predominance of continental compound. Still, intermediate values between 6 and 20 indicate areas subject to mixed origins.

3.3. Statistical Methods

Absolute and Relative abundance of foraminiferal dominant species were the database. The choice of species was based mainly on the kind of response that different species exhibit on the freshwater/marine balance. To compound results on transects foraminiferal species were selected as follow: four species of agglutinated foraminifera from mixohalines with greater freshwater influence: *Arenoparrella mexicana, Ammotium salsum, Haplophragmoides wilberti,* and *Trochammina inflata,* four species of foraminiferal mixohalines *A. tepida, E. excavatum, Elphidium poyeanum,* and *Quinqueloculina miletti* and three marine species of foraminifera: *Pararotalia sp., Hanzawaia boueana and Pseudononion atlanticum.*

4. RESULTS

4.1 Biological parameters

Table 1 and Figure 3 shows data on absolute number of indicator species in seven transects along Bertioga channel. Figures 4 to 6 show the distribution of relative frequency of indicator species.

Table 1: Absolute number of indicator species in transects along Bertioga channel.

Transects	T1				T2					T3				T4			T5			T6			T7		
Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ammonia tepida	308	68	52	306	280	258	272	56	88	66	224	260	78	4	60	168	0	40	8	11	24	20	102	8	4
A parkinsoniana	48	4	8	18	32	6	8	4	0	12	100	68	18	6	16	68	1	36	0	0	4	6	12	20	4
B. marginata	0	56	100	216	0	24	44	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	4	0
B. striatula	0	8	20	54	4	12	48	8	20	6	0	8	24	6	0	0	0	0	3	1	2	0	24	16	8
Bulimminela elegantissima	4	8	0	0	0	6	12	4	8	72	0	0	16	4	0	0	1	0	1	0	2	2	6	8	0
Elphidium excavatum	24	0	4	24	20	18	16	8	0	0	116	468	8	14	324	568	13	240	1	0	14	20	30	0	0
E. gunteri	8	0	0	0	0	6	0	4	0	0	140	60	12	10	28	8	0	0	0	0	0	26	48	0	0
Elphidium poyeanum	4	84	204	846	20	84	224	20	12	0	172	364	28	6	76	256	0	60	4	0	0	0	0	0	0
Hanzawaia boueana	0	174	252	708	0	102	184	20	0	0	4	4	6	0	0	0	0	0	1	0	0	0	24	4	0
Pararotalia sp.	0	332	512	168	24	984	612	208	232	306	16	100	106	138	88	4	29	4	8	25	4	0	138	64	20
Pseudononion atlanticum	0	204	272	900	24	204	176	68	0	24	0	8	22	0	0	0	0	0	0	2	4	0	42	16	0
Ammotium salsum	16	0	0	0	0	0	0	0	0	0	0	12	2	6	20	0	0	0	0	0	0	0	18	0	0
Arenoparrela mexicana	84	2	0	12	68	12	12	0	0	0	4	56	2	4	12	24	2	0	0	0	0	0	54	0	0
Gaudryna exillis	32	2	0	6	16	6	8	8	0	6	0	4	0	0	4	0	0	0	0	0	0	0	0	0	0
Haplophragmoides wilberti	60	0	0	0	8	0	4	4	0	0	0	4	4	8	12	16	2	0	0	0	0	2	18	4	4
Trochammina inflata	16	0	0	0	4	0	0	0	0	0	4	8	0	8	0	0	4	0	0	0	0	0	0	0	0
Quinqueloculina lamarckiana	0	42	0	216	4	12	20	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0

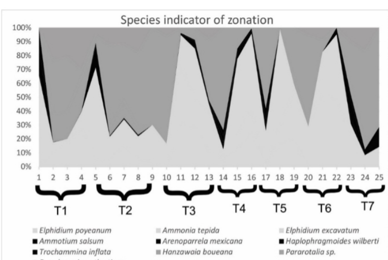

Figure 3: Species indicator of zonation.

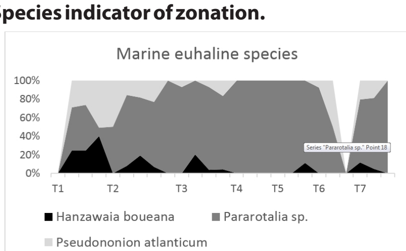

Figure 4: Absolute frequency of marine euhaline foraminiferal species in seven transects.

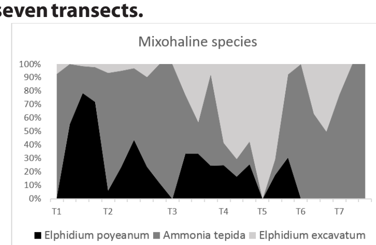

Figure 5: Absolute frequency of mixohaline foraminiferal species in seven transects.

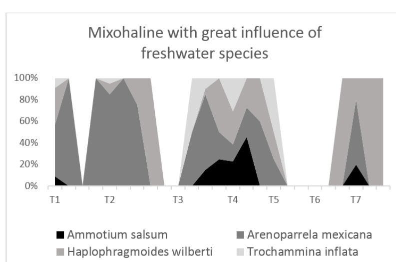

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Figure 6: Absolute frequency of mixohaline with great freshwater influence foraminiferal species in the 7 transects.

4.2 Sedimentological and hydrographic parameters correlated with biological parameters

The sedimentological and hydrographic data can be seen in Figure 7 and Table 2.

Table 2: The sedimentological and hydrographic data in transects.

	Stations	Location	Depth	Surf. temp.	Bot. temp.	Surf. salinity	Bot. salinity	CaCo3	Sand	Silt and clay	Carbon	Sulfur	Nitrogen
T 1	1	23.51.44 S 46.08.76 W	0,8	24,6	24,5	20	20	6,40	43,64	56,36	5,96	7,79	0,26
	2	23.51.44 S 46.08.76 W	3	24,6	25,3	20	33	3,60	99,90	0,1	0,25	0,03	0,02
	3	23.51.53 S 46.08.72 W	3,5	24,4	24,4	16	31	11,10	99,55	0,17	0,16	0,03	0,00
	4	23.51.62 S 46.08.66 W	3,5	24,8	24,5	18	32	5,00	99,84	0,16	0,12	0,03	0,00
T 2	5	23.51.82 S 46.09.49 W	1	24,8	24,2	11	24	5,40	82,32	17,68	3,78	1,78	0,21
	6	23.51.89 S 46.09.48 W	6	24,8	23,8	17	31	6,00	91,88	8,12	0,53	0,06	0,04
	7	23.51.96 S 46.09.53 W	5,5	24,4	23,4	11	30	6,90	99,84	0,11	0,21	0,03	0,01
	8	23.52.04 S 46.09.36 W	8	24,1	23,3	14	28	27,61	89,48	9,2	1,18	0,13	0,16
	9	23.52.17 S 46.09.33 W	4	23,7	23,7	18	31	8,42	0,08	92,23	3,59	0,72	0,23
T 3	10	23.52.70 S 46.12.36 W	0,5	26,1	26,1	20	20	16,13	0,10	92,59	8,62	17,83	0,45
	11	23.54.67 S 46.12.24 W	1	24,7	24,8	20	20	21,08	32,11	67,89	2,77	34,18	0,13
	12	23.54.75 S 46.12.18 W	5	24,5	23,6	20	24	8,38	47,68	52,32	6,45	10,13	1,99
	13	23.54.84 S 46.12.79 W	2	24,1	23,7	25	25	10,41	0,08	98,42	4,82	2,31	0,35
T 4	14	23.54.33 S 46.13.31 W	2	24,9	24,9	21	22	6,17	94,63	4,86	0,87	0,14	0,06
	15	23.54.56 S 46.13.28 W	5	24,7	23,3	20	24	7,50	37,08	62,91	2,76	1,93	0,14
	16	23.54.67 S 46.13.17 W	2	25	24,1	20	21	27,20	0,18	96,5	6,86	15,11	0,29
T 5	17	23.54.80 S 46.13.58 W	1	24,8	24	20	22	12,46	0,08	96,23	6,34	14,07	0,31
	18	23.54.68 S 46.13.60 W	6,5	25,2	23,4	18	24	10,20	21,75	78,25	5,27	13,97	0,25
	19	23.54.44 S 46.13.62 W	1,8	26,1	24,6	19	21	14,17	0,08	97,2	5,14	9,17	0,28
T 6	20	23.54.62 S 46.13.85 W	2,5	25,7	25,6	20	20	37,94	0,10	76,12	3,84	1,90	0,33
	21	23.54.71S 46.13.84 W	4	25,6	24	20	23	12,97	0,08	89,36	5,53	7,04	0,33
	22	23.54.83 S 46.13.70 W	2	25,4	23,7	20	24	23,92	0,08	96,15	5,44	4,76	0,25
T 7	23	23.55.00 S 46.13.87 W	1,5	24,5	24,5	20	22	5,57	13,43	86,57	5,86	33,14	0,24
	24	23.54.86 S 46.14.02 W	0,5	25,7	25,7	20	20	12,98	0,08	98,04	4,77	7,29	0,29
	25	23.54.58 S 46.14.32 W	1	26,4	26,1	20	20	7,33	0,07	89,54	5,59	11,36	0,27

Comparing biological data on table 1 it can be seen the occurrence of A. *tepida* and agglutinated is positively related to the percentage of organic components (carbon, nitrogen and sulfur) and silt + clay.

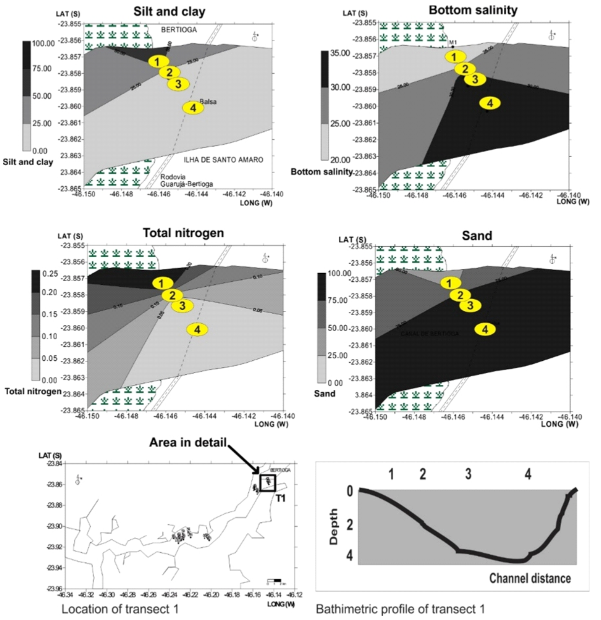
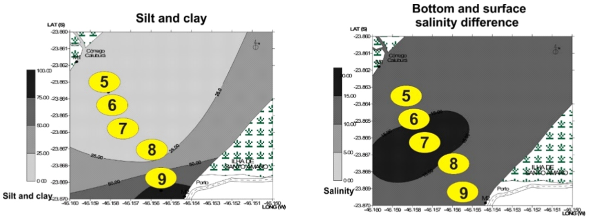


Figure 7: Sedimentological and hydrographical data found in transect 1.

The sedimentological and hydrographic data on transect 2 can be seen in Figure 8.



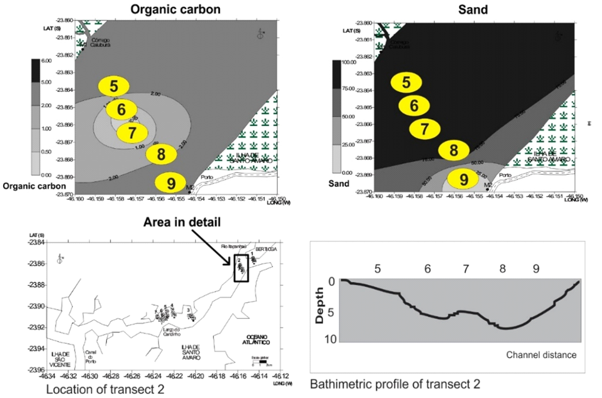
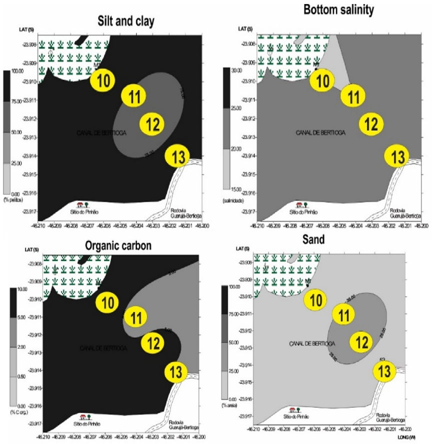


Figure 8: Sedimentological and hydrographical data found in transect 2.

The sedimentological and hydrographic data on transect 3 can be seen in Figure 9. Table 2 show that the highest amount of sand in the stations 11 and 12 are responsible for distribution of *Elphidium* spp. The highest amount of silt and clay (10 and 13) presents the highest concentration of *Pararotalia* sp.



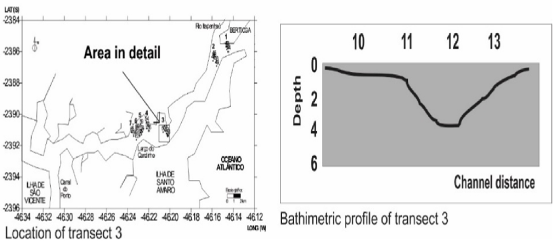


Figure 9: Sedimentological and hydrographical data found in transect 3.

The sedimentological and hydrographic data obtained in transects 4, 5, 6 and 7 can be seen in Figure 10.

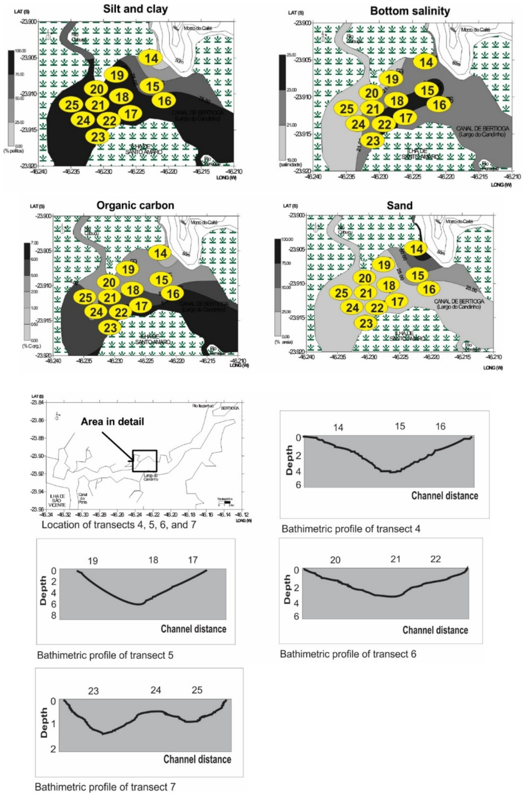


Figure 10: sedimentological data found in transects 4, 5, 6 and 7.

The distribution of main foraminiferal species observed in transects will be summarized below. Most species found in transects 1 and 2 are characteristic of euhalinos marine environments. Species that stand out are *P. atlanticum, Pararotalia sp* and *Hanzawaia boueana* (Figure 11).

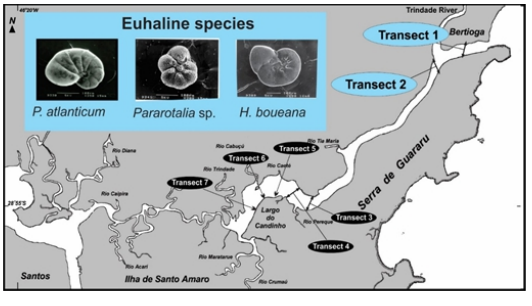


Figure 11: Euhaline foraminiferal species found in transects 1 and 2. Among mixohaline species found in all transects stand out *A. tepida and E. poyeanum* (Figure 12).

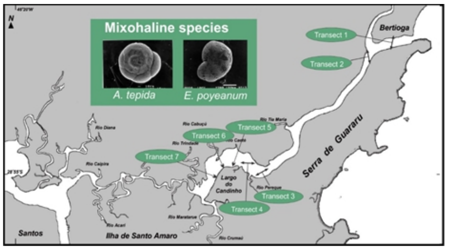


Figure 12: Mixohaline foraminiferal species found in transects 3, 4, 5, 6, and 7.

Figure 13 shows the occurrence of characteristic species of mixohalinos environments with great influence of freshwater (restricted environments).

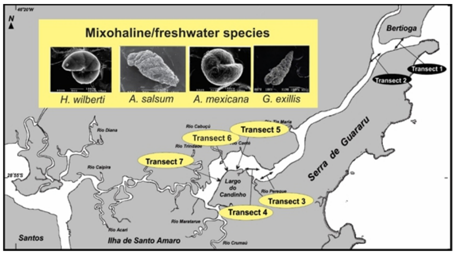


Figure 13: Mixohaline and fresh water foraminiferal species.

Transects 1, 2, 3, 6 and 7 were considered coastal marine environments rather than restricted, and transects 4 and 5 were considered a little confined environments. Restricted and totally confined environments were absent (Table 3 and Figure 14).

Table 3: Data on CI in transects.

	Stations	Confinement
T 1	41	0,69
	42	0,53
	43	0,05
	44	0,32
T 2	45	0,58
	46	0,17
	47	0,19
	48	0,19
	49	0,13
T 3	50	0,20
	51	0,36
	52	0,62
	53	0,25
T 4	54	0,41
	55	0,43
	56	0,59
T 5	57	0,47
	58	0,52
	59	0,58
T 6	60	0,19
	61	0,45
	62	0,33
T 7	63	0,43
	64	0,20
	65	0,50

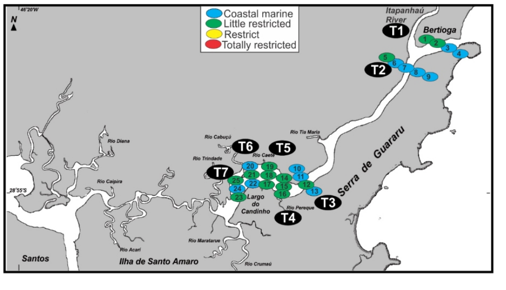


Figure 14: CI on the sampled transects.

Our study propose to divide the channel into three different environments. This division is mainly based on marine influence that is:

- Sites subject to saline water penetration through the eastern channel mouth,
- Sites subject to saline water penetration through the western

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mouth of the canal,

- Transition zone located mainly in Largo do Candinho, being influenced by the two mouths, since meeting of waters occurs at this location.

Transition zone presents great amount of agglutinated foraminifera, whereas in environments subject to saline water penetration through two mouths inhabits mainly euhaline foraminifera.

Values of C/N ratio obtained in the sediment from transects show differentiation in marine contributions, mixed and continental (Table 3, Figure 15).

	Stations	C/N ratio
T 1	1	23,2
	2	12,9
	3	-33,3
	4	-26,2
T 2	5	18,0
	6	13,8
	7	41,4
	8	7,4
	9	15,4
T 3	10	19,3
	11	20,5
	12	3,2
	13	14,0
T 4	14	15,1
	15	20,3
	16	23,4
T 5	17	20,5
	18	20,9
	19	18,2
T 6	20	11,7
	21	16,6
	22	22,2
T 7	23	24,4
	24	16,5
	25	21,0

Table 3: C/N ratio in transects.

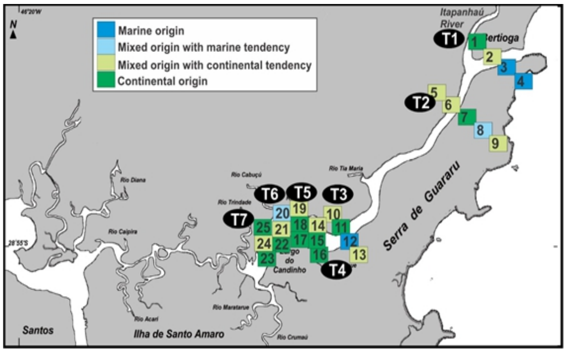
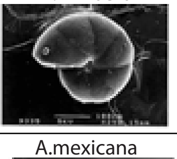
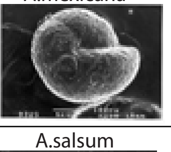
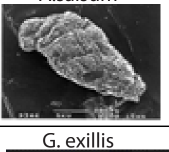


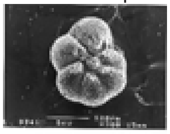
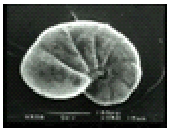
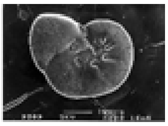
Figure 15: Ratio C/N obtained for samples of transects.

CI values (Figure 14) and C/N ratio (Figure 15) obtained in transects agree as to the origin of the sediment, since results demonstrate marine and continental environments and show the penetration of salt wedge through the eastern channel mouth.

Discussion

The basic features and estuarine species of foraminifera associated with three geographical areas form a synthesis of the environmental characterization of Bertioga Channel can be viewed in Table 4.

Table 4: Summary of information related to indicator species, geographical areas and estuarine characteristics of Bertioga Channel. Indicator species and genera	**Geographic location**	**Marine or continnetal influence**	**Sediment kind**	**Organic compounds**	**Stratification**	**Currents**
H. wilberti 	Mangroves, rivers and estuarine channels	Mixohaline and brackish, salinity: 0-25 PSU, with occurrence peak at 0-9 PSU	Fine with high percentage of silt and clay content	High carbon and nitrogen content	Environment range from weakly and highly stratified	Weak intensity (V<0,1 m/s-1)
A.mexicana 		Mixohaline and brackish, salinity: 0-25 PSU, with occurrence peak at 10-20				
A.salsum 		Mixohaline and brackish, salinity: 0-25 PSU				
G. exillis 		Mixohaline and brackish, salinity: 0-25 PSU				
A. tepida  Elphidium spp. 	Western mouth, Largo do Candinho, western and eastern inner parts (inner part dominated by river however still sea influenced)	Mixohaline, salinity: 20-30 PSU	Coarse sediment, continental with medium silt and clay content	Medium Carbon and Nitrogen content	Environment range from weakly and highly stratified	Medium intensity (-0,2<V<0,2) m/s-1

Pararotalia sp.  P. atlanticum  H. boueana 	Western and eastern part (High energy dominated by marine waters)	Euhaline e mixohaline, salinity higher than 28	Coarse sediment, continental with low silt and clay content	Low carbon and nitrogen content	Highly stratified	Medium and high intensity (-0,15<V<0,2) (-0,75<V<0,5) m/s-[1]

Foraminiferal indicators of increased fine sediment as *Ammonia tepida, Buliminella elegantissima* are associated with increased rainfall (low frequency change). The reduction in salinity is noted by the appearance of *Haplophragmoides wilberti* and *Arenoparella mexicana* in summer. In Rio Trindade the appearance of the infaunal *B. elegantissima* as elongated test, which seems to adapt to low oxygen environments (Den Dulke, et al. 1998). In Largo Candinho we have observed increasing in dominance of *A. tepida* and *Arenoparella mexicana*. The western and eastern mouth showed increased diversity due to the appearance ofaggltinated species. The penetration of cold water in the channel, also considered low-frequency temporal scale, is influential in the environment and considered as occasional event capable of acting in the estuary of the dynamic changing hydrological properties, still being capable of transporting tests of foraminiferal species. Largo do Candinho is a place where the width is the largest and lowest depths along the channel. This environment is influenced by the penetration of tides from two mouths, but tide from eastern mouth comes to Candinho Largo with greater intensity.

The "natural" capacity for renewal of BC waters:

- High efficiency in the renewal of the water, characteristic observed mainly in the eastern inner part and eastern mouth of the channel,
- Average efficiency observed in the western mouth, and Largo Candinho, and mangroves,
- Low efficiency observed in the western inner parts, Trindade River and mangroves. Interestingly the subdivision of eastern inner part into two parts: the eastern inner part I and eastern inner part II.

This division was based in accordance with the renewal rate of the water and foraminiferal species. Figure 16 shows the relationship between indicator species and the renewal rate for Bertioga Channel.

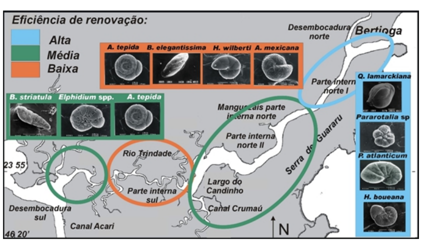


Figure 16: Relationship between indicator species and the renewal rate on the Bertioga Channel.

Figure 16 highlights the foraminiferal species indicative of the zonation related to the different rates of renewal. The sites considered with high-efficiency renovation present species of euhaline environments (Pararotalia sp., Pseudononion atlanticum, Hanzawaia boueana and Quinqueloculina lamarckiana), and therefore the least likely environments to suffer from environmental changes due to human-derived pollution Santos Bay. Places where the renewal efficiency is average hyaline calcareous species characteristics of mixohaline environments (Bolivina striatula, Ammonia tepida and Elphidium spp.) occur presenting hence lower turnover waters and moderate chances of support for environmental change. Where the water renewal efficiency is low foraminifera are characteristic of mixohaline waters (A. tepida, B. elegantissima, Elphidium spp. and from brackish waters (Haplophragmoides wilberti and Arenoparella mexicana), and therefore the environments more susceptible to anthropogenic pollution. The physical and geomorphological characteristics of "natural" system affect the estuarine circulation patterns and consequently the zonation of species of foraminifera. Although the boundaries between marine faunas, mixohaline, brackish and continental be gradational, the standards noted above are evidence of efficient use of foraminifera as environmental indicators in environmental assessment and diagnostic submitted brackish or no pollution. The renewal of the water, besides being related to physical characteristics of "natural" channel, is also related to the ability of renew certain amount of marine environmental pollution.

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