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Diatom indices in the biological assessment of the water quality based on the example of a small lowland river

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Key words: diatom indices, IO, IPS, GDI, Bacillariophyta, chemical water parameters, lotic waters

Abstract

The aim of the study was to compare the biological analyzes of the Linda River (Central Poland), which were based on three diatom indices: IO, GDI and IPS in order to select the best diatom index for the biological assessment of the lotic water quality. Additionally, the summary of the selected results of the biological and chemical analyzes was presented to show how precise the biological analyzes are as a basic tool in the assessment of the ecological status of the lotic waters. The results showed that each of the indices assessed the water in the Linda River to a specific but different quality class. The IO index showed class II of the water quality, while the IPS and GDI – class III. Statistical analysis conducted with the nonparametric Kruskal-Wallis test for independent samples (Kruskal, Wallis 1952) showed that differences in the values of individual indices at different sites were not statistically significant. It should be noticed that the IPS and GDI indices gave values that classify the water in the Linda River at least one class below.

The obtained results confirmed that the biological methods are most reliable in the assessment of the water quality. These methods are less sensitive to a single impact of the environmental factors, therefore they permit accurate determination of the ecological status of the water ecosystems.

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Introduction

The obligation of making the biological assessments of surface water bodies was introduced to the system of the Polish legal documents together with the access of Poland to the European Union and the implementation of the Framework Water Directive 2000/60/EC (WFD). The biological assessment of water ecosystems is the most objective way of gaining the knowledge of the conditions that occur in a given ecosystem. The assessment is carried out using aquatic organisms, which supply the precise information on the conditions occurring in the environment, because they are under continuous impact of physicochemical drivers resulting from the type and the degree of pollution. Until recently the water quality assessment was carried out on the basis of physicochemical analyzes, which determined the water quality only at the time of measurement. Such assessment was incomplete, because water quality may change over a short period of time, for example at the moment of uncontrolled sewage inflow. Therefore, the biological assessment is considered to be most important in the assessment of the ecological status of waters and is used together with physicochemical analyzes according to the Decree of the Minister of the Environment (Regulation of the Minister of the Environment a, b (OJ No 257, 258 pos. 1545, 1549 from 2011).

The ecological assessment of surface waters is based on the analysis of four groups of aquatic organisms: diatoms, aquatic invertebrates, fish and macrophytes. Diatom phytobenthos is now in Poland the basic tool for monitoring the quality of water ecosystems. Water quality classes are determined by diatom indices.

Large-scale research using diatom indices, including monitoring study, was conducted in France (Prygiel, Coste 1999; Prygiel 2002), Great Britain (Kelly et al. 1995, Kelly 2003, Kelly et al. 2008), and Finland (Eloranta, Soininen 2002). Diatom indices have also been found useful outside Europe, for example in Africa (Harding et al. 2005, Rey et al. 2004, Taylor et al. 2007).

In Poland, similar research was conducted by Picińska-Fałtynowicz (1998); Kwandrans et al. (1999); Bogaczewicz-Adamczak, Koźlarska (1999); Bogaczewicz-Adamczak et al. (2001); Rakowska (2001); Bogaczewicz-Adamczak, Dziengo (2003); Zgrundo, Bogaczewicz-Adamczak (2004); Żelazowski et al. (2004); Dumnicka et al. (2006); Szczepocka, Szulc (2009); Rakowska, Szczepocka (2011). Investigations into diatom indices, which concern the verification of lists of diatom taxa indicatory for various types of rivers, taking into account hydrological and physicochemical conditions, will permit the development of a diatom index that would precisely evaluate the water quality and would reflect the importance of biological assessment.

The aim of the present study was to indicate the most objective diatom index that can be used to assess the ecological status of the Polish lowland rives – on the example of the Linda River. The obtained results of the biological assessment of the water quality, performed using the Polish IO index − the Diatom Index (Picińska-Fałtynowicz 2006), were compared with the results obtained using two European indices such as GDI − Generic Diatom Index (Coste, Ayphassorho 1991), and IPS − the Specific Pollution Sensitivity Index (CEMAGREF 1982). On the basis of the selected samples, the results of the biological analyzes were also compared with the chemical analyzes of the water quality, which confirmed their usefulness in the monitoring of water ecosystems.

Materials And Methods

The Linda River, which is 12 km long, is a right-hand tributary of the Bzura River (Fig. 1). It has a natural river bed and its water is slightly polluted. A fragment of the Linda course flows across the "Grądy nad Lindą" reserve, which was created in

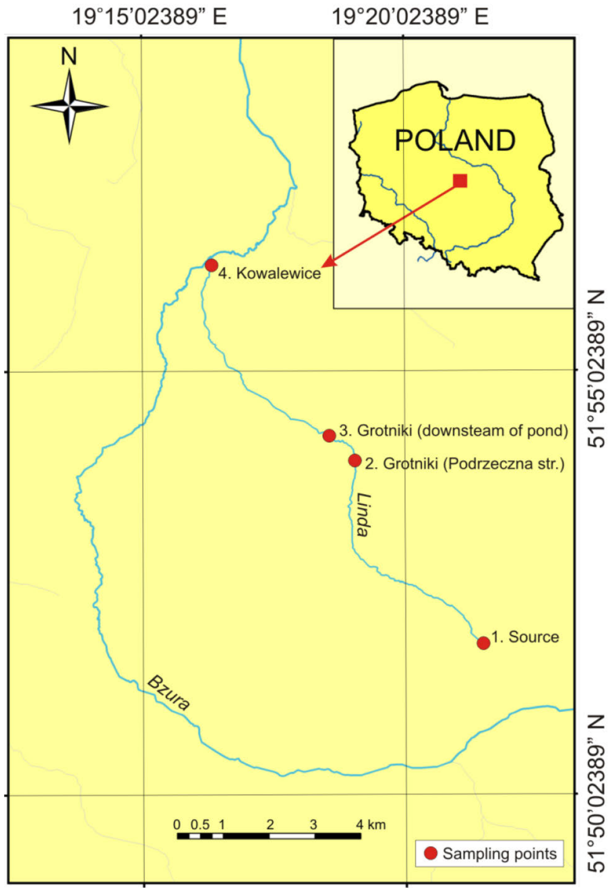

Fig. 1. Map of the study area

1997 to preserve the natural landscape, for which this forest river was an essential element. The sources of the river and its whole upper course are located in suburban communes of summer houses (Jedlicze, Grotniki), while further downstream, the Linda flows across a slightly urbanized area, thus it is not threatened with domestic and industrial pollutants. Four study sites were selected on the river: site 1 – the source, 2 – the upper course (Grotniki, Podrzeczna Str.), 3 – Grotniki (downstream of pond), 4 – Kowalewice.

Phytobentic samples were collected in the selected sites on the Linda River from March to November 2011. Microbenthos was collected from the sandy substrate. A total of 28 samples were collected. Diatom material was collected into 100 ml containers using a glass pipette, and then preserved in 4% formalin (PN-EN ISO 5667-6 (2003). The samples were combusted with a mixture of sulfuric and chromic acids. The cleaned silica frustules were mounted with Naphrax® resin and 400 frustules were counted on permanent slides. In this way, lists with a percentage of each taxon (Cholnoky 1968) were produced. Dominant (more than 5%) and subdominant (2-5%) species were identified.

The biological assessment of water quality was performed using three diatom indices: IO – Diatom Index (Picińska-Fałtynowicz 2006), GDI – Generic Diatom Index (Coste & Ayphassorho 1991), and IPS – Specific Pollution Sensitivity Index (CEMAGREF 1982). The IO index was calculated using a mathematical formula suitable for the specific type of river corresponding to the hydromorphology of the Linda River, while the IPS and GDI indices were calculated using the OMNIDIA 5.3 software. The ranges of the diatom indices and the ecological status that was indicated by the indices were used together with a water quality class for the IO index according to the regulation of the Minister of the Environment (OJ No 258, pos. 1549 from 2011), while the IPS and GDI indices were used after Dumnicka et al. (2006) (Table 1). The results of the biological analyzes are presented in Table 2. In order to indicate the changes in values of diatom indices at particular sampling sites, the Kruskal-Wallis nonparametric test for independent samples was used (Kruskal, Wallis 1952). In the case of phytobenthic samples from October and November 2011, the water samples were collected together with the algological material for chemical analyzes, which were carried out in an accredited laboratory according to valid norms. The following chemical parameters were analyzed: BOD_{5+2} (PN-EN 18991-2 2002), dissolved oxygen (PN-EN 25813 1997), OWO (PN-EN 1484 1999), nitrites (PN-EN ISO 13395 2001), nitrates (PN-EN ISO 13395 2001), Kjeldahl nitrogen (PB 108 edition No. 3 of 20 September 2011), orthophosphates (PN-EN ISO 15681-2 2002), silica (PN-EN ISO 11885 2009). The results of these chemical analyzes are presented Table 3. To indicate the differences in the water quality assessment on the basis of chemical parameters and diatom indices, the Kruskal-Wallis nonparametric test for independent samples (assuming a significance level of $\alpha = 0.05$) was used (Kruskal, Wallis 1952).

RESULTS

General taxonomic analysis

A total of 236 diatom taxa were identified in 28 samples, including 134 taxa at site 1 (the river source), 173 taxa at site 2 (the upper course – Grotniki, Podrzeczna Str.), 155 taxa at site 3 (Grotniki – upstream of the pond), and 169 taxa at

Table 1

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

Water Quality Class	Ecological State	IO	IPS	GDI
I	Very good	> 0.70	>17	>17
II	Good	0.50	15 – 17	14 – 17
III	Moderate	0.30	12 – 15	11 – 14
IV	Poor	0.15	12 – 8	11 – 8
V	Bad	< 0.15	< 8	< 8

Table 2

Values of diatom indices and water quality classes at the studied sites of the Linda River

Site/date*	Values of diatom indices /			Water Quality Class		
	IO	IPS	GDI	IO	IPS	GDI
1103s1	0.456	11.5	13.8	III	III	III
1104s1	0.459	10.1	9.1	III	IV	IV
1105s1	0.409	12.4	14.4	III	III	II
1106s1	0.565	11.6	12.6	II	IV	III
1108s1	0.619	15.4	13.8	II	II	III
1110s1	0.553	13.1	11.1	II	III	III
1111s1	0.601	14.0	11.4	II	III	III
1103s2	0.566	14.0	12.5	II	III	III
1104s2	0.462	14.2	13.2	III	III	III
1105s2	0.558	14.8	13.7	II	III	III
1106s2	0.606	13.7	13.0	II	III	III
1108s2	0.616	14.4	13.5	II	III	III
1110s2	0.622	13.8	14.6	II	III	II
1111s2	0.607	14.5	14.9	II	III	II
1103s3	0.547	11.9	12.0	II	III	II
1104s3	0.408	13.0	11.9	III	III	III
1105s3	0.468	15.0	13.4	III	III	III
1106s3	0.546	12.6	11.4	II	III	III
1108s3	0.524	13.1	12.4	II	III	III
1110s3	0.481	12.3	12.2	III	III	III
1111s3	0.658	13.7	13.5	II	III	III
1103s4	0.537	15.5	14.1	II	II	II
1104s4	0.485	15.3	14.0	III	II	III
1105s4	0.495	15.6	13.9	III	II	III
1106s4	0.540	13.8	12.8	II	III	III
1108s4	0.510	14.6	13.2	II	III	III
1110s4	0.607	14.6	13.9	II	III	III
1111s4	0.575	14.5	13.5	II	III	III

* The code of each sample consists of the following: two digits for the year of sampling, two digits for the month of sampling, the letter "s" and the number (1-4) of sampling site

Table 3

Values of chemical water parameters at the sampling sites of the Linda River in October and November 2011

Chemical water parameters	Site/date							
	1 10.2011	1 11.2011	2 10.2011	2 11.2011	3 10.2011	3 11.2011	4 10.2011	4 11.2011
BOD_{5+2} mg O_2 dm^{-3}	1.1	1.5	4.7	3.8	5.2	7.6	5.4	5.4
Dissolved oxygen (DO) mg O_2 dm^{-3}	1.6	2.0	7.7	10.6	9.0	11.3	8.0	11.6
Dissolved organic carbon (DOC) mg C dm^{-3}	1.0	1.2	8.7	3.8	4.1	4.3	5.4	5.3
NO_2 mg NO_2 dm^{-3}	0.013	0.013	0.079	0.066	0.110	0.079	0.013	0.069
NO_3 mg NO_2 dm^{-3}	1.5	1.9	11.0	12.0	7.5	11.0	2.3	5.3
Kjeldahl nitrogen (TKN) mg N_k dm^{-3}	1.4	1.4	2.2	1.4	2.7	1.4	1.9	1.6
PO_4 mg PO_4 dm^{-3}	0.25	0.26	0.12	0.13	0.13	0.20	0.22	0.12

site 4 (Kowalewice). A total of 47 dominant species were recorded in the whole river; the taxa were as follow: *Achnanthidium minutissimum* (Kütz.) Czarnecki, *Amphora pediculus* (Kütz.) Grun., *Cocconeis neodiminuta* Kram., *C. pediculus* Ehrenb., *Diploneis separanda* Lange-Bert., *Encyonema minutum* (Hilse) D.G. Mann, *Hippodonta capitata* (Ehrenb.) Lange-Bert., Metz. & Witk., *Navicula gregaria* Donkin, *Planothidium frequentissimum* (Lange-Bert.) Lange-Bert., *P. lanceolatum* (Brébisson ex Kütz.) Lange-Bert., *P. rostratum* (Østrup) Lange-Bert., *Puncticulata radiosa* (Grun.) H. Håkansson, *Sellaphora joubaudii* (Germain) Aboal.

Diatom indices

The biological assessment of the water quality, conducted on the basis of three diatom indices, showed a similar ecological status in the whole river (Table 2). The values of the IO index fluctuated between 0.408 and 0.658. Most of the analyzed samples reached their values for water quality class II. The IPS index ranged from 10.1 to 15.6, with the lowest values at site 1 in April and June 2011, the remaining samples were mostly in water quality class III. The same situation was with the GDI index; the values of this index were recorded in the range of 9.1-14.9. On the basis of the GDI index, water in the Linda River was classified into water quality class III. On the basis of the Kruskal-Wallis nonparametric test, there was no statistically significant differences in the values of the indices at particular sampling sites (Figs 2, 3, 4).

Chemical and biological evaluation of the Linda River water

The comparison of the results of the physicochemical and biological assessment of the water quality was performed for two selected months (October, November 2011); they were indicated in Table 2.

The chemical analyzes of the water parameters indicated different classes of the water quality depending on the analyzed factor (Tables 3 and 4). Due to the fact that the value of the parameter indicating the worst water quality is considered indicative of the water quality, the chemical evaluation classified the Linda water into water quality classes III, IV and V.

The biological analysis on the basis of the three diatom indices indicated water quality class II or III,

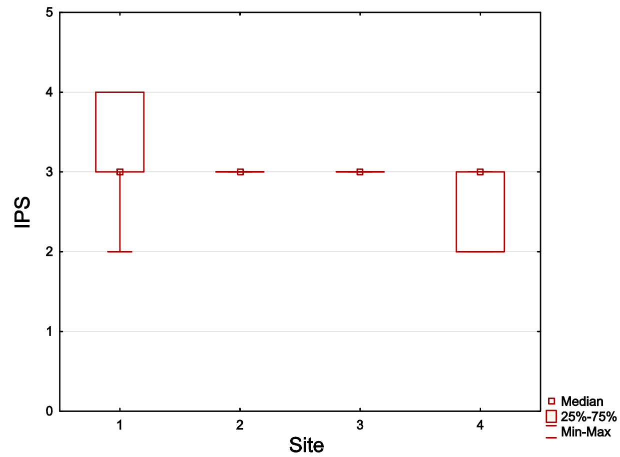

Fig. 2. Values of the IPS index for all the studied sites

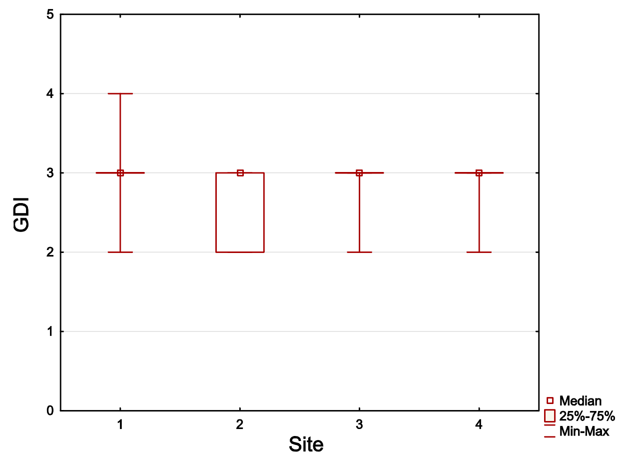

Fig. 3. Values of the GDI index for all the studied sites

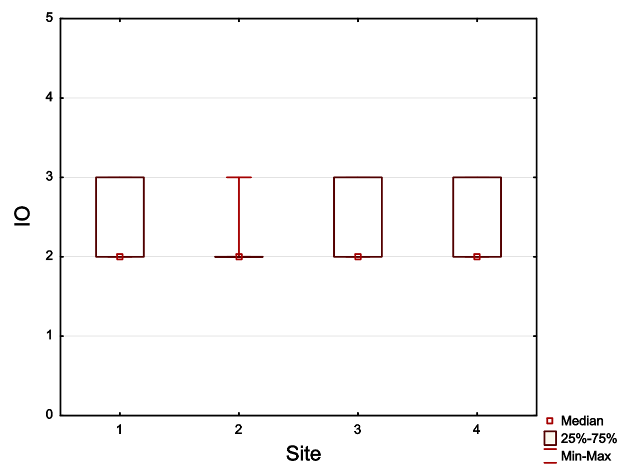

Fig. 4. Values of the IO index for all the studied sites

depending on which index was used (Table 2). Values of the IO index remained within a good ecological status except for one month at one site (October 2011, site 3), where the index indicated a moderate ecological status (Table 2). The IPS index qualified the Linda water to class III of water quality (moderate ecological status), while the index GDI indicated class III at sites 1, 3 and 4, but class II at site 2 (Table 2).

The nonparametric Kruskal-Wallis test (the significance level of $\alpha = 0.05$) indicated statistically significant differences between the values of given chemical parameters and water quality classes. All the differences were significant at $P = 0.000$ (Fig. 5).

No significant differences as regards the assessment of the water quality class were found for

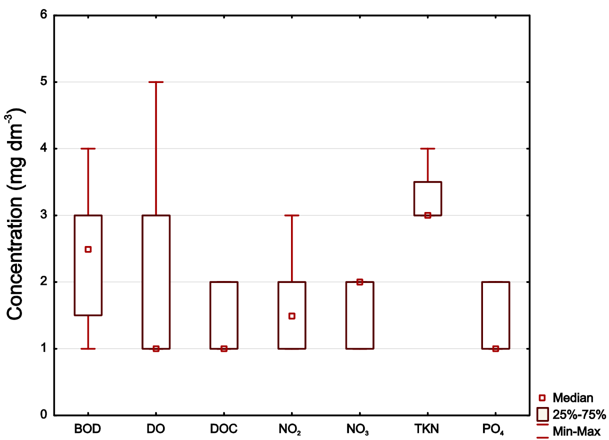

Fig. 5. Values of the selected physicochemical parameters for all the studied sites

indices IPS, GDI and IO (Figs 2, 3, 4); the P-value of the Kruskal-Wallis test was 0.14. In the case of the Kruskal-Wallis test for the IO index, the differences in the values of this index in particular months were not statistically significant and the P-value was 0.61.

DISCUSSION

The analysis of the diatom assemblages of the Linda River revealed high species diversity. A total of 236 diatom taxa were identified in 28 samples. The number of identified diatom species is frequently considered as a characteristic indicating the degree of water pollution. Rivers with water characterized by a low level of pollution are also characterized by a higher species diversity (Kawecka, Eloranta 1994; Rakowska 2001). The Linda River has a low level of organic pollution. In other clean rivers, such as the Rawka, Grabia or Pilica, similarly high numbers of identified taxa were recorded (Rakowska 2000, Szulc 2007).

Furthermore, a considerable part of the diatom species identified in the Linda River are species that prefer water with a low level of pollution, of the beta-mesosaprobic zones, according to indicator values after the OMNIDIA 5.3 database, which confirms the good ecological status of the river. Frequent and dominant species identified in the benthos of the Linda River, such as: *Achnanthidium minutissimum* (Kütz.) Czarnecki var. *jackii* (Grun.) Bukht., *Amphora pediculus* (Kütz.) Grun., *Diploneis fontanella* Lange-Bert., *D. separanda* Lange-Bert., *Meridion circulare* (Greville) Agardh, *Navicula exilis* Kütz., *Nitzschia homoburgiensis* Lange-Bert., *Nitzschia inconspicua* Grun., *Sellaphora joubaudii* (Germain) Aboal., *Stauroneis anceps* Ehrenberg, *Staurosira venter* (Ehrenb.) Cleve & Meller, *Staurosirella pinnata* (Ehrenb.) Williams & Round, were also found in other water ecosystems with a good water quality, e.g. Tertiary and Quaternary springs (Żelazna-Wieczorek 2011; Wojtal, Sobczyk 2012).

Biological assessment of the water quality conducted on the basis of three diatom indices − IO, IPS and GDI − has identified a similar ecological status along the whole river. This probably resulted from a small length of the river, the lack of disorders in the river continuity and the lack of pollution inputs. Each of the indices classified the water in the Linda River into a specific but different quality class. Generally, the IO index showed water quality class II, while IPS and GDI − class III. Statistical analysis showed that the differences in the values of the indices for particular sampling sites were not statistically significant.

The IO index is a Polish index adapted for the assessment of the surface waters used in the routine biomonitoring. The indicator values of the taxa that constitute the base for the index were verified for the Polish hydrobiological conditions (Picińska-Faltynowicz 2006). Diatom indices, which are commonly used in Europe, are based on the autecological lists created, among others, in France (Coste & Ayphassorho 1991, Prygiel et al. 1997, Prygiel et al. 1999), Germany (Lange-Bertalot 1979a, b; Hofmann 1994), Belgium (Descy, Ector 1996) and the Netherlands (van Dam et al. 1994). This group includes the two other indices analyzed in this paper (IPS and GDI). The IPS and GDI indices have already been used to assess the quality of water in the rivers of the southern part of Poland such as the Oder, the Vistula and the Raba. These indices seemed to be appropriate for the assessment of the fresh water quality (Kawecka et al. 1996, Kawecka et al. 1999, Kwandrans et al. 1999). Moreover, IPS and GDI were in the group of indices proposed for the assessment the quality of water of the Gulf of Gdansk (Bogaczewicz-Adamczak, Dziengo 2003; Zgrundo 2004). They were also used in the water quality assessment in two rivers in Central Poland: Bzura and Pilica (Szczepocka, Szulc 2009; Rakowska, Szczepocka 2011).

Diatom indices are commonly used to assess the quality of flowing water. In addition to the commonly used indices such as IPS, GDI, BDI (Biological Diatom Index − Lenoir, Coste 1991), SLA (Sládeček's index − Sládeček 1986), EPI-D (Eutrophication pollution index − dell'uomo 2004), TDI (Trophic Diatom Index − Kelly Whitton 1995), there are also indices which are created and adapted to specific hydrobiological parameters of a particular country, for example: PDI (Pampean Diatom Index) is used to assess the quality of flowing waters in Argentina (Gomez, Licursi 2001), or DI-CH (Swiss Diatom Index) in Switzerland (Hurlimann, Niederhauser 2006).

The comparison of the results of the biological assessment of one selected river, which were conducted on the basis of three different indices, showed differences in the water quality − the water quality assessed by IPS and GDI indices was lower. This may suggest that the list of diatom taxa on which the indices are based should be verified with respect to the Polish hydrological conditions. Only then it could be guaranteed that they are appropriate for the biological assessment of the Polish water quality. The IO index, which indicated class II of water quality, has proved to be the most accurate indicator which described the water in the Linda River according to its state.

The accuracy of the biological water quality assessment is dependent on the indicator value of the diatom taxa which should be adapted to the hydrology of a particular country. So far, only a few works review the list of diatoms in relation to the Polish conditions. From the area of Central Poland, the most valuable are results obtained by Rakowska (2001) and Szczepocka et al. (2014) on the diatom communities of different aquatic ecosystems and by Żelazna-Wieczorek (2011) who describes diatom communities identified in the springs of Łódź Hills.

Research on the bioindicator values of diatoms are considered necessary worldwide (Kelly et al. 2008; Round 2004; Potapova et al. 2004; Potapova and Charles 2005, 2007; Ector, Rimet 2005; Tison et al. 2005; Bathurst et al. 2010; Blanco et al. 2012; Venkatachalapathy et al. 2013). The obtained results confirm the rightness of the use of biological assessment in the evaluation of the ecological status of aquatic ecosystems.

In this study, the assessment of water quality of the Linda River was carried out according to the recommendations of the Water Framework Directive (2000), i.e. chemical and biological evaluations of phytobenthos were carried out. The results obtained with certainty confirmed the usefulness and indispensability of the biological assessment.

The analysis of chemical parameters: BOD_{5+2}, dissolved oxygen, OWO, nitrites, nitrates, Kjeldahl nitrogen, and orthophosphates, resulted in a wide dispersion of the values of water quality classes (Fig. 1). The water of the Linda River ranged from water quality class I to V (Table 3). Class V, which was determined on the basis of dissolved oxygen in the source, may be ignored because water in springs that flows from the Quaternary geological formations (to which the source of the Linda River belongs) is frequently characterized by low oxygen concentrations (Burchard et al. 1990, Żelazna-Wieczorek 2011). Consequently, the dissolved oxygen cannot be a good indicator for determining the water quality classes in springs.

As it was confirmed by the obtained results, chemical analysis indicates the momentary water quality, and the values of chemical analysis parameters are influenced by numerous factors, which may cause an equivocal water quality assessment. Despite the fact that the values of the analyzed chemical parameters were within the range of norms established for water quality classes I and II, the final class is determined by the parameter indicating the worst water quality class (OJ 2011a, b). Accordingly, the Linda water might be classified into water quality class IV, or even V, if the results of dissolved oxygen were not ignored. To sum up, the chemical analysis does not reflect the actual state of the water quality in the Linda, which is an example of a small and polluted river.

A reverse situation is indicated by the biological analysis. The applied diatom indices clearly determined the water quality, and thus the IO index indicated water quality class II in the whole river, the IPS index − class III also in the whole river, while

GDI indicated class II at site 2 and class III at the other sites. In general, the values of the indices varied only between water quality class II and III (Fig. 5).

Taking into account the given indices, the index IO turned out be the most objective one, and it evaluated the Linda water in congruence with its actual status. The index IO is now a standard used for the assessment of the ecological water quality in Poland. According to the Decree of the Minister of the Environment from 09 November 2011 (Regulation of the Minister of the Environment a, b (OJ No 257, 258 pos. 1545, 1549 from 2011) it has been accepted for continuous biomonitoring of Polish rivers.

CONCLUSIONS

The achieved results confirmed that the IO index proven to be the best tool in the biomonitoring of the Polish rivers. Indices IPS and GDI, commonly used not only in Europe but also for the Polish rivers, are good indicators in the biological assessment, but they need to be used cautiously because, as shown in this research, they may indicate a lower class of the water quality. On the basis of the statistical analysis, it was found that the differences in values of particular indices were not statistically significant.

Statistical analysis indicated that the most representative results of the water quality assessment are obtained by using biological methods. This is owing to the fact that the methods are less affected by momentary, unpredictable changes in environmental conditions. In contrast, the values of physical and chemical parameters may be affected by random phenomena, such as downpours, floods, or snow-melt events.

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