Effects of domestic sewage discharges in the estuarine region of the Itanhaém River basin (SP, Brazil).

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ABSTRACT: Effects of domestic sewage discharges in the estuarine region of the Itanhaém River basin (SP, Brazil). The estuarine region of Itanhaém River (São Paulo coastal region) is surrounded by the urban area of Itanhaém municipality. Some rivers from this region receive domestic sewage discharges with no treatment. The estuary and mangrove tidal creeks have been studied in order to evaluate the space and time variability of pollution levels in these environments. The results indicated a spatial gradient of pollution, which higher levels pollution were observed in the tributaries near the urban area and lower levels in the estuary, as well as there being a temporal variability of these levels. The low levels of pollution measured in the estuary of Itanhaém River, that receives the water from tributaries with high levels of pollution, probably is the result of the dilution of the sewage due to the seawater inflow at high tide and to the great volume of freshwater not polluted flowing from the upper part of the basin, which receives a contribution of the Parque Estadual da Serra do Mar.
Key-words: estuary, aquatic pollution, limnology, salinity.

RESUMO: Efeitos de descargas de esgotos domésticos na região estuarina da bacia do Rio Itanhaém (SP, Brasil). A região estuarina do Rio Itanhaém (litoral centro-sul paulista) é circundada pela área urbana do município de Itanhaém e recebe lançamentos de esgotos domésticos sem tratamento. O estuário e canais de mangue foram estudados com o objetivo de verificar a variabilidade espacial e temporal dos níveis de poluição nestes ambientes. Os resultados obtidos indicam um gradiente espacial de poluição, com altos níveis de poluição nos tributários próximos à área urbana e baixos níveis no estuário, assim como uma variabilidade temporal nestes níveis de poluição. Os baixos níveis de poluição medidos no estuário do rio Itanhaém, que recebe a água de tributários com altos níveis de poluição, provavelmente é resultado da diluição proporcionada pela entrada de águas marinhas na preamar e do grande volume de água doce não poluída proveniente da parte superior da bacia hidrográfica, localizada no Parque Estadual da Serra do Mar.
Palavras-chaves: estuário, poluição aquática, limnologia, salinidade.

Introduction

Estuaries are ecotones and, as transition ecosystem, act like an interface between freshwater and marine environments, presenting themselves as shelter, reproduction, nursery and recruiting areas for numerous species (Kennish, 1992). The environmental conditions in estuaries are highly variable. As a result of rainfall, overland runoff, meteorological conditions and tidal variation salinity fluctuates in a wider range (Day et al., 1989; Yüsek et al., 2006).

In function of the large human populations often associated with estuaries, rapid development in coastal watersheds and increasing commercial and recreational use of these environments, anthropogenic impacts threaten the long-term viability and health of these important ecotones (Kennish, 1992). Estuaries and mangrove swamps have long been regarded as convenient sites for the disposal of sewage and wastewater due to the tendency of pollutants to be recycled within these naturally eutrophic systems (Clough et al., 1983; Laws, 2000). Domestic sewage discharges in water courses increase the concentrations of organic matter and nutrients that can affect the productivity of the system, increase particulate materials and reduce the amount of dissolved oxygen, leading to excessive algal growth, increased metabolism, and changes in community structure (Day et al., 1989; Laws & Allen, 1996; Hall et al., 1999). Due to these impacts on water quality the need for characterizing environmental conditions and temporal trends in these conditions is correspondingly urgent (Jassby et al., 1997).

Over the past several decades there has been a great deal of scientific study of human impacts in estuaries (Day et al., 1989). Hager & Schemel (1992) noted that agricultural return flow drains and a municipal wastewater treatment plant were the largest sources of nutrients to northern San Francisco Bay, U.S.A. Uncles et al. (1998) estimate the water residence time of Humber Estuary, U.K., and nutrient fluxes to the coastal zone. Whitfield (1999) details factors (among these the pollution effects) influencing the ichthyofaunal community structure in South African estuaries. Chen et al. (2004) concluded that the ecosystem of the Pearl River, China's third longest river, is being threatened because it receives inflow from its tributaries, several of which are heavily polluted. García-Barcina et al. (2006) evaluate the success of almost 20 years pollution abatement in the Bilbao estuary watershed in northern Spain. Yüksek et al. (2006) reported changes in biodiversity of the extremely polluted Golden Horn Estuary, Turkey. In Brazilian estuaries some works were made. Carreira et al. (2004) evaluate the space–time variation of sewage inputs to Guanabara Bay (Rio de Janeiro) during the last century through the distribution of coprostanol and other sterols in sediment cores of this estuary, considered highly contaminated by substances derived from domestic and industrial effluents as well as from agricultural runoff. Braga et al. (2000) reported the eutrophication and bacterial pollution caused by industrial and domestic sewage in the Baixada Santista estuarine system. Camargo et al. (1995) verified the organic sewage influence on the diurnal variation of some limnological characteristics in the estuarine region of Cananéia. Specifically in the estuarine region of Itanhaém River basin Camargo et al. (1994), Camargo et al. (1996), Camargo et al. (1997), Camargo & Florentino (2000), Souza-Pereira & Camargo (2004) and Biudes & Camargo (2006) reported aspects relative to pollution effects in rivers and biota of the estuarine region.

In this paper we presented some limnological characteristics of the rivers and tidal creeks in the estuarine region of Itanhaém River basin that receives domestic sewage discharges in order to determine the spatial and temporal variability of pollution levels. It would contribute to prevent impacts to the biota of the related environments and to human health of the Itanhaém population.

Study area

The Itanhaém River basin (IRB) is located on the southern coast of the São Paulo State, southeastern Brazil (23° 50' and 24° 15' S; 46° 35' and 47° 00' W) and drains a watershed of about 950 km², with approximately 50 km length and 15 km width (Suguio & Martin, 1978; Pereira, 2002) (Fig. 1). The climate of the region is Af - Tropical (tropical super humid with no defined dry season - but with a higher rainfall during the summer), according to Köeppen (Setzer, 1966). The meteorological conditions present little variation due to its latitude and proximity to the Atlantic Ocean. Rain is abundant (annual mean of 2,183 mm), with more rainfall in March (279.9 mm) and less in August (84.7 mm). The atmospheric temperature in the region is high, with a maximum average of 26.2 °C (February) and minimum average of 19.0 °C (July) (Lamparelli & Moura, 1998).

The superior region of the basin is located in a mountainous area (600-800 m) that is covered by a well-preserved Atlantic Pluvial Forest (Mata Atlântica) (conservation area of the State Park of Serra do Mar). The intermediate region is located on the coastal plain and is covered by Coastal Plain Transitional Forest (Mata de Restinga) in which different types of anthropogenic impact are observed (sand pits, banana farms and deforestation). The lower region (0-5 m) is covered with mangrove vegetation. In this region, because of proximity of a sizable urban center, the rivers are impacted by deforestation, buildings and domestic drains without previous treatment. The basin shows a large diversity of water types (white, black, clear and brackish) (Camargo et al., 1996; Camargo et al., 1997; Camargo et al., 2002).

Itanhaém River Basin (IRB) is the second largest basin of the São Paulo state coast, Brazil (being smaller in area than the

Ribeira do Iguape River basin). The principal economic activity in the IRB is based on tourism activity. The total population of Itanhaém municipality was 71,995 inhabitants in the year 2,000, 97.27% in the urban region and 2.73% in the rural region (IBGE, 2004). The vacationers, however normally increase this number to about 220,000, during summer. Even during winter about 50,000 and during weekends about 2,000 people increase these total numbers. Itanhaém has, in 1996, 461,408 m of water supply system and 81% of municipality population served, 13,841m of sewer network and 8.5% municipality population served, 91.5% of houses have cesspit (SABESP, 2005).

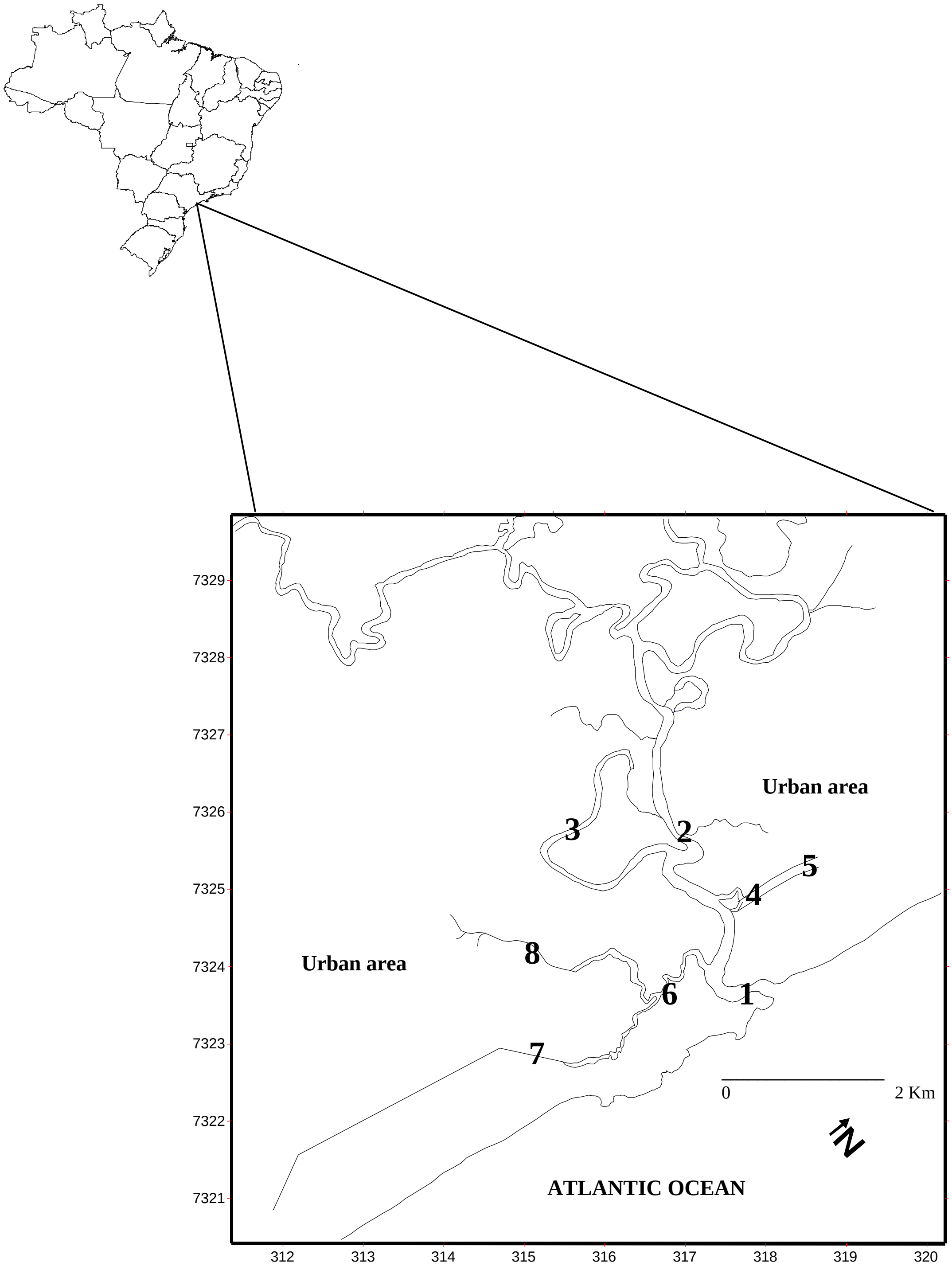

Figure 1: Map of estuarine region of Itanhaém River. Sample stations in Itanhaém River (1 and 2), Volta Deixada Meander (3), Campininha River (4 and 5), Guaú River (6), Poço River (7) and Bleudo Stream (8).

Material and methods

Eight sampling stations were established in the estuarine region of the IRB (Fig.1, Tab. I). Three replicate samples of water were collected in October 1997, February 1998, May 1998, August 1998, November 1998, February 1999, May 1999 and August 1999. Water samples were collected from the subsurface (10 cm) in right, left river margins and in the center of the river, in low tide. Approximately 0.5 litters of water were filtered (Whatman GF/C filter) few hours after collected in the laboratory of the Center of Research of Itanhaém River. The samples were conditioned in polyethylene bottles and immediately frozen at -20° C. In the Laboratory of Aquatic Ecology (Ecology Department/UNESP/Rio Claro), from the filtered samples, were measured the concentrations of ammoniacal nitrogen (ammoniacal-N) (Koroleff, 1976), nitrate (NO_3-N), nitrite (NO_2-N), total dissolved nitrogen (TDN) (Mackereth et al., 1978), ortho-phosphates (PO_4-P) and total dissolved phosphorus (TDP) (Golterman et al., 1978). Total inorganic nitrogen (TIN) was calculated by the sum of NO_3-N, NO_2-N and ammoniacal-N. Samples of non-filtered water were used to determine total nitrogen (TN) (Mackereth et al., 1978) and total phosphorus (TP) (Golterman et al., 1978). Dissolved oxygen concentrations (DO) were determinate by Winkler method (Golterman et al., 1978). Salinity levels (SAL) were measured using a Water Quality Checker Horiba (model U-10).

The results of the limnological variables were confronted using the analysis of variance and Tukey's Honest Significant Difference test (Zar, 1996) to verify significant differences ($p<0.05$) among the sampling stations in each sampling date. Cluster analysis (unweighted pair group Method - arithmetic average) was employed to verify the dissimilarity level among the sampling stations. The Statistica program (version 5.5) was used for the statistical analysis (Statistica, 2000).

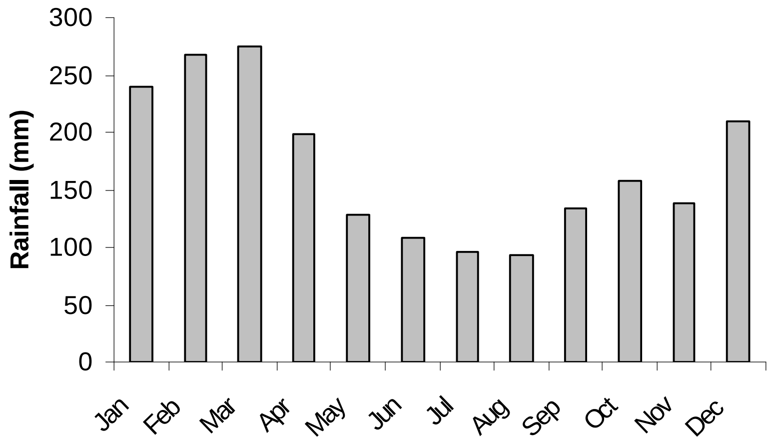

Figure 2: Total monthly rainfall averages (mm) from 1938 to 1999 in meteorological sampling station F3-005, located 3 m of altitude in the Itanhaém River basin (Integrated System of Hydric Resources Management of São Paulo State – Brazil) (http://www.sigrh.sp.gov.br).

Table I: Sampling stations in the estuarine region of the Itanhaém River basin.

Sampling Stations	Coordinates	Location
1	24°11'21 – 46°47'43	Itanhaém River (mouth)
2	24°10'20 – 46°48'00	Itanhaém River (upstream)
3	24°10'25 – 46°49'01	Volta Deixada Meander
4	24°10'47 – 46°47'36	Campininha River (mouth)
5	24°10'19 – 46°47'04	Campininha River (upstream)
6	24°11'18 – 46°48'06	Guaú River
7	24°12'26 – 46°49'58	Poço River
8	24°11'40 – 46°49'44	Bleudo Stream

Results

The results of the limnological variables presented significant differences (p<0.05) among the sampling stations. Spatial variations of the limnological variables were observed, for instance, in TN average values between sampling station 2 (0.3 mg.L^{-1}) and sampling station 4 (9.9 mg.L^{-1}) in August 1999, and in TP values between different stations in the same river, for instance sampling station 4 (247 mg.L^{-1}) and sampling station 5 (1132 mg.L^{-1}) in Campininha River in August 1999. Spatial variations were observed in the same sampling date, for instance in August 1998, which the highest average value of DO were observed in sampling station 2 (7.6 mg.L^{-1}) and the lowest in sampling station 8 (0.3 mg.L^{-1}). In February 1999 the TIN levels were higher in sampling station 8 (946 mg.L^{-1}) than in the sampling station 2 (55 mg.L^{-1}). In October 1997 TIN levels were lower in sampling station 1 (70 mg.L^{-1}) than in the sampling station 5 (387 mg.L^{-1}) and TN were lower in sampling station 1 and 2 (0.5 mg.L^{-1}) and higher in sampling station 8 (4.4 mg.L^{-1}) (Tab. II).

Table II: Average values and standard deviation of the chemical variables measured in October 1997 (A), February 1998 (B), May 1998 (C), August 1998 (D), November 1998 (E), February 1999 (F), May 1999 (G) and August 1999 (H). Distinct letters indicate significant differences (p<0.05) among sampling stations.

A	1	2	3	4	5	6	7	8
TIN (mg.L^{-1})	70±9.5a	80±36.0a	148±30.1a	325±39.9c	387±47.0c	162±19.0b	179.±38.1b	361.±15.5c
TDN (mg.L^{-1})	0.2±0.1a	0.2±0.1a	0.8±0.1b	2.4±0.1c	2.4±0.3 c	1.0±0.1b	0.5±0.1a	3.3±0.2d
TN (mg.L^{-1})	0.5±0.1a	0.5±0.1a	1.2±0.2 b	3.3±0.3c	3.2±0.3c	1.3±0.1 b	0.7±0.1a	4.4±0.1d
PO_4-P (mg.L^{-1})	5±0.1a	5±0.1a	24±12.2b	163±27.3c	167±37.9c	49±22.0b	41±21.2b	107±34.5d
TDP (mg.L^{-1})	29±3.0a	26±12.7a	109±28.3b	182±8.3c	239±31.9d	158±8.8c	100±22.9b	174±46.8c
TP (mg.L^{-1})	11±4.9a	10±11.8a	146±26.0b	928±236.6c	889±133.4c	206±46.2b	86±49.3b	216±23.1b
DO (mg.L^{-1})	5.5±0.1a	5.5±0.2a	1.6±0.1b	0.5±0.1c	0.8±0.1c	0.8±0.2c	1.2±0.3b	0.8±0.1c

B	1	2	3	4	5	6	7	8
TIN (mg.L^{-1})	47±4.8a	52±20.7a	54±15.5a	39±4.1a	123±13.0a	51±26.5a	221±55.7c	183±26.2b
TDN (mg.L^{-1})	0.3±0.1a	0.4±0.1a	0.3±0.1a	0.3±0.1a	1.1±0.1b	0.4±0.1a	1.1±0.1b	1.2±0.3b
TN (mg.L^{-1})	0.6±0.1a	0.5±0.1a	0.6±0.1a	0.5±0.2a	1.4±0.1b	0.5±0.1a	1.3±0.1b	1.4±0.3b
PO_4-P (mg.L^{-1})	5±0.1a	5±0.1a	5±0.1a	15±13.8a	66±7.4a	27±32.3a	120±58.4b	58±9.0a
TDP (mg.L^{-1})	19±5.9a	25±10.8a	20±4.2a	48±17.1a	105±8.7b	50±25.7a	123±48.3b	79±5.1a
TP (mg.L^{-1})	34±10.1a	25±17.6a	137±19.2a	198±39.1b	144±49.3a	136±37.3a	292±68.3c	190±56.2b
DO (mg.L^{-1})	5.9±0.2a	5.8±0.1a	4.1±0.1a	5.0±0.1a	1.5±0.1b	4.5±0.2a	1.7±0.3b	3.4±2.5a

C	1	2	3	4	5	6	7	8
TIN (mg.L^{-1})	114±8.7a	71±50.1a	51±31.1a	143±16.8a	300±14.3b	325±32.7b	49±11.9a	274±10.9b
TDN (mg.L^{-1})	0.2±0.1a	0.2±0.1a	0.4±0.1a	0.3±0.1a	3.9±0.7c	2.5±0.1b	0.4±0.1a	3.6±0.1c
TN (mg.L^{-1})	0.3±0.1a	0.2±0.1a	0.4±0.1a	0.3±0.1a	4.7±0.3c	2.2±0.1b	0.4±0.1a	4.0±0.1c
PO_4-P (mg.L^{-1})	5±1.0a	5±0.8a	5±1.1a	5±3.5a	46±7.0b	49±11.7b	9±5.1a	52±5.1b
TDP (mg.L^{-1})	21±7.5a	13±0.6a	210±20.8d	26±4.8b	141±4.4c	129±16.9c	69±6.7b	152±9.3c
TP (mg.L^{-1})	31±11.7a	18±3.3a	76±11.1a	54±16.1a	168±9.8b	231±57.0c	139±49.3b	477±80.1d
DO (mg.L^{-1})	5.8±0.1a	6.4±1.0a	6.2±0.3a	5.9±0.3a	1.5±0.6c	0.7±0.1c	3.3±0.1b	2.3±0.1b

Table II: Cont.

D	1	2	3	4	5	6	7	8
TIN ($mg.L^{-1}$)	50±26.8a	29±5.2a	53±6.9a	137±.7.8c	73±9.3b	153±19.9c	59±3.7b	78±13.5b
TDN ($mg.L^{-1}$)	0.3±0.1a	0.2±0.1a	0.5±0.1a	2.1±0.5c	2.5±0.3c	1.8±0.2b	1.3±0.4b	1.3±0.1b
TN ($mg.L^{-1}$)	0.4±0.1a	0.5±0.2a	0.6±0.1a	2.5±0.5c	2.8±0.4c	2.0±0.2c	1.6±0.1b	1.5±0.1b
PO_4-P ($mg.L^{-1}$)	15±7.7a	14±6.7a	22±2.4a	106±23.6b	161±8.2b	124±12.5b	126±19.6b	227±0.1c
TDP ($mg.L^{-1}$)	43±6.2a	29±4.8a	71±10.7a	155±14.9b	231±1.2c	193±37.5c	209±12.7c	511±0.1d
TP ($mg.L^{-1}$)	69±9.3a	51±5.8a	129±10.2a	379±76.5b	343±66.6b	319±27.3b	340±48.1b	1348±0.1c
DO ($mg.L^{-1}$)	7.3±0.2a	7.6±0.3a	7.1±0.1a	1.7±0.2b	0.7±0.3c	1.2±0.2b	0.5±0.1c	0.3±0.1c

E	1	2	3	4	5	6	7	8
TIN ($mg.L^{-1}$)	40±22.2a	105±33.8b	85±15.1a	82±4.1a	179±7.6c	109±6.8b	131±15.1b	149±2.4b
TDN ($mg.L^{-1}$)	0.2±0.1a	0.1±0.1a	0.1±0.1a	0.3±0.1a	5.7±0.2c	1.3±0.3b	1.3±0.1b	6.6±1.0c
TN ($mg.L^{-1}$)	0.3±0.1a	0.2±0.1a	0.4±0.1a	0.4±0.1a	6.6±0.3c	1.7±0.2b	1.7±0.1b	7.5±0.8c
PO_4-P($mg.L^{-1}$)	5±0.1a	5±0.1a	7±1.7a	7±0.6a	301±90.9c	103±37.9b	94±9.4b	134±97.0b
TDP ($mg.L^{-1}$)	7±1.0a	7±3.3a	10±5.8a	19±8.9a	482±30.9c	174±58.4b	126±13.8b	335±261.7c
TP ($mg.L^{-1}$)	29±16.2a	21±3.2a	42±10.5a	27±10.4a	603±210.4c	259±102.9b	307±159.9b	986±344.6d
DO ($mg.L^{-1}$)	5.9±0.2a	6.1±0.2a	3.9±0.1b	5.7±0.1a	0.1±0.1c	0.4±0.1c	0.5±0.1c	2.3±0.3b

F	1	2	3	4	5	6	7	8
TIN ($mg.L^{-1}$)	108±9.9a	55±19.8a	137±15.0a	318±28.3c	585±35.4d	204±49.8b	267±89.8c	946.1±89.8d
TDN ($mg.L^{-1}$)	0.2±0.1a	0.2±0.1a	0.4±0.1a	0.7±0.1a	1.9±1.1c	0.6±0.1b	0.7±0.1b	3.2±0.1d
TN ($mg.L^{-1}$)	0.9±0.2a	0.4±0.1a	0.6±0.2a	1.2±0.1b	2.9±0.3c	0.8±0.1b	1.1±0.2b	4.3±0.1c
PO_4-P ($mg.L^{-1}$)	5±1.8a	5±0.3a	5±0.1a	12±8.8a	14±5.7a	18±2.0b	16±3.0b	102±0.1c
TDP ($mg.L^{-1}$)	8±2.9a	5±1.0a	19±5.2a	50±3.3b	82±14.9c	37±18.5b	30±2.3b	122±0.1d
TP ($mg.L^{-1}$)	13±3.5a	7±1.6a	26±2.8a	107±26.7c	128±32.0c	94±17.5c	48±9.2b	496±0.1d
DO ($mg.L^{-1}$)	4.6±0.1a	4.6±0.1a	2.1±0.2b	1.9±0.1b	0.2±0.1c	2.2±0.2b	1.4±0.1b	0.3±0.1c

G	1	2	3	4	5	6	7	8
TIN ($mg.L^{-1}$)	73±18.4a	103±22.3a	63±0.1a	340±64.4c	224±18.7b	323±17.4c	74±21.0b	309±12.7c
TDN ($mg.L^{-1}$)	0.3±0.1a	0.2±0.1a	0.3±0.1a	0.8±0.1b	0.9±0.1b	0.7±0.1b	0.6±0.1b	1.6±0.1c
TN ($mg.L^{-1}$)	0.4±0.1a	0.3±0.1a	0.4±0.1a	1.0±0.1b	1.2±0.1c	0.8±0.1b	0.8±0.1b	1.8±0.2c
PO_4-P ($mg.L^{-1}$)	5±1.9a	5±2.3a	24±0.1b	66±8.1b	50±7.5b	43±5.0b	12±1.4a	10±5.1a
TDP ($mg.L^{-1}$)	14±3.1a	9±0.6a	70±0.1a	98±5.3c	98±49.2c	58±3.1b	92±7.0c	55±5.0b
TP ($mg.L^{-1}$)	25±4.4a	12±2.8a	42±3.8a	116±14.8c	82±5.9b	73±5.3b	108±3.3c	72±1.6b
DO ($mg.L^{-1}$)	5.8±0.1a	6.2±0.1a	4.5±0.1b	3.3±0.4b	1.3±0.3c	2.9±0.1b	2.3±0.1b	1.8±0.1c

H	1	2	3	4	5	6	7	8
TIN ($mg.L^{-1}$)	61±24.6a	42±9.9a	33±2.9a	119±7.4b	283±21.5d	217±8.9c	223±13.7c	206±10.1c
TDN ($mg.L^{-1}$)	0.3±0.1a	0.2±0.1a	0.2±0.1a	1.0±1.7b	8.1±0.5c	1.7±0.2b	2.3±0.2b	6.1±0.1c
TN ($mg.L^{-1}$)	0.4±0.1a	0.3±0.1a	0.3±0.1a	1.1±1.9a	9.9±1.3c	2.1±0.1b	2.8±0.1b	7.2±0.1c
PO_4-P ($mg.L^{-1}$)	11±4.2a	9±3.2a	16±6.5a	47±83.3a	798±100.1c	67±6.0b	109±20.4b	30±0.1a
TDP ($mg.L^{-1}$)	20±4.6a	19±1.3a	59±1.6a	110±10.2a	1098±233.3c	141±20.1b	166±12.0b	65±0.1b
TP ($mg.L^{-1}$)	33±3.0a	29±7.3a	58±6.6a	247±25.4b	1132±236.0c	173±16.6b	221±15.4b	115±0.1b
DO ($mg.L^{-1}$)	6.2±0.1a	6.2±0.1a	3.9±0.3a	1.6±3.2b	0.1±0.1c	1.3±0.5b	0.1±0.2c	0.2±0.1c

Temporal variations of the variables can be noted when were compared, for instance, the TP value in sampling station 8 in August 1998 (1348 mg.L^{-1}) and in May 1999 (72 mg.L^{-1}) and the TN value in sampling station 8 in November 1988 (7.5 mg.L^{-1}) and in February 1998 (1.4 mg.L^{-1}). Temporal variations were noted in the same season but at distinct dates, for instance autumn, which TP average value at sampling station 6 in May 1998 (231 mg.L^{-1}) was higher than the value in May 1999 (73 mg.L^{-1}) and TIN value at sampling station 5 in February 1998 (123 mg.L^{-1}) was lower than the value in February 1999 (585 mg.L^{-1}) (Tab. II).

The Cluster analysis was applied with the aim to establish a general view of the differences of the limnological characteristics measured in the eight sampling stations in eight sampling dates (Fig. 3). The dendrogram showed the dissimilarity level among the sampling stations, and a spatial gradient of pollution could be noted from left to right on this graph, which the unpolluted stations are in the left side and polluted stations are in the right side. By this way, three groups were distinguished, group A, which sampling stations 1, 2, and 3 presents less impacted, group B, which sampling stations 4, 6 and 7 presents medium impacts and group C, which sampling stations 5 and 8 presents severally impacted.

The SAL levels were plotted against TN, TP and DO values with the purpose to infer the influence of seawater in the pollution levels of the estuarine region (Fig. 4). The figure shows that in higher SAL levels the concentrations of TN and TP were lower and the concentrations of DO were higher. On the other hand in lower levels of SAL the concentrations of TN, TP and DO were both lower and higher.

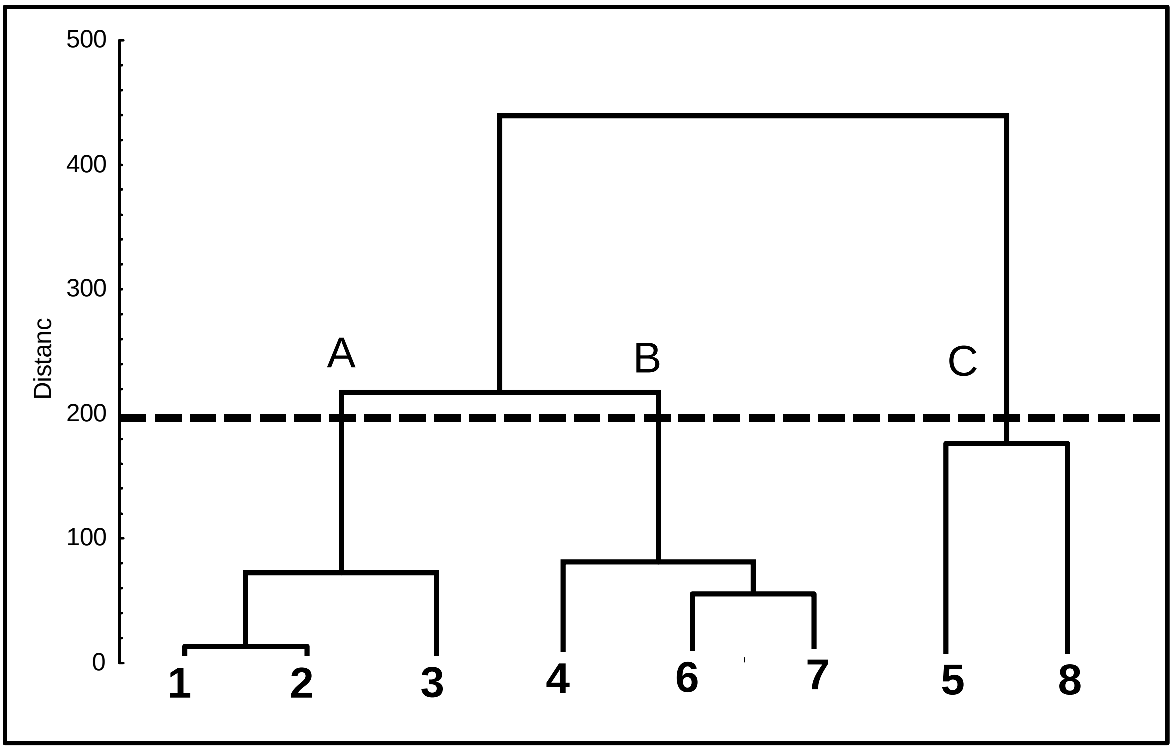

Figure 3: Dendrogram of classification of the sampling stations (1 and 2: Itanhaém River, 3: Volta Deixada Meander, 4 and 5: Campininha River, 6: Guaú River, 7: Poço River and 8: Bleudo Stream) in the estuarine region of Itanhaém River basin.

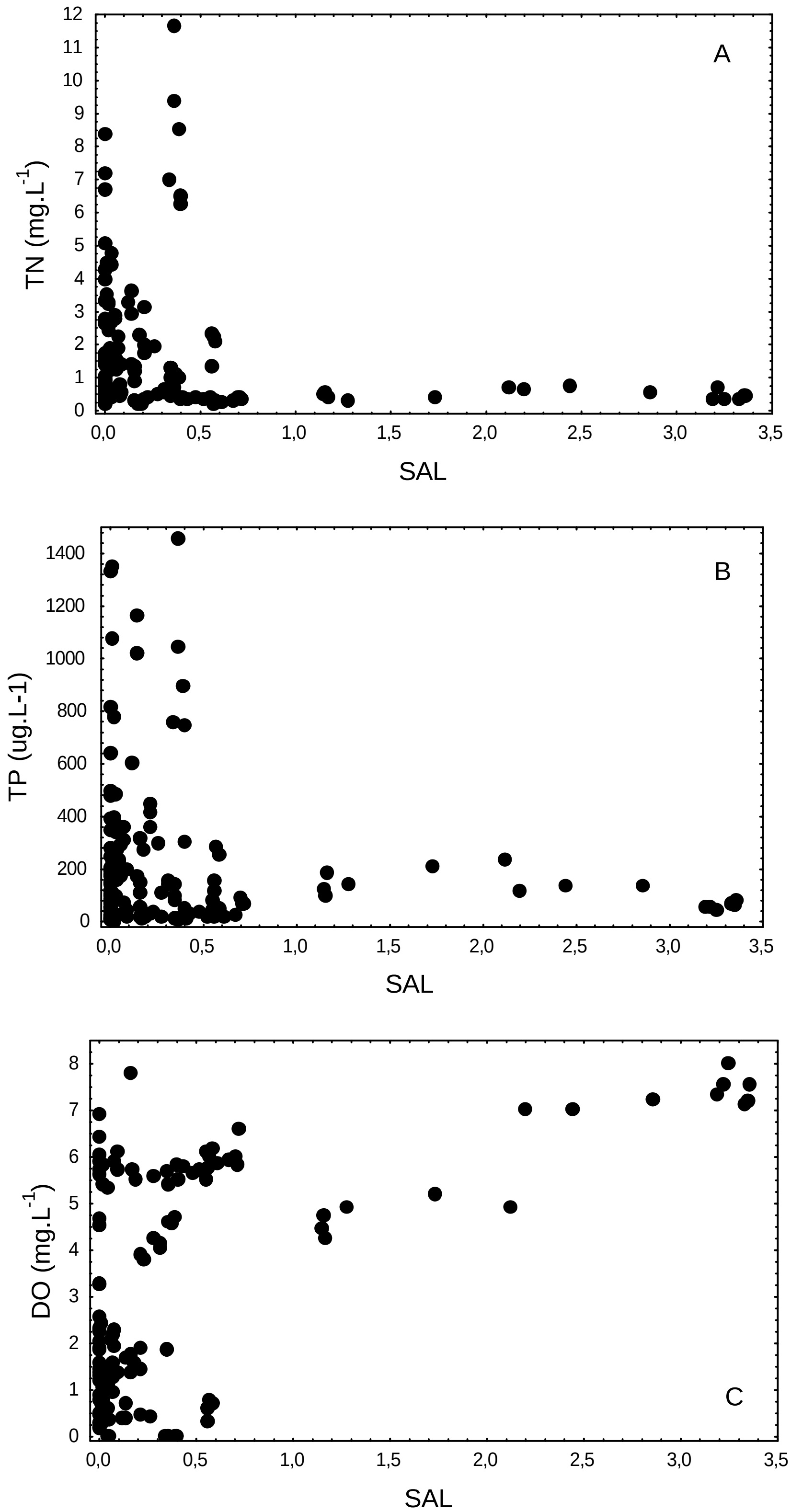

Figure 4: Concentrations of (A) total nitrogen, (B) total phosphorus and (C) dissolved oxygen with respect to salinity in the estuarine region of Itanhaém River basin.

Discussion

The results showed significant differences of pollution levels in the eight sampling stations in the estuarine region of IRB. The sampling stations more polluted (5 and 8) have higher N and P concentrations and lower values of DO. The higher levels of pollution in the stations 5 and 8, probably is related to the sewage launching in these rivers and the low rates of sewage dilution due to the higher distance of the Itanhaém River and the low water volume of these rivers. On the other hand, sampling stations 1, 2 and 3 could be classified as unpolluted or low polluted, probably due to sewage dilution conditions in these locals. In fact, stations 1 and 2 are located in the Itanhaém River main course that receives seawater and unpolluted freshwater from the upper part of the hydrographic basin. Sampling stations 4, 6 and 7 were considered median polluted, because are located in tidal creeks that receive wastes but with a short distance to the Itanhaém River and, probably these stations are subject to moderate dilution process.

Other authors observed the same pattern in other estuaries, that is, some locals considered higher polluted and others lower or unpolluted, and attributed this pattern to dilution and mixing process. Clough et al. (1983) and Laws (2000) reported that the fate of nutrients and other constituents of sewage effluent discharged into mangrove systems is largely influenced by hydrodynamic factors, such as tidal inundation and patterns of water movement and drainage, which affect effluent dispersal and mixing. Washburn et al. (2003) hypothesized that mixing processes would reduce the gradient of pollution over time as higher salinity, when ambient ocean waters mixed into the storm water plumes resulted from freshwater discharge in Santa Monica Bay, U.S.A.. Chen et al. (2004) noted that the mixing of seawater with river discharge and the accompanying biogeochemical processes reduce the pollution within the Pearl River estuary, China. In the Baixada Santista estuarine system (Brazil) Braga et al. (2000) reported a gradient of dilution of pollution levels from the estuary's interior to its mouth along the natural channels, which dissolved nutrients reached higher values in the direction to the estuary's head. In the estuarine region of Itanhaém River this gradient of pollution is evident too, because the sampling stations more distant from the estuary show higher levels of pollution.

The influence of sewage dilution by seawaters is evident in Figure 4, because in higher salinity the concentrations of N and P are always lower and DO higher. On the other hand in lower values of salinity N, P and DO can be higher or lower. The difficulty of dilution of sewage in low tide can explain the higher levels of pollution and the entrance of freshwater from the upper part of the basin can explain the lower pollution levels. The water from the upper part of the hydrographic basin has low concentrations of nutrients, higher values of DO, and pollution is absent because there are not any urban centre, small areas of agriculture and the presence of the Parque Estadual da Serra do Mar (Camargo et al. 1996; Camargo et al. 2002).

The importance of the river flows in the dilution of wastewater was observed in the northern San Francisco Bay (U.S.A) by Hager & Schemel (1992). These authors noted that anthropogenic sources supply most of the nutrients to northern San Francisco Bay during times of low river flows, whereas freshwater inflows affect exchange of water with other parts of the bay and dilution of waste sources entering the bay. Freshwater inflows also affect the residence times of waters in the rivers and bay, which influence the processing of the nutrients and their eventual transport to the ocean.

Aquatic pollution levels are declining in significance, for instance, in some U.K. estuaries (Matthiessen & Law, 2002) and in Bilbao estuary, Spain (García-Barcina et al., 2006), showing that legal controls over direct sewage and industrial discharges and legislative changes have brought about some reductions in discharges and improved environmental quality. Itanhaém municipality has two wastewater treatment plants, however only 4% of the produced sewage were treated (SABESP, 2005). The main factor responsible by the low levels of pollution in the Itanhaém River (stations 1 and 2) is the freshwater inputs from the headwaters. According Pereira (2002), although the Itanhaém River estuary has the same temporal and spatial dynamic of others estuaries, the values of SAL are low when compared with others estuaries located in the southern coast of São Paulo state probably due to the largest drainage area of this basin, which permits a higher freshwater inflow in the estuarine region. This higher inflow of freshwater probably is the main factor that determines the low levels of pollution in Itanhaém estuary.

Temporal variation on the pollution levels was observed in the estuarine region of IRB. However, the distribution of rain presents a seasonal pattern with higher rainfall in summer and lower in winter and add to that in summer the number of habitants increase around 4 times, the variation of pollution levels do not have a seasonal pattern. The increase of population in summer promotes the levels of pollution, but on the other hand, the increase of rainfall promotes dilution of wastes. In fact, Hager & Schemel (1992) observed in Sacramento River (San Francisco Bay, USA) higher concentrations of dissolved inorganic nitrogen and dissolved reactive phosphorous during periods of lower river flows. It is important to note that in the region of Sacramento River there is not a seasonal population density variation. Another aspect that probably influences the levels of pollution in the estuarine region of IRB is the rainfall inflow regime due to cold fronts entries that occur in all the year seasons. These cold fronts promote high levels of rainfall in short periods (2 or 3 days) in the coastal plain (Lamparelli & Moura, 1998). Add to that, with exception of sampling stations 1, 2 and 3, the others sampling stations are located in small rivers that increase the flows with a feel days of rain. It has a result, if the samples were made during or immediately again a period of rain the levels of pollution probably were lower due to dilution process.

Pollution in estuarine areas affects biological communities, and in the estuarine region of IRB other authors observed the influence of pollution upon some biological communities or species. Souza-Pereira & Camargo (2004) observed a positive relation between the density of nauplii of copepods and organic pollution in Volta Deixada Meander. Biudes & Camargo (2006) verified that domestic sewage in the water of the Guaú River fertilize Spartina alterniflora that have higher biomass, TN, TP, protein, lipids and soluble carbohydrates than the biomass of it species in Itanhaém River. Add to that, an over-enrichment by anthropogenic nutrients causes severe problems for the recreational use of some beaches and for human health (Braga et al., 2000).

We concluded that the pollution levels in the estuarine region of the IRB showed space and time variations. Both variations are explained by the dilution process of sewages. The dilution was made by seawater and freshwater from the upper region of the basin located in a conservation area.

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