ACTA HYDROBIOL.	35	2	133—151	KRAKÓW 1993

The effect of physical and chemical parameters on the dynamics of phyto- and zooplankton development in the Goczałkowice Reservoir (southern Poland)

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Manuscript submitted March 24, 1993, accepted June 24, 1993

Abstract - A highly significant dependence was found between the number of rotifers and the abundance of euglenoids and green algae. The numbers of copepods chiefly depended on the numbers of green algae and Chrysophyceae and to a very small degree of diatoms and blue-green algae. The total number of zooplankton depended on that of green algae, euglenoids, and desmids. No significant relation was found between Cladocera and 8 groups of the phytoplankton. The prevalence of small algal species was correlated with a greater content of phosphorus. In the case of euglenoids, green algae, desmids, and Chrysophyceae significant negative dependences upon N-NO_3 were observed. An increase in the number of desmids was associated with low concentrations of silicon in the environment.

Key words: dam reservoirs, water chemistry, phytoplankton, zooplankton.

1. Introduction

In recent years the eutrophication of water has been regarded as a problem of global importance. The ecological consequences of human activity are still insufficiently recognized, although this knowledge is indispensable for their efficient control. Thus, additional species studies, carried out in various aspects, are necessary for a deeper understanding of the functioning of a water body. The above being taken into consideration, a field experiment was carried out over several months in the Goczałkowice Reservoir and the results concerning trophic relations between phyto- and zooplankton were elaborated (Bucka, Żurek 1992).

The aim of the present investigation carried out in this reservoir was to analyse the physico-chemical parameters from the point of view of their effect on the development of phyto- and zooplankton communities and the dependences between their species composition and quantitative relations varying throughout the annual cycle.

2. Study area

Physico-chemical investigations of the water in the reservoir were carried out at a station 7.5 m in depth, situated in the zone near the dam, at a distance from it of about 1000 m and 500 m from the shore. Its counterpart was the station "Pomost" (4 m in depth) situated at the same distance from the dam but closer to the shore (about 150 m), where the phyto- and zooplankton were investigated (B u c k a, Ż u r e k 1992).

The investigation also took into consideration certain measurements carried out in the Bajerka bay (southern shore of the reservoir) and observations collected by the Frelichów meteorological station, situated on a drifting platform in the backwaters of the reservoir.

3. Material and methods

Samples of water for chemical analyses were usually taken at 3- or, rarely, 5-week intervals (from 13 June, 1988 to 14 June, 1989). Each time an averaged water sample from depths of 0, 1, 2.5, 5, and 7.5 m was investigated. Oxygen content was determined in the water from these depths. In winter (January-March) samples were taken from a water intake (depth of 0, 1 and 2.5 m) at a distance of about 400 m from the permanent sampling station. Determinations were carried out according to methods described by J u s t and H e r m a n o w i c z (1955, 1964) and G o l t e r m a n and C l y m o (1969). Chlorophyll content was measured according to the SCOOR Report, UNESCO (1966). Dry weight of the plankton was determined by filtering raw water through a GF/F filter and drying it to a constant weight. The amount of suspension was evaluated using the gravimetric method after filtering a known volume of water through a membrane filter (0.45 μm), transferring it onto a watch glass, drying, and weighing.

For evaluation of the developmental dynamics of phyto- and zooplankton, water samples were collected from mid-June 1988 to the end of June 1989 at weekly intervals in the summer, at two-week intervals in spring and autumn, and monthly in winter. The methods of sampling water for phyto- and zooplankton investigation, fixing the material, and determining numbers were the same as previously used by B u c k a and Ż u r e k (1992).

Statistical evaluation was carried out in a SYSTAT program, using MGLH procedure (the least square method and stepwise regression).

4. Results

4.1. Chemical composition of the water

No oxygen stratification was found in the reservoir during the period of the investigation. The oxygenation of water varied from 6.1-13.1 mg O_2 dm^{-3}, the maximum difference in oxygen content between samples from the surface and bottom water layers being 3.2 mg O_2 dm^{-3} (fig. 1). Water transparency measured with a Secchi disc ranged from 0.7-2.05 m (n=43) with an average of 1.21 m the most frequent value being 1.15 m. The highest value was noted in June and the lowest in April and August. The zones near the shores of the reservoir (the Bajerka bay showed a poorer visibility of the Secchi disc, varying from 0.50-1.30 m with 0.81 on the average and most frequently 0.75 m (n=32).

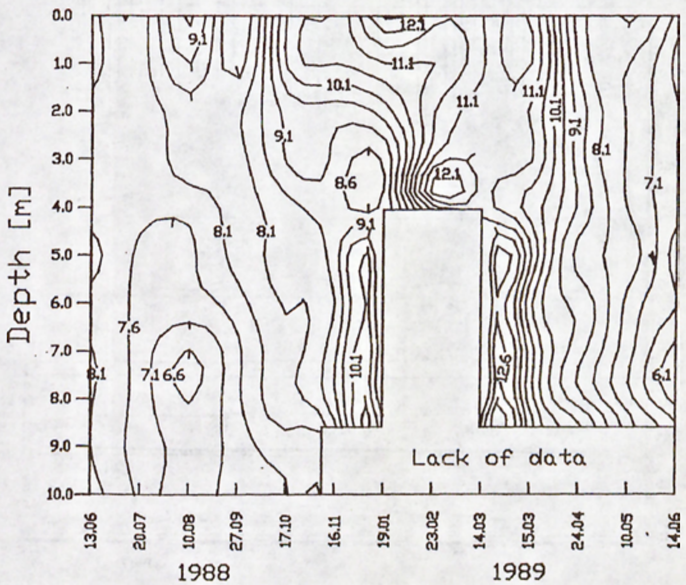

Fig. 1. Changes in oxygenation of reservoir waters

Dry weight of the seston varied within fairy narrow limits, i.e. 2.0-18.78 mg dm^{-3}, with an average of 8.76, the most frequent value being 4.0. The highest values were noted in July and April and the lowest in October. The littoral waters contained double the amount of seston with an average of 15.93 mg dm^{-3} and most frequently recorded value of 15.17mg dm^{-3} (fig. 2).

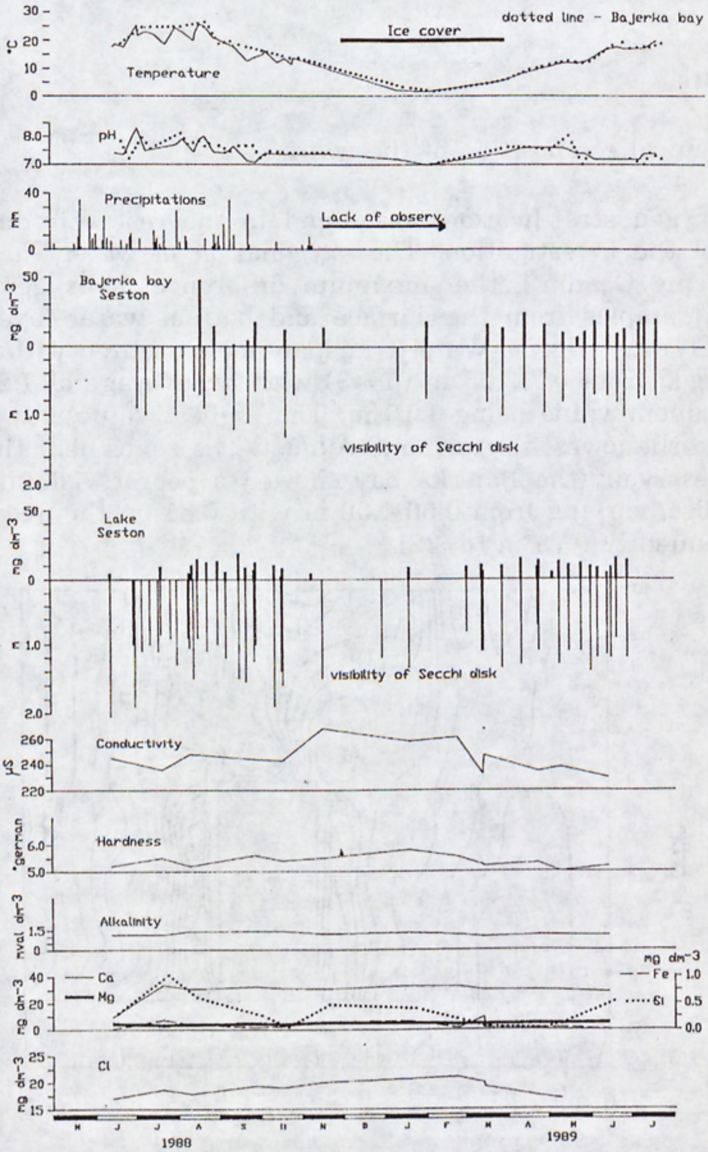

Fig. 2. Meteorological, physical, and chemical properties of the aquatic environment in the investigated reservoir

The seston reduced the visibility of Secchi discs, the correlation coefficients amounting to -0.51 for n=62 and -0.57 for logarithmicized values. Both coefficients were highly significant.

Among the mineral forms of nitrogen its nitrates prevailed. In the zone near the dam the concentration of nitrates did not exceed 1.1 mg N-NO_3 dm^{-3}. The concentration of nitrates was distinctly associated with the time of year. The lowest one occurred in summer and autumn (in the period August-November), not exceeding a value of 0.33 mg N-NO_3 dm^{-3}. In winter and spring the concentrations reached about 1 mg N-NO_3 dm^{-3}. The maximum concentration of ammonia nitrogen was 0.85 mg N-NH_4 dm^{-3}, those most frequently encountered varying from 0.40-0.25 mg N-NH_4 dm^{-3}. The pattern of ammonia nitrogen concentrations was the reverse of that of nitrates. In periods when high concentrations of N-NO_3 occurred, the amounts of N-NH_4 were small. The highest concentrations of this mineral form of nitrogen occurred in summer (June-August). The concentration of nitrite nitrogen did not exceed 0.03 mg dm^{-3}. The share of nitrite in the total nitrogen usually amounted to a percentage fraction. The content of nitrogen compounds was to a great degree affected by organically bound nitrogen, whose concentrations varied from 0.33-1.11 mg N dm^{-3}, most values ranging from 0.5-0.8 mg N dm^{-3} (fig. 3). Organic nitrogen was the prevailing form only in the autumn and constituted about 80%. In the remaining seasons its content was usually 40%.

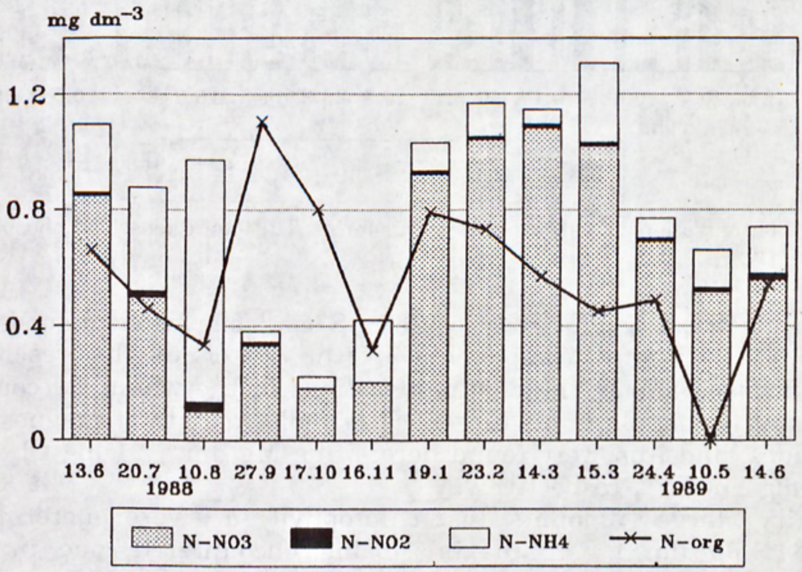

Fig. 3. Concentrations of various nitrogen forms

The concentrations of phosphate phosphorus changed from values approximating zero to 32 μg $P-PO_4$ dm^{-3}. The lowest values occurred in the winter (which was mild and with a transitory ice cover on the reservoir) and in early spring. The share of phosphate in total phosphorus varied from 0-50%, most frequently from a few to about 25%. The concentration of total phosphorus was from 36-94 μg P dm^{-3}, showing two maxima (early spring and early autumn) in the annual cycle (fig. 4). The gravimetric ratio $N_{tot.}/P_{tot.}$ was from 14-40 (50% of results were in the range 20-30), this showing that phosphorus was the factor limiting primary production.

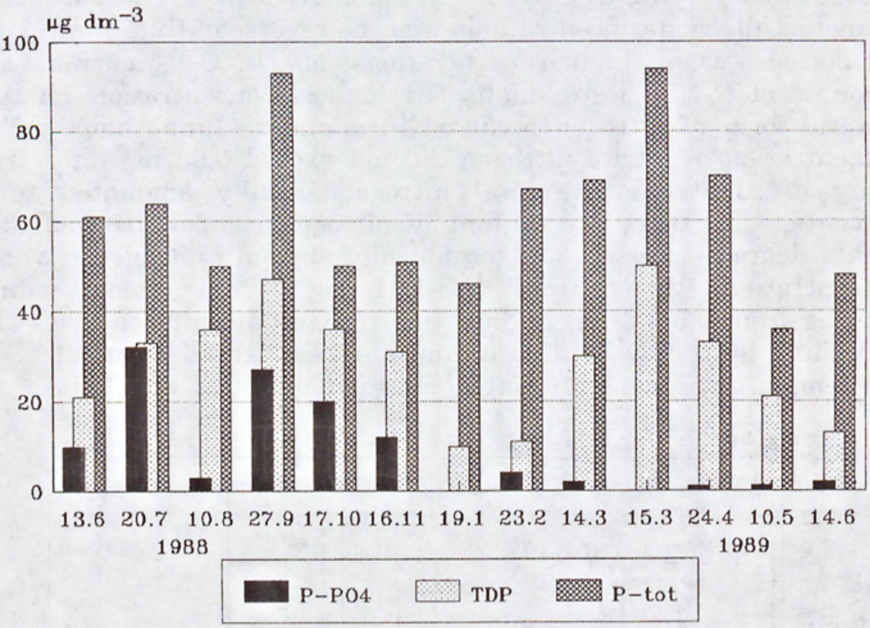

Fig. 4. Concentrations of various phosphorus forms. TdP - total dissolved phosphorus

An electrical conductivity of 268 μS cm^{-1} suggested a moderate content of mineral components in the water of the reservoir. Calcium was among the dominant cations in the water, its content reaching 34 mg Ca dm^{-3}. In general, small amounts of magnesium, chlorides, and iron were found here: 5 mg Mg dm^{-3}, 21 mg Cl dm^{-3}, 0.23 mg Fe dm^{-3}, respectively.

Fairy large amounts of chlorophyll *a* were determined (7.3-34.8 μg dm^{-3}), two maxima being encountered, one in late summer (34.8 μg dm^{-3}) and the other in early spring (24.7 μg dm^{-3}) (fig. 5.).

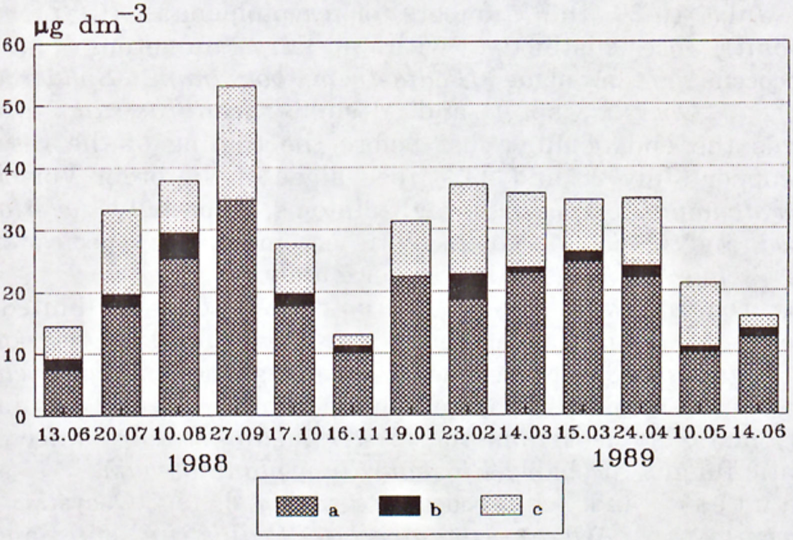

Fig. 5. Chlorophyll content

4.2. Phytoplankton

Early summer 1988 was characterized by a more abundant development of some algae, represented by several thousand (*Aphanizomenon flos-aquae, Melosira granulata* var. *angustissima*) or tens of thousands (*Cyclotella comta*) of individuals in 1 dm^3 water (fig. 6).

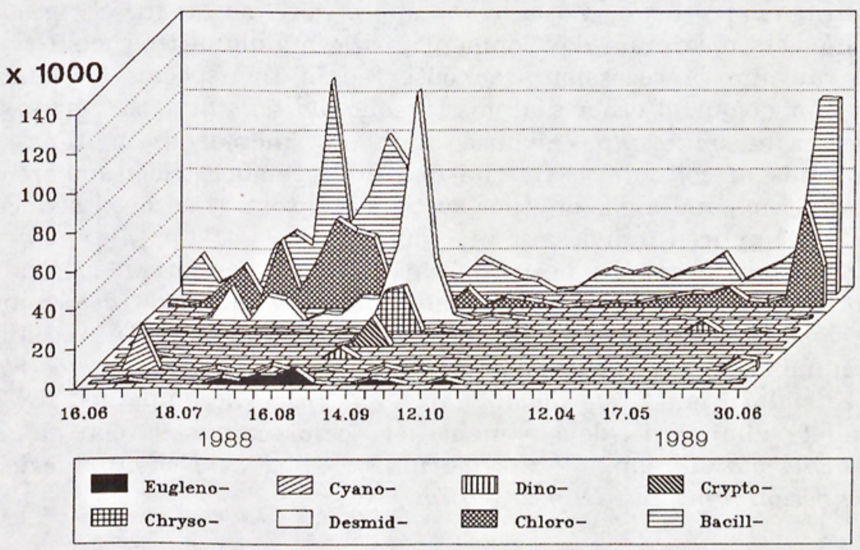

Fig. 6. Dynamics of numbers within main algal groups

From July 10-20 the numbers of cryptomonads (*Cryptomonas marssonii*) rose distinctly, with a fairy numerous share of chlorococcus green algae (*Pediastrum boryanum*, *Sphaerocystis schroeteri*, *Oocystis* spp.) and desmids (*Staurastrum gracile*). Towards the end of July, just before the coating of the reservoir with copper (July 28 and 29), green algae of the order Volvocales, *Chlamydomonas epiphytica*, and diatoms, especially *Asterionella formosa* and *Cyclotella comta* with accompanying species of the genus *Cyclotella*, occurred in greater numbers.

The coating with copper to a certain degree limited the development of algae; nevertheless already about 10 August some of them began rapidly to regenerate. Among them were *Cyclotella comta*, which attained some tens of thousands of cells per dm^{-3} of water, markedly less numerous *Asterionella formosa*, infected by parasitic fungus (probably *Rhizophydium planktonicum*

Canter), and chlorococcus green algae (*Oocystis* spp., *Coelastrum* spp., *Asterococcus superbus*, *Pediastrum* spp., and the genus *Scenedesmus* with the most abundant species composition). At that time they were accompanied by fairy numerous euglenoids (*Trachelomonas* spp. and *Euglena proxima).*

At the turn of August cryptomonads began to dominate, with *Cryptomonas marssonii* as the most numerous species, which on later dates occurred together with *C. erosa*. During the period 1-10 September a fairly abundant occurrence of the yellow-brown alga *Pseudokephyrion schilleri* and increased numbers of desmids (*Staurastrum gracile*, *Cosmarium* spp.) were observed. *S. gracile* attained its maximum development in the middle of this month.

In autumn a recession was observed of the species *Cyclotella comta* in favour of other diatoms (*Stephanodiscus hantzschii* and *S. astrea* var. *minutulus*) whose numbers increased to tens of thousands of cells dm^{-3}. By the end of December the numbers of both diatoms and algae of other systematic groups had been reduced to a few hundred individuals in 1 dm^3 water.

In samples from the period of early spring 1989 other species of diatom (besides those mentioned above, *Synedra acus* and *Asterionella zasuminensis*) occurred in small numbers. To mid-May the numbers of *Cyclotella comta* with accompanying *C. chaetoceras*, *C. catenata*, and *Asterionella formosa* rose, accompanied by a parallel abundant development of chlorococcus green algae (*Scenedesmus* spp., *Coelastrum* spp., *Dictyosphaerium ehrenbergianum*, and *D. pulchellum*).

On further sampling dates the diatom *Melosira granulata* var. *angustissima* began to dominate. Its numbers gradually increased, reaching a maximum development between 10-20 June. The end of this month was characterized by a very abundant occurrence of two diatoms (apart from that quoted above, also *Stephanodiscus astrea* var. *minutulus*). Among accompanying species greater numbers of chlorococcus green algae *Ankistrodesmus* spp. (particularly *A. pseudomirabilis*, and *A. acicularis*), cryptomonads (as above), and blue-green algae (*Aphanizomenon flos-aquae* and *Anabaena flos-aquae*) were encountered.

The checking of the dynamics of algal development in the investigated reservoir was accompanied by analysis of chlorophyll content. In early summer increases in the numbers of diatoms, then cryptomonads, and partly chlorococcus green algae corresponded to an increase in the content of chlorophyll *a* and *c*, contrary to chlorophyll *b* whose amounts were very small in the annual cycle of the investigation (fig. 5).

Apart from the chief algal communities mentioned above, smaller numbers of blue-green algae, euglenoids, and chrysophytes were also found in the Goczałkowice Reservoir. Among these cryptomonads usually contain chlorophyll *a* and *c*, while chlorophyll *b* is absent in their chromatophores (besides other pigments characteristic for this group). In diatoms chlorophyll *a* is the main pigment, chlorophyll *c* occurring in trace amounts. In chromatophores of green algae chlorophyll *a* and *b*, in chrysophytes chlorophyll *a* dominate.

The end of summer was characterized by a more abundant occurrence of chrysophytes, whose share also led to an increase in the content of chlorophyll *a*. The highest values of this pigment were found in early autumn, when diatoms and cryptomonads prevailed in the plankton. The latter were encountered in almost all samples during summer and autumn, ensuring a stabilized ratio between chlorophyll *a* and *c*. In the following year diatoms and the green algae Chlorococcales prevailed in the phytoplankton communities, the former attaining their greatest numbers towards the end of June, this being correlated with the prevalence of chlorophyll *a*.

Interactions between the total numbers of different groups of algae were also computed. For Cyanophyceae, Cryptophyceae, and Dinophyceae no significant dependence was found even upon the biogenes nitrogen and phosphorus. In a multiple correlation (Fe, Si, NO_3, and PO_4) Euglenophyceae showed a weak negative dependence upon nitrates, $p < 0.091$. The relation was improved if an equation of linear regression on nitrates only was computed for this group of algae.

The numbers of euglenoids may be prognosticated using the formula:

$$N_{Euglenoids} = 1641 - 1770\ N_{NO_3},\ r = 0.63\ \ p < 0.026 \qquad (1)$$

where N is the number of euglenoids in 1 dm^3 and N_{NO_3} the concentration of nitrate nitrogen in mg dm^{-3}.

Diatoms showed no dependence upon silicon, nitrates, or phosphates.

In the Goczałkowice Reservoir the numbers of the Chlorophyceae population are to a sufficient degree illustrated by the equation:

$$N_{Greens} = 16\,270 - 141\,P_{PO_4} - 1.55\,N_{NO_3},\ r = 0.73 \qquad (2)$$

with units as in equation (1). The confidence of the coefficient associated with nitrates is $p < 0.011$, being slightly poorer for phosphates.

The numbers of desmids negatively affected the concentration of nitrates ($p < 0.044$) and silica ($p < 0.01$), but not leading to a reduction in phosphate content ($p < 0.07$). The respective regression equation has the following form:

$$N_{Desmids} = 1500 - 2210\,Si + 66\,P_{PO_4} - 1343\,N_{NO_3},\ r = 0.89 \qquad (3)$$

The computation of regression of Chrysophyceae numbers upon Si, Fe, PO_4, and NO_3 resulted in a coefficient of multiple correlation 0.78 and a very weak negative dependence upon nitrates: $p < 0.096$. The variables Fe, Si, and PO_4 being discarded, the dependence on nitrates became negative and highly significant ($p < 0.01$), while the correlation coefficient decreased to 0.70 only.

The results covering the annual cycle of the investigation in the Goczałkowice Reservoir show that:

- small centric diatoms prevailed in the phytoplankton, their demand for phosphorus exceeding that of pennate diatoms,
- the prevalence of small species in the communities of planktonic algae was correlated with a greater content of phosphorus, this affecting the composition of succession in the vegetation season,
- the formula of algal succession repeated in the reservoir confirmed the opinion that phosphorus is the main factor controlling the growth of diatoms and effecting their dominance over green or blue-green algae,

- the greatest content of chlorophylls *a* and *c* corresponded to the dominance of diatoms and cryptomonads,
- the occurrence of the latter was noted in almost all samples in the summer and autumn period, this being decisive for the stabilized ration between chlorophylls *a* and *c*.

4.3. Zooplankton

Rotifers formed decisively the largest systematic group in the reservoir. In summer their numbers were usually 1500 indiv. dm^{-3} and in spring about 3000. In autumn these numbers fell to about 200, and in winter to 20 indiv. dm^{-3}. The numbers of cladocerans ranged from 50-500 indiv. dm^{-3} from spring to autumn, decreasing to a few individuals per 1 dm^3 in winter. Their relative share in the structure of zooplankton was reduced to 1-5%, similarly as that of rotifers (5-20%) in favour of copepods, whose presence increased to about 75-90% in different periods of the winter.

The dynamics of changes in the numbers of rotifers was characterized by transitory increases, rarely longer than two weeks. In the investigated reservoir about 40% of rotifers showed the pattern of dynamics with one annual maximum in numbers. The remaining 60% represented the type of two maxima with more or less constant occurrence as dominants. The conditions of the first type were fulfilled by *Brachionus angularis*, *B. falcatus*, *B. diversicornis*, *Cephalodella gibba*, *Conochilus unicornis*, *Filinia longiseta*, *Keratella cochlearis cochlearis* and *K. c. tecta*, *Kellicotia longispina*, *Notholca frigida*, *Polyarthra euryptera*, and *Trichocerca stylata*. Two or more maxima occurred in the case of *Asplanchna priodonta*, *Conociloides natans*, *Keratella quadrata*, *Polyarthra minor*, *P. major*, *Synchaeta tremula*, *S. pectinata*, and *Trichocerca similis*, *Cephalodella gibba*, *Conociloides natans*, *Notholca frigida* (March), while *Trichocerca stylata* (December-February) reached their maximum development in winter and *Polyarthra dolichoptera* in March-April.

It was observed that *Bosmina coregoni* and *B. longirostris* practically did not occur simultaneously. When one of them reached numbers above 50 indiv. dm^{-3}, that of the other was markedly below 1 indiv. dm^{-3}. It seems that *Daphnia cucullata* and *D. hyalina* formed a similar pair. When the former reached numbers of about 100 indiv. dm^{-3}, *D. hyalina* individuals fell 10 times. *D. cucullata* was the only cladoceran in the reservoir whose numbers in summer underwent constant variations from almost zero to about 100 indiv. dm^{-3} in a more or less monthly rhythm. The following sequence of appearance of adult copepods in the reservoir was observed: *Cyclops vicinus* emerged in April, its diminishing numbers then being overlapped by the increasing occurrence of *Diacyclops languidus*, not numerous up to that time. On the turn of May *Eudiaptomus gracilis* occurred abundantly, followed by a short, about 10-day increase in the numbers of *Acanthocyclops robustus* and by *Mesocyclops leuckarti* and *Thermocyclops crassus* in the second part of that month. In autumn (October) the numbers of adult *Eudiaptomus gracilis* again rose. Increases in the occurrence of nauplii and copepodite stages preceded the appearance of adult individuals of both sexes by about 2 month.

In the successive years exchanges between certain species were observed. In 1988 *Keratella cochlearis cochlearis* occurred in scarce numbers while *K. c. tecta* developed abundantly. A reverse situation was observed in 1989. Similarly *Brachionus falcatus* occurred in great numbers in 1988 and was replaced by *B. angularis* and *B. diversicornis* in 1989.

The taxonomic structure of zooplankton showed a prevalence of rotifers over cladocerans and copepods (fig. 7). *Keratella cochlearis cochlearis*, *K. quadrata*, *Synchaeta tremula*, *Trichocerca similis*, and *Pompholyx sulcata*, of copepods *Thermocyclops crassus* and *Mesocyclops leuckarti*, and 2 species of cladocerans, *Bosmina coregoni* and *Daphnia cucullata*, occurred in greater numbers.

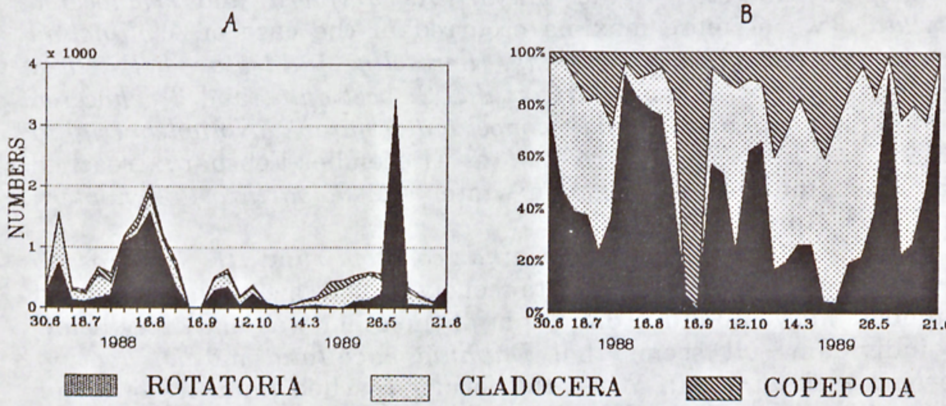

Fig. 7. Numbers of main taxonomic groups (A) and relative proportions of main zooplanktonic orders (B)

The numbers of rotifers, cladocerans, and copepods as a function of the numbers of the main algal groups were modelled by an equation of multiple regression. A highly significant dependence was obtained for rotifers (R=83) as depending on the numbers of euglenoids (E), green algae (G), and desmids (D).

$$N_{Rotifers} = 61 + 0.111E + 0.0114\,G - 0.0038\,D,\ P < 0.0000 \qquad (4)$$

the significance of independent variables were P < 0.0005, 0.0033, and 0.139, respectively.

Weaker dependences were obtained for copepods upon blue-green algae (BG), Chrysophyceae (Chrys), diatoms (Diat), and green algae (G):

$$N_{Copep.} = 159 - 0.0073\,BG - 0.00076\,Chrys - 0.0017\,Diat$$
$$+ 0.0045\,G \text{ with } r = 0.50\ ,\ P < 0.094 \qquad (5)$$

and the probabilities for independent variables P < 0.0178, 0.063, 0.119, and 0.037, respectively.

When blue-green algae and diatoms were discarded in the equation, the remaining variables were also non-significant. No dependence on the numbers of algae classified according to systematic groups could be found for the numbers of cladocerans.

The number of total zooplankton is the function of the numbers of three phytoplanktonic groups - euglenoids, green algae, and desmids:

$$N_{Zoop.} = 286 + 0.12\,E + 0.013\,G - 0.0049\,D$$
$$\text{with } r = 0.76\ ,\ P < 0.0000 \qquad (6)$$

and critical threshold probabilities for the successive variables are 0.0059, 0.016, and 0.089.

No significant dependence was found for the number of cladocerans.

5. Discussion

Water blooms (chiefly with the participation of planktonic blue-green algae) are a sign of progressing eutrophication of surface waters and a threat for water supply reservoirs. Their occurrence is decided by complex factors. According to data in the literature, the problem is controversial and in each situation investigations are necessary. In general, it is postulated that the factors responsible for water blooms are: constant high concentrations of nitrogen compounds in the water accompanied by an excessive content of phosphorus compounds (K a s z a, W i n o h r a d n i k 1986), even in periods of earlier intensive water blooms (e.g., the mass appearance of blue-green algae *Microcystis aeruginosa* in the Goczałkowice Reservoir in 1987, or with the participation of *Aphanizomenon flos-aquae* and *Gomphosphaeria compacata* in 1992 (B u c k a unpubl. data).

The concentration of chlorophyll is a reliable parameter in evaluating the eutrophication. It confirms the intensified eutrophy of waters in the Goczałkowice Reservoir, particularly pronounced in the midsummer and early autumn of 1988, when the highest concentrations of chlorophyll *a* coincided with periods of an intensive development of the phytoplankton, amounting to 7.3-34.8 μg dm^{-3}. B a r i c a (1981) gives greater values of chlorophyll *a* content (50 μg dm^{-3}) for eutrophic reservoirs with intensive water blooms and Secchi disc visibility of 1 m. In the Rybinsk Reservoir, whose trophy is less advanced, E l i z a r o v a (1973) recorded 3.5-9, 1.4-2, and 0.4-1 μg dm^{-3} for chlorophylls *a*, *b*, and *c*, respectively, during the vegetation season. On the basis she classified the reservoir in the mesotrophic type.

High concentrations of ammonia nitrogen in summer were associated with a fairy abundant development in the following time succession: first of blue-green algae and euglenoids, then diatoms, cryptomonads, and chlorococcus green algae.

The lowest concentration of phosphate phosphorus occurred in winter and early spring, while the content of total phosphorus increased more distinctly in early autumn and in spring. Changes in the content of phosphorus were reflected in the abundant development chiefly of diatoms. It should be stressed here that the evaluation of the effect of total phosphorus concentration on the development of phytoplankton in a water body is not precise and may be misleading. According to R i g l e r (1973) biologically assimilable phosphorus, i.e. dissolved organic or phosphate phosphorus, should be taken into account in this estimate.

In the period of increasing numbers of desmids reduced concentrations of nitrates and silica and at the same time high concentrations of phosphates in the water were observed. The content of mineral forms of nutrients chiefly depends on their inflow with water, mineralization processes, and the rate of assimilation. Large amounts of nutrients are differently utilized by primary producers, this being also connected with the type of reservoir (as, e.g. the limnic Goczałkowice Reservoir with 1-2 water exchanges annually).

Planktonic diatoms show a competitive ability chiefly with regard to nutrients which control growth (silicon, phosphorus, and nitrogen) (W i l l é n 1991). Periods when a high Si : P ratio in the water is noted are favourable for these organisms. The content of silica is a function of the size of cell. Small species of the genera *Cyclotella* and *Stephanodiscus* (the centric group), which require more phosphorus, are efficient competitors in the case of low concentrations of soluble reactive silicon (SRS), contrary to the genera *Nitzschia* and *Synedra* (the pennate group) which need relatively more SRS (T i l m a n et al. 1982). All pennate diatoms occur with a high Si : P ratio. In general, in freshwater ecosystems centric diatoms show a greater demand for phosphorus than the pennate species. The supply of silicon (SRS) and phosphorus ($P\text{-}PO_4$) has a strong effect on the rate of growth of many species. If larger amounts of phosphorus are available, the rate of growth of diatoms is intensified while the content of silica in their cells diminishes. A reverse process occurs when phosphorus is the growth limiting factor, this in turn bringing about a high SRS : $P\text{-}PO_4$ ratio (T h e r i o t 1987). Knowledge of the mutual relations of nutrients controlling the growth, i.e. silicon and phosphorus, explains not only the shifts in the succession of species in the communities of planktonic diatoms but also their dominance over blue-green and green algae and different groups of flagellates (W i l l é n 1991).

In the present study diatoms showed no dependence upon silicon, nitrates, or phosphates and the obtained negative relations with the probability of, successively, $p < 0.11$ and 0.15 should be regarded as a tendency suggesting exhaustion of nutrients.

Apart from the nutrients, one of the main factors regulating the development of diatoms is turbulence. The sequence of diatoms in a freshwater reservoir depends upon the degree of mixing of the water masses, only a certain number of species taking part in this process (R e y n o l d s 1980). In this connection M a r g a l e f (1978) divides the diatom microflora into two groups: one adapted to turbulence and the other to fairy high concentrations of nutrients. Owing to the progressing eutrophication of waters the content of silicon gradually decreases in relation to phosphorus and nitrogen (O f f i c e r, R y t h e r 1980).

The dominance of diatoms over green and blue-green algae occurs with a fairy high SRS : SRP ratio and an average temperature below 15°C (T i l m a n et al. 1982, 1986). The exhaustion of silicon might model the phytoplankton biocoenosis in the direction of blue-green algae and flagellates, since among their taxa some show the ability to develop in turbulent waters, poor light conditions, and low temperatures (Willén 1991).

According to Moegenburg and Vanni (1991), zooplankton affects phytoplanktonic communities by recycling nutrients, this being confirmed by these authors' studies in Lake Mendota, USA. With increasing biomass of the zooplankton there occurs a simultaneous increase in the excretion of nutrients, which reduce the deficiency of both nitrogen and phosphorus in the lake. The magnitude of defecation and excretion is the function of the size of animals. According to Elser et al. (1988), when a zooplankton community is dominated by larger animals, the phytoplankton shows a greater limitation by phosphorus and a smaller one by nitrogen.

Some diatoms may replace blue-green algae in conditions of high nitrogen and phosphorus concentrations in the water (Wang, Kang, Liu 1991). According to these authors, the species which are poor competitors in conditions of low phosphorus concentrations, begin to increase their competitive abilities with its rising content and will dominate over blue-green algae of large dimensions (e.g. *Microcystis aeruginosa*, *Anabaena flos-aquae*, and *Oscillatoria princeps*). In Lake Donghu species of small dimensions, the blue-green alga *Merismopedia glauca*, also *Cryptomonas erosa*, and some *Cyclotella* species being classified in their number, were poor competitors when the content of phosphorus was small. They began to dominate when it rose to a high level. The above data present almost the same pattern of succession as that found in the Goczałkowice Reservoir. Moreover, a biotic factor played a significant role here when an infection by a parasitic fungus attacked the diatom *Asterionella*, inhibiting its further development. The destruction of an entire population within 24 h by an analogical infection, which intensified in summer and autumn, was noted by Canter and Jaworski (1979) in lakes (the Lake District England). The destructive action of parasitic fungi is particularly severe in years with a mild winter (Donk 1983). In the present study of the dominants alternating throughout the year not one produced water blooms, since treatment with the algicide $CuSO_4$ in midsummer controlled this process. In consequence, a secondary more abundant development of diatoms and rapidly dividing chlorococcus algae, which showed varying responses to the changing environment, occurred in August. The maxima of their development showed a specific time dependence upon the content of nutrients, both mineral nitrogen compounds and phosphates, and hence upon the increasing chlorophyll content.

6. Polish summary

Wpływ czynników fizyko-chemicznych na dynamikę rozwoju fito- i zooplanktonu w Zbiorniku Goczałkowickim (Polska południowa)

W okresie badań Zbiornik Goczałkowicki był dobrze natleniony - ok. 13 mg O_2 dm^{-3} (ryc. 1). Miał niską przeźroczystość - w plosie średnia widzialność krążka Secchi'ego wynosiła 1.21 m (ryc. 2). Ilość azotu azotanowego nie przekraczała 1,1 mg dm^{-3} (ryc. 3). W okresie jesiennym przeważała forma azotu organicznego - 80%. Ilość fosforu wahała się od zera do 32 μg dm^{-3} (ryc. 4). Liczebność glonów określona globalnie, jako koncentracja chlorofilu *a* była dość wysoka 7,3-34,8 μg dm^{-3} (ryc. 5).

W fitoplanktonie z początkiem lata 1988 r. największe liczebności osiągnęły okrzemki, następnie kryptomonady, przy dość licznym udziale zielenic chlorokokkowych. Ich obfite występowanie poprzedziły licznie rozwijające się duże sinice, z towarzyszącą im dużą centryczną okrzemką *Melosira granulata* var. *angustissima* (ryc. 6). Bardzo licznie wystąpiły w tym składzie wrotki (*Polyarthra minor*, *P. major*, *Keratella quadrata*, *K. longispina*) i wioślarki (*Bosmina coregoni* i *Daphnia cucullata*).

Przeprowadzona z końcem lipca akcja miedziowania zahamowała rozwój glonów, które jednak szybko zaczęły się odradzać z początkiem sierpnia, zwłaszcza zielenice chlorokokkowe i okrzemki. Wśród tych drugich wzrost *Asterionella* został przerwany, w wyniku inwazji grzyba pasożytniczego.

W połowie lata pojawiły się eugleniny, jako glony towarzyszące, a z początkiem września złotowiciowce, wraz z potęgującą się liczebnością desmidii. W tym okresie glonom towarzyszyły wrotki (*Keratella cochlearis* f. *tecta*, *Polyarthra vulgaris*, *Trichocerca similis*, *Pompholyx sulcata*), wioślarki (*Daphnia cucullata*, *D. hyalina*) oraz liczne stadia kopepoditowe, naupliusowe i dorosłe *Mesocyclops leuckarti* i *Thermocyclops crassus*.

W jesieni *Cyclotella comta* została zastąpiona przez *Stephanodiscus hantzschii* i *S. astrea* var. *minutulus*. Towarzyszyły im *Synchaeta tremula* i *S. pectinata* oraz *Daphnia cucullata*, dorosłe *Eudiaptomus gracilis* i *Cyclops vicinus*.

Na samym początku wiosny 1989 r. skład zbiorowisk fitoplanktonu wzbogaciły swoim udziałem okrzemki, głównie z grupy pennate (*Synedra acus*), z towarzyszącą okrzemką *Asterionella zasuminensis*, a w dalszych terminach *Cyclotella comta* w zespole innych gatunków rodzaju *Cyclotella*.

Z początkiem lata, podobnie jak w poprzednim roku badań, na pierwszy plan wysunęła się populacja *Melosira*, przy znacznie mniejszym udziale zielenic chlorokokkowych i dużych wymiarów sinic (*Aphanizomenon flos-aquae* i *Anabaena flos-aquae*).

Okrzemki wykazywały brak zależności od krzemu, a także od azotanów i fosforanów. Liczebność populacji Chlorophyceae dała ujemną relację z fosforanami i azotanami. Liczebność desmidii rzutowała ujemnie na koncentrację azotanów i krzemionki, natomiast nie miała wpływu na zmniejszenie zawartości fosforanów. Współczynnik korelacji wielokrotnej liczebności Chrysophyceae od Si, Fe, PO_4 i NO_3 wynosił -0,78. Odrzucenie zmiennych Fe, Si i PO_4 spowodowało, że zależność od azotanów stała się ujemna i wysoce istotna.

Duży udział wrotków w strukturze zooplanktonu w okresie letnim oraz zmianę struktury na korzyść widłonogów, w okresie zimowym i wiosennym dokumentuje ryc. 7. 43% gatunków wrotków w tym zbiorniku posiadało jedno maksimum rozwoju w cyklu rocznym, a pozostałe dwa. Analiza następstwa poszczególnych gatunków wykazała, że unikają się wzajemnie *Bosmina coregoni* i *B. longirostris*, *Daphnia cucullata* i *D. hyalina*. W okresie zimy licznie występowały *Cephalodella gibba*, *Conochiloides natans*, *Polyarthra dolichoptera*, *Trichocerca stylata* i *Notholca frigida*.

Ustalono wysoce istotną zależność liczebności wrotków od ilości euglenin i zielenic. Liczebność copepoda zależała głównie od ilości zielenic i chrysofitów a bardzo słabo od okrzemek i sinic. Liczebność całkowita zooplanktonu zależała od ilości zielenic, euglenin i desmidii. Nie wykazano istotnej zależności Cladocera od 8 grup fitoplanktonu.

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