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The use of benthic diatoms in estimating water quality of variously polluted rivers

Ewelina Szczepocka[1], Bogusław Szulc[2]

Department of Algology and Mycology, University of Łódź
ul. 12/16 Banacha, 90-237 Łódź, Poland

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Abstract

Two rivers situated in Central Poland, the Bzura and the Pilica, were selected for analysis of their water quality using benthic diatom species as indicators. The Bzura River has previously been strongly contaminated with organic pollutants, while the Pilica River has been classified as having good water quality. Samples were collected from nine sites along the Bzura in April 2003 and seven sites along the Pilica in April 2006. The main aims of the study were to determine the dominant diatom species present in the rivers and to assess their usefulness as biological indicators. Water quality of the rivers was estimated on the basis of the SPI - Specific Pollution sensitivity Index (CEMAGREF 1982) and the GDI - Generic Diatom Index (Coste, Ayphassorho 1991) while trophic status was estimated using TDI - Trophic Diatom Index (Kelly, Whitton 1995).

[1] *evelina@biol.uni.lodz.pl*
[2] *ghijk@wp.pl*

Indices determining saprobic water pollution (SPI, GDI) indicated water quality of class III and IV for the Bzura River and class II and III for the Pilica River. The trophic status determined on the basis of the TDI index revealed the Bzura water to be classified in the eutrophic-to-hypertrophic zone and that of the Pilica River to the oligo-mesotrophic-to-eutrophic zone.

The diatom taxa that dominated in the Bzura River were species that are generally considered to be tolerant and resistant with respect to organic water pollution, including: *Cyclotella meneghiniana* Kützing, *Gomphonema parvulum* (Kützing) Kützing, *Nitzschia palea* (Kützing) W. Smith, *Nitzschia paleacea* Grunow, *Sellaphora pupula* (Kützing) Mereschkovsky, *Stephanodiscus hantzschii* Grunow, *Ulnaria ulna* (Nitzsch) Compere. In the Pilica River diatoms from groups that are sensitive and tolerant to organic pollution were seen to dominate, such as: *Achnanthidium minutissimum* (Kützing) Czarnecki, *Aulacoseira granulata* (Ehrenberg) Simonsen, *Cocconeis neodiminuta* Krammer, *Cocconeis placentula* Ehrenberg, *Cocconeis placuntula* var. *lineata* (Ehrenberg) Grunow, *Cyclotella radiosa* (Grunow) Lemmermann, *Fragilaria crotonensis* Kitton, *Geissleria decussis* (Øestrup) Lange-Bertalot et Metzeltin, *Melosira varians* Agardh, *Navicula reichardtiana* Lange-Bertalot, *Planothidium frequentissimum* (Lange-Bertalot) Lange-Bertalot, *Pseudostaurosira brevistriata* (Grunow) Williams & Round, *Rhoicosphenia abbreviata* (Agardh) Lange-Bertalot and *Staurosira pinnata* Ehrenberg.

INTRODUCTION

Diatoms are frequently used as bioindicators for water quality assessment. Knoweledge of their ecology enables exploitation of a number of species as indicators of water temperature, water velocity, pH, pollutants, nutrient content and overall assessments of water quality and the ecological state of aquatic ecosystems (Rakowska 2001). The computer program OMNIDIA (Lecointe et al. 1993), which utilizes indicator features of diatoms for water quality assessment purposes, was developed in France in 1993. The OMNIDIA software has been accepted by the European Union and is increasingly widely used in Europe, including Poland (Kwadrans et al. 1999; Bogaczewicz-Adamczyk, Koźlarska 1999; Rakowska 2001; Bogaczewicz-Adamczyk et al. 2001; Bogaczewicz-Adamczyk, Dziengo 2003; Zgrundo, Bogaczewicz-Adamczyk 2004; Żelazowski et al. 2004; Dumnicka et al. 2006).

Investigations into the use of diatom indices for the assessment of water quality in lowland rivers of Central Poland were initiated by Rakowska (2001, 2005, 2007).

The Water Framework Directive 2000/60/EC (WFD), which was accepted by the European Parliament and the Council of the European Union in 2000, is concerned with problems of ecology and water protection. According to the Water Framework Directive assessment of the ecological state of surface waters should be carried out on the basis of analysis of the intrinsic biota. Organisms that are employed for this purpose include invertebrates, fish, macrophytes and diatoms.

The aim of this study was to verify the usefulness of diatom indices for water quality assessments of two lowland rivers in Central Poland, the Bzura

River and the Pilica River, which have different degrees of organic pollution. To this end the dominant diatom taxa characteristic of these rivers were determined.

STUDY AREA

Investigations were carried out in two lowland rivers flowing through Central Poland (Fig. 1). The Bzura River is a left-side tributary of the Vistula River, which flows across the Łódzkie and Mazowieckie Voivodeships. It is a typical lowland river, 166.2 km long, with its sources in the town of Łódź and

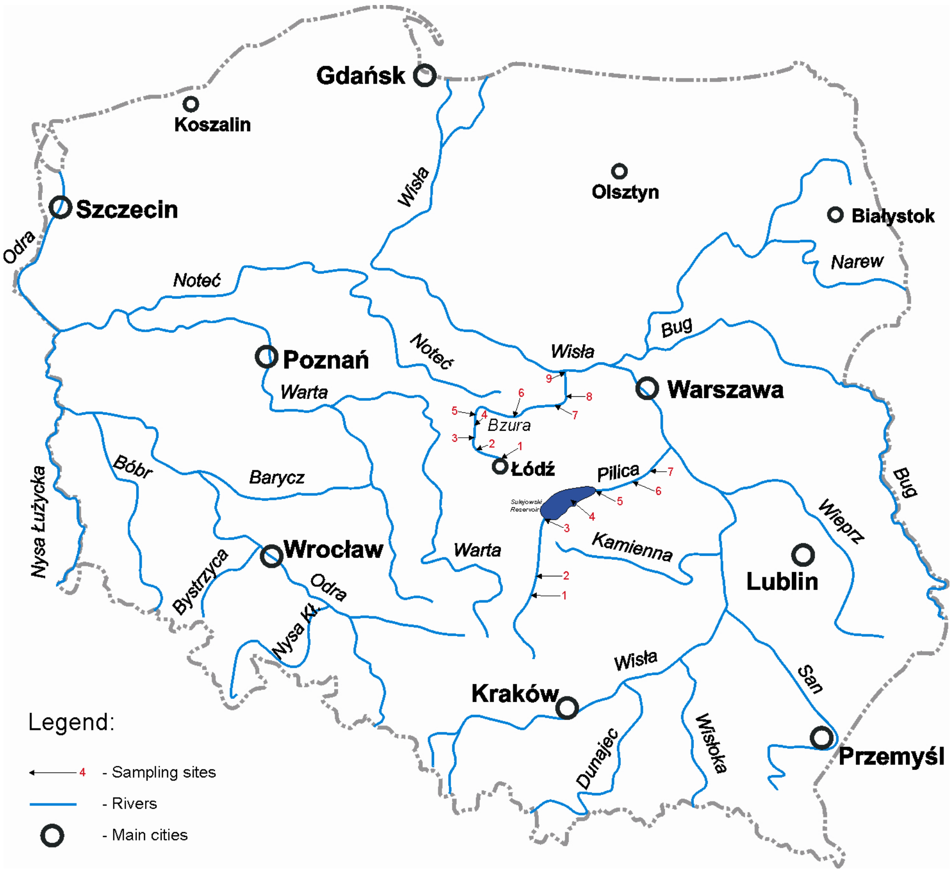

Fig. 1. Distribution of sample sites along the investigated rivers.

outflows at the town of Wyszogród. Nine sampling sites were established along the Bzura River: site 1 – Łódź-Arturówek, site 2 – Zgierz-Krzywie (upstream of the town of Zgierz), site 3 – Aniołów (downstream of the town of Zgierz), site 4 – Parzyce (downstream of the town of Ozorków), site 5 – Witaszewice (downstream of the town of Łęczyca), site 6 – Orłów, site 7 – Łowicz (upstream of the town of Łowicz), site 8 – Sochaczew (upstream of the town of Sochaczew), site 9 – Wyszogród (Table 1). From the 1960s until 1996 the Bzura River was one of the most polluted rivers in Poland with a huge amount of pollution introduced in the area of the river source, where the "Boruta" textile dye works (Zgierz) were located. Further downstream, unpurified sewage from 25 municipalities in the Bzura catchment flowed into the river. However, since 1998 an active decision to reduce the amount of pollution in the river has been pursued, but which has not completely freed the Bzura from pollution inputs. The river still receives domestic and industrial sewage, which are not always well purified and which negatively impact on the water quality and inhabiting organisms.

Table 1

Chemical water parameters at the investigated sites.

Site	Date	BOD_5	Dissolved oxygen	Ammonia nitrogen	Total nitrogen	Phosphates	Total phosphorus
	(April)	O_2 (mg l^{-1})	O_2 (mg l^{-1})	N (mg l^{-1})	N (mg l^{-1})	PO_4 (mg l^{-1})	P (mg l^{-1})
Bzura River							
Łódź-Arturówek	2003	-	-	-	-	-	-
Krzywie-upstream of Zgierz	2003	3.4	11.6	0.21	3.34	0.20	0.16
Aniołów-downstream of Zgierz	2003	5.8	9.8	0.25	8.12	1.19	0.71
Parzyce-downstream of Ozorków	2003	5.5	11.4	0.88	5.98	0.19	0.36
Witaszewice-downstream of Łęczyca	2003	4.4	10.6	0.93	7.15	0.14	0.18
Orłów	2003	3.3	9.7	0.39	8.91	0.14	0.18
Łowicz	2003	5.4	11.0	0.53	7.32	0.14	0.17
Sochaczew	2003	-	-	-	-	-	-
Wyszogród	2003	6.4	9.9	0.79	4.84	0.56	1.29
Pilica River							
Chałupy	2006	3.3	9.0	0.03	4.2	0.16	0.08
Przedbórz	2006	2.8	9.0	0.05	3.8	0.26	0.17
Sulejów	2006	2.9	9.5	0.05	4.0	0.14	0.09
Bronisławów	2006	2.4	9.8	0.12	5.42	0.12	0.09
Smardzewice	2006	2.1	9.7	0.13	5.44	0.12	0.09
Spała	2006	2.6	7.2	0.12	7.0	0.20	0.12
Inowłódz	2006	2.5	7.2	0.10	3.8	0.15	0.11

The Pilica River, which is 342 km long, is the longest inflow of the Vistula. The springs of the Pilica are located in the Kraków-Częstochowa Upland, close to the village of Wola Kącikowa. The Pilica enters the Vistula at km 457 of the river's course, near the village of Potycz. The water catchment area of the Pilica is over 9,252 km^2. Seven sampling sites were established along the Pilica River: site 1 – Chałupy, site 2 – Przedbórz, site 3 – Sulejów, site 4 – Bronisławów, site 5 – Smardzewice, site 6 – Spała, site 7 – Inowłódz (Table 1). The Pilica is regarded as a relatively unpolluted river, with water of purity class III.

The study rivers are monitored for water quality by the Voivodeship Inspectorates of Environmental Protection in the towns of Łódź and Warszawa, at sites from which diatoms were also collected for this study (Table 1).

MATERIALS AND METHODS

Samples were collected from the nine sites along the Bzura River in April 2003 and from the seven sites along the Pilica River in April 2006. Benthic sediments were collected for diatom analysis using a single volume pipette (25 cm^3) and a rubber bulb. The collected material (40 ml per sample) was poured into opaque bottles and preserved in 4% formalin.

The methods applied by Rakowska (2001) were used to assess qualitative and quantitative sample composition: percentages were calculated on the basis of 400 frustules (Cholnoky 1968) and dominant (over 5%) and subdominant (2-5%) species were distinguished (Trojan 1978).

Diatom taxa were identified following Krammer and Lange-Bertalot's (1986, 1988, 1991a, b) and Lange-Bertalot's studies (2000, 2001, 2002, 2003). In addition, diatom indices were calculated using the OMNIDIA program (Lacointe et al. 1993, Version 4), which provides a rapid calculation of 13 indices of trophic condition and saprobity (Rakowska 2001).

Water quality assessments were carried out using SPI (Specific Pollution sensitivity Index; CEMAGREF 1982) and GDI (Generic Diatom Index; Coste, Ayphassorho 1991). Trophic status was estimated using TDI (Trophic Diatom Index; Kelly, Whitton 1995). The SPI and GDI indices assign values in the range 1-20, with higher values of the index indicating better water quality. The TDI assigns values in the range 1-100 and has a reverse relationship; the higher value of the index the higher the trophic status and the worse the water quality. The values of the indices were juxtaposed with respective water quality classes, with a precise determination of water quality according to the Decree of the Minister of the Environment from 11 Feb 2004, Law gazette No. 32, pos. 284, and a respective ecological status. Consequently, a given range of the TDI index indicates a respective trophic status (Table 2).

Table 2

Ranges of SPI, GDI and TDI indices and respective water qualities (after Dumnicka et al. 2006, modified).

SPI	GDI	Water quality*	Water Quality Class*	Ecological status	TDI	Trophic status
> 17	> 17	very good	I	high	< 35	oligotrophic
15 – 17	14 – 17	good	II	good	35 – 50	oligo/mesotrophic
12 – 15	11 – 14	satisfactory	III	average	50 – 60	mesotrophic
8 – 12	8 – 11	unsatisfactory	IV	mediocre	60 – 75	eutrophic
< 8	< 8	bad	V	bad	> 75	hypertrophic

* according to the Decree of the Minister of the Environment from 11 Feb 2004, Dz. U. No 32, pos. 284.

RESULTS

The dominant diatom species in the Bzura River were *Cocconeis placentula* var. *lineata* (Ehrenberg) Van Heurck and *Planothidium rostratum* (Øestrup) Lange-Bertalot, which are considered to be sensitive to organic pollution, *Melorisa varians* Agardh, *Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin and Witkowski, and *Planothidium frequentissimum* (Lange-Bertalot) Lange-Bertalot, which are in the tolerant group, and *Cyclotella meneghiniana* Kutzing, *Gomphonema parulum* (Kützing) Kützing, *Nitzschia palea* (Kützing) W. Smith, *Nitzschia paleacea* Grunow, *Sellaphora pupula* (Kützing) Mereschkowsky, *Stephanodiscus hantzschii* Grunow, and *Ulnaria ulna* (Nitsch) Compere, which are in the resistant group.

The Bzura River was classified as water quality class III-IV on the basis of SPI, class III on the basis of GDI and class IV-V on the basis of TDI (Table 3).

In the Pilica River species from the sensitive group primarily dominated during the period of investigation, including *Achnanthidium minutissimum* (Kutzing) Czarnecki, *Cocconeis neodiminuta* Krammer, *Cocconeis placentula* Ehrenberg, *Cocconeis placentula* var. *lineata* (Ehrenberg) Grunow, *Fragilaria crotonensis* Kitton, *Geissleria decussis* (Øestrup) Lange-Bertalot et Metzeltin, *Melosira varians* Agardh, *Navicula reichardtiana* Lange-Bertalot, *Puncticulata radiosa* (Lemmermann) Håkansson, *Psuedostaurosira brevistriata* (Grunow in Van Heurck) Williams & Round, *Rhoicosphenia abbreviata* (Agardh) Lange-Bertalot, *Staurosira pinnata* (Ehrenberg). Representatives of the tolerant group seen were *Aulacoseira granulata* (Ehrenberg) Simonsen, *Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot and *Planothidium frequentissimum* (Lange-Bertalot) Lange-Bertalot, and from the resistant group *Gomphonema*

Table 3

Classification of water quality in the Bzura River calculated using the SPI, GDI and TDI (with water quality class in brackets).

Sites	SPI	GDI	TDI
	29 Apr 2003	29 Apr 2003	29 Apr 2003
Łódź-Arturówek	10.9 (IV)	12.0 (III)	67.4 (IV)
Krzywie-upstream of Zgierz	12.7 (III)	12.2 (III)	67.0 (IV)
Aniołów-downstream of Zgierz	10.3 (IV)	12.1 (III)	90.6 (V)
Parzyce-downstream of Ozorków	13.4 (III)	13.0 (III)	77.6 (V)
Witaszewice-downstream of Łęczyca	12.5 (III)	13.0 (III)	76.0 (V)
Orłów	13.0 (III)	13.2 (III)	69.1 (IV)
Łowicz	13.5 (III)	13.2 (III)	73.3 (IV)
Sochaczew-upstream of Sochaczew	12.6 (III)	12.8 (III)	76.1 (V)
Wyszogród	11.3 (IV)	12.5 (III)	70.3 (IV)

parvulum (Kützing) Kützing, *Nitzschia palea* (Kützing) W. Smith and *Stephanodiscus hantzschii* Grunow.

The Pilica River was classified in water quality class II-III on the basis of SPI, class II-III on the basis of GDI, and in class II-IV on the basis of TDI (Table 4).

Table 4

Classification of water quality in the Pilica River calculated using SPI, GDI and TDI (with water quality class in brackets).

Sites	SPI	GDI	TDI
	29 Apr 2006	29 Apr 2006	29 Apr 2006
Chałupy	15.3 (II)	13.8 (III)	58.7 (III)
Przedbórz	14.3 (III)	12.8 (III)	62.3 (IV)
Sulejów	15.7 (II)	14.3 (II)	44.2 (II)
Bronisławów	17.6 (I)	16.1 (II)	36.2 (II)
Smardzewice	14.1 (III)	12.9 (III)	69.6 (IV)
Spała	14.3 (III)	13.0 (III)	66.0 (IV)
Inowłódz	14.6 (II)	12.8 (III)	65.4 (IV)

On the basis of the diatom indices that determine organic water pollution (i.e. SPI and GDI) the water quality of the Bzura was class III to IV, while that of the Pilica River was class I to III. On the basis of the index determining trophic state (TDI) the Bzura was indicated as class IV to V and the Pilica River as class II to IV.

DISCUSSION

Assessment of water quality in the Bzura and Pilica Rivers was based on three diatom indices, SPI (CEMAGREF 1982), GDI (Coste, Ayphassorho 1991), and TDI (Kelly, Whitton 1995). These indices were selected since 100% of the diatom taxa have been incorporated into the OMNIDIA database. The results indicate marked differences in water quality between the two rivers, with the water quality of the Bzura at least one class lower than that of the Pilica River in all cases. The rivers also differ in terms of their chemical parameters, which are presented in the Environmental reports prepared by the Voivodeship Inspectorates of Environmental Protection. Lower values of BOD_5, nitrate concentrations and phosphate concentrations have been observed in the Pilica, while values of dissolved oxygen are higher in the Bzura. SPI and GDI indices have already been applied to assess the quality of the Odra, Vistula and Raba rivers in southern Poland, with good results (Kawecka et al. 1996, Kawecka et al. 1999, Kwadrans et al. 1999). Further, SPI and GDI are among the indices proposed for the assessment of the waters of the Gulf of Gdańsk (Bogaczewicz-Adamczyk, Dziengo 2003; Zgrundo 2004). In the case of lowland rivers SPI has been proposed as the best for determining water quality class, while TDI indicates a lower water quality class than either SPI or GDI.

CONCLUSIONS

Investigations in which diatom indices are used for the assessment of water quality of lowland rivers are being undertaken and require further analyses as to their efficacy. Pilot analyses indicate that SPI is the best index for estimating saprobic water pollution. The TDI, which does not incorporate the centric diatoms that are frequently dominant in lowland rivers, does not produce truly representational assessments of the trophic state of waters.

Physico-chemical analyses do not accurately reflect the actual condition of water quality, as they may be affected by pollution that is introduced just before sampling. It seems that biological analyses are a more reliable source of information because intermittent pollution has a less pronounced affect on indicator organism communities, and thus does not significantly affect biological water quality assessments.

The results presented reinforce the important and useful exploitation of diatoms as bioindicators, their role in the assessment of ecological states of surface waters being an important element of the implementation of the Framework Water Directive.

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