EKOLOGIA POLSKA (Ekol. pol.)	36	1 – 2	245 – 260	1988

Jolanta EJSMONT-KARABIN, Teresa WĘGLEŃSKA

Hydrobiological Station, Institute of Ecology, Polish Academy of Sciences,
Leśna 13, 11-730 Mikołajki, Poland

Department of Hydrobiology, Institute of Ecology, Polish Academy of Sciences,
Dziekanów Leśny (near Warsaw), 05-092 Łomianki, Poland

DISTURBANCES IN ZOOPLANKTON SEASONALITY IN LAKE GOSŁAWSKIE (POLAND) AFFECTED BY PERMANENT HEATING AND HEAVY FISH STOCKING

ABSTRACT: The effect was determined of water heating and intensified pressure of phytophagous fish – silver and bighead carps, on the abundance and species composition of the zooplankton. A low level of numbers and small proportions of larger forms, found in this lake, especially of crustaceans, seem to indicate an impact of the intensive feeding of the phytophagous fish. Narrow variation in zooplankton numbers during the season and an early appearance of summer forms in the rotifer community indicate that the abundance and structure of the zooplankton of the lake are intensively affected by higher water temperatures.

KEY WORDS: Heated lakes, fish pressure, phytophagous fish, Rotatoria, Crustacea.

1. INTRODUCTION

The functioning of lakes included in thermal power-plant cooling systems depends not only on the degree to which their waters are heated, but also on the method of heated-water discharge into a lake and its subsequent spreading in it, the latter process being dependent on lake morphometry, depth and lake-bed shape (Ejsmont-Karabin and Węgleńska 1988). If heated waters are discharged seasonally, then during non-discharge periods a lake in principle functions as a normal, unheated lake, but when the discharge is switched on, it experiences a cataclysm – a sudden and total upheaval of the thermal conditions then of the biology. Thus the functioning of a lake is split up into two distinct, regularly occurring stages (Ejsmont-Karabin and Węgleńska 1988).

A different situation should, however, be found in lakes whose entire volume has for

many years been incessantly and intensively heated. There is no „recovery" stage in them, which suggests that changes brought about by the heating may be lasting changes that may even accumulate.

During the growing season the structure and abundance of the zooplankton of moderate-zone lakes undergo succession changes consisting in the replacement, as the lake water temperature rises, of cold water species, dominant in winter and spring, by warm water species (M i r a c l e 1977). This succession is modified by biotic factors – food structure and abundance and predator pressure. The course of succession is specific, related to the lake trophical type and repeated in successive years (P e j l e r 1975). In heated lakes, changes in the thermal regime are thus followed by changes of the main agents determining the nature of seasonal changes in the zooplankton. It may therefore be expected that the effect of heated waters on the zooplankton living in them will be most marked by disturbances in the course, natural to a lake type, of the seasonal succession of the zooplankton.

Since 1972, that is, when the herbivorous fish – the silver and bighead carps were first introduced into Lake Gosławskie, changes in the plankton of this lake, caused by its heated waters, coincided with those brought about by the activity of these fish. Judging from the size of their catches in 1978 (Fig. 1), the final stock of the silver and bighead carps was similar to that used in the experiment described by K a j a k et al. (1975). The authors of that paper found that by intensively feeding on the plankton the silver carp can reduce phytoplankton blooms and change the dominance relations in it towards an increasing role of the nannophytoplankton and decreasing proportion of blue-green algae. In cages stocked with silver carp at the rate of 1350 kg · ha^{-1}

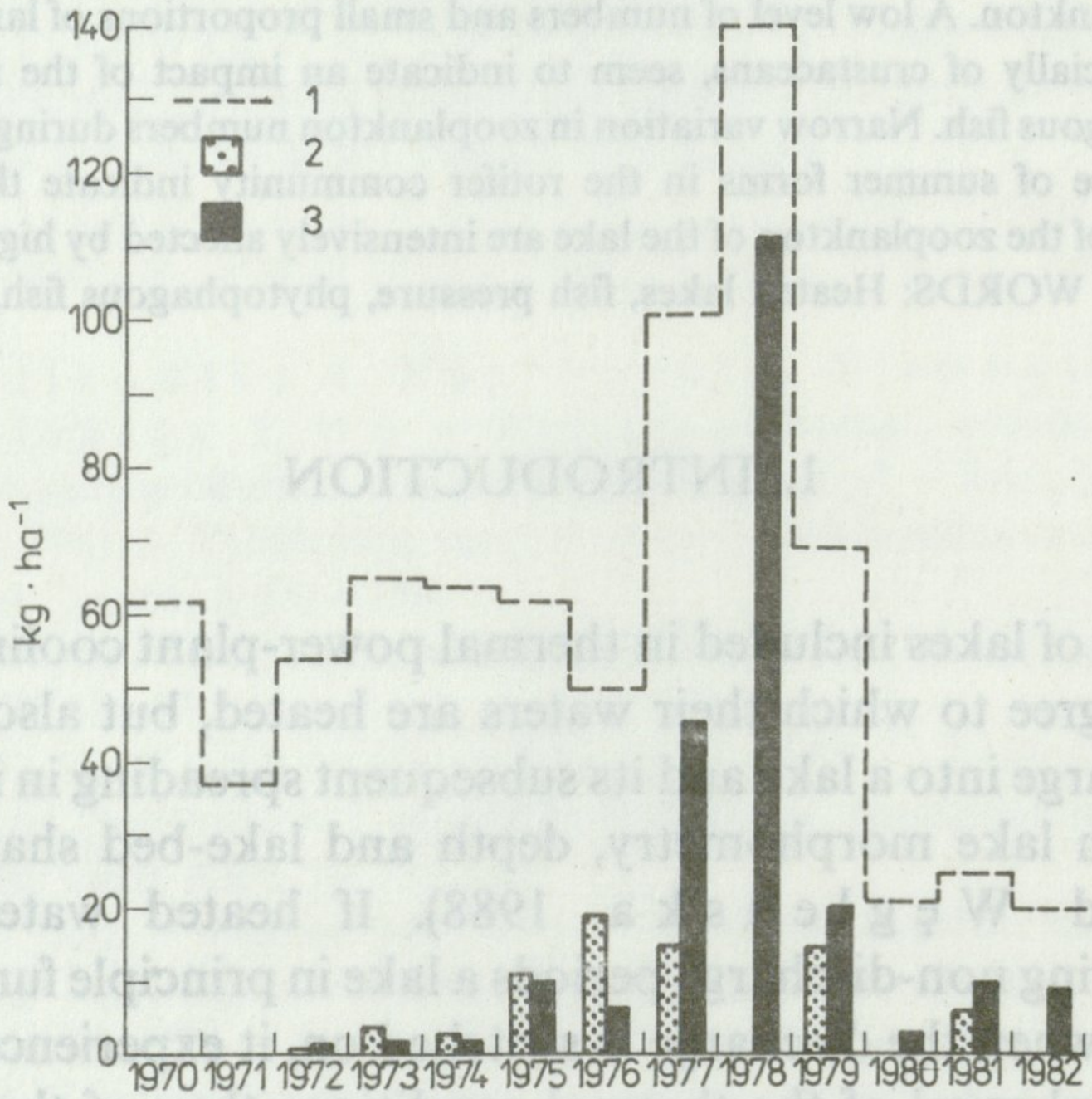

Fig. 1. Stocking of Lake Gosławskie with silver and bighead carps and their catches in relation to total catches including fish of low economic values: crucian carp, perch, bream, white bream, roach (B. Zdanowski – unpublished data)

1 – total catch, 2 – stocking with silver and bighead carps, 3 – catch of silver and bighead carps

zooplankton biomass was also lower, as much as 16 times. This decrease involved all zooplankton groups, although in cages with the highest fish stock the contribution of Rotatoria and Copepoda to zooplankton biomass increased, whereas that of Cladocera decreased. The presence of these herbivorous fish may therefore be expected to cause considerable changes in the structure and abundance of the zooplankton, by their direct pressure on it, as well as by an indirect effect – via changes in the zooplankton food supplies. The authors of the above paper also expressed their supposition that in heated waters the intensity of feeding of the silver carp and thereby its pressure on the ecosystem should be higher than in unheated lakes.

The impact of herbivorous fish on the zooplankton, manifested by lowered numbers of the latter, has already been observed many a time (e.g. Opuszyński 1978, Grygierek 1979). At the same time it has been found, however, that changes in zooplankton structure caused by the silver carp differ from those brought about by the bighead carp. The silver carp prefers phytoplankton, while the zooplankton eaten by it is dominated by rotifers and small cladocerans. If there is no animal food, this fish species can also feed on detritus (Omarov and Lazareva 1974, Opuszyński 1981). The bighead carp eats mainly large Cladocera and Copepoda, and in its diet zooplankton dominates over phytoplankton (Opuszyński 1969, 1981, Ciborowska 1972, Grygierek 1979). If both the silver and bighead carps are introduced, as in the case of Lake Gosławskie, then it must be expected that both will affect the whole lake plankton, and within it all zooplankton size groups.

To establish the effect of herbivorous fish pressure in a lake with permanently higher temperatures is one of the aims of this study concerned with the impact of higher water temperatures and an increased stock of herbivorous fish on the lake zooplankton. As the effects of these factors can not always be separated, they must in many cases be considered jointly.

2. STUDY AREA

Lake Gosławskie is part of the Konin lake complex consisting of five trough lakes between the valley of the Warta river and that of the Noteć river. The lake is included in the „small" cooling cycle of power-plant Pątnów that has been functioning since the middle of 1968, and since 1969 in full operation.

It is a eutrophic, shallow (maximum depth 3 m, average depth 1.3 m) pond-type lake, 378.9 ha in surface area. During the whole year heated waters of temperatures ranging from 30 to 35°C (temporarily up to 37 – 39°C) overflow into it through several spillways on its eastern bank. Water intake for the power plant is located in the western part of the lake. As a result, the whole lake is heated, its average water temperature being always 3 up to 5°C higher than natural temperatures.

Average temperatures for April and May varied considerably during the several years of studies (Table 1), but the changes were not directional. Summer temperatures were more stable, varying between 21.6°C in 1975 and 24.3°C in 1978, but no

Table 1. Water temperature (°C) in Lake Gosławskie in selected months of the period 1970–1984

Year	March	April	May	June	July/August	September
1970					22.0	
1972		14.0	20.0		24.2	
1973		11.1	18.8		22.5	
1975					21.6	
1978	13.4	13.5	16.6	19.5	24.5	16.0
1979					22.5	
1984		17.3	19.9		22.7	

temperature rise was recorded, in this case either, during the years of operation of the Pątnów power-plant.

From 1972 onwards Lake Gosławskie was stocked at an increasing rate with herbivorous fish – the silver and bighead carps. The highest introduction of these fish took place in 1976, and the highest catches were recorded in 1978 (Fig. 1). The level of stocking with the silver and bighead carps, and of their catches has been declining steadily since 1979. Catches of fish species other than the herbivorous ones, relatively high in the period 1970–1979, dropped drastically in the years 1980–1982, which coincided with the fish catch-size situation recorded for the other lakes of the Konin lake series (R o b a k 1985).

In 1978, comparatively high phytoplankton biomass values (3.7 to 102 mg per litre) were recorded for Lake Gosławskie. The dominant group was diatoms or nanno-phytoplankton, while the proportion of blue-green, and green algae and dinoflagellates was low (of the range of 5%) (S p o d n i e w s k a 1984).

3. MATERIAL AND METHODS

Seasonal variation of the zooplankton of Lake Gosławskie was studied in 1978. Samples were taken, at the deepest sampling station in the lake, every month with a 5-litre Bernatowicz-type sampler. Collected by 1 m depth steps, the samples were pooled together, condensed on a plankton net about 30 μm in mesh size and fixed with 4% formalin.

To find out whether the quantitative and qualitative zooplankton characteristics recorded in 1978 are not fortuitous but are fixed traits, or ones that undergo directional changes, data of 1978 were compared with those obtained from extensive studies carried out in Lake Gosławskie in the years 1970, 1972, 1973, 1975, 1978, 1979 and 1984. Comparisons were made for April and May, and for the turn of July. The sampling and sample-preparation methods used were the same as those for intensive studies.

Samples were analysed according to the methodology described in the papers by H i l l b r i c h t-I l k o w s k a and P a t a l a s (1967) and B o t r e l l et al.

(1976). All rotifers and crustaceans found in every sample were identified to the species. In the case of crustaceans the developmental stages were also considered.

In each sample 20 individuals of each rotifer species and of every developmental stage of each crustacean species were measured under the microscope. The wet weight of rotifers was calculated on the basis of the body length and breadth and body weight relationship described by R u t t n e r - K o l i s k o (1977). The biomass of crustaceans was calculated from their body-length to body-weight ratio, according to various references after H i l l b r i c h t - I l k o w s k a and P a t a l a s (1967).

4. RESULTS AND DISCUSSION

A relatively high phytoplankton abundance in Lake Gosławskie, recorded in 1978 (S p o d n i e w s k a 1984) seems to indicate also a high lake fertility. This is not, however, reflected in the total abundance of the zooplankton of that lake. This applies to both the rotifers, whose maximum number per litre does not exceed 1000 individuals being thus similar to the maximum quantities recorded for meso-eutrophic lakes, and crustaceans, whose average density is about 190 individuals per litre, and the maximum — 480 indiv.$\cdot l^{-1}$ (Fig. 2).

The above numbers are thus very low for the zooplankton of a shallow, fertile lake, especially when compared with the zooplankton densities in another shallow, fertile but heated seasonally (in winter) water body — Vasikkalampi pond (E l o r a n t a 1982). For in that lake the maximum rotifer numbers came up to over a dozen thousand individuals per litre of water during the hot-water discharge period (spring). However, the number of crustaceans in it was far lower, only about 2-fold higher than in Lake Gosławskie. Thus in the Vasikkalampi pond a much greater predominance of rotifers over crustaceans was recorded than in Lake Gosławskie.

Small also, relatively, was the variation in numbers of the rotifers of Lake Gosławskie during spring and summer (Fig. 2), from the minimum level of 346 indiv.$\cdot l^{-1}$ in May to the maximum — 976 indiv.$\cdot 1^{-1}$ in August (the ratio was thus less than 3). In this respect Lake Gosławskie highly differs from the Vasikkalampi pond. For in the latter very sharp peaks of numbers were found, of both individual species and rotifers as a whole (E l o r a n t a 1982). Strong and rapid changes in abundance were recorded in that pond also for the crustaceans, particularly for *Bosmina longirostris*.

Noteworthy in the species structure of the rotifers of Lake Gosławskie is a high dominance of practically two species: *Keratella cochlearis* and *Synchaeta kitina* throughout the study period (Fig. 2). So the pattern of seasonal succession, strong changes during the season in rotifer numbers and specific structure, typical of lakes, does not occur here.

Early in spring, dominant in the crustacean community (as in the Vasikkalampi pond — E l o r a n t a 1982) is *Bosmina longirostris*, in other months — Cyclopidae. The number of macrofilter-feeders (Diaptomidae, large *Daphnia* species) is noticeably low, in spite of the fact that the proportion of nannophytoplankton in the phytoplankton is so high that this crustacean group should be expected to pre-

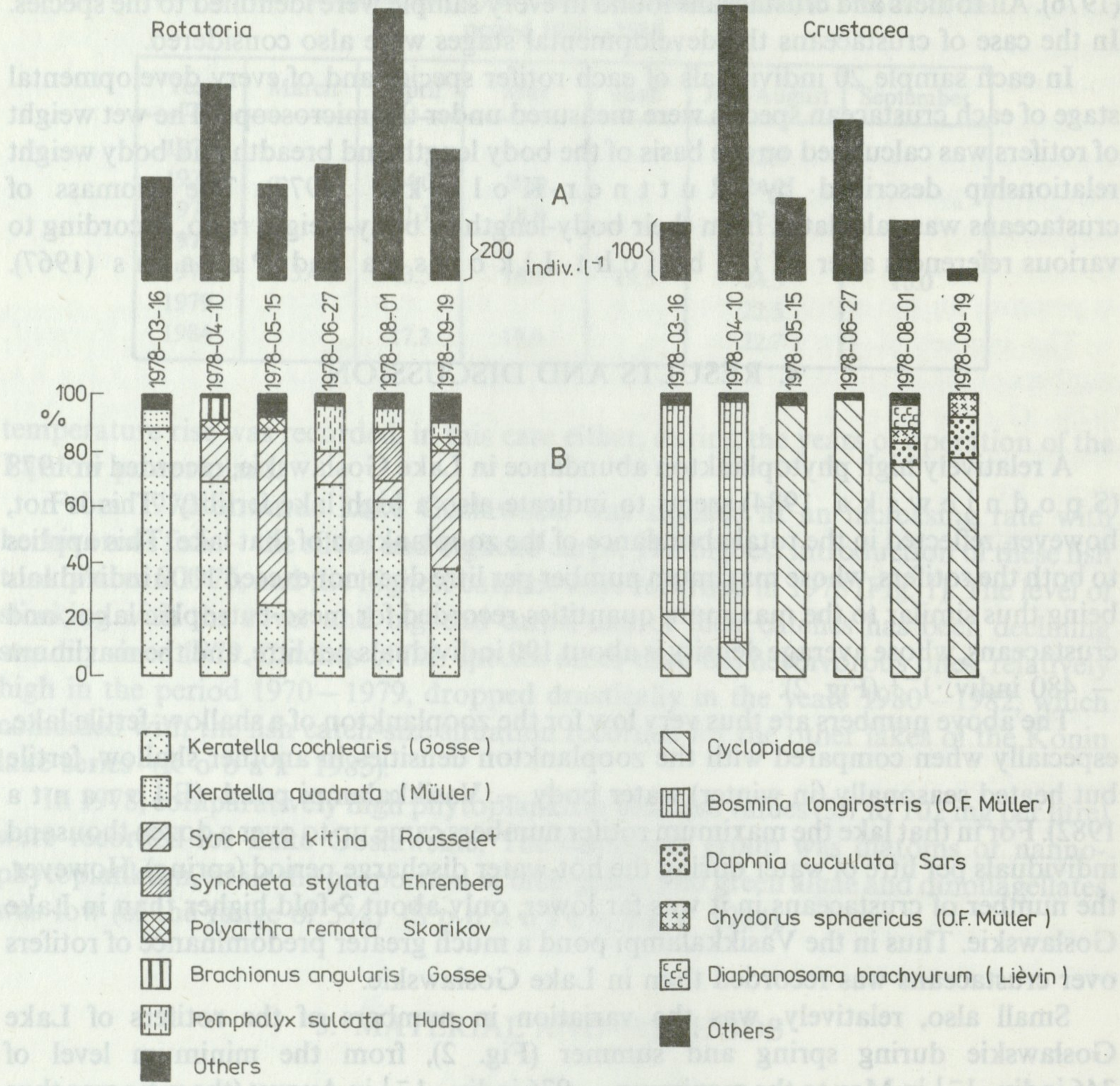

Fig. 2. Numbers (A) and proportions of dominant species (B) of Rotatoria and Crustacea in Lake Gosławskie in 1978

dominate. Here the supposition suggests itself that this may be the result of the pressure of the silver and bighead carps.

The non-typical course of the seasonal zooplankton succession seems to result from the influence of factors that are new to this water body: higher water temperatures, effects of the high stock of herbivorous fish. It was therefore necessary to find out when the zooplankton community observed in 1978 had been built. The numbers and structure of the 1978 community were also compared with those found six years later. The comparisons were made for periods most characteristic of the functioning of the lake – two spring months (April, May), and the period of highest temperatures – the turn of July (Fig. 3).

The comparison has demonstrated that, despite expectation, the low zooplankton

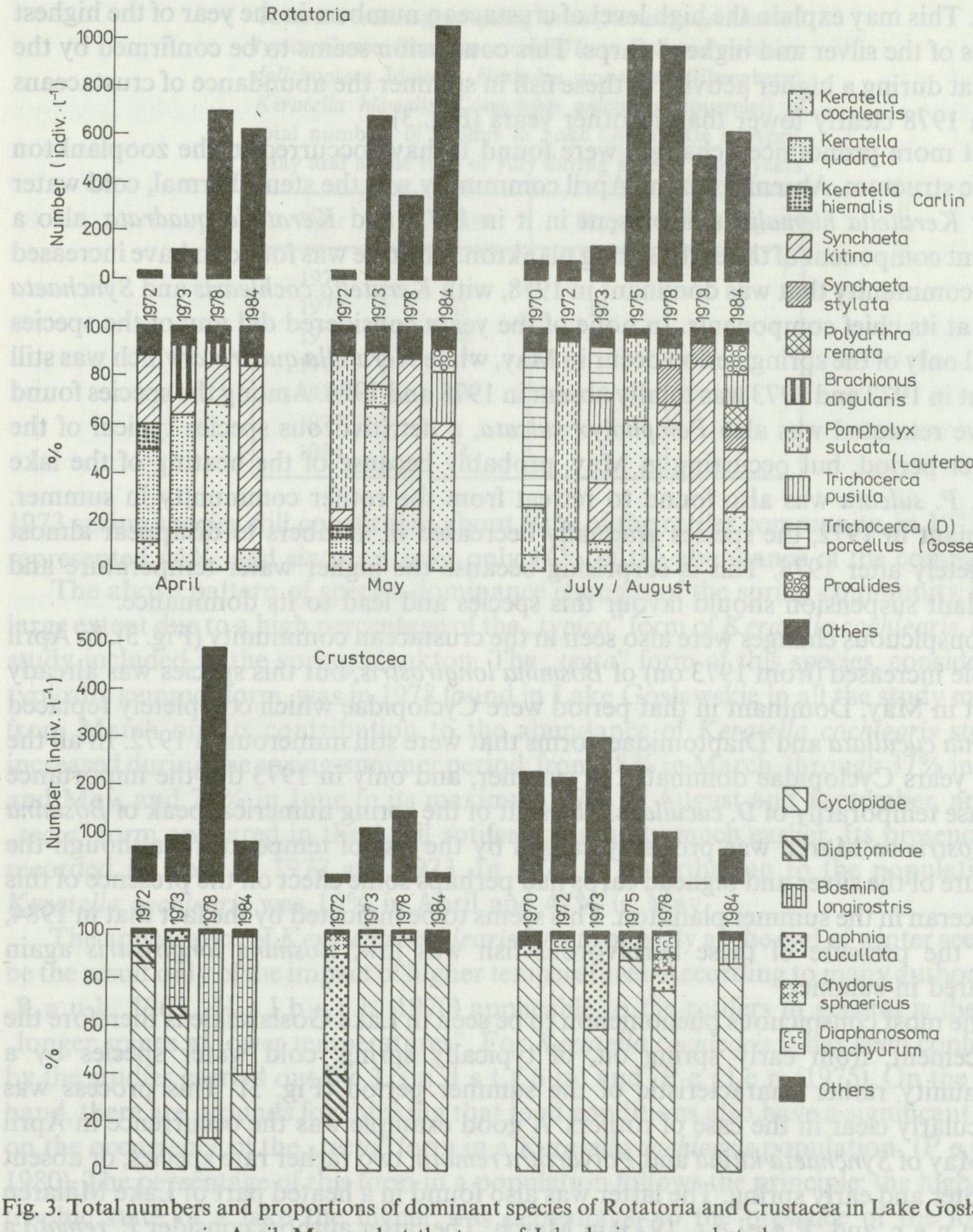

Fig. 3. Total numbers and proportions of dominant species of Rotatoria and Crustacea in Lake Gosławskie in April, May and at the turn of July during several study years

numbers of 1978 were not the results of their gradual decrease during the preceding years because in these years the numbers were even much lower. No reduction in zooplankton abundance was recorded following the introduction of the silver and bighead carps, either. Conversely, in the period 1973–1978 higher rotifer numbers were recorded than for the years 1970–1972. In the spring period of 1978 the abundance of crustaceans was even considerably higher than in the spring periods of other years, but the pressure of herbivorous fish on the zooplankton is also weaker in

spring. This may explain the high level of crustacean numbers in the year of the highest catches of the silver and bighead carps. This conclusion seems to be confirmed by the fact that during a higher activity of these fish in summer the abundance of crustaceans was in 1978 clearly lower than in other years (Fig. 3).

Yet more pronounced changes were found to have occurred in the zooplankton specific structure. Absent from the April community was the stenothermal, cold water rotifer *Keratella hiemalis,* still present in it in 1972, and *Keratella quadrata,* also a frequent component of the early, spring plankton. The role was found to have increased of the community that was dominant in 1978, with *Keratella cochlearis* and *Synchaeta kitina* at its chief components. In none of the years considered did any of the species typical only of the spring period occur in May, while *Keratella quadrata* which was still present in 1972 and 1973 was totally absent in 1978 and 1984. Among the species found to have retreated was also *Pompholyx sulcata,* a detritivorous species typical of the summer period, but occurring in May, probably because of the heating of the lake water. *P. sulcata* was also found to retreat from the rotifer community in summer. Dominant in 1972, the species gradually decreased in numbers to disappear almost completely after 1978. This is surprising because the higher water temperature and abundant suspension should favour this species and lead to its dominance.

Conspicuous changes were also seen in the crustacean community (Fig. 3). In April the role increased (from 1973 on) of *Bosmina longirostris,* but this species was already absent in May. Dominant in that period were Cyclopidae which completely replaced *Daphnia cucullata* and Diaptomidae, forms that were still numerous in 1972. In all the study years Cyclopidae dominated in summer, and only in 1973 did the importance increase temporarily of *D. cucullata.* The shift of the spring numerical peak of *Bosmina longirostris* to March was probably caused by the rise of temperature, although the pressure of the silver and bighead carps had perhaps some effect on the presence of this cladoceran in the summer plankton. This seems to be indicated by the fact that in 1984, when the pressure of these herbivorous fish was low, *Bosmina longirostris* again appeared in summer.

The most conspicuous phenomenon to be seen in Lake Gosławskie is therefore the replacement, from early spring on, of typically spring, cold water species by a community rather characteristic of the summer period (Fig. 3). This process was particularly clear in the case of rotifers. A good example was the occurrence in April and May of *Synchaeta kitina* and *Polyarthra remata,* two rather rare species, or absent in winter and early spring. The latter was also found in a heated part of Lake Mälaren (L a n n e r and P e j l e r 1973) in March. The latter authors consider *P. remata* a warm water stenothermal rotifer. They also mention that they have never found the species in winter before. The presence of *P. remata* already in April was also recorded by E l o r a n t a (1982) in the Vasikkalampi pond which is heated only in autumn and winter.

The process of disappearance of cold water forms from Lake Gosławskie has been illustrated in Table 2 where the proportion has been set out of „spring" forms in the total numbers of rotifers in 1972, 1973, 1978 and 1984. It is clear from the table that with the years of heating of Lake Gosławskie this proportion decreases. In April 1972 and

Table 2. Percentage of spring forms (*Keratella cochlearis* f. *typica* Gosse, *Brachionus calyciflorus* Pallas, *Polyarthra dolichoptera* Idelson, *Notholca acuminata* (Ehrenberg), *Keratella hiemalis, Conochilus unicornis* Rousselet) in total numbers of rotifers in Lake Gosławskie in April, May and at the turn of July during several study years

Year	April	May	July/August
1970			7
1972	61	19	3
1973	66	46	11
1975			6
1978	44	16	2
1979			1
1984	14	1	1

1973 spring species still constituted about 60% of the rotifer community, in 1978 they represented 44%, and six years later only 14% of the abundance of the community.

The above pattern of species dominance changes of the spring community is to a large extent due to a high percentage of the „*typica*" form of *Keratella cochlearis*, in this study included in the spring plankton. The „*tecta*" form of this species, considered a typically summer form, was in 1978 found in Lake Gosławskie in all the study months from March on. Its contribution to the abundance of *Keratella cochlearis* steadily increased during the spring-summer period: from 18% in March, through 37% in April and May, and 77% in June to its maximum 97% in August and September, and the „*tecta*" form appeared in the April rotifer community much earlier. Its presence was recorded in April in 1972 and 1973. In 1973 its contribution to the population of *Keratella cochlearis* was 16% in April and 47% in May.

The appearance of *Keratella cochlearis* f. *tecta* as early as the end of winter seems to be the result only of the impact of higher temperatures. According to many authors (e.g. R a u h 1963, H a l b a c h 1970) applicable to the rotifers in general is the rule: „longer spines at lower temperatures". For *Keratella cochlearis* it has been confirmed by the studies carried out by L i n d s t r ö m and P e j l e r (1975). On the other hand, there are grounds for thinking that food conditions also have a significant effect on the occurrence of the „*tecta*" form in a *Keratella cochlearis* population (P e j l e r 1980). The percentage of this form in a population follows the principle: the higher the trophic state of a lake the higher this percentage, so the presence of the form is considered a good indicator of the trophic states of lakes (K a r a b i n 1983). In polytrophic, shallow Loosdrecht Lakes in Holland, with blue-green algae as the dominant group, the „*tecta*" form is present throughout the year, also in winter, although its contribution to a *K. cochlearis* population is then small. In summing up these observations it may be assumed that the presence of the „*tecta*" form of *Keratella cochlearis* indeed depends on the trophic conditions, but even if these conditions are favourable for the occurrence of this form, it can only appear in a water body when the water temperature is not below a certain threshold; it is difficult to say what this threshold temperature is (probably slightly below 10°C).

In Lake Gosławskie, plankton changes clearly caused by rising temperatures must coincide with changes brought about by the introduction into it of the silver and bighead carps.

In shallow, polymictic lakes the introduction of these fish species was followed by a phytoplankton biomass growth, and a considerable proportion of the biomass was often contributed by blue-green algae (J a n u s z k o 1974, 1978, O p u s z y ń s k i 1978, K a j a k 1979). The effect of the silver carp on the phytoplankton, observed by K a j a k et al. (1975) in cages placed in a eutrophic and shallow Lake Warniak was manifested by phytoplankton structure changes towards the dominance of nanno-phytoplankton. Likewise, a high nannophytoplankton dominance was observed in Lake Gosławskie in 1978. It seems, however, that in this case the situation was brought about not so much by the action of the silver and bighead carps on the biocoenose as by the increased flow rate of the lake waters.

A high density of the silver carp can also cause a growth in detritus content due to larger quantities of fish faeces, and during periods of plankton food supply depletion, through an intensified bottom penetration (K a j a k et al. 1975), which, considering the small depth of Lake Gosławskie, may also cause a growth in detritus content in the water, even if part of it is eaten by the silver carp, intensively feeding on detritus when there is no animal food (O p u s z y ń s k i 1981).

Profusion of nannophytoplankton and detritus in a lake should favour the dominance of those zooplankton groups which are able to most efficiently utilize these two food sources. As regards Rotatoria, the above suggestion seems to be confirmed by the contributions, summarized in Figure 4, of individual groups of the zooplankton to its biomass.

K a r a b i n's (1985) classification of rotifers into trophic groups was used, according to which group I includes detritus-bacteria eaters, II and III – organisms of a various diet, feeding on detritus and bacteria and also on phytoplankton, group IV rotifers feeding on net algae, group V – species of the genus *Synchaeta,* feeding on net algae up to 50 μm in body size, and group VI – species of the genus *Polyarthra* whose diet includes only nannophytoplankton. Group VII rotifers, feeding on dinoflagellates have not been found in Lake Gosławskie.

The summary (Fig. 4) indicates that nearly throughout the year 1978 (except March) three trophic groups were dominant: I, V and VI, i.e., those rotifers which eat detritus or fine algae (nannophytoplankton and the smallest net algae forms).

A comparison of the percentages of individual trophic groups in rotifer biomass in the years preceding 1978 reveals gradual decline of wide-food-spectrum species, that is, those feeding on both detritus and algae (group III). However, the clear 3-group pattern, observable also in the following years, appeared after 1975.

Changes in the trophic structure of the crustaceans were less distinct (Fig. 4). In 1978, „inefficient" microfilter-feeders, eaters of detritus and the finest algae, were dominant in March and April, due to the dominance in this period of *Bosmina longirostris* (Fig. 2), and were permanently present, though not very abundant, in other months. But the percentage of predators was small, mainly predatory stages of Cyclopoida eating net algae in addition to zooplankton. The contribution to the

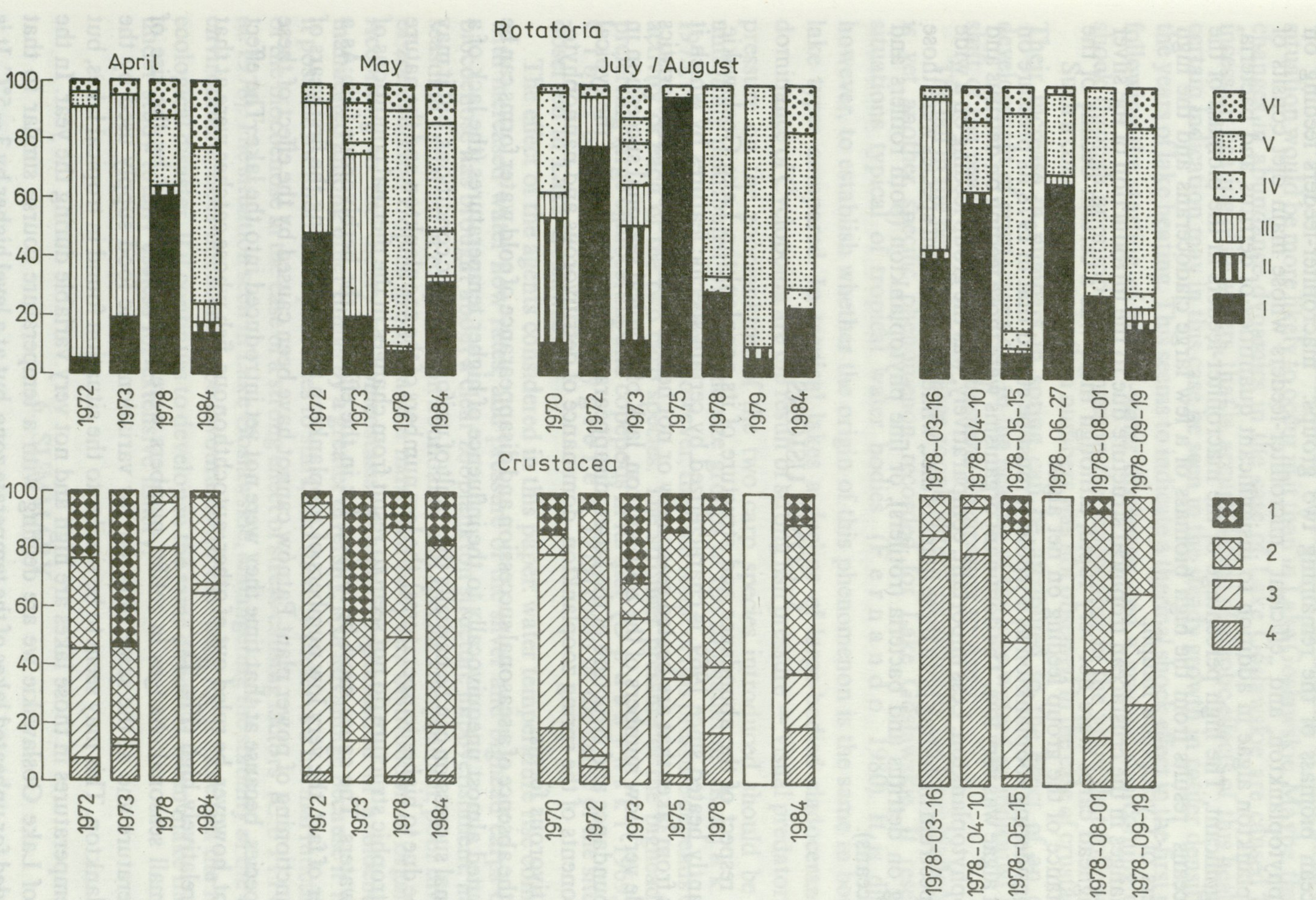

Fig. 4. Percentages of trophic groups (I – VI) in the biomass of Rotatoria and Crustacea (for explanations see the text) in Lake Gosławskie in April, May and at the turn of July in 1972, 1973 and 1984 and in March, April, May, August and September 1978
1 – predators, 2 – macrofilter-feeders, 3 – "effective" microfilter-feeders, 4 – "ineffective" microfilter-feeders

crustacean biomass of the remaining two groups: macrofilter-feeders feeding on nannophytoplankton, and „efficient" microfilter-feeders whose main diet consits of nannoplankton algae in addition to insignificant quantities of detritus and bacteria, was significant. The high percentage of the macrofilter-feeders in the biomass of the crustaceans results from the high biomass of a few large cladocerans and the high numbers of Cyclopoida nauplii.

Changes in the crustacean trophical structure due to the introduction of the silver and bighead carps were not very rapid, although there was a certain decline of the importance of the group feeding on net algae.

Considering zooplankton as a whole, it must be stated that in 1978 its pressure on the net algae was very low. The dominant organisms were those feeding on detritus and nannophytoplankton. Less important, comparatively, was the group feeding on a wide food spectrum including both these items of diet, while the dominant species were those feeding on detritus and bacteria (rotifers), or fine phytoplankton (both rotifers and crustaceans).

5. CONCLUSIONS

In respect of the abundance and structure of its zooplankton Lake Gosławskie, constantly heated since 1969, is characterized by certain specific features by which it differs from lakes that are heated seasonally or not heated at all. These characteristics include very low numbers of the zooplankton, lack of a typical seasonal succession in the abundance and structure of the latter, disappearance from April on of the typical components of the spring zooplankton, dominance of detritivorous and nannophytoplanktivorous forms.

If the absence of a seasonal succession and disappearance of cold water forms can be attributed almost unequivocally to the influence of higher temperatures (the lack of a seasonal succession can be partially the result of uniform trophic conditions, but it may also be due to higher temperatures), the low numbers of the zooplankton and the nature of its trophic structure do not seem to result from changes in the thermal conditions of lake waters. The cause must be looked for in the effect of the herbivorous fish. As a matter of fact, the very low numbers of zooplankton recorded during the first years of the functioning of power plant Pątnów cannot have been caused by the effect of these fish species, because at that time they were not yet introduced into the lake. The effect cannot, however, be ruled out of other, autochthonous, fish whose catches were at that time relatively high (Fig. 1).

Small seasonal changes in rotifer numbers were probably caused by the rise of temperature and at the same time narrow variation in the food supply used by the zooplankton. This may seem to be similar to the situation found in tropical lakes, but the temperatures in those lakes are high and not very variable during the year. In the case of Lake Gosławskie we are dealing with a temperature course similar to that recorded for unheated lakes of the temperate zone, but at a level higher by 3 – 5°C. It is surprising, however, that in the Vasikkalampi pond, heated only in autumn and winter, no such small seasonal changes in the abundance of rotifers were observed (E l o-

r a n t a 1982), although on account of the manner of heating of that pond such a situation would be more likely to occur in it than in Lake Gosławskie. Maybe, the small changes in abundance dynamics in the case of Lake Gosławskie are caused by the incessant heating of its waters, that is, accumulation of abiotic effects of this heating. A certain indication may in this case be seen in the steady growth in rotifer density with the years of lake heating. This seems to indicate a thermal shock effect in the first period following the starting of heated-water discharge, and a gradual overcoming of this shock through appropriate changes in the biocoenose in the years that followed.

Such a conspicuous growth in numbers was not observed in the case of crustaceans. Their increase in numbers in spring can be attributed to the effect of an earlier development of crustaceans due to the heating of the lake waters, as indicated by the shift of the peak abundance of *Bosmina longirostris* to April.

The fall in the percentage of large zooplankters (particularly the large cladocerans) is yet another specific phenomenon recorded for Lake Gosławskie. It resembles situations typical of tropical water bodies (F e r n a n d o 1980). It is difficult, however, to establish whether the origin of this phenomenon is the same in both the lake types compared. In tropical lakes a decline of large-bodied cladocerans and dominance of Cyclopoida are the result of strong fish pressure – visual predators. The pressure on the zooplankton of the two carp species introduced should be more uniformly distributed over all the size groups of the zooplankton (K a j a k et al. 1975, G r y g i e r e k 1979). However, the final result of this pressure depends on the activity of each of the two carp species. The stronger pressure of the bighead carp, preferring large cladocerans and copepods in its diet (O p u s z y ń s k i 1969, 1981, C i b o r o w s k a 1972, G r y g i e r e k 1979) could be the cause of the situation observed in Lake Gosławskie.

The effect of the agents considered in this paper: water temperature rise combined with increased water flow rates, and pressure of the silver and bighead carps on the biocoenose has brought about a clear zooplankton structure impoverishment: narrow seasonal variation in zooplankton abundance and specific composition, poor diversity of zooplankton trophic groups, and a narrowed body-size distribution of organisms. According to the theory of homeostasis, a higher organization of a biocoenose, manifested among other things by a greater diversity, is of advantage because it makes it possible for alternative processes to start, and thereby preserve a normal functioning of the biocoenose in the case of a strong effect of stress-causing factors (C o l l i e r et al. 1978). The situation seen in Lake Gosławskie, endangering the stability of the whole environment, does not seem to be favourable for the lake, for it increases the risk of ecological disaster. If it continues to develop in the same direction, it can make the lake under study totally useless for extensive fishery.

6. SUMMARY

The aim of the research carried out in 1978 in Lake Gosławskie which is a shallow water body, continuously heated since 1969, was to determine the effect of incessant heating of the lake waters, their

accelerated flow and a high stock of phytophagous fish – the silver and bighead carps – on the abundance and structure of the zooplankton.

Though the phytoplankton of the lake was relatively abundant, the numbers and biomass of its zooplankton were not equally high (Fig. 2). Comparatively narrow zooplankton abundance variation was also recorded for the growing season, combined with a relatively stable zooplankton specific composition during the same season (Fig. 2).

A comparison of the zooplankton abundance and species composition recorded in April, May and at the turn of July 1978 with those recorded for the same months in the preceding and in the following years has shown that during the first years of operation of the power plant the abundance was extremely low and it increased with time. No zooplankton abundance fall was recorded after the introduction of the carps, either (Fig. 3).

A feature very characteristic of the lake under consideration was the replacement, from early spring onwards, of typically cold water species, spring species by zooplankter communities rather peculiar to the summer period. This phenomenon was particularly marked in the case of rotifers (Table 2). For this community a steady decrease was recorded, with elapsing time of lake heating, in the percentage of cold water species, and of the "*typica*" form in the *Keratella cochlearis* population.

In the period preceding 1978 a gradual decline was recorded for rotifer species feeding on a wider spectrum of food. As a result, in 1978 three trophic groups were dominant (I, V and VI) – organisms feeding on either detritus or fine algae (Fig. 4). No such clear differences could be seen as regards the crustaceans, although in this case, too, the introduction of the silver and bighead carps was followed by a reduction in numbers of the net-algae eater group.

The effect of the agencies considered in this paper: water temperature rise, water flow acceleration and introduction of silver and bighead carps resulted in a noticeable zooplankton structure impoverishment – reduction in zooplankton seasonal variation, narrowed trophic group diversity and body-size distribution. This can reduce the stability of the ecosystem, and thereby make it more vulnerable to equilibrium disturbances when it is under the influence of strong external factors.

7. POLISH SUMMARY

Celem badań, wykonanych w roku 1978 na Jeziorze Gosławskim, płytkim zbiorniku stale podgrzewanym od roku 1969, było określenie wpływu trwałego podgrzania wód, ich przyspieszonego przepływu oraz wysokiej obsady ryb roślinożernych – tołpygi białej i pstrej – na obfitość i strukturę zooplanktonu.

Stosunkowo wysoka obfitość fitoplanktonu tego jeziora nie przejawiła się w równie wysokiej liczebności i biomasie zooplanktonu (rys. 2). Odnotowano również stosunkowo małe wahania liczebności zooplanktonu w ciągu sezonu wegetacyjnego połączone ze względną stałością składu gatunkowego zooplanktonu w tym samym okresie (rys. 2).

Porównanie liczebności zooplanktonu i jego składu w kwietniu, maju i na przełomie lipca i sierpnia w roku 1978 z notowanymi w tych samych miesiącach w latach poprzedzających i następnych ujawniło, że liczebności te w pierwszych latach funkcjonowania elektrowni były niezwykle niskie i rosły w miarę upływu lat. Nie odnotowano również spadku liczebności zooplanktonu po wprowadzeniu tołpyg (rys. 3).

Zjawiskiem bardzo charakterystycznym dla badanego zbiornika było natomiast wypieranie, począwszy od okresu wczesnowiosennego, gatunków typowo wiosennych, chłodnolubnych przez zespoły zooplanktonu typowe raczej dla lata. Zjawisko to szczególnie wyraźnie występuje w przypadku wrotków (tab. 2). W zespole tym notuje się postępujący w miarę upływu lat podgrzewania jeziora spadek udziału gatunków chłodnolubnych, jak też formy *typica* w populacji *Keratella cochlearis*.

W okresie poprzedzającym rok 1978 zanotowano stopniowe zanikanie gatunków wrotków o szerokim spektrum pokarmowym, tak że w roku 1978 dominowały trzy grupy troficzne (I, V i VI) – organizmy odżywiające się bądź detrytusem, bądź drobnymi glonami (Fig. 4). Równie wyraźnych różnic nie da się zauważyć w przypadku skorupiaków, choć i tutaj po wprowadzeniu tołpygi nastąpił spadek znaczenia grupy odżywiającej się glonami sieciowymi.

Oddziaływanie rozpatrywanych w niniejszej pracy czynników: wzrostu temperatury wód i tempa ich przepływu, jak też introdukcja tołpygi doprowadziło do wyraźnego strukturalnego zubożenia zooplanktonu – jego małej zmienności sezonowej, niskiego zróżnicowania grup troficznych i zawężenia rozkładu wielkościowego. Może to powodować małą stabilność ekosystemu, a więc jego zwiększoną podatność na zachwianie równowagi w przypadku oddziaływania silnych bodźców zewnętrznych.

8. REFERENCES

1. Bottrell H. H., Duncan A., Gliwicz Z. M., Grygierek E., Herzig A., Hillbricht-Ilkowska A., Kurasawa H., Larsson P., Węgleńska T. 1976 – A review of some problems in zooplankton production studies – Norw. J. Zool. 24: 419–456.
2. Ciborowska J. 1972 – Pokarm ryb roślinożernych (*Ctenopharyngodon idella* Val., *Hypophthalmichthys molitrix* Val. i *Aristichthys nobilis* Rich.) hodowanych z karpiem w przesadkach I [The food of phytophagous fish (*Ctenopharyngodon idella* Val., *Hypophthalmichthys molitrix* Val. and *Aristichthys nobilis* Rich.) reared with common carp in fry ponds] – Rocz. Nauk roln. H, 94: 41–58.
3. Collier B.D., Cox G.W., Johnson A.W., Miller P.C. 1978 – Ekologia dynamiczna [Dynamic ecology] – Państwowe Wydawnictwo Rolnicze i Leśne, Warszawa, 533 pp.
4. Ejsmont-Karabin J., Węgleńska T. 1988 – Spatial distribution of the zooplankton and its population features in two lakes of different heated-water through-flow – Ekol. pol. 36: 203–230.
5. Eloranta P. V. 1982 – Zooplankton in the Vasikkalampi pond, a warm water effluent recipient in Central Finland – J. Plankt. Res. 4: 813–838.
6. Fernando C. H. 1980 – The freshwater zooplankton of Sri Lanka, with a discussion of tropical freshwater zooplankton composition – Int. Revue ges. Hydrobiol. 65: 85–125.
7. Grygierek E. 1979 – Plankton as an ecological indicator of the influence of farming measures on pond biocenosis – Pol. ecol. Stud. 5: 77–140.
8. Halbach U. 1970 – Die Ursachen der Temporalvariation von *Brachionus calyciflorus* Pallas – Oecologia, 4: 262–318.
9. Hillbricht-Ilkowska A., Patalas K. 1967 – Metody oceny produkcji i biomasy oraz niektóre problemy metodyki ilościowej zooplanktonu [Methods of estimating production and biomass and some problems of quantitative calculation methods of zooplankton] – Ekol. pol. B, 13: 139–172.
10. Januszko M. 1974 – The effect of three species of phytophagous fish on alga development – Pol. Arch. Hydrobiol. 21: 431–454.
11. Januszko M. 1978 – The influence of silver carp (*Hypophthalmichthys molitrix* Val.) on eutrophication of the environment of carp ponds. Part III. Phytoplankton – Rocz. Nauk roln. H, 99: 55–79.
12. Kajak Z. 1979 – The possible use of fish, especially silver carp – *Hypophthalmichthys molitrix* Val. – to overcome water blooms in temperate water bodies – Symp. Biol. Hung. 19: 77–86.
13. Kajak Z., Rybak J.I., Spodniewska I., Godlewska-Lipowa W.A. 1975 – Influence of the planktonivorous fish *Hypophthalmichthys molitrix* (Val.) on the plankton and benthos of the eutrophic lake – Pol. Arch. Hydrobiol. 22: 301–310.
14. Karabin A., 1983 – Ecological characteristics of lakes in north-eastern Poland versus their trophic gradient. VII. Variations in the quantitative and qualitative structure of the pelagic zooplankton (Rotatoria and Crustacea) in 42 lakes – Ekol. pol. 31: 383–409.
15. Karabin A. 1985 – Pelagic zooplankton (Rotatoria + Crustacea) variation in the process of lake eutrophication. II. Modifying effect of biotic agents – Ekol. pol. 33: 617–644.
16. Lanner M., Pejler B. 1973 – The effect of cooling water discharges on zooplankton in a bay of Lake Mälaren – Rep. Inst. Freshw. Res., Drottningsholm, 53: 31–33.
17. Lindström K., Pejler B. 1975 – Experimental studies on the seasonal variation of the rotifer *Keratella cochlearis* (Gosse) – Hydrobiologia, 2–3: 191–197.

18. Miracle M. R. 1977 – Migration, patchiness, and distribution in time and space of planktonic rotifers – Arch. Hydrobiol. Beih. (Ergebn. Limnol.), 8: 19–37.
19. Omarov M. O., Lazareva L. P. 1974 – Pitanie belogo tolstolobika v vodoemach Dagestana – Gidrobiol. Ž. 10: 100–103.
20. Opuszyński K. 1969 – Produkcja ryb roślinożernych (*Ctenopharyngodon idella* Val. i *Hypophthalmichthys molitrix* Val.) w stawach karpiowych [Production of plant-feeding fish (*Ctenopharyngodon idella* Val. and *Hypophthalmichthys molitrix* Val.) in carp ponds] – Rocz. Nauk roln. H, 91: 221–307.
21. Opuszyński K. 1978 – The influence of the silver carp *Hypophthalmichthys molitrix* Val.) on eutrophication of the environment of carp ponds. Part VII. Recapitulation – Rocz. Nauk roln. H, 99: 127–151.
22. Opuszyński K. 1981 – Comparison of the usefulness of the silver carp and the bighead carp as additional fish in carp ponds – Aquaculture, 25: 223–233.
23. Pejler B. 1975 – On long-term stability of zooplankton composition – Rep. Inst. Freshw. Res., Drottningsholm, 54: 107–117.
24. Pejler B. 1980 – Variation in the genus *Keratella* – Hydrobiologia, 73: 207–213.
25. Rauh F. 1963 – Untersuchungen über die Variabilität der Radertiere. III. Die experimentelle Beeinflussung der Variation von *Brachionus calyciflorus* und *Brachionus capsuliflorus* – Z. Morph. Ökol. Tiere, 53: 61–106.
26. Robak S. 1985 – Charakterystyka zmian warunków siedliskowych i troficznych oraz połowów ryb w podgrzanych jeziorach konińskich [Description of changes in habitat and trophic conditions and fish catches in heated lakes of the Konin lake series] – Wydział Ochrony Wód i Rybactwa Śródlądowego, AR-T, Olsztyn, 44 pp.
27. Ruttner-Kolisko A. 1977 – Suggestions for biomass calculation of plankton rotifers – Arch. Hydrobiol. Beih. (Ergebn. Limnol.), 8: 71–76.
28. Spodniewska I. 1984 – Biomass and structure of phytoplankton in Konin lakes in the years 1976–1980 – Ekol. pol. 32: 289–306.

(*Received 29 January 1987*)