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The benthic flora in small forest streams with different water trophy level and pH status (Pogórze Wielickie Hills, southern Poland)*

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Abstract – On the basis of cluster analysis, 4 types of community were distinguished: Group I – the communities of the source of the main stream with dominating neutral diatoms, Group II – communities of the source of its tributary (low water pH, prevailing acidophilous diatoms and filamentous Chlorophyceae), Group III – communities developed within an overflow threshold of the main stream, which (especially diatoms) indicate alkaline conditions and high trophy level, and Group IV– communities developed in the middle and lower sectors of two streams, which differentiated owing to some physical parameters. The trophic and saprobic states ranged from oligotrophy and oligosaprobity in the sources of the streams, to mesotrophy and beta-mesosaprobity in their middle and lower sectors.

Key words: streams, communities, diatoms, diatom index, indicators pH, trophy, saprobity.

1. Introduction

The catchment area of the Ratanica stream as well as the whole area of the Pogórze Wielickie Hills have been affected by moderate but chronic industrial emissions for over 40 years (Grodzińska and Weiner 1993, Godzik and Krywult 1998). The ecological investigations carried out in the studied area showed disturbances in biogeochemical cycles of elements and in the ion balance (Szarek 1995, Grodzińska and Laskowski 1996), and damage to stands of trees causing changes in the flora of vascular plants (Różański et al. 1993). Thus was to be expected that its water and biocenoses would undergo substantial the chemical changes.

Water ecosystems of the Ratanica catchment area were studied mainly in chemical aspect (Wojtan and Galas 1993, Pawlik-Dobrowolski et al. 1993, Godzik and Krywult 1998). However, the quality of water, besides physico-chemical parameters, is determined by the structure of biocenoses, which on the one hand are formed depending on given physico-chemical conditions but on the other affect their changes in a very essential manner.

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Algal communities with defined population size and structure are good tools for the evaluation of water habitats and their changes, diatoms being a preferred group (among others, Patrick 1973, Van Dam 1974, McCormick and Cairns 1994, Kawecka and Eloranta 1994, Whitton and Rott 1996). The conception of biological indicators was a base for the development of several classifications and diatom indices, used to estimate, e.g., pH, trophic level, or saprobity of the waters.

The aim of this work was to study the characteristics of structure and ecology of benthic flora developed in the Ratanica stream and one of its tributary, in relation to different chemical conditions, and to determine trophic and saprobic states on the basis of diatom communities.

2. Study area

The catchment area of the Ratanica stream (49°51' N, 20°02' E) is located in the western part of the Pogórze Wielickie Hills, about 40 km south of Cracow. The stream, which once was a right-side tributary of the River Raba, now merges directly with the Dobczyce Reservoir, which provides drinking water for the agglomeration of Cracow. The structure of the stream catchment area is composed of Tertiary sandstone, covered in a lower part of the valley with loess-like quaternaries (Starkel 1991). The soil in this region is acid, scanty in soluble phosphorus compounds, and rich in potassium and magnesium, some heavy metals also being present in high concentration (Adamczyk et al. 1989). The agricultural--forested catchment is covered in the upper part with a mixed beech-pine forest whereas in the lower one there are meadows and ploughed fields (Grodzińska and Szarek 1995).

The total length of the Ratanica stream is 2.6 km. The study covered the upper and middle parts of the main stream (1.35 km long) together with its greater tributary (Fig. 1). The width of the stream varied from 20 cm near the source to 2 m at the forest border. The depth of the stream ranged from 2 to 25 cm. Periodically, during a dry season, its upper part dries up and freezes to the bottom in winter. The deepest location within the whole catchment is the spring of the Ratanica tributary (about 80 cm deep, diameter of 1 m). The bottom of the two streams was covered by gravel, sand, rotting leaves, and mosses.

Stream waters, from the chemical point of view, have relatively high conductivity, high alkalinity, and hardness caused by a high content of alkaline cations, (especially calcium and magnesium ions) (Table I). They also feature a raised concentration of nitrogen compounds and phosphates and good oxygen concentration (Godzik and Krywult 1998). The higher concentration of nitrogen and phosphate, and compounds of the water result from the effect of agriculture in the catchment area, domestic waste from houses located close to the Ratanica spring, and the forest border (Pawlik-Dobrowolski et al. 1993). Moreover, a strong inflow of nitrogen compounds from the atmosphere was observed (Szarek 1995). The range of water pH is wide, from acid (pH 3.5–6.0) in the springs of streams (Stations 1 and 5) to neutral and alkaline (pH 7.1–8.6) in their middle and low reaches. The values of physico-chemical parameters of the waters changed over the year. The lowest pH of the water was observed in spring. The sulphates, chlorides, and phosphates had the lowest level in autumn and the highest in spring. The concentration of ammonium was fairly stable (Godzik and Krywult 1998). A more detailed description of the catchment area was given by Grodzińska and Laskowski (1996).

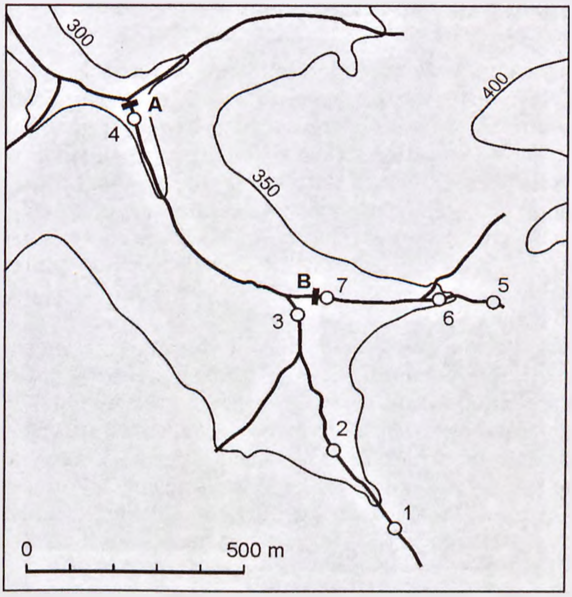

Fig. 1. Locations of sampling sites in the Ratanica stream catchment area: 1–4 – Ratanica, 5–7 – tributary, A – lower weir, B – upper weir.

Table I. Selected parameters of water chemistry in the Ratanica stream and its tributary (data according to Grodzińska and Laskowski 1996 and Godzik and Krywult 1998).

Parameters		Ratanica Stream			Tributary		
		Mean	Min.	Max.	Mean	Min.	Max.
Temperature	°C	9.8	4.0	16.8	9.2	0.5	16
pH		7.5	6.0	8.6	6.9	3.4	8.5
Alkalinity	mval L^{-1}	3.49	0.17	11.90	2.14	0.50	13.00
Total hardness	mg $CaCO_3$ L^{-1}	143	56	206	112	58	221
Oxydability	mg O_2 L^{-1}	5.64	1.24	13.21	5.16	0.56	21.78
O_2	mg L^{-1}	11.47	7.47	23.20	11.27	7.30	24.86
CO_2	mg L^{-1}	8.55	4.00	20.00	12.52	4.20	70.00
$N\text{-}NO_3^-$	mg L^{-1}	0.63	0.06	1.81	2.59	0.16	9.30
$N\text{-}NH_4^+$	mg L^{-1}	0.16	0	1.00	0.01	0	0.86
$P\text{-}PO_4^{3-}$	mg L^{-1}	0.63	0	2.61	0.53	0	1.88
SO_4^{2-}	mg L^{-1}	204	80	310	186	80	263
Cl^-	mg L^{-1}	7.35	3.80	13.99	10.15	3.80	19.60
Ca^{2+}	mg L^{-1}	151	51	313	113	27	232
Mg^{2+}	mg L^{-1}	36.6	14.5	66.3	27.9	15.6	65.7

3. Material and methods

The samples were collected from 7 stations, i.e. Stations 1–4 situated on the main Ratanica stream, and Stations 5, 6, and 7 situated on its tributary (Fig. 1). The samples were collected every month from January until December, 1994, except for the stations that dried up periodically, namely Station 1, where the materials were collected only twice: in May and June, 1994, and Station 6, where the materials were not collected in January, or in August. The majority of stations were of natural character, two of them, namely Stations 4 and 7, were so-called "overflows" with the bottom lined with concrete plates or boards, similarly to the partially concrete reinforcements of the banks at Station 5, which formed artificial habitats for algae.

Compilation and elaboration of the material were based on the methods used in the study of algae in running waters, according to Starmach (1969) and Kawecka (1980). Communities were described by number of species, their abundance, and scale of coverage. The results were presented in a seasonal form, after calculation of the means from a whole study period. The estimation of the coverage of cyanobacteria and algae forming uniform macroscopic aggregations was assessed on a determined surface of the stream bottom with the use of a 5-score scale of coverage as follows: 1 – organisms form small aggregations, 2 – cover less than 25% of the bottom area, 3 – cover 25–50%, 4 – 50–75%, 5 – 75–100%. As numerous species were considered those which reached a degree higher than 3 in the scale of coverage. Abundance of microscopic forms, mainly diatoms, was determined by calculating individual species in 10 visual fields of a microscope. Next, the percentage content of each species in a community was calculated. Those species which reached over 10% content in a community were defined as dominants; those within the range of 1–10% as co-dominants, and others as rare. Taxonomic determinations and terminology of diatoms were elaborated and accepted mainly according to the keys by Krammer and Lange-Bertalot (1986, 1988, 1991*a*, 1991*b*). The autecological characteristics of the species, including the division of diatoms into groups according to their preferences towards water pH, was elaborated according to Hustedt (1938, 1939), Van Dam et al. (1981, 1994), Hkansson (1993). The trophic state of the water, based on diatom composition, was determined according to the Hofmann (1994) classification system, and Trophic Diatom Index (TDI) according to Kelly and Whitton (1995) was also calculated. The TDI index varied from 1 (low nutrient concentration) to 5 (very high nutrient concentration). Saprobity of the water was determined according to Van Dam et al. (1994). Communities of diatoms on individual sites were compared using cluster analyses (Pearson correlation and average linkage method).

4. Results and discussion

4.1. Characteristics of algal communities

A total of 107 algal taxa, representing 5 taxonomic groups were found (Table II). At all stations the dominant group, by number of taxa, were diatoms, the majority of which occurred in small numbers. Other groups were represented by a small number of species and by various degrees of their coverage (Table II).

Because of geomorphological diversification and varying catchment area use, the examined streams differed in the chemical composition of the water, especially in trophy level and pH value (Table I). The water reaction varied from acid in the

Table II. Relative abundance of cyanobacteria and algae found in the Ratanica stream and its tributary in 1994: +++ – >10%, ++ – 1–10%, + – <1%, 1–4 – scale of coverage of the taxa forming macroscopic aggregations.

Species	Sampling sites						
	1	2	3	4	5	6	7
CYANOPROKARYOTA							
Lyngbya sp.				1			
Oscillatoria limosa Ag.				1			2
Phormidium sp.		1	1				
– *autumnale* (Ag.) Gomont				3			2
– *favosum* (Bory) Gomont.				3			
Pseudanabaena sp.				1			
EUGLENOPHYTA							
Euglena spp.		+	+	+			+
Phacus spp.				+			+
BACILLARIOPHYCEAE							
Achnanthes sp.		+	+	+			
– *biasolettiana* Grun. var. *biasolettiana*		+	+	+			+
– *lanceolata* (Bréb.) Grun. var. *lanceolata*		+++	+++	++	+	+++	+++
– *lanceolata* ssp. *rostrata* (Ostr.) Lange-Bertalot			+	+			
– *marginulata* Grun.					++		
– *minutissima* Kütz. var. *minutissima*	+	+++	+++	+++	+	+++	+++
Amphora ovalis (Kutz.) Kütz.				+			
– *pediculus* (Kutz.) Grun.		++	+++			+	++
Anomoeoneis brachysira (Bréb.) Grun.	+				+		
Caloneis molaris (Grun.) Krammer	+				++	+	+
Cocconeis pediculus Ehr.				+			
– *placentula* Ehr.		+		+			+
– *placentula* var. *euglypta* Grun.		++	++	+			+
Cymbella minuta Hilse ex Rabh.		+	+	+	+	+	+
– *perpusilla* A. Cleve		++	+	+			
– *silesiaca* Bleisch		+	+	+++	+		+
– *sinuata* Greg.		+	+	+			+
Cyclotella sp.							+
Denticula tenuis Kutz.				+			
Diatoma hyemalis (Roth.) Heib.	+						
– *moniliformis* Kutz.							+
– *vulgaris* Bory			+	+			
Diploneis sp.						+	+
Eunotia bilunaris (Ehr.) Mills	++	+			+++	+	
– *exigua* (Bréb.) Rabh.	+		+		+++	+	+
– *exigua* var. *tridentula* Oestr.	+				+		
– *minor* (Kutz.) Grun.	+	+	+		++	++	
– *paludosa* Grun.					+		
– *paludosa* var. *trinacria* (Krasske) Nörpel	+				+		
– *rhomboidea* Hust.	+				+++	++	
– *tenella* (Grun.) Hust.	++		+	+	++	+	
Epithemia sp.		+		+			
Fragilaria arcus (Ehr.) Cl.	+						
– *brevistriata* Grun.				+			

Table II. *continued*

Species	Sampling sites						
	1	2	3	4	5	6	7
– *capucina* Desm. var. *capucina*		+	+				
– *capucina* var. *vaucheriae* (Kutz.) Lange-Bertalot				+		+	+
– *construens* (Ehr.) Grun. f. *construens*			+	+++	+		+
– *pinnata* Ehr.				+			
– *ulna* (Nitzsch.) Lange-Bertalot var. *ulna*		+	+	+	+	+	+
– *virescens* Ralfs	+++	++	++	+	++	+	+
Frustulia rhomboides (Ehr.) De Toni							
– *rhomboides* var. *saxonica* (Rabh.) De Toni	+				+		
– *vulgaris* (Thwaites) De Toni		+	+	+		++	+
Gomphonema sp.				+			+
– *acuminatum* Ehr.		+					
– *angustatum* (Kütz.) Rabh.	+		+				
– *gracile* Ehr.							
– *olivaceum* (Hornemann) Bréb.		++	++	+++	+	+	+
– *parvulum* (Kutz.) Kutz.		++	++	++	+	++	++
Gyrosigma acuminatum (Kutz.) Rabh.			+				
Meridion circulare (Greville) C.A. Ag.	+++	++	++	++	+	++	++
Navicula capitatoradiata Germain					+		
– *cincta* (Ehr.) Ralfs				+			
– *contenta* Grun.	+	+			++		
– *cryptocephala* Kutz.			+	+	+		+
– *gallica* (W.M. Smith) Lagerst. var. *perpusilla* (Grun.) Lange-Bertalot	+	++	+++			+	+
– *goeppertiana* (Bleisch) H.L. Sm.				+			
– *gregaria* Donkin			+	++		++	++
– *lanceolata* (Ag.) Ehr.		+	+	++		+	+
– *menisculus* Schumann	+	+		+++	+	++	+
– *minima* Grun.				+			
– *pupula* Kutz.							+
– *radiosa* Kutz.						+	
– *soehrensis* (Krasske) var. *hassiaca* Lange-Bertalot	+				++		
Neidium sp.		+					
– *affine* (Ehr.) Pfitzer				+			+
Nitzschia sp.		+					
– *amphibia* Grun.							+
– *capitellata* Hust.		+		+			
– *dissipata* (Kutz.) Grun.		++	+	+++		+	+
– *fonticola* Grun.				+			
– *linearis* (Ag.) W. Smith		+++	++	+		+++	+++
– *palea* (Kutz.) W. Smith				+			+
Pinnularia sp.	+						
– *appendiculata* (Ag.) Cleve	++	+		+	+++	++	+
– *borealis* Ehr.				+			+
– *interrupta* W.M. Smith					+		
– *microstauron* (Ehr.) Cl.	+	+	++	+	++	++	++
– *subcapitata* Greg.	+		+		++		+
– *sudetica* (Hilse) M. Peragallo	+	++	++	+	+	++	++

Table II. *continued*

Species	Sampling sites						
	1	2	3	4	5	6	7
Rhoicosphenia abbreviata (Ag.) Lange-Bertalot		+++	+++	++	+	+++	+
Stauroneis sp.							+
– *anceps* Ehr.							+
– *phoenicentron* (Nitzsch.) Ehr.			+				+
– *smithii* Grun.		+					
Stephanodiscus hantzschii Grun.							+
Surirella angusta Kütz.		++	+	+		+	++
– *brebissonii* Krammer et Lange-Bertalot		+	++	+			++
– *brebissonii* var. *kuetzingii* Krammer et Lange-Bertalot							+
– *linearis* W. Smith				+	+		
– *minuta* Bréb.		++	+	+		+	+
Tabellaria flocculosa (Roth.) Kutz.	+	+			++		+
CHLOROPHYTA							
Gongrosira sp.		2	2				1
Klebsormidium rivulare (Kutz.) Morison et Sheath					4		
Microspora sp.					1		
Mougeotia sp.					4		
Spirogyra sp.					4		
Stigeoclonium tenue (Ag.) Kütz.				1			1
Oedogonium sp.		1	1	1			
Ulothrix variabilis Kutz. + *Ulothrix* sp.				3	1		1
RHODOPHYTA							
Audouinella chalybaea (Roth.) Fries			1	1			1

springs of two streams (Station 1–pH about 6, Station 5–pH about 4), to neutral and alkaline waters along the course of both streams (pH from 7 to 8.5). Concentrations of nitrogen compounds and phosphates in general were high, but in the main stream (Stations 1, 2, 3, 4) the level of nitrate compounds was higher than that of ammonium ions, while in its tributary (Stations 6 and 7) it was just the opposite (Table I). Moreover, the differences in water chemistry were especially significant along the small sector of the tributary. In the spring of the tributary had the lowest pH value (3.4), which increased to pH 6, during seasons and to over 8 pH-units along the course of the stream. The concentration of nitrate, potassium, and chloride as well as heavy metal ions decreased downstream, while those of ammonium, phosphate calcium, and magnesium ions increased. This may be evidence of the effect of land used for agriculture, as well as of an unidentified waste source from the surrounding households (Pawlik-Dobrowolski et al.1993, Grodzińska and Laskowski 1996).

In consequence, along the stream reaches, on a relatively small area, various algal communities had developed. Four groups of different type of communities were distinguished (Fig. 2). Considerably different from others were communities on Stations 1, 5, and also on Station 4.

Group I included communities formed in the source of the Ratanica stream, Station 1. They were characteristic of a small number of algal species (24–26) and

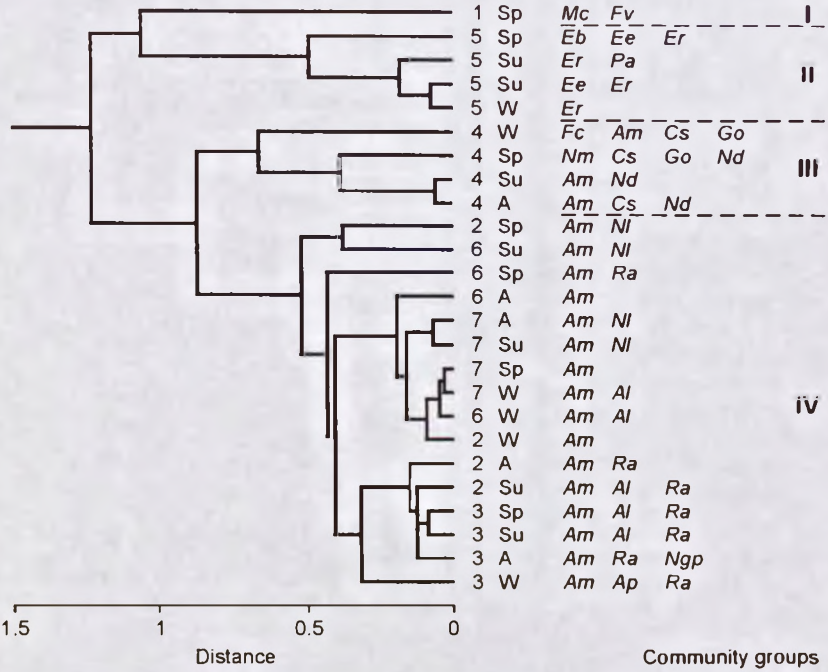

Fig. 2. Comparison of the diatom community at the investigated sites in the Ratanica stream (Stations 1–4) and its tributary (Stations 5–7) in particular seasons in 1994 (Sp – spring, Su – summer, A – autumn, W – winter), according to Pearson correlation and average linkage clustering. Dominants: *Am* – *Achnanthes minutissima* Kütz., *Al* – *A. lanceolata* (Bréb.) Grun., *Ap* – *Amphora pediculus* (Kütz.) Grun., *Cs* – *Cymbella silesiaca* Bleisch, *Eb* – *Eunotia bilunaris* (Ehr.) Mills, *Ee* – *E. exigua* (Bréb.) Rabh., *Er* – *E. rhomboidea* Hust., *Fc* – *Fragilaria construens* (Ehr.) Grun., *Fv* – *F. virescens* Ralfs, *Go* – *Gomphonema olivaceum* (Hornemann) Bréb., *Mc* – *Meridion circulare* (Greville) C.A. Ag., *Ngp* – *Navicula gallica* (W.M. Smith) Lagerst. var. *perpusilla* (Grun.) Lange-Bertalot, *Nm* – *N. menisculus* Schumann, *Nd* – *Nitzschia dissipata* (Kütz.) Grun., *Nl* – *N. linearis* (Ag.) W. Smith, *Pa* – *Pinnularia appendiculata* (Ag.) Cleve, *Ra* – *Rhoicosphenia abbreviata* (Ag.) Lange-Bertalot.

high abundance of diatoms, which often form the main component of phytocenoses of the sources (Round 1981). Besides diatoms, only fragments of filamentous cyanobacteria and bacteria were found. The species composition and the structure of algal communities indicated that the waters were well oxygenated, had a relatively low level of nutrients, and slightly acid reaction (pH about 6.0 in the studied period). The dominant species were the following: *Fragilaria virescens* (62%), and *Meridion circulare* (16%) (Fig. 3). The first one usually grows well in waters of pH ca. 7.0, with high oxygen concentration and oligotrophic to mesotrophic, and is tolerant towards low concentration of organic nitrogen (Van Dam et al. 1994). The second species with a broad ecological spectrum can be found in oligotrophic to hypereutrophic, but well oxygenated and not polluted waters (Van Dam et al. 1994), often occurring in cold springs (Round 1981). In relation to water pH the most numerous group of diatoms were circumneutral, reaching over 60 % of the total community (Fig. 3).

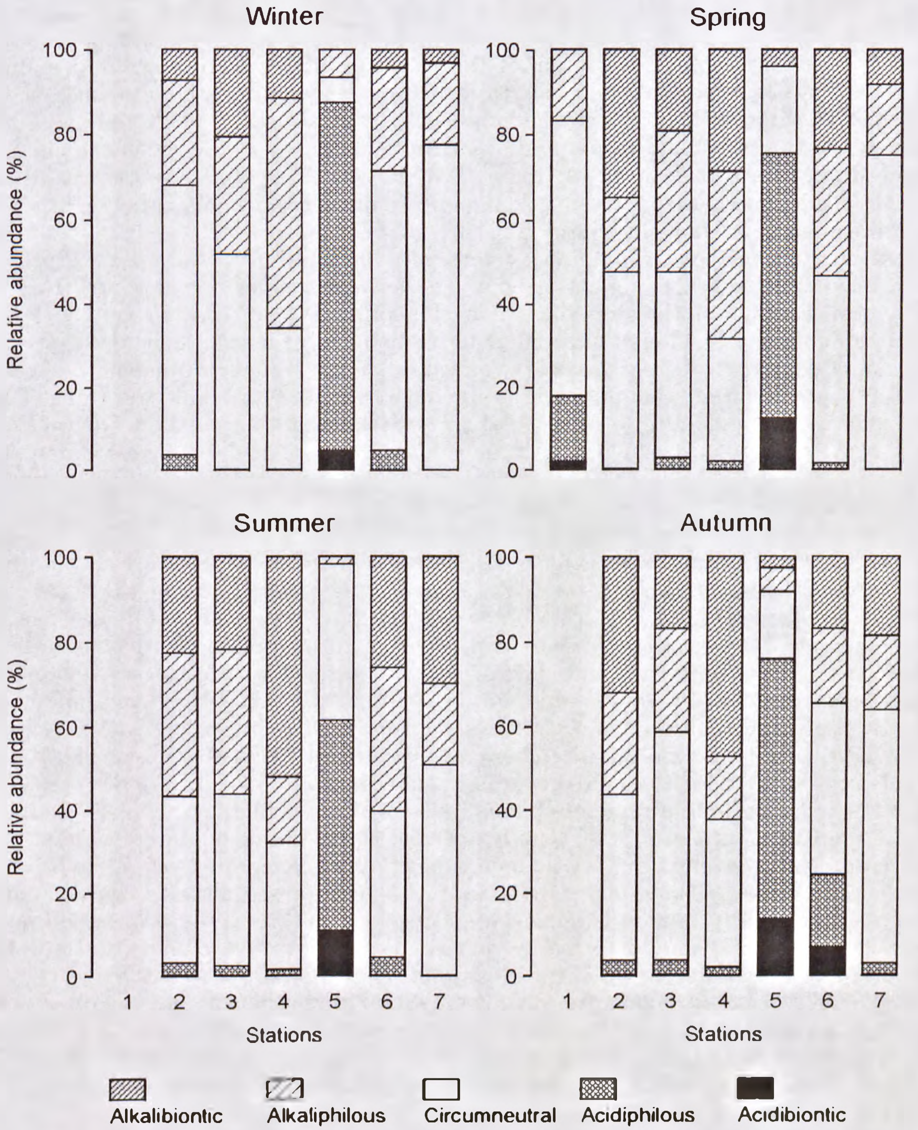

Fig. 3. The contributions of diatom pH-groups at the investigated sites in the Ratanica stream (Stations 1–4) and its tributary (Stations 5–7).

Group II included algal communities developing in a tributary source (Station 5). From spring to autumn, with maximum coverage in summer, there abundantly occurred aggregations of filamentous Chlorophyceae. More numerous were *Klebsormidium rivulare*, *Spirogyra* sp., *Mougeotia* sp., and *Ulothrix variabilis*. The first species is known for its high resistance to extreme environmental conditions such as acid water, freezing, and drying (Hargreaves and Whitton 1976, Morrison and Sheath 1985). It can be found in extremely oligotrophic streams of the high

Alps (Kawecka 1980), and in acid streams of the Beskid Śląski mountains (Kwandrans 1989, 1993). The number of diatom taxa varied in the seasons from 24 to 35, reflecting strong fluctuation of the water pH. They were populated mainly by thalli of Chlorophyceae and mosses, which developed over a stony fringe of the source. The flora of diatoms was dominated by several species of *Eunotia* (Fig. 3), which are the most characteristic diatoms in acid waters of the moderate climate zone (inter alia Van Dam et al. 1981, 1994, Round 1990, 1991, Kwandrans 1993, 1994). Acidophilous taxa formed a dominant group over the whole period of studies, with a maximum share in winter (Fig. 3).

Group III included communities developed on Station 4, situated within an overflow threshold of the main stream. The species composition and structure of phytocenoses domination are indicative of alkaline waters of high trophic level. Throughout the period of studies algae formed abundant macroscopic aggregations. Diatoms occurred in great numbers, represented by a greater number of species (48–50) than other communities. Periodically more numerous were also the ubiquitous blue-green algae *Lyngbya* sp., *Phormidium autumnale* and *Phormidium favosum*, and green algae *Ulothrix variabilis*, accompanied by *Oedogonium* sp., *Stigeoclonium* sp., and *Ulothrix* sp. The most common diatoms were those associated with alkaline waters and euthrophy but with a relatively low level of organic pollution: *Fragilaria construens*, *Cymbella silesiaca*, *Gomphonema olivaceum*, and *Nitzschia dissipata*. High abundance was reached by *Achnanthes minutissima* var. *minutissima*, which was present as dominant also on the majority of other stations (Fig. 2). *Achnanthes minutissima* var. *minutissima*, which is circumneutral in relation to water pH, belongs to a species of broad ecological spectrum concerning nutrient levels and is commonly present in mountain (Kawecka 1980) and upland waters of various types (Round 1990, Van Dam et al. 1994, Kelly and Whitton 1995). At the same time it is among organisms especially sensitive to organic matter (Steinberg and Schiefele 1988). As far as pH of the water is concerned a dominant group was composed of alkalibiontic taxa in summer and autumn and alkaliphilous taxa in winter and spring (Fig.3).

Group IV (Stations 2, 3, 6, and 7) included communities of similar domination structure (Fig. 3), and not very abundant populations, generally with a majority of circumneutral and alkaliphilous diatoms (Fig. 3), and those tolerant towards higher water trophy. According to Grodzińska and Laskowski (1996), the above-mentioned stations in general were featured by very similar chemical parameters of the water (especially pH and nutrient concentration). The differences in the character of individual types of community resulted mainly from physical environmental conditions, which were sometimes a limiting factor. The number of algal species varied at particular sites, from the lowest number at Station 6 to the highest at Station 7 (31–57). The main group was diatoms. Among dominant species, along with the forms especially linked with nutrient-rich waters (*Achnanthes lanceolata*, *Nitzschia linearis*, *Rhoicosphenia abbreviata*, *Amphora pediculus*) and eurytopic (*Achnanthes minutissima* var. *minutissima*), in winter an oligotrophic diatom *Navicula gallica* var. *perpusilla* reached domination. It grows in very well oxygenated and neutral waters (Van Dam et al. 1994), and in places of low light intensity and little or minimal water (Krammer and Lange-Bertalot 1986). Within this group Station 6 should be distinguished. The stream bottom was covered here mainly with ferrous bacteria of the genus *Leptothrix*, commonly present in waters with a high concentration of ferrous compounds (Starmach 1989). The algal community was characterised by a small number of species and remarkably poor quantitative development. Filamentous cyanobacteria and scarce diatoms could be found sporadically, growing more intensively only at the end of winter. The factor limiting the growth of algae could not be fully identified. To some extent it might be unfavourable physical conditions such as a lack of stable substrate, small water flow, and very considerable dimness caused by exuberant growth, from spring to late autumn, of terrestrial vegetation (inter alia *Dryopteris filix-mas* (L.) Schott and *Petasites albus* (L.) Gaerth).

4.2. Water quality assessment by diatom communities

Different types of diatom community structure reflected very well the difference in water pH (Fig. 3), and also the characteristics of water trophy and saprobity (Figs 4–6). According to Hofmann's classification system (1994), the range of

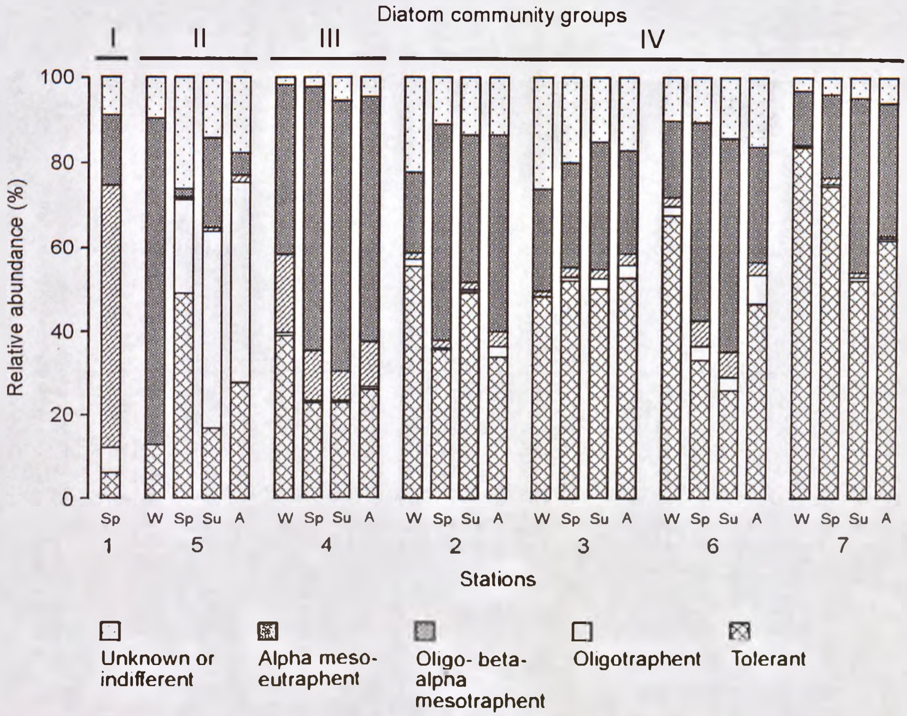

Fig. 4 The relative contributions of diatom trophic indicators at the investigated sites in the Ratanica stream (Stations 1–4) and its tributary (Stations 5–7) in 1994: Sp – spring, Su – summer, A – autumn. W – winter.

trophic state was from oligotrophy to meso-eutrophy (Fig. 4). The most natural, acid, oligotrophic type of waters was distinguished at the source of the confluent (site 5), this being characterized by a greater share of oligotraphent and tolerant species. In the spring oligotraphent species decreased in relation to the increasing tolerant ones, which may evidence the effect of agricultural land use practices. Also community Group I developed in the source of the Ratanica stream (Station1), where tolerant species became the prevailing group, indicating rather a natural clean type of water, belonging to the oligo-beta-mesotrophy type The highest

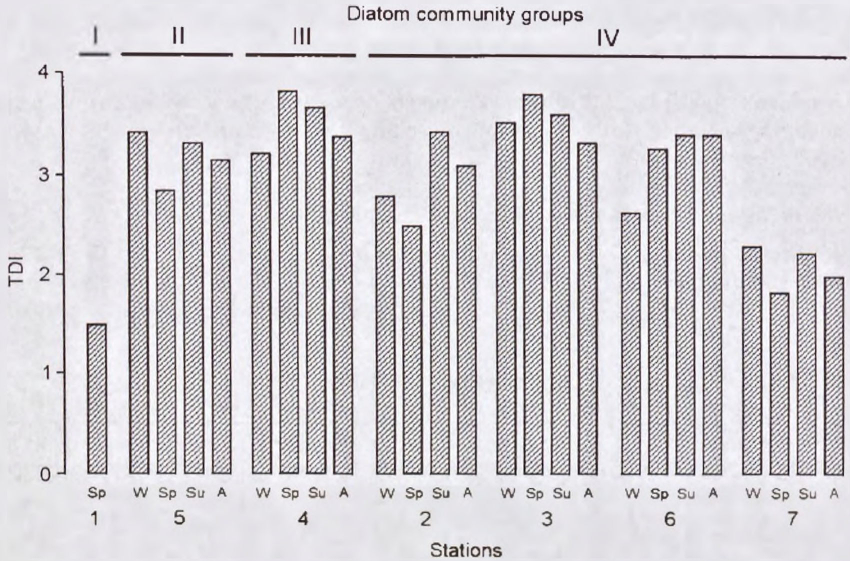

Fig. 5. Changes in Trophic Diatom Index (TDI) at the investigated sites in the Ratanica stream (Stations 1–4) and its tributary (Stations 5–7) in 1994: Sp – spring, Su – summer, A – autumn, W – winter.

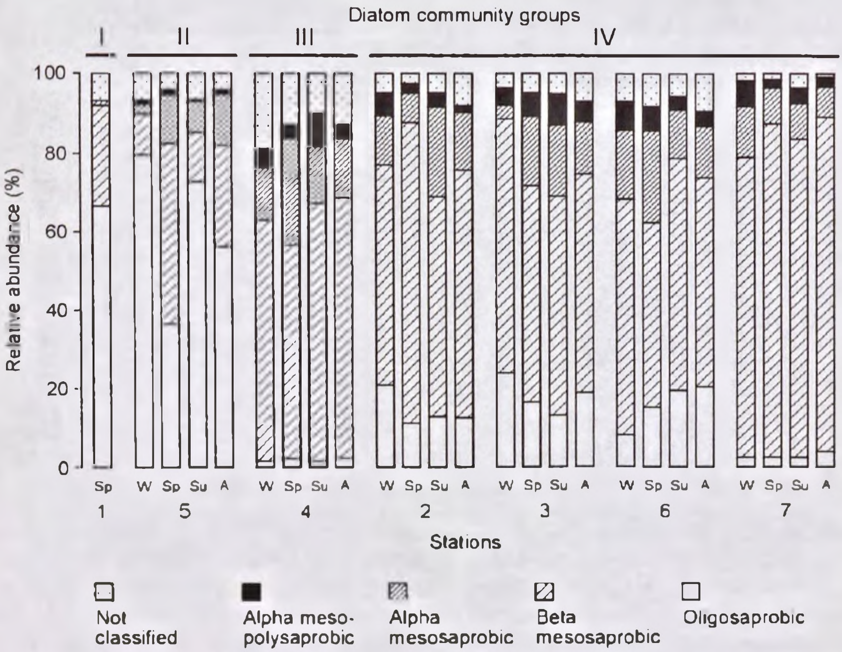

Fig. 6. The relative contributions of diatom saprobic indicators at the investigated sites in the Ratanica stream (Stations 1-4) and its tributary (Stations 5–7) in 1994: Sp – spring, Su – summer, A – autumn, W – winter.

trophy level was observed in the lower sector of the Ratanica stream (Station 4), the greatest share of alpha-mesoeutraphent and eutraphent species being found there. Oligotraphent diatom species were almost absent at this site. Among communities of Group IV (Stations 2,3,6,7), most were characterized by a large share of tolerant species, and also alpha-mesoeutraphent and eutraphent ones, which in general classified those sectors also as mesotrophic.

Water trophic level was also estimated according to the Trophic Diatom Index (TDI), as in Kelly and Whitton (1995). The value of TDI ranged from ca. 1.5 indicating low nutrient concentration to almost 4.0, indicating high nutrient concentration (Fig. 5). The lowest value, TDI, gave for the community I, indicating natural, clean waters at Station 1. Moreover, TDI showed only a slightly higher trophic degree for Station 7, belonging to community-Group IV. The remaining sites were more or less equal in this scale and high, indicating eutrophic waters. No very distinct differences between the seasons were observed. The results of this index differed in some cases from those obtained by the Hofmann method (1994), especially in relation to the estimation of trophic level at Station 5. Probably this was due to the restriction of species within the number of *Eunotia* genus in the list of 86 selected taxa used by the authors for TDI.

On the basis of diatom communities of the stream according to the classification of Van Dam et al. (1994), the saprobic status of the investigated streams was also assessed (Fig. 6). According to this system the diatoms were grouped into saprobity classes. The most distinctly clear oligosaprobic were Stations 1 and 5. The lower part of those streams (Stations 2, 3, 4, 6, 7) was included in the beta-mesosaprobic class, although there were some differences between particular stations. Stations 2, 3, and 6 constituted a separate group with 10–20 % of oligosaprobic diatoms. Oligosaprobic taxa occurred in small numbers at Stations 7 and 4. The beta--mesosaprobic taxa dominated especially at Station 7. The relative share of alpha--meso and polysaprobic diatoms was not high and somewhat similar to those at most of the lower sites. However, the groups were represented by very small numbers at the clean Stations 1 and 5.

In summing up the results of the floristic analyses, the water ecosystems of the Ratanica catchment area were subject to eutrophication. Only the spring sectors of both streams had a more natural character, where the effect of high hydrogen-ion concentration was stronger than that of the eutrophic factor. In the lower part the trophic level increased with higher water pH and buffering capacity, and also owing to effects of the management of the surrounding area. This causes the eutrophication of waters of the Ratanica stream, this being highly unfavourable since that these waters merge with the drinking water reservoir at Dobczyce. Eutrophicated and polluted waters of the River Raba and many of its tributaries (Kwandrans et al. 1998) reduce the quality of water in the reservoir itself, causing its fertility and pollution, which can be observed in the numerous blooms of diatoms and some cyanobacteria (Bucka 1998). According to Godzik and Krywult (1998), the Ratanica catchment area is also subject to acidification, originating from atmospheric pollution. However, the low stage of acidification and correlation of pH with calcium evidence the high buffer capacity of those waters.

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