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Application of Diatom Indices in a Planted Ditch Constructed for Tertiary Sewage Treatment in Schwaan, Germany

key words: organic pollution, trophy, diatom index, periphyton, tertiary treatment

Abstract

The present study quantified the decrease of organic and trophic pollution in a constructed wetland used for tertiary sewage treatment. Different diatom indices [the saprobic zoning system of Lange-Bertalot (1978, 1979), the saprobic index (SI) of Rott *et al.* (1997), as well as the trophic indices of Schiefele and Kohmann (1993); Kelly and Whitton (1995) and Rott *et al.* (1999)] were tested for their effectiveness in detecting changes in water quality of highly organic and trophic waters. The saprobic zoning system detected nearly the same pollution levels as the chemical data, but the measured saprobic characteristics (e.g. TOC: Total Organic Carbon) did not correspond to significant changes in the diatom assemblages. The data suggested that the results of the saprobic zoning system were influenced by differences in nitrate concentrations. The trophic diatom indices correlated relatively well with the inorganic compound chemical data.

1. Introduction

Diatoms are useful indicators of water quality because of their worldwide distribution, their specifity to certain environmental conditions, their species richness, and their quick response to changes in physical and chemical characteristics of a water body (Dixit *et al.* 1992; Mccomick and Cairns, 1994). Recently, there has been a renewed interest in river monitoring based on diatom analysis. Earlier studies attempted to meet the on-going need to assess organic pollution of running waters through the use of diatoms as bioindicators (Sladecek 1986; Lange-Bertalot, 1978, 1979). In some European countries, several diatom-based pollution indices have been developed and are now on their way to being routinely used (Prygiel and Coste, 1996; Rott *et al.*, 1997). However, the widespread use of diatoms for the biomonitoring of organic pollution of running waters in Germany did not occur because of the lack of official standards (DIN-Norm) for using autotrophic organisms to assess saprobic status. Furthermore, the complicated taxonomy of diatoms limited the practical application of this technique to the scientific community.

In the last few decades, the development of wastewater treatment plants by industrialized nations resulting in effective decomposition of organic compounds (Schmedtje *et al.*, 1998) has the effect of higher mineral loading of sewage plant effluents. The status of many rivers has therefore changed from systems stressed by organic pollution to systems loaded by inorganic pollution. Correspondingly, more emphasis has been placed on evaluating pollution by estimating trophic variables. Steinberg and Schiefele (1988) added two groups of trophic preference to the saprobic zoning system of Lange-Bertalot (1978, 1979). Further indices were subsequently developed to assess the trophic status of running waters (Schiefele and Kohmann, 1993; Kelly and Whitton, 1995; Schmedtje *et al.*, 1998; Rott *et al.*, 1999; Coring, 1999). Several authors (e.g. STOERMER and YANG, 1970, TILMAN *et al.*, 1982; HOFMANN, 1994) showed that diatoms are useful indicators of trophic status in lakes. However, verification of new indices is necessary before their widespread application in monitoring studies. The previously mentioned studies indicated a high correlation between diatom composition and both organic pollution and trophy of waters. The difficulty remains in distinguishing between the effects of organic and inorganic pollution (KELLY and WHITTON, 1995; KELLY, 1998).

The present study investigated a constructed wetland used for tertiary sewage treatment. The biologically treated efflux of the sewage plant in Schwaan (Mecklenburg-Vorpommern; Germany) runs through a planted ditch for further cleaning by microbial and other natural self-cleaning processes. This ditch can be defined as a small macrophyte-dominated running water system. The ditch flows directly into the Warnow River, which serves as the drinking water reservoir for Rostock and its surroundings, supplying approximately 200,000 people. Therefore, the objective of the study was to include a broad chemical analysis to quantify the decrease in organic and trophic pollution of the sewage by tertiary treatment.

The effectiveness of five different diatom indices was tested. The investigation focused on the reaction of the diatom community to spatial (from input to output) and temporal (seasonal) changes of chemical parameters in the ditch. We want to test the hypothesis that the epiphytic diatom flora of the ditch mainly reflects changes in the surrounding water body and could therefore be used for application of diatom indices. Both saprobic and trophic indices were chosen in order to: 1) test whether organic or inorganic pollution was dominant, and 2) identify the most useful index for quantifying all pollution levels.

2. Methods

Samples were collected from 6 stations located every 100 m along the ditch (length: 600 m; width; 1–2 m; Fig. 1). The sampling period was January to October 1998, with samples for chemical analysis collected every two weeks and benthic diatom samples taken monthly. Epiphytic diatoms were either

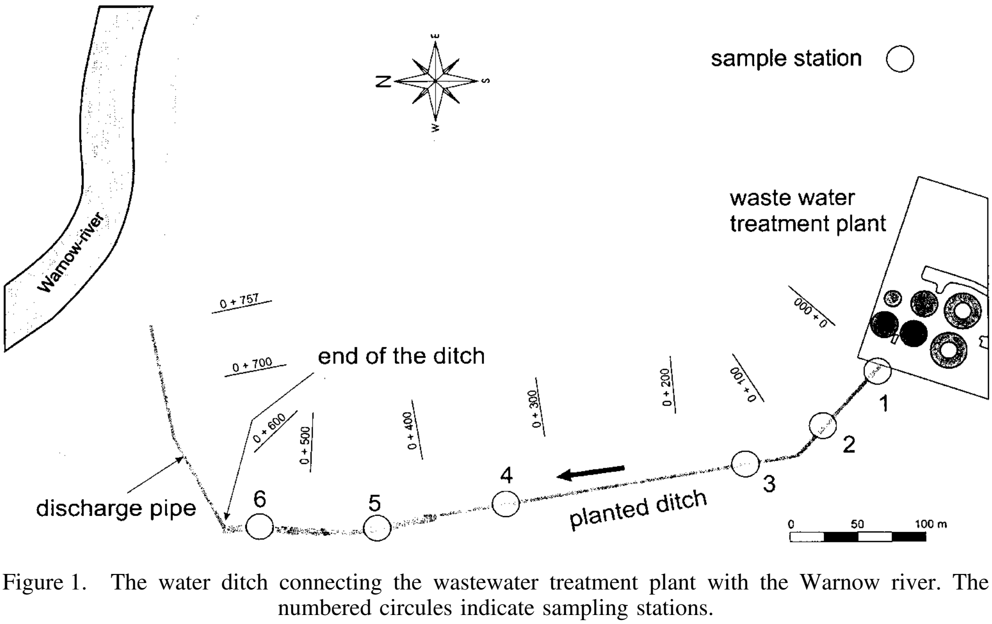

Figure 1. The water ditch connecting the wastewater treatment plant with the Warnow river. The numbered circules indicate sampling stations.

collected as separate samples from two plant species (e.g. *Phragmites australis, Cardamine amara*) or, if insufficient material was available because of seasonal changes in ditch vegetation, a mixed sample from both species was used (total number of samples = 46). On eight occasions a parallel sample was obtained from an artificial substrate. We attached a rectangular PVC sheet (15 cm × 5 cm) to a pole set in the middle of the channel. For each sampling a piece of nearly 5 cm^2 was cut from the end of this submerged sheet. Following our hypothesis that the epiphytic diatom flora reflects conditions in the surrounding water body we used the mixed samples to calculate the pollution indices.

Organic matter in the diatom samples was removed by ignition at 500 °C, and the cleaned valves were mounted in Naphrax^{TM} prior to identification. At least five hundred frustules were counted and, if necessary, further identification was carried out using an electron microscope (Zeiss DSM 960). Taxonomic identification followed the nomenclature of KRAMMER and LANGE-BERTALOT (1986–91). The relative abundance of every taxon was calculated and applied in the following five diatom indices:

To assess organic pollution, classified in levels of saproby introduced by KOLKWITZ and MARSSON (1908):

1) the saprobic zoning system of LANGE-BERTALOT (1978, 1979),
2) the SI = Saprobic Indication according to ROTT *et al.* (1997)
   and for monitoring eutrophication:
3) the TDI (Trophic Diatom Index) according to KELLY and WHITTON (1995), which estimates five levels of ortho-phosphate concentration,
4) the TDI = Trophic Diatom Index, following SCHIEFELE and KOHMANN (1993), a "double" index which reflects phosphorus levels (TDI-P) as well as combined phosphorus-nitrogen levels (TDI-PN)
5) the TI_{Dia} (ROTT *et al.* 1999), which detects total phosphorus concentrations.

All of these indices are based on diatom assemblages at a species level, except for the TDI of KELLY and WHITTON (1995), which selected certain dominant indicator species and groups many other species into genus groups.

Chemical analyses were carried out at the University of Rostock, Institute of Aquatic Ecology, by applying standard methods (KÖSTER, 1998).

3. Results

3.1. Chemical Characterization

Mean nitrate (NO_3–N) concentrations decreased from input (station 1) to output (station 6) by an average of 33% between January and October, with a 47% decrease between April and October (Fig. 2). Analysis of Variance (ANOVA) showed that the decrease between January and October was significant ($p = 0.035$). Mean ammonia (NH_4–N) concentrations decreased by 27%, but remained unaffected by season. The sewage effluent, which had a relatively low orthophosphate content (mean 1–10/98: 0.09 ± 0.09 mg/l PO_4–P; median: 0.05), reflected the very effective removal of phosphate by technical treatment. Between input and output stations, orthophosphate increased slightly throughout the study period (on average 27%).

The organic parameters (Biological Oxygen Demand: BOD, Chemical Oxygen Demand: COD, Total Organic Carbon: TOC, Dissolved Organic Carbon: DOC) showed no notable differences between ditch input and output stations. The mean chloride concentrations of the effluent (316 ± 90 mg/l) exceeded the treatment plant limit by threefold, however this concentration was significantly reduced (ANOVA $p = 0.011$), on average by 18%, between the input and the output station. We excluded the outlayer sample of the 13th May 1998 from the analysis (115 mg/l at station 1, whereas at station 2 the concentration of 333 mg/l was mesured).

3.2. Application of Diatom Indices

The analysis of the benthic diatom assemblages according to the saprobic zoning system of LANGE-BERTALOT (1978, 1979) indicated an improvement of water quality within the ditch. The average abundance of the most pollution-resistant (polysaprobic) taxa decreased

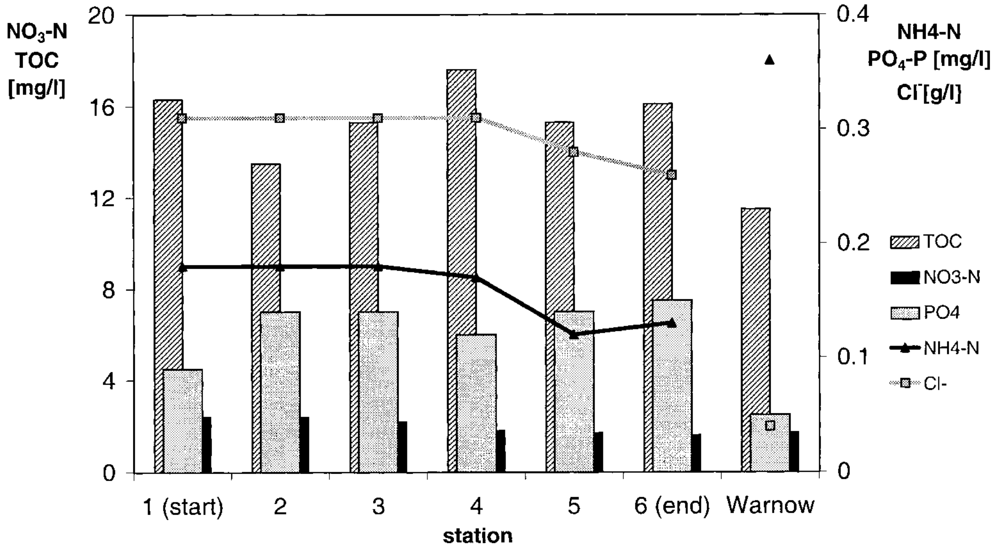

Figure 2. Mean values of chemical parameters at six stations along the ditch and in the Warnow river (1 km upstream of the ditch inflow into the river) from January to October 1998.

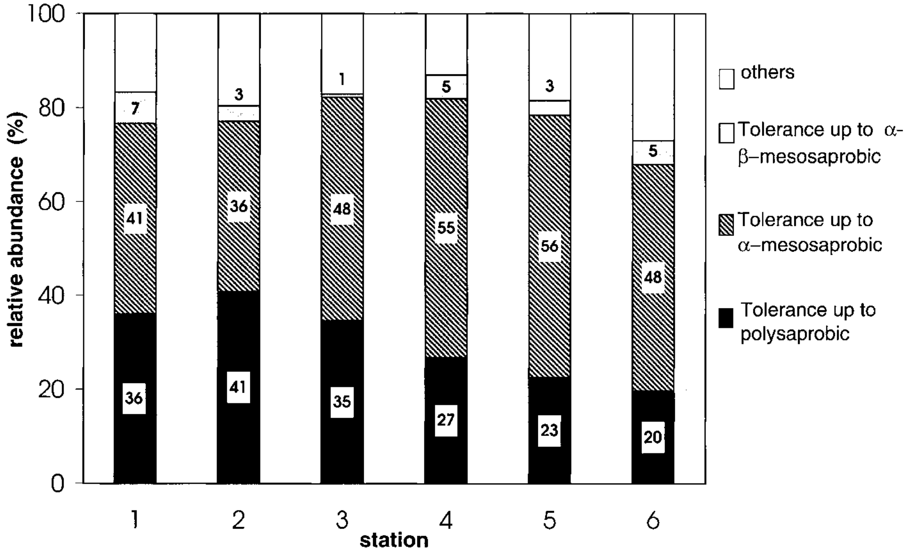

Figure 3. Characterization of six stations along the ditch according to the diatom index of LANGE-BERTALOT (1978, 1979). Mean relative abundance of four saprobic tolerance groups from January to October 1998.

Table 1. Ecology and mean abundance of the dominant taxa in the ditch (stations 1 to 6). Saprobic status (LANGE-BERTALOT 1978, 1979) A: most pollution-resistant group (taxa tolerant up to polysaprobic); B: taxa tolerant up to α-mesosaprobic, C: taxa tolerant up to • – mesosaprobic. FESEL (1984) BSB: Biological Oxygen Demand, species abundance correlated with: + slightly high, ++ high, +++ very high, – low, –– very low, ––– extremely low concentration of the parameter: TDI (KELLY and WHITTON 1995): index values comply with ortho-phosphate concentrations: 5: >0.3 mg/l; 4: >0.1 < 0.3 mg/l; 3: >0.035 < 0.1 mg/l; 2: >0.01 < 0.035 mg/l; 1: <0.01 mg/l.

Taxon	Mean abundance (%) at station						maximal abundance (%)	FESEL 1984	LANGE-BERTALOT (1978, 1979)	TDI K and W
	1	2	3	4	5	6				
Achnanthes lanceolata ssp. *frequentissima*	4.8	3.0	6.3	1.9	4.5	2.5	19.4	NO_2++	B	5
Achnanthes lanceolata ssp. *lanceolata*	3.3	15.9	29.7	22.7	27.3	21.4	79.3	NO_2++	B	5
Achnanthes hungarica	0.0	0.0	0.1	4.6	1.3	0.5	47.5		B	3
Eunotia bilunaris var. *bilunaris*	0.2	1.3	0.2	1.1	1.0	3.4	26.6			1
Fragilaria famelica	5.0	4.3	13.9	3.1	5.7	7.1	64.7			2
Fragilaria ulna	2.1	0.8	0.8	7.5	8.9	8.7	34.0		A	2
Gomphonema parvulum	5.1	5.7	11.9	1.3	2.0	6.4	52.6	BSB+, NH_4+	A	3
Melosira varians	11.3	2.5	7.4	8.5	18.4	19.9	78.6		B	4
Navicula atomus var. *atomus*	1.3	0.6	0.8	0.2	0.2	0.2	14.0	BSB+++, NH_4+++, PO_4++	A	5
Navicula veneta	5.3	1.9	2.4	2.2	3.1	2.1	20.5	BSB–, NH_4––	A	5
Navicula minima	4.8	9.4	2.8	3.8	2.3	1.7	42.3		A	5
Navicula seminulum	3.8	7.7	5.4	3.1	2.3	1.0	36.8	BSB–––, NH_4–, PO_4–, NO_3+	A	5
Nitzschia amphibia	7.2	1.7	0.5	0.6	0.6	0.4	42.3	NH_4–––, PO_4–––, NO_3++	B	4
Nitzschia fonticola	2.1	0.5	0.2	2.1	0.7	0.4	11.2		C	4
Nitschia palea	3.7	1.2	1.0	0.3	0.7	0.3	22.7		A	4
Nitschia paleacea	1.6	0.9	1.9	0.3	0.4	0.3	7.4		B	4

by 16% between station 1 and 6 (Fig. 3). The percent abundance of *Navicula veneta* KÜTZING, *N. minima* GRUNOW, *N. seminulum* GRUNOW and *Nitzschia palea* (KÜTZING) W. SMITH decreased the most (about 4% for each taxon). The relative abundance of *Gomphonema parvulum* (KÜTZING) KÜTZING remained constant (7%), whereas *Fragilaria ulna* (NITZSCH) LANGE-BERTALOT became more abundant at the end of the ditch (Tab. 1). The less pollution-resistant group of species (= tolerant up to α-mesosaprobic) reached peak values at station 4, remaining stable between stations 3 to 6 (48–56%). This group was mainly represented by *Melosira varians* AGARDH, *Achnanthes lanceolata* ssp. *lanceolata* (BRÉBISSON) GRUNOW and ssp. *frequentissima* LANGE-BERTALOT, and *Nitzschia amphibia* GRUNOW. The percentages of the two dominating groups (tolerant up to polysaprobic and α-mesosaprobic) between station 1 and 6 were not significantly different (ANOVA $p = 0.11, 0.63$).

The highest relative abundance of the more sensitive group (tolerant up to β-mesosaprobic), represented by *Fragilaria famelica* (KÜTZING) LANGE-BERTALOT, *F. capucina* (KÜTZING) LANGE-BERTALOT, *Achnanthes minutissima* KÜTZING, and *Eunotia bilunaris* (EHRENBERG) MILLS, was found at stations 3 and 6.

Based on LANGE-BERTALOT (1978, 1979), the first two stations after the treatment plant were classified as α-meso- to polysaprobic (III–IV), whereas the stations 3, 4, 5 and 6 were categorized as α-mesosaprobic (III). These assessments correlated well with the chemical analyses, which detected a quality level of III–IV at all stations [using BOD measures, based on LAWA criteria (1992)].

As organic loading was not correlated with changes in the diatom assemblages, we also tested the influence of inorganic nutrients. The only parameters that improved in conjunction with the diatom index were chloride and the nitrogen compounds, especially nitrate.

In order to investigate whether seasonal effects on diatom composition corresponded to changes in either chloride (Fig. 4) or nitrate concentrations (Fig. 5) we compared these parameters with the detailed diatom data, including each sampling day at station 1 and 6 (Fig. 6).

Figure 6. indicates differences throughout the year in the abundance ratio of the most pollution-resistant group (tolerant up to polysaprobic) to the group of more sensitive taxa (tolerant up to α-mesosaprobic). At the end of the ditch, the highest abundance of the most sensitive taxa and the lowest abundance of the pollution-resistant taxa were found in summer, indicating the best water quality at this time. In winter and early spring, however, the frequency of these two groups showed no obvious differences at stations 1 and 6. Nitrate concentrations appeared to show seasonal patterns, with nitrate removed within the ditch in spring and summer only (Fig. 5). The chloride concentrations continuously decreased throughout the ditch and did not appear to be influenced by seasonal factors (Fig. 4).

The saprobic index (SI) by ROTT *et al.* (1997) showed only small differences in the diatom populations along the ditch (Tab. 2). Station 3 had the highest mean value (2.7: α-mesosaprobic). The best water quality (2.3: α-β-mesosaprobic) was found at station 6, at the end of the ditch. Generally, the SI values at all stations indicated a lower pollution index (i.e. one level "better") than the pollution index of LANGE-BERTALOT (1978, 1979) as well as the chemical analysis of organic compounds.

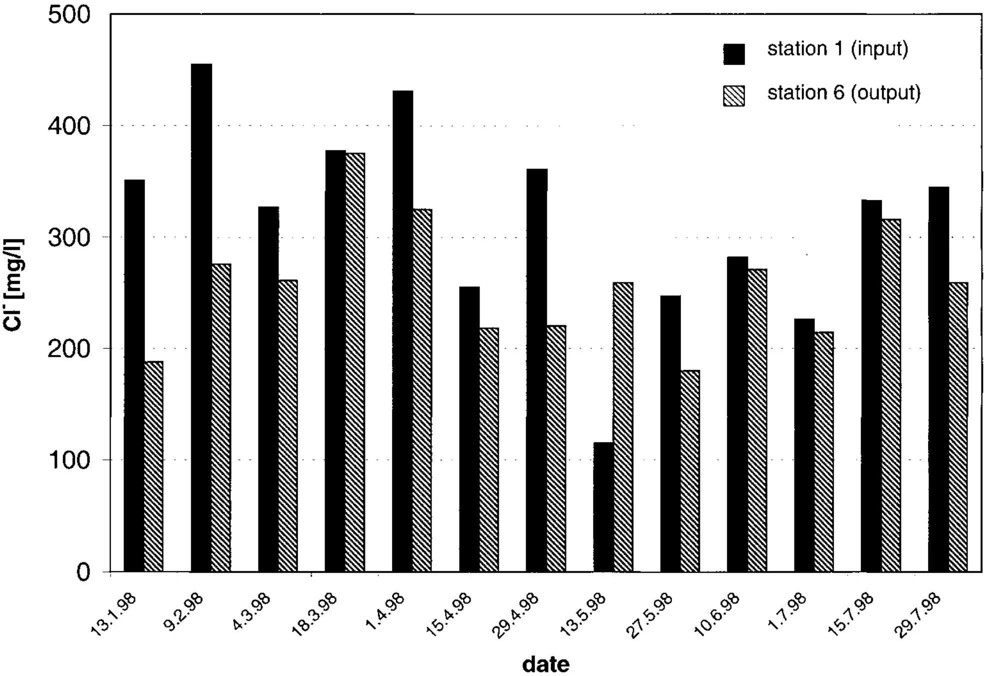

Figure 4. Chloride concentrations at the input (station 1) and the output (station 6) of the ditch.

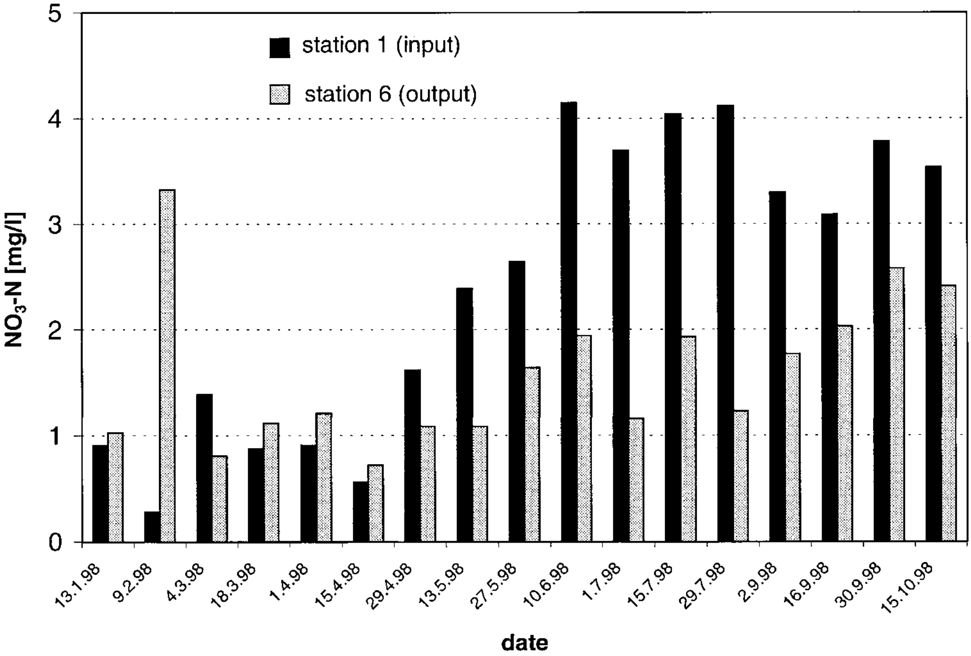

Figure 5. Nitrate concentrations at the input (station 1) and the output (station 6) of the ditch.

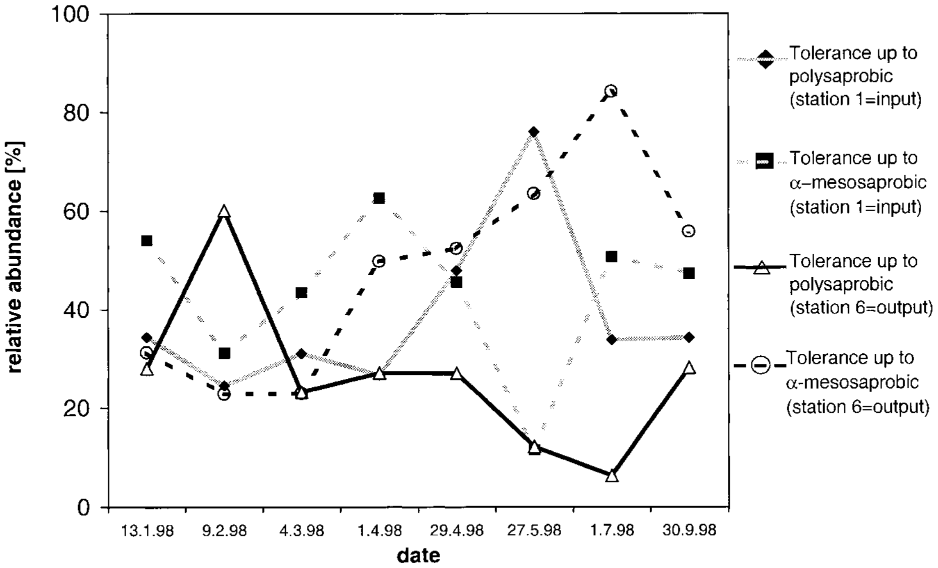

Figure 6. Seasonal changes in diatom community at the input (station 1) and putput (station 6) of the ditch. Relative abundance of the tolerance groups "tolerant up to polysaprob" and "tolerant up to α-mesosaprob".

Table 2. Saproby- and trophy-indication of the six stations follwing LANGE-BERTALOT (1978, 1979) (L.-B.), the SI (ROTT *et al.* 1997) TDI-P, TDI-NP (SCHIEFELE and KOHMANN 1993), TI_{Dia} (ROTT *et al.* 1999). Average index values and standard deviation (given in parentheses) from January to October 1998. Organic pollution levels: II–III = α-β-mesosaprob; III = α-mesosaprob; III–IV = α-mesosaprob-polysaprob. Trophy levels: eh = eutroph-hypertroph; e = eutroph, p = polytroph.

	Stat. 1	**Stat. 2**	**Stat. 3**	**Stat. 4**	**Stat. 5**	**Stat. 6**
L.-B.	III	III	III–IV	III–IV	III–IV	III–IV
SI	2.6 (0.18) II–III	2.4 (0.25) II–III	2.7 (0.16) III	2.6 (0.24) II–III	2.5 (0.26) II–III	2.3 (0.16) II–III
TDI-P	3.1 (0.49) e	3.1 (0.10) e	3.1 (0.21) e	3.2 (0.16) eh	3.2 (0.14) eh	3.1 (0.16) e
TDI-PN	3.1 (0.34) e	3.1 (0.06) e	3.1 (0.12) e	3.1 (0.10) e	3.1 (0.09) e	3.1 (0.06) e
TI_{Dia}	3.0 (0.45) p	2.9 (0.29) p	3.0 (0.26) p	3.1 (0.22) p	3.0 (0.23) p	3.1 (0.18) p

The Trophic Diatom Index following SCHIEFELE and KOHMANN (1993) correlated strongly with the chemical analyses. The measured mean orthophosphate concentration of 0.1 mg/l PO_4–P corresponds to an index value of 3.5, and the measured mean total phosphorus concentration (0.15 mg/l) classifies as 3.0. The estimated diatom index corresponds closely to these values, with an estimate of 3.1–3.2, which represents a polytrophic level. A better water quality was indicated by the TDI-PN. Ammonia and nitrate concentrations were 0.15 mg/l NH_4–N and 2 mg/l NO_3–N, corresponding to an index of 2.0. The TDI-PN reflected these conditions, with a continuous diatom-estimated index value of 3.1 at all stations indicating polytrophic to eutrophic conditions.

The TI_{Dia} (ROTT *et al.,* 1999) corresponded well with the other indices; all mean values of the stations were classified as polytrophic (Tab. 2).

In addition, calculations following the TDI of KELLY and WHITTON (1995) corresponded closely with the measured orthophosphate concentrations (Tab. 3). All stations were classified by the diatom index as level 4 (polytrophic), which refers to orthophosphate concentrations between 0.1 and 0.3 mg/l PO_4–P. The mean values of the chemical measures at each station corresponded to the diatom index, with estimates between 0.09 and 0.15 mg/l PO_4, showing no obvious deviations from this average over the study. Moreover, the proximity of those concentrations to the lower limit of the "polytrophic" level was reflected by index values between 4.0 and 4.5.

Table 3. Phosphate-cassification of the six stations following TDI (KELLY and WHITTON 1995) in comparison with chemical anayses.

	Stat. 1	**Stat. 2**	**Stat. 3**	**Stat. 4**	**Stat. 5**	**Stat. 6**
TDI	4.3 (0.23)	4.4 (0.28)	4.6 (0.25)	4.0 (0.29)	4.1 (0.27)	4.1 (0.32)
PO_4–P [mg/l] TDI-estimated			$\geq 0.1 < 0.3$			
PO_4–P [mg/l] measured	0.09	0.14	0.14	0.12	0.14	0.15

4. Discussion

Most of the applied diatom indices showed a high correlation with the chemical data. Using the saprobic zoning system of LANGE-BERTALOT (1978, 1979), the diatom composition broadly reflected the organic loading measured by chemical analyses. Therefore, the saprobic system appeared to be appropriate for the highly polluted water of our study, although REICHARDT (1991) noted that this system fails to estimate the quality of less polluted waters. An improvement of water quality within the ditch was indicated by the decrease of the most pollution resistant diatom group, but this pattern was not observed in the estimates in organic pollution, neither was this statistically proven. ANOVA resulted in non-significant p-values, perhaps resulting from the high seasonal variability (e.g. the abundance of the group tolerant up to polysaprobic varied between 6.3% in July and 60.1% in February) and the small number of the available data (eight sampling dates). However, the diatom groups of saprobic tolerance showed seasonal changes reflecting similar changes in nitrate concentrations. Therefore, we suggest that this index, in addition to organic factors, also incorporates differences in a trophic parameter such as nitrate. One may argue that nitrate could not influence the diatom assemblage because of the high N/P-ratio suggesting that nitrogen was not a limiting factor here. Further study is needed to clarify the effects of nitrate on diatoms.

The trophic diatom indices were reasonably well correlated with the inorganic compounds. The TDI-P (SCHIEFELE and KOHMANN, 1993) characterized the investigated water as "polytrophic" [as did the TDI of KELLY and WHITTON (1995) and the TI_{Dia} by ROTT *et al.* (1999)]. These results were validated by the accompanying chemical analyses. A better water quality was indicated by the TDI-PN, supporting SCHIEFELE and KOHMANN's (1993) conclusions that this latter index may underestimate pollution levels. Nonetheless, the decrease of average nitrate concentrations within the ditch from 2.4 to 1.6 mg/l could not be identified with this method. An index value of 2.0 encompasses a wide range of nitrate concentrations (2.0 to 2.6 mg/l), which may explain the lack of sensitivity.

The SI_{Dia} (ROTT *et al.*, 1997) generally underestimated the organic pollution. The source of these differences can be found in the characterization of the dominant taxa *Achnanthes lanceolata* spp., *Gomphonema parvulum* and *Melosira varians*; they represent the majority of the calculation and are here classified one level lower than in the index of LANGE-BERTALOT (1978, 1979). The result is the classification of the ditch by this diatom index into the saproby levels II–III (α-β-mesosaprobic) or III (α-mesosaprobic), which complies with a BOD of 4–7 mg/l or 7–13 mg/l, respectively. In contrast, the chemical analyses estimated mean BOD values of 17–18 mg/l at all sampling stations. Further tests of this index would be useful before application for monitoring organic pollution of running waters.

As discussed above, practicability is the criterion for the widespread use of diatom indices in water quality monitoring programs. The TDI of KELLY and WHITTON (1995) offers a good compromise between the exact estimation of trophic parameters and the need to simplify the practical (especially the taxonomic) work. However, the indices using diatoms at the species level may present a opportunity for assessing the trophic status in a more precise manner. Nevertheless, KELLY *et al.* (1995) found a lower correlation between the TDI-P and phosphate than between phosphate and the Generic Diatom Index (GDI, RUMEAU and COSTE, 1988), suggesting that the TDI-P is less effective than other species-based indices.

Overall, we found only a few parallels between our results and those of FESEL (1984, Tab. 1), who correlated diatom species abundances to several limnological parameters. Only *Nitzschia amphibia* and *Navicula seminulum,* which FESEL (1984) described as being correlated positively with high nitrate concentrations, decreased in abundance as nitrate decreased. For the other dominant species in our study (e.g. *Melosira varians, Navicula veneta, Fragilaria famelica*), he provided no suggestions concerning nitrate.

Our results seem to reflect the integration of complex environmental relationships, an advantage of using bioindication versus chemical analyses. We showed that monitoring water quality based on the index of LANGE-BERTALOT (1978, 1979) might not be explained fully by parallel measurements of organic pollution (e.g. BOD or TOC). The difficulty in separating the effects of saproby and trophy on diatoms at high levels of pollution has often been discussed (ELSTER, 1962; ENGELBERG, 1987; KELLY and WHITTON, 1995; KELLY, 1998). High organic pollution is always accompanied by elevated nutrient concentrations because of decomposition processes. For this reason, species living in highly organic waters are often also indicators of high nutrient loading, as a multitude of factors determine the optimal conditions for a taxon.

KELLY and WHITTON (1995) and KELLY (1998) proposed to calculate the total percentage of valves of taxa characteristic of organically polluted water in order to complement the interpretation of the TDI results. At all sites sampled for this study, the proportion of taxa tolerant to organic pollution exceeded 61% if all those taxa described as being tolerant up to polysaprobic and up to α-mesosaprobic (LANGE-BERTALOT, 1978) were included. KELLY and WHITTON (1995) suggested that such results are not only induced by the phosphorus concentration but also by the presence of organic matter in the water body. Many taxa that indicate a high trophic status (TDI 4 or 5) also tolerate considerable organic pollution (e.g. *Achnanthes lanceolata, Gomphonema parvulum, Nitzschia amphibia*). Thus, we cannot be certain that the high correlation between TDI and the phosphate data solely reflects trophic conditions. This could only be confirmed through application in a eutrophic, but less organically polluted system.

Several authors (CHOLNOKY, 1968; LANGE-BERTALOT, 1978; SCHARF, 1984; FESEL, 1984) have suggested that certain diatom species feed on organic matter, as these species are dominant in highly organic loaded waters, e.g. in wastewater treatment plants. Whether these diatoms react directly to the organic loading (i.e. by being heterotrophic), or whether they compete successfully under other challenging conditions related to strong organic pollution (toxic concentrations of ammonia or low oxygen saturation) remains to be determined. We found some "heterotrophic" forms in our samples, for example *Nitzschia amphibia*. This species reached the highest average abundance (7.2%) at station 1, directly at the plant effluent, and decreased significantly at the following stations along the ditch. There was no considerable content of TOC and DOC in the plant effluent which could have provided an abundant supply for heterotrophic nutrition. However, the samples at station 1 were obtained from *Phragmites* stems of the preceding year, which were decomposing during the research period and could be a source of organic material for the epiphytic community.

In conclusion, our results indicate that a saprobic index such as the zoning system of LANGE-BERTALOT yields good results at high levels of organic pollution. Trophic indices, however, seem to accurately estimate the nutrient loading of waters from oligo- to polysaprobic levels. Our results support the conclusions of HOFMANN (1994), who suggested that the best method for monitoring freshwater systems by diatoms is the combined application of saproby- and trophy-indicating systems.

5. Acknowledgements

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