Epilithic diatoms as organic contamination degree indicators in Guaíba Lake, Southern Brazil

Diatomáceas epilíticas indicadoras de graus de contaminação orgânica no Lago Guaíba do extremo sul do Brasil

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Abstract: With the aim to recognize the epilithic diatoms that identify sites with different organic contamination degrees in Guaíba Lake (29° 55'-30° 24' S and 51° 01'-51° 20' W), every three months sampling was performed at six stations, two classified as oligosaprobic (BOD < 2 mg.L^{-1}), three as β-mesosaprobic (BOD < 4 mg.L^{-1}) and one as oligo a β-mesosaprobic, between June 2005 and February 2006. The samples were collected using epilithic diatoms samplers (EDS) exposed for four weeks in the lake. After species identification, the organism with chloroplasts were quantified by the Utermöhl method and the indicators species were recognized by multivariate analyses (TWINSPAN) and the habitat specificity analysis. As a result, among the 49 taxa identified, *Cocconeis placentula* var. *lineata*, *Encyonema minutum, Eolimna subminuscula* and *Navicula cryptotenella* were indicators of oligossaprobic conditions. The species richness and community density did not show a relationship with the organic contamination degrees.

Keywords: diatoms, bioindicators, organic gradient, lentic system.

Resumo: Com o objetivo de reconhecer as diatomáceas epilíticas que identificam locais com diferentes graus de contaminação orgânica no lago Guaíba (29° 55'-30° 24' S e 51° 01'-51° 20' W), amostragens trimestrais foram realizadas em seis estações, duas classificadas como oligossapróbicas (BOD < 2 mg.L^{-1}), três como β-mesossapróbicas (BOD < 4 mg.L^{-1}) e uma como oligo a β-mesossapróbica, no período entre junho de 2005 a fevereiro de 2006. As amostras foram coletadas usando amostradores EDS exposto por quatro semanas no lago. Após identificação das espécies e quantificação dos organismos com cloroplastos pelo método de Utermöhl, o reconhecimento das espécies indicadoras foi efetuado através da análise multivariada (TWINSPAN) e análise de especificidade de habitat. Como resultado, dentre as 49 espécies identificadas, *Cocconeis placentula* var. *lineata*, *Encyonema minutum, Eolimna subminuscula* e *Navicula cryptotenella* foram indicadoras de condições oligossapróbicas. A riqueza de espécies e densidade da comunidade não mostrou relação com os graus de contaminação orgânica.

Palavras-chave: diatomáceas, bioindicadoras, gradiente orgânico, lentic system.

1. Introduction

The high population density and the development of economic activities in large urban centers have been caused an increase in environmental impacts on the hydrographic basins, especially regarding to domestic and industrial wastes. The intensity of these impacts is directly related to the effluent volume and load, as well as, to the flow in the receiving system.

Water quality in aquatic ecosystems is generally monitored by physical and chemical analyses. These analyses provide information only on environmental conditions at the time measurements are performed. The analysis of biological variables, specifically, the evaluation of epilithics diatoms, can supply more precise information on environmental changes that may have occurred, not only in the present, but also in the recent past.

Diatoms, organisms that are generally abundant and diverse in aquatic systems, respond to changes in environmental conditions, and therefore they have been widely used as indicators of organic pollution and eutrophication (Descy and Ector, 1999; Prygiel and Coste, 1993).

European Union countries are using diatoms as part of routine monitoring programs to evaluate water quality, as well as acidification and eutrophication in rivers (Schoeman and Harworth, 1986; Round, 1993; Kelly and Whitton, 1995; Whitton and Rott, 1991, 1996; Kelly, 2002).

In Brazil, studies using diatoms as water quality indicators are basically concentrated in the Southern State (Lobo and Torgan, 1988; Lobo et al., 1996, 1999, 2002, 2004a, b, c; Lobo and Bender, 1998; Mourthé-Jr, 2000; Rodrigues and Lobo, 2000; Souza, 2002; Salomoni, 2004; Salomoni et al., 2006). However, in previous studies the results were based on oxidized material only. Since this deals with bioindication, it is important to observe also whether the species are viable (with intact chloroplasts).

Our goal was to identify the epilithic diatoms that can identify the habitats with different degrees of organic contamination in Guaíba Lake for future use of this algal group in biomonitoring.

2. Material and Methods

2.1. Study area

Guaíba Lake (29° 55'-30° 24' S and 51° 01'-51° 20' W) contains a volume of water of approximately 1.5 billions cubic meters. The Jacuí, Caí, Sinos and Gravataí Rivers discharge directly into this lake, and their drainage areas together are 82,439 km^2 (DMAE, 1986). Guaíba lake is used for public supplying leisure, tourism, recreation and fishing. Therefore, this system receives a large load of domestic and industrial sewage compromising its water quality. The sampling were carried out in this Lake at six stations (Figure 1) located next to the water intake for the Water Treatment Stations named: E1 – Ilha da Pintada; E2 – Moinhos de Vento; E3 – José Loureiro da Silva; E4 – Tristeza; E5 – Belém Novo and E6 – Lami, every three months from June 2005 to February 2006.

2.2. Epilithic diatom sampling

The samples were collected using epilithic diatoms samplers (EDS) according to Salomoni et al. (2007), which consists of three medium-sized stones, supported by an artificial floating system at a depth of 20 cm. The substrata were exposed for four weeks, following the recommendations of Lobo and Buselato-Toniolli (1985). Twenty samples were used for quantitative analysis where the upper surfaces of three stones were scraped off the upper surfaces of three stones using a toothbrush, totalizing a composite sample of 75 cm^2 preserved with 4% formaldehyde.

The organisms were quantified in a 2 or 5 mL settling chamber and efficiencies were at least 80% according to Pappas and Stoermer (1996) and previously identified. Only organisms with chloroplasts were quantified. The density estimates was expressed as the number of individuals per cm^2. For a precise taxa identification the quantified aliquots were cleaned with potassium permanganate and hydrochloric acid and mounting these on slides using Naphrax®. Species identification were based on Krammer and Lange-Bertalot (1986; 1988; 1991a, b), Lange-Bertalot (1993; 1995; 1996a, b, 2001), Lange-Bertalot and Metzeltin (1996) and Metzeltin and Lange-Bertalot (1998, 2002). To determine abundant and dominant species the criterion of Lobo and Leighton (1986) was followed. Samples are stored in the Herbarium, at the Natural Science Museum, Zoobotanical Foundation of Rio Grande do Sul, numbered HAS 107066 to 107088.

2.3. Abiotic variables and data analysis

The abiotic variables (turbidity, conductivity, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3), organic nitrogen (Norg), nitrate (NO_2-N), nitrite (NO_3-N), total phosphate (PO_4T), thermotolerant coliforms and total coliforms were analyzed according to the American Public Health Association – APHA (1992). The results of the analyses were supplied by the "Departamento Municipal de Àgua e Esgoto" (DMAE).

Initially, in order to verify the similarity among the sampling units based on the environmental variables, cluster analysis was used through Euclidean distance (Ward's method) with the abiotic variables transformed into log x + 1. To identify possible indicator species, the analysis of habitat specificity for indicator species was performed (Dufrêne and Legendre, 1997), and the Monte Carlo Test was applied (999 permutations; $p < 0.05$), where the indicative values ranged from 0 to 100. The analysis was applied on the density matrix and the sampling stations were considered the categorical variable. This method combines information on the species abundance in a given group of sampling units and of its occurrence reliability to the group. For the same purpose, program TWINSPAN was used (double entry analysis for indicator species), which consists of a hierarchical technique that concurrently classifies species and samples (Hill, 1979). The analysis followed the dichotomy levels 2.5; 5.0; 7.5, and 10, preserving the quantitative information of the data. The software used for multivariate analyses was the PC-ORD, program version 4.10 for Windows (McCune and Mefford, 1999). The saprobic classification, oligosaprobic (BOD < 2 mg.L^{-1}), and β-mesosaprobic (BOD < 4 mg.L^{-1}) classification was based on Cox (1996).

3. Results

3.1. Water quality

The abiotic variables analyzed montly at six stations in the Guaíba Lake from March 2005 to May 2006, showed that the water was turbid (transparency < 1.1 m), and varied from slightly acidic pH (6.6) to basic pH (8.3) condictions, however the stations were different to some variables that determine organic contamination degrees. The cluster analysis revealed two large groups (Figure 2). Group I (GI) includes stations E1, E5, and E6 which presented the best water quality conditions, with high mean DO values

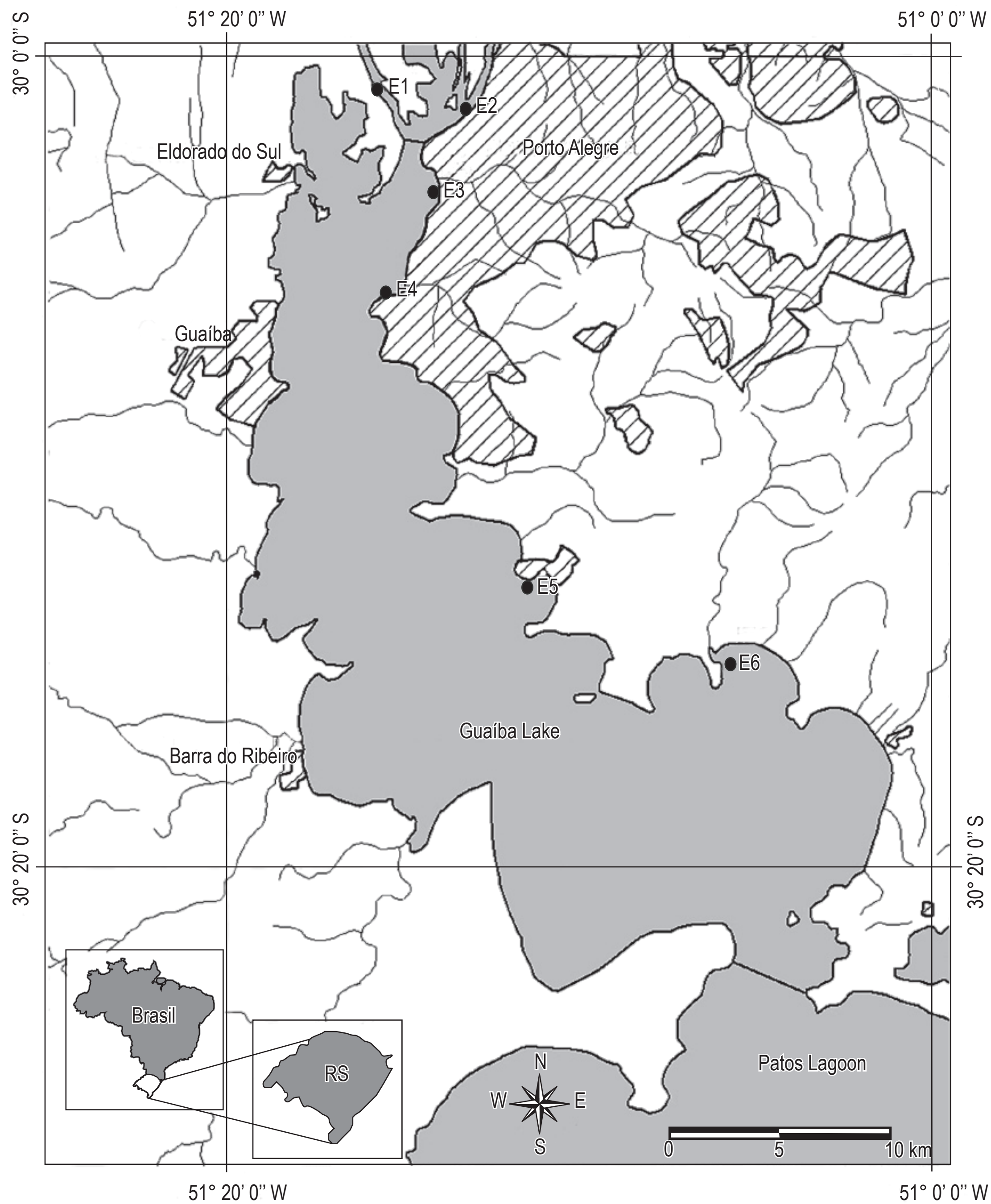


Figure 1. Location of the six sampling stations at the Guaíba Lake, in the State of Rio Grande do Sul, Brazil.

(8.13 mg.L^{-1} ± 0.91), and low BOD_5 (1.29 mg.L^{-1} ± 1.10), conductivity (66.6 µS.cm^{-1} ± 15.7), and ammonium values (0.18 mg.L^{-1} ± 0.14), and relatively low values of thermotolerant coliforms (219 NMP.100 mL^{-1} ± 378) and total coliforms (85 NMP.100 mL^{-1} ± 3767). Group II (GII), which includes stations E2, E3, and E4, presented low mean DO values (6.41 mg.L^{-1} ± 0.85), higher BOD_5 (2.08 mg.L^{-1} ± 0.83), conductivity (82,4 µS.cm^{-1} ± 20.4), and ammonium values (0.67 mg.L^{-1} ± 0.34) and more elevated thermotolerant coliforms (15,742 NMP.100 mL^{-1} ± 21,790) and total coliforms (100,642 NMP.100 mL^{-1} ± 105,029).

The BOD_5 during the sampling period (Table 1) showed that the Ilha da Pintada (E1), and Lami (E6) stations were characterized by having less organic contamination (oligosaprobic); Belem Novo (E5) station as oligo to β-mesosaprobic, and, the Cais do Porto (E2), Menino Deus

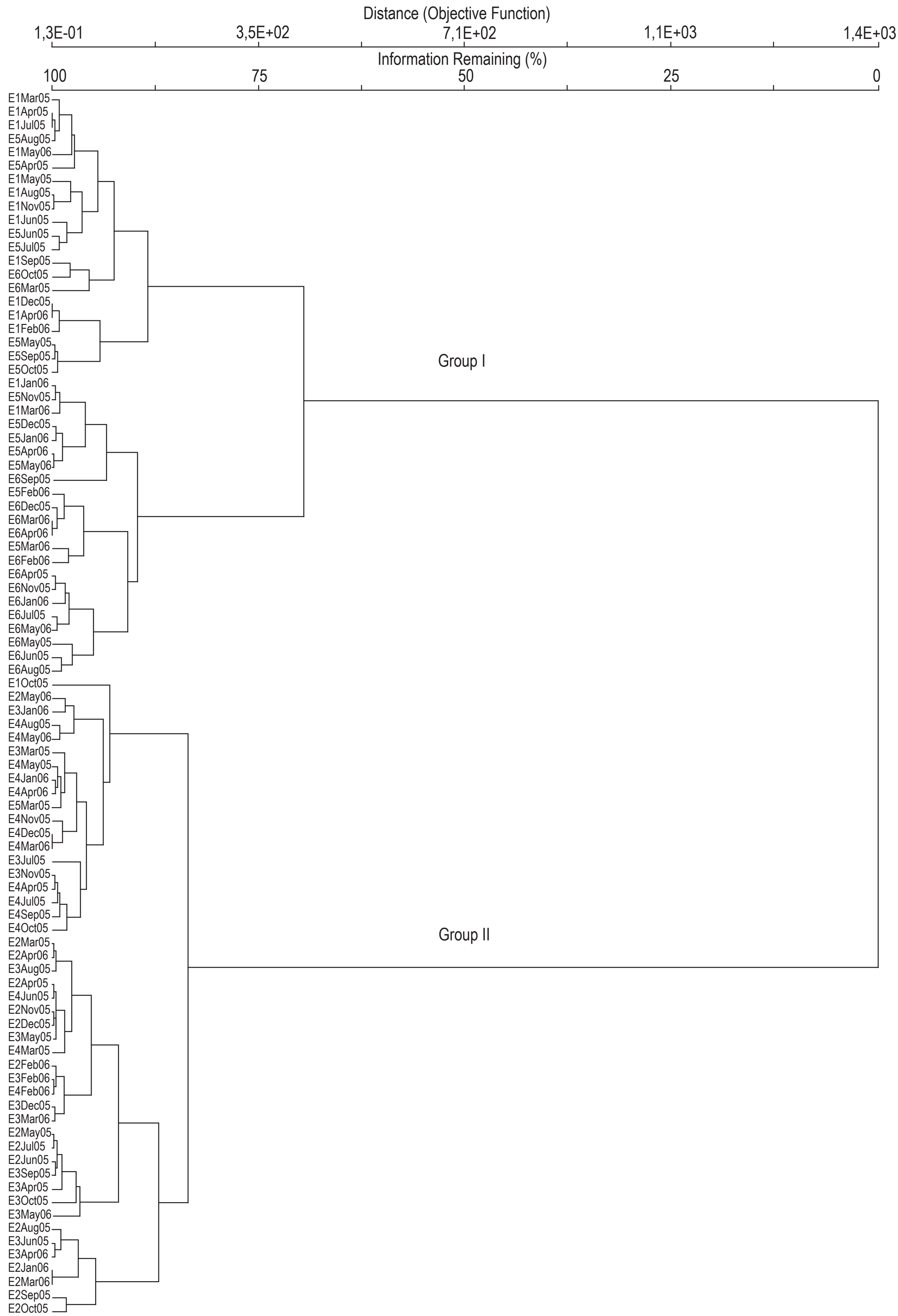


Figure 2. Dendrogram (euclidean distances) resulting from cluster analysis based on similarities among the abiotic variables.

Table 1. Mean value (± standard deviation [sd]), minimum and maximum values of water variables at six sampling stations in the Guaíba Lake during the four sampling seasons: June/2005-Autumn; September/2005-Winter; November/2005-Spring; February/2006-Summer (Data supplied by DMAE).

Variables	E1	E2	E3	E4	E5	E6
Temperature (°C)	20,6 ± 5,85 15-28	21,1 ± 5,66 16 - 28	21,5 ± 5,85 15-28	21,5 ± 5,85 15-28	21,1 ± 6,01 16-27,5	21,8 ± 6,09 16-27,5
Depth (m)	4,0 ± 0,15 3,8-4,1	6,7 ± 0,17 6,5-6,8	9,4 ± 0,74 8,9-10,5	4,7 ± 1,49 3,1-6,5	4,0 ± 0,54 3,5-4,7	2,0 ± 0,66 1,3-2,7
Secchi depth (m)	0,5 ± 0,37 0,2-1,0	0,4 ± 0,14 0,3-0,6	0,4 ± 0,13 0,25-0,5	0,5 ± 0,13 0,3-0,6	0,5 ± 0,10 0,4-0,6	0,8 ± 0,25 0,5-1,1
Turbidity (UNT)	37,6 ± 27,17 10-7,3	31,8 ± 14,8 12-44,8	29,3 ± 11,46 44,5-18	27,9 ± 10,59 18-42,5	27,4 ± 8,96 19-39,1	29,1 ± 28,10 13-71,2
Conductivity ($\mu S.cm^{-1}$)	53,7 ± 4,49 48,2-58,9	88,1 ± 5,97 81,5-95,8	77,0 ± 17,89 65,8-103,7	71,8 ± 15,75 60,6-95	67,3 ± 8,43 55,6-75,4	60,2 ± 21,91 29,1-77,4
pH	7,1 ± 0,30 6,9-7,5	6,9 ± 0,38 6,6-7,4	7,0 ± 0,29 6,7-7,4	7,1 ± 0,31 6,8-7,5	7,5 ± 0,54 7,1-8,3	7,5 ± 0,15 7,4-7,7
DO ($mg.L^{-1}\ 0_2$)	8,0 ± 1,27 6,6-9,6	6,0 ± 0,66 5,4-6,9	6,5 ± 0,79 5,7-7,3	6,7 ± 0,68 6-7,4	8,5 ± 0,61 7,6-8,9	8,0 ± 0,97 7-9
DO saturation %	87,8 ± 4,92 84 - 95	66,5 ± 8,35 55 - 74	73,8 ± 12,53 61-91	76,1 ± 12,33 68-94,5	95 ± 10,1 88-110	90,0 ± 2,94 86-93
BOD ($mg.L^{-1}\ 0_2$)	0,8 ± 0,43 0,2-1,2	2,5 ± 0,88 1,8-3,6	2,1 ± 0,56 1,4-2,7	1,5 ± 0,69 0,9-2,5	1,7 ± 0,70 0,8-2,4	0,9 ± 0,59 0,3-1,6
COD ($mg.L^{-1}\ 0_2$)	16,5 ± 14,40 4,8-37,4	17,8 ± 5,74 13,2-25,8	14,3 ± 1,98 11,7-16,2	14,7 ± 3,32 10,1-17,5	13,7 ± 4,94 9,3-20,4	13,1 ± 2,98 10,5-16,8
NH_3 ($mg.L^{-1}$ N)	0,1 ± 0,05 0,08-0,2	0,7 ± 0,16 0,54-0,89	0,6 ± 0,46 0,28-1,28	0,5 ± 0,46 0,28-1,23	0,3 ± 0,17 0,08-0,44	0,2 ± 0,07 0,1-0,24
Norg ($mg.L^{-1}$ N)	0,3 ± 019 0,12-0,39	0,4 ± 0,35 0,14-0,64	0,5 ± 0,18 0,41-0,66	0,4 ± 0,28 0,25-0,64	0,4 ± 0,45 0,09-0,73	0,5 ± 0,01 0,53-0,54
NO_2-N ($mg.L^{-1}$ N)	0,0 ± 0,02-0,02	0,0 ± 0,02 0,02-0,05	0,0 ± 0,02 0,02-0,05	0,0 ± 0,02 0,01-0,04	0,0 ± 0,01 0,01-0,02	0,0 ± 0,0 0,02-0,02
NO_3-N ($mg.L^{-1}$ N)	0,8 ± 0,43 0,54-1,48	0,7 ± 0,40 0,4-1,32	0,7 ± 0,09 0,58-0,79	0,7 ± 0,12 0,57-0,86	0,7 ± 0,43 0,29-1,31	0,8 ± 0,48 0,08-1,18
PO_4T ($mg.L^{-1}\ PO_4$)	0,1 ± 0,05 0,05-0,17	0,2 ± 0,07 0,11-0,28	0,1 ± 0,03 0,12-0,19	0,3 ± 0,34 0,12-0,82	0,1 ± 0,01 0,09-0,11	0,1 ± 0,01 0,09-0,11
Thermotolerant coliforms ($NMP.100\ mL^{-1}$)	370 ± 238 170-690	22925 ± 19685 8700-52000	16150± 18651 4400-44000	8850± 4416 4600-14000	553 ± 666 20-1300	15 ± 20 1-38
Total coliforms ($NMP.100\ mL^{-1}$)	3250± 870 2400-4400	114750 ± 83136 28000-200000	99500 ± 81410 28000-170000	52000 ± 23051 32000-84000	3550 ± 4080 1000-9600	2170 ± 3421 340-7300

(E3) and Tristeza (E4) were environments β-mesosaprobic environments.

3.2. Community of epilithic diatoms

The community was composed by 49 taxa distributed in 12 families and 23 genera. *Encyonema* Kützing, *Gomphonema* Agardh, *Navicula* Bory and *Pinnularia* Ehrenberg were the genera with the highest species richness.

The attributes of community (richness and density) did not show a relationship with the organic contamination degree. Richness (Figure 3) was highest at station E2 (mean of 17 taxa) compared with stations E5 and E6 (mean of 9 to 11 taxa), respectively. The density (Figure 4) varied between the mean estimates of 25,254 to 36,330 ind.cm^{-2} among stations E2 and E6, and it was much higher at station E1, (mean 110,247 ind.cm^{-2}) and lowest at station E6 (mean 3,829 ind.cm^{-2}).

As to species distribution, *Gomphonema parvulum* (Kützing) Kützing; *Navicula cryptotenella* Lange-Bertalot and *Nitzschia palea* (Kützing) Smith were present throughout the study period. The species restricted to GI, which included stations E1, E5, and E6 with less organic contamination were: *Amphipleura lindheimeri* Grunow, *Cocconeis placentula* (Ehrenberg) Cleve var. *lineata*, *Encyonema silesiacum* (Bleisch) D.G. Mann, *Encyonema perpusillum* (A.Cleve) D.G. Mann, *Synedra goulardii* Brébisson, *Geissleria aikenensis* (Patrick) Torgan and Oliveira, and *Planothidium dubium* (Grunow) Round and Bukhtiyarova. Furthermore, the species exclusive to GII, which consisted of stations E2, E3, and E4 with a higher degree of organic contamination were: *Achnantidium microcephalum* Kützing, *Cyclotella meneghiniana* Kützing, *Frustulia saxonica* Rabenhorst, *Gomphonema mexicanum* Grunow, *Neidium* sp., *Pinnularia microstauron* (Ehrenberg) Cleve, *Planothidium frequentissimum* (Lange-Bertalot) Round and Bukhtiyarova, *Sellaphora pupula* (Kützing) Moreschkowskly, and *Surirella angusta* Kützing.

The abundant taxa of GI were: *Encyonema minutum, Eolimna subminuscula*, *Eunotia pectinalis, Gomphonema augur, G. angustatum, G. parvulum, Luticola goeppertiana, Navicula cryptotenella, Nitzschia palea* and *Sellaphora seminulum/Eolimna minima* and *Syndedra goulardii.*

For GII the abundant and/or dominant taxa were *Achnanthidium microcephalum*, *Eolimna subminuscula, Gomphonema angustatum*, *G. augur*, *G. turris* f. *coarctata*, *G. mexicamum, G. parvulum, Navicula cryptotenella, Nitzschia palea, Pinnularia microstauron, Planothidium frequentissimum, Sellaphora seminulum, Sellaphora pupula* and *Ulnaria ulna*, and many of these also occurring abundantly in GI.

Species analysis of species indicating habitat specificity (Table 2) showed four species: *Cocconeis placentula* var. *lineata, Encyonema minutum, Eolimna subminuscula* and *Navicula cryptotenella*, the first since it only occurs at E1, and the others due to their high density at the same station, as indicators of water with a lower degree of organic contamination.

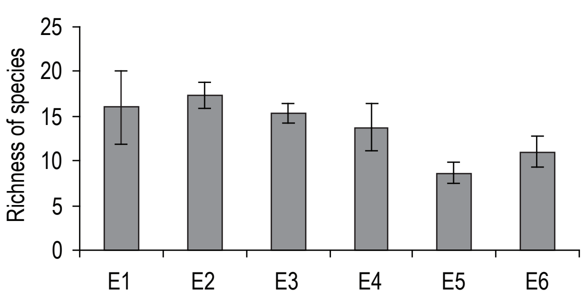


Figure 3. Mean value (± standard deviation [sd]) of the community richness from June 2005 to February 2006, at the six sampling stations in the Guaíba Lake.

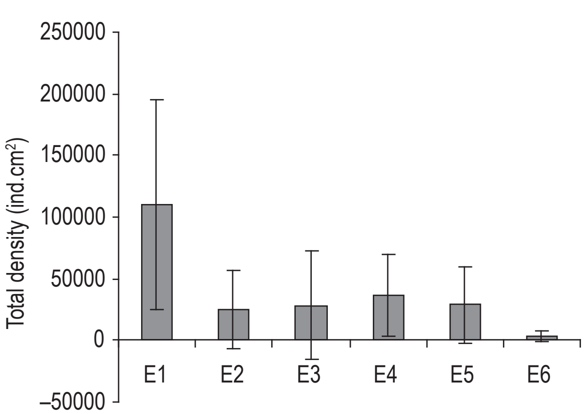


Figure 4. Mean value (± standard deviation [sd]), of the community density from June 2005 to February 2006, at six sampling stations in the Guaíba Lake.

Figure 5 presents the results of the analysis and Twinspan classification for the diatoms found in the 20 sampling units, in which six clusters could be identified (G1-G6). This analysis complemented the habitat specificity analysis and the similarity analysis between sampling units, distinguishing clusters G1, G5, and G6 with species that are more sensitive to organic contamination from clusters G2, G3, and G4 with species that are more tolerant to this type of contamination.

In G1 we have *Cocconeis placentula* var. *lineata*, which was limited to station E1 in autumn and winter 2005, and *Synedra goulardii* which was outstanding for its abundance at G5 and G6, which corresponding to E5 and E6 in the spring of 2005 and summer of 2006. It is interesting to note that *Encyonema minutum* was outstanding in G6 by its absence at E6.

In G2, G3, and G4 the outstanding ones were *Gomphonema mexicanum, Achnantidium microcephalum* and *Gomphonema mexicanum* was abundant at stations E2, E3 and E4 and E6, especially in winter, while *Achnanthidium microcephalum* was abundant at stations E3 and E4, in winter and autumn 2006, respectively (Figure 6).

4. Discussion

The epilithic diatoms demonstrated a significant relationship only with the station E1 by their exclusivity or by their highest density. *Cocconeis placentula* var. *lineata* (Figure 7) was limited to station E1, whereas *Encyonema minutum* (Figure 8), *Eolimna subminuscula* (Figure 9) and *Navicula cryptotenella* (Figure 10) demonstrated their highest density at the same station. This fact proved to be species that can indicate habitat suffer less impact from organic matter. The Ilha da Pintada (E1) differs from the others by its position in the Basin, almost exclusively receiving water from the Jacuí River, which has the best water quality and by have the lowest BOD_5 (Table1).

Some results can be confirmed by the literature. *Cocconeis placentula* var. *lineata* was also considered sensitive to organic pollution in Germany rivers (Lange-Bertalot 1979, Krammer; Lange-Bertalot 1986) and in a recent study on epilithic diatoms influenced by fish farming in the Antas river (Schneck et al., 2007) where a high density of this variety occurred at less impacted stations.

Encyonema minutum was also classified by Kobayasi and Mayama (1989) as a species sensitive to organic pollution. At the Guaíba Lake this species was present in the majority of the stations; however its high density at E1 makes it likely an indicator of water with a lower degree of saprobity. This species was considered an indicator of α-mesosaprobic conditions by Lobo and Torgan (1988) in

Table 2. Results of indicator species analysis according to Dufrêne and Legendre's (1997).

Species	Groups	Value	Mean	S.Dev	p *
1 *Achnanthidium microcephalum*	4	32.6	42.0	18.23	0.6051
2 *A. exiguum*	4	18.7	24.0	13.69	0.5591
3 *Achnanthes coarctata*	4	25.0	30.0	4.08	1.0000
4 *Amphipleura lindheimeri*	1	25.0	30.0	4.08	1.0000
5 *Caloneis* sp.	4	25.0	30.0	4.08	1.0000
6 *Cocconeis placentula*	1	75.0	27.5	14.12	0.0103*
7 *Cyclotella meneghiniana*	4	24.1	33.0	10.76	1.0000
8 *Diadesmis confervacea*	4	22.1	31.3	11.28	1.0000
9 *Encyonema minutum*	1	66.3	37.6	10.47	0.0098*
10 *E. mesianum*	1	20.6	35.7	15.96	0.7818
11 *E. perpusillum*	5	66.7	29.2	12.13	0.0636
12 *E. silesiacum*	1	48.8	29.6	14.55	0.1443
13 *Eolimna subminuscula*	1	56.4	29.0	12.16	0.0430*
14 *Eunotia* sp.	2	33.3	30.0	4.08	0.6001
15 *E. bilunaris*	5	12.9	26.3	13.72	0.7931
16 *E. pectinalis*	4	18.0	29.5	13.49	0.7906
17 *Fragilaria* sp.	2	17.5	23.3	13.74	0.9154
18 *Frustulia crassinervia*	1	18.2	30.9	14.22	1.0000
19 *F. saxonica*	2	56.0	30.0	15.04	0.0573
20 *Geissleria aikenensis*	1	25.0	30.0	4.08	1.0000
21 *Gomphonema pseudoaugur*	4	31.7	37.3	8.95	0.7715
22 *G. turris*	4	20.6	32.2	14.33	0.7891
23 *G. gracile*	3	44.3	35.5	11.81	0.2478
24 *G. mexicanum*	3	31.5	28.5	10.08	0.3152
25 *G. angustatum*	2	39.1	29.5	12.51	0.1847
26 *G. parvulum*	1	59.1	56.5	8.96	0.3742
27 *G. acuminatum*	1	25.0	30.0	4.09	1.0000
28 *Luticola goeppertiana*	1	45.5	51.6	20.35	0.5491
29 *Navicula pseudoanglica*	6	33.3	30.0	4.08	0.6017
30 *N. cryptotenella*	1	52.6	33.8	6.55	0.0100*
31 *N. laevissima*	3	23.1	25.7	13.30	0.6635
32 *N. radiosa*	5	26.7	27.2	12.76	0.3781
33 *N. rostellata*	1	37.5	30.3	15.14	0.2651
34 *N. symmetrica*	1	54.0	33.7	15.04	0.1002
35 *Neidium* sp.	4	21.8	31.1	11.42	1.0000
36 *Nitzschia clausii*	2	71.4	37.5	16.56	0.0524
37 *N. palea*	5	43.1	46.9	6.72	0.7079
38 *Pinnularia acrosphaeria*	4	52.0	30.1	14.00	0.0679
39 *P. braunii*	4	11.8	25.1	14.37	1.0000
40 *P. microstauron*	4	37.6	39.1	17.60	0.4764
41 *Pinnularia* sp.	1	25.0	30.0	4.09	1.0000
42 *Planothidium frequentissimum*	3	66.7	32.8	10.98	0.0649
43 *P. dubium*	1	50.0	26.8	12.90	0.1266
44 *Sellaphora pupula*	4	16.1	34.2	16.38	1.0000
45 *S. seminulum*	1	27.6	37.2	14.99	0.7410
46 *Surirella angusta*	3	33.3	30.0	4.08	0.6008
47 *Synedra goulardii*	6	37.4	25.3	14.54	0.2107
48 *Ulnaria ulna*	4	25.0	33.6	12.47	0.7896
49 *Tryblionella victoriae*	2	19.0	22.7	13.91	0.6328

In the classification, species only with ($p < 0.05$)* were selected. Proportion of randomized trials with indicator value equal to or exceeding the observed indicator value.

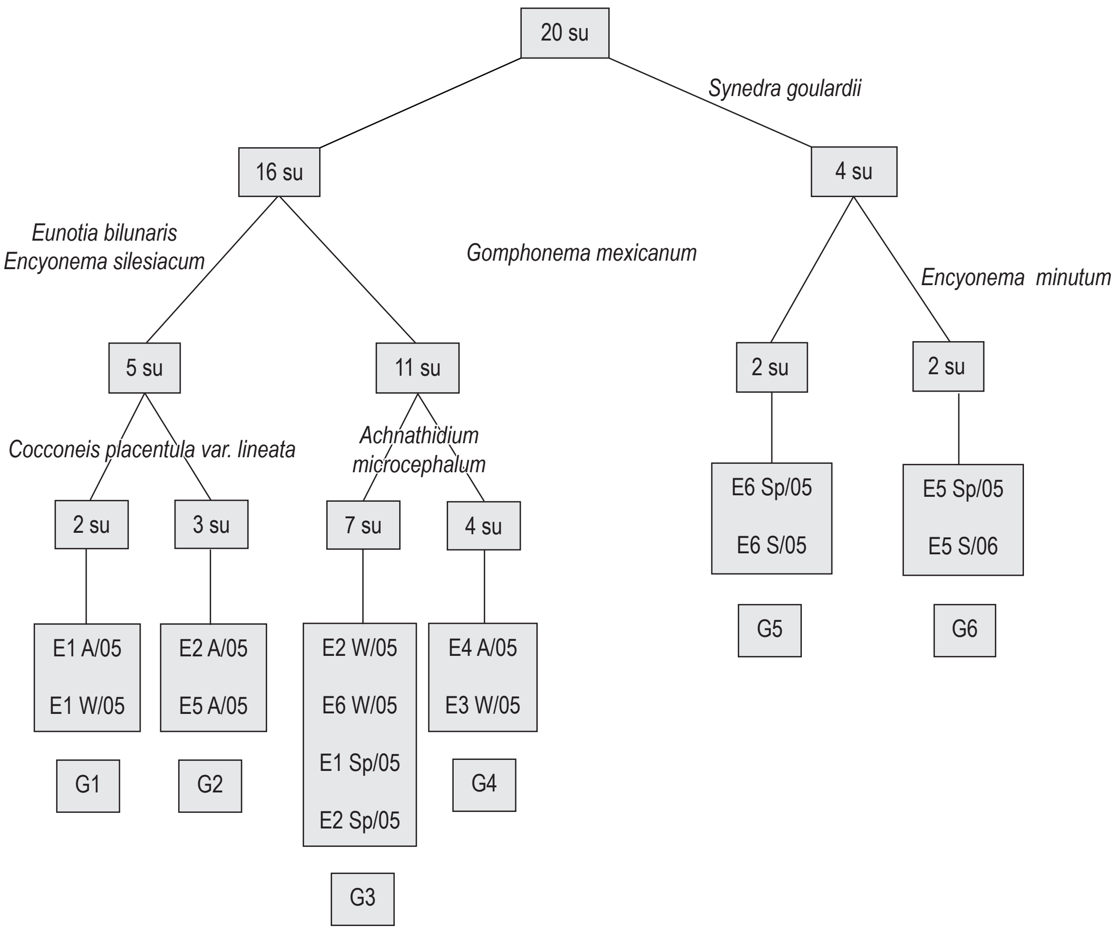


Figure 5. TWINSPAN analysis classification for 20 sampling units (su). The stations (E) and the seasons of the years (A = autumn, W = winter, Sp = spring, S = summer) are shown inside the squares.

plankton samples in Guaíba Lake, but this study did not consider the viability of the cells.

Eolimna subminuscula is considered as less tolerant to organic pollution according to Lobo and Kobayasi (1990). Van Dam et al. (1994) classified this species as an indicator of α-meso/polysaprobic conditions, eutrophic, with low O_2 concentrations. Souza (2002) recorded this species in abundance in Monjolinho River, São Paulo, classifying it as α-mesosaprobic. In Gravataí River, Salomoni et al. (2006) found a greater density of this species in the more eutrophic portion of the river, where domestic and industrial effluents are discharged, considering it tolerant to organic pollution. In Guaíba Lake, *E. subminuscula* also proved be tolerant to organic contamination; it was abundant at E2 in autumn and winter (Figure 6), but it has high density at E1, and therefore may be considered an indicator of a less impacted habitat.

There is some controversy about *Navicula cryptotenella* = *Navicula radiosa* Kützing var. *tenella* (Brébisson) Grunow. It was considered by Sládeček (1973) and Patrick and Palavage (1994) as oligosaprobic, occurring in natural water and it is not tolerant in large amounts of organic pollution. On the other hand, Van Dam et al. (1994), Salomoni et al. (2006) and Lobo et al. (2002) mentioned this species as tolerant to a range of conditions, varying from β-mesosaprobic, α-mesosaprobic, and α-polysaprobic, respectively. In Guaíba Lake this species was present at every stations, showing a saprobic tolerance, but its maximum density peaks was in station E1, where the conditions were oligosaprobic.

Encyonema silesiacum was exclusive to E1. These species were found in oligo to mesosaprobic waters (Patrick and Reimer, 1966; Sládeček 1973; Whitmore, 1989; Van Dam et al., 1994). *Gomphonema mexicanum*, in our study, presented an adaptation to the different saprobity conditions, it was abundant at the stations with different organic contamination degrees. On the other hand, *Achnanthidium microcephalum* was abundant at more organic matter impacted stations (E3 and E4).

Synedra goulardii was limited to E5 and E6, but little information is available on its ecology. According to Silva-Benavides (1996) this species prefers waters without organic pollution and Aguiar and Martau (1979) mentioned that this species is an oligosaprobic indicators.

Gomphonema parvulum and *Nitzschia palea*, did not prove to be indicators species in Guaíba Lake. These species were present at every stations during the annual cycle and

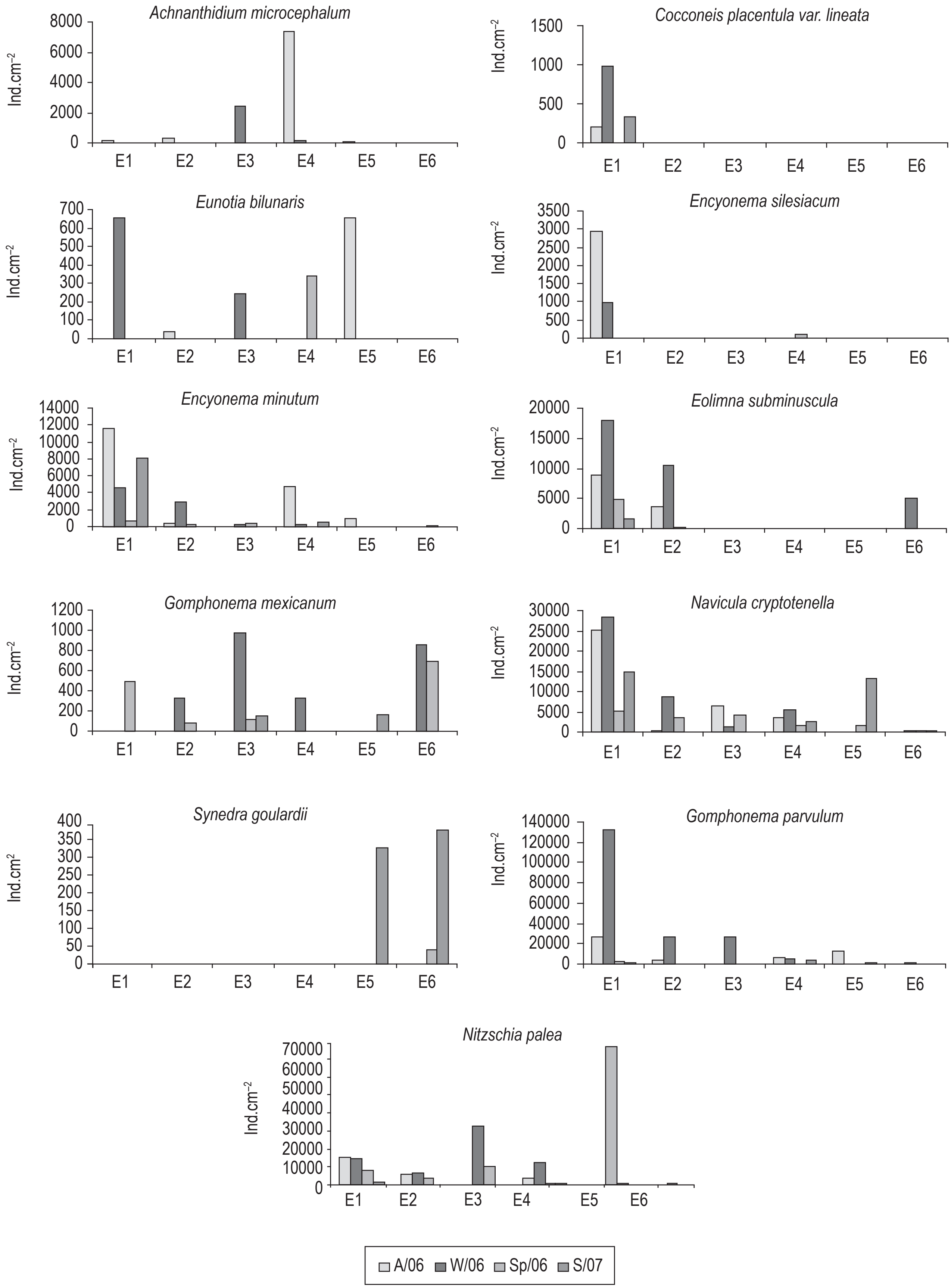
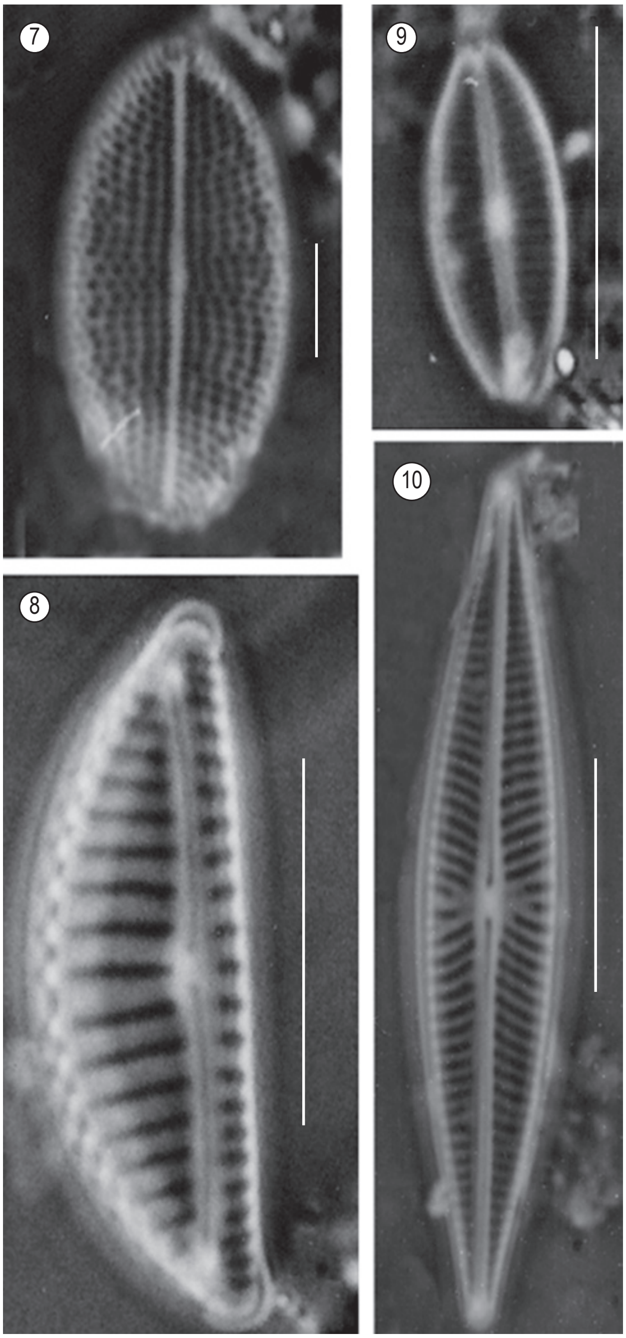


Figure 6. Density variation of the diatoms at six sampling stations in the Guaíba Lake, from June/05 to Feb./06 and four sampling seasons: June/05 – Autumn (A); Sept./05 – Winter (W); Nov./05 – Spring (Sp); Feb./06 – Summer (S).



Figures 7-10. 7. *Cocconeis placentula* var. *lineata;* 8. *Encyonema minutum;* 9. *Eolimna subminuscula;* and 10. *Navicula cryptotenella*.

the highest density of *G. parvulum* and *N. palea* (Figure 6) were found at the oligosaprobic and β-mesosaprobic condictions respectively. In more recent studies performed in Brazilian rivers *G. parvulum* was also recorded in high densities in oligosaprobic environments (Rodrigues and Lobo 2000; Lobo et al. 2002; Souza 2002; Salomoni et al. 2006).

In summary, we can conclude that the richness and density of the epilithic diatoms could not distinguish environments with higher or lower organic impact. However, the indicator species analyses proved be effective in recognizing the diatom species that could identify habits with lower degree of organic contamination in Guaíba Lake.

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References

AGUIAR, LW. and MARTAU, L. Diatomáceas de lagos do parque Zoológico, Rio Grande do Sul, Brasil. *Iheringia*. *Série* Botânica, Porto Alegre, 1979, vol. 25, no. 1, p. 27-110.

American Public Health Association - APHA. *Standard methods for the examination of water and wastewater*. Washington: APHA, 1992. 1316p.

COX, EJ. *Identification of freshwater diatoms from live material*. London, UK, Chapman & Hall, 1996. 158p.

Departamento Municipal de Água e Esgotos - DMAE. *O rio Guaíba*: suas características físico-químicas e biológicas. Porto Alegre: DMAE, 1986, v.5 no. 43. 361p.

DESCY, JP. and ECTOR, L. Use of diatoms for monitoring rivers in Belgium and Luxemburg. In PRYGIEL, J., WHITTON, BA. and BUKOWSKA, J. (Eds.). *Use of algae for monitoring rivers III*. Douai: Agence de l'Eau Artois-Picardie, 1999. p. 128-137.

DUFRÊNE, M. and LEGENDRE, P. Species assemblages and indicator species: the need for a flexible asymmetrical approach by the Ecological Society of America. *Ecological Monographs*. 1997, vol. 67, no. 3, p. 345-366.

HILL, MO. *Twinspan*: a Fortran Program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. New York: Cornell University, 1979. 60 p.

KELLY, MG. Role of benthic diatoms in the implementation of the Urban Wastewater Treatment Directive in the River Wear, North-East England. *Journal of Applied Phycology.* 2002, vol. 14, p. 9-18.

KELLY, MG. and WHITTON, BA. The tropic diatom index: a new index for monitoring eutrophication in rivers. *Journal of Applied Phycology* 1995, no. 7, p. 433-444.

KOBAYASI, H. and MAYAMA, S. Evaluation of river water quality by diatoms. *The Korean Journal of Phycology*, Tokyo, 1989, vol. 4, p. 121-133.

KRAMMER, K. and LANGE-BERTALOT, H. Freshwater flora of Central Europe. Bacillariophyceae: Naviculaceae. In ETTL, H., GERLOFF, I., HEYNING, H. and MOLLENHAUER,

D. (Eds.). *Süsswasseflora von Mitteleuropa*. Stuttgart: G. Fischer, 1986. 876p.

KRAMMER, K. and LANGE-BERTALOT, H. Freshwater flora of Central Europe. *Bacillariophyceae: Bacillariaceae, Ephitemiaceae, Surirellaceae*. In ETTL, H., GERLOFF, I., HEYNING, H. and MOLLENHAUER, D. (Eds.). *Süsswasseflora von Mitteleuropa*. Stuttgart: G. Fischer, 1988. 596p.

KRAMMER, K. and LANGE-BERTALOT, H. Freshwater flora of Central Europe. *Bacillariophyceae: Centrales, Fragilariaceae, Eunotiaceae*. In ETTL, H., GERLOFF, I., HEYNING, H. and MOLLENHAUER, D. (Eds.). *Süsswasseflora von Mitteleuropa*. Stuttgart: G. Fischer, 1991a. 576 p.

KRAMMER, K. and LANGE-BERTALOT, H. Freshwater flora of Central Europe. *Bacillariophyceae: Achnanthaceae, Kritische Ergänzungen zu Navicula (Lineolatae) und Gomphonema.* In ETTL, H., GERLOFF, I., HEYNING, H. and MOLLENHAUER, D. (Eds.). *Süsswasseflora von Mitteleuropa*. Stuttgart: G. Fischer, 1991b. 437p.

LANGE-BERTALOT, H. Pollution tolerance of diatoms as a criterion for water quality estimation. *Nova Hedwigia*, *Beiherft*, Weiheim, 1979, vol. 64, p. 285-304.

LANGE-BERTALOT, H. 85 new taxa and much more than 100 taxonomic classifications supplementary to freshwater flora of Central Europe. *Bibliotheca Diatomologica,* 27. J. Cramer, Stuttgart, 1993, vol. 2, no. 1-4, 454p.

LANGE-BERTALOT, H. Taxonomy. *Iconographia Diatomologica*. vol. 1 Lange-Bertalot, H.(ed) Koeltz Scientific Books, 1995. 107p.

LANGE-BERTALOT, H. Indicators of Oligotrophy. Ecology-Diversity-Taxonomy *Iconographia Diatomologica* vol. 2. Lange-Bertalot, H.(ed) Koeltz Scientific Books, 1996a. 390p.

LANGE-BERTALOT, H. Taxonomy. *Iconographia Diatomologica*. vol. 4 Lange-Bertalot, H. (ed) Koeltz Scientific Books, 1996b. 287p.

LANGE-BERTALOT, H. Diatoms of Europe. Diatoms of the European Inland Waters and Comparable Habitats. Lange-Bertalot, H. (ed) vol.2: *Navicula sensu stricto 10 Genera Separated from Navicula sensu lato Frustulia.* Koeltz Scientific Books, Gantner Verlag. Königstein, 2001. 526p.

LOBO, EA. and BUSELATO-TONIOLLI, TC. Tempo de exposição de um substrato artificial para o estabelecimento da comunidade perifítica no curso inferior do Rio Caí, Rio Grande do Sul, Brasil. *Rickia*, 1985, vol. 12, no.1, p. 35-51.

LOBO, EA. and LEIGHTON, G. Estruturas comunitarias de las fitocenosis planctonicas de los sistemas de desembocaduras de rios y esteros de la zona central de Chile. *Revista de Biologia Marinha,* Valparaiso, 1986, vol. 22, no.1, p. 1-29.

LOBO, EA. and TORGAN, LC. Análise da estrutura da comunidade de diatomáceas (Bacillariophyceae) em duas estações do sistema Guaíba, RS, Brasil. *Acta Botânica Brasilica* 1988, vol. 1, no. 2, p. 103-119.

LOBO, EA. and KOBAYASI, H. Shannon's diversity index applied to some freshwater diatom assemblages in the Sakawa River System (Kanagawa Pref. Japan) and its use as an indicator of water quality. *Japanese Journal of Phycology* 1990, vol. 38, no. 3, p. 229-243.

LOBO, EA., CALLEGARO, VLM., OLIVEIRA, MA., SALOMONI, SE., SCHULER, S. and ASAI, K. Pollution Tolerant Diatoms from lotic Systems in the Jacuí Basin, Rio Grande do Sul, Brasil. *Iheringia. Série Botânica,* Porto Alegre, 1996. vol. 47, no.1, p. 45-72.

LOBO, EA. and BENDER, P. Aplicabilidade de sistemas de sapróbio para avaliação da qualidade de águas correntes fortemente poluídas, no sul do Brasil, utilizando diatomáceas. *Anais do IV Congresso Latino Americano de Ficologia, 1996.* Minas Gerais, 1998. vol.1. p. 401-422.

LOBO, EA., BEN DA COSTA, A. and KIRST, A. Avaliação da qualidade da água dos arroios Sampaio, Bonito e Grande, município de Mato Leitão, RS, Brasil, segundo a resolução do CONAMA 20/86. *Revista Redes*, Santa Cruz do Sul, 1999, vol. 4, no. 2, p. 129-146.

LOBO, EA., CALLEGARO, VLM. and BENDER, P. *Utilização de algas diatomáceas epilíticas como indicadoras da qualidade da água em rios e arroios da Região Hidrográfica do Guaíba, RS, Brasil*. Santa Cruz do Sul: EDUNISC, 2002. 127p.

LOBO, EA., BES, D., TUDESQUE, L. and ECTOR, L. Water quality assessment of the Pardinho river, RS, Brazil, using epilithic diatom assemblages and faecal coliforms as biological indicators. *Vie et Milieu – Life & Environment* 2004a, vol. 54, no. 2-3, p. 115-126.

LOBO, EA., CALLEGARO, VLM., HERMANY, G., GOMEZ, N. and ECTOR, L. Review of the use of microalgae in South America for monitoring rivers, with special reference to diatoms. *Vie et Milieu – Life & Environment* 2004b, vol. 54, no. 2-3, p. 105-114.

LOBO, EA., CALLEGARO, VLM., HERMANY, G., BES, D., WETZEL, CA. and OLIVEIRA, MA. Use of epilithic diatoms as bioindicators from lotic systems in southern Brazil, with special emphasis on eutrophication. *Acta Limnologica Brasiliensia* 2004c, vol. 16, no. 1, p. 25-40.

McCUNE, B. and MEFFORD, MJ. *PC-Ord. Multivariate analysis of ecological data, version 4.10*. Oregon: MJM Software Design, 1999. 237p.

METZELTIN, D. and LANGE-BERTALOT, H. Tropical Diatoms of South America 1. Diversity-Taxonomy-Geobotany. *Iconographia Diatomologica* vol.5 Lange-Bertalot. In LANGE-BERTALOT, H. (ed.). Königstein: Koeltz Scientific Books, 1998. 695p.

METZELTIN, D. and LANGE-BERTALOT, H. Diatoms from the `Island Continent Madagascar. In LANGE-BERTALOT, H. (Ed.). *Iconographia Diatomologica*. Königstein: Koeltz Scientific Books, 2002. 286p.

MOURTHÉ-JUNIOR, CA. *Modificações estruturais na comunidade de diatomáceas em um gradiente de poluição hídrica. Trecho superior da bacia do rio das Velhas (região metropolitana de Belo Horizonte – MG).* Belo Horizonte: Universidade Federal de Minas Gerais - UFMG, 2000. 87p. Tese de Doutorado.

PAPPAS, JL. and STOERMER, EF. Quantitative method for determining a representative algal sample count. *Journal of Phycology,* 1996, vol. 32, p. 693-696.

PATRICK, R. and PALAVAGE, DM. The value of species as indicators of water quality. *Proceedings of the Acasdemy of Natural Sciences of Philadelphia* 1994, vol. 145, p. 55-92.

PATRICK, R. and REIMER, CW. *The diatoms of the United States*. Philadelphia: Livingston Publishers, 1966. 688p.

PRYGIEL, J. and COSTE, M. The assessment of water quality in the Artois-Picardie water basin (France) by the use of diatoms indices. *Hydrobiologia.* 1993, vol. 269/270, p. 343-349.

RODRIGUES, LM. and LOBO, EA. Análise da estrutura de comunidades de diatomáceas epilíticas no arroio Sampaio, município de Mato Leitão, RS, Brasil. *Caderno de pesquisas, Série Botânica Santa Cruz do Sul* 2000, vol. 12, no. 2, p. 5-27.

ROUND, FE. *A review and methods for the use of Epilithic Diatoms for detecting and monitoring changes in river water quality*. London: HMSO Publisher, 1993. 63p.

SALOMONI, SE. *Diatomáceas epilíticas indicadoras da qualidade de água na Bacia do rio Gravataí, Rio Grande do Sul, Brasil*. São Carlos: Universidade Federal de São Carlos - UFSCar, 2004. 230p. Tese de Doutorado.

SALOMONI, SE., ROCHA, O., CALLEGARO, VLM. and LOBO, EA. Epilithic diatoms as indicators of water quality in the Gravataí river, Rio Grande do Sul, Brazil. *Hydrobiologia*. 2006, vol. 559, p. 233-246.

SALOMONI, SE., TORGAN, LC. and ROCHA, O. Sampler collection gadget for epilithic diatoms. *Brasilian Journal of Biology*. 2007, vol. 67, no. 4, p. 631-637.

SCHOEMAN, FR. and HAWORTH, EY. Diatom as indicator of pollution. In *Proceedings of the Eighth International Diatoms Symposium*, 1984. Koenigstein: Koeltz Scientific Books, 1986. p. 757-766.

SCHNECK, F., TORGAN, LC. and SCHWARZBOLD, A. Epilithic diatom community in a high altitude stream impacted by fish farming in southern Brazil. *Acta Limnologica Brasiliensia.* 2007, vol. 19, no. 3, p. 341-355.

SILVA-BENAVIDES, AM. The epilithic diatom flora of a Pristine and a polluted river in Costa Rica, Central America. *Diatom Research*. 1996, vol. 11, no. 1, p. 105-142.

SLÁDEČEK, V. System of water quality from a biological point of view. *Archiv für Hydrobiology, Ergebnisse der limnologie*. 1973, vol. 7, p. 1-2189.

SOUZA, MGM. *Variação da comunidade de diatomáceas epilíticas ao longo de um rio impactado no município de São Carlos – SP e sua relação com variáveis físicas e químicas*. São Carlos: Universidade Federal de São Carlos - UFSCar, 2002. 168p. Tese de Doutorado.

VAN DAM, H., MERTENS, A. and SINKELDAM, J. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. *Netherlands Journal Aquatic Ecology*. 1994, vol. 28, no. 1, p. 117-133.

WHITMORE, TJ. Florida diatom assemblage as indicators of trophic state and pH. *Limnology and Oceanography,* 1989, vol. 34, no. 5, p. 882-895.

WHITTON, BA., ROTT, E. and FRIEDRICH, G. (Eds.). Use of algae for monitoring rivers. In *Proceedings of the International Symposium*, May 26-28, Germany: [s.n.], 1991. 183p.

WHITTON, BA. and ROTT, E. (Eds.). Use of algae for monitoring rivers II. In *Proceedings of the II International Symposium,* September17-19, 1995. Innsbruck: [s.n.], Austria, 1996. 196p.

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