Environmental degradation
in the Czarna Wisełka
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Western Carpathians
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Phytoplankton communities in the Wisła-Czarne dam reservoir in 1993–1994

Zbiorowiska fitoplanktonu w zbiorniku zaporowym Wisła-Czarne w latach 1993–1994

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Abstract: The presented studies were carried out in 1993 and 1994 to examine the influence of dolomite treatment of an acidified stream (the Czarna Wisełka) and on the structure and development of phytoplankton communities inhabiting the Wisła-Czarne dam reservoir (Western Carpathians). It has been found that, over the period studied, the number of taxa increased from 39 at its beginning in 1993 to 61 taxa in the year following dolomite application (1994). It should be noted, however, as lower than in the previous years (113 taxa). The structure of phytoplankton changed from chlorophyte (*Planctococcus sphaerocystiformis*) to dinoflagellate type (*Ceratium hirudinella*, *Gymnodinium uberrimum*) with their periodically variable dominance in the presence of different accompanying species as indicators of acidic habitats (*Peridinium* spp., *Botrydiopsis arhiza*) or eutrophic ones (*Dinobryon* spp., *Crucigenia apiculata*).

Key words: dam reservoir, phytoplankton, dolomite use.

Treść: W latach 1993 i 1994 przeprowadzono badania nad wpływem dolomitowania kwaśnych wód potoku Czarna Wisełka na strukturę i rozwój fitoplanktonu w zbiorniku zaporowym Wisła-Czarne (Karpaty Zachodnie). Stwierdzono wzrost liczby taksonów z 39 na początku badań w 1993 r. do 61 po dolomitowaniu w następnym roku 1994, a zarazem ich redukcję w odniesieniu do wyników z wcześniejszych lat badań (113 taksonów). Nastąpiła zmiana struktury fitoplanktonu, z typu zielenicowego (*Planctococcus sphaerocystiformis*) na bruzdnicowy (*Ceratium hirundinella, Gymnodinium uberrimum*), z ich okresowo zmienną dominacją, w obecności różnych gatunków towarzyszących, jako wskaźników kwaśnych środowisk (*Peridinium* spp., *Botrydiopsis arhiza*) lub eutroficznych (*Dinobryon* spp., *Crucigenia apiculata*).

1. Introduction

The history of the Wisła-Czarne dam reservoir began in 1974 upon its filling. In the following twenty years which have passed since its construction, water in the dam reservoir has been studied in terms of its chemical composition (Kasza 1986), zoobenthos (Krzyżanek 1986), zooplankton (Krzanowski 1987) and phytoplankton in 1981 to 1983 (Pająk 1986).

The current two years of phytoplankton study (1993–1994) was part of a comprehensive team research planned and led by Prof. Dr. hab. Stanisław Wróbel. The aim of this research was to examine the influence of dolomite applied in 1993 in the middle part of the acidified Czarna Wisełka stream on the chemical composition of its waters which feed the Wisła-Czarne dam reservoir.

Over many years, literature has provided evidence of a great interest having been devoted to the problem of acidification and its influence on the communities of water organisms. Reports have been published on abiotic conditions and their relationship to the development and production of autotrophic organisms.

However, a serious gap can be noticed in the area which regards the acidification of dam reservoirs in comparison with lakes, the latter having been paid considerable attention in global research.

In this context, changes in the structure and abundance of algae communities and dominant species developing in lakes subjected to diverse environmental conditions have been considered. Special attention has been paid to those species which, upon increase and subsequent mass development, create problems in water treatment due to their morphological characteristics.

2. Research area

The Wisła-Czarne dam reservoir, built on the Vistula River, was filled with water in 1974. It is a drinking water supply for several towns of the surrounding area: Wisła, Ustroń and others as well as providing flood control. The reservoir is fed by two streams: the Czarna Wisełka and the Biała Wisełka, whose springs are located on the SW and NE slopes of Mt. Barania Góra, respectively (Fig. 1). The valleys of those streams differ in their geological structure, which is reflected in their water composition; the pH of the Biała Wisełka is higher (7.0) in the lower part of the stream where calcium concentration is higher as well. In contrast, the Czarna Wisełka is characterised by lower calcium concentration and strong acidification of water. In the period of the present study, the pH of the Czarna Wisełka in the upper part fluctuated in the range of 3.9–5.5 while in the lower part (before dolomite application), in the range 5.7–6.4.

The specific characterization of the research area, as well as the description of research stations was detailed in Punzet's article (1995) while the hydrochemical data of water of both streams are contained in Wróbel's papers (1995, 1998).

The chemical composition of the water in both Czarna Wisełka and Biała Wisełka (particularly that of the Czarna Wisełka) influence the chemistry of water in the reservoir (Wróbel 1995). The area of the dam reservoir, which belongs to rheolimnic type (water is replaced 9–14 times a year) with a lower outlet, is relatively small. In the period of replenishment, its maximum area equals 40 hectares, the capacity of which reaches 5 million m^3 and depth close to the impoundment – 30 m (Kasza 1986).

In 1993–1994, the reservoirs depth near the dam ranged from 15 to 20 m. The Wisła-Czarne dam reservoir is one of the highest dam reservoirs – in terms of altitude – in Poland (547 m a.s.l.). This results in a shortening of the vegetation period that is of fair significance for the co-existence of various organisms inhabiting the reservoir.

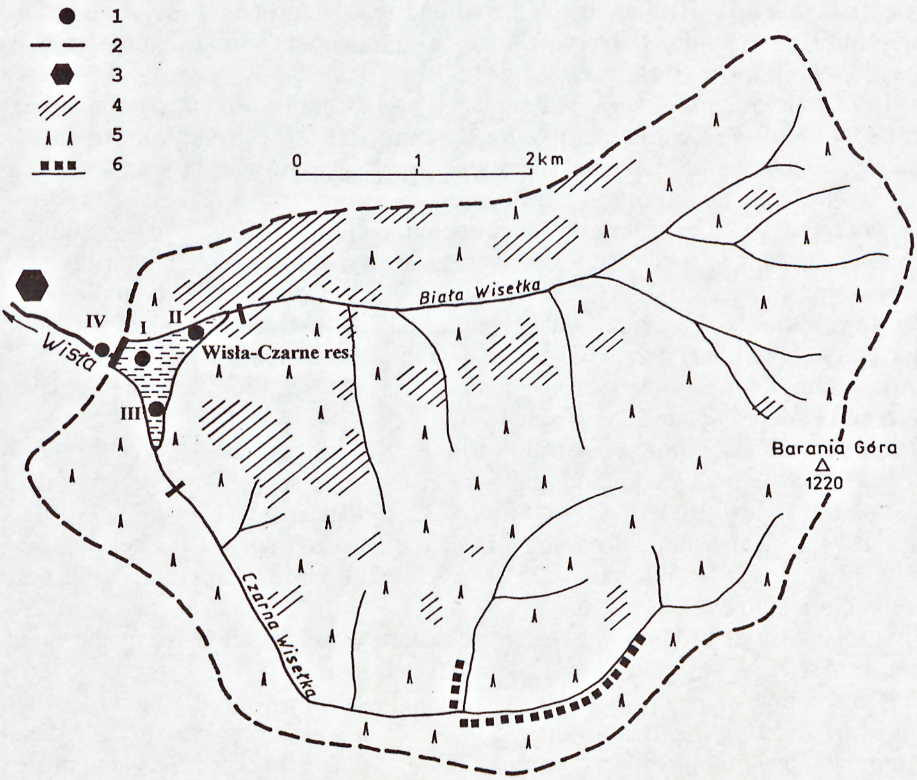

Fig. 1. Catchment area of the Wisła–Czarne dam reservoir: 1 – stations I, II, III, IV, 2 – borderline of the catchment, 3 – hatchery, 4 – meadows and fields, 5 – forests, 6 – dolomiting zone.

Ryc. 1. Zlewnia zbiornika Wisła–Czarne: 1 – stanowiska I, II, III, IV, 2 – granica zlewni, 3 – pstrągarnia, 4 – łąki i pola, 5 – lasy, 6 – strefa dolomitowania.

The area surrounding the reservoir is visited by multitude of tourists each year due to its picturesque landscape.

In the present study, samples were taken at three stations within the reservoir: I – close to the dam (depth 15–20 m), II – the Biała Wisełka bay (depth 8–12 m), III – the Czarna Wisełka bay (depth 7–10 m), and an additional station, IV – at the dam reservoir's outlet.

3. Materials and methods

In 1993–1994, at each station, two samples of water were taken using the bathometer of Patalas: the first one consisted of the residue remaining after the filtration of 50 dm^3 of water through plankton net No 25, and the second contained 1 dm^3 of unfiltered water for sedimentation studies to detect nannoplankton algae under laboratory conditions. A mixture of alcohol and glycerine, supplemented with a crystal of thymol, was added to the filtered samples (Starmach 1963). Lugol's solution, prepared according to Untermöhl's (1958) procedure as reported by Starmach (1963), was also added to the unfiltered samples at the station.

Forty six samples of water (both filtered and unfiltered ones) were collected at the 4 stations, mostly at one-month intervals, six times throughout the first year of research (from 25 May to 4 November 1993).

In 1993 a field experiment was conducted consisting of dolomite application in the middle section of the Czarna Wisełka for the purpose of water neutralization. Dolomite application began on 4 September and ended in the beginning of December. 280 tons of dolomite was deposited in the stream.

In the second year, 56 samples were collected (including strained and unstrained ones) at the same stations at seven dates between 31 March and 11 November 1994.

The samples, usually collected at a depth of 0–5 m were considered to be an average of the dam reservoir's vertical water profile. There was an exception in the summer (August and September), when the abundance of algae increased and mass development followed. Samples were taken at various depths, e.g. at station I, near the dam, at the surface and at depths of 1, 2.5, 10 and 15 m.

Diatoms were determined according to new Krammer's and Lange-Bertalot's keys (1988, 1991), which changed the nomenclature of some species and genera. Old names were reported as well (in parenthesis) according to Siemińska (1964).

Several physical-chemical parameters at the studied stations in the dam and both streams, as analysed by Wróbel (1995), were used at the interpretation of the results of phytoplankton studies.

Phytoplankton abundance per 1 dm^3 of water was calculated using the method of Starmach (1969), as similar to the other studies (Bucka 1987).

The percentage shares of various phytoplankton groups in horizontal distribution at stations I, II and III in the dam reservoir, in both years of the study were calculated. The total numbers of phytoplankton communities served as a basis for the calculation of the circles' diameter to emphasise the changes in the structure and quantitative proportions which took place in 1993 and 1994.

The Lohmann's equation (shown below) was applied for the calculation (Starmach 1955) and presentation of a vertical quantitative distribution of the dominating phytoplankton species during their intense and mass development in 1993 and 1994.

$$R = \sqrt[3]{\frac{V}{4.19}}$$

According to this formula, a radius of a sphere (R) of a given volume (V) equal to an abundance of a certain taxon in 1 dm^3 of water, is calculated first, then it is multiplied by 2 and becomes a co-ordinate in the graph.

4. Results

4.1. Phytoplankton structure

At the chosen stations in the dam reservoir, 39 phytoplankton taxa were identified in 1993 and 61, in 1994. An increase in taxa number was found in three groups of algae: diatoms (from 11 to 17), green algae – chlorophytes (from 10 to 17) and dinoflagellates (from 5 to 9). The remaining groups did not significantly contribute to phytoplankton of the reservoir (Tab. 1).

Table 1. The species composition of the differentiated phytoplankton communities at the investigated stations of the Wisła-Czarne dam reservoir (I – near the dam, II – the Biała Wisełka Bay, III – the Czarna Wisełka Bay, IV – outflow from the dam; see Fig 1) in the years 1993 (a) and 1994 (b); „+"– presence.

Tabela 1. Skład gatunkowy zbiorowisk fitoplanktonu wyróżnionych na badanych stanowiskach w zbiorniku zaporowym Wisła-Czarne (I – blisko zapory, II – zatoka Białej Wisełki, III – zatoka Czarnej Wisełki, IV – odpływ ze zbiornika; por. Ryc. 1) w latach 1993 (a) i 1994 (b); „+" – obecność.

Taxons Taksony	I		II		III		IV	
	a	b	a	b	a	b	a	b
CYANOPHYCEAE (Cyanobacteria):								
Nostoc sp.					+			
Oscillatoria brevis (Kütz.) Gom.						+		
O. limosa Agardh	+		+			+		
Oscillatoria sp.	+							+
Phormidium sp.							+	
Pseudoanabaena sp.					+			
Tolypothrix sp.							+	+
Total – Razem	2		1		2	2	2	2
EUGLENOPHYCEAE:								
Trachelomonas furcata Dolgoff				+		+		
T. pseudofelix Defl.							+	
T. scabra Playf.		+						
Strombomonas sp.				+				+
Total – Razem		1		2		1	1	1
DINOPHYCEAE:								
Ceratium hirundinella (O. F. Müll.) Bergh	+	+	+	+	+	+	+	+
Glenodinium sp.		+	+					+
Gloeodinium montanum Klebs		+				+		
Gymnodinium uberrimum (Allman) Kofoid et Swezy		+		+		+		+
Gymnodinium sp.	+	+		+	+			
Peridinium cinctum (O. F. Müll.) Ehr.	+	+		+		+		
P. willei Huitfelt-Kaas		+						+
Peridinium sp.	+	+	+	+	+	+	+	
Phytodinium globosum Pascher		+	+			+		
Cysts of dinophytes - cysty dinofitów	+							
Total without cysts - Razem bez cyst	4	9	4	5	3	6	2	4
CRYPTOPHYCEAE:								
Cryptomonas marssonii Skuja	+	+		+		+		
Cryptomonas sp.	+	+	+	+	+			+
Total –Razem	2	2	1	2	1	1		1
XANTHOPHYCEAE:								
Botrydiopsis arhiza Borzi	+		+	+			+	+
Tribonema sp.		+						+
Total –Razem	1	1	1	1			1	2

Table 1 cont.

Taxons Taksony	I		II		III		IV	
	a	b	a	b	a	b	a	b
CHRYSOPHYCEAE:								
Chrysococcus biporus Skuja							+	
Chrysosphaerella longispina Lauterborn								+
Dinobryon cylindricum Imhof		+		+		+		+
D. divergens Imhof	+	+		+		+		+
Dinobryon sp.		+		+		+		+
Kephyrion rubri-claustri Conrad					+			
Ochromonas sp.						+		
Pseudokephyrion sp.							+	
Synura uvella Ehr.				+		+		+
Synura sp.	+							
Cysts of chrysophytes – cysty chryzofitów	+	+		+		+		+
Total without cysts - Razem bez cyst	2	3		4	1	5	2	5
BACILLARIOPHYCEAE:								
Achnanthes sp.		+						
Caloneis bacillum (Grun.) Mer.		+						
Cyclotella bodanica Grun.		+						
C. meneghiniana Kütz.		+						
Cymbella minuta Hilse – (*Cymbella ventricosa* Kütz.)		+						
C. naviculiformis (Auerswald) Cleve			+					
Cymatopleura elliptica (Bréb.) W. Sm.				+				
Diatoma vulgaris Bory	+							
Epithemia turgida (Ehr.) Kütz.				+				
Eunotia exiqua (Bréb.) Rabenh.	+							+
E. lunaris (Ehr.) Grun.					+		+	
Fragilaria arcus (Ehr.) Cleve (*Ceratoneis arcus* (Ehr.) Kütz.)	+	+				+	+	+
F. ulna (*Nitzsch*) *Lange-Bertalot* – (*Synedra ulna* (Nitzsch) Ehr.)				+			+	+
F. ulna group acus – (*Synedra acus* Kütz.)	+	+		+		+		+
Fragilaria sp.								+
Gomphonema acuminatum Ehr. v. – (*G. coronatum* (Ehr.) W. Sm.)		+						
Gomphonema sp.		+						+
Navicula rhynchocephala Kütz.				+				
Nitzschia hungarica Grun.		+						
N. paleacea Grun.								+
N. recta Hantzsch								+
N. vermicularis (Kütz.) Hantzsch								+
Nitzschia sp.					+		+	
Pinnularia mesolepta (Ehr.) W. Sm.					+			
P. viridis (Nitzsch) Ehr.		+				+		
Stephanodiscus minutulus (Kütz.) Cleve, Möller – (*Stephanodiscus astrea v. minutula* (Kütz.) Grun.)	+							
Stephanodiscus tenuis Hust.						+		
S. hantzschii Grun.				+				
Surirella ovalis Bréb.								+
S. splendida (*Ehr.*) *Kütz.* – (*Surirella robusta* Ehr. v. *splendida* (Ehr.) V. H.)					+		+	
Tabellaria fenestrata (Lyngb.) Kütz.								+

Table 1 cont.

Taxons Taksony	I		II		III		IV	
	a	b	a	b	a	b	a	b
T. flocculosa (Roth) Kütz.	+						+	+
Tabellaria sp.								+
Total – Razem	6	11	1	6	4	4	6	13
CHLOROPHYCEAE:								
Ankistrodesmus acicularis (A. Br.) Korschik.	+		+		+		+	
Crucigenia apiculata Schmidle	+	+	+	+	+	+		+
C. tetrapedia (Kirchn.) W. et W.		+						
Dictyosphaerium ehrenbergianum Näg.			+					
Eudorina elegans Ehr.	+							
Golenkinia radiata Chod.		+						+
Klebsormidium sp. – (*Chlorhormidium flaccidum?* (Kütz.) Fott)		+		+		+		+
Microspora tumidula Hazen								+
Microspora sp.		+				+	+	+
Nautococcus piriformis Korschik.								+
Neochloris pseudostigmatica Bisch.	+							
Oocystis sp.	+							
Pandorina morum (Müll.) Bory							+	
Pediastrum boryanum (Turp.) Menegh.		+		+				
P. duplex Meyen				+				
Planctococcus sphaerocystiformis Korschik.	+	+	+	+	+	+	+	+
Scenedesmus acutus Meyen *f. costulatus* (Chod.) Uherkov.		+		+				
S. armatus Chod.				+				
S. lefevrii Defl.				+				
S. obtusiusculus Chod.				+				+
S. soli Hortob.				+				
S. spinosus Chod.				+				
S. quadricauda Chod. v. *westii* G. M. Sm.				+				
S. quadricauda Chod. v. *maximus* W. et G. S. West				+				
Scenedesmus spp.				+				
Schroederia spiralis (Printz) Korschik.	+							
Ulothrix subtilissima Rabh.	+						+	
Ulothrix sp.	+	+						
Total – Razem	9	9	4	14	3	4	5	8
ZYGNEMALES:								
Mougeotia sp.								+
Spirogyra sp.		+					+	+
Zygnema sp.		+						+
DESMIDIALES:								
Closterium acerosum (Schrank) Ehr.				+		+	+	
C. tumidum Johns							+	
C. striolatum Ehr.	+							
Cosmarium botrytis Menegh.	+						+	
Spondylosium rectangulare (Wolle) W. et W.		+						
Staurastrum sp.	+		+					
Total – Razem	3	3	1	1		1	4	3

Station I (near the dam). The number of phytoplankton taxa at this station was low (29 and 39, respectively) in both years, yet, at the same time it was the richest in comparison with the other stations. In 1994, an increase in a number of diatom, green alga and dinoflagellate taxa was noted. Among diatoms, the following species were characteristic in the first year of the study: *Diatoma vulgaris*, *Eunotia exiqua*, *Stephanodiscus minutulus*, *Tabellaria flocculosa*; in the second year, *Caloneis bacillum*, *Cyclotella meneghiniana*, *Cymbella minuta*, *Eunotia lunaris and Pinnularia viridis*. The species *Fragilaria arcus* and *F. ulna* group *acus* were found in phytoplankton in both years.

One of the species of chlorococcous green algae – *Planctococcus sphaerocystiformis*, which appeared in greater abundance in 1993, deserves special attention. In addition, the following species were noted*: Ankistrodesmus acicularis*, *Schroederia spiralis*, volvoceous green alga *Eudorina elegans*, filamentous as U*lothrix* sp., and of the Desmidiales: *Closterium striolatum*, *Cosmarium botrytis* and *Staurastrum* sp.

In 1994, the following species of green algae were repeatedly found in the phytoplankton samples: *Golenkinia radiata*, *Klebshormidium* sp., *Pediastrum boryanum*, *Scenedesmus acutus* f. *costulatus*, and *Spirogyra* and *Zygnema* of the *Conjugales. Crucigenia apiculata* of *Chlorococcales* was also common in phytoplankton samples in both years.

Out of the dinoflagellates: *Gymnodinium uberrimum*, *Peridinium willei* (preferring station I exclusively) and *Phytodinium globosum* were the most common species of phytoplankton recorded in 1994, whereas *Ceratium hirudinella* and *Peridinium cinctum* were discovered in phytoplankton samples collected in both years.

A limited number of species of the other groups, e.g. blue-greens – also termed cyanophytes or cyanobacteria – (*Oscillatoria limosa*), euglenoids (*Trachelomonas scabra*), cryptomonads (*Cryptomonas marssonii*), xanthophytes (*Botrydiopsis arhiza*) and chrysophytes (*Dinobryon divergens*, *D. cylindricum*) were common in both years studied.

Station II (the Biała Wisełka bay). In 1993, the number of taxa at this station was two times lower than at station I, whereas in the following year the number increased to become almost equal to it. Chlorococcous green algae prevailed – mainly *Scenedesmus* spp. and *Pediastrum* spp, and *Closterium acerosum* of the desmids.

The following species of diatoms were frequently noted in the second year of the study: *Cymatopleura elliptica*, *Fragilaria ulna*, *F. ulna* group *acus*, and *Tabellaria flocculosa*. Dinoflagellates and chrysophytes were represented by the same species as at station I.

Station III (the Czarna Wisełka bay). This station was poor in taxa, analogically as station II. The number of taxa increased slightly in 1994 yet retained the lowest level in comparison with other stations. The composition of dinoflagellates and chrysophytes was the same as at station II in 1993, whereas in the following year, *Synura uvella* (chrysophytes) and *Trachelomonas furcata* (euglenoids) were common components of phytoplankton in both bays. Two diatom species – *Pinnularia mesolepta* and *P. viridis* particularly preferred this station in the first year of the study.

Station IV (at the dam reservoir's outlet). The number of taxa (23 and 39, respectively) and species composition were almost the same as at station I in 1993 and 1994. However, in 1994, there was an increase in a number of diatoms, found only at that station (e.g. *Nitzschia vermicularis*, *N. paleacea*), and green algae, mainly filamentous (*Klebshormidium* sp. and *Microspora* sp.), *Zygnemales* (*Spirogyra* sp. and *Zygnema* sp.) and *Desmidiales* (*Closterium* spp.), all of which frequently inhabited this station in the study period.

4.2. Phytoplankton abundance

The percentage shares of various phytoplankton groups noted at the three stations in 1993 are presented in Fig. 2. This spatial distribution of total phytoplankton in the surface layer of water clearly shows that its abundance, given in percentage, reached the highest value in the Czarna Wisełka bay (station III) and the lowest in the Biała Wisełka bay (station II). At all stations studied, the dominating communities were of chlorococcous green algae (with a massive appearance of *Planctococcus sphaerocystiformis*) accompanied primarily by cryptomonads and dinoflagellates at station III, dinoflagellates, diatoms, xanthophytes, and cyanophytes at station I, and diatoms and cyanophytes at station II (constituting a lower percentage of the total value).

In 1993, phytoplankton of green algae type prevailed, as connected with a „water bloom" caused by the aforementioned species, which was observed throughout the entire dam reservoir.

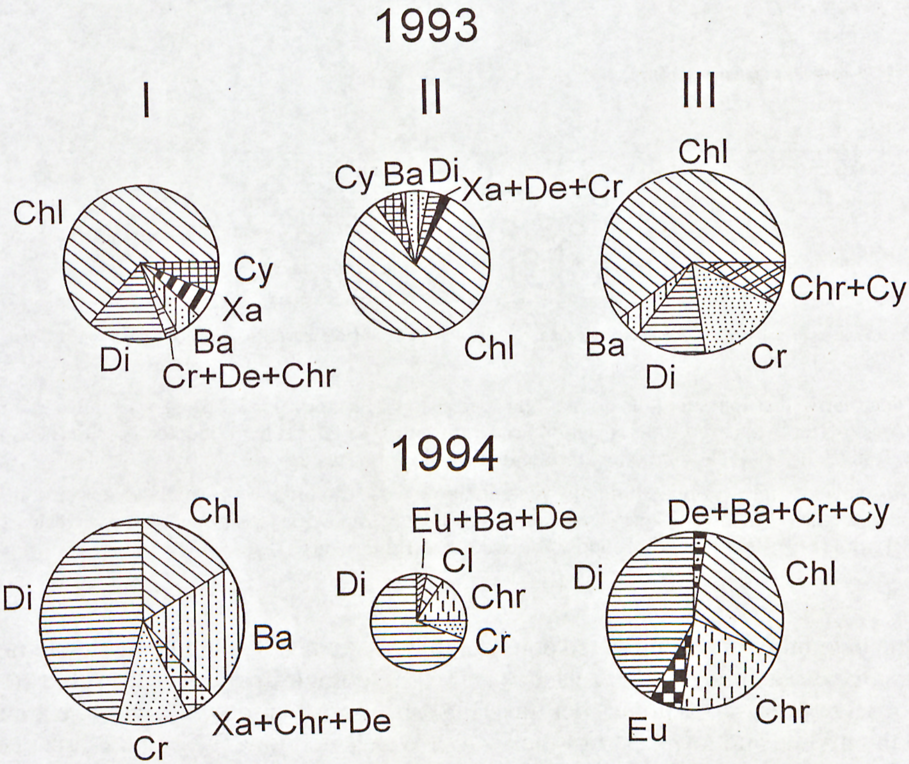

Fig. 2. Percentage share of taxonomic groups in the phytoplankton communities found in the surface waters of the Wisła-Czarne dam reservoir at the investigated stations: I – near the dam, II – the Biała Wisełka bay, III – the Czarna Wisełka bay. Cy – *Cyanophyceae*, Eu – *Euglenophyceae*, Di – *Dinophyceae*, Cr – *Cryptophyceae*, Ba – *Bacillariophyceae*, Chl – *Chlorophyceae*, De – *Desmidiales*, Xa – *Xanthophyceae*, Chr – *Chrysophyceae*.

Ryc. 2. Procentowy udział grup taksonomicznych w zbiorowiskach fitoplanktonu znalezionych w powierzchniowych warstwach wody zbiornika zaporowego Wisła-Czarne na badanych stanowiskach: I – blisko zapory, II – zatoka Białej Wisełki, III – zatoka Czarnej Wisełki.

Several peaks of phytoplankton development were noted at station I beginning at the end of May and ending at the beginning of November, 1993. The first peak appeared at the end of June and was the signal of a „water bloom" formation with the major participation of colonial green alga (*Planctococcus sphaerocystiformis*), enclosed in a gelatinous sheet. Upon the appearance of the second peak on August 10, the greatest numbers of this species population were found (4.65 x 10^5 colonies in 1 dm^3 of water). At that time, during a mass appearance of green alga *Planctococcus,* the distribution of its colonies in a vertical profile (Fig. 3a) reached the highest value in water layers from the surface down to 5 m (with accompanying, not numerous dinoflagellate *Ceratium hirundinella*), while the population density decreased down to 10 and 15 m (1.28 x 10^5 colonies per dm^3).

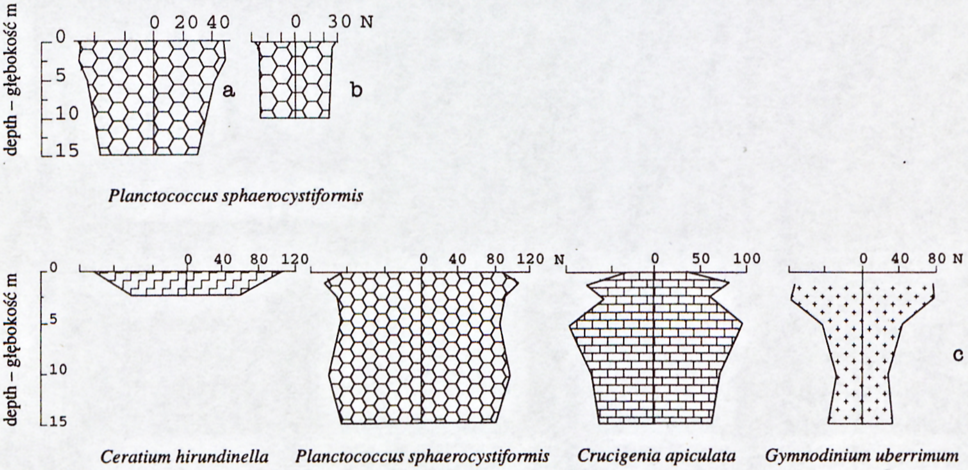

Fig. 3. Quantitative distribution of the dominating species in vertical profile according to Lohmann's formula in the Wisła-Czarne dam reservoir at station I (near the dam): August 10th (a), September 3rd (b) in 1993, and July 12th (c) in 1994. N – numbers of individuals in 1 dm^3 of water.

Ryc. 3. Ilościowe rozmieszczenie dominujących gatunków w profilu pionowym według wzoru Lohmann'a w zbiorniku zaporowym Wisła-Czarne na stanowisku I (przy zaporze): 10 sierpień (a), 3 wrzesień (b) w 1993 r. i 12 lipiec (c) 1994 r. N – liczebność osobników w 1 dm^3 wody.

In the beginning of September, a considerable decrease in the numbers of colonies of *Planctococcus* was noted at the surface (1.03 x 10^5 colonies per dm^3), as well as to the depth of 10 m (4.8 x 10^4 colonies per dm^3)(Fig. 3b). At the same time, dolomite application in the middle and lower part of the Czarna Wisełka commenced. In the first decade of October, an increase in population density of the aforementioned species reappeared at station I (1.93 x 10^5 colonies per dm^3 of water), along with a fairly substantial contribution of green alga *Crucigenia apiculata* and of cryptophytes as *Cryptomonas marssonii*). In the beginning of November, those species entirely disappeared and only a sparse appearance of *Eunotia exigua* and *Botrydiopsis arhiza* was noted.

In August 1993, in the Czarna Wisełka bay (similar to station I) the population density of *Planctococcus sphaerocystiformis* reached the highest value, forming almost a monoculture (1.33 x 10^6 colonies per dm^3 of water). In September, however, the abundance of this species fell abruptly. It increased again in October, with a small share of accompanying species as *Gymnodinium* sp. of dinoflagellates and *Ankistrodesmus acicularis* of green algae (1.25 x 10^5 individuals per dm^3 of water, in total).

In the same period, in the Biała Wisełka bay, the abundance of *Planctococcus sphaerocystiformis*, with a small share of other species, was slightly higher than at the station close to the dam, and amounted to 5.18 x 10^5 per dm^3 of water, which evidenced its expansion throughout the entire dam reservoir.

In the beginning of September, its abundance significantly decreased, but it increased again in October, reaching 1.87 colonies x 10^5 per dm^3 of water. The dominating species was accompanied by not numerous green algae *Crucigenia apiculata* and *Ankistrodesmus acicularis*.

In 1993, the appearance of the greatest numbers of phytoplankton, with guiding species, at the station located at the reservoir's outlet, coincided with their increase and maximum development at station I near the dam.

In 1994, the structure of dominating communities changed completely at particular stations within the reservoir (Fig. 2). The percentage share of dinoflagellates reached the highest value (massive appearance of *Ceratium hirundinella* and *Gymnodinium uberrimum*) consecutively at stations I, III and II (in decreasing order). The dominating dinoflagellates were accompanied mainly by: chlorophytes, diatoms, and partially, cryptophytes, chlorophytes and chrysophytes, and in most cases, by chrysophytes at stations III and II.

In 1994, phytoplankton was generally of dinoflagellate type; it changed, however, periodically into a mixed type, with various composition at the investigated stations, particularly during most intensive development of dominants (e.g. at station I – of dinoflagellate - chlorophyte - diatom type, at station II – of dinoflagellate - chrysophyte type, and at station III – of dinoflagellate - chlorophyte - chrysophyte type).

In the period from the end of March to the second decade of November 1994, the two peaks of phytoplankton development were noted at station I, located near the dam: the first one appeared in the beginning of August and the second, in the mid-September. The former caused an intensive "water bloom" (1.10 x 10^6 cells per dm^3 of water) with participation of both aforementioned dinoflagellates accompanied by other dinoflagellate *Peridinium cinctum* (Fig. 3c).

At the beginning of the second decade of June, this bloom was preceded by an increase in numbers of four species: *Planctococcus sphaerocystiformis*, *Crucigenia apiculata*, *Ceratium hirudinella* and *Gymnodinium uberrimum*, with a small share of *Peridinium willei* and chrysophytes *Dinobryon* spp. Their numbers in a vertical profile were the greatest in the layers from the surface (Fig. 3c) down to 1 m (2.0 x 10^5 individuals per dm^3 of water) and stretched down to 15 m, except for *Ceratium* (dinoflagellate) which was most numerous only in the surface waters to the depth of 1 m. In the case of the populations of both green alga species, their numbers decreased with depth (particularly from 2.5 to 10 m) more evenly in comparison with dinoflagellate *Gymnodinium*.

A considerable decrease in the abundance of dinoflagellates was observed in the second decade of August (2.10 x 10^5 cells per dm^3 of water). At the same time, the colonial, previously dominating chlorophytes disappeared and the representatives of other algae communities appeared, in very low numbers, however (e.g. *Fragilaria ulna*, *F. arcus*, *Cyclotella* spp. of diatoms, and *Cryptomonas* spp. of cryptomonads).

The second peak of phytoplankton development was noted at station I in the middle of September. Again, a big share of dinoflagellates rich in species was observed (4.49 x 10^5 cells per dm^3 of water). Their numbers fell abruptly in the first decade of November (3.0 x 10^4 cells per dm^3).

The pattern of phytoplankton development in the Czarna Wisełka bay differed from that of the Biała Wisełka bay.

In the Czarna Wisełka bay, the great abundance of phytoplankton (3.0 x 10^5 individuals per dm^3 of water) was found at the end of spring and in the mid-summer. They were mainly dinoflagellates with prevailing *Ceratium hirundinella* and *Gymnodinium uberrimum*, associated with green alga *Planctococcus sphaerocystiformis*, chrysophyte *Dinobryon divergens,* and only once by euglenoid *Trachelomonas furcata*. At the end of summer, the phytoplankton abundance reached its maximum and was two times as high as at earlier dates. The aforementioned species of dinoflagellates predominated (7.17 x 10^5 individuals per dm^3 of water) and were accompanied by chrysophytes and cryptophytes.

In the Biała Wisełka bay, the peak of phytoplankton development occurred at the end of the second decade of August and dinoflagellate species (*Peridinium cinctum* and others aforementioned) were almost exclusive components of phytoplankton at that time (16.8 x 10^4 individuals per dm^3 of water), along with rare *Cryptomonas* spp. Their quite ample development (up to 9.0 x 10^5 cells per dm^3 of water) was also noted at the end of spring, in the middle and at the end of summer. They were accompanied by chlorococcous green algae (mainly *Scenedesmus* spp. rich in species, *Pediastrum* spp., and *Closterium acerosum* of desmids).

At the station located in the reservoir's outlet, an increase in the abundance of phytoplankton (up to approximately 6.0 x 10^5 individuals per dm^3 of water) was observed at the end of the first decades of June and July 1994 and it did not coincide with their intensive development in the reservoir at station I. At the outlet of the reservoir, some species of diatoms (e.g. *Nitzschia vermicularis*), chlorophytes (*Klebshormidium* sp., *Nautococcus piriformis*) and of *Conjugales* (*Zygnema* and *Spirogyra*) appeared; they clearly favoured this station.

5. Discussion

Comparing the results of the present research with earlier data obtained at the beginning of the eighties (Pająk 1986), it is easy to recognize a significant difference both in a number of taxa as well as in phytoplankton abundance in those two periods of time. In the latter study, the author identified 113 taxa, 23 of which periodically dominated. The abundance of these species amounted to 7.76 x 10^6 individuals per dm^3 of water. The author emphasized a variability of phytoplankton structure and abundance in the period of 1981–1983. The following groups then dominated in three consecutive years: cyanophytes and chlorophytes, dinoflagellates and chlorophytes, and cyanophytes, dinoflagellates and chlorophytes. The most numerous species among cyanophytes were: *Gomphosphaeria lacustris* and *Rabdoderma* sp.; of chlorophytes – *Ankistrodesmus* sp., *Chlamydomonas* sp., *Chlorella vulgaris* and *Crucigenia fenestrata*; and of dinoflagellates – *Peridinium willei.* The latter species occurred periodically in masses constituting then 93% of the whole phytoplankton. Moreover, the above cited author paid attention to only a sporadically greater share of the representatives of cryptophytes (e.g. *Cryptomonas* sp.) and chrysophytes (*Dinobryon cylindricum*, *D. sertularia*).

Some of the aforementioned algae species were found also in samples collected in the present study (mainly among chrysophytes and dinoflagellates) with the exception of blue-greens, which were poor in number of taxa and abundance. This group played negligible role in phytoplankton communities in 1993 and 1994 (Tab. 1).

With reference to the present study, the number of taxa determined (61 taxa in 1994) was 2-fold lower than in 1981–1983. Nevertheless, a comparison of the data with that obtained in 1993 and 1994 provides clear evidence that the number of taxa increased from 39 to 61, respectively, in the course of one year.

In 1993, phytoplankton of chlorophyte type prevailed in connection with a "water bloom" caused by colonial algae covered with a gelatinous sheet of *Planctococcus sphaerocystiformis* (accompanied by not numerous *Ceratium hirudinella* of dinoflagellates) that had spread over the whole reservoir (Fig. 3a, b). At that time, the greatest density of this species population occurred in the Czarna Wisełka bay where it almost formed a monoculture.

Planctococcus sphaerocystiformis appeared periodically as dominant in the acidic or nearly neutral water of the Wisła-Czarne dam reservoir due to the gelatinous sheet which protected its dense population. This sheet created major problems in the water treatment process because of its tendency to clogging filters.

The phenomenon of mucus production is encountered in many algae as well, and in some blue-greens of *Oscillatoriacae* family, which, in spite of their sensitivity to low pH, can dominate in acidic waters owing to increased production of mucus, as has been shown in the Swedish lake Gärdsjön (Geelen, Leuven 1986).

An increase in population density of *Planctococcus sphaerocystiformis* (mainly at station I near the dam) coincided with a rise in pH and chlorophyll *a* concentration (Tab. 2). This relationship has been detected not only in surface layers of water but also in the vertical distribution of this species throughout the water column. However, it is necessary to emphasize that increased values in water pH were a consequence of the sudden development of this alga species as accompanied with intensive photosynthesis, and not a cause of its mass occurrence. This has been supported then by a high (exceeding 100%) oxygen saturation of water – even up to depths of 10 m. The highest values of oxygen saturation were noted at 5 m and amounted to approximately 155% (Wróbel 1998).

At the same time, a fairly significant difference (equalling +6.7°C) in water temperature was noted between the surface and near the dam's bottom water layers (Tab. 2).

At the very beginning of September (before dolomite application) a decrease in this green alga abundance was strongly marked by a decrease in pH (7.36 at station I) and in the concentration of chlorophyll (at station I – 4.49 μg of chlorophyll per dm^3 of water).

At the beginning of October (a month after dolomite application), an increase in phytoplankton abundance (with a substantial contribution of chlorophyte *Crucigenia apiculata*) was not associated with a significant change in aforementioned parameters.

Sparse but frequently appearing species: *Eunotia exigua* and *Tabellaria flocculosa*, as well as xanthophyte *Botrydiopsis arhiza*, as reported in peat bog ditches (Starmach 1968), enriched the composition of phytoplankton in the middle of summer (especially at station I). Both diatoms were found by Kwandrans (1995) at the station located close to the outflow of the Czarna Wisełka into the dam reservoir. Kwandrans classified the former species as acidobiontic and the latter as acidiphilous, according to the classification of

Table 2. The values of some physical and chemical parameters at the investigated stations in the Wisła-Czarne dam reservoir and its inflows in 1993 (according to Wróbel 1995)

Tabela 2. Wartości niektórych fizycznych i chemicznych parametrów na badanych stanowiskach w zbiorniku zaporowym Wisła-Czarne i jego dopływów w 1993 r. (za Wróblem 1995)

Stations Stanowiska	Depth Głębokość m	t°C	pH	chlorophyll chlorofil μg dm^{-3}
I – near the dam	surface powierzchnia	20.6	9.37	9.89
	1	20.4	9.14	16.63
	2.5	19.2	9.37	19.32
	5.0	16.3	9.37	22.47
	10.0	14.4	7.74	8.99
	15.0	13.9	7.16	2.24
II – the Biała Wisełka bay zatoka Białej Wisełki	surface	21.2	9.11	15.73
III – the Czarna Wisełka bay zatoka Czarnej Wisełki	surface	20.7	9.11	15.73
IV – below the dam (outflow) poniżej zbiornika (odpływ)		14.8	7.17	2.24
The Biała Wisełka before settlement Biała Wisełka przed osiedlem		14.2	7.20	–
The Czarna Wisełka before inflow to the reservoir Czarna Wisełka przed wpłynięciem do zbiornika		15.1	6.40	–

Hustedt (1939). The presence of these species and those of *Desmidiales* (*Closterium*, *Cosmarium*, *Staurastrum*) are characteristic of acidic waters (Rosa et al. 1978), as well as green alga *Eudorina elegans* (which prefer hard waters), indicated a trophic state of the dam reservoir.

In 1994, phytoplankton structure changed completely as dinoflagellates took over as the dominants throughout the entire reservoir (Figs 2 and 3c).

Phytoplankton of dinoflagellate type changed periodically into a mixed one of diverse composition: dinoflagellate - chlorophyte - diatom type (at station I), dinoflagellate - chrysophyte (at station II), and dinoflagellate - chlorophyte - chrysophyte (at station III).

At the end of spring, an acidic pH (6.64–6.94) persisted throughout the reservoir. An increase in pH value (up to pH 7.09) was noted in conjunction with a depth increase from 1 to 10 m (at station I) in July, coinciding with the vast development of four algae species: *Ceratium hirudinella*, *Gymnodinium uberrimum*, *Planctococcus sphaerocystiformis* and *Crucigenia apiculata* (Fig. 3c), with a small contribution of *Peridinium willei*. The latter dinoflagellate species caused a very heavy „water bloom" in the eighties (Pająk 1986). It is a common species, living in various water bodies in wide range of environmental conditions (pH 4–8), tolerating even slightly brackish waters (Starmach 1974).

Additionally, in the second year of the study (similar to 1993), a significant difference in water temperature was noted between the surface and the bottom (+9.3°C) as accompanied by lower values of water pH (pH 6.8–6.9, respectively).

This indicated an influence of water from the Czarna Wisełka, flowing into the reservoir through the lower inlet, which, in turn, reacted upon the outflowing waters.

In 1994, no correlation was observed between phytoplankton abundance and the concentration of chlorophyll. A greater population density of the aforementioned species was noted at depths of 1 m. The measured chlorophyll *a* concentrations were very low – 3.82 μg of chlorophyll per dm^3 of water (station I).

At that time the oxygen saturation in the surface layers of the water never exceeded 100–110% at any station within the reservoir. In the next few months, these values dropped towards the bottom, beginning at 5 m; however, a decrease below 10 m was of even greater significance (Wróbel 1995).

The greatest phytoplankton numbers (in the second half of August and the first half of September) corresponded with the highest concentrations of chlorophyll *a* (25.84 and 30.34 μg of chlorophyll per dm^3 of water, respectively, at a pH 7.00 and 7.42) in the Czarna Wisełka bay. Next, the smallest numbers of phytoplankton were in accordance with the lower concentrations of chlorophyll *a* (13.71 and 16.85 μg of chlorophyll per dm^3 of water, consecutively, at the same pH as above in the Biała Wisełka bay).

The mean number of green algae (*Eudorina elegans*), diatoms (*Fragilaria ulna, F. arcus, Cyclotella* sp.) and cryptomonads (*Cryptomonas* spp.) appeared in the composition of phytoplankton at station I (Tab. 1).

In the phytoplankton structure of the Czarna Wisełka, dinoflagellates (mainly *Ceratium hirudinella* and *Gymnodinium uberrimum* accompanied by green alga *Planctococcus sphaerocystiformis*) dominated. There also occurred chrysophytes (*Dinobryon* spp. and *Synura uvella*) and an euglenoid (*Trachelomonas furcata*), the latter appearing only once.

The aforementioned dinoflagellate species and *Peridinium cinctum* took an almost exclusive part in the phytoplankton structure of the Biała Wisełka. This species has low requirements in regards to an environment and appears often in masses in freshwaters (Starmach 1974). The dinoflagellates were accompanied by chrysophytes (with the species cited above) and chlorococcous green algae, being typical of eutrophic waters (especially genera *Scenedesmus* and *Pediastrum*, rich in species).

Geelen and Leuven (1986) emphasize that acidification of water bodies may change the phytoplankton structure on several levels, i.e. in species richness, their composition and dominance.

The present study validates an assumption that the diversity of a phytoplankton species increases with a rise in pH (Lydén, Grahn 1985, Geelen, Leuven 1986), since the number of taxa appearing in the dam reservoir in 1994 (61) was significantly greater than in 1993 (39) (Tab. 1). This fact indicates an improvement in the water environment. The exclusive dominance of colonial green alga *Planctococcus sphaerocystiformis*, covered with a gelatinous sheet (Hindák 1977) which caused problems for Water Treatment Station at town-Wisła, has been stopped. It became a constituent of a group of several, numerously developing algae species. It is a species inhabiting both pure ponds and lakes (Huber-Pestalozzi et al. 1983).

According to Almer et al. (1978), a decrease in a number of chlorophytes and chrysophytes as well as disappearance of diatoms and blue-greens is a characteristic of acidic lakes in Sweden. In the opinion of Chrisman et al. (1980), an increase in the acidity of lakes in Florida is reflected by a rise in the number of taxa, and especially an abundance of chlorophytes and by decrease in those of cyanophytes. The present study has shown that blue-greens played a minimal role in the phytoplankton communities of the dam reservoir. This is a positive feature in the aspect of the eventual eutrophication of the dam reservoir and the toxic effect of blue-greens on drinking water.

In the summer 1994, a highly abundant development of two dinoflagellate species - *Ceratium hirudinella* and *Gymnodinium uberrimum* (associated with some green algae) was noted. The first of the mentioned dinoflagellates inhabits waters at wide temperature range between 5 and 30°C, the optimal temperature being 15–16°C (Starmach 1974). The mass appearance of this large dinoflagellate, which is poorly consumed by zooplankton, may persist for a long time in a dam reservoir. Owning to its ability to migrate in depths of water, it can find nourishment which favours its development with more ease. It vanishes in water upon appearance of blue-greens. This wide autecological amplitude allows it to play various roles in lakes of diverse trophic types: in eutrophic lakes, it is a dominant species accompanied by subdominants; in mezo- and polytrophic lakes, it is a subdominant; and in oligotrophic lakes, it occurs as species accompanying other dominants (Burchardt et al. 1994). These authors suggest that it is a qualitative and quantitative indicatory species, as not only its existence but also its abundance point to a certain trophic level. Margalef et al. (1976) observed an abundant appearance of this species in plankton of lowland reservoirs with water that contained high concentrations of calcium and magnesium.

The second dinoflagellate species – *Gymnodinium uberrimum* appears in small oligotrophic ponds and lakes in summer. Starmach (1974), citing Höll (1928), notified that the optimal CaO concentration for this species ranged from 10 to 20 mg per dm^3 and its pH equaled 6.0. Lydén and Grahn (1985) – as well as Almer et al. (1978) – stated the dominance of dinoflagellates (mainly *Peridinium incospicuum* – the species typical of acidic waters) as associated with *Gymnodinium uberrimum*. They stressed the fact that the majority of algae species determined was commonly found in not acidified, oligo- and distrophic lakes. In their opinion, indicatory species, more sensitive and resistant to acidification, are important here, i.e. the aforementioned dinoflagellate *Peridinium*. In both cases under consideration, some similarities have been found within the group of indicatory species occurring as subdominants (e.g. *Gymnodinium* mentioned above), and other accompanying species, typical of acidic waters (*Eunotia exigua*, *Botrydiopsis arhiza*, *Closterium* spp.) and non-acidified, oligotrophic waters (*Tabellaria flocculosa*).

The interpretation of my own results became simpler by comparison with the patterns of phytoplankton communities described by other authors, e.g. Scandinavian (Almer et al. 1978, among others) or American (e.g. Siegfried 1988). In general, their results regarding phytoplankton structure are similar to the findings presented in this paper. However, water pH in lakes studied by those authors was, as a rule, lower ($pH < 5.0$) than in the Czarna Wisełka (before its inflow to impoundment) and in the Wisła-Czarne dam reservoir itself.

It seems that dolomite application in the Czarna Wisełka brought about some changes in the structure of communities in the dam reservoir, indicating a certain analogy with the results obtained by Bukaveckas (1988) in the first year after the liming of several acidic lakes in the New York state. In one of them, a neutral pH persisted for three years after liming causing an increase in phytoplankton abundance. However, in other lakes, a return to the initial situation existing before liming occurred much quicker. This may be expected to happen in the Wisła-Czarne dam reservoir as well.

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Streszczenie

Przeprowadzono badania nad wpływem dolomitowania kwaśnych wód potoku Czarna Wisełka na rozwój i strukturę fitoplanktonu w zróżnicowanych warunkach środowiskowych zbiornika Wisła-Czarne. Zbiornik ten, napełniony w 1974 r., został zbudowany w celu dostarczania wody pitnej dla miasta Wisły oraz zapobiegania powodziom. Zasilają go dwa potoki, Biała Wisełka i Czarna Wisełka, o różnej budowie geologicznej dolin, wypływające z Baraniej Góry. Jest to zbiornik mały, z dolnym upustem (pełna wymiana wody dokonuje się 9–14 razy w roku). Należy do najwyżej położonych w Polsce zbiorników zaporowych (547 m npm.). Badaniami objęto w nim następujące stanowiska: I – przy zaporze (głębokość 15–20 m), II – w zatoce Białej Wisełki (8–12 m), III – w zatoce Czarnej Wisełki (7–10 m) i dodatkowe stanowisko IV – przy odpływie ze zbiornika (Ryc. 1).

W 1993 r. fitoplankton był typu zielenicowego (Ryc. 2), co wiązało się z masowym rozwojem kolonijnej zielenicy *Planctococcus sphaerocystiformis*. Wytwarza ona otoczkę galaretowatą, wskutek czego jest bardzo uciążliwa do usunięcia w procesie uzdatniania wody. Największą liczebność populacji tego gatunku – 4,65 x 10^5 kolonii w dm^{-3} wody zanotowano 10 sierpnia na stanowisku I w powierzchniowych warstwach wody do głębokości 5 m (Ryc. 3a, b). W tym samym terminie sierpniowym gatunek ten wystąpił masowo w obu zatokach, przy czym największą gęstość populacji osiągnął w zatoce Czarnej Wisełki, gdzie wytworzył prawie monokulturę (1,33 x 10^3 kolonii w 1 dm^3 wody).

Przeprowadzony w 1993 r. eksperyment terenowy polegał na rozprowadzeniu 280 t dolomitu w środkowym odcinku potoku Czarna Wisełka, celem zneutralizowania jego kwaśnych wód (początek dolomitowania – 4 wrzesień, koniec – początek grudnia).

W 1994 r. nastąpiła całkowita zmiana w strukturze zbiorowisk fitoplanktonu (dotychczas typu zielenicowego) i przejęcie dominacji przez bruzdnice w całym zbiorniku. Zielenica *P. sphaerocystiformis* przestała dominować, przechodząc wraz z innymi gatunkami (*Crucigenia apiculata*, *Peridinium* spp., *Dinobryon* spp.) do grupy glonów towarzyszących. Masowo występującymi bruzdnicami były *Ceratium hirundinella* i *Gymnodinium uberrimum*; razem z gatunkami towarzyszącymi posłużyły one do charakterystyki fitoplanktonu zbiornika (Ryc. 3c). Pierwsza z wymienionych bruzdnic, o szerokiej amplitudzie ekologicznej, żyje w wodach o temperaturze 5–30°C w jeziorach o różnej trofii. Jest ona słabo konsumowana przez zooplankton z racji dużych wymiarów, a zanika z pojawem sinic. Druga z wymienionych bruzdnic preferuje wody oligotroficzne; optimum jej rozwoju występuje przy pH 6,0. Zakwaszenie może zmienić strukturę fitoplanktonu

w kilku poziomach, tj. bogactwie gatunków, ich składzie i dominacji. Bogactwo gatunków w fitoplanktonie wzrasta wraz z podniesieniem się wartości pH, co potwierdziła w obecnych badaniach większa liczba taksonów, oznaczonych w planktonie zbiornika w 1994 r., tj. w następnym roku po dolomitowaniu (Tab. 1). Fakt ten wskazuje na wyraźną poprawę środowiska wodnego.

Sinice odgrywały znikomą rolę w fitoplanktonie zbiornika w obu sezonach badawczych (Ryc. 2), co jest cechą pozytywną w aspekcie ewentualnej eutrofizacji i ich toksycznego wpływu na wodę pitną.

Wydaje się więc, że dolomitowanie przeprowadzone w potoku Czarna Wisełka miało pewien dodatni wpływ na zmianę struktury zbiorowisk w samym zbiorniku. Należy się jednak spodziewać powrotu do sytuacji początkowej w przypadku zaprzestania dolomitowania.