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From a water resource to a point pollution source: the daily journey of a coastal urban stream

Rörig, LR.[a*], *Tundisi, JG.*[b], *Schettini, CAF.*[a], *Pereira-Filho., J.*[a], *Menezes, JT.*[a], *Almeida, TCM.*[a], *Urban, SR.*[a], *Radetski, CM.*[a], *Sperb, RC.*[a], *Stramosk, CA.*[a], *Macedo, RS.*[a], *Castro-Silva, MA.*[a] *and Perez, JAA.*[a]

[a]Centro de Ciências Tecnológicas, da Terra e do Mar, Universidade do Vale do Itajaí (CTTMar – UNIVALI), Rua Uruguai, 458, CEP 88302-202, Itajaí, SC, Brazil

[b]International Institute of Ecology, Rua Bento Carlos, 750, CEP 13560-660, São Carlos, SP, Brazil

*e-mail: rorig@univali.br

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(With 5 figures)

Abstract

The aim of this study was to understand how a stream ecosystem that flows from its fountainhead to its mouth inside a city, changes from a water resource to a point pollution source. A multidisciplinary descriptive approach was adopted, including the short-term temporal and spatial determination of physical, chemical, biological and ecotoxicological variables. Results showed that water quality rapidly decreases with increasing urbanization, leading the system to acquire raw sewage attributes even in the first hundred meters after the fountainheads. Despite the tidal circulation near the stream mouth being restricted by shallowness, some improvement of the water quality was detected in this area. The multidisciplinary evaluation showed to be useful for obtaining a more realistic understanding of the stream degradation process, and to forecast restoration and mitigation measures.

Key words: urban streams, runoff, aquatic pollution, ecotoxicology, Santa Catarina.

De recurso hídrico a fonte pontual de poluição: a jornada diária de um córrego urbano costeiro

Resumo

Este trabalho teve o objetivo de compreender como um ecossistema de córrego que flui desde as nascentes até sua desembocadura dentro de uma cidade, transforma-se de recurso hídrico em fonte pontual de poluição. Foi adotada uma abordagem descritiva multidisciplinar, incluindo a determinação espacial e temporal em escala diária de variáveis físicas, químicas, biológicas e ecotoxicológicas. Os resultados mostraram que a qualidade da água rapidamente diminui com o aumento da intensidade espacial de urbanização, levando o sistema a adquirir características típicas de esgoto bruto já após suas primeiras centenas de metros de curso. Apesar da circulação relacionada à maré junto a desembocadura ser restrita devido às baixas profundidades, foi registrada certa melhora na qualidade da água nessa área. A avaliação multidisciplinar se mostrou útil para obter uma compreensão mais realista do processo de degradação do córrego e para propor medidas de restauração ou mitigação dos impactos.

Palavras-chave: Córregos urbanos, escoamento superficial, poluição aquática, ecotoxicologia, Santa Catarina.

1. Introduction

Urban streams provide one of the most explicit examples of how human activities can change an ecosystem (Gilbert, 1991). The occupation of these environments in Brazil is followed by a sequence of uses of decreasing constraint. In the first stage, they are used for transportation, water and food supply. In the second stage, following the development of urbanization, streams become basically pathways for runoff and wastewater discharge. In the final stage, the heavily polluted stream represents risks to the stability of urban structures and tends to be impounded and channeled. Despite that many developed countries are now reversing this cycle and restoring their urban streams (Quadra Planning Consultant Ltd., 1997; Ebersole et al. 1997), this trend is still incipient in Brazil.

Urbanization causes many types of changes in stream ecosystems, including: a) suppression of riparian zones; b) surface impermeability of the draining area; c) increase

in pollution loads; and d) impoundment or channeling of the stream bed (Harding et al. 1998; Gilbert, 1991). The U.S. Environmental Protection Agency found that urban runoff can contain high concentrations of metals such as zinc, lead, copper, chromium, arsenic, cadmium, nickel, antimony, and selenium and heavy organic loads (Norman, 1991). On the other hand, the point sources of pollution, besides its high loads of organic matter and nutrients, can contain a myriad of pollutants such as surfactants, halogenated hydrocarbons, pesticides, metals and many other toxic compounds (Bitton, 1994). White and Rasmussen (1998) found that more than 90% of the genotoxic loading in a Montreal urban community is non-industrial.

Several approaches can be used to detect and evaluate the impacts of human activities on water quality. The most common are traditional chemical analysis, the analysis of bioindicators and toxicity testing. Determination of pollutant concentration by chemical analysis is essential to recognize the pollution typology of a water body, but does not allow the verification of impacts on the biota. Analysis of benthic and planktonic communities allows the detection of bioindicators, which integrate all external factors into their physiological responses (Klumpp, 2001). Toxicity tests, in turn, are capable of detecting bioavailability and interaction among chemical agents, with the advantage of being standardized and usually performed in controlled conditions, leading to more categorical responses (Bertoletti, 2001). Integrated use of these methodologies enhances the ability of understanding the degradation processes of aquatic ecosystems leading to more secure conclusions.

The aim of the present work was: a) to understand how the Schneider Stream, a tropical coastal stream that flows from its fountainhead to its mouth inside a medium sized city (Itajaí, SC, Brazil) changes from a water resource to a point pollution source; and b) to verify how the local hydrological and ecological processes interact with the impacts of urbanization. A multidisciplinary descriptive approach was adopted, including the short-term temporal and spatial determination of physical, chemical, biological and ecotoxicological variables in water and sediments. The Schneider Stream was choosen for this study for two reasons: 1) its basin has been rapidly occupied over the last forty years, reflecting a poorly planned urbanization process; and 2) a municipal project of sewage channeling and treatment is to be executed in the area. This kind of snapshot of the system will enable future comparisons and evaluations of the expected improvement generated by sewage treatment.

2. Material and Methods

2.1. Study area

This study was conducted in the Schneider Stream basin (Figure 1), located in the city of Itajaí (26° 54.7' S and 48° 38.1' W), in Santa Catarina State, Southern Brazil. Itajaí has 170,000 inhabitants, with an annual growth rate of 2.45% (census data from the Brazilian Institute of Geography and Statistics, IBGE), and it includes one of the most important fishing and industrial ports of Brazil. The Schneider Stream is the last tributary on the right bank of the Itajaí River, whose basin covers 15,500 km^2, and has a total population of about 1,200,000 and considerable urban, industrial and agricultural development. The Schneider Stream has a total course of 2,640 m and a basin area of 4.9 km^2. Next to its fountainhead, there is an impoundment whose reservoir of 200 m^3 of water has supplied part of the local community for more than 50 years. The mouth is located in the estuarine-lagoon area of the Rio Itajaí (Saco da Fazenda Lagoon), at 1,000 m from the confluence with the Atlantic Ocean. The drainage area is predominantly urban, practically lacking industry. Details about land use presented in Figure 1 were determined by Rörig et al. (in prep.). The lack or insufficient sewage treatment in the area has resulted in the mouth of the Schneider Stream being categorized as a point source of pollution in regional studies (CTTMar/UNIVALI, 2003).

2.2. Sampling stations and procedures

The samples for this study were collected on August 30, 2004, at spring tide, from 8 until 19 hours. Six sampling stations were established in the Schneider Stream (Figure 1), all along a gradient of urbanization. The most elevated station (#0) was considered as the blank control. The following variables were determined in water and sediment. **In water:** current speed ($m.s^{-1}$) and direction, pressure (water level, mBar), temperature (°C), turbidity (NTU), salinity (%), dissolved oxygen ($mg.L^{-1}$ and %), pH, conductivity ($\mu S.cm^{-1}$), dissolved inorganic nutrients – DIN ($N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$ and $Si(OH)_4$; $mg.L^{-1}$), biochemical oxygen demand (BOD_5; $mg.L^{-1}$), chemical oxygen demand (COD; $mg.L^{-1}$), surfactants ($mg.L^{-1}$), adsorbable organic halogenates (AOX; $mg.L^{-1}$), chlorophyll-a ($mg.m^3$), fecal coliforms ($cells.100\ mL^{-1}$), total bacteria ($cell.mL^{-1}$), phototrophic picoplankton ($cell.mL^{-1}$), nano and microplankton ($cell.ml^{-1}$), toxicity to *Daphnia magna* Straus, 1820, *Skeletonema costatum* (Greville, 1866) Cleve, 1873 and *Vibrio fischeri* (Beijerinck, 1889) Lehmann and Neumann, 1896. **In sediment:** sediment granulometry, % carbonates, % organic matter, metals (Al, Cd, Cr, Cu, Fe, Pb and Zn; $mg.kg^{-1}$), macrobenthos, elutriate toxicity to *Daphnia magna*, elutriate toxicity to *Skeletonema costatum* and elutriate toxicity to *Vibrio fischeri*. Table 1 presents the methods, equipment and references used for determining all of these variables.

The variables for water were determined or collected in 4 sampling schemes differentiated for the 6 stations, based on the differences in tidal influence and logistic limitations: a) single sampling (a single water sampling/determination), b) tidal sampling (one sampling/determination at high tide and one at low tide), c) hourly sampling (sampling/determination every hour) and d) continuous sampling (automatic sampling/determination every 10 minutes). Thus, the results for the water analy-

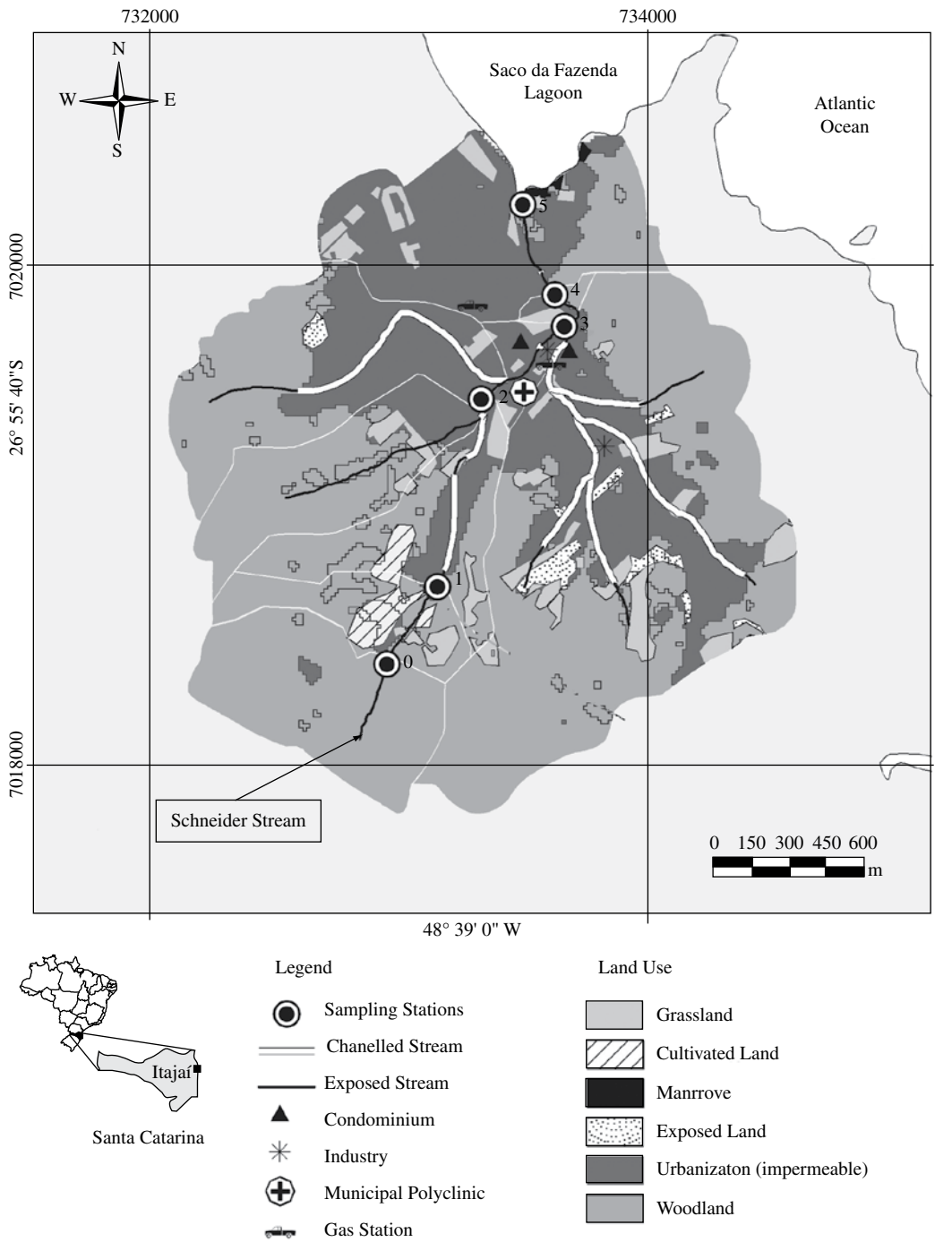

Figure 1. Location of the Schneider Stream Basin showing the sampling stations and information about land use.

ses would be determined spatially, considering all the stations, and temporally in the case of Station #5 (hourly or continuously). The variables for sediment were determined one time. Not all variables for water and sediment were determined at all the stations.

3. Results

3.1. Spatial analysis

For spatial analysis, the data from the stations influenced by the tide (#4 and #5) were considered at

Table 1. Methods and equipments used to determine the different variables in the present study, and respective references.

Variable	Method/equipment	Reference
Water		
Pressure (mBar), Temperature (°C), Turbity (FTU), Salinity (‰), Dissolved Oxygen (mg.L^{-1} and %)	Saiv A/S ™ SD204 CTD for station #5 and Horiba U-10® water analyzer for other stations	-
Current Speed (m.s^{-1}) and Direction	Falmouth ™ 2D-ACM acoustic current meter	-
pH	Potenciometry, Horiba U-10® water analyzer	-
Dissolved Inorganic Nutrients – DIN (N-NH_4^+, N-NO_2^-, N-NO_3^-, P-PO_4^{3-}, $SiOH_4$; mg.L^{-1})	Colorimetry, Shimadzu® UV-160 A spectrophotometer	Strickland and Parsons (1972)
Chemical Oxygen Demand (COD; mg.L^{-1}), Surfactants (mg.L^{-1}) and Adsorbable Organic Halogens (AOX; mg.L^{1})	Colorimetry with CECIL® 1000 spectrophotometer*[1]	APHA-AWWA-WPCF (1998)
Biochemical Oxygen Demand (BOD_5; mg.L^{-1})	5 days incubation, dissolved oxygen measurements with YSI® 5000 oxymeter	APHA-AWWA-WPCF (1998)
Chlorophyll-a (mg.m^{-3})	*In vivo* measurements with Turner Designs® TD-700 fluorometer *[2] (optical kit TD 7000-963)	-
Fecal coliforms (cells.100 mL^{-1})	Colilert system kits	Edberg et al. (1991).
Total bacteria (cell.mL^{-1})	Fluorescence Microscopy, Olympus® BX-40 epifluorescence microscope	Hobbie et al., 1997
Phototrophic Picoplankton (cell.mL^{-1})	Autofluorescence Microscopy, Olympus® BX-40 epifluorescence microscope	MacIsaac and Stockner (1993)
Nano and microplankton (> 2 µm) (cell.ml^{-1})	Sedimentation and enumeration in inverted microscope Nikon® Eclipse	Utermöhl (1958)
Toxicity to *Daphnia magna*	*Daphnia magna* motility inhibition test, 48 hours incubation	ISO 6341 (1996)
Toxicity to *Skeletonema costatum*	*Skeletonema costatum* algal growth rate inhibition test, 72h incubation	ISO 10253 (1995)
Toxicity to *Vibrio fischeri*	Inhibition of luminescence in *Vibrio fischeri* (LUMISTOX test)	ISO 11348-1 (1998)
Sediment		
Particle size (granulometry)	Washing, sieving and weighing of granulometric classes	Krumbein (1934); Shepard (1954)
% Carbonates and % Organic Matter	Gravimetry	Dean (1974)
Metals*[3] (Al, Cd, Cr, Cu, Fe, Pb, Zn; mg.kg^{-1})	Sequential extraction and determination by atomic absorption spectrophotometry; Varian Techtron® AA-5	Tessier et al. (1979)
Elutriate obtention	Mechanical stirring of sediment with distilled water followed by centrifugation to clarify the resultant liquid sample	USEPA (1998)
Elutriate Toxicity to *Daphnia magna*	*Daphnia magna* motility inhibition test, 48 hours incubation	ISO 6341 (1996)
Elutriate Toxicity to *Skeletonema costatum*	*Skeletonema costatum* algal growth rate inhibition test, 72 hours incubation	ISO 10253 (1995)
Elutriate Toxicity to *Vibrio fischeri*	Inhibition of luminescence in *Vibrio fischeri* (LUMISTOX test)	ISO 11348-1 (1998)
Macrobenthos	5 sub-samples were collected with a 15 cm diameter PVC corer, at 30 cm intervals. Samples were washed in a sieve with 0.5 mm mesh size and fixed in 4% formalin.	-

*[1] Samples with salinity were diluted to lower the chloride concentration to less than 1,000 mg.L^{-1}, and to prevent interference by salts.

*[2] Some samples were also filtered through GF/C filters and the filters extracted with 10 mL of 90% (v/v) acetone for 24 hours in the dark in the freezer to calibrate the in vivo determinations (fluorescence measurement of chlorophyll-a by extraction according to Parsons et al., 1989).

*[3] Previous regional studies indicated these metals as more likely to be found in high concentrations in local contaminated sediments (Silva and Silva, 1999).

two times, that is, at low tide (LT, in the morning) and high tide (HT, in the afternoon), for the purpose of pointing out the differences that can occur at a location due to the processes of tidal transport.

The results for physical-chemical, chemical and biological variables are shown in Table 2. The progressive decrease in water quality was accompanied by the increase of urbanization density, with a small improvement in samples influenced by the tide (#5 LT and #5 HT). Chlorophyll-a was lowest at the stations closest to the fountainheads (#0 and #1), increased at the intermediate stations and decreased slightly at station #5. This pattern was followed by phototrophic picoplankton and not well related to nano and microplankton indicating that phytoplankton is mainly represented by small sized organisms. Upon inspection of the taxonomic and functional composition of nano and microplankton, there appears to be a broad predominance of filamentous bacteria, which are associated with sewage (Figure 2). There was numerical predominance of microalgae at stations #0, due to the presence of benthic diatoms, and #5 at high tide, due to the presence of marine planktonic diatoms. Excluding this last sample, there was a large predominance of benthic microalgae (Figure 2). There was a notable presence of bacterivorous ciliated protozoa at stations #0, #2, #3 and #4 at low tide (Figure 2), with a lesser importance in samples from stations with marine influence. The fecal coliforms were not totally related to the progressive increase of wastewater downstream, but showed high peaks at station #3 and #4 HT. This indicates the interference of physical and chemical factors in the numbers of this biological variable (e.g. sunlight, toxicity).

An exploratory Principal Component Analysis with regard to physical, chemical and biological characteristics of the water samples, from the spatial approach, showed in a simplified manner evidence of relationships among these variables as well as among samples (Figure 3). In this analysis, the first axis explained 58% of the variance and the second explained 18% of the variance. Three groups of variables were classified: group (1) composed of salinity, % dissolved oxygen and conductivity; group (2) composed of $N\text{-}NO_3^-$ and DO, and group (3) formed by all the other variables. Group (1) was related to the second axis and showed only the tidal influence over conductivity and oxygen saturation, a situation best exemplified by station #5 at high tide. Groups (2) and (3) were associated with the first axis at opposite positions. It can be assumed that the variables positively associated with group (3) indicate the component of organic contamination (sewage influence) and the variables of group (2) show the opposite situation, where an increase in dissolved oxygen probably allowed for certain purification of the system.

Table 2. Physical-chemical, chemical and biological variables in the water of Schneider Stream for the spatial analysis. DO = dissolved oxygen; %DO = dissolved oxygen saturation; COD = chemical oxygen demand; BOD_5 = biochemical oxygen demand; AOX= adsorbable organic halogens; $N\text{-}NH_4^+$ = ammonium; $N\text{-}NO_2^-$ = nitrite; $N\text{-}NO_3^-$ = nitrate; $Si(OH)_4$ = silicate; $P\text{-}PO_4^{-3}$ = phosphate; Phot. Picopl. = phototrophic picoplankton; FC = fecal coliforms; N-M Plank. = nano and microplankton; LT = low tide; HT = high tide. Obs.: there is no data for BOD_5 at station #4-LT.

Variable	#0 16:40	#1 16:10	#2 14:00	#3 10:45	#4 LT 10:15	#4 HT 14:30	#5 LT 08:00	#5 HT 14:00
Salinity (‰)	0.0	0.0	0.3	0.2	0.3	1.1	7.4	11.2
Temperature (°C)	19.1	22.1	23.5	22.2	21.8	25.0	19.9	20.8
Turbidity (NTU)	3.0	2.0	298.0	80.0	60.0	87.0	13.1	4.7
Conductivity ($\mu S.cm^{-1}$)	113	152	701	588	713	2,460	7,510	14,500
pH	6.75	5.71	6.95	6.84	6.81	6.69	6.44	6.50
DO ($mg.L^{-1}$)	7.25	9.23	2.10	0.96	1.43	0.77	0.02	1.36
DO (%)	0.00	0.00	0.30	0.20	0.30	1.10	0.19	16.30
$N\text{-}NH_4^+$ ($mg.L^{-1}$)	0.03	0.56	6.90	6.64	6.71	5.82	4.25	0.56
$N\text{-}NO_2^-$ ($mg.L^{-1}$)	0.01	0.00	0.03	0.05	0.02	0.01	0.02	0.02
$N\text{-}NO_3^-$ ($mg.L^{-1}$)	0.06	0.09	0.00	0.00	0.01	0.00	0.06	0.07
$Si(OH)_4$ ($mg.L^{-1}$)	0.76	1.51	2.39	2.03	3.68	4.49	3.84	2.18
$P\text{-}PO_4^{3-}$ ($mg.L^{-1}$)	0.02	0.10	2.05	2.38	1.85	1.87	1.68	0.06
COD ($mg.L^{-1}$)	40.2	63.0	265.7	350.4	249.4	128.8	213.5	167.9
BOD_5 ($mg.L^{-1}$)	1.48	2.24	74.46	78.86	-	76.46	24.26	3.66
Surfactants ($mg.L^{-1}$)	0.00	0.08	3.38	3.19	2.92	3.12	0.76	0.28
AOX ($mg.L^{-1}$)	0.24	0.19	0.42	0.72	0.29	0.31	0.38	0.54
Chlorophyll-a ($mg.m^{-3}$)	0.02	0.09	0.54	0.47	0.44	0.43	0.29	0.26
Total Bacteria ($cell.mL^{-1}$)	1.8×10^8	2.1×10^8	4.3×10^9	2.5×10^9	2.7×10^9	3.0×10^9	3.7×10^9	7.6×10^9
Phot. Picopl. ($cell.mL^{-1}$)	2.4×10^4	4.4×10^4	1.4×10^5	1.7×10^5	1.2×10^5	9.9×10^4	3.1×10^4	9.4×10^4
FC ($cell.100\ mL^{-1}$)	0	5,200	2,419,600	85,400	111,700	2,419,600	78,800	24,300
N-M Plank. ($cell.mL^{-1}$)	24	204	6,797	12,615	11,897	31,834	1,262	1,297

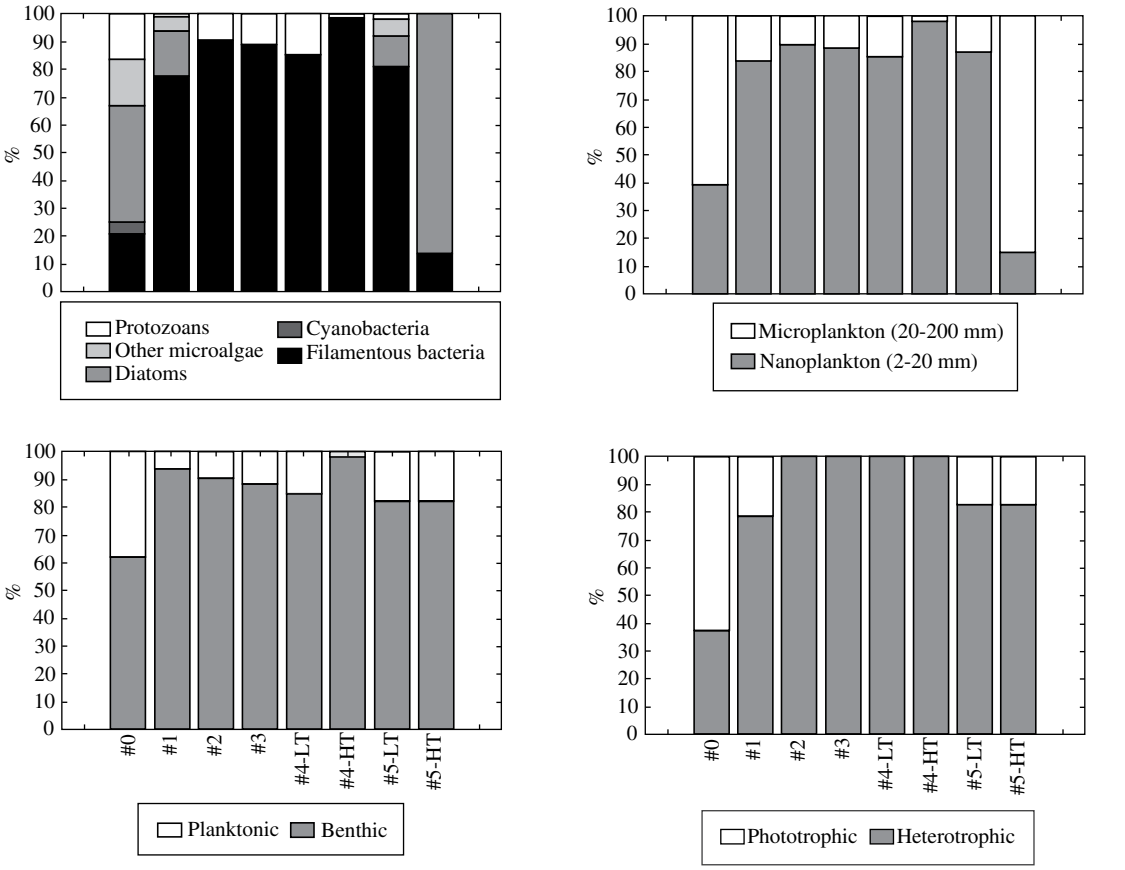

Figure 2. Taxonomic and functional characteristics of the nanoplankton and microplankton of Schneider Stream in the spatial analysis. LT = low tide; HT = high tide.

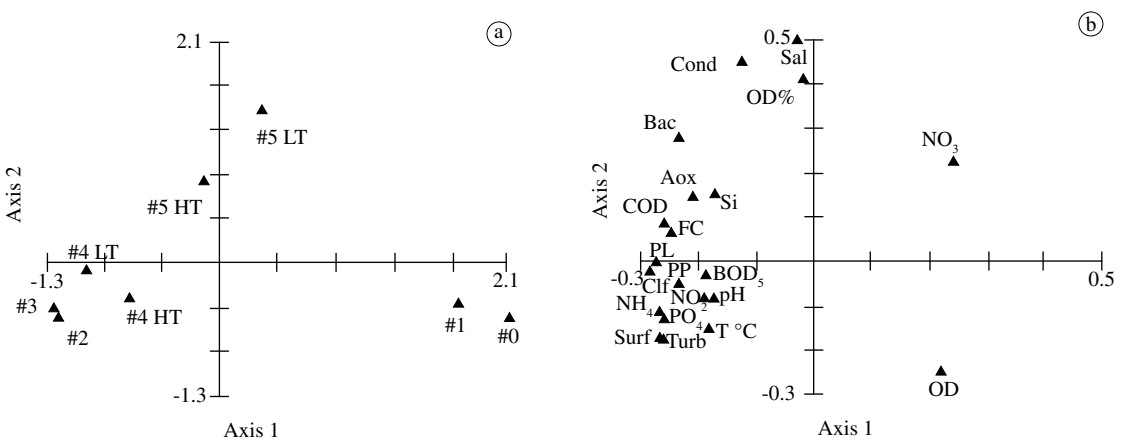

Figure 3. Principal Component Analysis (PCA) with the physical, chemical and biological variables of Schneider Stream's water for the spatial analysis, where a) is the analysis showing samples coordinates and b) is the analysis showing variables coordinates. LT = low tide; HT = high tide; Aox = adsorbable organic halogens; Bac = total bacteria; BOD_5 = biochemical oxygen demand; Clf = chlorophyll-a; COD = chemical oxygen demand; Cond = conductivity; OD = dissolved oxygen; OD% = dissolved oxygen saturation; FC = fecal coliforms; NH_4 = ammonium; NO_2 = nitrite; NO_3 = nitrate; pH = hidrogenionic potential; PP = phototrophic picoplankton; PL = total density of nano and microplankton; PO_4 = phosphate; Sal = salinity; Si = silicate; Surf = surfactants; Turb = turdidity; T °C = water temperature.

All of the sediment samples were predominantly sand, with greater proportions at stations #2 and #3, which had smaller proportions of fine sediments. Station #5 differed from all the others by having greater proportions of fine sediments (silt and clay). Station #5 also showed the highest percentages of organic material and carbonates, as opposed to stations #2 and #3. Station #0 had the second highest value of organic material, which was related to the presence of plant detritus from the surrounding forest (Table 3). With respect to metals, there was a clear positive relationship with the percentage of organic material and fine sediments, where station #5 was characterized as the most contaminated with metals. However, Cd and Pb, the most toxic among the metals assayed, were not detectable at any of the stations (Table 3). If the values for station #0 were taken as background, that is, dividing the concentrations of metals at other stations by those of station #0, only station #5 showed evidence of significantly increased levels (4.5 fold for Al; 3.4 fold for Cr; 6.6 fold for Cu; 8.6 fold for Fe and 9.6 fold for Zn).

In relation to macrobenthos, a total of 2,490 animals were collected of which the oligochaetes were clearly the most abundant, making up more than 70% of the fauna. Also in notable abundance were leeches (14%) and insect larvae (13%) (Table 4).

The total density of the macrofauna, as well as the taxonomic richness, showed marked differences among the sampling locations ($H_{Total\ dens.} = 19.8$; $p = 0.0005$ and $F_{Tax.Rich.} = 66.3$; $p < 0.0001$). The total density was greatest at station #5 followed by station #1, showing the same pattern for taxonomic richness. However, the taxonomic richness at station #0 was slightly higher than that at stations #2 and #3, despite having a low total density of organisms. The faunistic composition showed significant differences among the locations sampled ($R_{Global} = 0.772$; $p = 0.1\%$), and when compared pair to pair using Similarity Analysis (ANOSIM; Zar, 1999), only for the pairs #2-#3 and #2-#0 no significant differences were detected.

The samples of surface water from stations #2, #3, #4 (high and low tide) and #5 (low tide) showed toxic effects in at least 2 toxicity tests, whereby all three toxicity tests were positive for samples from stations #2 and #3, characterizing these locations as having the most toxic profile (Table 5). None of the elutriate samples showed a toxic effect in any of the tests, demonstrating a low concentration of toxic substances in the sediments.

3.2. Temporal analysis

Figure 4 presents the time series of physical variables measured during the study. The tides presented a mixed pattern, when consecutive high and low tides show different heights. The meteorological influence on the sea level may also play a role in this behavior.

The current record presented a very erratic pattern (Figure 4). During all the recorded period, the current direction varied in terms of minutes, changing from upstream to downstream and again to upstream in a matter of 10 min. Despite having a short sampling interval, the current speed showed a poor relationship with the tide. This behavior appears to have been strongly controlled by natural oscillation of the Saco da Fazenda Lagoon.

Salinity and temperature variations were related to changes in the tide and probably the discharge of sewage also influenced the temperature (Figure 4). The water was completely anoxic from the beginning of the study until 11:50 hours, when the dissolved oxygen ($mg.L^{-1}$ and %) started to show an oscillation pattern. Turbidity showed peaks related to the first and third period of zero concentration in dissolved oxygen (Figure 4). It seems that a migrating water mass with no oxygen and high turbidity is the cause of these patterns, being induced by water level variation (tide effect).

The absence of some chlorophyll-a data during the morning limits the explanation of its pattern of variation,

Table 3. Granulometric and chemical characteristics of sediment samples collected from Schneider Stream.

Variable	#0	#1	#2	#3	#5
% Silt	3.73	4.09	3.49	3.26	11.47
% Clay	11.01	8.42	0	0	40.88
% Sand	47.77	56.41	70.01	68.43	46.08
% Pebble	37.49	31.07	26.5	28.30	1.57
% Organic matter	2.63	2.16	1.14	0.78	9.17
% Carbonate	1.94	3.17	2.2	1.75	5.55
Al ($mg.kg^{-1}$)	303.55	206.28	146.84	246.56	1,368.57
Cd ($mg.kg^{-1}$)	n.d.	n.d.	n.d.	n.d.	n.d.
Cr ($mg.kg^{-1}$)	3.62	3.74	2.41	2.52	12.3
Cu ($mg.kg^{-1}$)	3.00	3.84	5.1	3.92	19.77
Fe ($mg.kg^{-1}$)	442.99	155.53	61.04	345.42	3,808.92
Pb ($mg.kg^{-1}$)	n.d.	n.d.	n.d.	n.d.	n.d.
Zn ($mg.kg^{-1}$)	8.55	5.78	10.74	16.6	82.28

Table 4. Composition and abundance of macrobenthos collected from Schneider Stream.

Taxon	#0	#1	#2	#3	#5	Absolute Abundance	Relative Abundance (%)
Mollusca							
Bivalves	4	2	1	-	-	7	0.28
Gastropods	-	1	-	-	-	1	0.04
Arthropoda							
Crustacea	-	-	-	-	-	-	-
Amphipoda	-	-	-	-	-	-	-
Gammaridea	-	-	1	-	-	1	0.04
Decapoda	-	-	-	-	-	-	-
Brachyura	-	-	-	-	2	2	0.08
Isopoda	-	-	1	-	-	1	0.04
Insecta	-	-	-	-	-	-	-
Collembola larvae	-	-	-	-	7	7	0.28
Tipulidae larvae	1	6	-	1	4	13	0.52
Syrphidae larvae	-	1	-			1	0.04
Chironomidae larvae	2	287	5	7	2	303	12.17
Acarina	-	-	-	-	6	6	0.24
Anellida	-	-	-	-	-	-	-
Polychaeta	-	-	-	-	-	-	-
Capitellidae	-	-	-	-	14	14	0.56
Nereididae	-	-	-	-	2	2	0.08
Hesionidae	-	-	-	-	2	2	0.08
Oligochaeta	-	-	-	-	-	-	-
Oligochaeta #1	13	83	50	109	1232	1487	59.72
Oligochaeta #2	-	151	0	-	124	275	11.04
Hirudinea	3	352	2	1	1	359	14.42
Amphibia							
Tadpoles	-	2	-	-	-	2	0.08
Unidentified organisms	6	1	-	-	-	7	0.28
Total	29	886	61	118	1396	2490	100
N° of Organisms per 0.007 m^2							
Mean	5.8	177.2	12.2	23.6	279.2	-	-
S.D.	1.65	21.8	3.02	6.7	43.6	-	-
N° of Taxa							
Mean	3.2	5.8	2.4	2.2	6.4	-	-
S.D.	0.73	0.66	0.4	0.49	0.24	-	-

Table 5. Results of the toxicity tests for surface water of Schneider Stream. EC_{50} = Median effective concentration; CNOE = concentration showing no observable effect; N.T. = not toxic; N.C. = toxic but EC_{50} not calculable.

Test	End Point	#0 16:40	#1 8:15	#2 14:45	#3 10:45	#4 HT 10:15	#4 LT 14:30	#5 HT 8:00	#5 LT 14:00
Daphnia magna motility inhibition	EC_{50}	No toxic effect	No toxic effect	45.9%	100%	N.T.	N.T.	N.T.	No toxic effect
	CNOE			25%	50%				
Skeletonema costatum growth inhibition	EC_{50}			10.7%	17.6%	17.7%	17.2%	55.1%	
	CNOE			6.25%	12.5%	12.5%	12.5%	25%	
Vibrio fischeri luminescence inhibition	EC^{50}			24.3%	72.8%	72.5%	67.4%	N.C.	
	CNOE			0%	0%	0%	0%	0%	

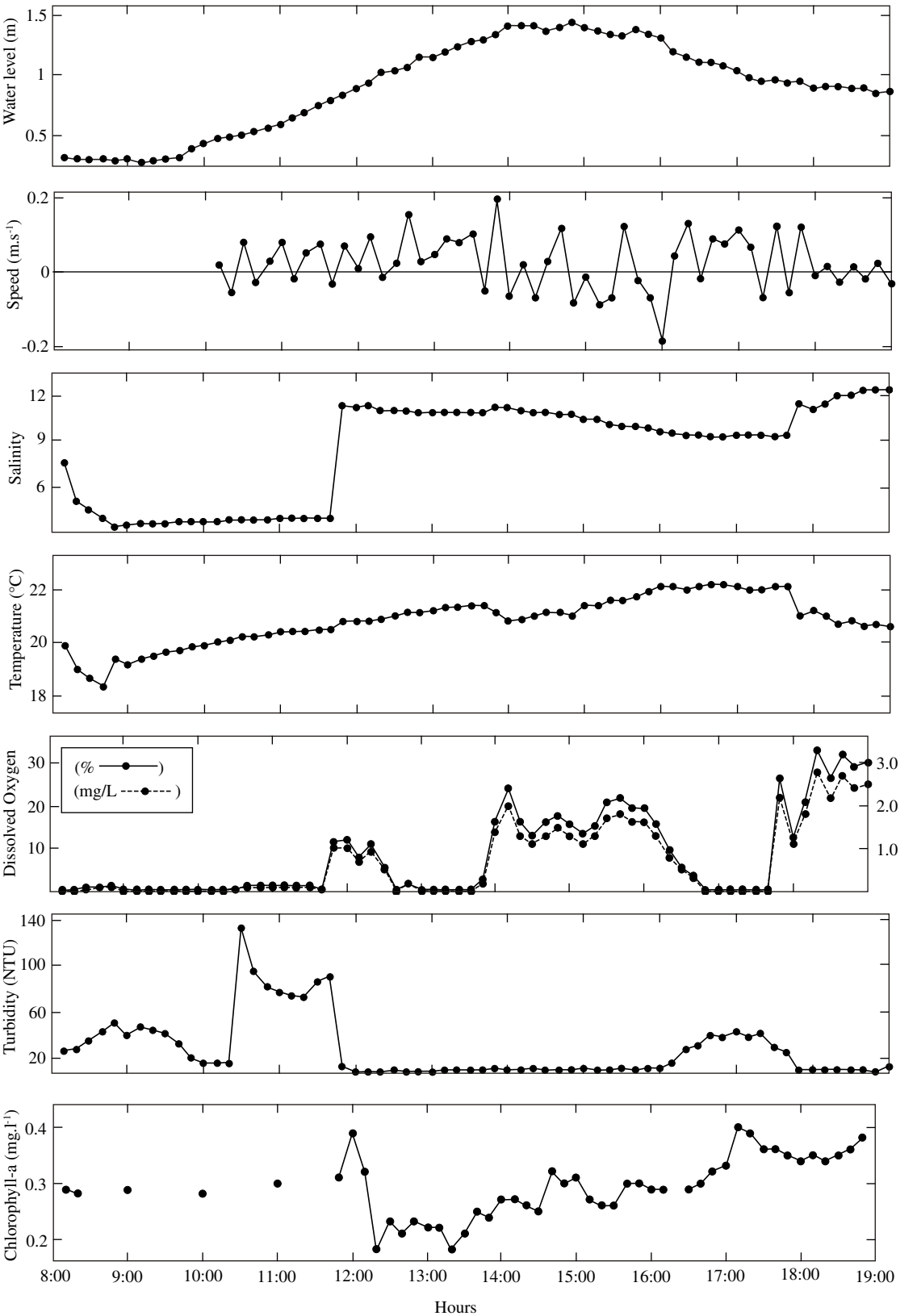

Figure 4. Time series of the physical and physical-chemical variables and chlorophyll-a in station #5 of Schneider Stream acquired at 10-minute rate.

but it was clear that there was an increase with salinity, showing the introduction of planktonic populations from outside the stream (Figure 4).

The data for BOD_5, $P\text{-}PO_4^{-3}$, $Si(OH)_4$, $N\text{-}NH_4^+$, and $N\text{-}NO_2^-$ showed a pattern related to the water level. All these variables declined with the increase in tide and salinity, which would be expected by a diluting effect. The values for $N\text{-}NO_3^-$, on the contrary, increased with the rise in the tide, indicating a possible effect of nitrification due to greater concentrations of dissolved oxygen from external waters coming into the stream (Figure 5). Nonetheless, it appears that the periodic monitoring of the concentrations of nutrients and BOD_5 was insufficient for attaining a detailed understanding of the variations determined. A continuous system of integrating samples would probably yield better results in this case.

With respect biological variables, the pattern was also complex and their comprehension aggravated by the accidental loss of samples from 13:00 and 17:00 hours. However, a sudden rise was seen in levels of photoptrophic picoplankton and total bacteria and diminution in fecal coliforms, with a sharp rise in salinity resulting from the flowing tide at midday (Figure 5). While fecal coliforms are mainly from sewage transported from upstream and tend to decline with the influence of salinity and sunlight (Jones, 1971), photoptrophic picoplankton and total bacteria have better growth conditions in the area of the Saco da Fazenda Lagoon. These midday conditions would reflect then the presence of external waters in the stream. The increase in fecal coliforms at the end of the sampling period could have been related to new discharges of wastewater, along with the effect of the ebbing tide.

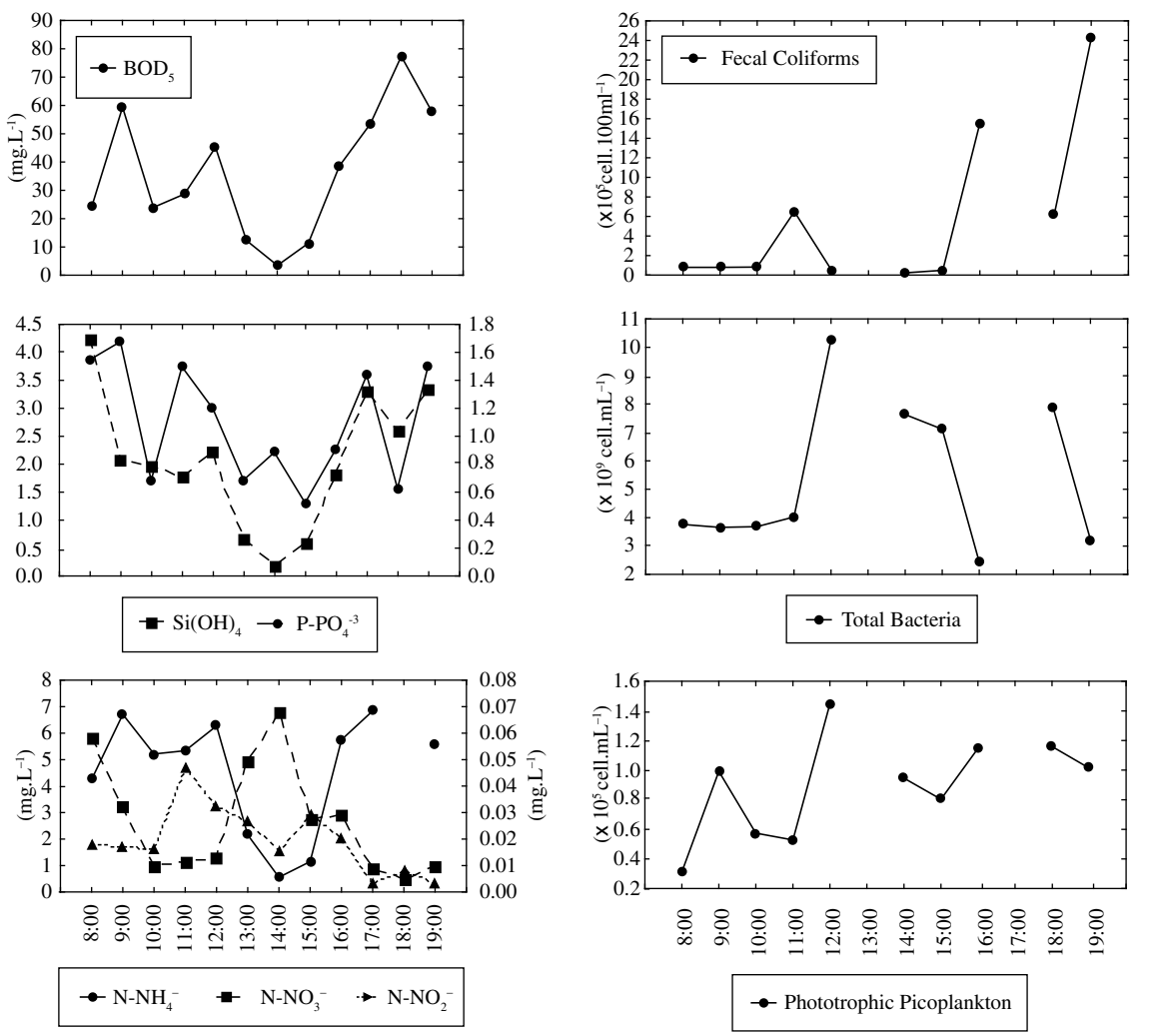

Figure 5. Chemical and biological variables in station #5 of Schneider Stream during the temporal sampling. BOD_5= biochemical oxygen demand; $N\text{-}NH_4^+$ = ammonium; $P\text{-}PO_4^{-3}$ = phosphate; $N\text{-}NO_2$- = nitrite; Si = silicate; $N\text{-}NO_3^-$ = nitrate. Obs.: There are no data for $N\text{-}NH_4^-$ at 18:00 hours and for biological variables at 14:00 and 18:00 hours.

4. Discussion

The spatial and temporal analysis of physical, chemical and biological variables evidenced a critical condition of Schneider Stream in terms of pollution. Unplanned urbanization impacts and untreated sewage may have been the causes of the water transformation, from a clean condition in the Atlantic Tropical Rainforest located at the fountainhead to near sewage conditions 1,000 m downstream.

The physical driving forces acting in the lower Schneider stream are primarily related to the hydrodynamics of the Saco da Fazenda Lagoon, which in turn is influenced by the Itajaí-Açu River estuary. The interaction between the Saco da Fazenda lagoon and the Itajaí-Açu River estuary is established mainly through a 10 m wide and 8 m deep pass, and also a totally permeable mole. In such a shallow and small environment, a significant exchange of the water volume occurs during each tidal cycle. This exchange, however, is mostly limited to the deeper areas and rarely affects marginal waters, as these are normally restrained by internal moles and other shore roughness. Therefore, in spite of the regular water exchange of Saco da Fazenda Lagoon, water quality in their marginal areas, including the lower reach of Schneider stream, remains poor.

The sudden salinity jump from 4 to 11, which occurred between 11:40 and 12:00 hours, suggests the passage of a density front through the monitored cross section. Because salinity was more stable during the previous hours and the hours after the jump, it is implied that water exchange is limited during such periods. The gradual salinity decrease observed after 14:00 hours probably is a result of a fresh water input. Unclear salinity increase was observed during the last 1.5 hours of monitoring. Possibly a residual advection caused by seiching may have overcome tidal advection, producing a net upstream transport of another density front. This explanation, however, is hypothetical and can only be clarified by a wider sampling strategy, with additional monitoring stations.

Considering the reference levels for chemical and biological variables, defined by CONAMA (The Brazilian Council of the Environment) for "Class 2" rivers, to which the Schneider Stream belongs, only station #0 presented acceptable values. Stations #2 and #3 were the most polluted ones, exceeding up to 6 fold the allowed limits for surfactants, 15 fold for BOD, 90 fold for $P\text{-}PO_4^{-3}$ and 2,400 fold for fecal coliforms. Samples collected in these stations were also very toxic for the three tested organisms. As pollution in the area is mostly domestic, these data support that sewage tends to be a complex mixture of highly toxic compounds. Today about 30,000 hazardous chemicals are present in household wastewater and little is known about their toxicity and fate in aquatic environments. (Palmquist and Hanæus, 2004). Nitrogenous nutrient profiles indicated the occurrence of nitrification at the extreme stations (#0 and #5), as resulting from the presence of dissolved oxygen. An annoxia condition, however, was evidenced in all stations but #0 and #1. This condition was frequently found even in the estuarine area, where water is partly renewed by tidal transport.

Regarding microbiological variables, some situations were noteworthy. Firstly, fecal coliforms peaked at station #2 declining subsequently at station #3. Because station #2 is located right after the channeled portion of the stream, it is possible that the change from closed to open and sunlight exposed flow contributes to fecal coliform decay from this site onwards. Toxicity observed in the stream waters may also have been the cause of fecal coliform decay, as these stations were also the most toxic. Low fecal coliform concentrations obtained in station #5, particularly during high tide periods, may not only reflect water dilution and transport, but also the effect of sunlight and increasing salinity. Despite the noisy and incomplete data, an inverse relationship between fecal coliforms and total bacteria is noted, especially during temporal sampling and under the tide influence. Such condition may reflect the input of more saline and oxygenated waters from estuarine areas, which limit fecal coliform viability, but can improve growing conditions of other bacteria.

Planktonic microalgae (nano and microplankton) were found in moderate densities in stations under tidal influence, evidence of the intrusion of external populations to the stream system. Other microalgae were mostly benthic. Phototrophic picoplaknton, in turn, was the most important fraction of autotrophic organisms in the analyzed samples. These microorganisms predominate as primary producers in aquatic oligotrophic environments (Fogg, 1995), but their occurrence in Schneider Stream may indicate their adaptation to extreme organic pollution. Nano and microplankton composition in the waters of Schneider Stream revealed the predominance of filamentous bacteria and ciliates, typically associated to sewage, another indication of a strongly altered environment. In stations under tidal influence, results contrast with an expected presence of dense phytoplanktonic populations. It is possible that elevated toxicity levels and eventual anoxia, limit growth and survival of populations transported by tidal flushing. On a larger scale, such limitation process has been observed 500 m away from the study site, at the Itajaí-açu River estuary during a high river discharge (Schettini, et al., 1998; Rörig et al., 2003). In this case, however, limitation was caused by low irradiance generated by high turbidity of fluvial waters, and resulted in the predominance of heterotrophic protozoans.

Toxicity data show that a complete neutralization of Schneider Stream would require a two to ten fold water dilution (i.e. #5 and #2 respectively). In the stations not affected by the tides, such dilution is unlikely, since the required water volume increase would be necessarily derived from rainfall over urbanized areas, which, in turn would lead to the input of more pollutants through surface runoff (Norman, 1991). In the stations under

tidal effect, water dilution or dispersion is possible but also uncertain because the lagoon environment next to the stream is also polluted and presents limited circulation patterns. It is important to note that sampling was conducted during spring tides, when water renewal is largest. Sampling being repeated in an ebb tide situation could show an even more dramatic scenario regarding pollution and toxicity of the stream environment.

The analysis of benthic communities and sediment contamination are among the most indicated proceedings to evaluate the impacts on quality of running waters (Meybeck et al., 1992). In the present study such analysis revealed coherent trends of environmental quality degradation, particularly observed in stations #1 and #5, which presented the lowest internal variability. Both stations differed by the dominance of Hirudinea and Chironomidae larvae in station #1 and Oligochaeta in station #5; the former requiring highly oxygenated waters and the latter physiologically adapted to hypoxic environments.

Results obtained for metals in sediments were not alarming. This situation evidences that, despite the presence of contribution sources, there is no tendency to metal accumulation in the stream bottom. Probably this is related to the sediment characteristics, composed predominantly of sand. The situation is more critical in the estuarine area, where sedimentation, saline floculation and adsorption to organic matter and fine sediments can generate accumulation (Spencer, 1975). Another possibility regarding the metal levels in station #5 is their origin from out of the stream system, that is, from Itajaí-açu River, which is known to have significant metallic pollution sources along its heavily industrialized watershed (Silva and Silva, 1999; Laitano and Resgalla Jr., 2000).

In a general analysis, the multiparameter evaluation indicated three different sections along the 2,600 m of Schneider Stream: 1) a section near the fountainhead (first 400 m), whose water is clean but largely deviated before generating flow to the stream; 2) an intermediary section of about 1,600 m long, 50% of channelization, several affluents also channelized, heavily polluted and limiting to the biota; and 3) an estuarine section also heavily polluted, but which shows a little improvement of water quality because of the tidal transport processes.

Before or simultaneously to the implantation of sewage treatment systems in the Schneider stream basin, some measures could be executed such as to open channelized sections, to cancel new projects of channelization and to interrupt or control the water withdraw at the fountainheads. Stream channelization, among other negative effects, limits gas exchange; limits the self-depuration capacity of stream water; represents the removal of buffer areas (riparian forest); blocks the groundwater recharge; generates habitats for zoonosis vectors; retards the trophic equilibrium; intensifies the storm flow; in some areas, increases the flood event occurrences; and in general, buries the problem instead of solving it.

The dam near the fountainheads, apart from being a misappropriation of a natural resource, contributes to the aggravation of pollution and increase of sanitary risks, since it limits the water flow. The water withdrawl is even greater in dry periods, causing concentration of pollutants and biological contaminants along the system. The dam, however, could persist because it can be used to flow regularization to the stream, but it must be accompanied by a forest preservation/recuperation program in the surrounding area.

Regarding water quality analysis, the most diagnostic variables were the toxicity tests, the dissolved inorganic nutrients, the dissolved oxygen, the pollutants (surfactants and AOX) and the BOD_5. These variables clearly expressed the pollution degree and did not show confusing patterns. Nevertheless, the pollutants considered present methodological limitations when samples are salty or brackish, requiring manipulation. Obviously, determination of all these variables must be accompanied by measurements of physical variables (current speed, water level, salinity etc.), especially in coastal streams where complex patterns of circulation related to tide are present.

This work generated results from few and temporally restricted samples. Nevertheless, the data were suitable to discern how a highly impacted coastal stream system works during a typical spring tide period, allowing us to infer about general trends of water quality and impacts on the biota.

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References

APHA-AWWA-WPCF., 1998. *Standard methods for the examination of water and wastewater*, 17th Ed. American Public and Health Association, American Water Works Association and Water Pollution Control Federation. Washington, DC.

BERTOLETTI, E., 2001. Ecotoxicologia aquática. In MAIA, NB., MARTOS, HL., BARRELA, W. (Eds.). *Indicadores ambientais: conceitos e aplicações.* EDUC, São Paulo, p. 219-228.

BITTON, G., 1994. *Wastewater Microbiology*. Wiley-Liss, New York. 478p.

CTTMar/UNIVALI., 2003. *Desenvolvimento de um Sistema de Informações Baseado na Internet para suporte ao Levantamento das Coordenadas Geográficas dos Usuários de Água da Bacia do Itajaí.* Itajaí, CTTMar – UNIVALI. Technical Report. 16p.

DEAN, JWE. (1974). Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. J. Sediment. Petrol., vol. 44, p. 242-248.

EBERSOLE, JL., LISS, W.J.; FRISSELL, C.A. 1997. Restoration of Stream Habitats in the Western United States: Restoration as Reexpression of Habitat Capacity. *Envir. Manag*., vol. 21, no. 1, p. 1-14.

EDBERG, SC., F. LUDWIG, and D. B. SMITH., 1991. *The Colilert system for total coliforms and Escherichia coli*. American Water Works Research Foundation, Denver.

FOGG, GE., 1995. Some comments on picoplankton and its importance in the pelagic ecosystem. *Aquat. Microb. Ecol*., vol. 9, no. 11, p. 33-39.

GILBERT, OL., 1991. *The Ecology of Urban Habitats.* Chapman and Hall, London. 369p.

HARDING, JS., BENFIELD, EF. BOLSTAD, PV., HELFMAN, GS. and JONES III, EBD. 1998. Stream Biodiversity: The ghost of land use past. *Proc. Natl. Acad. Sci. (Ecology)*, vol. 95, no. 25, p. 13843-14847.

HOBBIE, JE., DALEY, RJ., JASPER, S., 1997. Use of Nuclepore Filters for Counting Bacteria by Fluorescence Microscopy. *Appl. Environ. Microbiol*., vol. 33, no. 5, p. 1225-1228.

ISO 10253, 1995. Water quality - Marine algal growth inhibition test with *Skeletonema costatum* and *Phaeodactylum tricornutum*.

ISO 11348-2, 1998. Water quality - Determination of the inhibitory effect of water samples on the light emission of *Vibrio fischeri* (Luminescent bacteria test) - Part 1: Method using freshly prepared bacteria.

ISO 6341, 1996. Water quality - Determination of the inhibition of the mobility of *Daphnia magna* Straus (Cladocera, Crustacea) - Acute toxicity test.

JONES, GE., 1971. The fate of freshwater bacteria in the sea. *Dev. Ind. Microbiol.* vol. 12, p. 141-151.

KLUMPP, A., 2001. Utilização de bioindicadores de poluiçãoem condições temperadas e tropicais. In MAIA, NB., MARTOS, HL., BARRELA, W. (Eds.). *Indicadores ambientais: conceitos e aplicações.* EDUC, São Paulo, p. 77-94.

KRUMBEIN WC., 1934. Size frequency distributions of sediments. *J. Sediment. Petrol*., vol. 4, no. 2, p. 65-77.

LAITANO, K., RESGALLA Jr., C., 2000. Uso de testes de toxicidade com larvas de *Arbacia lixula* e juvenis de *Metamysidopsis elongata atlantica* na avaliação de qualidade do sedimento dos rios Camboriú e Itajaí-açu. In ESPÍNDOLA, ELG., PASCHOAL, CMRB., ROCHA, O., BOHRER, MBC., OLIVEIRA NETO, AL. (Eds.). *Ecotoxicologia: Perspectivas para o Século XXI.* Rima, São Carlos, p. 29-42.

MACISAAC, EA. and STOCKNER, JG. 1993. Enumeration of phototrophic picoplankton by autofluorescence microscopy. In KEMP, PF., SHERR, BF., SHERR, EB., COLE, JJ. (eds.), Handbook of Methods in Aquatic Microbial Ecology, Lewis Publishers, Boca Raton. p. 187-197.

MEYBECK, M., FRIEDERICH, G., THOMAS, R. and CHAPMAN, D. 1992. Rivers. In CHAPMAN, D. (Ed.) Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring - 2nd Ed. UNESCO/WHO/UNEP, Paris.

NORMAN, CG., 1991. Urban runoff effects on Ohio River water quality. *Water Environ. Tech.* vol. 3, no. 6, p. 44-46.

PALMQUIST, H. and HANÆUS, J. 2004. A Swedish overview of selecting hazardous substances as pollution indicators in wastewater. Man. Env. Qual. Int. Jour., vol. 15, no. 2, p. 186-203.

PARSONS, TR., MAITA, Y. and LALLI, CM., 1989. *A Manual of Chemical and Biological Methods for Seawater Analysis*. Pergamon Press, Oxford. 173p.

QUADRA PLANNING CONSULTANTS., 1997. *Urban Stream Protection, Restoration and Stewardship in the Pacific Northwest: are we achieving desired results?* New Westminster: Quadra Planning Consultants Ltd. 150p.

RÖRIG, LR., RESGALLA JR., C. and SCHETTINI, CAF., 2003. Estrutura da assembléia planctônica através do estuário e da pluma do Rio Itajaí-açu. *Rev. Est. Amb*., vol. 5, no. 1, p. 76-94.

SCHETTINI, CAF., KUROSHIMA, KN., PEREIRA FOJ., RÖRIG, LR. and RESGALLA Jr. C. (1998). Oceanographic and ecological aspects on the Itajaí-açu river plume during a high discharge period. *An. Acad. Bras. Ciênc. (Special Issue: Land Ocean Interaction in the Coastal Zone).* Rio de Janeiro, no. 70, vol. 2, p. 335-351.

SHEPARD, FP. 1954. Nomenclature based on sand-silt-clay ratios. *Jour. Sed. Petrol*., vol. 24, no. 3, p. 151-158.

SILVA, MR., SILVA, E., 1999. Teores de metais pesados e caracterização de sedimentos de superfície no Rio Itajaí-Açu e seus afluentes na região de Blumenau: um estudo preliminar. *Rev. Est. Amb*., vol. 1, no. 2, p. 95-107.

SPENCER, CP., 1975. The Micronutrients Elements. In: Riley, J.P. and Skirrow, G (Eds.) *Chemical Oceanography*, vol. 2. Academic Press, London, p. 245-300.

STRICKLAND, JD., PARSONS, TR., 1972. A practical handbook of seawater analysis. *Fisheries Research Board of Canada Bulletin*, 2nd. edition, 1-311.

TESSIER, A., CAMPBELL, PGC., BISSON, M., 1979. Sequential extraction procedure for the speciation of particulate trace metals. *Anal. Chem*., vol. 51, no. 7, p. 844-850.

USEPA, 1998. *Evaluation of Dredged Material Proposed for Discharge inWaters of the U.S. - Testing Manual.* U. S. Environmental Protection Agency and U.S. Army Corps of Engineers, Washington D.C. 409p.

UTERMÖHL, H., 1958. Zur Vervollkommnurg der quantitativen Phytoplankton Methodik. *Int. Ver. Theor. Angew. Limnologie,* vol. 9, p. 1-38.

WHITE, PA., RASMUSSEN, JB., 1998. The genotoxic hazards of domestic wastes in surface waters. *Mut. Res.*, vol. 410, p. 223-236.