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Diatom diversity and water quality of a suburban stream: a case study of the Rzeszów city in SE Poland

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Abstract: The aim of this work was to investigate the diversity of diatom assemblages developed in the Przyrwa stream, to assess water quality based on benthic diatoms and to make an attempt at the identification of physicochemical factors having the greatest impact on the differentiation of diatom assemblages. Studies were conducted in 2011-2012 on the Przyrwa stream, a left-side tributary of the Wisłok River flowing through the city of Rzeszów and with its spring section located on the borders of the city. A total of 259 diatom taxa were identified in the Przyrwa stream during three studied seasons. At all investigated sites, the most abundant population consisted of *Ulnaria ulna* (Nitzsch) Compère, *Cocconeis pediculus* Ehrenb., *Achnanthidium minutissimum* (Kütz.) Czarnecki var. *minutissimum, Navicula gregaria* Donkin, *Planothidium frequentissimum* (Lange-Bert.) Lange-Bert., *P. lanceolatum* (Brébisson) Lange-Bert., *Navicula lanceolata* (C. Agardh) Ehrenb., *Amphora pediculus* (Kütz.) Grunow, *Eolimna minima*, (Grunow) Lange-Bert., *Melosira varians* C. Agardh and *Cyclotella meneghiniana* Kütz. Based on IPS (Specific Pollution Sensitivity Index) and GDI (Generic Diatom Index) indices, the ecological status of the Przyrwa stream was assessed as moderate to poor (mostly III-IV class of water quality), while the TDI (Trophic Diatom Index) index indicated a poor to bad ecological status (mainly IV-V class of water quality).

Key words: diatom indices IPS, GDI, TDI, species richness, water quality, RDA, Rzeszów City

1. Introduction

Diatoms are producers of organic matter in water and, as such, are the basis of the food chain in seas, oceans and inland waters. Due to a high content of proteins and fat, they provide high-energy food for invertebrates. Diatoms take part in the purification of polluted waters through water oxygenation (photosynthesis), absorption of heavy metal ions (nickel, lead, zinc and titanium), consumption of nutrients, and excretion of compounds that function as antibiotics, etc. (Round 1962). They are characterized by a great diversity of adaptation to ecological conditions. They live in natural waters, artificial reservoirs, in clean and polluted waters and even in sewers in which there are no plants or animals. They are found even in deserts where fog often occurs. The presence of diatoms in such diverse environments is made possible by a large adaptability to environmental factors and because they are able to develop on nearly every kind of substrate. Diatom assemblages are characteristic for each of these habitats (Krammer & Lange-Bertalot 1986; Rakowska 2001).

Diatoms, as excellent bioindicators, are commonly used in Europe to assess the ecological status of surface waters (Whitton *et al*. 1991; Lecointe *et al*. 1993; Prygiel & Coste 1993; Kelly & Whitton 1995; Whitton & Rott 1996; Prygiel *et al*. 1999; Prygiel 2002; Kelly 2003, 2013; Kelly *et al*. 2008; Bennion *et al.* 2014). In Poland, diatoms are used as indicators of environmental conditions and their changes, for studying present and past (paleoecological) ecological status of various

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ecosystems and in environmental monitoring (Gołdyn 1989; Kwandrans *et al*. 1998, 1999; Kwandrans 2000, 2002; Rakowska 2001; Bogaczewicz-Adamczak & Dziengo 2003; Gołdyn & Szeląg-Wasielewska 2004; Szeląg-Wasielewska 2004; Żelazowski *et al*. 2004; Dumnicka *et al*. 2006; Szczepocka & Szulc 2009; Messyasz *et al*. 2010, 2014; Rakowska & Szczepocka 2011; Witak 2013). In the assessment of water quality, specific kinds of software (such as Omndidia) are also used, containing indicative values and degrees of sensitivity of individual diatom taxa (Lecointe *et al*. 1993).

Research on the diversity of diatoms growing mainly in flowing waters was conducted in the Subcarpathian Voivodeship regularly since 2007 (Noga & Siry 2010; Tambor & Noga 2011; Noga 2012; Bernat & Noga 2012; Pajączek *et al*. 2012; Noga *et al*. 2013a, 2014a, 2014b, 2015; Peszek *et al*. 2015). Similar studies focusing on the diversity of diatoms, using their indicative roles, were conducted within boundaries of the City of Rzeszów (Noga *et al*. 2012, 2013b; Kocielska-Streb *et al*. 2014).

The research in this paper comprised the entire length of the Przyrwa stream (from the spring to outlet into the Wisłok River). Preliminary results of this research were presented in a paper dealing with rare and endangered diatom species of Rzeszów (Noga *et al*. 2012).

The aim of the study was to investigate the diversity of diatom assemblages developing along the Przyrwa stream, to assess water quality based on benthic diatoms, and to identify the physicochemical factors exerting the greatest impact on the differentiation of diatom assemblages.

2. Study area

Rzeszów is located in the south-eastern part of Poland, on the northern border of the Subcarpathian Voivodeship and the Outer Western Carpathian mountain range. The central part of the city lies within the Rzeszowskie Foothills (Fig. 1), but the northern and north-eastern areas of the city are part of the Subcarpathian Proglacial Valley (also called "Rynna Podkarpacka"). Both units belong to the Sandomierska Valley macro-region. The south-eastern part of the city lies within the Outer Western Carpathians and is part of the Dynowskie Foothills mesoregion (Kondracki 2001; Raińczuk 2009).

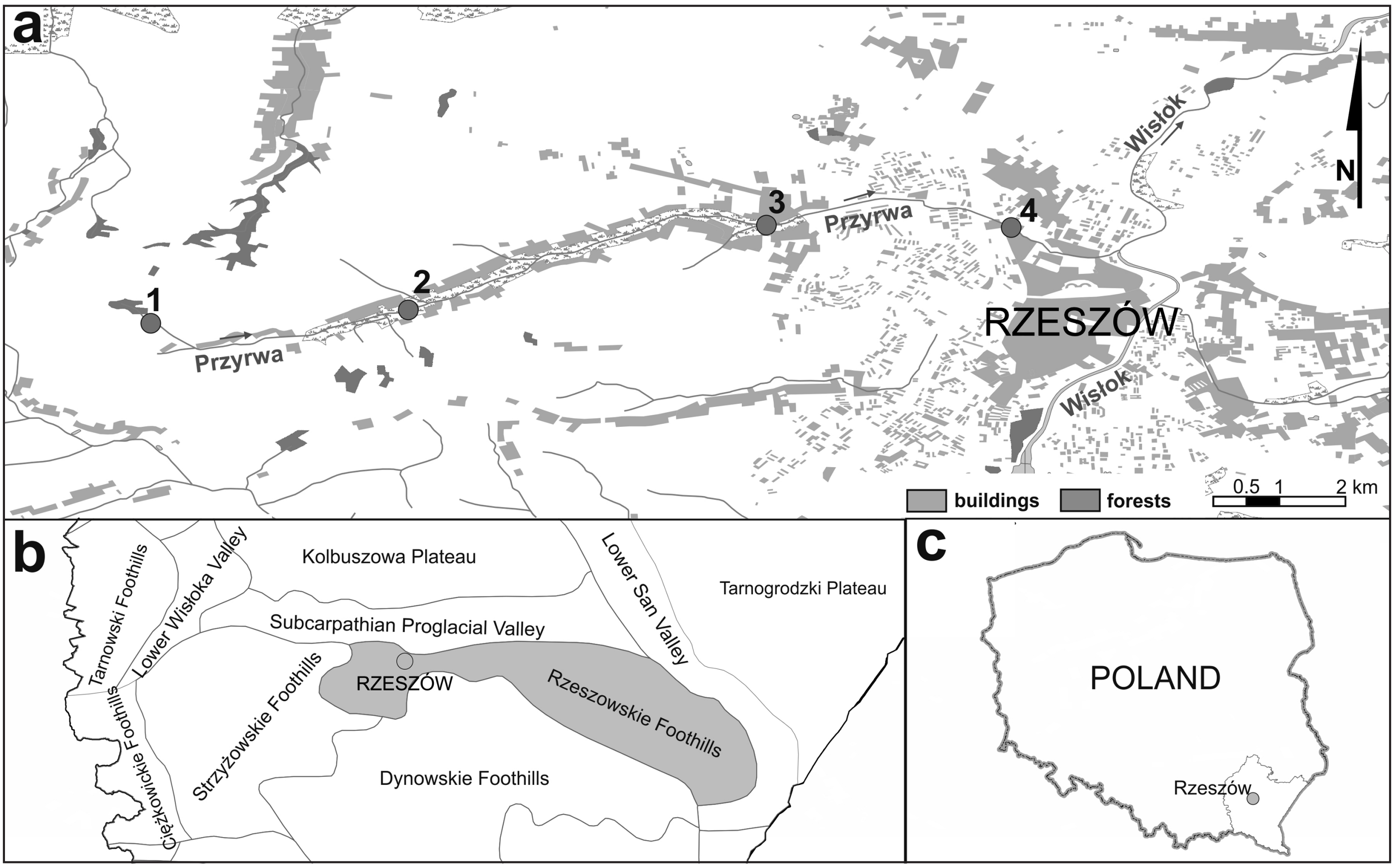

Fig. 1. Study area
Explanations: a – location of sampling sites (1-4) in the Przyrwa stream; b – location of the study area within major geomorphological units, c – location of the study area in Poland

The specific location of the city is reflected in the terrain. Areas belonging to the Subcarpathian Proglacial Valley are characterized by the least diversified terrain. The area within the city is flat (201-207 m a.s.l.), gently sloping to the north-east. The Przyrwa stream is a left-bank tributary of the Wisłok River. The upper part of the stream is located in Bzianka (within the municipality of Świlcza), with the middle and the lower sections flowing through the territory of Rzeszów. The Przyrwa stream is a submontane watercourse, with a catchment area of 23.65 km^2 and a length of 12.10 km. The spring of the stream is located at the altitude of 258 m a.s.l., while the estuary sits at 192 m a.s.l. The Przyrwa stream originates in Bzianka, then flows through Rzeszów (districts: Przybyszówka, Baranówka, the southern part of the Staromieście district) along Dębicka Street and Wyzwolenia Avenue. At the intersection of Siemiński Street and General Maczek Street (the area of the Załęski Bridge), it joins the Wisłok River. It is managed from Lubelska Street trough upstream, up to Route E40, while the section from Lubelska Street to Siemiński Street is not managed. It is a local collector of rainwater. In addition to the existing tributaries, rainwater from collectors is brought from the following areas: Przybyszówka Dworzysko, Przybyszówka near Dębicka Street and Kontorówka. Moreover, rainwater from the upper part of the catchment area (the villages of Bzianka, Bzianka Górna, Kielanówka, Tralówka, Pustki, Przybyszówka Górna, Przybyszówka Dolna and Świdrówka) is introduced into the collector. This significant inflow of rainwater means that during heavy rainfall, the riverbed cannot contain the water and, therefore, overflows (both in the upper part and within the territory of Rzeszów). The Przyrwa stream, like many other Wisłok tributaries, is not currently being analyzed by the Voivodeship Inspectorate for Environmental Protection in Rzeszów. Archived results from the period 1994-1997 indicated that these tributaries had clearly polluted water (Słysz *et al*. 2004; Basiak 2008; Raińczuk 2009).

3. Material and methods

Materials for the studies were collected over two years at four designated sampling sites (1-4) along the Przyrwa stream, including the spring, middle and lower sections of the watercourse (Fig. 1). The first site was designated in the spring section of the Przyrwa stream in the village of Bzianka. It is the only site which remains under minimal influence of anthropogenic pressure (there are meadows and pastures nearby). Site number two was located on the Przybyszówka estate near Dębicka Street and Ciche Wzgórze Street. Site number three was located near Wyzwolenia Avenue on the Baranówka estate in Rzeszów, 50 meters from a housing block on Starzyńskiego Street. At this site, the stream was regulated; both banks and the river channel were paved with hexagonal concrete panels. Torrential rains in consecutive sampling seasons led to a complete destruction of stream regulation, leaving the bed consisting mainly of stones and gravel. Here, down flooding of the surrounding areas by stream waters often takes place. The last site was located in Rzeszów, near the hospital on Rycerska Street.

Materials for the studies were collected in April and September of 2011 and May of 2012. Diatoms were collected, depending on the availability of substrate, from tough substrate – concrete slabs and rocks (algae was scraped using a toothbrush), from silt pipette (suction) and aquatic plants. Samples were collected to 100 ml containers and preserved in a 4% formalin solution in a laboratory. A total of 20 samples were collected (from one to three samples, depending on substrate availability). For diatom indices calculation, samples collected from rocks were only used.

Water temperature, pH and conductivity were measured directly in the field. Water for chemical analysis was taken at the same time. Chemical oxygen demand (COD-Cr), biochemical oxygen demand (BOD_5), total nitrogen, total phosphorus, nitrates and ammonia were measured. Chemical analyses were performed using MACHEREY-NAGEL and HACH-LANGE photometry method cuvette tests in the "Wodociągi Dębica" Ltd., Laboratory of Wastewater Treatment. Oxygen content was measured using a field oxygen meter. Ecological status classifications were adopted according to the Decree of the Minister of the Environment from 30 October 2014.

Laboratory processing of diatoms was carried out applying methods used by Kawecka (1980). In order to obtain pure valves of diatoms, part of the obtained material was subjected to maceration in a mixture of sulphuric acid and potassium dichromate at 3:1 proportion and rinsed in a centrifuge (at 2 500 $rev \times min^{-1}$). Cleaned diatoms were embedded in Pleurax synthetic resin (refractive index 1.75).

Diatoms were identified and counted under a Nikon ECLIPSE 80i light microscope under 1000× magnification according to Krammer & Lange-Bertalot (1986, 1988, 1991a, 1991b), Krammer (2000, 2002, 2003), Lange-Bertalot (1993, 2001), Reichard (1999), Werum & Lange-Bertalot (2004) and Hofmann *et al*. (2011). The number of given species was obtained through calculating specimens in random light microscope view fields until a total number of 400 valves were obtained. Species whose participation in a given community was 5% or more were considered as numerous.

The analysis of diatom community structure was conducted using OMNIDIA software (version 4.2, database no. 2015a) to determine the ecological status

Table 1. The range of indices values and corresponding ecological status according to Dumnicka *et al.* (2006)

Water Quality Class*	Ecological status	IPS	GDI	TDI	Trophic state
I	high	>17	>17	<35	oligotrophic
II	good	15-17	14-17	35-50	oligo/mesotrophic
III	moderate	12-15	11-14	50-60	mesotrophic
IV	poor	8-12	8-11	60-75	eutrophic
V	bad	<8	<8	>75	hypertrophic

Explanation: * – according to the Regulation (2014)

of water. The software contained an ecological and taxonomic database of diatoms and their bioindication values. Water quality of the Przyrwa stream was assessed based on three diatom indices (IPS, GDI, and TDI) and also the % of PT indicator. These indices were chosen because they are most commonly used and recommended by many authors to assess water quality in Poland, particularly IPS and GDI (Kawecka *et al*. 1999; Kwandrans *et al*. 1999; Żelazowski *et al*. 2004; Dumnicka *et al*. 2006; Rakowska & Szczepocka 2011; Szczepocka *et al*. 2014).

The IPS index (Specific Pollution Sensitivity Index – Coste in CEMAGREF 1982) and GDI index (Generic Diatom Index – Coste & Ayphassorho 1991) are scaled from 1 to 20 (an increase in the value of the indicator means an increase in water quality). The TDI (Trophic Diatom Index, Kelly & Whitton 1995) is scaled from 1 to 100 (the higher the value, the higher trophic state of water). The percentage of pollution tolerant taxa (PT) must be taken into account in the interpretation of the TDI index. There is a possibility of organic pollution if the PT values are above 20%. The classification schemes of Dumnicka *et al*. (2006) were used to evaluate the ecological status (Table 1).

Species diversity in diatom assemblages was determined using the Shannon-Wiener (H’) indicator (Krebs 1997):

$H' = \Sigma\ (ni/N \cdot \log ni/N)$

N – total number of taxa

ni – number of individual diatoms of the ‘i-th’ species

In this paper, we distinguished categories of risk for individual diatom taxa using the Red List of Algae for Poland (Siemińska *et al*. 2006): E – endangered, V – vulnerable, R – rare, I – indeterminate.

Table 2. The values of physico-chemical parameters measured in the Przyrwa stream in 2011-2012 and sampling sites characteristic

Sampling site	1			2			3			4		
Date	06. 2011	09. 2011	03. 2012	06. 2011	09. 2011	03. 2012	06. 2011	09. 2011	03. 2012	06. 2011	09. 2011	03. 2012
Depth [m]	0.1-0.2			0.3-0.5			~ 0.1			0.3-0.4		
Width [m]	0.2-0.4			~ 0.5			2.0			3.0-4.0		
Insolation	average			high			high			low		
Type of the bottom	muddy sandy			muddy sandy			concrete plates/stones lack of silt			pebble and gravel at the shore silted		
Temperature [^{0}C]	17.2	14.4	5.6	17.0	15.2	5.9	17.6	16.0	6.5	16.8	15.7	5.7
pH	8.1	8.0	7.6	8.0	7.9	7.9	8.4	8.0	7.9	7.8	7.8	8.0
Conductivity [µS/cm]	570	662	300	667	697	558	736	767	654	840	855	716
COD-Cr [mgO_2/l]	11	11	8	19	15	12	15	13	11	12	12	13
BOD_5 [mgO_2/l]	1	1	1	6	3	4	2	2	3	3	2	3
$N\text{-}_{NH4}$ [mg/l]	0.05	<0.01	0.12	1.7	0.44	0.68	<0.01	0.10	0.41	0.60	0.57	0.76
$N\text{-}_{NO3}$ [mg/l]	0.9	0.9	0.7	1.7	2.7	1.5	2.1	2.2	1.6	1.8	1.9	1.6
Total N [mg/l]	3	1	1	5	4	3	4	3	2	4	3	3
Total P [mg/l]	0.2	0.1	0.1	0.3	0.2	0.1	0.1	0.2	0.1	0.2	0.2	0.1

In order to determine the influence of environmental factors on diatom species composition, the redundancy analysis (RDA) was used, with centering and standardization by response variables. The RDA method was selected on the basis of the detrended correspondence analysis (DCA), which had a linear character (length of gradient 0.42). Statistical calculations and graphical interpretations were performed using Canoco 5.03 software. Data was considered statistically significant if the level of significance was less than 0.05 (Ter Braak & Šmilauer 2012). Selected chemical parameters were used for analysis (COD, BOD_5, nitrates, ammonia).

4. Results

Water pH during the study was alkaline and had similar values (7.6-8.1) at all sampling sites. Water temperature was within the range of 5.7 to 16.6°C depending on sampling season. Electrolytic conductivity increased along the course of the stream. The lowest values of conductivity were recorded in early spring of 2012, the highest – in summer at all sampling sites. Chemical water parameters showed a deviation from the standard corresponding to the first quality class only at site two. BOD_5, $N\text{-}NO_3$ and phosphorus corresponded to the second quality class, while the content of $N\text{-}NH_4$ showed a below good ecological status. Other sampling sites had similar chemical parameter values, which classified them as first class (Table 2).

In all, 259 diatom taxa were recorded in the Przyrwa stream in the three studied seasons (selected diatom taxa are shown in Fig. 2). The most frequent were taxa from the *Nitzschia* (39), *Gomphonema* (28) and *Navicula* (27) genera. The greatest species richness was at site two, where 172 taxa were found. The smallest number of taxa was recorded in the spring section, at site one – 147 taxa (see Appendix 1). The highest values in the Shannon-Wiener (H') species diversity index were recorded in

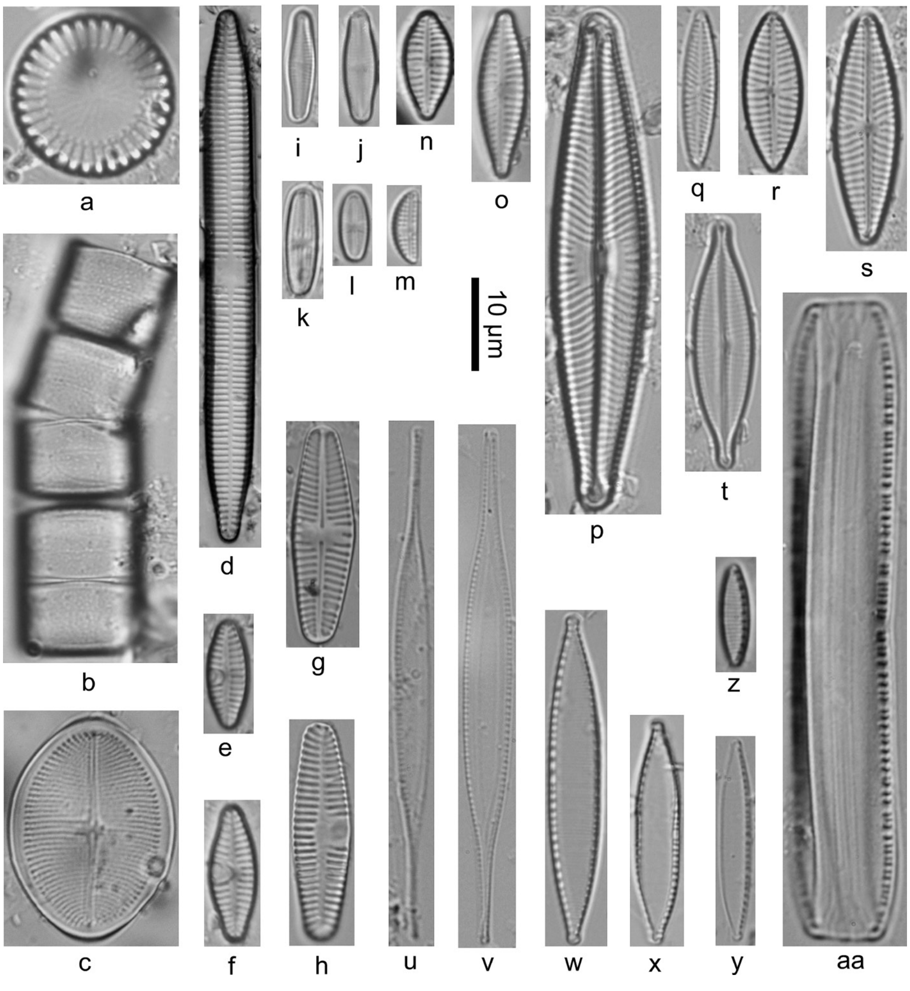

Fig. 2. LM micrographs of dominant diatom taxa recorded in the Przyrwa stream

Explanations: a – *Cyclotella meneghiniana*, b – *Melosira varians*, c – *Cocconeis pediculus*, d – *Ulnaria ulna*, e-f – *Planothidium frequentissimum*, g-h – *P. lanceolatum*, i-j – *Achnanthidium minutissimum* var. *minutissimum*, k-l – *Eolimna minima*, m – *Amphora pediculus*, n-o – *Gomphonema parvulum* var. *parvulum*, p – *Navicula lanceolata*, q – *N. tenelloides*, r-s – *N. antonii*, t – *N. gregaria*, u-v – *Nitzschia acicularis*, w – *N. palea* var. *palea*, x – *N. capitellata*, y – *N. pusilla*, z – *N. frustulum* var. *frustulum*, aa – *N. linearis*

Table 3. The IPS, GDI, TDI indices and %PT values at all sampling sites in the Przyrwa stream in 2011-2012

Date	Site	IPS	GDI	TDI	%PT
06.2011	1	12.6	10.3	77.7	28.8
	2	12.4	11.7	73.4	44.6
	3	12.5	10.8	85.6	32.0
	4	13.9	12.5	71.7	27.1
09.2011	1	12.7	11.0	77.2	17.6
	2	7.4	9.4	74.0	30.8
	3	11.2	11.9	81.8	19.5
	4	10.6	10.6	84.4	28.6
03.2012	1	13.1	11.9	77.1	14.7
	2	11.4	11.4	78.5	29.0
	3	13.5	11.7	84.8	30.7
	4	12.0	10.6	84.4	36.3

Explanations: ecological status – moderate, – poor, – bad

March 2012 at site number two, the lowest – in June 2011 at site number three (Table 2).

Among 259 diatom taxa, 20 taxa were considered as abundant species (i.e. those that accounted for a min. 5% of relative abundance) (see Appendix 1 – dominant taxa are bolded). The highest relative abundance (>20%) were achieved for *Ulnaria ulna* (Nitzsch) Compère (in summer, at site number one) and *Cocconeis pediculus* Ehrenb. (in spring, at site number three). The spring section was characterized by numerous development of *Planothidium frequentissimum* (Lange-Bert.) Lange-Bert. and *P. lanceolatum* (Brébisson) Lange-Bert. The most numerously occurring taxa in the middle and lower sections were *Navicula gregaria* Donkin, *N. lanceolata* (C. Agardh) Ehrenb., *Amphora pediculus* (Kütz.) Grunow and *Eolimna minima* (Grunow) Lange-Bert. (at site number three) and *Melosira varians* C. Agardh (at site number four). *Cyclotella meneghiniana* Kütz. (only in summer) and *Achnanthidium minutissimum* (Kütz.) Czarnecki var. *minutissimum* (in spring) occurred numerously. At all sites, *Achnanthidium minutissimum* var. *minutissimum* and *Navicula gregaria* were always dominant taxa (Fig. 2).

Water quality investigations were performed using diatom indices calculated employing OMNIDIA software (Lecointe *et al*. 1993), in order to determine the ecological status of the Przyrwa stream based on the structure of the identified diatom assemblages. IPS and GDI indices showed a better ecological status of the Przyrwa stream (mostly III-IV class) at all sampling sites and seasons compared to the TDI index (indicating mainly IV-V class). The lowest IPS and GDI index values were recorded at site number two in summer, while the highest values were recorded at site number four in spring. Based on diatom indices, the Przyrwa stream was characterized by a moderate and poor water quality. The TDI diatom index value indicated mostly eutrophic and hypertrophic water, the % of PT indicated the possibility of organic pollutant that could contribute significantly to the eutrophication. The lowest PT values were recorded at site number one in the early spring of 2012 (14.7%), whereas the highest were recorded at site number two in the spring of 2011 (44.6%) – Table 3.

Statistically significant correlations between environmental factors and the structure of diatom assemblages were found (F=1.6, p=0.03). RDA analysis explained a fitted variation of 28.5% in the first axis, 42.2% – in the second axis, 51.8% – in the third axis and 59.8% – in the fourth axis. The environmental factors which were shown to have the most statistically significant influence (p<0.05) on the differentiation of diatom assemblages were nitrate ions (which explained 25.5% of variability), electrolytic conductivity (20.1% of variability) and BOD_5 (16.5% of variability).

Based on statistical analyses performed using RDA, site number one was distinguished and formed a separate group consisting of all sampling seasons. Separation of this group was associated with the occurrence of *Nitzschia linearis* (C. Agardh) W. Smith, *Navicula antonii* Lange-Bert., *N. tenelloides* Hust., *Planothidium frequentissimum* and *P. lanceolatum*, which were mostly negatively correlated with the content of the studied chemical indicators (Fig. 3).

In the Przyrwa stream, 23 diatom taxa from the Polish Red List of Algae (Siemińska *et al.* 2006) were recorded, which constituted 8.9% of all recorded diatom taxa. Most diatoms were of the R (rare) category – 10 taxa: *Achnanthes coarctata* (Brébisson) Grunow, *Caloneis fontinalis* (Grunow) Lange-Bert. & Reichardt, *C. lancettula* (Schulz-Danzing) Lange-Bert. & Witkowski, *C. molaris* (Grunow) Krammer, *Fallacia subhamulata* (Grunow) D.G. Mann, *Luticola acidoclinata* Lange-Bert., *Mayamaea excelsa* (Krasske) Lange-Bert., *Navicula cincta* (Ehrenb.) Ralfs, *Stauroneis termicola*

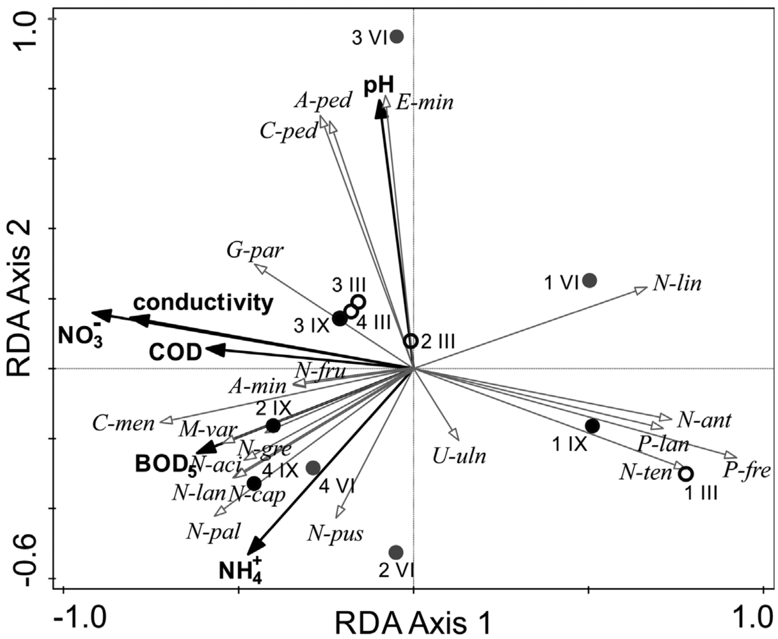

Fig. 3. Diagram of the redundancy analysis (RDA) presenting the relationships between the analyzed diatom assemblages and environment variables (white dots – samples from March, grey dots – samples from June, black dots – samples from September)

Explanations: A-min (*Achnanthidium minutissimum* var. *minutissimum*), A-ped (*Amphora pediculus*), C-ped (*Cocconeis pediculus*), C-men (*Cyclotella meneghiniana*), E-min (*Eolimna minima*), G-par (*Gomphonema parvulum* var. *parvulum*), M-var (*Melosira varians*), N-ant (*Navicula antonii*), N-gre (*N. gregaria*), N-lan (*N. lanceolata*), N-ten (*N. tenelloides*), N-aci (*Nitzschia acicularis*), N-cap (*N. capitellata*), N-fru (*N. frustulum* var. *frustulum*), N-lin (*N. linearis*), N-pal (*N. palea* var. *palea*), N-pus (*N. pusilla*), P-fre (*Planothidium frequentissimum*), P-lan (*P. lanceolatum*), U-uln (*Ulnaria ulna*)

(Petersen) Lund and *Surirella brebissonii* Krammer & Lange-Bert. var. *brebissonii*. Endangered taxa (E) were represented by the following six taxa: *Eunotia botuliformis* Wild, Nörpel & Lange-Bert., *Fallacia lenzii* (Hust.) Lange-Bert., *Pinnularia subrupestris* Krammer var. *subrupestris*, *P. viridiformis* Krammer, *Sellaphora pseudopupula* (Krasske) Lange-Bert. and *Navicula wildii* Lange-Bert. In the vulnerable category, (V) five taxa were noted: *Gomphonema sarcophagus* Gregory, *Neidium ampliatum* (Ehrenb.) Krammer, *Psammothidium lauenburgianum* (Hust.) Bukhtiyarova & Round, *Stauroneis gracilis* Ehrenb. and *S. phoenicenteron* (Nitzsch) Ehrenb. Two taxa were found representing category I (indeterminate threat): *Eunotia valida* Hust. and *Ulnaria oxyrhynchus* (Kütz.) Aboal. The selected diatom taxa recorded in the Przyrwa stream are presented in Figure 4.

5. Discussion

Annual quality assessment and classification of watercourses were based on the analysis of water physicochemical properties. Biological monitoring studies were used sporadically – usually a saprobic system was used, and the index value was determined on the basis of planktonic microorganisms. According to the Water Framework Directive, ecological status is assessed on the basis of biological, physicochemical and hydro-morphological elements. In keeping with the above Directive, the most important elements on which the status of water should be classified are biological elements, while other elements (physicochemical and hydro-morphological) complement them (Panek 2011; Śliwa-Dominiak & Deptuła 2012).

Monitoring studies were performed on the Przyrwa stream using diatoms to assess water quality by employing three diatom indices from which IPS and GDI are commonly used in bioindication studies based on diatoms in flowing waters. The study conducted showed that the waters of the Przyrwa stream were always of an alkaline character (pH>7) over the entire length of the watercourse. Most investigated rivers and streams in the Subcarpathian Voivodeship have alkaline or close to neutral reaction, especially in their upper sections (Pajączek *et al*. 2012; Noga 2012; Noga *et al*. 2013a, 2013b, 2013c).

The chemical parameters indicated a very good ecological status of the Przyrwa stream – quality class I at sites one, two and three. Elevated values of BOD_5, ammonia, nitrates and phosphorus at site two reduced water quality of the stream, indicating a good (II class of water quality) chemical status (Decree of the Minister of the Environment from 30 October 2014). Electrolytic conductivity values were medium or high (300-855 µS/cm). This may have been caused by the discharge of sewage from adjacent buildings located in close proximity to the watercourse or may have resulted from agricultural activities (especially in the upper part), runoff from streets and penetration of nutrients from residential areas (in the middle and lower sections). A relatively small and shallow stream favors a greater concentration of nutrients, especially at low water levels, and contributes to the fertility of waters. Comparing the chemical parameters of the Przyrwa stream with other investigated waters in the Subcarpathian Voivodeship, water quality was found similar in Różanka and Matysówka streams and the Mleczka and Morwawa Rivers (Pajączek *et al*. 2012; Noga *et al*. 2013b, 2013c).

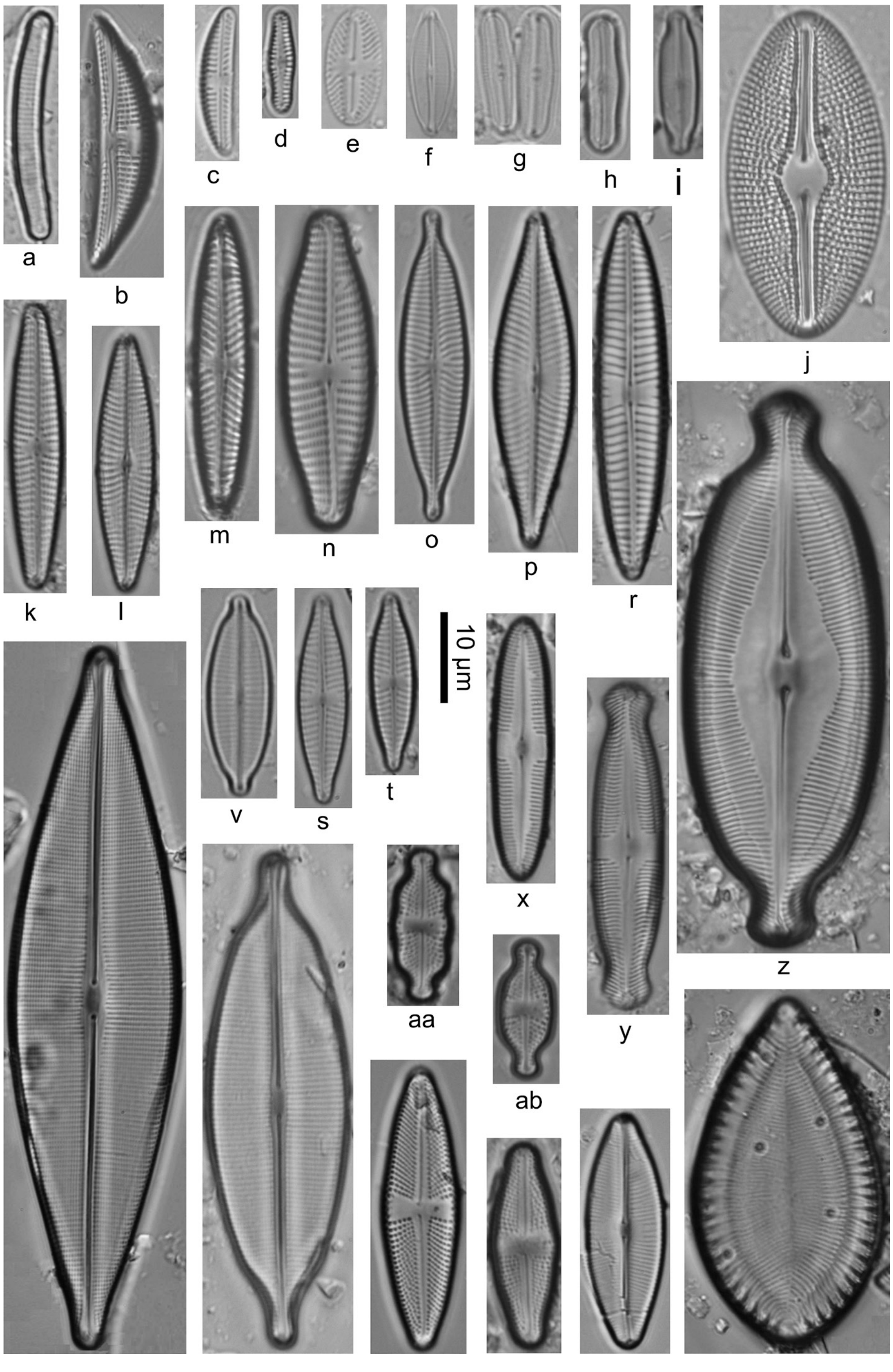

Fig. 4. LM micrographs of selected diatom taxa recorded in the Przyrwa stream

Explanations: a – *Eunotia botuliformis*, b – *Amphora copulata*, c – *Amphora inariensis*, d – *Chamaepinnularia muscicola*, e – *Mayamaea asellus*, f – *Craticula molestiformis*, g-h – *Fallacia lenzii*, i – *Adlafia bryophila*, j – *Diploneis krammeri*, k – *Navicula libonensis*, l – *N. erifuga*, m – *N. cari*, n – *N. slesvicensis*, o – *N. capitatoradiata*, p – *N. trivialis*, r – *N. tripunctata*, s-t – *N. veneta*, u – *Craticula cuspidata*, v – *C. accomoda*, w – *C. ambigua*, x – *Caloneis molaris*, y – *C. macedonica*, z – *C. amphisbaena*, aa – *Luticola nivalis*, ab – *L. ventricosa*, ac – *L. goeppertiana*, ad – *L. acidoclinata*, ae – *Sellaphora bacilloides*, af – *Surirella ovalis*

During the studies conducted in the Przyrwa stream in 2011-2012, the total of 259 diatom taxa was identified. In terms of species richness, the stream does not stand out significantly from other courses in the Subcarpathian Voivodeship – similar numbers of taxa were recorded in the Matysówka (271 taxa) and Różanka streams (202) and in the Morwawa (224) and Mleczka Rivers (277) (Pajączek *et al*. 2012; Noga *et al*. 2013b). Many more taxa – 401 – were identified in the Wisłok River (Noga 2012) and in the Żołynianka stream (427) (Peszek *et al*. 2015). The investigated sites in the Przyrwa stream were characterized by a similar number of diatom taxa, and high species diversity indicates that there were favorable conditions for development. A high diatom species richness was also confirmed by Shannon-Wiener (H') species diversity index values ranging from 3.83 to 5.91; it reached the highest value at the second site, at which the most diatom taxa were noted. The Przyrwa stream was characterized by the occurrence of 20 abundant taxa. At all sites, *Navicula gregaria* were dominant. *Achnanthidium minutissimum* var. *minutissimum* were dominant taxa at all sites but only in June 2011. The largest populations (>20%) consisted of *Ulnaria ulna* (in summer, the first site) and *Cocconeis pediculus* (in spring, at the third site).

Achnanthidium minutissimum var. *minutissimum* is one of the most common diatoms in waters with different hydrological conditions. It prefers waters from oligo- to eutrophic, β-mesosaprobic (II class). It has a wide spectrum of tolerance in terms of pH (from 4.3 to 9.2). It occurs most frequently in the upper sections of watercourses, in clean and well oxygenated waters, prefers mountain streams with stony beds and high-speed water flows (Krammer & Lange-Bertalot 1991b; Van Dam *et al*. 1994; Hofmann *et al*. 2011). In the Przyrwa stream, species occurred at all four sampling sites in the spring season in June 2011, reaching 10-20% in number at site two and 5-10% of the number at site one. Currently, new species separated from *Achnanthidium minutissimum* complex are described, but their ecology is still not specified (Novais *et al*. 2015). However, cells growing in the Przyrwa stream were typical for *A. minutissimum* var. *minutissium*. In the Subcarpathian Voivodeship, the taxon occurs in many rivers and streams, often reaching the rank of dominant, especially in upper sections of watercourses (Noga & Siry 2010; Tambor & Noga 2011; Noga 2012; Pajączek *et al*. 2012; Noga *et al*. 2013a, 2013b, 2013c, 2014a, 2014b, 2015; Peszek *et al*. 2015).

In the middle and lower reaches of the Przyrwa stream, *Navicula gregaria* developed numerously (about 20% of the total in the spring season of 2011). It is a cosmopolitan species in Central Europe, one of the most common diatoms, and has been characterized as meso-halophilous. It occurs in marine habitats, brackish waters up to oligotrophic freshwaters with an average content of electrolytes. Optimum occurrence is at lower temperatures and is tolerant to pollution up to α-mesosaprobic (Krammer & Lange-Bertalot 1986). It is found most often in the lower reaches of rivers, where waters significantly slow down and bring a large amount of sediment. It is one of the most dominant species in most of the rivers and streams in the Subcarpathian Voivodeship, especially in their middle and lower sections (Bernat & Noga 2012; Noga 2012; Pajączek *et al*. 2012; Noga *et al*. 2013a, 2013b, 2013c, 2014a, 2015; Peszek *et al*. 2015).

Another dominant species in the Przyrwa stream, *Cocconeis pediculus,* occurred massively in the spring of 2011 at the third site, reaching more than 20% in number. It is an epiphytic and cosmopolitan diatom, occurring in inland waters with a medium to high content of electrolytes and in coastal salt waters. The species often massively covers other green algae and taller plants submerged in water by wearing a coat in the form of so-called "scum" (Krammer & Lange-Bertalot 1991b).

Ulnaria ulna occurs in oligo- to polytrophic and oligo-saprobic to α-mesosaprobic waters (Hofmann *et al*. 2011). It is a diatom resistant to and tolerant of saprobic water pollution and its presence in the Przyrwa stream (>20% of the number at site 1 in the summer of 2011) showed the eutrophic character of the stream.

Statistical analysis (using RDA method) showed that in terms of the domination structure, the first site, associated with *Navicula antonii*, *N. tenelloides*, *Nitzschia linearis*, *Planothidium frequentissimum* and *P. lanceolatum*, was the most distinguished among the other ones. These species were mostly negatively correlated with the studied chemical parameters. These diatoms have a wide ecological amplitude of occurrence in different types of waters, often alkaline and rich in calcium (*Navicula tenelloides, Nitzschia linearis*) and, frequently, under conditions of medium to high trophy (Krammer & Lange-Bertalot 1986, 1988, 1991b; Lange-Bertalot 2001; Hofmann *et al*. 2011). In the Subcarpathian Voivodeship, they often achieve their highest numbers in the upper reaches of small rivers and streams (Noga & Siry 2010; Bernat & Noga 2012; Pajączek *et al*. 2012; Noga *et al*. 2013b, 2013c; Peszek *et al*. 2015).

Comparing diatom indices with chemical parameters, which classify the Przyrwa stream mostly at I and II class of water quality, the obtained index values greatly underestimated the quality of the watercourse, pointing to a moderate, poor or bad ecological status of the stream (III-V class). Chemical analyses characterize the water at the time of measurement, while aquatic organisms are influenced by specific physicochemical conditions resulting from the type and degree of pollution. They allow us to better determine water quality through changes in the environment for longer periods of time (Kołodziejczyk *et al*. 1998).

IPS and GDI indices of general pollution showed better water quality along the entire length of the Przyrwa stream (mostly moderate and poor ecological status – III or IV class) compared with the TDI trophic index, which indicated a poor or bad ecological status of the stream (IV-V class). The values of PT for most studied sites were higher than 20%, which suggests the possibility of organic pollution, especially in the middle and lower reaches of the stream. At the second site in the spring season, the PT was 44.6%, indicating that the factor limiting growth of diatoms need not have been phosphates but other factors like, for example, organic pollution. In the case where the PT index values were lower than 20%, the TDI index could give a reliable indication of the nutrient status of the river (Kelly & Whitton 1995; Kelly *et al*. 2001). Only in the upper section, the PT index showed less than 20%. For this reason, IPS and GDI indices seem to work better in the assessment of water quality in Poland.

IPS and GDI indices were previously used to assess the quality of rivers in the southern part of Poland (Kawecka *et al*. 1999; Kwandrans *et al*. 1999; Dumnicka *et al*. 2006). Moreover, IPS and GDI indices were among those proposed for water assessment in the Gulf of Gdansk (Bogaczewicz-Adamczak & Dziengo 2003). Studies carried out in central Poland showed that the IPS index works best in assessing water quality and can be widely used in Poland to assess saprobic pollution of flowing waters (Szczepocka & Szulc 2009; Rakowska & Szczepocka 2011). Its universality results from the fact that it includes the largest number of taxa – about 2 500 (Prygiel 2002). During the studies carried out so far, the highest correlation with environmental factors was obtained just using the IPS index (Kawecka *et al*. 1999; Kwandrans *et al*. 1999; Bogaczewicz-Adamczak & Dziengo 2003). Also in Finland and France, the IPS index yielded the best results in the assessment of water quality (Descy & Coste 1990; Eloranta & Kwandrans 1996). The analysis of relationships between diatoms indices and abiotic factors showed that IPS is the most adequate index for water quality assessment in many European Union countries (Prygiel & Coste 1993; Szabó *et al*. 2004; Gomà *et al*. 2005; Blanco *et al*. 2007).

In the Subcarpathian Voivodeship, studies are being conducted using diatom indices, which also confirm that GDI and IPS indices work better than TDI in the assessment of water quality (Noga *et al*. 2013a, 2013b, 2013c, 2015; Peszek *et al*. 2015). The trophic index significantly indices worse investigated waters quality, reaching the highest values (bad ecological status), especially in small streams (Noga *et al*. 2013b, 2013c; Peszek *et al*. 2015).

In the flora of the Przyrwa stream, 23 diatom taxa from the Polish Red List of Algae were found – 8.9% of the total of indicated diatoms. The Matysówka stream was characterized by a similar number of taxa from the Red List (25 taxa). That stream flows through the territory of the city of Rzeszów (Noga *et al*. 2012, 2013b).

Six taxa were noted as endangered (E): *Eunotia botuliformis*, *Fallacia lenzii*, *Pinnularia subrupestris*, *P. viridiformis*, *Sellaphora pseudopupula* and *Navicula wildii*. Most of them occurred in many investigated watercourses within the territory of the Subcarpathian Voivodeship, but often in the form of single cells (Noga & Siry 2010; Tambor & Noga 2011, 2012; Bernat & Noga 2012; Pajączek *et al*. 2012; Noga *et al*. 2013b, 2013c, 2014a, 2014b, 2015; Peszek *et al*. 2015), some, like *Eunotia botuliformis* or *Navicula wildii*, occurred very rarely.

Eunotia botuliformis was found in the Przyrwa stream only at the second site, as a single cell. The optimum occurrence of this species was determined in streams with a siliceous bed in the lowlands of northern Germany, where it formed very large populations in places. It occurred in streams and stagnant waters at medium-height mountainous areas and, less frequently, in lowlands. It was found especially in anthropogenically altered, oligotrophic or dystrophic low-electrolyte waters (Hofmann *et al*. 2011). It occurred very rarely in springs in southern Poland (Wojtal 2013) and the upper part of the San River (Noga *et al*. 2014b).

Navicula wildii also occurred in the Przyrwa stream, but only in spring sections as a single cell. It develops in less numerous populations, in calcium-rich, oligo- to slightly mesotrophic lakes. Optimum occurrence is in alpine and sub-alpine areas, and it is rarely noted in lowlands of northern Germany. It is an indicator of very good water quality (Hofmann *et al*. 2011). So far, it was very rarely reported in the area of NW Poland (Witkowski *et al*. 2011).

Among the diatoms indicated in the Przyrwa stream, species very rare to Poland were found. These species do not appear on the Polish Red List of Algae, but have a very interesting ecology, as does *Caloneis macedonica*. It is a species recorded in the Balkans, Sinai and the lakes of northern Germany (Krammer & Lange-Bertalot 1986). It was also noted in springs in central Poland (Żelazna-Wieczorek 2011). Within the territory of the Subcarpathian Voivodeship, a single specimen was also found in the Mleczka River (Pajączek *et al*. 2012). In the Przyrwa stream, the species occurred in the form of single specimens at the second and third sites.

All species that were considered rare or endangered had an average value of indication (indicator value 2). Their ecological range was contained mainly between stenoency (indicator value 3) and euryency (indicator value 1) – according to OMNIDIA 4.2.

The Przyrwa stream, in the middle and lower sections flowing through urban areas, was transformed anthropogenically. Nevertheless, in the waters of the stream, a number of rare and endangered species from the Polish Red List of Algae were noted. Also, other watercourses flowing through Rzeszów area are characterized by a high species richness and presence of rare and interesting diatoms (Noga *et al*. 2012, 2013a). Construction of sewage systems in all towns located along the course of the stream could further contribute to the improvement in water quality, which is currently characterized by very high fertility and provides habitats to many eutrophic diatom taxa.

Most chemical parameters showed a very good chemical status of the Przyrwa Stream waters (first class), while the diatom indices showed poorer quality of water (moderate and poor ecological status). Living organisms such as diatoms are influenced by many environmental factors (water chemistry, the nature of the substrate, diversity of habitats, insolation, flow volume, etc.). Therefore, in the anthropogenically transformed stream, they will indicate inferior water quality compared to chemical parameters.

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Appendix 1. The list of diatom taxa recorded in the Przyrwa stream in 2011-2012 (dominant taxa are bolded)

Achnanthes coarctata (Brébisson) Grunow
Achnanthes expressa J.R.Carter
Achnanthidium eutrophilum (Lange-Bert.) Lange-Bert.
Achnanthidium minutissimum* (Kütz.) Czarnecki var. *minutissimum
Achnanthidium pyrenaicum (Hust.) Kobayasi
Adlafia bryophila (Petersen) Lange-Bert.
Adlafia minuscula (Grunow) Lange-Bert. var. *minuscula*
Amphora copulata (Kütz.) Schoeman & Archibald
Amphora inariensis Krammer
Amphora indistincta Levkov
Amphora lange-bertalotii Levkov & Metzeltin
Amphora lange-bertalotii var. *tenuis* Levkov & Metzeltin
Amphora ovalis (Kütz.) Kütz.
***Amphora pediculus* (Kütz.) Grunow**
Anomoeneis sphaerophora Pfitzer
Brachysira calcicola ssp. *pfisteri* Lange-Bert. & Werum
Brachysira sp.
Caloneis amphisbaena (Bory) Cleve
Caloneis fontinalis (Grunow) Lange-Bert. & Reichardt
Caloneis lancettula (Schulz-Danzing) Lange-Bert. & Witkowski
Caloneis macedonica Hust.
Caloneis molaris (Grunow) Krammer
Caloneis silicula (Ehrenb.) Cleve
Chamaepinnularia muscicola (Petersen) Kulikovskiy, Lange-Bert. & Witkowski

Chamaepinnularia submuscicola
(Krasske) Lange-Bert.
***Cocconeis pediculus* Ehrenb.**
Cocconeis placentula var. *euglypta* (Ehrenb.) Grunow
Cocconeis placentula var. *lineata*
(Ehrenb.) Van Heurck
Craticula accomoda (Hust.) D.G. Mann
Craticula ambigua (Ehrenb.) D.G. Mann
Craticula cuspidata (Kütz.) D.G. Mann
Craticula molestiformis (Hust.) Lange-Bert.
***Cyclotella meneghiniana* Kütz.**
Cymatopleura solea (Brébisson) W. Smith var. *solea*
Cymatopleura solea var. *apiculata* (W. Smith) Ralfs
Cymbella cymbiformis C. Agardh
Cymbella excisa Kütz.
Cymbella subcistula Krammer
Cymbopleura inaequaliformis Krammer
Cymbopleura inaequalis (Ehrenb.) Krammer
Cymbopleura subaequalis (Grunow) Krammer
var. *subaequalis*
Denticula subtilis Grunow
Denticula tenuis Kütz.
Diadesmis contenta (Grunow) D.G. Mann
Diadesmis paracontenta ssp. *paracontenta*
Lange-Bert. & Werum
Diadesmis sp.
Diatoma vulgaris Bory
Diatoma cf. *moniliformis* (Kütz.) D.M. Williams
Diploneis fontanella Lange-Bert.
Diploneis krammeri Lange-Bert. & Reichardt
Diploneis minuta Petersen
Diploneis oculata (Brébisson) Cleve
Diploneis separanda Lange-Bert.
Discostella pseudostelligera (Hust.) Houk & Klee
Encyonema minutum (Hilse) D.G. Mann
Encyonema silesiacum (Bleisch) D.G. Mann
Encyonema ventricosum (C. Agardh) Grunow
Encyonopsis minuta Krammer & Reichardt
***Eolimna minima* (Grunow) Lange-Bert.**
Eolimna subminuscula
(Manguin) Moser, Lange-Bert. & Metzeltin
Epithemia adnata (Kütz.) Brébisson
Epithemia sorex Kütz.
Eunotia bilunaris (Ehrenb.) Schaarschmidt
Eunotia botuliformis Wild, Nörpel & Lange-Bert.
Eunotia valida Hust.
Eunotia sp.
Fallacia lenzii (Hust.) Lange-Bert.
Fallacia monoculata (Hust.) D.G. Mann
Fallacia pygmaea (Kütz.) A.I. Srickle & D.G. Mann ssp.
pygmaea
Fallacia pygmaea ssp. *subpygmaea*
Lange-Bert., Cavacini, Tagliaventi & Alfinito
Fallacia subhamulata (Grunow) D.G. Mann
Fistulifera saprophila
(Lange-Bert. & Bonik) Lange-Bert.
Fragilaria capucina Desmazières var. *capucina*
Fragilaria gracilis Østrup
Fragilaria perminuta (Grunow) Lange-Bert.
Fragilaria radians (Kütz.) Lange-Bert.
Fragilaria recapitellata Lange-Bert. & Metzeltin
Fragilaria rumpers (Kütz.) Carlson
Fragilaria vaucheriae (Kütz.) Petersen
Frustulia saxonica Rabenh.
Frustulia vulgaris (Thwaites) De Toni
Gomphonema acidoclinatum Lange-Bert. & Reichardt
Gomphonema acuminatum Ehrenb. var. *acuminatum*
Gomphonema capitatum Ehrenb.
Gomphonema clavatum Ehrenb.
Gomphonema drutelingense Reichardt
Gomphonema exillisimum
(Grunow) Lange-Bert. & Reichardt
Gomphonema gracile Ehrenb.
Gomphonema insigne Gregory
Gomphonema italicum Kütz.
Gomphonema micropus Kütz.
Gomphonema minutum (C. Agardh) C. Agardh
Gomphonema olivaceum (Hornemann) Brébisson
var. *olivaceum*
Gomphonema pala Reichardt
Gomphonema parvulius
(Lange-Bert. & Reichardt) Lange-Bert. & Reichardt
Gomphonema parvulum* (Kütz.) var. *parvulum
Gomphonema parvulum Lange-Bert. & Reichardt
var. *parvulum* f. *saprophilum*
Gomphonema pumilum
(Grunow) Reichardt & Lange-Bert.
Gomphonema sarcophagus Gregory
Gomphonema subclavatum (Grunow) Grunow
Gomphonema utae Lange-Bert. & Reichardt
Gomphonema cf. *bohemicum* Reichelt & Fricke
Gomphonema cf. *pumilum*
(Grunow) Reichardt & Lange-Bert.
Gomphonema cf. *sarcophagus* Gregory
Gomphonema sp. 1
Gomphonema sp. 2
Gomphonema sp. 3
Gomphonema sp. 4
Gyrosigma acuminatum (Kütz.) Rabenh.
Gyrosigma attenuatum (Kütz.) Rabenh.
Gyrosigma obtusatum
(Sullivant & Wormley) C.S. Boyer
Halamphora montana (Krasske) Levkov
Halamphora normannii (Rabenh.) Levkov
Hantzschia abundans Lange-Bert.
Hantzschia amphioxys (Ehrenb.) Grunow
Hantzschia calcifuga Reichardt & Lange-Bert.
Hippodonta capitata
(Ehrenb.) Lange-Bert., Metzeltin & Witkowski
Lemnicola hungarica (Grunow) Round & Basson
Luticola acidoclinata Lange-Bert.
Luticola dismutica (Hust.) D.G. Mann
Luticola goeppertiana (Bleisch) D.G. Mann
Luticola mutica (Kütz.) D.G. Mann
Luticola nivalis (Ehrenb.) D.G. Mann
Luticola ventriconfusa Lange-Bert.
Luticola ventricosa (Kütz.) D.G. Mann
Luticola cf. *dismutica* (Hust.) D.G. Mann
Luticola sp.
Mayamaea atomus (Kütz.) Lange-Bert. var. *atomus*
Mayamaea atomus var. *permitis* (Hust.) Lange-Bert.
Mayamaea asellus (Weinhold) Lange-Bert.
Mayamaea excelsa (Krasske) Lange-Bert.
Mayamaea fossalis (Krasske) Lange-Bert.
var. *fossalis*.
Mayamaea cf. *agrestis* (Hust.) Lange-Bert.
***Melosira varians* C. Agardh**
Meridion circulare (Grèville) C. Agardh
var. *circulare*
Meridion circulare var. *constrictum*
(Ralfs) Van Heurck
***Navicula antonii* Lange-Bert.**
Navicula aquaedurae Lange-Bert.
Navicula capitatoradiata Germain
Navicula cari Ehrenb.
Navicula cariocincta Lange-Bert.
Navicula cincta (Ehrenb.) Ralfs
Navicula cryptocephala Kütz.
Navicula cryptonella Lange-Bert.
Navicula erifuga Lange-Bert.
***Navicula gregaria* Donkin**
Navicula kotschyi Grunow
Navicula lacuum
Lange-Bert., G. Hofmann, Werum & Van de Vijver
***Navicula lanceolata* (C. Agardh) Ehrenb.**
Navicula libonensis Schoeman

Navicula lundii Reichardt
Navicula radiosa Kütz.
Navicula reichardtiana Lange-Bert.
Navicula slesvicensis Grunow
***Navicula tenelloides* Hust.**
Navicula tripunctata (O.F. Müller) Bory
Navicula trivialis Lange-Bert.
Navicula vandamii Schoeman & Archibald var. *vandamii*
Navicula veneta Kütz.
Navicula vilaplanii (Lange-Bert. & Sabater) Lange-Bert. & Sabater
Navicula viridula (Kütz.) Ehrenb.
Navicula wiesnerii Pantocsek
Navicula wildii Lange-Bert.
Neidium ampliatum (Ehrenb.) Krammer
Neidium binodeforme Krammer
Neidium cf. *affine* (Ehrenb.) Pfitzen
***Nitzschia acicularis* (Kütz.) W. Smith**
Nitzschia acidoclinata Lange-Bert.
Nitzschia adamata Hust.
Nitzschia amphibia Grunow
Nitzschia archibaldii Lange-Bert.
Nitzschia calida Grunow
***Nitzschia capitellata* Hust.**
Nitzschia communis Rabenh.
Nitzschia constricta (Kütz.) Ralfs
Nitzschia debilis (Arnott) Grunow
Nitzschia desertorum Hust.
Nitzschia dissipata (Kütz.) Grunow ssp. *dissipata*
Nitzschia dissipata var. *media* (Hantzsch) Grunow
Nitzschia dubia W. Smith
Nitzschia frustulum* (Kütz.) Grunow var. *frustulum
Nitzschia gracilis Hantzsch
Nitzschia hantzschiana Rabenh.
Nitzschia heufleriana Grunow
Nitzschia hungarica Grunow
Nitzschia intermedia Hantzsch
***Nitzschia linearis* (C. Agardh) W. Smith**
Nitzschia palea var. *debilis* (Kütz.) Grunow
Nitzschia palea* (Kütz.) W. Smith var. *palea
Nitzschia paleacea (Grunow) Grunow
Nitzschia perminuta (Grunow) M. Peragallo
***Nitzschia pusilla* Grunow**
Nitzschia recta Hantzsch
Nitzschia sigma (Kütz.) W. Smith
Nitzschia sigmoidea (Nitzsch) W. Smith
Nitzschia solgensis Cleve-Euler
Nitzschia sublinearis (?) Hust.
Nitzschia subtilis Grunow
Nitzschia supralitorea Lange-Bert.
Nitzschia tenuis W. Smith
Nitzschia tubicola Grunow
Nitzschia umbonata (Ehrenb.) Lange-Bert.
Nitzschia vermicularis (Kütz.) Hantzsch
Nitzschia cf. *ovalis* Arnott
Nitzschia sp.
Pinnularia appendiculata (C. Agardh) Cleve
Pinnularia borealis Ehrenb. var. *borealis*
Pinnularia borealis var. *sublinearis* Krammer
Pinnularia brebissonii (Kütz.) Rabenh.
Pinnularia kuetzingii Krammer
Pinnularia neomajor Krammer
Pinnularia obscura Krasske
Pinnularia subrupestris Krammer var. *subrupestris*
Pinnularia viridiformis Krammer
Pinnularia sp. cf. *kuetzingii* Krammer
Placoneis paraelginensis Lange-Bert.
Planothidium bipromum (Hohn & Hellerman) Lange-Bert.
***Planothidium frequentissimum* (Lange-Bert.) Lange-Bert.**
Planothidium rostratum (Østrup) Lange-Bert.
***Planothidium lanceolatum* (Brébisson) Lange-Bert.**
Platessa conspicua (A. Mayer) Lange-Bert.
Platessa holsatica (Hust.) Lange-Bert.
Psammothidium bioretii (Germain) Bukhtiyarova & Round
Psammothidium lauenburgianum (Hust.) Bukhtiyarova & Round
Reimeria sinuata (Gregory) Kociolek & Stoermer
Rhoicosphenia abbreviata (C. Agardh) Lange-Bert.
Rhopalodia gibba (Ehrenb.) O. Müller var. *gibba*
Sellaphora joubaudii (Germain) Aboal
Sellaphora bacilloides (Hust.) Levkov, Krstic & Nakov
Sellaphora pseudopupula (Krasske) Lange-Bert.
Sellaphora pupula (Kütz.) Mereschowsky
Sellaphora seminulum (Grunow) D.G. Mann
Sellaphora cf. *pseudopupula* (Krasske) Lange-Bert.
Simonsenia delognei (Grunow) Lange-Bert.
Stauroneis anceps Ehrenb.
Stauroneis gracilis Ehrenb.
Stauroneis leguminopsis Lange-Bert. & Krammer
Stauroneis parathermicola Lange-Bert.
Stauroneis phoenicenteron (Nitzsch) Ehrenb.
Stauroneis reichardtii Lange-Bert.
Stauroneis separanda Lange-Bert. & Werum
Stauroneis smithii Grunow
Stauroneis tackei (Hust.) Krammer, Lange-Bert., Kusber & Metzeltin
Stauroneis termicola (Petersen) Lund
Surirella angusta Kütz.
Surirella brebissonii Krammer & Lange-Bert. var. *brebissonii*
Surirella brebissonii var. *kuetzingii* Krammer & Lange-Bert.
Surirella helvetica Brun
Surirella linearis W. Smith
Surirella minuta Brébisson
Surirella ovalis Brébisson
Surirella tenera Gregory
Surirella terricola Lange-Bert.
Tabularia fasciculata (C. Agardh) D.M. Williams & Round
Ulnaria acus (Kütz.) Aboal
Ulnaria biceps (Kütz.) Compère
Ulnaria oxyrhynchus (Kütz.) Aboal
***Ulnaria ulna* (Nitzsch) Compère**