

Ecological characteristics of communities of sessile algae in the Biała and Czarna Wisłoka streams, headwaters of the River Vistula (Silesian Beskid, southern Poland)

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Abstract — The structure of algal communities was differentiated according to the changing living conditions along the stream course. In sections of streams with a low calcium content in the water and acidic water reaction scarce acidophilous species of diatom and the yellow-green alga *Ellipsoidion anulatum* developed. Those where the waters had a higher calcium content and pH and with greater resources of biogenic compounds were characterized by richness of forms and an abundant quantitative development of algae. The structure of algal communities at particular stations showed seasonal changes.

Key words: montane streams, sessile algae, community, numbers, diversity, water chemism, seasonal changes.

1. Introduction

Algological studies in the upper Vistula have a long tradition. They were initiated by Starmach (1938b) and continued by Rumeck (1957), Turoboyski (1962), Kyselowa and Kysel (1966), Hanak-Schmager (1974), Pudo (1977), Pająk (1986), Bednarz and Zurek (1988), and Kwadrans (1988). The above elaborations cover the River Vistula from the submontane region to the vicinity of Kraków, but the literature concerning its headwaters is fragmentary.

The first data about the occurrence of algae in headwater streams of the Vistula were reported by Starmach (1938a) when discussing the sites of blue-green algae in Poland. Later data given by the same author (1959) concern algal species characteristic for montane streams and among others include the Biała and Czarna Wisłoka. Moreover, hydrobiological studies on the lower course of the headwater streams of the Vistula and the Wisła-Czarne reservoir constructed at their confluence

were carried out from 1974 by a team of workers of the Hydrobiological Station of the Laboratory of Water Biology of the Polish Academy of Sciences at Goczałkowice. These investigations resulted in the elaboration of the chemical composition of the waters (Kasza 1986), phyto- and zooplankton, and the bottom fauna (Krzyżanek 1986, Krzaniowski 1987, Strzelecki, Cierniak — unpubl. data).

The aim of the present study was to investigate the structure and ecology of algal communities developing in the Biała and Czarna Wisetka streams — the headwaters of the Vistula. The investigation included differentiation of algal communities along the course of the streams as depending upon the kind of habitat, and changes in the communities during successive vegetation seasons.

2. Study area

2.1. Situation and relief

The headwater streams of the River Vistula, the Biała and Czarna Wisetka, flow from the slopes of Mt. Barania Góra (alt. 1220 m) in the Silesian Beskid range, which constitutes the western part of the Western Beskids. It is situated between the valleys of the Rivers Olza and Soła. The central part of the Silesian Beskid is divided by the valley of the River Vistula. The highest mountain is Skrzyczne (1257 m).

The area of the Silesian Beskid is characterized by gentle ridges with numerous flattenings, sometimes wet in character, and great relative altitudes (400—700 m). The valleys are narrow and their bottoms wholly occupied by the stream beds; only in the Biała Wisetka valley can some widening be observed. The valley sides are usually symmetrical, the only exception being the valley of the Biała Wisetka whose left slope is very steep and the right gentle (Dyński 1961).

2.2. Geology and soils

The Silesian Beskid is built of a complex of sandstones, conglomerates, and shales, defined as the Carpathian flysch, originating from the Cretaceous. The Biała and Czarna Wisetka streams flow in the area of the so-called Istebna and Godula series. The formations of the Istebna series are coarse-grained, easily weathering, dark sandstones with intercalations of shales and conglomerates. The formations of the Godula series are thin-bedded little weathering light sandstones with intercalations of loamy shales (Burtanówna et al. 1937). The chemical composition of these layers is very varied. In general, they show a very small content of calcium and magnesium and a large one of silica, potass-

ium, aluminium, and sulphates (Pasternak 1962). The entire well-head area of the two streams and the valley of the Czarna Wisiełka are built of Istebna layers, while the Biała Wisiełka stream also crosses sandstones of the Godula series over about 2 kilometres of its course (Dynowski 1961).

The type of developed soils is associated with the rocks of the substratum. On the coarse-grained Istebna sandstones there were formed permeable sandy-loamy soils, easily retaining water while the poorly resistant Godula sandstones originated brown stony waste with a lesser water retention capacity. On the shale substratum there appear poorly permeable loamy soils, i.e., montane brown soils (Waksmundzki 1968). In general, none of these soils contain carbonates; they are strongly acidic and have a poor content of phosphorus and assimilable nitrogen and a large one of silica, potassium, iron, and sulphates (Pasternak 1962).

2.3. Climate and vegetation

The Barania Góra massif is one of the areas with the most abundant moderately warm climatic zones (Hess 1965), has the montane type of climate. The mean annual air temperature is fairly low (about 7°C), the annual amplitude of temperatures reaching about 19°C (Waksmundzki 1968).

The Barania Góra massif is one of the areas with the most abundant atmospheric precipitation in Poland. The mean annual rainfall exceeds 1300 mm and is even higher in shoulder parts, especially on the southern and western slopes, since horizontal precipitation (mist and drizzle) also plays an important role there (Dynowski 1961). The snow cover remains for a long period, in higher parts being maintained for more than 150 days in the year.

With regard to the geobotanical character the discussed area belongs to the montane province, the Carpathian sub-province, the section of Western Carpathians, and the Beskid district (Szafer, Zarzycki 1972). In comparison with the remaining part of the Western Carpathian Mts the flora of the Beskid range is very poor, the chief reason being the almost complete absence of limestones. Forests prevail in the vegetal cover of the Silesian Beskid. They cover 88.9% of the catchment basin, the remainder consisting of a few meadows, clearings, and cultivated fields (Dynowski 1961). In forest communities there occur fir-beech stands, relics of a former natural lower montane forest zone, and spruce stands characteristic for the upper forest zone. On account of inappropriate management based on the transformation of natural mixed forests into those of one species, large areas of the lower montane forest zone are covered by spruce.

2.4. Hydrography

The investigated area is drained by the Biała and Czarna Wisieka streams and their affluents, the larger of which are the Roztoczny, Wątrobny, and Wolny (fig. 1). The density of the river network is 1.65 km km^{-2} on the average, increasing to about 2.5 km km^{-2} in the upper part of the basin (D y n o w s k i 1961). The permanent waters prevail over temporary ones. The latter occur only in unforested parts of the basin and in source areas. The Czarna Wisieka is regarded as the headwater stream of the Vistula because its trickles appear higher and it is longer.

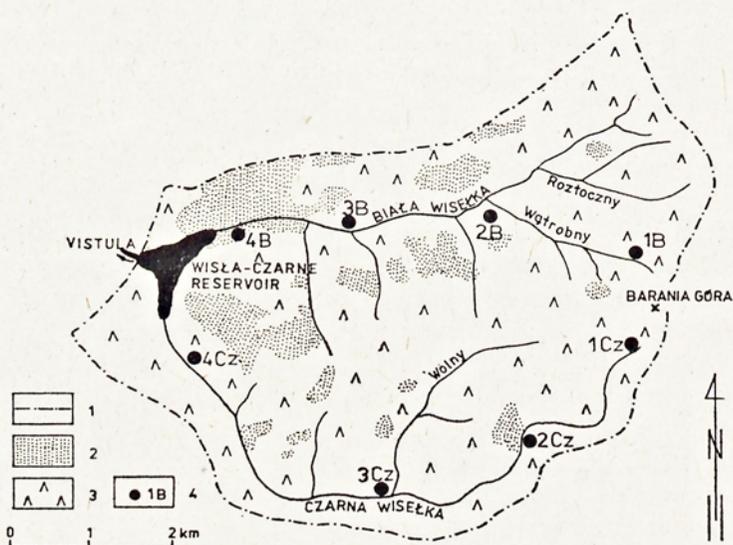


Fig. 1. Map of the study area. 1 — borderline of the catchment basin; 2 — meadows and fields; 3 — forests; 4 — stations: 1B—4B on the Biała Wisieka stream, 1Cz—4Cz on the Czarna Wisieka stream

Both streams originate from springs, usually from helocrene marshes, and rheocrene. The streambeds are narrow, cut in solid rock, with numerous vertical steps, rapids, and waterfalls. The largest, the Sklepki waterfall, about 10 m in height, lies in the Biała Wisieka valley at the crossing of the Istebna and Godula layers.

In both streams the magnitude of water discharge is subject to great variations depending upon the abundance and type of precipitation. In their water level two maxima are noted: a summer one in June and July brought about by heavy rain followed by a sudden rise and then a rapid return to the initial state, and a lower winter-spring maximum occurring most frequently in April, accounted for by meltwaters. The lowest water

levels are observed in autumn, from October to November (Waks-mundzki 1968).

The water current is differentiated in several categories depending on the gradient of the terrain and magnitude of flow; strong current from $1-1.7 \text{ m sec}^{-1}$, medium from $0.4-0.9 \text{ m sec}^{-1}$, and weak from $0.2-0.4 \text{ m sec}^{-1}$. The water temperature is low, varying from $6.5-15.0^\circ\text{C}$ in summer and from $0.2-4.0^\circ\text{C}$ in winter. In winter partial icing of the streams is observed.

2.5. Description of streams and stations

The Czarna Wiselka flows from a number of marshes on a wide plain on the southwestern slopes of Mt Barania Góra at an altitude of about 1100 m (fig. 2). About 400 m from the springs the flat terrain ends and the stream flows in a deeply cut valley. The valley is narrow and covered with dense forest. The flow is about 9,3 km in length. About 3 km from the springs (between Stations 2Cz and 3Cz) on the Przysłop Glade there is a tourist shelter whose wastes enter the stream without, however, hav-

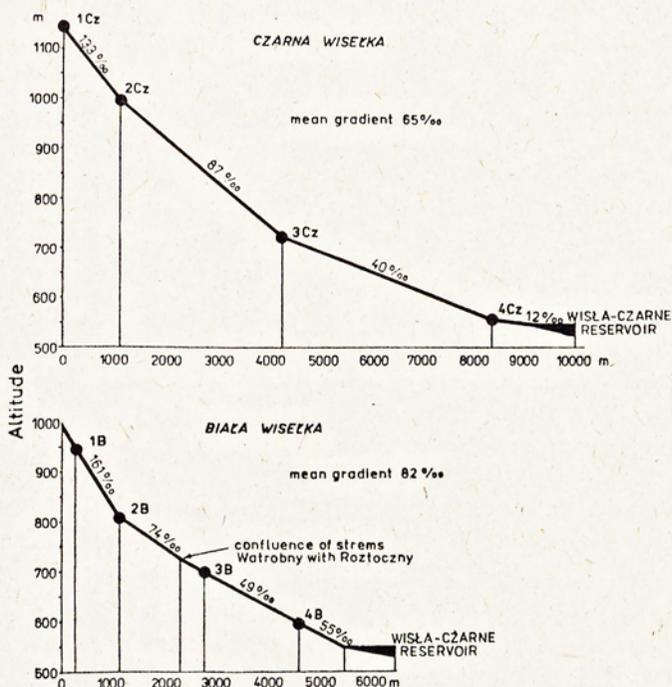


Fig. 2. Longitudinal profile of the Biała and Czarna Wiselka streams and the stations of the investigations

ing any significant effect on the increase in fertility of the stream waters so far.

The Biała Wisetka originates from rocky springs lying on the western slopes of Mt Barania Góra at an altitude of about 1000 m (fig. 2). In its upper course the Biała Wisetka is composed of two streams — the Roztoczny and Wątrobny. At about 725 m alt. the two affluents merge, and the stream valley widens and becomes distinctly asymmetrical. The left side of the valley is very steep but the right gentle. In the Biała Wisetka valley a stand of loose forest is separated by meadows and glades. The stream is 6.7 km in length. In the Biała Wisetka valley particularly intensive felling is carried out in the upper course of the stream. In this connection the waters are turbid and loaded with large amounts of suspension.

At an altitude of about 560 m the Biała and Czarna Wisetka streams merge and drain their waters to an artificial lake, the Wisła-Czarne Reservoir.

8 stations were established along the course of the investigated streams: 4 on the Biała Wisetka and 4 on the Czarna Wisetka (fig. 1). They are described in Table I.

2.6. Chemical composition of the water in the streams

Detailed chemical analysis of the water from Stations 2Cz, 3Cz, 4Cz, 2B, 3B, and 4B was carried out four times during successive vegetation seasons (spring, summer, autumn, and winter) at the Hydrobiological Station of the Polish Academy of Sciences at Goczałkowice.

In spite of the close proximity of the two streams, the chemical composition of their waters differs considerably on account of the different geological structure of the substrata of the two valleys. The differences are above all expressed by a higher concentration of calcium in the water of the Biała Wisetka (Table II).

The concentration of calcium and acid carbonates plays a basic role in buffering the water and affecting its reaction. Apart from the headwater section (Station 1B with low pH 3.5—5.0) the reaction of water in the Biała Wisetka varies around pH 7. The water of the Czarna Wisetka which flows over strongly peaty slopes shows lower pH values. It reaches 3.5—5.2 in the headwaters and in the upper sectors, varying from acidic to neutral in the lower course.

It should be stressed that the acid reaction of the stream water is probably due not only to the low content of calcium in the rocks and to the strong acidification of forest soils but also to deposits from atmospheric pollution flowing in through the Morawa Gate. This is shown by the lowest values of pH usually observed in snow melt periods.

Table I. Characteristics of the stations

Parameter	Czarna Wisielka					Biała Wisielka			
	10z	20z	30z	40z	1B	2B	3B	4B	
Stream Stations	sources	upper stream course	middle stream course	lower stream course	outflow from the source	upper stream course	middle stream course	lower stream course	
Locality									
Altitude m	1140	1000	725	560	950	800	700	580	
Gradient ‰	4	87	40	12	161	74	49	55	
Current speed m sec ⁻¹	very slow	0.8-1.2	0.4-1.5	0.5-1.6	0.5-1.0	0.8-1.5	0.2-1.2	0.6-1.7	
Width of streambed m	0.2-0.5	1.0-1.5	5.0-6.0	6.0-8.0	0.2-0.3	3.0-4.0	6.0-8.0	6.0-8.0	
Depth m	0.1-0.2	0.3-0.5	0.2-0.5	0.5-1.0	0.2-0.3	0.5-0.8	0.3-0.8	0.5-1.0	
Character of the bottom	mud and coniferous needles	gravel, large and medium stones	mud at the bank, large and medium stones, rocky blocks	mud and sand at the bank, large stones, rocky blocks	gravel and sand at the bank, small and medium stones	mud and sand at the bank, large and medium stones	mud at the bank, shale, large and medium stones, solid rock	mud at the bank, large and medium stones, rocky blocks	
Type of banks	flat	low, slightly steep	right bank high and gentle, left bank low and steep	right bank gentle, left bank steep and fairly high	steep and high	flat and low	right bank low with a wide belt of stone deposits, left bank high and steep	right bank at the bank, flat, then steep, left bank high and steep	
Vegetation	<i>Polytrichum attenuatum</i> Menz., <i>P. commune</i> Hedw., <i>Sphagnum girgensohnii</i> Riss., spruce	<i>Scapania undulata</i> (L.) Dum., <i>Polytrichum commune</i> Hedw., spruce	<i>Scapania undulata</i> (L.) Dum., <i>Rhacomitrium fasciculare</i> (Hedw.) Brid., spruce, fir	<i>Rhacomitrium fasciculare</i> (Hedw.) Brid., spruce, fir, beech	<i>Scapania undulata</i> (L.) Dum., <i>Pellia endiviaefolia</i> (Dicks.) Dum., <i>Sphagnum nemorosum</i> Scop., spruce	<i>Scapania undulata</i> (L.) Dum., spruce	<i>Rhacomitrium fasciculare</i> (Hedw.) Brid., spruce, fir	<i>Rhacomitrium fasciculare</i> (Hedw.) Brid., spruce, fir, beech	
Geology	Istebna layers	Istebna layers	Istebna layers	Istebna layers	Istebna layers	Istebna layers	Godula layers	Godula layers	
Insolation	very good	poor	good	medium	poor	very poor	very good	good	
Range of temperature °C	1.5-15.2	0.8-9.6	0.2-11.0	0.4-12.2	2.8-10.5	0.8-13.2	0.2-15.4	0.2-15.8	
pH	3.5-5.0	3.5-5.2	5.8-7.0	5.8-7.0	3.5-5.0	6.4-7.2	6.4-7.3	6.5-7.5	

Table II. Range of variation of certain chemical indices of water in the Biała and Czarna Wisiełka streams in 1981-1982 (according to Kasza unpubl. data) . tr - trace

Parameter	Stream Station	Biała Wisiełka				Czarna Wisiełka			
		2B	3B	4B	20z	30z	40z		
Conductivity	$\mu S\ cm^{-1}$	95.06-101.58	94.32-104.22	103.58-115.23	52.5-106.2	59.69-76.2	69.02-83.6		
pH		6.4-7.2	6.4-7.3	6.5-7.5	3.5-5.2	5.8-7.0	5.8-7.0		
Alkalinity	aval dm^{-3}	0.35-0.45	0.3-0.55	0.38-0.70	0.2-0.45	0.22-0.50	0.18-0.70		
Hardness	og	2.80-3.25	2.50-2.80	2.60-3.15	1.20-2.40	1.15-2.50	1.65-2.25		
Calcium	mg Ca dm^{-3}	12.15-14.29	12.15-13.93	12.86-15.72	3.57-5.0	5.72-8.57	3.93-11.07		
Magnesium	mg Mg dm^{-3}	2.82-5.42	2.60-4.34	2.60-4.34	2.38-7.37	2.17-5.63	2.38-5.42		
Chlorides	mg Cl dm^{-3}	3.0-4.0	2.75-4.75	3.25-9.0	2.75-4.50	3.5-10.0	3.0-6.5		
Silica	mg Si dm^{-3}	2.82-2.96	2.70-2.96	2.78-3.04	2.50-3.56	2.96-3.34	2.28-3.56		
Ammonia nitrogen	mg N dm^{-3}	0.004-0.104	0.0-0.078	0.0-0.127	0.301-0.214	0.0-0.09	0.0-0.106		
Nitrite nitrogen	mg N dm^{-3}	0.0-0.0044	0.0-0.0028	tr-0.009	0.0-0.0026	0.0-0.0026	0.0-0.0026		
Nitrate nitrogen	mg N dm^{-3}	2.15-3.80	2.12-3.05	1.77-2.58	3.4-1.30	1.17-1.83	1.20-2.70		
Phosphates	mg P dm^{-3}	tr-0.004	tr-0.003	0.001-0.011	0.0-0.011	0.0-0.002	0.0-0.003		
Total phosphorus	mg P dm^{-3}	0.004-0.025	0.003-0.040	0.002-0.065	0.003-0.02	0.008-0.31	0.002-0.025		
Oxidability	mg O ₂ dm^{-3}	2.16-6.0	1.96-3.44	1.92-5.24	5.16-8.48	3.36-5.20	2.40-4.24		
BOD ₅	mg O ₂ dm^{-3}	2.08-3.20	1.44-2.40	0.96-3.52	0.64-3.68	0.32-2.72	0.80-2.88		
Oxygen dissolved	mg O ₂ dm^{-3}	10.40-12.16	10.00-12.32	9.92-12.16	9.76-12.10	9.92-12.80	9.44-12.80		
Oxygen saturation	% O ₂	85.44-90.35	89.40-91.80	89.93-103.33	83.42-86.17	87.95-91.9	86.92-93.63		

The content of basic nutritive compounds (mineral nitrogen compounds and phosphates) in the water of the Biała and Czarna Wisiełka is typical for montane sylvan streams (Bom bó w n a 1965, 1976). It is characterized by a decisive prevalence of nitrates over ammonia nitrogen and by a poor content of phosphates. At the same time, the fairly high concentration of nitrates should be stressed, slightly smaller amounts of these compounds being found in the water of the Czarna than in that of the Biała Wisiełka (Table II).

In the upper sector of the Czarna Wisetka (Station 2Cz) the concentration of phosphates is higher than in its middle and lower courses (Stations 3Cz and 4Cz), while in the Biała Wisetka their content increases in the lower course (Station 4B) as compared with the upper and middle ones (Stations 2B and 3B).

The water of the Biała and Czarna Wisetka contains few organic compounds. However, there sometimes occur periods when oxidability exceeds $5 \text{ mg O}_2 \text{ dm}^{-3}$ and BOD_5 $3 \text{ mg O}_2 \text{ dm}^{-3}$, this being mostly after rain. The poor content of organic compounds, considerable gradients of the streambeds, and rapid current account for the good oxygenation of the water; nevertheless, oxygen saturation very rarely exceeds 100%.

3. Material and method

The basis of the investigation consisted of 400 samples collected in the period 1981—1982. They were taken at 4-week intervals throughout the year at Stations 2B, 3B, 4B, 3Cz, and 4Cz. Because of icing during winter and a thick snow cover in spring, the material of the Czarna Wisetka was collected at Station 1Cz in the period April-October and at Station 2Cz from March to November, and of the Biała Wisetka at Station 1B from May to October.

During each sampling the temperature of the water was measured and its reaction determined by the colorimetric method. To check the accuracy of determination a potentiometric pH-meter was simultaneously used on one sampling date, coincident results of the two measurements being obtained.

The speed of the current was measured using a chronograph and a weighted cork.

The collection and description of the material was based on methods given by S t a r m a c h (1969) and K a w e c k a (1980).

Algae were washed from the surface of stones with a brush, mosses and bank muds also being collected. The material was fixed in a 4% solution of formalin. Permanent silica slides were prepared from part of the material. In order to remove the internal content of diatom cells the material was macerated in a chromic acid cleaning mixture during 48 hs, centrifuged, and again macerated for a further 48 hs. Diatom shells were separated from impurities by sedimentation and centrifugation at 3000 r/min. Of each sample two permanent preparations were made in the artificial resin "pleurax". The remaining part of the prepared material was stored in distilled water. Algae were investigated using a Zeiss "Amplival" light microscope, with a net micrometer mounted in the eyepiece.

Algal communities were characterized by determining the number of

species and their abundance, degree of coverage and, in the case of diatoms, also the index of species diversity and their biomass. The degree of coverage of algae occurring in the form of homogeneous macroscopic aggregations was estimated according to a 5-grade scale from an area of the bottom (about 1—10 m²), depending on the size of the streambed (K a w e c k a 1980):

- 1 — organisms form small aggregations,
- 2 — organisms cover less than 25% of the bottom,
- 3 — organisms cover 25—50% of the bottom,
- 4 — organisms cover 50—75% of the bottom,
- 5 — organisms cover 75—100% of the bottom.

Species reaching the third degree and over in the scale of coverage were regarded as dominants and those of the 1st and 2nd degree as adominants.

Analysis of number of microscopic forms (chiefly diatoms) was carried out by counting the cells of particular species in 10 microscopic fields of view at a magnification of the eyepiece 10× and of the objective 40×, using a net micrometer. It was conventionally accepted that if a species occurred in a sample but was not found in the count it was given the value 0.1. In this way the number of each species in the sample was obtained. The mean number of a species at the given station was also computed. On the basis of percentage shares the dominant and adominant species were identified. Those showing a share in the community of at least 5% were regarded as dominants while the remainder were classified as adominants. The coefficient of coverage was computed in order to determine the role of particular species in the community. For this purpose the relative size of cells was determined by comparing them with the mesh size of the net micrometer (this size being given in multiples or parts of squares of the net); the number of cells of the given species was then multiplied by the average size of a cell. When this value was multiplied by two the assimilative surface of algal cells was conventionally obtained. The sum of coefficients of coverage at the particular stations represents the so-called index of diatom biomass which allows conventionally the comparison of magnitudes of diatom production (S t a r m a c h 1969, K a w e c k a 1980). In the investigated streams this index reached values in the range 96—716. The following scale of values of the index was accepted:

- low — 96—300,
- medium — 301—500,
- high — over 500.

The communities of algae were compared using mathematical similarity analysis according to the Sokal formula (1961):

$$D_{jh} = \sqrt{\sum_{i=1}^n (P_{ij} - P_{ih})^2}$$

where:

D_{jh} — distance between communities j and h ,
 P_{ij} — abundance of species i in community j ,
 P_{ih} — abundance of species i in community h ,
 n — number of species.

The similarity of algal communities was presented in the form of dendrograms.

The identified groups of similar communities were characterized by the so-called constant species, i.e., organisms occurring in 70—100% of the investigated samples.

Besides, the H' index of species diversity was computed for diatom communities according to the Shannon-Weaver (1949) formula:

$$H' = - \sum_{i=1}^s x_i \ln x_i, \quad x_i = \frac{n_i}{N}$$

where:

n_i — abundance of species i ,
 N — abundance of all species,
 s — number of species.

To facilitate interpretation a magnitude standardized to unity was introduced. This was determined as the standardized index of species diversity of diatoms (E) — "evenness" which reached values in the interval of [0,1]. The greatest diversity occurred when E approximated to 1 and the least when it approached 0. The index E was computed according to the formula:

$$E = \frac{H'}{\ln s}$$

where:

s — the number of species.

The aim of analysis of lithorheophilic, pelorheophilic, and phytorheophylic communities of diatoms was to investigate whether the characteristic communities of diatoms correspond with the particular habitats. In the discussion only Stations 3B and 4B were taken into account, since diatoms abundantly developed in mass in these sectors. A total of 67 samples was analysed. At each sampling date the diversity of habitats of diatoms was taken into consideration (stones, mud, moss, and thalli of other algae accompanied by diatoms). In each investigated habitat species whose cells were most numerous were selected and the percentage share was computed in each of them.

4. Results

4.1. Description of algal communities along the course of the Czarna Wiselka stream

Altogether 80 taxonomic units of algae were determined in the Czarna Wiselka stream, among them representatives of 7 systematic groups being found (Table III). The differentiation of the structure of algal communities along the course of this stream is shown in Table III and fig. 3.

Table III. Number of taxa of different systematic groups of algae at the particular stations (percentage share given in brackets)

Taxa	Stream	Czarna Wiselka				Biała Wiselka			
	Station	1Cz	2Cz	3Cz	4Cz	1B	2B	3B	4B
Cyanophyta				5 (7.7)	7 (11.3)		9 (11.2)	7 (7.5)	8 (7.8)
Euglenophyta		2 (7.4)							
Chrysophyceae				1 (1.6)	1 (1.6)			1 (1.0)	1 (0.9)
Bacillariophyceae		20 (74.0)	22 (78.6)	53 (82.8)	47 (75.8)	20 (80.0)	67 (82.7)	80 (85.1)	85 (82.6)
Xanthophyceae		1 (3.7)	1 (3.6)			1 (4.0)			
Chlorophyta		4 (14.9)	5 (17.8)	4 (6.3)	6 (9.7)	4 (16.0)	4 (4.9)	6 (6.4)	7 (6.8)
Rhodophyta				1 (1.6)	1 (1.6)		1 (1.2)		2 (1.9)
Total number of taxa		27	28	64	62	25	81	94	103

With regard to the number of taxa diatoms constituted the largest group, the share of blue-green and green algae also being large, while the other groups were represented by a small number of species. The largest number of taxa was found in the middle and lower course of the stream (Stations 3Cz and 4Cz) and the smallest in the headwater section and in the upper course (Stations 1Cz and 2Cz).

In the headwater section of the stream (Station 1Cz) ferric bacteria of the genus *Gallionella* played an important role. The number of species of algae was small. *Vaucheria* sp. and euglenoids *Euglena intermedia* (Klebs) Schmitz and *E. geniculata* Dujardin em. Schmitz, which occurred in smaller numbers and only in this region, periodically dominated. The yellow-green alga *Ellipsoidion anulatum* Pascher and the green alga *Chlorhormidium rivulare* Kütz. Starmach also grew here. Of the numerous occurring diatoms the acidophilous species *Eunotia exigua* (Bréb.) Rabh., *E. trinacria* Krasske, *E. lunaris* (Ehr.) Grun., *Frustulia rhomboides* var. *saxonica* (Rabh.) De Toni, *Pinnularia microstauron* (Ehr.) Cl., and *P. viridis* var. *sudetica* (Hilse) Hust. dominated.

The index of diatom biomass reached average values.

In the upper course the stream (Station 2Cz) the number of species continued to be small. The chief role was played by yellow-green alga *Ellipsoidion anulatum* and acidiphilous species of diatom. Among them cells of *Eunotia exigua* and *E. tenella* (Grun.) Hust. prevailed. The share of *Eunotia trinacria* and *Pinnularia microstauron* decreased but they were still among the dominants.

The index of diatom biomass reached average values.

In the middle course (Station 3Cz) the number of species of alga increased. *Hydrurus foetidus* Kirchn. whose thalli covered stones almost in the entire cross-section of the stream, dominated here. A great role was periodically played by the green alga *Chlorhormidium rivulare* with its most abundant development. Blue-green algae, which were absent hitherto, appeared here. Larger numbers of *Lyngbya kützingiana* (Kütz.) Kirchn. and also *Homoeothrix janthina* (Boret. et Flah.) Sarmach and *Chamaesiphon polonicus* (Rostaf.) Hansg. occurred. In this section diatoms showed very small numbers and a low index of biomass. The dominant species were *Eunotia exigua*, *E. tenella*, and *Pinnularia microstauron*.

Lower down the stream (Station 4Cz) the floristic composition of the community and quantitative relations showed a great similarity to the community in the middle course. The share of *Hydrurus foetidus* and also *Chamaesiphon polonicus* and *Homoeothrix janthina* decreased, while *Chlorhormidium rivulare* and *Lyngbya kützingiana* developed more abundantly. In shady places the red alga *Chantrasia chalybaea* (Roth.) Fries occurred in larger aggregations. Diatoms played no great role and the index of their biomass had lower values. The dominant species were *Eunotia exigua*, *E. tenella*, *Pinnularia microstauron*, and *Surirella linearis* W. S m.

4.2. Description of algal communities along the course of the Biała Wiszka stream

133 taxonomic units of algae identified here belong to 6 systematic groups (Table III). The differentiating structure of algal communities along the course of this stream is presented in Table III and fig. 4.

Diatoms constituted the dominant group with regard to number of taxa; blue-green and green algae were also numerous, while the share of other groups of algae was small. The largest number of taxa was found in the lower course (Station 4B) and the smallest in the headwater section (Station 1B).

numbers of diatoms were small and the index of biomass approximated to the lower limit of average values. *Surirella linearis*, species of the genus *Achnanthes*, *Fragilaria capucina* var. *lanceolata* Grun., *Gomphonema intricatum* var. *pumilum* Grun., *Diatoma hiemale* with the variety *mesodon* (Ehr.) Grun., and *Ceratoneis arcus* (Ehr.) Kütz. developed the most.

In the middle course of the stream (Station 3B) the community was characterized by a larger number of species and profuse quantitative development. *Hydrurus foetidus* dominated and the share of *Phormidium subfuscum* (Agardh) Kütz., *Chamaesiphon polonicus*, and *Homoeothrix janthina* increased. Also *Ulothrix zonata* (Weber et Mohr) Kütz. accompanied by *U. variabilis* Kütz. developed intensively near the bank. Diatoms appeared in large numbers. They numerously accompanied thalli of other groups of algae and periodically also formed distinct macroscopic aggregations. The index of their biomass reached high values. Among the dominant species were *Ceratoneis arcus*, *Diatoma hiemale* with the variety *mesodon*, *Fragilaria capucina* var. *lanceolata*, *Cymbella ventricosa* Greg., *Synedra ulna* (Nitzsch) Ehr. and species of the genus *Achnanthes*.

In the lower course of the stream (Station 4B) a community of the greatest diversity of forms and an abundant quantitative development was observed. The number of taxa was large with *Phormidium subfuscum*, *Ulothrix zonata* with the accompanying species *U. variabilis* and *Chantransia chalybaea* playing the chief role. *Hydrurus foetidus* covered smaller areas than at the preceding station but was still among the dominant species. The degree of coverage of *Chamaesiphon polonicus* and *Homoeothrix janthina* was also reduced. Abundantly developing diatoms constituted a significant component of the community. Of all the communities discussed the index of diatom biomass reached its highest values here. Similarly as at the preceding station, the dominant species were *Ceratoneis arcus*, *Diatoma hiemale* with its variety *mesodon*, species of the genus *Achnanthes*, *Fragilaria capucina* var. *lanceolata*, *Cymbella ventricosa*, and *Synedra ulna*.

4.3. Seasonal development of communities

Depending upon the season of the year, the structure of algal communities changed with regard to the number and abundance of species, their coverage, and the magnitude of the index of diatom biomass (figs 3, 4). Changes in the development of algae throughout the year were studied at the particular stations along the course of the two streams. The following division of the year was accepted: winter — the period De-

cember-March, spring — April-June, summer — July-August, and autumn — September-November.

The Czarna Wisetka stream

At Station 1Cz the number of species of alga reached a maximum in June and a minimum in April. In spring the bottom of trickles was covered with aggregations of ferrous bacteria of the genus *Gallionella*, accompanied by diatoms. The number of diatoms decreased during the snow melt (in May) and then again increased. Towards the end of this season bacteria disappeared altogether, while the appearance of *Vaucheria* sp., *Ellipsoidion anulatum*, and *Chlorhormidium rivulare* was observed. In July the trickles partly dried up and the number of diatoms decreased. After a period of higher water level in August the number of diatoms again increased and the index of their biomass reached the highest values for the entire period of the investigation. Moreover, the development of *Vaucheria* sp. was intensified. In autumn the community of algae was impoverished. The abundant development of diatoms was reduced markedly and *Vaucheria* sp. and *Ellipsoidion anulatum* appeared in small numbers.

At Station 2Cz the community showed great stability. The number of species of alga was maintained at an almost constant level throughout the period of study with *Ellipsoidion anulatum* and diatoms *Eunotia exigua* and *E. tenella* as dominants. In the population of diatoms there appeared differences in the seasonal development. The index of their biomass reached maximum values in September and minimum in March.

At Station 3Cz the number of species of alga was maintained at a more or less uniform level throughout the year. In winter a mass development of *Hydrurus foetidus* was observed and small areas were overgrown by blue-green algae. In spring the share of *Hydrurus foetidus* decreased and the streambed was covered by films of the green alga *Chlorhormidium rivulare* which dominated in summer. In autumn growth tendencies of the blue-green algae *Lyngbya kützingiana*, *Chamaesiphon polonicus*, and *Homoeothrix janthina* were observed. Towards the end of October *Hydrurus foetidus* reappeared. The development of diatoms was poor, showing a slight quantitative increase in late spring and in autumn when the index of their biomass showed higher values.

Also at Station 4Cz the number of species of alga was maintained at a fairly uniform level. Throughout the winter period *Lyngbya kützingiana* and in January *Chantransia chalybaea* dominated. Larger aggregations of *Hydrurus foetidus* appeared in March. The green alga *Chlorhormidium rivulare* developed in mass in spring and summer. In autumn the

coverage of this species gradually decreased while that of blue-green alga *Lyngbya kützingiana* increased. During the entire period of investigation diatoms occurred in small numbers, the index of their biomass having very low values. Only in spring did this value increase.

The Biała Wiselka stream

At Station 1B the community of algae showed great stability. The number of algal species was maintained at a uniform level. *Ellipsoidion anulatum* and the acidophilous species of diatom *Eunotia exigua*, *E. tenella*, and *E. trinacria* dominated throughout the study period. In the population of diatoms a quantitative variation was observed; the largest abundance and highest index of their biomass occurred in June, and the smallest abundance and lowest value of the biomass index in August.

At Station 2B the communities of algae were mechanically damaged by intensive felling of forests hence it was difficult to determine tendencies in their seasonal development. Throughout the period of study the blue-green alga *Phormidium corium* occurred more numerous while in summer its share was reduced and the green alga *Chlorhormidium flaccidum* attained a larger coverage. Diatoms showed larger numbers and maximum values of the biomass index in winter and late autumn.

At Stations 3B and 4B the development of algal communities was similar. The number of algal species varied in the successive seasons of the year, the greatest variation occurring in June and the least in December. In winter *Hydrurus foetidus* dominated in the community. Diatoms reached a developmental peak in February, the index of their biomass showing the highest values at that time. Subsequently, this value fell rapidly with the snow melt in March. In spring the coverage of *Hydrurus foetidus* was gradually reduced while the green algae *Ulothrix zonata* and *U. variabilis*, and diatoms developed. At Station 4B the coverage of *Phormidium subfuscum* and *Chantransia chalybaea* periodically increased. In summer green algae decisively prevailed at both stations while only in August the red alga *Chantransia chalybaea* was numerous at Station 4B. The development of diatoms was poorer and the index of their biomass fell to its lowest value at Station 3B in July and at Station 4B in August. In autumn blue-green algae and diatoms dominated.

From the above observations some regularities appear suggesting the existence of certain tendencies in the development of species and their groups during the year. In the investigated streams blue-green algae occurred throughout the year with a distinct intensification of growth in autumn; green algae appeared in spring, reaching a maximum of development in summer, while in autumn their share decreased to reach a minimum in winter. *Hydrurus foetidus* developed intensively in the

winter-spring months and masses of the yellow-green alga *Ellipsoidion anulatum* were observed over the whole year. In general, seasonal changes in the population of diatoms were of quantitative character. Dominant species of a given stream section appeared throughout the year there, showing differences only in the value of the coefficient of coverage. In most cases the index of diatom biomass reached its highest winter value in February, that of spring in May or June, and of autumn in September or October. Its lowest values were found in March or April and in August. In both cases this was brought about by the destruction of the algal cover by rises in water level. Only in the headwaters of the Czarna Wisetka (Station 1Cz) did the number of diatoms increase considerably in August.

4.4. The occurrence of algae depending on the type of habitat

With the exception of headwater trickles of the Czarna Wisetka (Station 1Cz), the dominant habitat of algae was a stony substratum. Mosses habitat and also mud deposited on shallow places outside the zone of the main current were less important in their settlement.

In the lotic zone of the streams the stony substratum was readily settled by rheobiotic species of alga, such as *Lemanea fluviatilis* or *Hydrurus foetidus*. On stones in the zone of both rapid or medium current there occurred *Phormidium corium*, *P. subiuscum*, *Lyngbya kützingiana*, *Chamaesiphon polonicus*, *Homoeothrix janthina*, *Ulothrix zonata*, *U. variabilis*, *Chantransia chalybaea*, and *Ellipsoidion anulatum*. *Chlorohormidium rivulare* and *Ch. flaccidum* developes in masses on stones but usually above the water surface.

Deposits of mud in lenitic zones were chiefly settled by diatoms. In headwater trickles of the Czarna Wisetka where mud was the dominant habitat of algae, besides the numerously developing diatoms there occurred *Ellipsoidion anulatum*, *Vaucheria* sp., and euglenoids limited to this habitat alone. In the moss habitat diatoms prevailed, occasional filaments of blue-green and green algae being sporadically encountered.

Diatoms were numerous in all the habitats mentioned above. Lithorheophilous communities developed on stones, pelorheophilous in mud deposits, and phytorheophilous in clumps of mosses and thalli of other algae. It was found that in general these communities had a similar species composition and approximate quantitative relations. The small differences that appeared did not give a separate character to the communities of algae but only suggested a certain tendency of the particular species to develop in greater numbers in a given habitat. Species of the genus *Achnanthes* formed larger aggregations directly on stones. In thalli of *Hydrurus foetidus*, *Ceratoneis arcus* and in tangles of filaments

of blue-green and green algae *Fragilaria capucina* var. *lanceolata* developed more numerously. With regard to species diversity the pelorheophilous community had the richest composition and that developing in thalli of *Hydrurus foetidus* the poorest (fig. 5).

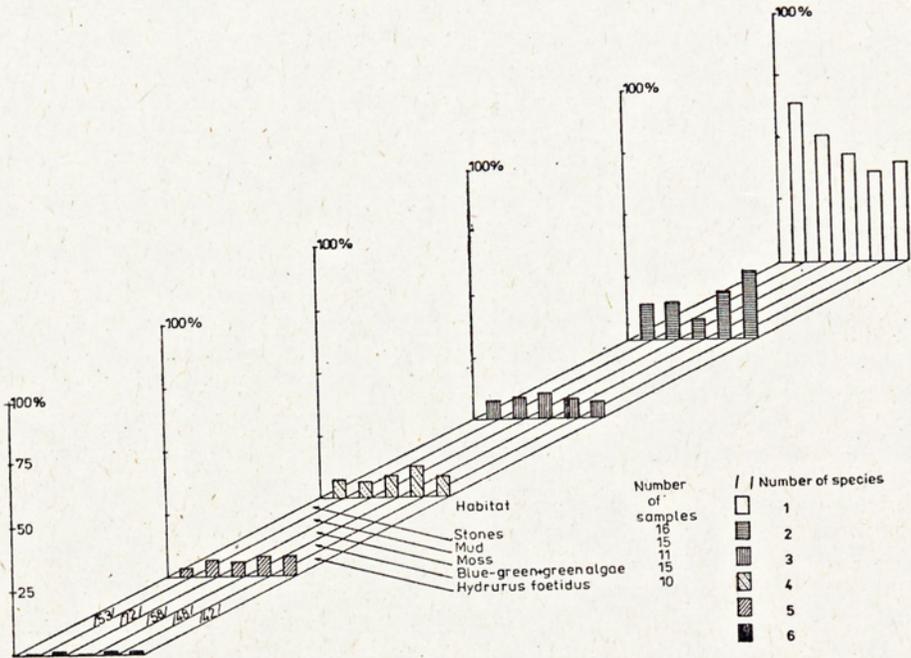


Fig. 5. Number of diatom species in percentage share of the most numerous species in different habitats. 1 — species of the genus *Achnanthes*; 2 — *Ceratoneis arcus*; 3 — *Cymbella ventricosa*; 4 — *Fragilaria capucina* var. *lanceolata*; 5 — *Diatoma hiemale* + *D. hiemale* var. *mesodon*; 6 — *Synedra ulna*

4.5. General description of communities

The communities of algae distinguished along the stream course were compared with each other on the basis of floristic observations confirmed by the results of mathematical similarity analysis. 5 types of com-

Table IV. Distances between groups of similar communities

	1B	2B	3B	4B	1Cz	2Cz	3Cz	4Cz
1B	0							
2B	250.0	0						
3B	289.5	87.0	0					
4B	326.2	130.3	62.2	0				
1Cz	171.6	149.7	207.5	256.0	0			
2Cz	87.5	213.0	257.6	298.1	147.5	0		
3Cz	171.0	147.0	184.6	236.1	69.4	138.4	0	
4Cz	184.3	144.3	183.0	235.0	76.7	149.4	19.4	0

munities were differentiated (Table IV, figs 6, 7) each described by the number of species, constant species including their coverage or coefficient of spatial distribution, index of species diversity of diatoms, and index of diatom biomass.

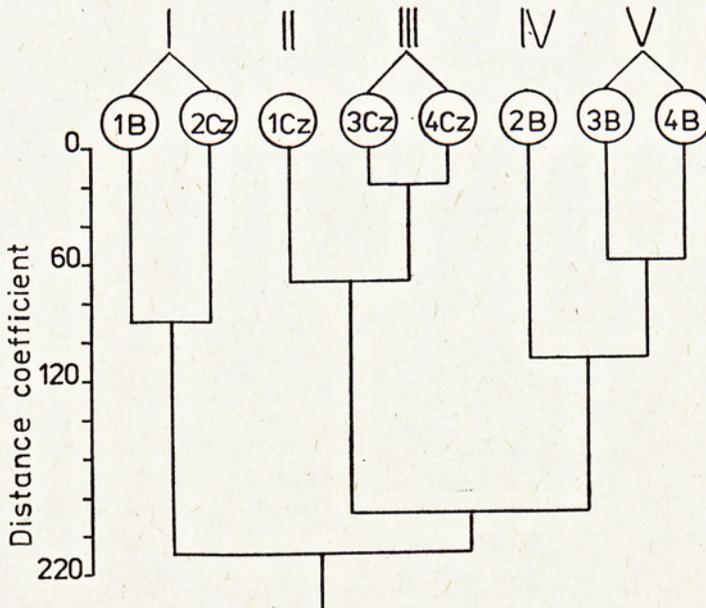


Fig. 6. Dendrogram of similarity of the communities of sessile algae at the particular stations in the Biała and Czarna Wisłoka streams. I—V — types of communities

Type I embraced algal communities which develop at Stations 1B and 2Cz. It was characterized by a small number of taxa. Constancy was attained by 14 species of alga, with diatoms prevailing among them. Of the constant species the yellow-green alga *Ellipsoidion anulatum* and acidobiontic and acidophilous species of diatom of the genus *Eunotia* dominated. The index of biomass showed average values and the index of species diversity was low.

Type II included a community of algae at Station 1Cz which was also characterized by a small number of taxa. Constant species were *Ellipsoidion anulatum* and 8 species of diatom with *Eunotia exigua*, *E. trinacria*, and *Pinnularia microstauron* as dominants. The index of diatom biomass reached an upper limit of mean values and that of species diversity an average level. According to mathematical comparative analysis this community shows similarity with type III. In the floristic aspect community II is associated rather with type I, showing a small number of species and an abundant development of acidophilous species of diatom.

Type of community	I		II		III		IV		V	
Station	1B	2Cz	1Cz	3Cz	4 Cz	2B	3B	4 B	700	580
Altitude (m)	950	1000	1140	725	560	800	700	580		
Water temperature °C	08-10.5		15-52		0.2-122		02-132		02-15.8	
pH	3.5-5.0	3.5-5.2	3.5-5.0	5.8-7.0	5.8-7.0	6.4-7.2	6.4-7.3	6.5-7.5		
Number of species	25	28	27	64	62	81	94	103		
Diatom biomass index	4.56	4.32	4.58	1.29	96	3.32	6.29	7.16		
Index diversity of diatoms	0.24	0.22	0.30	0.33	0.38	0.35	0.29	0.29		
Ellipsoidium anulatum	●	●	●							
Microthamion kützingianum	●	●								
Chlorohormidium flaccidum	●					●				
Chlorohormidium rivulare		●		●	●					
Lyngbya kützingiana				●	●					
Homoeothrix janthina				●			●			
Chamaesiphon polonicus				●			●			
Phormidium corium						●		●		
Phormidium subfuscum							●	●		
Hydrurus foetidus				●	●		●	●		
Chantransia chalybaea					●	●		●		
Lemanea fluviatilis								●		
Ulothrix zonata + U. variabilis								●	●	
0.5) Eunotia exigua	■	■					+			
0.75) Eunotia fenella	■	■	+	+	+					
1.50) Pinnularia microstaurois	+	+	■							+
6.0) Pinnularia viridis	+	+	+	+	+					
4.5) P. viridis var. sudetica										
4.0) Frustulia rhomboides var. saxonica	+	+	+	+	+					
1.50) Eunotia lunaris	+	+	+	+						
0.25) Eunotia trinacria										
6.0) Diatoma hiemale										
1.0) D. hiemale var. mesodon					+	+	+	+		■
0.75) Fragilaria capucina var. lanceolata					+	+	+			
2.5) Ceratoneis arcus							+	■	■	■
0.25) Genus Achnanthes					+	+		■	■	■
2.0) Cymbella ventricosa					+	+	+			
2.0) Cocconeis placentula							+	+	+	
1.5) C. placentula var. euglypta										
8.0) Synedra ulna									+	+
0.75) Synedra vaucheriae								+	+	+
1.0) Meridion circulare								+	+	+
1.0) Pinnularia molaris				+	+					
2.5) Eunotia fallax	+	+			+					
1.5) Eunotia bigibba var. pumila	+	+								
3.0) Surirella linearis					+	■				+
1.0) Gomphonema angustatum					+	+	+	+	+	+
0.75) Gomphonema intricatum var. pumilum							+			+
1.0) Gomphonema olivaceum							+	+	+	
0.25) Navicula contenta	+								+	+
1.5) Surirella ovata							+	+	+	
2.0) S. ovata var. pinnata										
0.5) Denticula tenuis var. crassula									+	+
0.75) Cymbella sinuata							+			

a ● 1 ● 2 ● 3 ● 4 ● 5 b () c □ ■ dominanty
+ adomanty

Fig. 7. Communities of algae characteristic for the Biała and Czarna Wisetka streams (constant species). a — scale of coverage; b — size of a cell; c — coefficient of coverage

Type III embraced the communities of algae developing at Stations 3Cz and 4Cz. In relation to the communities described above the number of taxa considerably increased similarly as the number of constant species. Among 20 constant species *Hydrurus foetidus* and *Chlorhormidium rivulare* dominated. Besides, *Lyngbya kützingiana* occurred fairly numerously. The quantitative development of diatoms was very poor, *Eunotia exigua* and *Pinnularia microstauron* reaching the largest numbers. The index of diatom biomass showed the lowest values in relation to all other communities while the index of species diversity varied within the range of average and high values.

To type IV belonged the community of algae developing at Station 2B. The community was characterized by a fairly large number of taxa. Constancy was achieved by 18 species. In this group *Phormidium corium* showed the greatest coverage while species of the genus *Achnanthes* and *Surirella linearis* played a chief role among diatoms, whose quantitative development was poor. The index of diatom biomass reached the lower limit of mean values and the index of species diversity was average. This community is slightly associated with type V.

Type V included a community developing at Stations 3B and 4B. It was characterized by a large number of taxa and an abundant development of organisms. Of the 25 constant species *Hydrurus foetidus* dominated; besides, *Phormidium subfuscum*, *Chamaesiphon polonicus*, *Homoethrix janthina*, *Ulothrix zonata*, and *U. variabilis* occurred in large numbers. Diatoms constituted a significant component of the community. In the group of constant species *Ceratoneis arcus*, *Diatoma hiemale* with the variety *mesodon*, *Fragilaria capucina* var. *lanceolata*, *Cymbella ventricosa*, and species of the genus *Achnanthes* dominated. The index of diatom biomass reached high values while that of species diversity was low.

5. Discussion

The investigation showed differentiation of algal communities in fairly short sections of the course of the streams. Changes concerned the species composition, number and abundance of species, and the system of dominance. At the same time, it was found that the communities of algae of the two streams basically differed, with the exception of the headwaters and the upper parts of their course where the developing communities showed many similarities.

Since certain sections of the two neighbouring streams flow on different geological substrata, the chemical composition of their waters varies, this suggesting that the differences or similarities of the communities chiefly originated from the chemical properties of the water.

In the opinion of Blum (1956) and Backhaus (1968b), the factors decisive for the character of algal communities are above all alkalinity and water reaction. According to Kann (1978), these factors are the content of calcium and the temperature of the water, while Butcher (1949) stresses that not calcium but nitrogen and phosphorus play the chief role.

Analysis of the chemical data shows that the waters of the Biała and Czarna Wiselka streams chiefly differ in the content of calcium and concentration of hydrogen ions. It seems that the differences in the content of these parameters may significantly affect the algal communities settling these streams. On the basis of the degree of similarity, 8 communities of algae differentiated in the streams were grouped in 5 types of community whose character was to a great degree correlated with the chemical properties of the waters.

In community types I and II (Stations 1B, 1Cz, and 2Cz) having a small number of species, the factors decisive for their number and qualitative composition were the low calcium content and the strongly acidic reaction of the water. The data in the literature show that a low pH of water reduces the number of species and, in general, is an unfavourable factor in the environment (Gessner 1955, Backhaus 1968b, Cholnoky 1968, Nisbet, Verneaux 1970). In waters with a pH below 4.0 Bennet (1969) (quoted by Hargreaves et al. 1975) found only 25 species of alga and Fabri and Leclercq (1979) 40 species with a pH 3.4–5.6. In experimental cultures aimed at determining the limits of tolerance with regard to water reaction, Moss (1973) obtained the growth of only two species of alga (*Eunotia exigua* and *Euglena mutabilis*) out of 25% tested in water with a pH below 4.0.

In the qualitative composition of community types I and II *Ellipsoidium anulatum* dominated; this is a species new for Poland, recorded from pools and montane bogs of acid water reaction (Gruia 1970) and likewise from ponds, among them those with a calciferous-dolomite substratum (Ettl 1978). Of the small number of diatom taxa, species of the genera *Eunotia* and *Pinnularia* determined according to the Hustedt system (1939), as acidobionts and acidophils, dominated. *Eunotia exigua*, an acidobiontic species characteristic for strongly acid waters, reached the greatest numbers (Cholnoky 1968, Fabri, Leclercq 1979, Van Dam et al. 1981).

Among the unfavourable effects of the acidic reaction of water observed in the investigated population of diatoms, there appeared changes in the morphology of cells with regard to linear dimensions, number of striae, and shape of valves (Kwandrans 1986). Similar morphological changes of diatom cells in an acid environment were described by Van Dam et al. (1981) and Hargreaves et al. (1975). Hargreaves and Whitton (1976) also quote species from other groups of algae

which underwent a remarkable morphological differentiation owing to low pH values.

Moreover, in community types I and II there also appeared green algae, while no representatives of blue-green algae were found although in other sections of the streams they developed numerously.

Among green algae, apart from desmids which are to a particularly great degree associated with an acid reaction of the water (Wherle 1926/27, Gessner 1959), species of the genera *Stigeoclonium*, *Mougeotia*, or *Ulothrix* (Blum 1956) also occur in waters with a pH below 4.0. With pH below 3.0 there appears *Chlorohormidium rivulare*, a species known for a great resistance to low pH ranges and great variation in the water reaction (Hargreaves, Whitton 1976).

On the other hand, blue-green algae decidedly avoid waters of acid reaction and rarely occur at a pH below 5.0 (Brock T.D., M.L. Brock 1970).

In community type III (Stations 3Cz and 4Cz) the number of species was larger. *Hydrurus foetidus* and *Chlorohormidium rivulare* occurred more numerously. There appeared blue-green algae with *Lyngbya kützingeriana* attaining a slightly greater coverage. The distinctly poor development of diatoms was striking here, the index of their biomass approximating to the values observed by Kaweck a (1980) and Kaweck a and Leo (1985) in exceptionally poor diatom communities of glacial streams.

Analysis of chemical data showed that in the middle and lower sections of the Czarna Wiselka stream the chemical composition of the water changes as compared with the upper one. The content of calcium increases and the reaction of the water shifts in a neutral direction. Moreover, the concentration of phosphates decreases. This low concentration of phosphates, frequently reaching analytical zero, and perhaps also the absence of soluble forms of phosphorus in some periods, are probably factors inhibiting the development of diatoms in the discussed sections of the Czarna Wiselka. Phosphorus is widely regarded as a factor limiting the development of algae and the absence of its soluble forms may result in an inhibition of algal growth (Blum 1956). According to Kuhl (1962) (quoted by Cholnoky 1968), Stumm, Morgan (1970), Dickson (1978), Almer et al. (1978) (quoted by Van Dam et al. 1981), the solubility of phosphates is controlled by the concentration of hydrogen ions. With a pH of the water 5.0—6.0 this solubility is negligible, increasing with a pH below 5.0 and above 6.0.

Diatoms are a group sensitive to chemical changes in the water (Scheele 1952, Cholnoky 1968, Patrick 1977) and probably strongly responsive to deficiency in biogenes in the environment. According to Kaweck a (1980), one of the reasons for the poor development of diatoms in glacial streams is an insufficient content of biogene components. This was demonstrated by a quantitative increase in these

algae observed by the present author below the inflow of sewage, the other conditions being unchanged.

In contrast the oligotrophic stenothermal species *Hydrurus foetidus*, which develops numerous also in glacial streams, is more resistant to a deficiency of biogenes in the environment, similarly as *Chlorhormidium rivulare*, an organism recorded also from the extremely oligotrophic waters of streams in the High Tatra Mts (K a w e c k a 1971).

Type IV was represented by a poor community (Station 2B) in spite of favourable chemical conditions of the environment, i.e., a larger content of calcium, higher pH of the water, and a slightly greater amount of biogene compounds. The poor development of algae is due to changes in the living conditions brought about by human activity. Intensive forest management leads to frequent mechanical devastation of communities. Moreover, the stream water becomes turbid with large quantities of suspension which to a great degree reduces the access of light. Here, only green alga *Chlorhormidium flaccidum* achieved a larger coverage, settling stones above the water surface, and also the blue-green alga *Phormidium corium*, which seemed to be well adapted to low light intensity (K a n n 1978). Diatoms developed poorer. This may be due to the large content of suspension which, as was shown by P a t r i c k (1977), cuts off light from the environment and negatively affects the development of diatoms.

Type V (Stations 3Cz and 4Cz) differed from the communities described above. The number of species was large. Algae formed large macroscopic aggregations, giving characteristic colours to the stream bottom depending on the time of year. Diatoms were very numerous, this resulting from changes in the living conditions. The abundant suspension in the upper course of the Biała Wisiełka stream disappears, the flowing water becomes transparent and, in comparison with the remaining sections of the streams, is more fertile, the content of calcium is larger, and the pH value higher. In response to these more favourable environmental conditions, there developed varied and abundant epiphytic communities of algae.

The waters of both streams are among cold waters flowing on a substratum of poor calcium content. It is therefore necessary to compare the communities of sessile algae in these streams with communities developed in waters of similar environmental conditions. Here belong the streams of the Tatra Mts of very poor calcium content, flowing on a crystalline substratum (K a w e c k a 1971). Alpine streams elaborated by K a n n (1978), or the River Danube, flowing from the Black Forest Mts (in the southern part built of crystalline granites and gneisses), whose algal communities were described by B a c k h a u s (1968a, 1968b, 1968c). Moreover, from other crystalline massifs of European mountains one may quote the streams of the montane forest zone in the Alps, and

the Rila and the Fagaras Mts in the southern Carpathians, described by K a w e c k a (1980).

A comparison of algal communities from various regions of European mountains with those in the headwater streams of the Vistula shows a different structure of the latter. The specific flora of algae in the headwater sections of both streams and the upper course of the Czarna Wiselka with the dominants *Ellipsoidion anulatum*, *Eunotia exigua*, *E. tricarina*, *E. tenella*, or *Pinnularia microstauron* very distinctly differs from other communities mentioned above. The middle and lower course of the Czarna Wiselka is also unique owing to the exceptionally poor development of diatoms. Only the middle and lower course of the Biała Wiselka have numerous species common with most communities of algae in montane streams. Here belong species frequently encountered in waters flowing down from mountains — *Chamaesiphon polonicus*, *Homoeothrix janthina*, *Hydrurus foetidus*, *Ceratoneis arcus*, *Diatoma hiemale* with a variety *mesodon*, *Achnanthes minutissima*, *Chantransia chalybaea*, and the ubiquitous species *Phormidium subiuscum*, *Cymbella ventricosa*, or *Ulothrix zonata*. On the other hand, there is a total absence of *Cladophora glomerata* and *Diatoma vulgare* with varieties which are particularly frequent in flysch streams of the Beskid Mts (C h u d y b a 1965, 1968, W a s y l i k 1965) or in subalpine sections of streams flowing from the Tatras (K a w e c k a 1971, W a s y l i k 1971).

A separate problem taken into consideration in the present work were seasonal changes in algal communities and the dependence of the occurrence of species and their communities upon the kind of habitat. According to F a b r i and L e c l e r c q (1979), in oligotrophic streams with a low pH of the water there occurs a negligible tendency to changes in the seasonal development of algae, unlike waters with a larger content of biogenes and a higher pH, where distinct differences occur in the development of algae during successive vegetation seasons. This opinion supports the observations of the present author. In the headwaters and the upper sections of the Czarna and Biała Wiselka streams with a low pH, the communities of algae showed great stability throughout the investigation period, while down stream, with the water reaction shifted towards neutral, there appeared differences in the number of species and degree of their development.

Opinions concerning the reasons for seasonal changes in algal communities are divided. S c h e e l e (1952) claims that their pattern depends on the individual predisposition of particular species which respond in different ways to the varying environmental factors throughout the vegetation seasons. In the opinion of B l u m (1956) and P a t r i c k (1977), such a decisive factor is temperature. M o o r e (1978) associates the spring maximum in the development of algae with day length, and the summer decrease in the density of population with the change of tem-

perature and reduction of components in the substratum. Bursche (1962) suggests the effect of light and Kann (1978) stresses a close relation of the two factors light and temperature. The variation in water flow also significantly affects the seasonal development of algae. Growth of algae may be to a great degree destroyed by increased discharge (Backhaus 1968a, Kann 1978), while immediately after floods a rapid development of algae takes place (Chudýba 1965, Backhaus 1968a, Moore 1978).

The dependence between the occurrence of algae and the type of habitat presents a complex problem and its solution has been attempted in numerous experiments on artificial substrata, carried out among others by Butcher (1946), Bursche (1962), Sladečková (1962), Backhaus (1968a), Patrick (1977), and Kann (1978). According to the last author, the character of the substratum, whether it is living or dead, its chemical composition, and the kind of surface is highly significant for its settlement by algae. Patrick (1977) postulates that the size of the surface and its nature is an important factor in the formation of diatom communities. Kawecka (1980) remarks that the kind of substratum may affect the structural formation of an algal community, while Wasylík (1965, 1971) and Chudýba (1965) find no distinct differences between communities developing on various substrata.

Analysis of litho-, pelo- and phytophilous communities of diatoms showed small quantitative differences in the investigated streams, indicating only weak tendencies in the development of certain species in the given habitat. On account of the diversity of habitat in streams, the collection of a homogeneous patch of a community is extremely difficult from the point of view of methodology. Hence, it is difficult to draw a final conclusion concerning the problem of differentiation of algal communities as depending upon the kind of substratum. Its solution requires further studies based on large quantities of material from different microhabitats.

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6. Polish summary

Ekologiczna charakterystyka zbiorowisk glonów osiadłych w Białej i Czarnej Wisełce, źródłowych potokach rzeki Wisły (Beskid Śląski, Polska Południowa)

Badania miały na celu poznanie struktury i ekologii zbiorowisk glonów rozwijających się w źródłowych potokach rzeki Wisły (ryc. 1, 2, tabele I, II). Rozpatrzono problem różnicowania się zbiorowisk glonów wzdłuż biegu potoków, w ciągu kolejnych sezonów wegetacyjnych (tabela III, ryc. 3, 4) oraz w zależności od rodzaju siedliska (ryc. 5).

Spośród 8 wyróżnionych w potokach ugrupowań glonów wyłoniono zależnie od stopnia podobieństwa 5 typów zbiorowisk (ryc. 6, 7, tabela IV).

Zbiorowisko I typu obejmowało ugrupowania glonów wykształcone w odcinkach potoków o niskiej zawartości wapnia i silnie kwaśnej reakcji wody — stanowiska 1B i 2Cz. Zbiorowisko to cechowała niska liczba taksonów przy znacznym ich rozwoju ilościowym. Spośród gatunków stałych dominował różnowiciowiec *Ellipsoidion anulatum* i kwasolubne gatunki okrzemek z rodzaju *Eunotia*. Wskaźnik biomasy okrzemek osiągał wartości średnie.

Zbiorowisko II typu obejmowało ugrupowania glonów wykształcone na stanowisku 1Cz. Czynnikiem determinującym liczbę taksonów i skład gatunkowy była również silnie kwaśna reakcja wody. Zbiorowisko charakteryzowała niska liczba taksonów. W grupie gatunków stałych dominowały okrzemki: *Eunotia exigua*, *E. trinacria* i *Pinnularia microstauron*. Wskaźnik biomasy okrzemek osiągał górne granice wartości średnich.

Zbiorowisko III obejmowało ugrupowanie glonów rozwijające się na stanowiskach 3Cz i 4Cz, gdzie zawartość wapnia była wyższa, a odczyn wody wahał się od kwaśnego do obojętnego (tabela III). W zbiorowisku wzrosła liczba taksonów, lecz ogólny ich rozwój ilościowy był słaby. Wśród gatunków stałych dominowały *Chlorochormidium rivulare* i *Hydrurus foetidus*. Cechą charakterystyczną był wybitnie słaby rozwój okrzemek. Wskaźnik ich biomasy utrzymywał się na niskim poziomie.

Zbiorowisko IV, do którego zaliczono ugrupowanie glonów wykształcone na stanowisku 2B, cechował słaby rozwój ilościowy glonów. Było to spowodowane w głównej mierze mechanicznym niszczeniem zbiorowiska i brakiem dostatecznej ilości światła w wyniku intensywnie prowadzonej na tym odcinku gospodarki leśnej. W grupie gatunków stałych najwyższe pokrycie osiągała sinica *Phormidium corium*. Z okrzemek dominowały gatunki z rodzaju *Achnanthes* i *Surirella linearis*. Wskaźnik biomasy uzyskał dolne granice wartości średnich.

Zbiorowisko V obejmowało ugrupowania glonów wykształcone na stanowiskach 3B i 4B. Zbiorowisko to wyróżniało się wysoką liczbą taksonów i bujnym ich rozwojem. Wśród licznych gatunków stałych dominował złotowiciowiec *Hydrurus foetidus*, a z okrzemek: *Ceratoneis arcus*, *Diatoma hiemale* z odmianą *mesodon*, *Fragilaria capucina* var. *lanceolata*, *Cymbella ventricosa* oraz gatunki z rodzaju *Achnanthes*. Wskaźnik biomasy okrzemek osiągał wysokie wartości.

Struktura zbiorowisk glonów w badanych potokach zmieniała się w ciągu roku w różnym stopniu. W obszarze o niskim pH wody zbiorowiska glonów wykazywały dużą stabilność. Na pozostałych odcinkach potoków obserwowano zmiany pod względem

składu gatunkowego, liczby i liczebności gatunków oraz wielkości wskaźnika biomasy okrzemek.

Po przeprowadzeniu analizy lito-, pelo- i fitoreofilnych zbiorowisk okrzemek stwierdzono, że zbiorowiska te miały podobny skład gatunkowy i zbliżone stosunki ilościowe. U niektórych gatunków obserwowano niewielkie tendencje do występowania liczniej w określonym siedlisku. Najbogatsze w taksony było zbiorowisko peloreofilne, najuboższe zbiorowisko fitoreofilne rozwijające się w plechach *Hydrurus foetidus*.

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