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Diatoms in the biological assessment of the ecological state of waters using the Czarna Staszowska River as an example

by

Ewelina Szczepocka*,
Barbara Rakowska

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

Abstract

The object of the present research was the Czarna Staszowska River, which is located in south-eastern Poland and which is a left tributary of the upper Vistula River. The length of the river is 61 km and its sources are situated in the Świętokrzyskie Mountains. The river flows across an area covered by Mesozoic rocks, mostly carbonate and sulfate ones. The upper and middle course of the river is of natural character, while increased pollution occurs downstream of the Chańcza Reservoir.

In the present study, the water quality of the Czarna Staszowska is investigated in the pure and polluted sections using diatom indices, such as IO – Diatom Index, IPS – Specific Pollution Sensitivity Index, GDI – Generic Diatom Index and TDI – Trophic Diatom Index. In the four river sections distinguished on the basis of the hydrology and the degree of water pollution, the occurrence of different indicator species was determined in the respective diatom assemblages. Indicator species were determined, i.e. characteristic of oligosaprobic and mesosaprobic, limestone and silicon-rich waters. Also taxa indicating an increased trophic status of the river (occurring in its polluted sections) were identified.

Key words: Bacillariophyta, rivers, diatom indices, indicator diatoms

* Corresponding author: *evelina@biol.uni.lodz.pl*

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Introduction

At present benthic diatoms are the basic tool of water quality assessment in Poland. Research on the bioindicator values of diatoms is considered necessary worldwide (Kelly et al. 2008; Round 2004; Potapova et al. 2004; Potapova, Charles 2005, 2007; Ector, Rimet 2005; Tison et al. 2005; Bathurst et al. 2010; Blanco et al. 2012; Venkatachalapathy et al. 2013). For many years diatom indices have been used to assess the ecological state of waters in Europe and other parts of the world (France – Prygiel 2002, Great Britain – Kelly et al. 1995, Kelly 2003, Kelly et al. 2008, Finland – Eloranta, Soininen 2002, in Africa – Harding et al. 2005, Rey et al. 2004, Taylor et al. 2007). Investigations of diatom indices, which concern the verification of the lists of diatom taxa that are indicators of various types of rivers, take into account hydrological and physicochemical conditions.

The study area was the Czarna Staszowska River, in south-eastern Poland, which is the left tributary of the Vistula (Wisła). This river flows through the physiographical region named the Połaniec Hollow and is part of the Nida Hollow. The geologic structure of the river's valley is characterized by the occurrence of carbonate and sulfate rocks. This specific structure of the area has affected the development of diatom communities in the river, which are typical of waters rich in calcium. Before the present research the river was not an object of algological studies, and some taxa till then not reported from Poland, as well as rare species have now been determined.

The aim of the study was the biological assessment of water quality in the river on the basis of qualitative and quantitative composition of diatom assemblages using diatom indices, such as IO – Diatom Index (Picińska-Fałtynowicz et al. 2006), IPS – Specific Pollution Sensitivity Index (CEMAGREF 1982), GDI – Generic Diatom Index (Coste, Ayphassorho 1991) and TDI –Trophic Diatom Index (Kelly, Whitton 1995). Indicator taxa, i.e. characteristic of oligosaprobic and mesosaprobic, calcareous and silica-rich waters, were distinguished. Also taxa typical for an increased trophic status of the river (occurring in its polluted section) were distinguished.

Study area

The Czarna Staszowska River flows in south-eastern Poland. It is a left tributary of the Vistula (Wisła) River, outflowing to the latter at 222 km of its course. The length of the river is 61 km, and its catchment area is 1358.6 km^2. The spring section is in the Świętokrzyskie Mountains at 302-408 m a.s.l., where two streams, the right from the Białe Ługi peat-bog reserve, and the left one from the Cisów Forest Reserve, have their origin. After 9 km, the two streams merge at the Holendry village (250 m a.s.l.) to form one river which flows through the villages and towns of Drogowle, Raków, Kurozwęki, Staszów, and Rudniki, and outflows to the Vistula downstream of the Połaniec town. The large man-made Chańcza Reservoir is located at the 34th km of the river's course. The river mouth is at 150 m a.s.l., and its slope is 1.5% to 2%, while the average discharge is 5.0 m^3 s^{-1} (Dynowska 1986, Zieliński 2013). The bottom of the river is sandy, gravely-stony, and muddy at the banks. The banks are high, usually overgrown with alders and pine forest.

The tributaries of the Czarna Staszowska River are the right-bank Wschodnia River and the left-bank rivers: Łukawka, Łagownica and Desta.

The Czarna Staszowska River flows through the physiographical region named the Połaniec Hollow and is part of the Nida Hollow. The geographic structure of the river's valley is related to the occurrence of carbonate and sulfate rocks. The area of the valley was formed in the course of the larmic phase of the alpine orogenesis at the end of the Cretaceous and at the beginning of the Tertiary Period. The older Tertiary Period is represented by loam, mudstones, sandstones, quartz sandstones (containing 95% of SiO_2), limestone, sands. Sediments of chemical origin, such as gypsum, anhydrites and sulfate limestones occur in these formations. Gypsum layers may be up to 55 m thick and are still exploited (close to the Borków village), while sulfur was exploited in the past near the Grzybów village. In the area of the Połaniec Hollow, natural karst phenomena occur, particularly in the vicinity of the Staszów town (Zieliński 2013).

Four specific sections may be distinguished in the river: section one – the source part, between the Holendry village and the Drogowle village, section two – the middle part, from the Drogowle village to the Raków village, section three – downstream of the Chańcza Reservoir, section four – the outflow part, which is strongly polluted by the sewage from the villages and towns of Staszów, Grzybów, Rytwiany, Rudniki and Połaniec. In each of the sections, microbenthos sampling sites were established.

Five sampling sites were distinguished in the given sections of the river: section one (the source part) – the Smyków village (site 1), section two (the middle part) – the Drogowle village (site 2) and the Raków village (site 3), section three – downstream of the Chańcza Reservoir (site 4), section four (the outflow part) – the Rudniki village (site 5) (Fig. 1).

Materials and methods

Samples were collected in 2004 (August) and 2013 (August and November). Diatom material was sampled from the river bottom, using a glass pipette, in 100 ml containers, and then preserved in 4% formalin (PN-EN ISO 5667-6: 2003). The collected epipsammon was treated with a mixture of a sulfuric and chromic acids, which destroys the protoplasm of cells. Empty diatom valves were fixed in Naphrax® and permanent slides were prepared from them. In each slide, 400 valves were counted, and in this way the lists of percentage contribution of each taxon were compiled (Cholnoky 1968). Dominant, subdominant, and accompanying species were distinguished (Rakowska 2001).

The taxonomic identification of diatom assemblages was carried out using the identification keys published by Hofmann et al. (2011), Krammer, Lange-Bertalot (1986, 1988, 1991a, b), Krammer (2000, 2002, 2003), Lange-Bertalot (2001) and Werum, Lange-Bertalot (2004). Results of physicochemical analyses from 2012 come from a Report of the Voivodeship Inspectorate of Environmental Protection in the Kielce town that was published in 2013 (annual means) (Table 1).

The assessment of the ecological state of the Czarna Staszowska River was carried out on the basis of diatom indices: IO – Diatom Index (Picińska-Fałtynowicz et al. 2006), IPS – Specific Pollution Sensitivity Index (CEMAGREF 1982), GDI – Generic Diatom Index (Coste, Ayphassorho 1991) and TDI – Trophic Diatom Index (Kelly, Whitton 1995). The IO

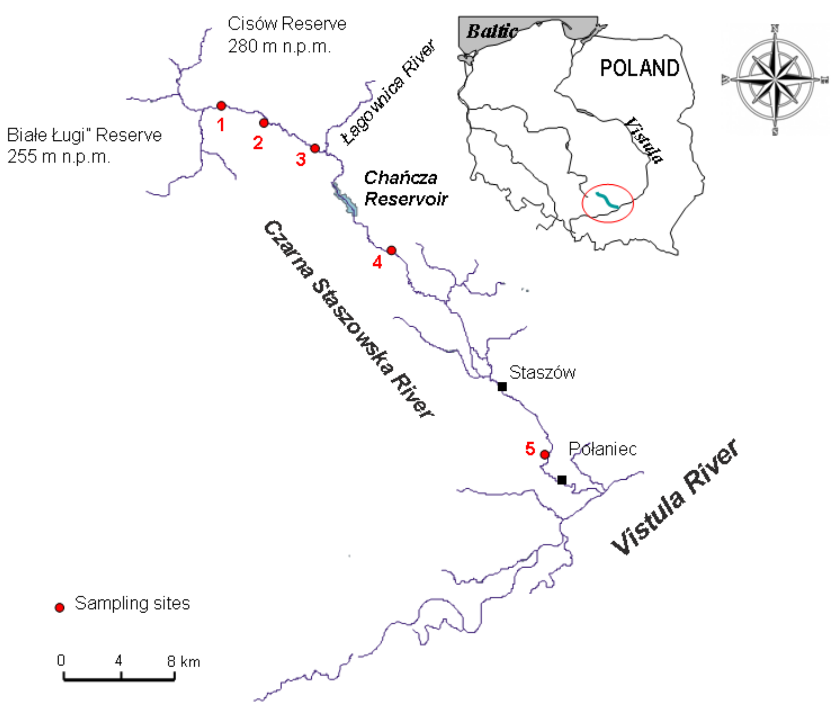

Figure 1

Map of the Czarna Staszowska River

index was calculated using a mathematical formula suitable for the specific type of river corresponding to the hydromorphology of the Czarna Staszowska River, while the IPS, GDI and TDI indices were calculated using the OMNIDIA 5.3 software. The ranges of the diatom indices and the ecological state indicated by the indices, together with a water quality class, were used for the IO index according to the regulation of the Minister of the Environment (OJ No 258, pos. 1549, from 2011), while for the IPS, GDI and TDI indices – after Dumnicka et al. (2006) (Table 2).

Results

The assessment of the ecological state of the Czarna Staszowska River's water on the basis of the IPS index indicated differences in the water quality between the investigated sites. The best water quality was determined at site 1 (water quality class II), i.e. the water was in a good ecological state. At sites 2, 3, and 4, the water was of quality class III – average state, while at site 5, the water was of the poorest quality (water quality class IV) – in poor ecological state. The GDI index differentiated the investigated sites in such a way that only water quality classes III and IV were determined (Table 3). The IO index indicated water quality class III, i.e. an average water quality, at all the investigated sites. The TDI index assessed the oligomesotrophic level at the first site, and the eutrophic level at the next sites (2, 3, 4, 5) (Table 3).

Four specific sections were distinguished in the Czarna Staszowska River and in each of the sections, characteristic diatom assemblages occurred with different indicator species whose autecological characteristics are presented on the basis of Bąk et al. (2012), Hofmann et al. (2011), Werum, Lange-Bertalot (2004). A total of 238 diatom taxa were identified.

In the source section (site 1), which was affected by the Białe Ługi peat-bog, taxa typical of dystrophic and oligotrophic waters, poor in electrolytes and rich

Table 1

Values of physical and chemical water parameters in the river sections from 2012

Water parameters	Units	The river section		
		Spring section (sites 1, 2)	Middle section (site 3)	Lower section (sites 4, 5)
Temperature	°C	9.0	10.5	11.8
pH		7.7	7.8	7.8
Conductivity 20°C	$\mu S\ cm^{-1}$	271	405	434
Dissolved oxygen (DO)	$mg\ O_2\ dm^{-3}$	10.0	10.0	10.0
BOD_5		1.6	1.9	2.6
$N\text{-}NH_3$	$mg\ dm^{-3}$	0.06	0.23	0.16
$N\text{-}NO_3$		1.5	2.0	1.4
Total N		2.146	2.783	2.375
$P\text{-}PO_4$		0.10	0.13	0.14
Total P	$mg\ P\ dm^{-3}$	0.08	0.13	0.15
Chlorides	$mg\ Cl\ dm^{-3}$	7	-	-
Calcium	$mg\ Ca\ dm^{-3}$	48	64	75
Magnesium	$mg\ Mg\ dm^{-3}$	4	10	7
Total hardness	$mg\ CaCO_3\ dm^{-3}$	135	202	214

Table 2

Ranges of IO, IPS, and GDI indices, and their respective Water Quality Classes, and ecological state of water (OJ No 258, pos. 1549 from 2011, Dumnicka et al. 2006, modified)

Water Quality Class	Ecological State	IO	IPS	GDI	TDI	Trophic State
I	Very good	> 0.70	>17	>17	< 35	oligotrophic
II	Good	0.50	15 – 17	14 – 17	35 – 50	oligomesotrophic
III	Moderate	0.30	12 – 15	11 – 14	50 – 60	mesotrophic
IV	Poor	0.15	12 – 8	11 – 8	60 – 75	eutrophic
V	Bad	< 0.15	< 8	< 8	> 75	hypertrophic

Table 3

Values of diatom indices, ecological state and water quality classes at studied sites of the Czarna Staszowska River

	site 1	site 2	site 3	site 4	site 5
	source Smyków	Drogowle	Raków	Kurozwęki downstream of the Chańcza Reservoir	outflow section Rudniki
IO	III moderate state	III moderate state	III moderate state	III moderate state	III moderate state
IPS	II good state	III moderate state	III moderate state	III moderate state	IV poor state
GDI	III moderate state	III moderate state	IV poor state	III moderate state	IV poor state
TDI	oligomesotrophic	eutrophic	eutrophic	eutrophic	eutrophic

in calcium and silicon, were identified. The following species were very abundant at the site: *Achnanthidium minutissimum* var. *jackii* (Rabenhorst) Lange-Bertalot (8%), *Caloneis silicula* (Ehrenberg) Cleve (12.0%) *C. falcifera* Lange-Bertalot (0.25%) (Fig. 2.11), *Eunotia bilunaris* (Ehrenberg) Schaarschmidt (4.7%), *E. implicata* Nörpel-Schempp, Alles & Lange-Bertalot (2.5%) (Fig. 2.2), *Entomoneis ornata* (Bailey) Reimer (0.5%) (Fig. 2.28), *Fragilaria bicapitata* A. Mayer (2.5%), *F. leptostauron* var. *dubia* (Grunow) Hustedt (4.0%), *Frustulia vulgaris* (Thwaites) De Tonii (2.5%), *Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski (7.5%), *Navicula cryptocephala* Kützing (5.0%) (Fig. 2.10), *N. radiosa* Kützing (8.0%), *N. tenelloides* Hustedt (2.0%), *Pinnularia borealis* Ehrenberg (2.5%), *Planothidium rostratum* (Østrup) Lange-Bertalot (4.0%), *Sellaphora americana* Ehrenberg (7.5%) (Fig. 2.21), *S. pupula* (Kützing) Mereschkowsky (3.7%), *Stauroneis kriegeri* Patrick (3.2%), *Staurosira construens* Ehrenberg (7.5%), *S. pinnata* Ehrenberg (8.5%), *Tabellaria flocculosa* (Roth) Kützing (4.0%) (Fig. 2.37, 38).

Taxa characteristic of this type of waters, but not occurring in large numbers, are represented by *Amphipleura pellucida* (Kützing) Kützing (Fig. 2.17) (silica waters, calcareous waters, poor in electrolytes), *Cavinula lapidosa* (Krasske) Lange-Bertalot (Fig. 2.5) (rare species, waters rich in silica), *Diadesmis contenta* (Grunow) D.G. Mann (silicate waters), *D. perpusilla* (Grunow) D.G. Mann (silicate waters), *Frustulia saxonica* Rabenhorst, *Gomphonema auritum* A. Braun ex Kützing (calcareous waters with silica), *G. exilissimum* (Grunow) Lange-Bertalot & Reichardt (silicate waters), *Luticola acidoclinata* Lange-Bertalot, *Navicula moskalii* Metzeltin, Witkowski & Lange-Bertalot (calcareous waters, silicate waters), *Nitzschia homburgensis* Lange-Bertalot (silicate waters), *N. bremensis* Hustedt (Fig. 2.34), *Placoneis hambergii* (Hustedt) Bruder (Fig. 2.36) (springs, peat-bogs), *P. paraelginensis* Lange-Bertalot, *Planothidium peragalli* (Brun & Hèribaud) Round & Bukhtiyarowa (Fig. 2.4), *Psammothidium bioretii* (Germain) Bukhtiyarowa & Round, *Rossithidium petersenii* (Hustedt) Aboal, Alvares-Cobelas, Cambra & Ector, *R. pussila* (Grunow) Round & Bukhtiyarowa, *Sellaphora laevissima* (Kützing) D.G. Mann, *S. mutatoides* Lange-Bertalot & Metzeltin (oligo-, calcareous waters) (Fig. 2.22), *Stauroneis agrestis* Petersen (springs), *S. kriegeri* Patrick (silicate waters), *S. leguminopsis* Lange-Bertalot & Krammer (Fig. 2.14). *S. parathermicola* Lange-Bertalot (Fig. 2.15), *S. prominula* (Grunow) Hustedt (Fig. 2.16), *S. silvahassiaca* Lange-Bertalot & Werum, *S. thermicola* (Petersen) Lund (silicate waters).

The genus *Eunotia*, which is an indicator taxon of waters with good ecological quality, as well as of oligotrophic and dystrophic waters, including those of springs and peat-bogs, was abundantly represented by the following species: *Eunotia bidens* Ehrenberg (Fig. 2.1), *E. bilunaris* (Ehrenberg) Schaarschmidt, *E. botuliformis* Wild, Nörpel & Lange-Bertalot, *E. formica* Ehrenberg (Fig. 2.3), *E. implicata* Nörpel-Schempp, Alles & Lange-Bertalot (Fig. 2.2), *E. incisa* Gregory, *E. pectinalis* (Kützing) Rabenhorst. The genus *Pinnularia* was also abundantly represented by the following species: *Pinnularia borealis* Ehrenberg, *P. brebissonii* (Kützing) Rabenhorst, *P. frequentis* Krammer (Fig. 2.44), *P. divergens* W. Smith (Fig. 2.43), *P. gibba* Ehrenberg, *P. marchica* IIka Schönfelder ex Krammer, *P. microstauron* (Ehrenberg) Cleve, *P. neomajor* Krammer, *P. nodosa* (Ehrenberg) W. Smith, *P. obscura* Krasske,

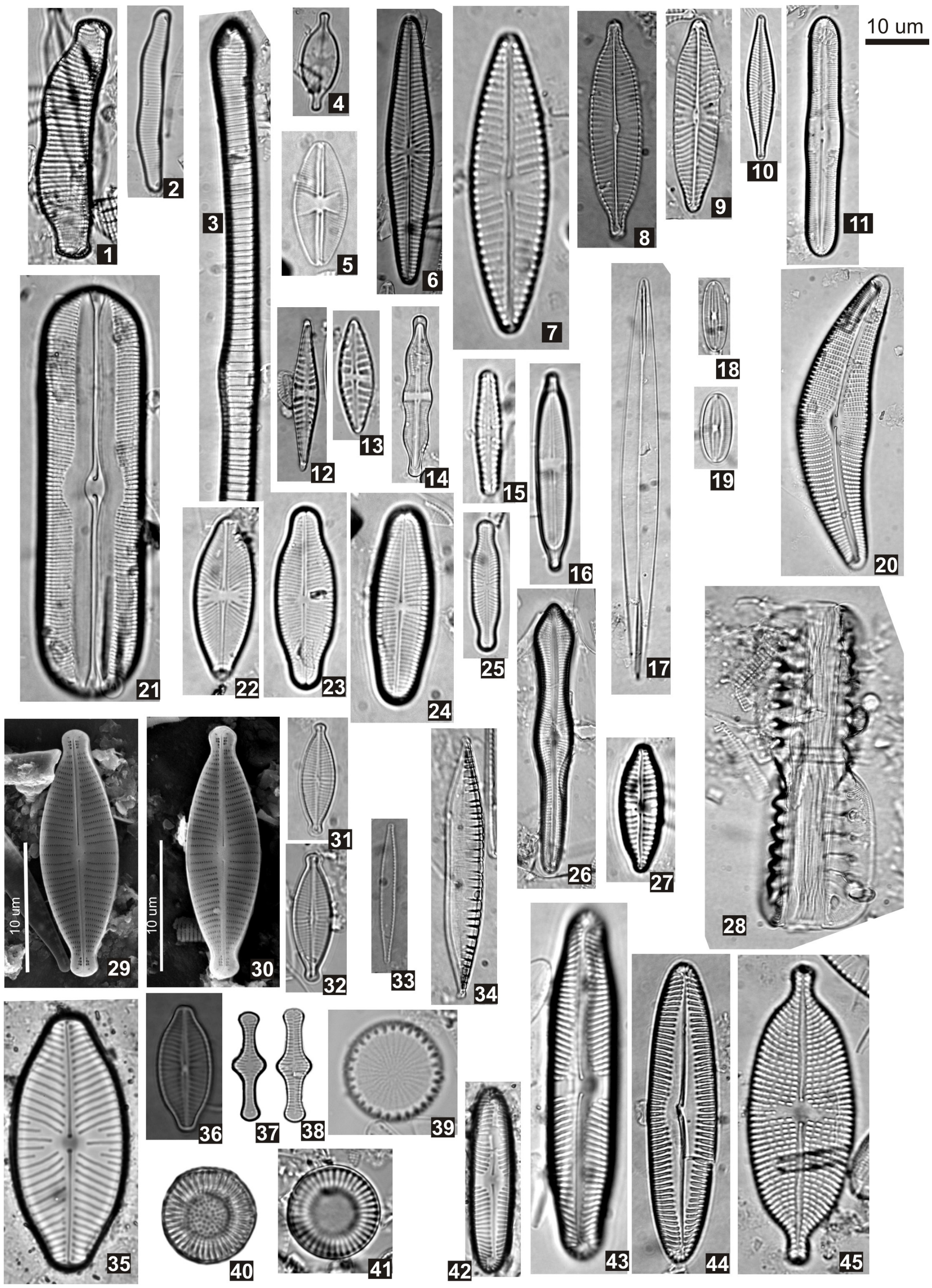

Figure 2

1 – *Eunotia bidens*; 2 – *E. implicata*; 3- *E. formica*; 4 – *Planothidium peragalli*; 5 – *Cavinula lapidosa*; 6 – *Navicula oppugnata*; 7 – *N. concentrica*; 8 – *N. rostellata*; 9 – *N. novaesiberica*; 10 – *N. cryptocephala*; 11 – *Caloneis falcifera*; 12 – *Hippodonta lueneburgensis*; 13 – *H. costulata*; 14 – *Stauroneis leguminopsis*; 15 – *S. parathermicola*; 16 – *S. prominula*; 17 – *Amphipleura pellucida*; 18, 19 – *Diploneis peterseni*; 20 – *Cymbella proxima*; 21 – *Sellaphora americana*; 22 – *S. mutatoides*; 23, 24 – *Parlibellus protractus*; 25 – *P. protractoides*; 26 – *Gomphonema montanum*; 27 – *G. sphenovertex*; 28 – *Entomoneis ornata*; 29, 30, 31, 32 – *Geissleria declivis*; 33 – *Nitzschia archibaldii*; 34 – *N. bremensis*; 35 – *Placoneis gastrum*; 36 – *P. hambergii*; 37, 38 – *Tabellaria flocculosa*; 39 – *Stephanodiscus hantzschii*; 40, 41 – *Cyclostephanos dubius*; 42 – *Pinnularia schoenfelderi*; 43 – *P. divergens*; 44 – *P. frequentis*; 45 – *Aneumastus stroesei*

P. schoenfelderi Krammer (Fig. 2.42), *P. subcapitata* Gregory and *P. subrupestris* Krammer. The genus *Frustulia*, which is characteristic of waters poor in electrolytes, oligo- to dystrophic (springs, peat-bogs), was represented by the species: *Frustulia crassinervia* (Brébisson) Lange-Bertalot & Krammer, *F. saxonica* Rabenh., *F. vulgaris* (Thwaites) De Tonii. The *Neidium* genus was represented by *Neidium affine* (Ehrenberg) Pfitzer, *N. alpinum* Hustedt and *N. bisculatum* (Lagerstedt) Cleve.

Between its springs in the Świętokrzyskie Mountains and the Chańcza Reservoir, the river carries water that is classified into water quality class I or II (Table 1). The indicator species of very good water quality were as follows *Achnanthidum linearioides* (Lange-Bertalot) Lange-Bertalot, *Encyonema neogracile* Krammer, *Fragilaria acidoclinata* Lange-Bertalot & G. Hofmann, *Frustulia crassinervia* (Brébisson) Lange-Bertalot & Krammer, *F. saxonica* Rabenhorst, *Gomphonema vibrio* Ehrenberg, *Nitzschia hantzschiana* Rabenhorst, *Psammothidium subatomoides* (Hustedt) Bukhtiyarowa & Round, *P. ventrale* (Krasske) Bukhtiyarowa & Round and *Planothidium peragalli* (Brun & Hèribaud) Round & Bukhtiyarowa (Fig. 2.4).

The characteristic species of the source section of the river were: *Diploneis krammeri* Lange-Bertalot & Reichardt, *D. parma* Cleve, *D. petersenii* Hustedt (Fig. 2.18-19), *Sellaphora americana* Ehrenberg (Fig. 2.21).

The middle section of the river was represented by sites 2 and 3, from the Drogowle village to the Raków village. Physicochemical parameters indicated a good ecological water quality – class I or II (Table 1).

In this section, diatom taxa different from those of the source section are observed. Besides, species characteristic of dystrophic and peat-bog waters progressively disappeared. However, a high abundance of the following taxa still continued to occur: *Fragilaria brevistriata* Grunow in Van Heurck (2.2%), *Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski (3.0%), *Navicula cryptocephala* Kützing (2.0%) (Fig. 2.10), *N. radiosa* Kützing (1.2%), *Parlibellus protractus* (Grunow) Witkowski, Lange-Bertalot & Metzeltin (1.0%) (Fig. 2.23-24), *Sellaphora pupula* (Kützing) Mereschkowsky (4.0%), *Staurosira construens* Ehrenberg (3.0%) and Ehrenberg *Staurosirella pinnata* (Ehrenberg) D.M. Williams & Round (2.5% at Drogowle, 6.0% at Raków).

Taxa not found in the source section were recorded at site 2 (Drogowle, 5 km downstream of the Smyków village). They were: *Aneumastus stroesei* (Østrup) Mann & Stickle (0.2%) (Fig. 2.45), (chalk-rich waters, oligo- to mesotrophic), *Amphora copulata* (Kützing) Schoeman & Archibald (2.0%), *Cymbella proxima* Reimer (0.2%) (Fig. 2.20), *Geissleria declivis* (Hustedt) Lange-Bertalot & Metzeltin (1.0%) (Fig. 2.29-32), *G. decussis* (Hustedt) Lange-Bertalot & Metzeltin (1.7%), *Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski (3.0%), *Navicula concentrica* Carter & Bailey-Watts (6.0%) (Fig. 2.7), *Navicula gregaria* Donkin (1.5%), *Navicula novaesiberica* Lange-Bertalot (8.5%) (Fig. 2.9), *Navicula rostellata* Kützing (13.0%) (Fig. 2.8), *Nitzschia archibaldii* Lange-Bertalot (7.7%) (Fig. 2.33), *N. dissipata* (Kützing) Grunow (2.5%), *N. pussilla* Grunow (3.0%) and *Rossithidium pussillum* (Grunow) Round & Bukhtiyarowa (2.5%).

Gomphonema extentum Reichardt & Lange-Bertalot, *G. sphenovertex* Lange-Bertalot & Reichardt (Fig. 2.27), *G. montanum* Schumann (Fig. 2.26), *Navicula antonii* Lange-Bertalot, *N. lanceolata* (Agardh) Ehrenberg, *N. oppugnata* Hustedt (Fig. 2.6), *N. reinchardtii* (Grunow) Grunow, *N. striolata* (Grunow) Lange-Bertalot, *Nitzschia fibulafissa* Lange-Bertalot, *Parlibellus protractus* (Grunow) Witkowski, Lange-Bertalot & Metzeltin (Fig. 23-24), *P. protractoides* (Hustedt) Witkowski, Lange-Bertalot & Metzeltin (Fig. 2.25), *Psammothidium subatomoides* (Hustedt) Bukhtiyarowa & Round, *Planothidium peragalli* (Brun & Hèribaud) Round & Bukhtiyarowa (Fig. 2.4) and *Sellaphora mutatoides* Lange-Bertalot & Metzeltin (Fig. 2.22) occurred with smaller abundance.

At site 3 (Raków), the following species still abundantly occurred: *Geissleria declivis* (Hustedt) Lange-Bertalot & Metzeltin (2.0%) (Fig. 2. 29-32), *G. decussis* (Hustedt) Lange-Bertalot & Metzeltin (3.0%), *Navicula gregaria* Donkin (2.0%), *Navicula novaesiberica* Lange-Bertalot (0.7%) (Fig. 2.9) and *Navicula rostellata* Kützing (3.2%) also still occurred but their abundance decreased (Fig. 2.8). Species occurring with smaller abundance include: *Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski (1.7%), *Melosira varians* Agardh (1.5%), *Navicula cryptocephala* Kützing

(3.0%) (Fig. 2.10), *Nitzschia dissipata* (Kützing) Grunow (2.0%), *N. linearis* (Agardh) W. Smith (3.5%), *Parlibellus protractus* (Grunow) Witkowski, Lange-Bertalot & Metzeltin (1.0%) (Fig. 2.23-24), *P. protractoides* (Hustedt) Witkowski, Lange-Bertalot & Metzeltin (2.2%) (Fig. 2.25), *Surirella angusta* Kützing (2.0%), *S. brebissonii* Krammer & Lange-Bertalot (1.0%), *S. helvetica* Brun (1.0%), *Navicula oblonga* (Kützing) Kützing (0.2%) and *N. notha* Wallace (0.2%).

Site 4 (Kurozwęki) was located in the river section downstream of the Chańcza Reservoir. The site was affected by waters from the reservoir and from the polluted section of the Łagownica River. In addition to species occurring in the second section, such as *Geissleria decussis* (Hustedt) Lange-Bertalot & Metzeltin (5.3%), *Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski (4.7%), *H. costulata* (Grunow) Lange-Bertalot, Metzeltin & Witkowski (4.0%) (Fig. 2.13), *Navicula gregaria* Donkin (2.0%), *N. novaesiberica* Lange-Bertalot (6.7%) (Fig. 2.9), *N. rostellata* Kützing (3.2%) (Fig. 2.8), *Sellaphora pupula* (Kützing) Mereschkowsky (4.3%), also diatoms tolerant to organic water pollution occurred at site 4, up to the β-α-mesosaprobic zone; they were: *Navicula capitatoradiata* Germain (3.0%), *N. tripunctata* (O.F. Müller) Bory (6.0%), and taxa originating from the plankton of the dam reservoir: *Aulacoseira granulata* (Ehrenberg) Simonsen (6.0%), *Cocconeis placentula* Ehrenberg (4.3%), *Cyclostephanos dubius* (Fricke) Round (7.0%) (Fig. 2.40-41), *Fragilaria crotonensis* Kitton (5.7%), *Melosira varians* Agardh (3.3%), *Placoneis gastrum* (Ehrenberg) Mereschkowsky (2.0%) (Fig. 2.35). *Nitzschia angustata* (W. Smith) Grunow (0.2%), *N. hungarica* Grunow (0.2%), *S. neoastrea* Håkansson & Hickel (0.3%) occurred with lower abundance. However, taxa characteristic of waters rich in calcium were still recorded: *Aneumastus stroesei* (Østrup) Mann & Stickle (Fig. 2.45), *Diploneis parma* Cleve, *Hippodonta lueneburgensis* (Grunow) Lange-Bertalot, Metzeltin & Witkowski (Fig. 2.12), *Navicula gottlandica* Grunow in Van Heurck, *Navicula moskalii* Metzeltin, Witkowski & Lange-Bertalot, *Navicula oppugnata* Hustedt (Fig. 2.6), *Nitzschia brunoi* Lange-Bertalot, *N. fibulafissa* Lange-Bertalot, *Sellaphora mutatoides* Lange-Bertalot & Metzeltin (Fig. 2.22), and *Sellaphora pseudopupula* (Krasske) Lange-Bertalot.

The outflow section is represented by site 5, at the Rudniki village, which was affected by the water of the dam reservoir and sewage from the Staszów town and the Grzybów village. Physicochemical parameters of water indicated water quality class III (Table 1). Taxa characteristic of waters rich in electrolytes, polluted with municipal sewage, occurred in this section: *Luticola goeppertiana* (Bleisch) D.G. Mann, *Navicula amphiceropsis* Lange-Bertalot & Rumrich, *N. cincta* (Ehrenberg) Ralfs, *N. cryptocephala* Kützing (Fig. 2.10), *N. reinchardtiana* (Grunow) Grunow, *N. veneta* Kützing, *N. viridula* (Kützing) Ehrenberg, *Nitzschia acicularis* (Kützing) W. Smith, *N. gracilis* Hantzsch, *N. hungarica* Grunow, *N. intermedia* Hantzsch, *N. palea* (Kützing) W. Smith, *N. sigmoidea* (Nitzsch) W. Smith, *N. umbonata* (Ehrenberg) Lange-Bertalot, *N. trybionella* Hantzsch, *Sellaphora tolerans* nom. prov., *Stephanodiscus hantzschii* Grunow (Fig. 2.39). The following species continued to occur with high abundance: *Aulacoseira granulata* (Ehrenberg) Simonsen (6.2%), *Cocconeis placentula* Ehrenberg (3.7%), *Fragilaria crotonensis* Kitton (2.2%), *Gyrosigma acuminatum* (Kützing) Rabenhort (2.2%), *Navicula capitatoradiata* Germain (2.2%), *N. tripunctata* (O.F. Müller) Bory (4.0%) and *N. gregaria* Donkin (3.0%). At this site, the presence of *Fallacia pygmea* (Kützing) A.J. Stickle & D.G. Mann (waters rich in electrolytes), *F. subhamulata* (Grunow) D.G. Mann (waters of high trophy) and *Navicula erifuga* Lange-Bertalot (waters rich in electrolytes) was recorded.

Discussion and conclusions

In the four river sections distinguished on the basis of the hydrology and the degree of water pollution, the occurrence of different indicator species was determined in the respective diatom assemblages. The spring section was characterized by oligo- to dystrophic waters. Indicator species characteristic of good ecological quality waters as well as calcareous and silicate waters were observed there. The following species occurred: *Amphipleura pellucida* (Kützing) Kützing, *Caloneis silicula* (Ehrenberg) Cleve, *Cavinula lapidosa* (Krasske) Lange-Bertalot, *Diploneis petersenii* Hustedt, *Luticola acidoclinata* Lange-Bertalot, Navicula concentrica Carter & Bailey-Watts, *N. moskalii* Metzeltin, Witkowski & Lange-Bertalot, *N. oblonga* (Kützing) Kützing, *N.*

tenelloides Hustedt, *Nitzschia archibaldii* Lange-Bertalot, *N. hantzschiana* Rabenhorst, *N. nana* Grunow, *Planothidium peragalli* (Brun & Hèribaud) Round & Bukhtiyarowa, *Sellaphora americana* Ehrenberg, *S. laevissima* (Kützing) D.G. Mann and *S. mutatoides* Lange-Bertalot & Metzeltin.

The impact of the Białe Ługi peat-bog spring was reflected in the occurrence of taxa from the genera: *Eunotia*, *Frustulia*, *Neidium*, *Pinnularia*, *Stauroneis*, *Tabellaria*. A similar species composition was observed in oligo-dystrophic Lake Julma Ölkky in Finland (Lange-Bertalot, Metzeltin 1996) and in the spring section of a stream with low pH in Beskid Śląski (Silesian Beskids) – Biała Wisełka (Kwandrans 1986), where the genera of *Eunotia*, *Pinnularia* and *Frustulia* were abundant. In addition to species characteristic of acid water, indicator species of calcareous waters occurred there.

Taking into account publications on mountain streams and springs (Kawecka 1980, 1981; Wasylik 1985; Kwandrans 1986; Noga et al. 2013; Delgado et al. 2013; Żelazna-Wieczorek 2011; Wojtal, Sobczyk 2006; Wojtal 2013), species common with those in the Czarna Staszowska and, at the same time, dominant ones were as follows: *Fragilaria brevistriata* Grunow in Van Heurek, *Planothidium frequentissimum* (Lange-Bertalot) Lange-Bertalot, *P. lanceolatum* (Brébisson ex Kützing) Lange-Bertalot, *Staurosira construens* Ehrenberg and *S. pinnata* Ehrenberg in the streams of the Tatra Mountains; *Hannaea arcus* (Ehrenberg) Patrick in Patrick & Reimer and *Diatoma mesodon* (Ehrenberg) Kützing were characteristic species, in addition to those mentioned above and in addition to those that were not recorded in the Czarna Staszowska.

In the middle section (sites 2 and 3) with water quality of class I or II, the characteristic species were as follows: *Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski, *H. costulata* (Grunow) Lange-Bertalot, Metzeltin & Witkowski, *Navicula concentrica* Carter, *N. cryptocephala* Kützing, *N. notha* Wallace, *N. novasiberica* Lange-Bertalot, *N. rostellata* Kützing, *Nitzschia archibaldii* Lange-Bertalot, *N. pusilla* Grunow, *Parlibellus protractoides* (Hustedt) Witkowski, Lange-Bertalot & Metzeltin, *Planothidium peragalli* (Brun & Hèribaud) Round & Bukhtiyarowa and *Rossithidium pussillum* (Grunow) Round & Bukhtiyarowa.

A taxon that distinguishes this river section was *Geissleria declivis* (Hustedt) Lange-Bertalot & Metzeltin. The species, which was recently described for the first time from Poland and Europe (Noga et al. 2013), is typical of oligosaprobic and beta-mesosaprobic waters, rich in calcium.

The following species characteristic of lakes occurred in the river section below the Chańcza Reservoir, i.e. site 4 (Kurozwęki): *Aulacoseira granulata* (Ehrenberg) Simonsen, *Cocconeis placentula* Ehrenberg, *Cyclostephanos dubius* (Fricke) Round, *Fragilaria crotonensis* Kitton, *Melosira varians* Agardh, *Stephanodiscus hantzschii* Grunow, *S. neoastrea* Håkansson & Hickel (Scheffler, Morabito 2003; Wojtal, Kwandrans 2006; Bucka, Wilk-Woźniak 2007; Burchardt 200). Compared to the previous section, the abundance of the following species was higher: *Geissleria decussis* (Hustedt) Lange-Bertalot & Metzeltin, *Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski, *H. costulata* (Grunow) Lange-Bertalot, Metzeltin & Witkowski, *Navicula capitatoradiata* Germain, *N. novasiberica* Lange-Bertalot, *N. tripunctata* (O.F. Müller) Bory and *Sellaphora pupula* (Kützing) Mereschkowsky.

The outlet section, i.e. site 5 (Rudniki), is the most polluted fragment of the river. Taxa tolerant to severe water pollution, up to the polysaprobic zone, occurred there: *Luticola goeppertiana* (Bleisch) D.G. Mann, *Navicula erifuga* Lange-Bertalot, *N. gregaria* Donkin, *N. viridula* (Kützing) Ehrenberg (Lange-Bertalot 1979 a, b, Hoffman 1994, van Dam et al. 1994). The genus *Nitzschia* was abundantly represented: *Nitzschia acicularis* (Kützing) W. Smith, *N. gracilis* Hantzsch, *N. palea* (Kützing) W. Smith and *N. sigmoidea* (Nitzsch) W. Smith. On the other hand, the abundance of the following species decreased: *Geissleria decussis* (Hustedt) Lange-Bertalot & Metzeltin, *Hippodonta capitata* (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski, *Navicula novaesiberica* Lange-Bertalot and *N. rostellata* Kützing.

Species not reported from Poland were represented by *Parlibellus protractus* (Grunow) Witkowski, Lange-Bertalot & Metzeltin, identified in the Ohrid Lakes, characteristic of calcareous waters, from oligo- to eutrophicated (Levkov et al. 2007). In the Czarna Staszowska River, the species occurred in the spring section (sites 1, 2 and 3).

Species rarely recorded in other rivers, or not reported from Poland and characteristic of the Czarna Staszowska are represented by: *Cavinula lapidosa* (Krasske) Lange-Bertalot, *Geissleria declivis* (Hustedt) Lange-Bertalot & Metzeltin, *Luticola acidoclinata* Lange-Bertalot, *N. ricardae* Lange-Bertalot, *N. moskalii* Metzeltin, Witkowski & Lange-Bertalot, *Nitzschia archibaldii* Lange-Bertalot, *N. brunoi* Lange-Bertalot, *Parlibellus protractus* (Grunow) Witkowski, Lange-Bertalot, *P. protractoides* (Hustedt) Witkowski, Lange-Bertalot & Metzeltin, *Placoneis hambergii* (Hustedt) Bruder, *P. undulata* (Østrup) Lange-Bertalot, *Sellaphora americana* Ehrenberg and *S. mutatoides* Lange-Bertalot & Metzeltin.

On the basis of the selected diatom indices (IO, IPS, GDI, TDI), it was determined that only indices IPS and GDI showed differences in the water quality between the investigated sites. The values of these indices definitively indicated a better water quality in the source section of the river and a deteriorated quality in the outflow section, which is affected by the pollution from the dam reservoir and the Staszów town and Grzybów village. On the other hand, the IO index showed the same ecological state in the whole river, which is not consistent with the conditions determined by the indicator species and physicochemical parameters. The TDI index indicated the oligomesotrophic zone at site 1, and the eutrophic zone at the other sites.

The IO index is a measure presently used in Poland to assess the ecological state of flowing waters according to the regulation of the Minister of the Environment (OJ No 258, pos. 1549 from 2011) (Picińska-Fałtynowicz at al. 2006). The other indices (IPS, GDI, TDI) are used in routine monitoring in Europe and depend on autecological diatom lists developed, among others, in France (Coste, Ayphassorho 1991; Prygiel, Coste 1999; Prygiel 2002), in Germany (Lange-Bertalot 1979a, b; Hofmann 1994), Belgium (Descy, Coste 1991), and The Netherlands (van Dam et al. 1994). Despite the other indices having been produced in other countries than Poland they were applied, for example, to the waters of the Bay of Gdańsk (Bogaczewicz-Adamczak, Dziengo 2003; Zgrundo, Bogaczewicz-Adamczak 2004), water of the rivers of Central Poland: Bzura and Pilica (Szczepocka, Szulc 2009; Rakowska, Szczepocka 2011), and also to the rivers of the southern part of Poland: Odra (Oder), Wisła and Raba (Kawecka et al. 1996, 1999; Kwandrans et al. 1999). Information on the precise assessment of the ecological state of water using these indices is available in all the above mentioned studies. They seem to be a good tool for the biological assessment of flowing waters.

The obtained results of the biological assessment of water using the Czarna Staszowska as an example indicate that the IO index did not differentiate the water quality at the studied sites of the river, which implies that the sensitivity of this index to changes in the inflow of pollutants is low. This low sensitivity may be caused by incorrectly selected indicator values of the diatoms from the list on which this index is based, or a too high number of eurytopic species, of wide occurrence spectrum. The index works correctly for rivers with clear water (Szczepocka et al. 2014a), but in polluted rivers, it definitely overestimates the water quality. The other saprobic indices differentiated the quality between the study sites in the river, which implies their higher sensitivity to changes in the water quality. The sensitivity of diatom indices depends mostly on indicator values of diatoms on which a given index is based. Studies of diatom autecology are an important stage in biological assessment. There are few studies that have revised the diatom lists for Polish conditions, including the following studies from Central Poland: by Rakowska (2001) and Szczepocka et al. (2014b) on the diatom indices of various water ecosystems, and Żelazna-Wieczorek (2011) on diatoms occurring in the springs of Łódź Hills.

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