ACTA HYDROBIOL.	28	3/4	345—360	KRAKÓW 1986

Phytoplankton of the Rożnów dam reservoir in the years 1982—1983 (Southern Poland)*

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Manuscript submitted January 29, 1986, accepted April 15, 1986

Abstract — The phytoplankton of the Rożnów dam reservoir and of the River Dunajec above and below this water body was investigated. Current results in comparison with those obtained in earlier studies showed a change in the composition of algal communities and species domination. The phytoplankton was successively dominated by chrysophytes-dinoflagellates or diatoms, or diatoms-green algae in the 1940's, diatoms-dinoflagellates and diatoms-chrysophytes-dinoflagellates-blue-green algae in the fifties, diatoms-cryptomonads in the sixties, and blue-green-green algae in the eighties. This indicates that the reservoir, initially of riverine type, gradually changed into one of stagnant water type. A mutual effect of phytocenoses of the river on the reservoir and vice versa was observed.

Key words: river, dam reservoir, algal communities, temporal changes.

1. Introduction

The present work, based on material collected in 1982 and 1983, is part of a hydrobiological and fishery team investigation carried out by the Institute of Freshwater Biology of the Polish Academy of Sciences, in dam reservoirs lying in the area of southern Poland.

The phytoplankton in the Rożnów dam reservoir was successively

* The investigation was carried out within Project No MR.II.15.

investigated by Olszewski (1946), Siemińska (1952, 1953), Biernacka (1959, 1963), and Bucka (1965).

The aim of the current study of phytoplankton in the Rożnów reservoir was to determine the changes which had occurred in the structure of algal communities during the years since its filling. In addition, attention was paid to the qualitative relations of algae, especially of those which reached the largest numbers, chiefly during the formation of algal blooms. The investigation also aimed at determining the mutual influence, both of the reservoir on algae communities developing below the dam and of the sector of the River Dunajec just below its inflow to the reservoir, on the phytocenoses appearing there. The River Dunajec has a specific microflora which in a certain measure affects the character of the phytoplankton in the reservoir lying on it.

2. Study area

The Rożnów reservoir, built on the River Dunajec in 1942, is of submontane type. It has a frequency of water exchange exceeding 10 times annually is classed as rheolimnic (Starmach 1958). This is reflected in the dynamics of algal development since, as is well known, their numbers and species composition depend upon the frequency of water exchange. Other data concerning the reservoir from recent years are given according to Głodek (1980) and Dumnicka et al. (1986).

Station 1. The River Dunajec, the inflow at Marcinkowice (22 km from the dam), 40 cm to 1 m in depth (fig. 1). The left bank of the river is low and stony, neighbouring upon pastures and fields. The right bank is steep with an embankment covered with grass and willows, next to a highway.

Station 2. Backwaters of the reservoir at Zbyszyce (13 km from the dam), 1.5—4.5 m in depth. The bottom muddy, grey, in summer yellowish on the surface, sandy near the old riverbed; it is partly uncovered at low water level.

Station 3. The central part of the reservoir at Lipie (7.5 km from the dam), 11—14 m in depth. The bottom muddy with a large admixture of sand near the banks which neighbour upon fields and small mixed woods.

Station 4. The "Zakole" part of the dam at Rożnów (about 500 m from the dam) 16—20 m in depth. The muddy bottom is black and covered with a layer of yellowish-grey mud, several centimetres thick. Above the left bank is a steep mountain slope with mixed forest. The right bank, similarly tree-covered, falls steeply to the highway.

Station 5. The River Dunajec, the outflow at Rożnów (600 m from the dam), 30 cm to 1.5 m in depth. Both banks are steep, especially the left one with mixed forest extending above it.

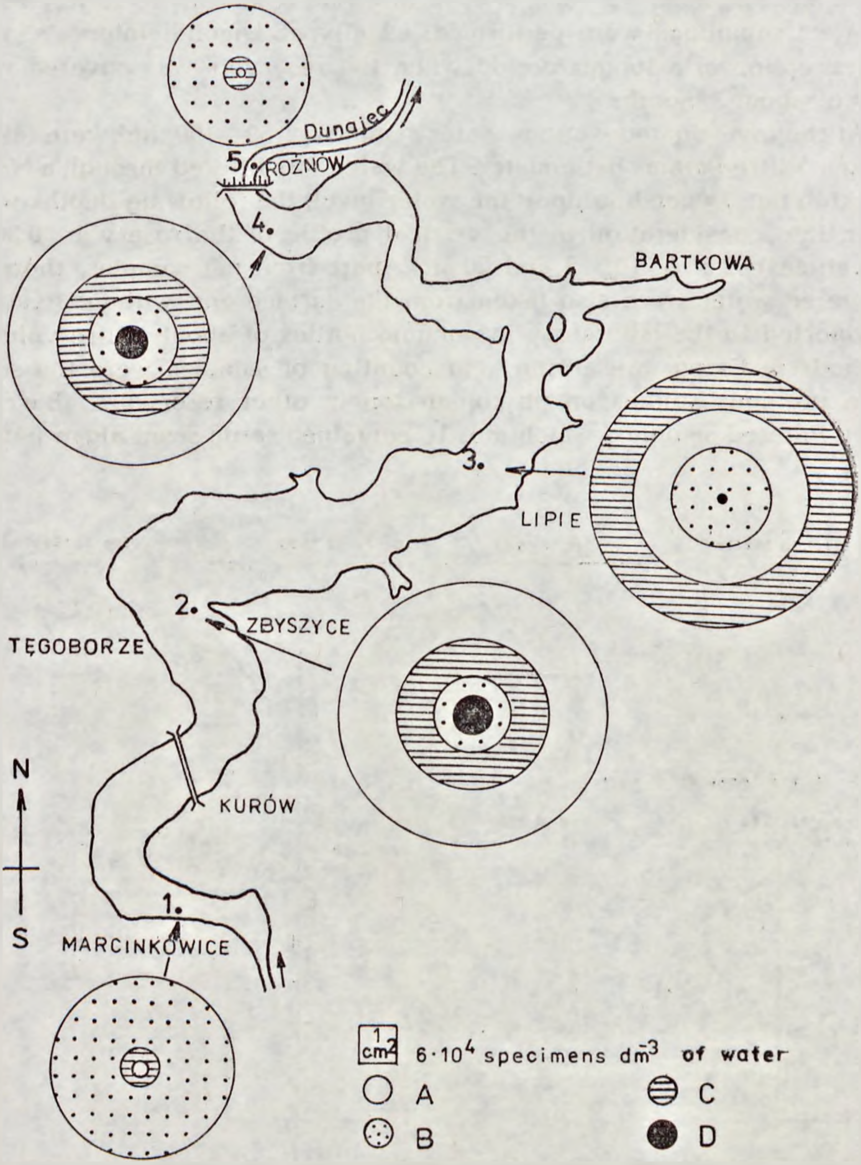

Fig. 1. Average annual quantities of various algal systematic groups in dm^{-3} of water and their surface distribution at all investigated stations. A — blue-green algae; B — diatoms; C — green algae with desmids; D — others: euglenoids (St. 2), chrysophytes with cysts, cryptomonads, dinoflagellates, euglenoids (St. 3), cryptomonads, chrysophytes with cysts, euglenoids (St. 4)

3. Material and method

The sampling of phytoplankton was begun on September 10, 1982 and ended on September 12, 1983. A total of 8 (the reservoir) to 10 (the River Dunajec) samplings were performed, usually at 1-month intervals, with the exception of a longer period when the reservoir was covered with ice, i.e., about 3 months.

At the investigated stations water samples of 50—100 dm³ were taken, using a 5-litre Patalas bathometer. The water was filtered through a No 25 plankton net. Depending upon the water level, the following depths were taken into consideration in the vertical profile of the reservoir: 0.30, 1 (sometimes), 2.5, 5, 10, 15 and 20 m. Apart from net samples, those of unfiltered water were also taken from the surface and without fixation, transported to the laboratory in vacuum bottles of about 1 litre volume. Methods in fixing, preserving, and counting of samples were the same as in previous studies on phytoplankton in other reservoirs (B u c k a 1985). Filtered samples, which mostly contained large-sized algae (*Apha-*

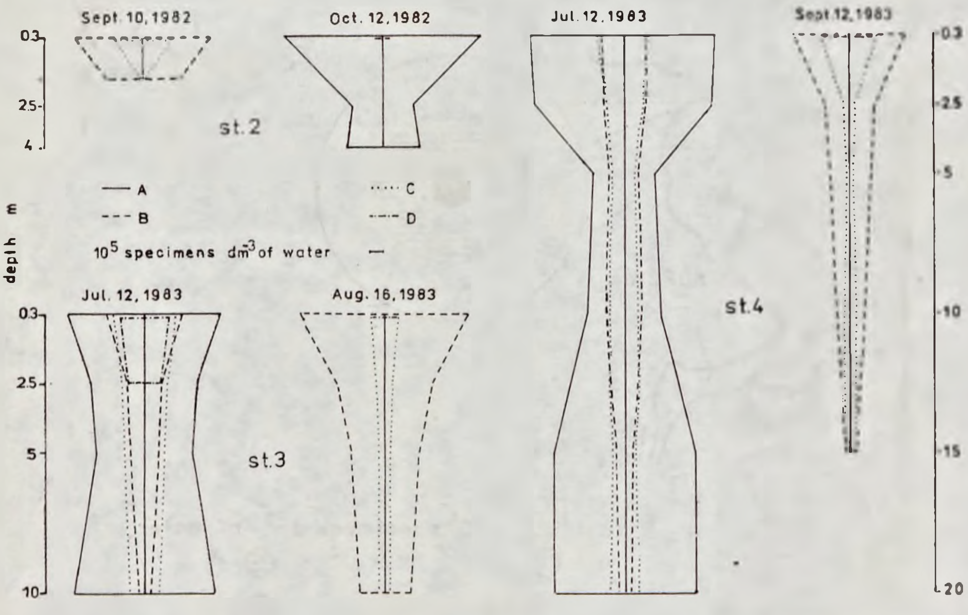

Fig. 2. Vertical distribution of numbers of *Aphanizomenon flos—aquae* during its "water bloom" and of accompanying species according to L o h m a n n's formula (S t a r m a c h 1955) in the Rożnów dam reservoir. A — blue-green alga; B — green algae with desmids; C — diatoms; D — others: chlorococcous algae, chrysophytes, cryptomonads (St. 2), euglenoids, dinoflagellates, cryptomonads, chrysophytes with cysts, desmids (St. 3), chroococcous blue-green alga, cryptomonads, chrysophytes with cysts (st. 4)

nizomenon, *Melosira*, and *Pediastrum*), were the basis for determining the number of algae. Unfiltered samples, whose species composition was more differentiated, were generally useful for supplementing the list of identified algae. However, when in the unfiltered samples large numbers of nannoplankton algae (in the order of 10^5 or more cells dm^{-3} of water, such as *Stephanodiscus hantzschii* G r u n.) or their mass occurrence (about 10^6 cells dm^{-3} of water, e.g., *Phacotus lenticularis* (E h r.) S t e i n) were found, it was impossible to neglect them and they were taken into consideration in evaluating the total number of identified algal communities. Also, the annual mean numbers were calculated for the three basic groups of algae (blue-green algae, diatoms, and green algae) and of the remaining groups in the surface water layers at all the investigated stations (fig. 1). The vertical distribution of the blue-green alga *Aphanizomenon flos-aquae* (L.) R a l f s, which developed in masses, and of algae which accompanied it at 3 stations in the reservoir are presented in fig. 2. The floristic spectrum (Table I) separately contains the number of species, and of varieties and genera of algae, identified in various communities. Changes in the structure of algal communities observed by different authors in the course of previous studies are given in Table II.

Table I. Floristic spectrum including species (a), varieties (b), genera (c), and taxa determined only as to genera (d) in the period 1982-1983

Systematic groups	Station											
	1				2, 3, 4				5			
	a	b	c	d	a	b	c	d	a	b	c	d
Cyanophyta	3		2		6		5	1	4		3	
Euglenophyta					6	1	3	1				
Cryptophyceae							1	1				
Dinophyceae					1		2	1				
Chrysophyceae					3		4	1				
Bacillariophyceae	23	7	15		25	7	14		25	8	15	
Chlorophyta	8			1	52	6	27	2	21	2		2
Conjugatae			1	1	5		4	2				
Total	34	7	18	2	98	14	60	9	50	10	18	2

4. Results

4.1. Characteristics of phytoplankton communities

During the entire period of investigation diatoms decisively prevailed over the groups of algae in the phytoplankton of the River Dunajec (Station 1), their mean annual number constituting 96% of the total (fig. 1). Among them the most numerous and the same time predominating species were: *Diatoma vulgare* B o r y with the variety *ehrenbbergii* (K ü t z.) G r u n., var. *productum* G r u n., and var. *capitulatum* G r u n., followed by *Cocconeis placentula* Ehr. var. *euglypta* (Ehr.) Cl. and *C. pediculus* Ehr., *Navicula cryptocephala* Kütz. with var. *veneta* (Kütz.) Grun. and var. *intermedia* Grun., and *Nitzschia palea* (Kütz.) W. Sm. Among species frequently found in the samples but whose numbers were small were: *Stephanodiscus hantzschii, S. astrea* (Ehr.) Grun. var. *minutulus* (Kütz.) Grun., *Nitzschia acicularis* W. Sm., *N. sigmoidea* (Ehr.) W. Sm., *N. dissipata* (Kütz.) Grun., *Navicula gracilis* Ehr., *Cyclotella meneghiniana* Kütz., *Synedra ulna* (Nitzsch) Ehr., *Gomphonema olivaceum* (Lyngb.) Kütz., *G. augur* Ehr., *Melosira varians* Ag., *Cymbella ventricosa* Kütz., *Cymatopleura solea* (Bréb.) W. Sm., *C. elliptica* (Bréb.) W. Sm., *Surirella ovata* Kütz., and *Fragilaria intermedia* Grun. Their more abundant development occurred in late autumn 1982 and in the spring of the following year. In these periods they were accompanied by some chlorococcous green algae: usually *Scenedesmus quadricauda* (Turp.) Bréb., *S. acuminatus* Meyen, *Pediastrum boryanum* (Turp.) Menegh., and *P. duplex* Meyen, and of filamentous algae *Oedogonium* sp., *Cladophora glomerata* (L). Kütz., and *Ulothrix zonata* (Weber and Mohr) Kütz. Single specimens of some blue-green algae (*Gloeocapsa turgida* (Kütz.) Hollerb. and *Oscillatoria limosa* Agardh) and the desmid *Closterium* sp. were also found here. Numerous flocci of the bacterium *Sphaerotilus natans* Kütz. were also encountered.

In the backwaters of the Rożnów reservoir (Station 2) blue-green and green algae constituted a larger and diatoms a smaller share of the phytoplankton that at Station 1 (fig. 1). Their mean annual number exceeded 66, 25, 7% respectively, of the total number of all groups of algae. A particularly intensive development took place in the autumn of 1982, when there appeared bloom (almost monoculture) of the species *Aphanizomenon flos-aquae.* In surface layers its numbers reached $15 \cdot 10^5$ filaments dm^{-3} of water. At this time the species was accompanied by single specimens of chlorococcous green algae (*Coelastrum cubicum* Naeg., *Scenedesmus bijuga* (Turp.) Lagerh., and *Pediastrum boryanum*) and also the chrysophyte *Synura uvella* Ehr., the diatom *Gomphonema parvulum,* and *Cryptomonas sp.* In midsummer 1983 other blue--green algae, such as *Oscillatoria limosa* and *O. tenuis* Agardh, were fairly numerous here. Another important group were green algae of the orders *Chlorococcales* and *Volvocales.* The former abundantly appeared in September 1982. Besides those mentioned at Station 1, chiefly noted here were *Coelastrum sphaericum* Naeg., *C. microsporum* Naeg., and *Scenedesmus quadricauda* (Trup.) Bréb. var. *maximus* W. and W. (fig. 2). Green algae of the *Volvocales* order were represented only by one nannoplankton species, *Phacotus lenticulris,* which reached maximum numbers in the middle of August 1983 (10^5 cells dm^{-3} of water). Diatoms played a small role at this station. Among more numerous species the following may be mentioned: *Diatoma vulgare* with var. *productum*, *Cyclotella meneghiniana*, *Gomphonema olivaceum*, *G. parvulum* (Kütz.) Grun., *Nitzschia sigmoidea*, *Synedra ulna*, *Asterionella formosa* Hass., and *Stephanodiscus hantzschii*. Among species which appeared frequently but not numerously were: *Cyclotella ocellata* Pant., *Surirella robusta* Ehr. var. *splendida* (Ehr.) V.H., *Synedra acus* Kütz., *Navicula gracilis*, *N. cryptocephala* with its varieties (cf. Station 1), *Fragilaria capucina* Desm., *F. intermedia*, *Nitzschia palea*, and *Melosira granulata* (Ehr.) Ralfs var. *angustissima* (O.F.M.) Hust. Among euglenoids 2 epizoophyte species, *Colacium vesiculosum* Ehr. and *C. simplex* Hub.-Pest., were fairly numerous. In late autumn they formed aggregations on plankton animals which were numerous at that time (*Cyclops*, nauplius).

At station 3 green algae, followed by blue-green algae and diatoms, quantitatively predominated among other groups, their mean annual numbers reaching 57, 28, and 13%, respectively, of the total number of phytoplankton (fig. 1). In October 1982, contrary to the backwaters of the reservoir at the same time, only a small number of the species *Aphanizomenon flos-aquae* (in the order of $5 \cdot 10^3$ filaments dm^{-3} of water in the surface water layer) and a similar one of *Microcystis aeruginosa* Kütz. in the layer near the bottom were recorded. They were accompanied by single specimens of other blue-green algae (*Anabaena spiroides* Kleb., *Merismopedia tenuissima* Lemm., and *Gloeocapsa turgida*) and by the sporadically occurring chlorococcous green algae mentioned above (cf. Station 2), the diatom *Melosira granulata* var. *angustissima*, *Cryptomonas* sp., *Peridinium* sp., and cysts of chrysophytes. In samples from November of the same year a more abundant development of the diatom *Stephanodiscus hantzschii* and euglenoids (*Colacium* spp.) attached to *Daphnia cucullata* Sars. or *Cyclops sp.* was observed, chiefly to a depth of 5 m. In the middle of May 1983, 3 diatoms developed abundantly — *Melosira granulata* with *M. granulata* var. *angustissima*, followed by *Synedra acus* with *S. acus* var. *angustissima* Grun., and *Cyclotella comta* (Ehr.) Kütz. (about $27 \cdot 10^4$ specimens dm^{-3} of water). In July and August the first of the above-mentioned species and its variety accompanied the more intensive development of blue-green and green algae, successively. In July 1983 its occurence coincided with a mass appearance of *Aphanizomenon flos-aquae*, which was chiefly noted in a layer from the surface to a depth of 2.5 m (fig. 2). At that time the number of this blue-green alga was about $67 \cdot 10^4$ filaments dm^{-3} of water. During the period of its blooms, besides *Melosira granulata* and its variety, the following species occurred fairly abundantly: the green alga of the *Volvocales* order *Carteria klebsii* (Dang.) Dill, various chlorococcous green alga (chiefly *Scenedesmus bijuga*, *S. spinosus* Chod., *S. quadricauda* var *maximus*), the chrysophyte *Mallomonas* sp., and single specimens of other blue-green algae, such as *Anabaena scheremetievi* Elenk. and *Microcystis aeruginosa*. In the middle of August of the same year very large numbers of a small green alga of the *Volvocales* order, *Phacotus lenticularis*, were observed, reaching $95 \cdot 10^4$ cells dm^{-3} of water. At that time numerous species of chlorococcous green algae appeared but their numbers were small (this especially concerns *Oocystis solitaria* Wittr., *O. pseudocoronata* Korschik., *Scenedesmus* spp., *Crucigenia apiculata* (Lemm.) Schmidle and *Sphaerocystis schroeteri* Chod.). Also desmidia *Staurastrum tetracerum* Ralfs and *S. gracile* Ralfs constituted a fairly large share. Other chlorococcous green algae (especially *Coelastrum sphaericum, Pediastrum* spp., *Lagerheimia ciliata* (Lagerh.) Chod., and *L. longiseta* (Lemm.) Printz) developed more abundantly at the end of the first decade of September in both years of investigation (fig. 2). Station 3, which lay almost in the centre of the reservoir, was characterized by a great variability and intensive development of green algae (fig. 1).

At the dam (Station 4) the composition of the phytoplankton was similar to that noted at the preceding stations within the reservoir. This chiefly concentrated the prevailing species of blue-green and green algae. These communities were decisive for the phytoplankton structure also in the lower part of the reservoir, constituting 59 and 29%, respectively, of its total number while diatoms reached 9% only (fig. 1). The species *Aphanizomenon flos-aquae* showed its most abundant development in July 1983. It brought about the formation of much denser water-blooms ($12 \cdot 10^5$ filaments dm^{-3} of water to a depth of 2.5 m) than at Station 3 in this period. In deeper water layers the numbers of this blue-green alga decreased, only to increase from a depth of 15 m to the bottom. It was accompanied by single specimens of another blue-green alga, *Microcystis aeruginosa*, and also by the diatom *Melosira granulata* var. *angustissima* (about $24 \cdot 10^3$ filaments dm^{-3} of water), which was fairly numerous, particularly in surface water layers, and small numbers of various of chlorococcous green algae (especially *Pediastrum boryanum* and *P. duplex, Coelastrum microporum, C. sphaericum*, and *Sphaerocystis schroeteri*). Their vertical distribution was fairly uniform. In general, the species composition of the blue-green algal communities was poor but it was enriched by the nannoplankton species *Merismopedia tenuissima*, which occurred frequently though not numerously at this station. Besides the species mentioned above, the following were recorded: *Scenedesmus quadricauda* var. *maximus, S. longus* Meyen var. *naegelii* (Bréb.) G. M. Smith, *S. brasiliensis* Bohlin, *S. acuminatus* (Lagerh.) Chod. var. *biseriatus* Reinsch, *S. spinosus, S. bijuga, S. ecornis* (Ralfs) Chod., *Oocystis solitaria* and *O. borgei* Snow, *Crucigenia apiculata, Lagerheimia ciliata, L. wratislaviensis* Schroeder, *Golenkinia radiata* Chod., *Tetraëdron caudatum* (Corda)

Table II. Comparison of mass and numerous occurrence of algae in plankton of the Rożnów dam reservoir (R), of the River Dunajec above (a) and below (b) the reservoir in various years of the investigations. Occurrence of taxa: ++++ - in mass; +++ - very numerous; ++ - numerous; + - single

Period of investigation	19.IV.-14.XII.1943	13.V.1946-5.IX.1949			21.VI.-27.VI.1957			1.VI.-30.VI.1958	21.V.1963-20.V.1964			10.IX.1982-12.IX.1983		
Data after	Olszewski (1946)	Siemińska (1952)			Biernacka (1959)			Biernacka (1963)	Bucka (1965)			Bucka (1986)		
Taxa	R	a	R	b	a	R	b	R	a	R	b	a	R	b
<u>Cyanophyta</u>														
Anabaena Scheremetievi			++++	+									+	
- spiroides								++++					+	
Aphanizomenon flos-aquae													++++	
Oscillatoria princeps f. recta					++	+	++							
<u>Euglenophyta</u>														
Euglena spp. (E. acus, E. proxima)	+								+	++	+			
<u>Dinophyceae</u>														
Peridinium cinctum		+	+++	+		++++	++++	++++						
- lubieniense			+++											
Ceratium hirundinella	++	+	++++	+	+	++++	++		+	++				
<u>Cryptophyceae</u>														
Cryptomonas spp.	+								+	++++	++		+	
<u>Chrysophyceae</u>														
Dinobryon divergens and cysts			++++	+				++++	+	+++	+			
- sertularia	+++													
- stipitatum and cysts		+	++++											
<u>Bacillariophyceae</u>														
Asterionella formosa	+++	+	+++	++		++++	++++	++++	+	++	+		+	+
Attheya Zachariasii								++++						
Ceratoneis arcus	+								++	+	+	+	+	+
Cocconeis spp. (C. pediculus, C. placentula var. euglypta)												++	+	+
Cyclotella comta			++++	+										
- ocellata	+	+	+++	+++										
Cyclotella spp. (C. meneghiniana)									+++	++++	++	+	+	+
Cymbella cistula	+				++	+	++++							
- lanceolata					++	++++	++							
- tumidula						++++								
Cymatopleura solea	+				++++	++++			++	++		+	+	
Diatoma elongatum	+++	+	++	+					++	+				
- vulgare (var. Ehrenbergii, var. productum, var. capitulatum)												+++	++	+
Fragilaria crotonensis		+	++++	+++		++++	++++	++++	+	+++	++		+	+
Melosira granulata									+	+++	++	+	+	+
- - var. angustissima									+	+		+	+++	++
Navicula ambigua						++++								
- cryptocephala (var. intermedia var. veneta)												++	+	+
Nitzschia palea												++	+	+
- sigmoidea					++++	++						+	+	+
Stephanodiscus spp. (S. Hantzschii, S. astrea var. minutulus)												+	++	++
Synedra acus					++++	++++				+++			++	+
- - var. angustissima									+	+++	+		++	+
- ulna	++				+	++++			++	+	+	+	+	+
<u>Chlorophyceae</u>														
Phacotus lenticularis	+++		++++										++++	+
Coelastrum spp. (C. sphaericum, C. cubicum)													+++	++
Pediastrum spp. (P. Boryanum, P. duplex)									+	++	+	+	+++	++
Scenedesmus spp. (S. acornis, S. quadricauda var. maximus, S. bijuga, S. spinosus)									+	++	+	+	++	+
Oocystis spp. (O. solitaria, O. pseudocoronata)													++	+

Hansg., and *Westella botryoides* (W. West) Wild. From desmids *Staurastrum gracile* and *S. tetracerum*, and from green algae of the *Volvocales* order *Phacotus lenticularis* were also noted. As at Station 5, the last species, together with *Coelastrum* spp. and *Pediastrum* spp., reached their maximum development in the second decade of September 1983 (about $27 \cdot 10^4$ cells dm^{-3} in surface water layers) (fig. 2). Diatoms played a small role in the phytoplankton of this station. In the winter the community was very poor. In samples taken towards the end of January specimens of *Diatoma vulgare, Synedra ulna, Stephanodiscus hantzschii, Melosira varians*, and cysts of chrysophytes were sporadically noted while in samples from the spring period, such diatoms as: *Diatoma vulgare* var., *ehrenbergii, Cyclotella comta, C. ocellata, Fragilaria capucina, Rhoicosphaenia curvata* (Kütz.) Grun., *Gyrosigma attenuatum* (Kütz.) Rabh., *Nitzschia acicularis, Synedra* acus var. *angustissima, Melosira granulata* var. *angustissima*, and *Stephanodiscus hantzschii* were more numerous. In May, the last three species of diatoms developed more abundantly, reaching over $11.2 \cdot 10^4$ specimens dm^{-3} of water.

In the outflow sector of the River Dunajec (Station 5) diatoms prevailed in the phytoplankton, constituting 96% (green algae with desmids 3% and other groups 1%) of the total number of algae (fig. 1). Among the most numerous diatoms were: *Melosira granulata* var. *angustissima*, large numbers of which were observed especially in October, and *Cocconeis placentula* var. *euglypta, C. pediculus, Gomphonema olivaceum, G. augur, G. constrictum* Ehr., and *G. ventricosum* Greg. which were most numerous in December 1982. Among species rarely found in the period of late winter the following were: *Cymbella ventricosa, C. prostrata* (Berk.) Cl., *Diatoma vulgare, Nitzschia palea, N. dissipata, Fragilaria intermedia, Rhoicosphaenia curvata, Achnanthes minutissima* Kütz., *Navicula cryptocephala* with its variety *veneta*, and *N. gracilis*. Among them *Melosira granulata* var. *angustissima* was the first to develop most abundantly in the middle of May 1983. It was accompanied by a few specimens of *Synedra acus* with the variety *angustissima* or by sporadically encountered species such as *Synedra ulna, Cocconeis placentula* var. *euglypta, Diatoma vulgare* var. *ehrenbergii, Stephanodiscus astrea* var. *minutulus*, and *Ulothrix zonata, Cladophora glomerata, Merismopedia tenuissima, Oscillatoria limosa*, and *O. tenuis*. Another and more abundant occurrence of the diatom *Melosira* was observed in July 1983 and was accompanied by single specimens of *Synedra acus* and its variety *angustissima* and *Navicula cryptocephala* with var. *veneta*, and some chlorococcous green algae, i.e. *Pediastrum* spp., *Coelastrum* spp., *Scenedesmus quadricauda* var. *maximus* and *S. longus* var. *naegelii*. The community of green algae did not appear here in any large numbers until the second decade of September 1983, this being correlated with their maximum development at Station 4. Neither the qualitative composition nor the quantities of phytoplankton at Station 5 always reflected the conditions found in the reservoir at the dam in periods of intensive development of some algae. This was particularly evident in the case of the blue-green alga *Aphanizomenon* during its blooms in July 1983. In the outflow from the reservoir very small numbers of the species appeared in phytoplankton samples, while it was more frequent and numerous in the communities of sessile algae (S a n e c k i 1986).

5. Discussion

5.1. Changes in the structure of phytoplankton communities in different years after the filling of the reservoir

Algae found in the study represented various systematic groups with a decisive predominance of blue-green and green algae, followed by diatoms. A total of 98 spcies of alga with 14 varieties from 15 genera were identified, besides which 13 algae were classified as to genus (Table I).

In the first studies on the Rożnów dam reservoir the following species of alga occurred in masses: blue-green algae *Anabaena scheremetievi* and *A. spiroides*, dinoflagellates *Ceratium hirundinella* and *Peridinium cinctum*, chrysophytes *Dinobryon divergens*, diatoms *Asterionella formosa*, *Cyclotella comta*, *Fragilaria crotonensis*, and *Attheya zachariasii*, and the green alga of the *Volvocales* order *Phacotus lenticularis*. In the following years they were eliminated by *Cryptomonas* sp. and the diatom *Cyclotella meneghiniana*, and finally by *Aphanizomenon flos-aquae*.

The comparison of results obtained in previous studies suggests current changes in the composition of phytoplankton in the Rożnów dam reservoir. In the forties chrysophytes-dinoflagellates-blue-green algae or only diatoms or diatoms-green algae prevailed there (S i e m i ń s k a 1952); in the fifties the prevailing groups were diatoms-dinoflagellates and diatoms-chrysophytes-dinoflagellates-blue-green algae (B i e r n a c k a 1959, 1963). Recently, the change appeared as a transition from the diatom-cryptomonad type of the sixties (B u c k a 1965) to the blue-green-green algae type (Table II).

It seems that changes noted in the composition and numbers of phytoplankton communities indicate a gradual blurring of the riverine character of the reservoir with traits typical for stagnant water reservoirs becoming more and more pronounced.

The present study also showed a greater variability of species, chiefly of diatoms, followed by minute chlorococcous green algae (*Coelastrum*, *Pediastrum*, and *Scenedesmus*), which replaced large forms of green algae of the *Volvocales* order (*Gonium*, *Eudorina*, *Pandorina*, and *Volvox*). At present the blue-green alga *Aphanizomenon flos-aquae* (which was not noted in the reservoir in earlier studies) predominated over other algae in the phytoplankton. The mass appearance of this species was also observed in Gołysz fishponds fertilized with nitrogen-phosphorus fertilizers (Bucka 1966). In this latest investigation the species was found to form almost a monoculture about mid-October 1982 at Station 2 (fig. 2). According to Huber-Pestalozzi (1938), it is a euplankton species attached to stagnant waters. This was confirmed by its mass occurrence at the above station (backwaters of the reservoir), lying in the quiet zone at a certain distance from the old riverbed. Its second mass appearance (about mid-July 1983) was chiefly noted at Station 4, when its numbers were reduced by half in the central part of the reservoir, and it did not occur in the upper part. Probably, the rate of its distribution was greatly affected by movements of the water masses.

The largest numbers of this blue-green alga during its bloom were recorded to a depth of 2.5 m, with a distinct decrease in deeper water layers and again an increase from 10 m to the bottom (Station 4). The vertical distribution of this blue-green alga might depend upon the presence of gas vacuoles (also characteristic for other species of blue-green algae, especially plankton ones), which made it possible for them to float in the upper water layers. Experimental results show that this N_2-fixing species requires more light energy (72%) than other non-N_2-fixing blue-green algae, e.g., *Oscillatoria*, to reach the same rate of growth. In the process of dinitrogen fixation the greater demand for light energy is chiefly associated with the production of heterocysts (Zevenboom, Mur 1980), which in turn yield nitrogenase, an important enzyme for this process (Krupka 1984).

Among species which developed very abundantly during the recent investigation is the nannoplankton green alga *Phacotus lenticularis*, which formed algal blooms in the initial period after the filling of the reservoir. Now, it reached the most numerous occurrence in August 1983 at Station 3. In general, in August and September the most intensive development was observed of chlorococcous green alga (*Oocystis*, *Scenedesmus*, and *Crucigenia*) and of green algae of the *Volvocales* order (*Phacotus* and *Carteria*), which represented nannoplankton and grouped in surface water layers to a depth of 2.5 m (fig. 2). Contrary to the large-sized blue-green alga *Aphanizomenon*, the above green algae might be used as food by filter-feeding zooplankton which developed fairly abundantly at this depth (rotifers *Keratella cochlearis* and *Polyarthra minor*). At a depth of 5 m, besides the rotifer *Pompholyx sulcata*, numerous cladocerans (e.g., *Daphnia cucullata* and *D. hyalina*) were observed. Their more abundant development might also stimulate an increase in the number of minute algae. According to Grzybowska and Wodzińska (1984), the development of zooplankton may be correlated with a reduction in consumed nannoplankton. The above authors found that when zooplankton disappeared in the Rybnik dam reservoir, nannoplankton algae regained predominance in the phytoplankton. It seems that in the discussed cases (blue-green alga, minute green algae) zooplankton did not play the role of an important factor limiting the development of phytoplankton. However, a more comprehensive interpretation of this dependence should be based on special studies supported by laboratory tests.

5.2. Conditions of the intensive development of *Aphanizomenon flos-aquae*

The formation of water-blooms depends among other factors on the frequency of water exchange. The investigated water body at Rożnów is a rheolimnic flow reservoir with a frequency of water exchange exceeding 10 times annually. It was built on a montane river in a valley with a steep gradient, hence variations in the water level of this deep and long reservoir uncover its upper part only. Sewage from the town of Nowy Sącz is brought in with the water of the River Dunajec to the backwaters zone of the reservoir, this perhaps being the cause of intensive blooms of *Aphanizomenon*, which even becomes a monoculture here.

According to L i n (1972), this species reached its maximum production in Lake Astotin (North American prairies) when the water temperature rose to nearly 23°C and rapidly disappeared when it fell to 16°C. According to S t a r m a c h et al. (1976), *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* showed their maximum development at 25°C. During *Aphanizomenon* blooms in the Rożnów reservoir the temperature of the water just under the surface was 14.9°C (backwaters), 15.9°C (the centre), and 15.8°C (the dam) in autumn 1982 and 20, 24.8, and 24.5°C, respectively, in summer 1983. At these stations the pH values were in autumn 1982 7.8 in the upper part of the reservoir and 7.4 in the central and lower parts, while in summer 1983 the corresponding values were: 7.8, 8.6, and 8.8. Acccording to P r e s c o t t (1951), *Aphanizomenon flos--aquae* blooms depend upon high pH value correlated with high concentrations of calcium carbonate and mineral nitrogen compounds. In the present study this was confirmed by the results of chemical analysis of the water sampled at the above stations in the same period (B o m b ó w - n a unpubl.). The results of the authors mentioned concerning such parameters as the temperature and pH of the water did not always correlate with water blooms observed in the present investigation. During the blooms in July high pH values were distinctly noted at Stations 3 and 4 but less distinctly at Station 2 in October, similarly as in the case of the water temperature. According to P r e s c o t t (1951), *Aphanizomenon* may be used as an indicatory organism for high pH values and, usually, a large content of nitrogen and carbonate, chiefly in the period of blooms. The species appears alone or is accompanied by other blue-green algae, such as *Microcystis aeruginosa* and *Anabaena spiroides*. It is rarely found, except in eutrophic lakes or slowly flowing streams of hard polluted waters. The species was also exceptionally found in Lake Rahr, Wisconsin, in medium hard water and acidophilous offshore vegetation. The alga can overwinter in the vegetative state and sometimes develops under ice. Its generative cells, the so-called gonidia, formed through the fragmentation of filaments, permit the survival of the organism under unfavourable environmental conditions. Like *Oscillatoria rubescens* (DC) G o m., *Aphanizomenon* brings about oxygen depletion in shallow lakes, owing to excessive development, followed by the dying and decomposition of algae. B a r i c a (1978) reported massive fish kills resulting from intensive development of this blue-green alga in a shallow eutrophic lake of the North American prairie. According to that author, a rapid destruction of biomass of algae resulted in the collapse of blooms, at first partial, of at least 70 $\mu g\ dm^{-3}\ week^{-1}$ of chlorophyll a, then total of over 70 $\mu g\ dm^{-3}\ week^{-1}$ of chlorophyll a. This is accompanied by oxygen depletion below the level required by the rainbow trout. Finally, the mortality in this fish species exceeded 90%. B a r i c a (1978) also drew attention the fact that in mixed blooms of *Aphanizomenon, Microcystis,* and *Anabaena* the biomass produced was not so large and no fish kills resulted. He suggests that warm and sunny weather with short summer nights secures optimum conditions for the formation of *Aphanizomenon* blooms. A rapid change of temperature, the wind, or a reduction in solar energy in cloudy weather bring about the collapse of blooms and, hence, a rapid decomposition of algae with the action of bacteria. However, it is hard to differentiate the effect of light and that of the temperature because they increase simultaneously (H y - n e s 1972). Frequently, an advanced decrease in chlorophyll content precedes a rapid drop in temperature. Numerous collapses of water--blooms were observed at a temperature maintained above 20° C because it favoured a high rate of algal growth (B a r i c a 1978).

The mass occurrence of the blue-green alga *Aphanizomenon* may be approached from a different aspect, i.e., that of the value of blue-green algae as food for zooplankton and the interdependence phytoplankton--zooplankton against the background of the dimensions of producers in relation to the consumers. S t a r m a c h (1966) stated that blue-green algae are not suitable food for zooplankton animals because they contain 65% of carbohydrates resistant to hydrolysis. Also, they release toxins to the water which, depending upon their concentration, may be noxious for fish. The blue-green alga *Aphanizomenon* is classed as a microplankton but owing to its large size (filaments about 120 μm in length, on the average) it is not a suitable food for filter-feeding zooplankton, unlike the minute though less numerous chlorococcous green algae. In periods of blooms of this blue-green alga in the reservoir filter-feeding zooplankton was represented by large numbers of rotifers, such as the species *Polyarthra remata* and *P. vulgaris* at Station 2 and very large numbers of the rotifer *Pompholyx sulcata* and nauplius at Station 4 (Dumnicka et al. 1986), Thus, the more abundant development of zooplankton might negatively affect the number of nannoplankton algae.

5.3. The interaction of river-reservoir-river on the development of phytoplankton

The obtained results show the effect of phytocenoses of the river on the reservoir lying below, as was illustrated by its phytoplankton with frequently occurring attached diatoms, typical for running waters (*Cocconeis placentula, Rhoicosphaenia curvata, Ceratoneis arcus* Kütz., *Gomphonema olivaceum, Diatoma vulgare,* and *Cymbella ventricosa*). On the other hand, the effect of the reservoir (chiefly Station 4) on the composition and numbers of phytoplankton in the river below the dam, was decisive in the case of the more abundant development of chlorococcous green algae, in contrast to the mass appearance of the blue-green alga *Aphanizomenon* not recorded in earlier studies on phytoplankton in the reservoir. The negligible number of this species in plankton samples taken at the station below the dam is probably associated with its destroying and decomposition in the reservoir brought about by the strong movements of water masses. The blue-green algae *Aphanizomenon* was more frequently found in the communities of sessile algae (Sanecki 1986), this probably being associated with the lower outflow of waters through the dam. It is a euplankton species, characteristic for stagnant waters. This was also confirmed by its occurrence in the backwaters of the reservoir, in the quiet zone, far from the old riverbed, where it developed almost alone. The discussed blue-green alga indicates progress in the process of eutrophication in the reservoir. On the other hand, the rich composition and abundance of different species of chlorococcous green algae (*Coelastrum, Pediastrum,* and *Scenedesmus*) flowing out of the reservoir, increase the self-purification potential of the river. This coincides with the period of their intensive development, particularly in the zone at the dam which affects the character of biocenoses in the river just below its outflow from the reservoir.

6. Polish summary

Fitoplankton zbiornika Rożnowskiego w latach 1982—1983 (Polska Południowa)

Badania fitoplanktonu prowadzono w odstępach przeważnie miesięcznych, na trzech stanowiskach w obrębie zbiornika oraz dwóch na rzece Dunajec, powyżej (dopływ) i poniżej zbiornika (odpływ) (ryc. 1). Ogólną liczbę oznaczonych glonów zawiera ta-

bela I. Rozmieszczenie w słupie wody masowo rozwijającej się sinicy *Aphanizomenon flos-aquae* przedstawiono na ryc. 2. Celem niniejszej pracy było uchwycenie zmian zaistniałych w strukturze zbiorowisk glonów w ciągu lat od momentu napełnienia zbiornika (tabela II) i porównanie z jego aktualnym stanem. Ponadto badano też wzajemny wpływ zarówno samego zbiornika na fitocenozy rozwijające się poniżej zapory, jak i wpływ odcinka Dunajca powyżej zbiornika na jego fitoplankton. Reprezentowały go różne grupy systematyczne, przy czym zdecydowaną przewagę miały kolejno: sinice, zwłaszcza *Aphanizomenon* (stanowiska 2, 4), następnie zielenice, przeważnie *Coelastrum* spp., *Pediastrum* spp., *Scenedesmus* spp., *Phacotus lenticularis* (stanowiska 3, 2) i okrzemki, głównie *Melosira granulata* var. *angustissima*, *Stephanodiscus hantzschii*, szczególnie obfite na wiosnę (stanowiska 3, 4). Natomiast na stanowiskach 1 i 5 z reguły dominowały okrzemki, a jedynie okresowo zielenice chlorokokkowe (stanowisko 5). Wśród okrzemek *Diatoma vulgare* var. *ehrenbergii* i *Cocconeis placentula* var. *euglypta* były liczne na stanowisku 1, a *Melosira granulata* var. *angustissima* i *Gomphonema olivaceum* na stanowisku 5. Największą liczebność osiągnęła w zbiorniku euplanktonowa sinica *Aphanizomenon* (nie notowana tutaj we wcześniejszych badaniach) w czasie jesiennego zakwitu, dającego w efekcie prawie monokulturę (stanowisko 2), i letniego, zwłaszcza na stanowisku 4. Jej pionowe rozmieszczenie głównie w górnych warstwach wody można by przypisać obecności wodniczków gazowych, typowych dla większości sinic planktonowych. Gatunek ten pochłania więcej energii świetlnej podczas wiązania azotu atmosferycznego niż na wiążące go inne sinice. Jest mu ona potrzebna głównie do produkcji heterocyst, biorących udział w powyższym procesie. Drugim bardzo obfitym gatunkiem była nannoplanktonowa zielenica toczkowata *Phacotus lenticularis*, tworząca zakwit na początku istnienia zbiornika. Obecnie osiągnęła największą liczebność w sierpniu na stanowisku 3, na którym we wrześniu najintensywniej rozwinęły się zielenice chlorokokkowe, od powierzchni do głębokości 2,5 m.

Stwierdzono wpływ fitocenoz rzeki na usytuowany poniżej zbiornik (obecność okrzemek porośłowych w jego planktonie), a samego zbiornika na rzekę poniżej zapory, jedynie w przypadku wzmożonego rozwoju zielenic chlorokokkowych. W fitoplanktonie zbiornika nastąpiła zmiana, obserwowana w latach badań, w składzie jego zbiorowisk, na obecnie wyróżniony typ sinicowo-zielenicowy.

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