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VARIATION IN THE STRUCTURE OF THE SUMMER ZOOPLANKTON OF FOUR LAKES DURING INORGANIC FERTILIZATION AND AFTER ITS CESSATION*

ABSTRACT: Summer zooplankton of four lakes was studied for 11 years. In the years 1971–1974 the lakes were treated with inorganic fertilizers (NPK) and then the fertilization was stopped. Significant changes indicating a higher trophic state could be seen in the years of inorganic fertilization in lakes with an initially low pH. The ceasing of fertilization resulted in an insignificant drop of the trophic state of the study lakes, the stronger the zooplankton initial response to inorganic fertilization, the greater the fall of the trophic state. This did not, however, cause the summer zooplankton communities to recover an abundance and structure level similar to that recorded in the control year (1970).

KEY WORDS: Lakes, fertilization, recovery, rotifers, crustaceans.

Contents

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1. INTRODUCTION

Of many ecosystem degradation signs lake eutrophication arouses the greatest, relatively, anxiety. For this reason, hydrobiologists become more and more interested in both the course of this process and its effects. One of the methods for studying the eutrophication mechanisms is based on eutrophication-simulating treatment. Generally speaking, it consists of two field experiment types. One of them consists in studying the response of isolated (by means of bags, or exclosures) ecosystem fragments to an enrichment with the basic eutrophication-causing substances such as, e.g., nitrogen and phosphorus compounds (Dickman and Efford 1972, Lean et al. 1975, DeCosta et al. 1983 and others). In the other method the response is studied of the whole lake to the nutrients introduced into it, usually once only, in a specified amount (e.g., Schindler et al. 1971, Schindler and Fee 1974, Schindler 1975, Węgleńska et al. 1975, Bnińska et al. 1976, LeBrasseur et al. 1978, Lundgren 1978, Persson 1978).

An equally important problem is to establish whether or not a lake ecosystem changed considerably due to a high initial nutrient dose recovers, i.e., returns to its initial state after part of the external nutrient input is cut off. In studies of the response of lakes to a partial reduction of nutrient input the features most often noted were changes in particular biocoenose parts, indicating a decrease in the productivity of the water body concerned (Ahlgren 1978, Cooke and Kennedy 1978), and it has been found that in this case different communities of water organisms may vary in their response (Andersson, Berggren and Hamrin 1975).

The aim of the present study was to assess changes that occurred in the summer zooplankton of four lakes, as a result of inorganic fertilization and its cessation. The paper presents the results of studies carried out in continuation of those began in 1970 (the control year), and carried on in the years 1971 – 1974 (when NPK treatment was applied). The effect of inorganic fertilization, used by the Inland Fisheries Institute in Olsztyn, on the lakes under study has been described in the papers: Węgleńska et al. (1975), Zdanowski et al. (1975, 1978), Bnińska et al. (1976), Zdanowski (1976, 1982), Bnińska and Zdanowski (1978), Ejsmont-Karabin et al. (1980), Hillbricht-Ilkowska and Zdanowski (1983). The present paper has been expanded relative to the previous ones by including the results from the studies carried out in the years 1975 – 1980, after ceasing the fertilization.

2. DESCRIPTION OF STUDY AREA AND EXPERIMENT

The studies covered four lakes of the Masurian Lakeland: Smolak, Piecek, Dgał Mały and Czarna Kuta, differing by their trophic states and morphometry (Table I).

For the fertilization effects to be well contrasted, the study lakes chosen were strongly differentiated as regards the trophic state. The lakes also showed certain differences in their thermal stratification (Table I).

Table I. General characteristics of the study lakes before inorganic fertilization

Parameters	Lakes			
	Smolak	Piecek	Dgał Mały	Czarna Kuta
Surface area (ha)	5.3	23.3	14.3	25.2
Depth (m) average	2.4	3.4	4.3	1.3
maximum	5.1	8.4	15.8	3.6
Oxygen conditions (summer)	major deficit in July	major deficit in June, July	no oxygen, H_2S from May to Sept.	periodic deficit
pH (mean) in water	4.6	6.6	8.0	8.2
Mixis	dimictic	dimictic	dimictic	polymictic
Percentage of littoral zone overgrown with macrophytes	0	8.4	22.0	10.0
Fish yield ($kg \cdot ha^{-1}$)	2.0 (perch-pike)	2.5 (bream)	80.5 (bream)	115.5 (bream, carp)
Other information	a mid-forest lake	no inflows and outflows	located in a deep valley surrounded by sandy hills overgrown with a coniferous forest, the area at the inflow and outflow is lower and wet	small inflows (sewage from the village of Kuta and waters from pastures and meadows) and an outflow

The above-mentioned four lakes were studied in four stages:

Stage I covered the year 1970, the control year, in which the lakes were not treated. According to S a l a z k i n ' s (1976) classification, two of the lakes, Dgał Mały and Czarna Kuta, were eutrophic, neutral-alkaline, Lake Smolak was oligotrophic, mesoacid, and Lake Piecek – eutrophic, oligoacid.

Stage II – 1971 – 1974; in each of these years nitrogen- and phosphorus-containing fertilizers were introduced into all the lakes three times: in May, June and July. Treatment with potassium-containing fertilizers was applied once a year – in May: Lake Piecek was the only lake not treated, because of its high potassium content in the waters. Liming of the two dystrophic lakes (Smolak and Piecek) was applied in winter, on the ice cover.

The theoretical concentrations of nutrients after their being dissolved in the water should amount to 4 mg K, 1 mg N, 0.1 mg P and 40 mg Ca in one litre of water (Zdanowski 1976). Annual doses expressed in $g \cdot m^{-2}$ amounted to 0.3 – 0.9 for phosphorus and 3.9 – 10.9 for nitrogen (Hillbricht-Ilkowska and Zdanowski 1983), being much higher than the dangerous loading rates given by Vollenweider (1968) for shallow lakes with a long retention time.

The inorganic fertilization applied caused a generally considerable increase in Ca content and a pH rise to the neutral-alkaline value in lakes originally dystrophic, a growth of P tot. and N tot. concentrations in the first year of treatment (when the phytoplankton showed a weak response to fertilization) and a decrease in the following years, but the values continued to be higher than in the control year (Hillbricht-Ilkowska and Zdanowski 1983). The most intensive changes in phytoplankton production and chlorophyll content were recorded for Lake Smolak: in the years 1971, 1972, there occurred a growth, and in the years 1973, 1974 a decrease in the values of both parameters. In Lake Piecek a growth in phytoplankton production and chlorophyll content was seen in the second year of fertilization. In Lake Czarna Kuta, on the contrary, signs of lake degradation were observed (primary production decrease and retreating of submerged macrophytes) (Zdanowski et al. 1978).

Zooplankton response was also more conspicuous in originally poorer lakes. Though a growth in numbers of the zooplankton in fact occurred in all the lakes, the greatest changes in its density and structure were recorded for Lake Smolak. The changes were caused by two factors – changes in the pH and in the trophical state of the lake. After the four years' fertilization the zooplankton of the study lakes appeared to be more uniform in respect of density and structure (Ejsmont-Karabin et al. 1980).

In the last treatment year Zdanowski (1976) classified the lakes under study on the basis of primary production values as follows: Lake Piecek – a highly productive (polytrophic) lake, lakes Smolak and Dgał Mały with a medium production level – eutrophic, Lake Czarna Kuta – after a two-year decrease in productivity, polytrophic again.

Stage III – covering the years 1975 – 1980 when inorganic fertilization was stopped. The objective of the studies carried out at this stage was to analyse the ability of aquatic ecosystems to withdraw a part of the nutrients from the cycle, and to determine the time the study lakes needed to recover their original state as estimated in 1970. High pH levels (above 7.0) stayed in the lakes under study until the end of the studies (Zdanowski et al. 1978, B. Zdanowski – unpublished data). In the summer periods of the years 1975 – 1980 N tot. concentrations were always below the control year level in the study lakes (Fig. 1). P tot. concentrations were in the years 1975 – 1979 in general lower than in the control year, especially in Lake Czarna Kuta. In 1980, the summer P tot. concentrations rose in all the study lakes. As a result, in lakes Piecek and Dgał Mały these concentrations clearly exceeded in that year the control year level (Fig. 1).

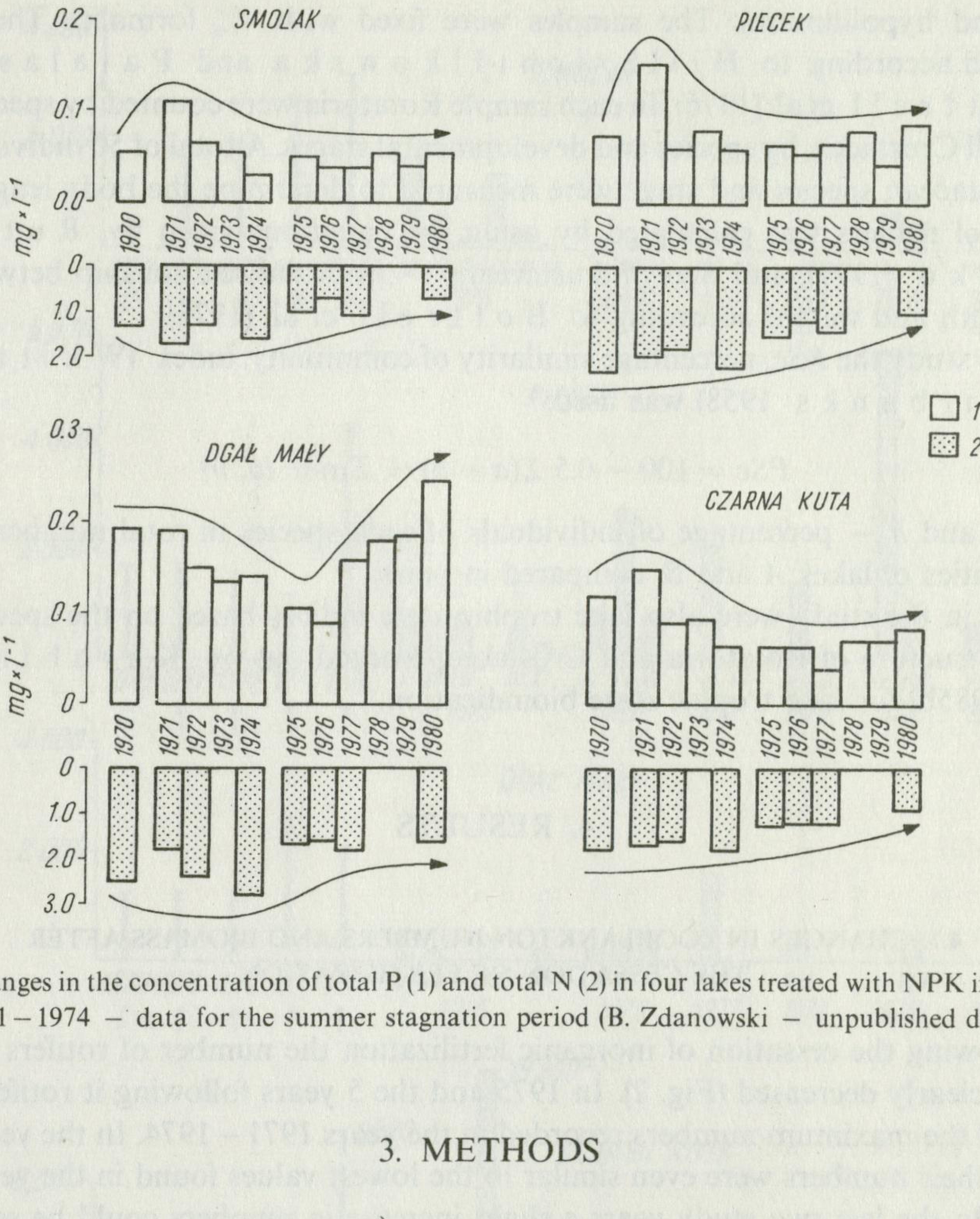

Fig. 1. Changes in the concentration of total P (1) and total N (2) in four lakes treated with NPK in the years 1971 – 1974 – data for the summer stagnation period (B. Zdanowski – unpublished data)

3. METHODS

In the years 1975 – 1980, zooplankton samples were collected in the study lakes 1 – 6 times a year. However, data used for further analyses, were obtained from studies of the summer zooplankton collected during the summer stagnation, usually at the end of July or the beginning of August. Used for the purpose of comparison were also data relating to the summer zooplankton of the study lakes in the years 1970 – 1974. The results of all-year studies of that period have been published in the paper E j s m o n t-K a r a b i n et al. (1980).

Zooplankton samples were collected from the deepest site of each lake, using a 5-litre Bernatowicz sampler. In the shallower lakes (Smolak, Piecek, Czarna Kuta) samples were collected at one-metre intervals, from the surface down to the bottom. They were then pooled and condensed by means of a plankton net (about 60 μm in mesh diameter). From Lake Dgał Mały, which is thermally stratified, samples were collected every 1 metre and pooled separately for each of the two layers: from the surface to the depth of 7 m (epilimnion) and from the depth of 8 m to the bottom (meta- and hypolimnion). The samples were fixed with 4% formalin. They were elaborated according to Hillbricht-Ilkowska and Patalas (1967) and Bottrell et al. (1976). In each sample Rotatoria were counted by species, and so were all Crustacea, by species and developmental stages. A total of 50 individuals of each crustacean species and stage were measured to determine the body length. The biomass of rotifers was calculated by using the equations given by Ruttner-Kolisko (1977), and that of crustaceans – from the relationship between the body length and weight according to Bottrell et al. (1976).

In the study the *PSc*, percentage similarity of community, index (Whittaker and Fairbanks 1958) was used:

$$PSc = 100 - 0.5\ \Sigma(a - b) = \Sigma\text{min.}\ (a, b)$$

where: a and b – percentage of individuals of each species in total numbers of the communities of lakes A and B, compared in pairs.

Used in the study were also lake trophic state indices based on the specific and trophic structure of Rotatoria and Crustacea, worked out by Karabin (1983, 1985a, 1985b) for lake trophic state bioindication.

4. RESULTS

4.1. CHANGES IN ZOOPLANKTON NUMBERS AND BIOMASS AFTER THE CESSATION OF FERTILIZATION

Following the cessation of inorganic fertilization the number of rotifers in Lake Smolak clearly decreased (Fig. 2). In 1975 and the 5 years following it rotifers never exceeded the maximum numbers recorded in the years 1971 – 1974. In the years 1976 – 1978, their numbers were even similar to the lowest values found in the years 1972 – 1974. In the last two study years a slight increase in numbers could be seen.

A similarly clear response did not occur in the remaining lakes (Fig. 2). In the years 1975 – 1980, changes in numbers of the rotifers varied, and did not seem to be directional. In Lake Piecek in the period concerned variations in numbers could be observed; in 1979, rotifer numbers attained a level typical of highly eutrophic lakes – about 5.7 thous. ind.$\cdot l^{-1}$. In Lake Dgał Mały in the years following the cessation of fertilization rotifer numbers were lower than during the last two inorganic-treatment years. In Lake Czarna Kuta, too, there occurred a decrease in rotifer numbers, but only in 1976. In 1975, the level of these numbers was very high; the highest value recorded amounted to about 19.8 thous. ind.$\cdot l^{-1}$, that is, a value typical of polytrophic water bodies. The decrease in rotifer numbers in this lake to a level below 1 thous. ind.$\cdot l^{-1}$ in the years 1976 – 1978 was followed by an increase in the following years to 6 – 7 thous. ind.$\cdot l^{-1}$.

It must be noted that since samples were collected twice a year, and in several cases once a year, the real abundance peaks may have been omitted. It seems, however, that

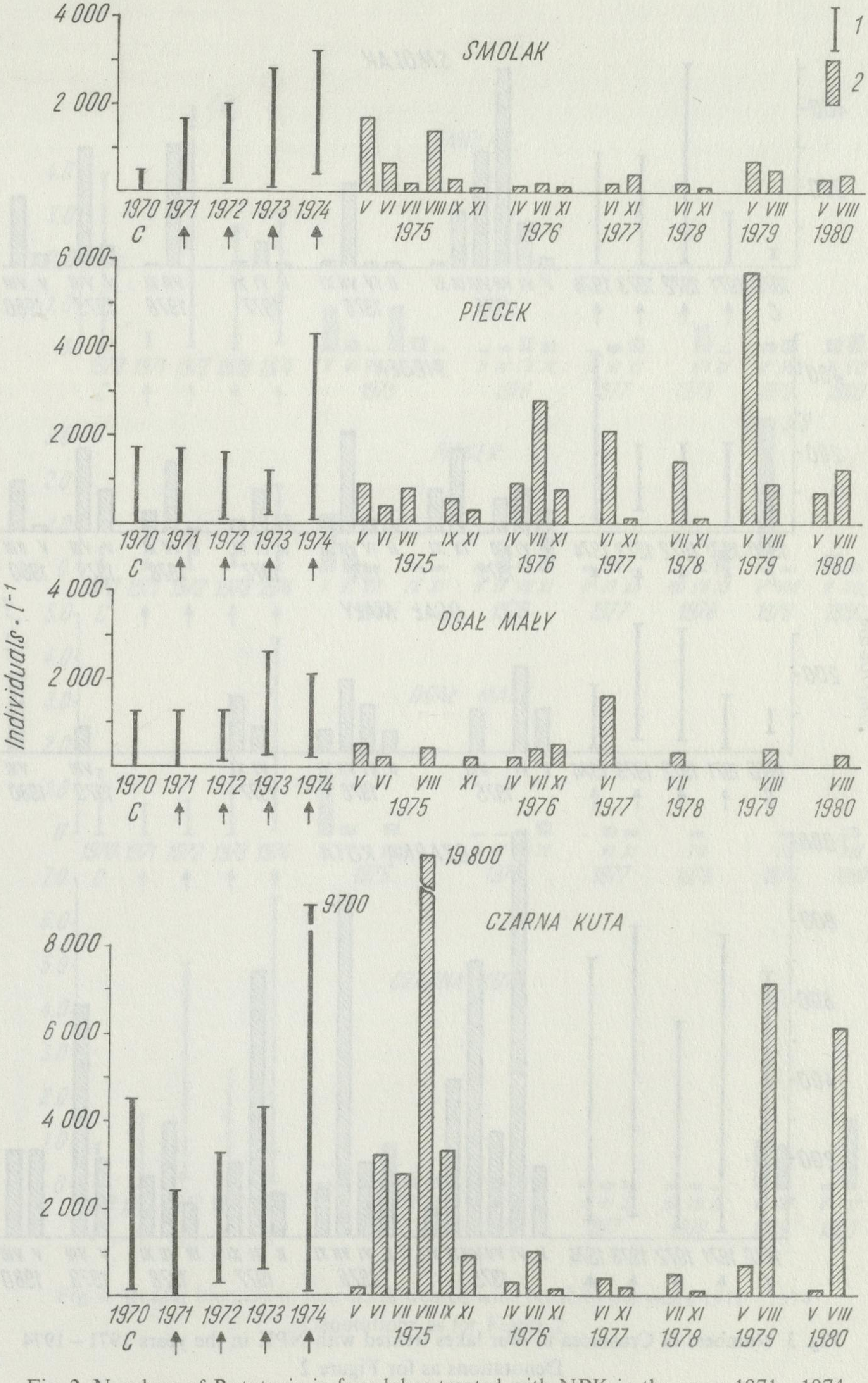

Fig. 2. Numbers of Rotatoria in four lakes treated with NPK in the years 1971 – 1974
C – control year, arrows indicate fertilization years, 1 – range of numbers encountered throughout the study season, 2 – data from particular sampling dates

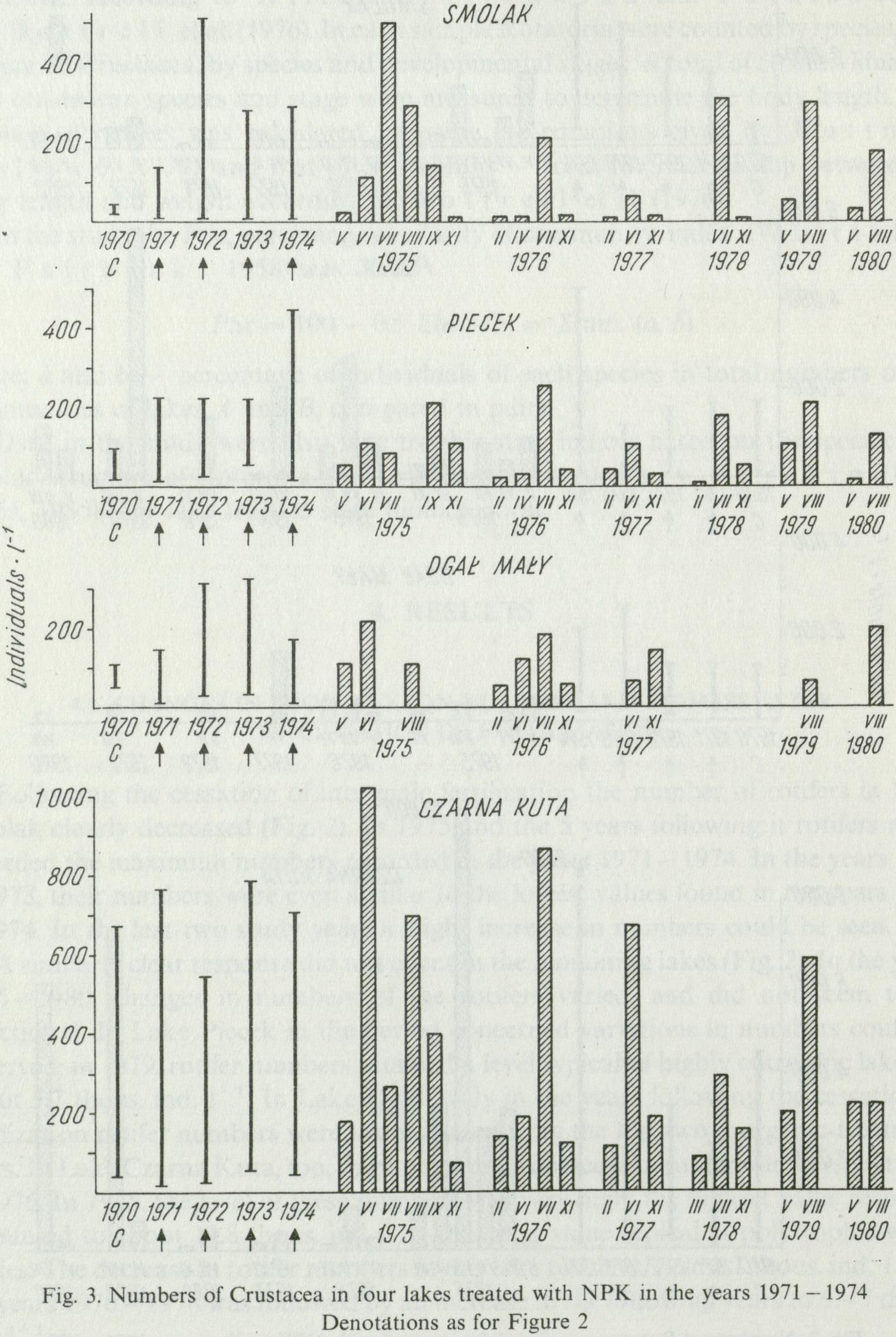

Fig. 3. Numbers of Crustacea in four lakes treated with NPK in the years 1971 – 1974
Denotations as for Figure 2

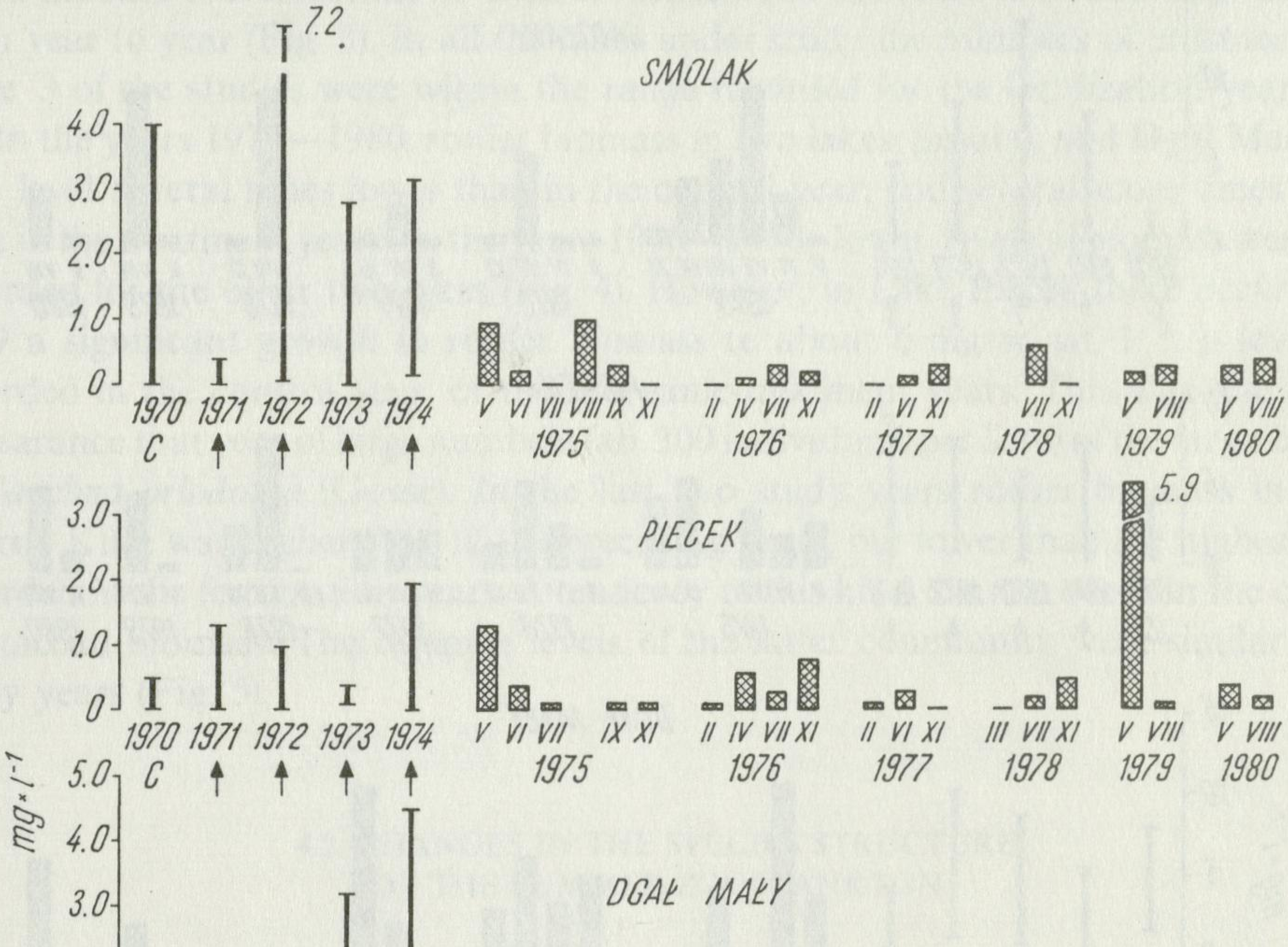

Fig. 4. Rotifer biomass in four lakes treated with NPK in the years 1971 – 1974
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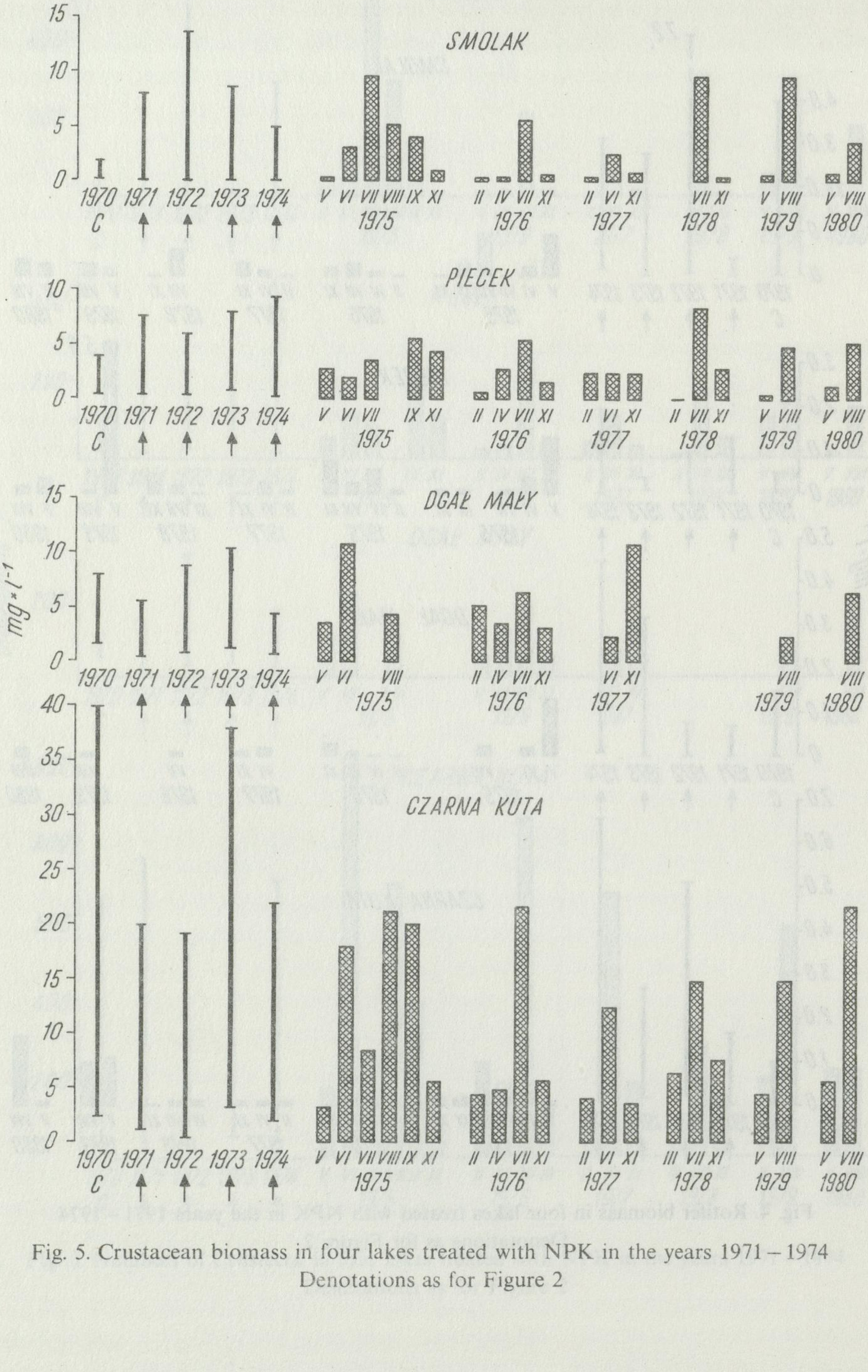

Fig. 5. Crustacean biomass in four lakes treated with NPK in the years 1971 – 1974
Denotations as for Figure 2

in spite of their being sketchy, these data may indicate certain tendencies in zooplankton abundance variation.

In the case of crustaceans no clear tendencies can been seen in abundance variation from year to year (Fig. 3). In all the lakes under study the numbers of crustaceans at stage 3 of the studies were within the range recorded for the fertilization years.

In the years 1976 – 1980, rotifer biomass in two lakes: Smolak and Dgał Mały was at a level several times lower than in the control year, and several score times lower than in the treatment years. In the years 1976 – 1978, lower levels of biomass were also recorded for the other two lakes (Fig. 4). However, in Lake Piecek there occurred in 1979 a significant growth in rotifer biomass to about 6 mg w. wt.$\cdot l^{-1}$, a level not recorded in the control year, or the inorganic-treatment years. This was due to the appearance that year of large numbers (ab. 300 individuals per litre) of the large-bodied *Asplanchna priodonta* (Gosse). In the last two study years rotifer biomass in Lake Czarna Kuta was higher than in the preceding years, but lower than the highest level recorded in the fertilization years. A tendency of this kind did not occur in the case of crustacean biomass. The biomass levels of the latter community were similar in all study years (Fig. 5).

4.2. CHANGES IN THE SPECIES STRUCTURE OF THE SUMMER ZOOPLANKTON

The most intensive changes were seen in Lake Smolak (Fig. 6). A complete change, due to fertilization, of the taxonomic structure of the rotifers, i.e., disappearance from the summer community of *Asplanchna priodonta* and *Gastropus stylifer* Imhof, dominant in 1970, was followed by an increase in the years 1971 – 1974 of the importance of the species of the genus *Polyarthra* (dominant temporarily were also other representatives, e.g., *Synchaeta* in 1971, *Anuraeopsis fissa* (Gosse) in 1972, species of the genus *Trichocerca* in 1973). In the last fertilization year *Keratella cochlearis* (Gosse) and *Polyarthra vulgaris* Carlin dominated. The cessation of fertilization in 1975 was followed by the appearance of *Conochiloides coenobasis* Skorikov, and in 1976 the importance of *Keratella cochlearis* increased. The proportion of the latter decreased steadily in the following years, so much so that in 1980 *Keratella* accounted for about 34% of the abundance of rotifers. Besides it there was *Conochilus unicornis* Rousselet (21%) and species of the genus *Trichocerca* (10%). Thus in each of the summer seasons under study there was a different rotifer community. The changes that took place at stage III of the studies, although drastic in nature, did not result in the formation of a summer community similar to that recorded in the control year.

Considerably less significant qualitative changes in the rotifer community were observed in Lake Piecek (Fig. 6). In the control year rotifers of the genera *Keratella* and *Trichocerca* were dominant in it. In the first fertilization year dominant in this community were already *Keratella* and *Pompholyx sulcata* Hudson, and in the next two years *Filinia longiseta* (Ehrenberg) and *Polyarthra vulgaris* appeared, whereas in 1974 *Pompholyx sulcata* was definitely dominant. The latter also persisted in the subsequent

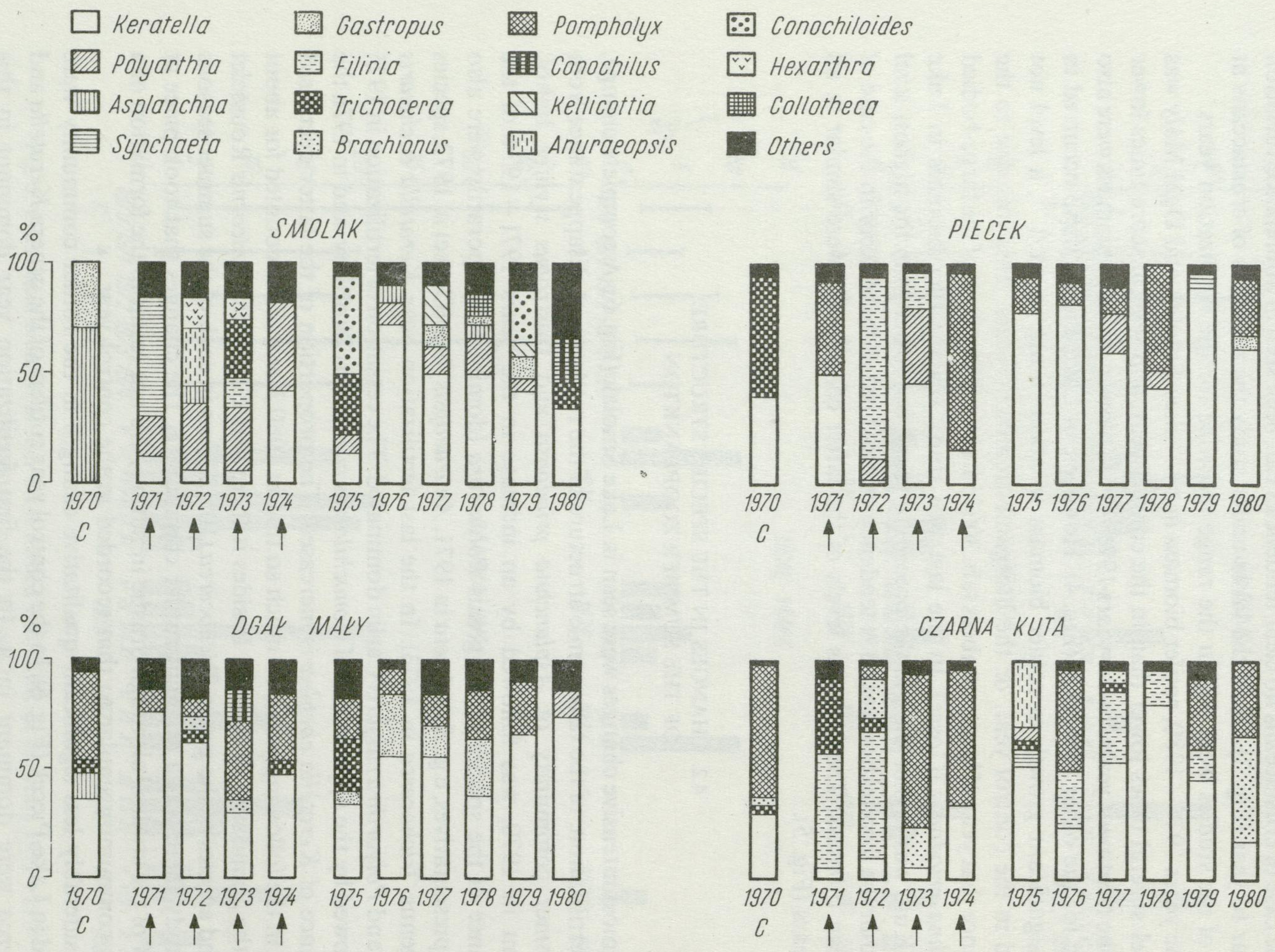

Fig. 6. Changes in the percentage of Rotatoria genera in their overall numbers during the summer stagnation in four lakes treated with NPK in the years 1971 – 1974
C – control year, arrows indicate fertilization years

years, although it no longer attained such a high dominance level. In those years the dominant species was *Keratella cochlearis*. Thus in the last study year the occurrence was mainly recorded of *Keratella* (62%), *Pompholyx sulcata* (26%) and *Brachionus* (6%). In this case, too, as in Lake Smolak, the 1980 rotifer community differed from the control year rotifer community, except that the percentage of *Keratella* was in both years high.

At all study stages Lake Dgał Mały was characterized by small, relatively, changes in the rotifer species structure (Fig. 6). The species composition of the summer rotifer community changed little under the influence of fertilization, and in fertilization year IV the composition was similar to that recorded in the control year, that is to say, *Keratella* and *Pompholyx sulcata* were dominant. After the cessation of fertilization, in 1975 *Gastropus stylifer* occurred in larger numbers, but it disappeared in 1979. In the last study year *Pompholyx sulcata* also disappeared from the community. Consequently, the rotifer community of the last study year differed from that of the control year more than did the community recorded in the last fertilization year!

In Lake Czarna Kuta (Fig. 6) inorganic fertilization at first caused a radical change in the specific structure of the rotifers. The 1970 community, dominated by *Pompholyx sulcata* and *Keratella cochlearis*, was in 1971 and 1972 replaced by a community in which *Filinia longiseta* dominated. However, in 1974 a recovery took place, and the situation was almost identical with that of the control year. Cessation of fertilization was followed by the appearance of *Anuraeopsis fissa* (in 1975), and in the subsequent years *Filinia longiseta* appeared again in larger numbers. In the last study year a high dominance was recorded of species of the genus *Brachionus* (primarily *B. angularis* Gosse and *B. diversicornis* (Daday)), *Pompholyx sulcata* and *Keratella cochlearis*. The state found prior to fertilization was not recovered in this case either. The feature by which the communities of both years differed was the proportion of species of the genus *Brachionus* – low in 1970 and very high in 1980.

Thus in none of the study lakes was the initial state recovered during the 6-year period following the cessation of fertilization. The most intensive changes in the rotifer species structure were in most cases recorded in the turning years – immediately after the application of inorganic fertilization and after its cessation.

In the successive study years the species structure of the summer crustacean community of Lake Smolak varied significantly (Fig. 7). In the second study year the community lost *Ceriodaphnia quadrangula* (O. F. Müller) – a dominant species in the control year. In 1972, the community was entirely dominated by *Bosmina longirostris* (O. F. Müller), and in the following year the percentage increased of species of the family Cyclopidae, whereas in the last fertilization year two *Daphnia* species (*D. cucullata* Sars and *D. langispina* O. F. Müller) appeared in the community. After the cessation of fertilization, in 1975 and following years, *C. quadrangula* appeared again in significant numbers, being a constant, besides Cyclopidae, component of the community until the last study year in which *Bosmina longirostris* also represented a considerable proportion. The crustacean species composition was in 1980 somewhat

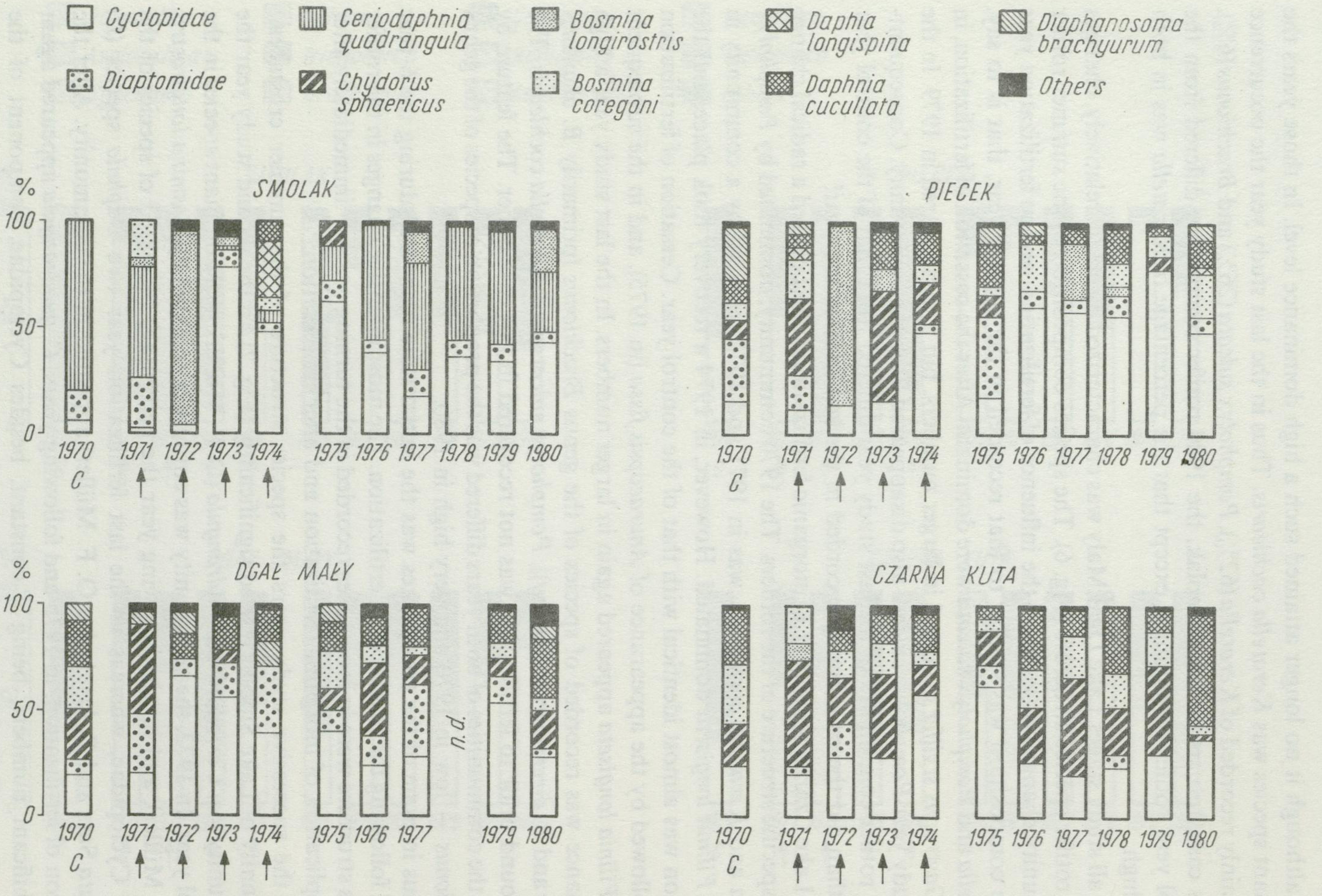

Fig. 7. Changes in the percentage of species in total numbers of Crustacea during the summer stagnation in four lakes treated with NPK in the years 1971 – 1974
C – control year, arrows indicate fertilization years, n.d. – no data

similar to the control year state owing to the high percentage of *C. quadrangula*, and to fertilization year IV because of the high proportion of Cyclopidae (Fig. 7).

In 1972, a high *Bosmina longirostris* dominance was also recorded in Lake Piecek (Fig. 7). In this case, too, the species replaced Diaptomidae and *Diaphanosoma brachyurum* (Lievin), both recorded for the community in 1970. In the last fertilization year Cyclopidae showed a high dominance, *Daphnia cucullata* and *Chydorus sphaericus* (O. F. Müller) constituting a considerable percentage. Following the cessation of fertilization, in 1975 the proportion of Diaptomidae increased (at the expense of Cyclopidae). In the subsequent years dominant were again Cyclopidae, in addition to species of the genera *Bosmina* and *Daphnia*. *Chydorus sphaericus*, a species typical of eutrophic water bodies, did not gain dominance in any of the years. Nevertheless, the species composition of Crustacea was in 1980 definitely different from that recorded in the control year.

No drastic changes, such as disappearance of species, were seen in Lake Dgał Mały. Subject to variation was the proportion of species (e.g., an increase in the percentage of *Chydorus sphaericus* in fertilization year I, a decrease in the proportion of Cyclopidae in the years 1973 – 1974, following a high dominance of this group in 1972, etc.). In 1980, the crustacean species composition was in effect similar to that recorded in the control year, but it clearly differed from that found in fertilization year IV (Fig. 7).

A similar course of changes was observed in Lake Czarna Kuta. Its summer crustacean community was subject to quantitative rather than qualitative (in the sense of a complete exchange of species) changes. In all the study years the community mainly consisted of Cyclopidae, *Chydorus sphaericus*, *Bosmina coregoni* (Baird) and *Daphnia cucullata*. In the fertilization years the percentage of Cyclopoida increased at the expense primarily of *Bosmina coregoni*. Following the stoppage of fertilization, in 1976 the crustacean species composition was almost the same as in the control year. In the next years, however, the crustacean communities differed more from the 1970 community. In 1980, *Daphnia cucullata* and Cyclopidae accounted for 90% of the community. Six years after the cessation of fertilization *Chydorus sphaericus* and *Bosmina coregoni*, which in 1970 accounted for nearly 50% of the community numbers, represented as little as about 8% of the abundance of the community.

The response of the crustaceans to changes taking place in their environment was thus weaker than the response of the rotifers. As in the case of rotifers, the termination of fertilization was not followed by formation, during the six-year study period, of summer communities typical of the study lakes in the control year.

In the analysis of changes in the zooplankton specific structure, indicating changes in the trophical state of the lakes the indicator species groups given by Karabin (1985a) were used. In his classification the latter author distinguished three indicator groups. Ecological group I includes rotifers most frequently occurring in mesotrophic lakes: *Conochilus hippocrepis* (Schrank), *Chromogaster ovalis* (Bergendal), *Ascomorpha ecaudis* Perty, *Gastropus stylifer* and *Polyarthra major* Burckhardt. Ecological group II comprises species that occur most abundantly in eutrophic lakes. The following are members of this group: *Keratella cochlearis* f. *tecta*, *Keratella quadrata* (Müller),

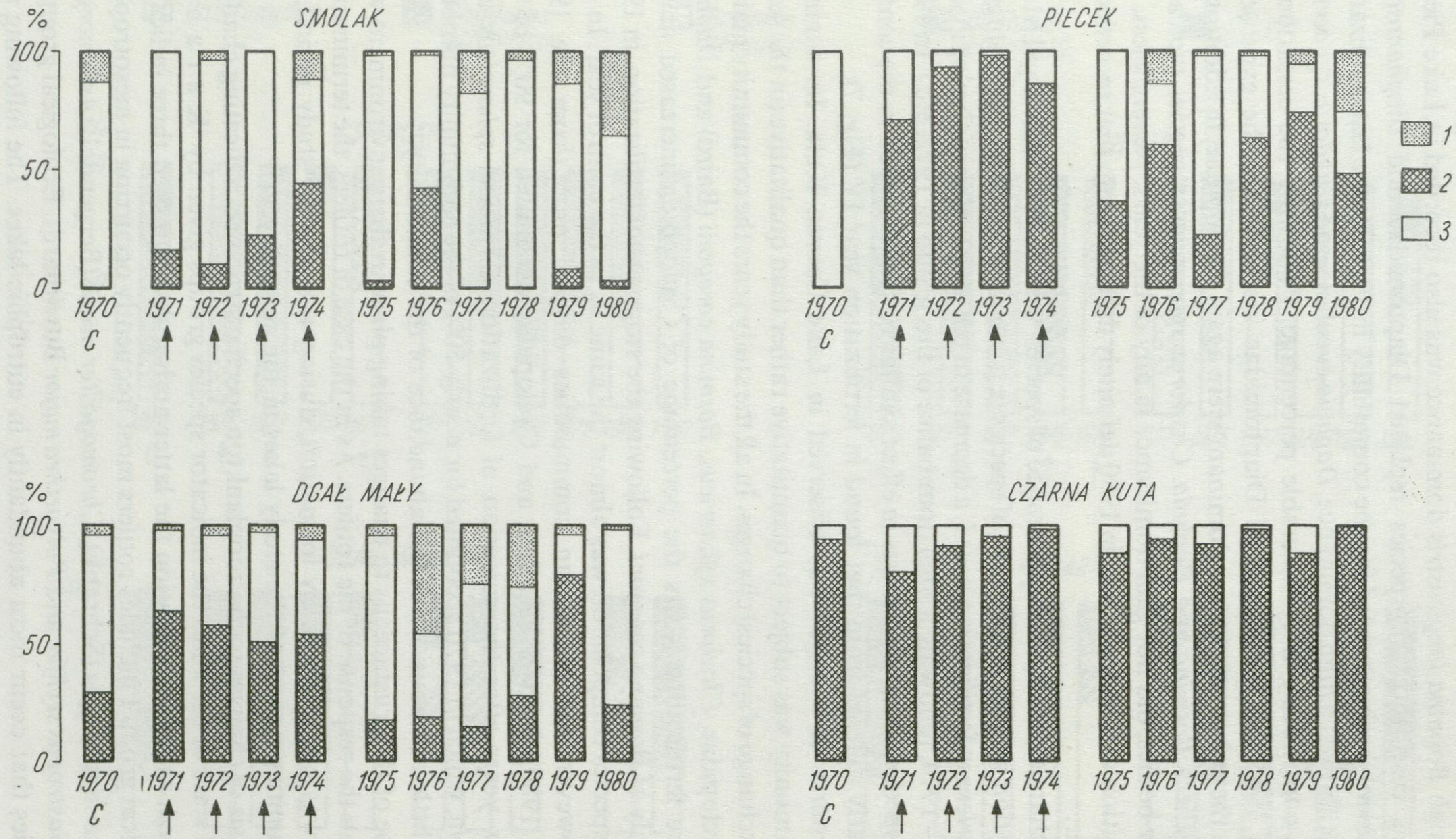

Fig. 8. Changes in the percentage of ecological groups of rotifers in their total biomass in four lakes fertilized with NPK in the years 1971 – 1974

1 – indicator group indicative of mesotrophy, 2 – indicator group indicative of eutrophy, 3 – rotifers present irrespective of lake trophic state, other denotations as for Figure 7

Pompholyx sulcata, *Filinia longiseta*, *Anuraeopsis fissa*, *Trichocerca pusilla* (Lauterborn), *Brachionus angularis* and other species of the genus *Brachionus*, *Proales micropus* (Gosse) and bdelloids. Species making up ecological group III are characterized by the lack of a relationship between their presence and the lake trophical state. This group includes first of all the eurytopic species, and all those species that occur sporadically.

A comparison of the percentages of the above-enumerated three ecological groups in the rotifer biomass (Fig. 8) has revealed considerable differences between the lakes in respect of the presence of each of the groups in their zooplankton. In Lake Smolak group III species prevailed in all the study years. Group II species appeared already in fertilization year I. The highest proportion of this group in the rotifer biomass was recorded in fertilization year IV, and in the 2nd year following the cessation of treatment. In the last study year group III (neutral) prevailed, group I (mesotrophic) represented a high proportion, whereas the percentage of group II was insignificant (6%).

Changes in the ecological groups of rotifers were in Lake Piecek similar to those described for Lake Smolak. In the control year only neutral (III) species were found in this lake. From fertilization year I onwards the proportion of group II species increased, attaining a level of 86 – 98% in the years 1972 – 1974. After the termination of fertilization the contribution of this group decreased almost by half, and at the same time there appeared group I species (Fig. 8). In the last study year the proportion of each of the three groups was high. This situation differs completely from what was found in the control year when group I and group II species were not present in the zooplankton at all.

Less conspicuous were the changes observed in Lake Dgał Mały, although here, too, group II species increased their percentage (almost doubled it) in the treatment years, and decreased it after the cessation of treatment (except that in 1979 the proportion of ecological group II was about 80%). The percentage of group I in the control year, fertilization years and in the first year following the cessation of fertilization remained at the same, very low level. In the years 1976 – 1978, the contribution of this group grew to attain the level of 25 – 45%, whereafter it dropped again. Consequently, the ecological group ratio in 1980 was almost the same as in the control year.

Fertilization and its cessation did not, however, cause any significant changes in the proportions of the ecological groups of rotifers in Lake Czarna Kuta. In all the study years group II species positively dominated, and variation in the contribution of this group to the biomass of rotifers was small, between 80 and 100%. In this lake also species of ecological group I were found to be absent.

Ecological group I of the crustacean community includes species which find optimum growth conditions in a mesotrophic environment: *Heterocope appendiculata* Sars, *Bythotrephes longimanus* Leydig, *Bosmina berolinensis* Imhof, *Daphnia cucullata*, *D. longispina* and *D. cristata* Sars. Group II consists of species the presence of which is indicative of eutrophical lakes, although all of them can be considered eurytopic: *Mesocyclops leuckarti* (Claus), *M. oithonoides* (Sars), *Chydorus sphaericus*, *Diaphano-*

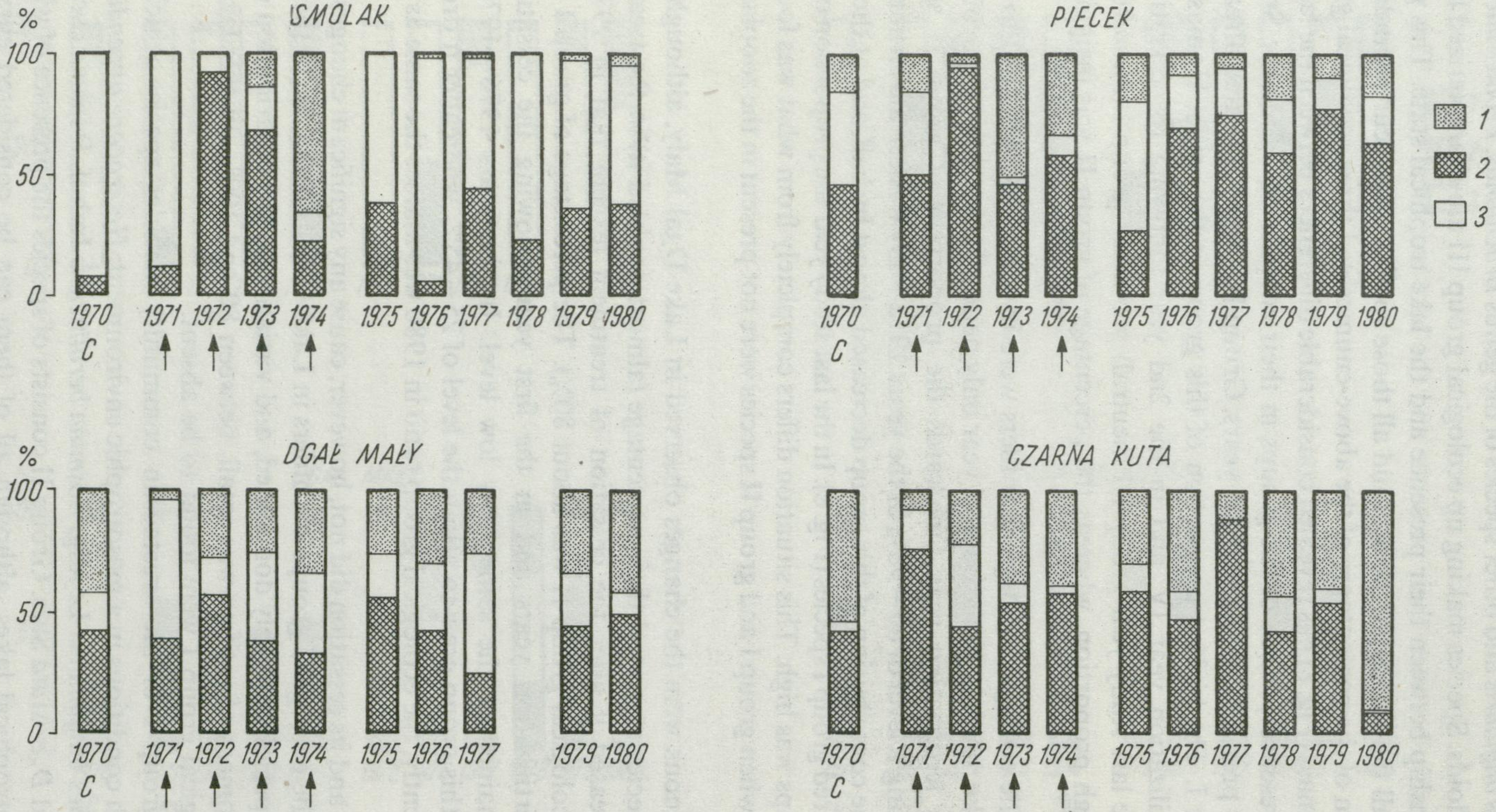

Fig. 9. Changes in the percentage of ecological groups of crustaceans in their total biomass in four lakes treated with NPK in the years 1971 – 1974
Denotations as for Figure 7 and 8

soma brachyurum, *Bosmina longirostris* and *B. coregoni*. Group III does not show any relationship to a particular trophic state of water bodies, and includes generally littoral species, as well as those found sporadically (K a r a b i n 1985a).

Changes in the contribution of the three ecological groups to the biomass of the crustacean communities were less noticeable than in the case of rotifers (Fig. 9).

In Lake Smolak the percentage of species of ecological group II increased in fertilization year II, but it decreased considerably in fertilization year IV. Over 60% of the biomass of the community was contributed which is surprising, by species peculiar to mesotrophy. After the cessation of fertilization species of ecological group III represented about $\frac{1}{3}$ of the community biomass, while group I species did not exceed 5% of that biomass (Fig. 9).

Similar tendencies were recorded in Lake Piecek. Here also a considerable growth of the role of ecological group II (to about 95%) was only seen in fertilization year II. In fertilization years III and IV, as in Lake Smolak, the percentage of group I increased considerably. In the following years the proportion of group II remained at a relatively high level (about 60 – 70%), and species of ecological group I also were always present (up to 20% of the community biomass) (Fig. 9).

No directional changes were, however, noticed in the relations of the crustacean ecological groups in Lake Dgał Mały. In all the study years group I species were comparatively abundant (about 20 – 40% of the community biomass), and so were group II species (about 40 – 50%) (Fig. 9).

Surprising proportions of the ecological groups of crustaceans were found in Lake Czarna Kuta. In spite of the high trophic state of this lake, in all the study years the percentage of ecological group I was high (about 40%), and in the last study year it contributed as much as 90% of the community biomass. This high level is the result of a high percentage of *Daphnia cucullata* (Fig. 7). It must be noted that Lake Czarna Kuta is a polymictic water body, and K a r a b i n ' s (1985a) classification of ecological groups of crustaceans applies to stratified lakes.

To sum up, in lakes Smolak and Piecek inorganic fertilization caused immediate changes in the proportions of the particular rotifer ecological groups (growth of the role of group II – indicative of high eutrophy), and an increase in the percentage of crustacean ecological group II in fertilization year II. Cessation of fertilization changed the relations of the ecological groups by a decrease in the percentage of the crustacean species typical of eutrophy. In the remaining two lakes the above tendencies were marked only in the case of rotifers in Lake Dgał Mały. The response of the rotifers to both treatments was generally more pronounced than the response of the crustaceans.

To check whether as a result of the cessation of fertilization the zooplankton of the study lakes, made similar during fertilization (E j s m o n t-K a r a b i n et al. 1980), became differentiated again, the percentage similarity of community (*PSc*) (W h i t t a k e r and F a i r b a n k s 1958) (Figs. 10, 11) was used.

Particularly noteworthy is the result of comparison of the rotifer community of Lake Smolak with the communities of the remaining study lakes (Fig. 10). In the control year the lake pair Smolak-Czarna Kuta had no common species, and only 2%

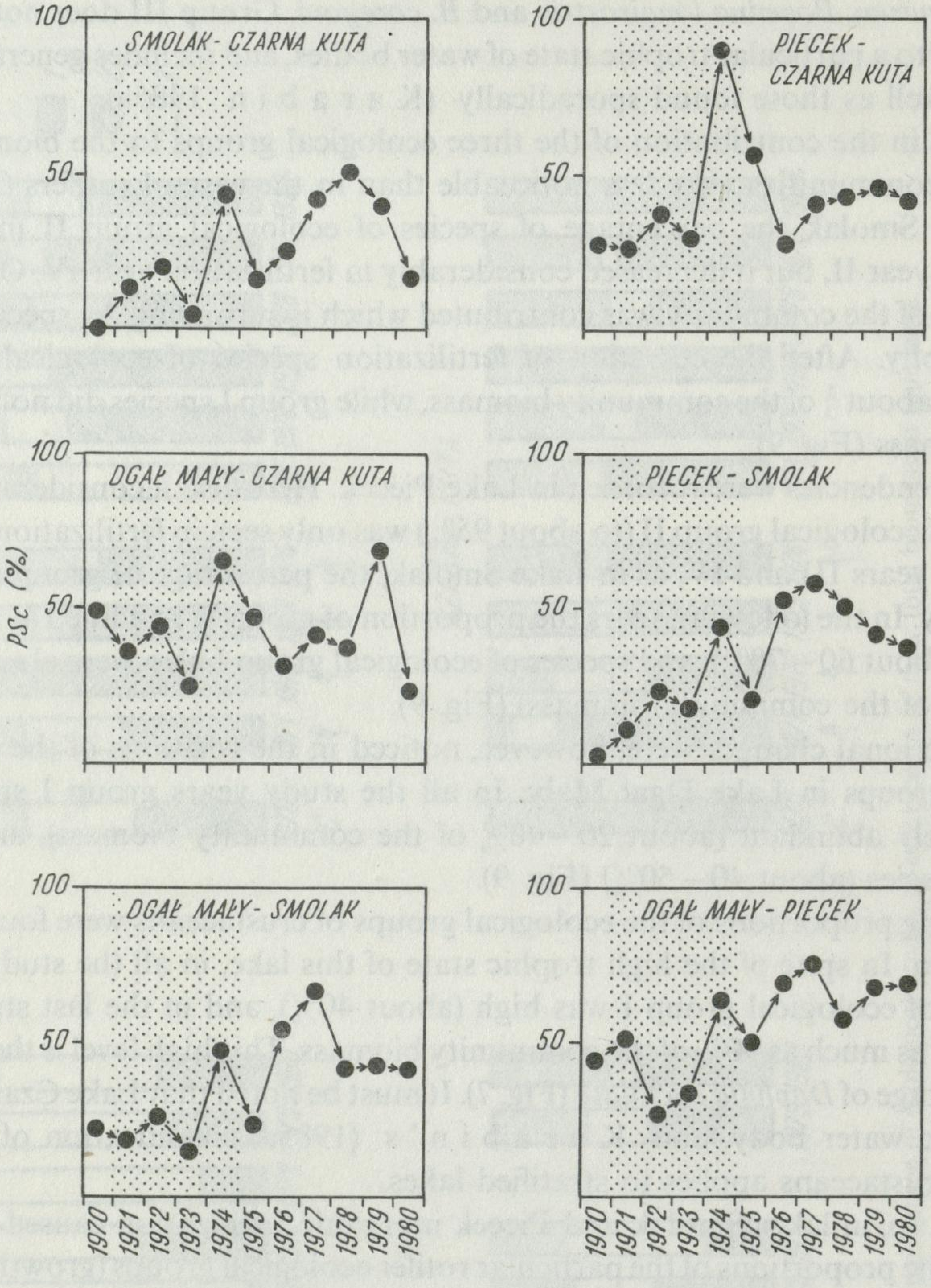

Fig. 10. Changes of the percentage similarity of community for the rotifer community of four lakes treated with NPK in the years 1971 – 1974
Stippled area comprises fertilization years

of the community was common for the pair Smolak-Piecek, and 22% for the pair Smolak-Dgał Mały. From as early as fertilization year I the percentage of common species increased considerably, e.g., for the pair Smolak-Czarna Kuta the *PSc* was 14%. In fertilization year IV Lake Smolak had almost half the rotifer community in common with the remaining lakes. In the first year following the cessation of fertilization the *PSc* value dropped again and then increased anew. In 1980, the *PSc* for the lake pair Smolak-Czarna Kuta was 17%. In the last fertilization year most similar were the rotifer communities of the pair Piecek-Czarna Kuta (*PSc* = 91%), and in the last study year of the lakes Piecek-Dgał Mały (*PSc* = 69%). Cessation of fertilization did not

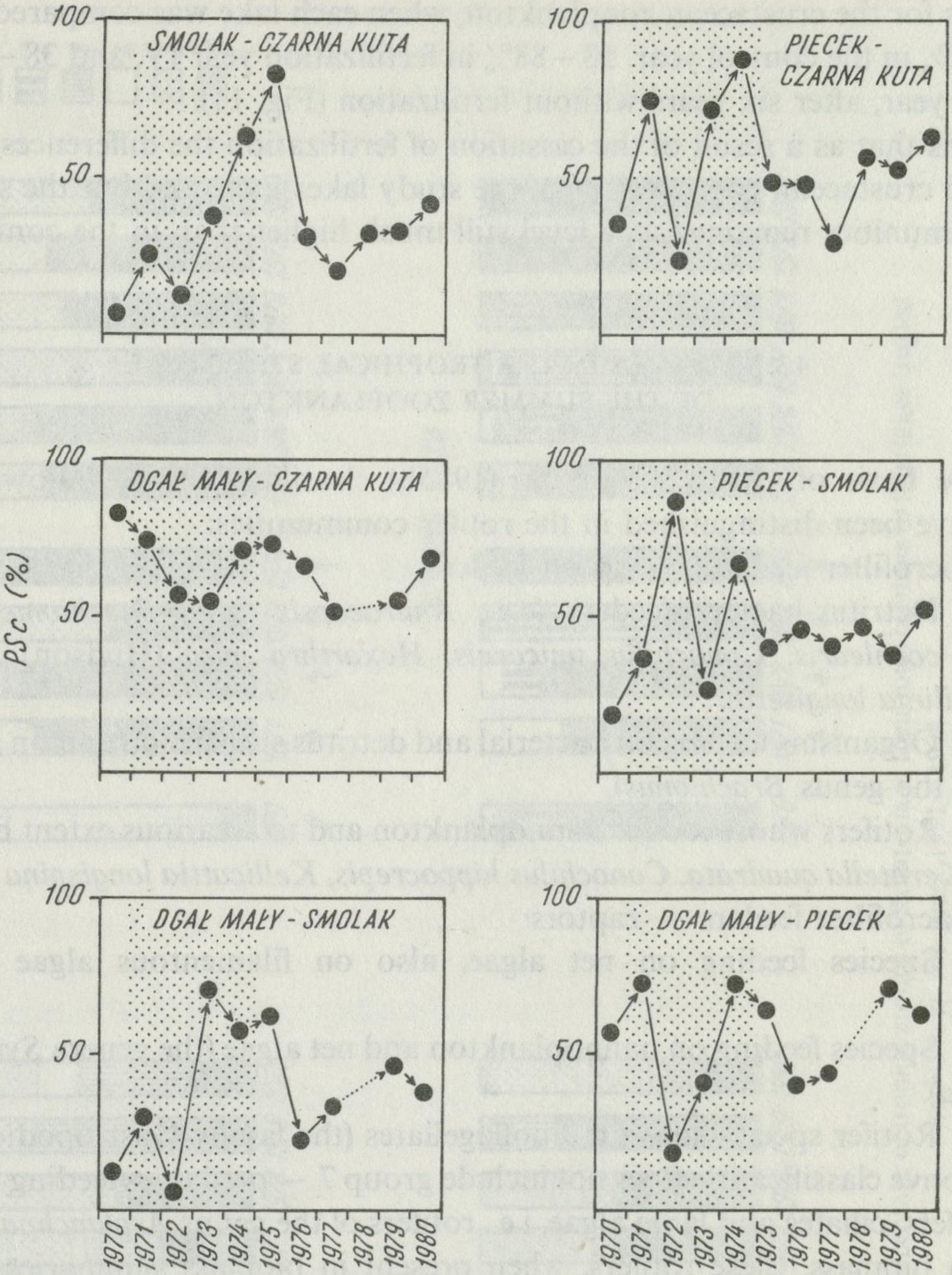

Fig. 11. Changes of the percentage similarity of community for the crustacean community of four lakes treated with NPK in the years 1971 – 1974
Denotations as for Figure 10

cause any drastic variation of the summer communities of rotifers in the lakes under study, made very similar during the fertilization. Though the zooplankton of these lakes was less similar in the years 1975 – 1980 than in the last study year, its similarity was greater than in the first three fertilization years.

Similar tendencies were also seen when summer communities of crustaceans were compared (Fig. 11). In this case, too, in the course of fertilization the crustacean communities of the lakes Smolak-Czarna Kuta grew similar, from an 8% similarity in the control year to 63% in 1974. The high *PSc* value for this lake pair persisted still in post-fertilization year I (*PSc* = 88%), and then dropped to 20 – 41%. The range of the

PSc values for the crustacean zooplankton, when each lake was compared with each, was 8 – 82% in the control year, 58 – 88% in fertilization year IV, and 38 – 69% in the last study year, after six years without fertilization (Fig. 11).

It seems that as a result of the cessation of fertilization the differences among the rotifer and crustacean communities of the study lakes increased but the similarity of these communities remained at a level still much higher than in the control year.

4.3. CHANGES IN THE TROPHICAL STRUCTURE OF THE SUMMER ZOOPLANKTON

On the basis of Karabin's (1985b) classification the following trophic groups have been distinguished in the rotifer communities:

(A) Microfilter-feeders – deposit-feeders:

(1) Detritus-bacteria-feeders (e.g., *Anuraeopsis fissa*, *Brachionus angularis*, *Keratella cochlearis*, *Conochilus unicornis*, *Hexarthra mira* (Hudson), *Pompholyx sulcata*, *Filinia longiseta*).

(2) Organisms feeding on bacterial and detritus suspension and on algae (other species of the genus *Brachionus*).

(3) Rotifers whose food is nannoplankton and to a various extent bacteria and detritus (*Keratella quadrata*, *Conochilus hippocrepis*, *Kellicattia longispina* (Kellicott)).

(B) Macrofilter-feeders – raptors:

(4) Species feeding on net algae, also on filamentous algae (the genus *Trichocerca*).

(5) Species feeding on nannoplankton and net algae (the genera *Synchaeta* and *Polyarthra*).

(6) Rotifer species sucking dinoflagellates (the family Gastropodidae).

The above classification does not include group 7 – predators feeding basically on small rotifers, ciliates and large algae, i.e., rotifers of the genus *Asplanchna*. Because of their high biomass, these rotifers, when present in biomass summaries, practically eliminate all other groups, notably all fine-bodied detritus-feeders.

As indicated by the studies of Hillbricht-Ilkowska (1977) and Karabin (1985b), the trophic structure of the rotifers varies considerably with lake trophic state changes; a rise of the trophic state is accompanied by increasing importance of minute rotifers feeding on bacteria and detritus.

Fertilization caused trophic state changes in some of the lakes (Ejsmont-Karabin et al. 1980), hence one could also expect changes in the trophical structure of the summer community of rotifers.

An analysis of changes in the rotifer trophical structure in the lakes under study (Fig. 12) has revealed its wide variation between the successive study years. Particularly clear changes could be observed in Lake Smolak. In 1970, *Asplanchna priodonta* (of group 7 not included in the summary) was a clear dominant, whereas algivores (groups 5, 6) prevailed among the remaining species. Forms capable of using detritus and

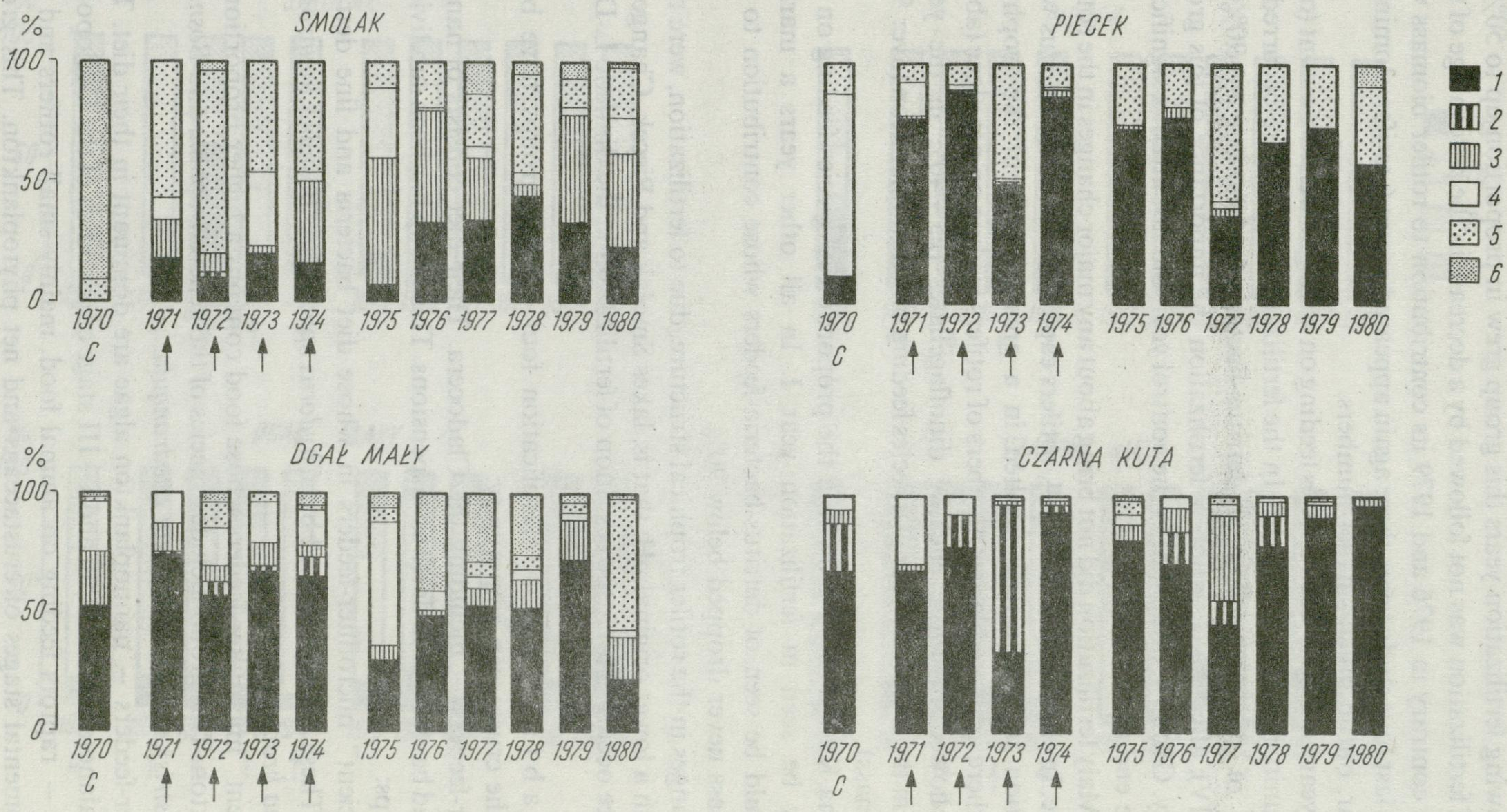

Fig. 12. Changes in the percentage of trophic groups of Rotatoria in their total biomass in four lakes treated with NPK in the years 1971 – 1974

C – control year, arrows indicate fertilization years, 1 – detritus-bacteria-feeding organisms, 2 – with a diet of bacteria, detritus and minute eutrophic algae, 3 – with a mixed diet (nannoplankton, bacteria, detritus), 4 – feeding on net algae, 5 – on nannophytoplankton, 6 – animals sucking dinoflagellates bacteria (groups 1, 3) appeared in the summer rotifer community as early as fertilization year I. In the following fertilization years this group grew in proportion up to 50% in 1974. Cessation of fertilization was not followed by a decrease in the percentage of this group, but on the contrary in 1976 and 1979 its contribution to rotifer biomass was nearly 80%. In the last four study years there again appeared group 6 rotifers dominant in the control year, but in much smaller numbers.

In the control year, in Lake Piecek species feeding on net algae were dominant (over 70% of the community biomass – Fig. 12). In the fertilization years there occurred an intensive growth of the proportion of detritus-bacteria-feeders (up to 90% in fertilization year IV); after the cessation of fertilization the importance of this group diminished slightly. Group 4, dominant in the control year, did not attain a significant percentage till the end of the studies.

In Lake Dgał Mały fertilization did not bring about any major changes in the rotifer trophical structure. In the years 1970–1974, rotifers capable of utilizing detritus were dominant. Cessation of fertilization resulted in a great change in the trophical structure: at first there appeared larger numbers of rotifers feeding on net algae (about 50% in 1975), followed by those sucking dinoflagellates (25–40% in the years 1976–1978), and in the last study year – species feeding on nannoplankton (over 50% of the rotifer biomass).

In Lake Czarna Kuta a slight growth in the proportion of species feeding on net algae could only be seen in fertilization year I. In all other years a marked predominance could be seen of detritus-bacteria-feeders whose contribution to the total rotifer biomass never dropped below 90%.

Significant changes in the rotifer trophical structure, due to fertilization, were thus found in lakes with a lower original pH, that is, lakes Smolak and Piecek. Changes of greater significance occurred after the cessation of fertilization in the dimictic L. Dgał Mały.

Using K a r a b i n ' s (1985b) classification four trophic groups have been distinguished in the crustacean community:

(1) Microfilter-feeders – including the Cladocera. Their diet consists of nanno-phytoplankton and bacterial and detritus suspensions. This group has been subdivided into two subgroups:

(a) "Inefficient" microfilter-feeders in whose diet bacteria and fine detritus particles prevail. These are represented by: *Chydorus sphaericus*, *Bosmina longirostris* and *Diaphanosoma brachyurum*.

(b) "Efficient" microfilter-feeders whose food contains a higher proportion of nannophytoplankton. This group includes species of the genera *Daphnia* and *Bosmina* (except *B. longirostris*) and *Ceriodaphnia quadranqula.*

(2) Macrofilter-feeders – nannoplankton algae are dominant in their diet. This group includes Calanoida and nauplii and I–III stage copepodids of the Cyclopoida.

(3) Predators – raptors feeding on animal food, mainly small rotifers and the youngest developmental stages of crustaceans and net phytoplankton. This group

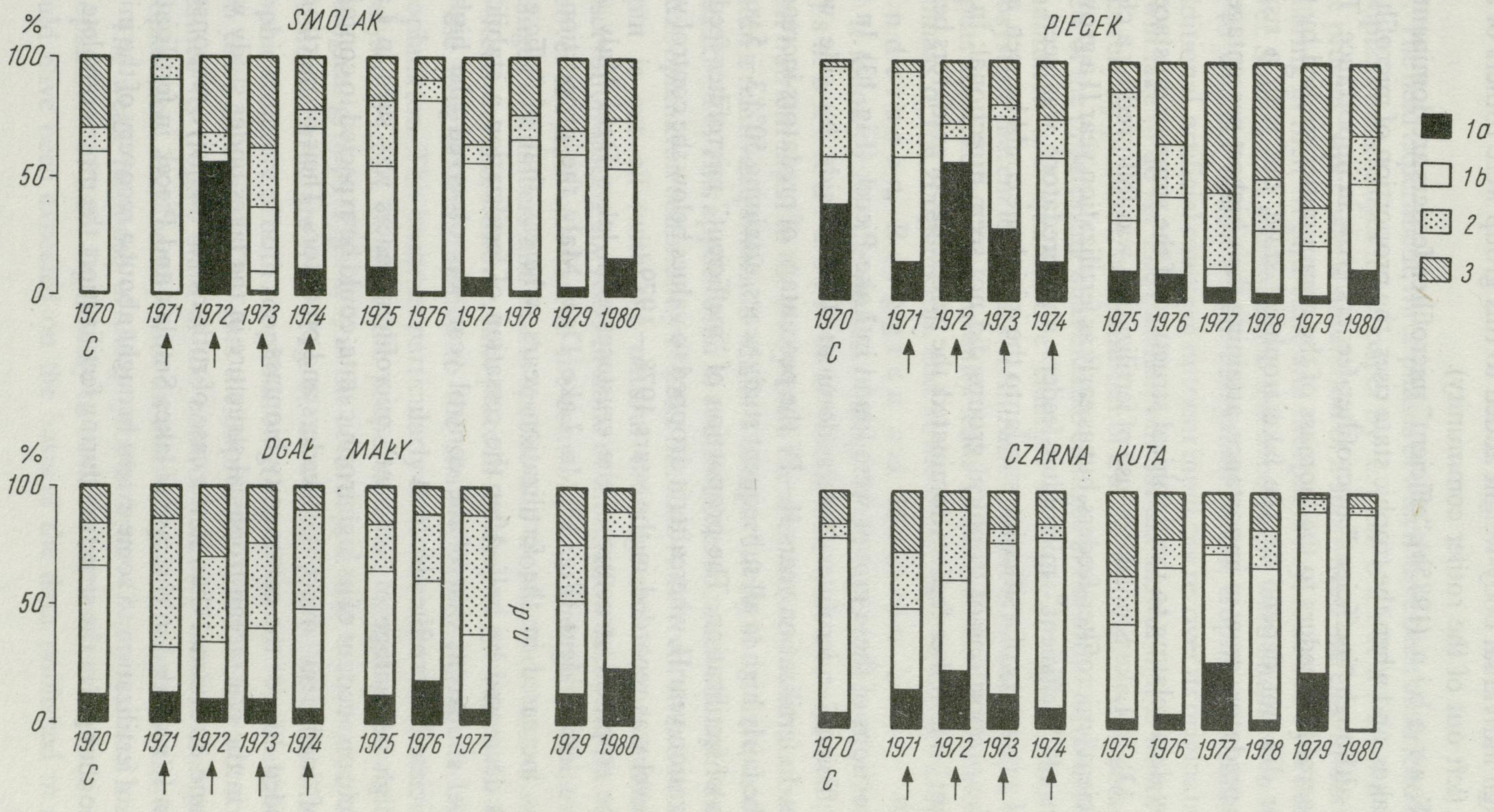

Fig. 13. Changes in the percentage of trophic groups of Crustacea in their total biomass in four lakes treated with NPK in the years 1971 – 1974
1 – microfilter-feeders: a – inefficient, b – efficient, 2 – macrofilter-feeders, 3 – predators – raptors, n.d. – no data. Other denotations as for Figure 12

includes adult individuals and IV – VI stage copepodids of *Mesocyclops*, and on account of their high individual body-weight added to this group were rotifers of the *Asplanchna* genus (left out of the rotifer community).

According to Karabin (1985b), "efficient" microfilter-feeders are dominant in low trophic state lakes, and when the trophic state rises, the proportion of microfilter--feeders decreases, although "inefficient" microfilter-feeders grow in importance. The contribution of macrofilter-feeders to the biomass of the communities studied by the last-quoted author did not depend on the lake trophical state, but with a rising trophical state the predators grew in importance, attaining their highest percentage in eutrophy.

As indicated by data relating to the trophical structure of the summer crustacean zooplankton (Fig. 13), in Lake Smolak the use of fertilization was followed by a clear dominance of "efficient" microfilter-feeders, but as early as fertilization year II a growth in the proportion of "inefficient" microfilter-feeders and predators was seen. In fertilization year II a recovery of a situation similar to the initial one could be seen, and the variation of the proportions of trophical groups did not seem directional. In all those years "efficient" microfilter-feeders dominated, the percentage of predators being comparitively high.

Different proportions of these groups were found in Lake Piecek (Fig. 13). In the control year "inefficient" microfilter-feeders dominated there side by side with macrofilter-feeders. In fertilization years II – IV the percentage of predators increased and continued to be fairly high in all subsequent study years, attaining 50% 3 – 5 years after the cessation of fertilization. The proportion of "inefficient" microfilter-feeders increased in fertilization year II, whereafter it dropped to values below the control year value, its lowest level was recorded in the years 1978 – 1979.

Changes in the trophical structure of the crustaceans in lakes Dgał Mały and Czarna Kuta were less evident (Fig. 13). In Lake Dgał Mały the proportion of macrofilter-feeders increased in the fertilization years, whereas that of "efficient" microfilter-feeders decreased by half. After the cessation of fertilization a stabilized situation at a level similar to that of the control year was observed (the highest percentage of "efficient" microfilter-feeders).

A strikingly high percentage of "efficient" microfilter-feeders was seen in Lake Czarna Kuta, which, on account of its high trophic state, could be expected to contain a high percentage of "inefficient" microfilter-feeders and predators. Their proportion in fact seldom exceeded 30% of the community biomass.

Thus changes in the crustacean trophical structure in the lakes under study were less conspicuous and directional than in the case of rotifers. An intensive response to fertilization was only recorded in the case of lakes Smolak and Piecek in fertilization year II. Cessation of fertilization to some extent brought about a recovery of the initial state, the lesser the changes in the structure during fertilization, the more complete the recovery.

5. DISCUSSION

The field experiment, three phases of which have been described and illustrated with zooplankton changes in the paper by Ejsmont-Karabin et al. (1980) and in the present paper, was a simulation of a short-lived increase in nutrient input to lakes differing in their trophic state and morphometry, followed by a decrease to the initial level. Studies that accompanied this experiment were intended to answer the question as to whether or not a lake ecosystem with a trophic state raised by applying an additional, artificial source of nutrient input can recover its original state, and how long it will take to do so. The question one should answer first is whether such a complete recovery by plankton communities of a state from before ten years can be expected in view of the progressing unavoidable changes in the areas surrounding lakes, including qualitative and quantitative changes in nutrient inputs from outside the lake ecosystem, therein four years' fertilization. What is known is that cessation of nutrient inputs to stratified lakes usually leads to a considerable decrease in numbers and biomass of the zooplankton, and in the percentage of species indicative of eutrophy (Andersson, Berggren and Hamrin 1975).

It follows from the results of stage II of the experiment, presented in the paper Ejsmont-Karabin et al. (1980), that with a considerably increased permanent nutrient input to the study lakes the zooplankton communities of these lakes can attain a relative equilibrium within a comparatively short time, as early as fertilization year III – IV. This applies even to communities so much changed due to fertilization as the zooplankton community of Lake Smolak. A different situation arises when such an input is cut off (with the natural drainage-area input unaffected). During the observation lasting six years in none of the shallow lakes did the rotifer communities recover the state recorded in the control year, although there occurred considerable changes in numbers and in the species and trophic structure of the zooplankton.

Recovery did, however, take place in the deeper, dimictic Lake Dgał Mały, in spite of the insignificant, relative to the shallow lakes, changes in the structure of its zooplankton. This becomes particularly clear when the crustacean specific structure is analysed (Fig. 7), or when the proportions are compared of rotifer and crustacean ecological groups (Figs. 8, 9) in the control year and in the last study year. The rotifer taxonomic structure itself (Fig. 6), as well as, this being particularly important, the trophic structure of both zooplankton groups (Figs. 12, 13) were different in each of the two years compared. One gets the impression that this lake not so much attained as retained its trophic state of the control year, but with a changed structure of its zooplankton, and thereby with an altered cycle of matter in the food web.

The weak response of the phytoplankton (Zdanowski et al. 1978) and zooplankton of Lake Dgał Mały to both the increase and reduction in nutrient input could have been expected on the basis of the data published in many papers (e.g., Einsele 1941, Smith 1969, Schindler et al. 1971) which described rapid uptake and expulsion from the epilimnion of clearly stratified lakes of the phosphorus added to it. The fact should be noted here that the summer concentrations of P-total in Lake Dgał Mały dropped in the fertilization years and rose several years after its cessation (Fig. 1). Such a response seems to indicate that sedimentation was stimulated by an increased plankton production. Maybe a similar interpretation would apply to the considerable decrease in P-total concentration during fertilization in the polytrophic Lake Czarna Kuta. However, it must be assumed that the productivity of the latter could be limited by factors other than the concentration of nutrients (e.g., low water transparency).

It is interesting that a similar trend of changes in the summer concentrations of total P and total N can also be seen in lakes Smolak and Piecek, also stratified, but much shallower than Lake Dgał Mały. During treatment with NPK and liming the zooplankton of these lakes underwent considerable changes, mainly due to pH changes, especially in Lake Smolak, originally very acid (Ejsmont-Karabin et al. 1980). Apart from changes connected with pH variation, there also occurred changes that may indicate a rise of the trophic state of these lakes, e.g., the proportion increased of detritus-feeding species in the summer rotifer community (Fig. 12), and the percentage of crustacean species peculiar to eutrophy (Fig. 9). The increase in the proportion of rotifer species typical of eutrophy was not, however, so conspicuous; in Lake Smolak it occurred only in fertilization year IV, in Lake Piecek it grew at first and then diminished (Fig. 8). Cessation of fertilization did not cause a fall in the summer total P and total N concentrations (on the contrary, they rose gradually) or, which is also important, a drop in pH. In this situation the zooplankton communities could not be expected to recover their state of the control year, and they did not really do so. This is particularly evident from the taxonomic structure of rotifers (Fig. 6) and crustaceans (Fig. 7).

Characteristically also, the response of rotifers was much stronger than that of crustaceans. A stronger response of rotifers than that of crustaceans to a high-rate fertilization of the stratified Great Central Lake was also recorded by LeBrasseur et al. (1978), the changes affected numbers and the number of species – in either case a growth was observed. This is understandable inasmuch as, as indicated by Karabin's (1985b) studies, rotifers are more, relative to crustaceans, sensitive to trophic state variation, and more precisely to the associated changes in their food basis. Thus the response of rotifers can be a better indicator of the processes taking place in lakes that are under anthropopressure. The great changes, observed in the present studies in the rotifer community of lakes Smolak and Piecek did not, however, lead to a recovery of these communities to their state of the time prior to fertilization.

According to Ryding (1981), the response of shallow, polluted lakes to a nutrient input reduction varies greatly in spite of the fact that the clear lowering of phosphorus concentration in the water of the lakes is similar. This is because such lakes are more sensitive to seasonal variation in nutrient input and output. Data from studies based on monitoring covering only a short part of the growing season, the summer stagnation period, may present an incomplete picture of the changes going on in these water bodies. This fact must be taken into account in the interpretation of the changes that took place in the small, shallow lakes: Smolak, Piecek, Czarna Kuta.

It may, however, be stated that cessation of fertilization caused changes in numbers and structure of the zooplankton (mainly rotifers) of the lakes that had been treated; the stronger the initial response of the communities to fertilization, the more intensive the post-cessation changes (the strongest in lakes Smolak and Piecek, weaker or absent in lakes Dgał Mały and Czarna Kuta).

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6. SUMMARY

In the years 1975 – 1980 summer zooplankton was studied in four lakes: Smolak, Piecek, Dgał Mały, Czarna Kuta. The lakes, which differed in morphometry and initially also in their trophic state (Table I), had been treated with NPK in the years 1971 – 1974. The treatment was terminated in 1975. In two originally dystrophic lakes (Smolak and Piecek) cessation of fertilization failed to cause a lowering of the summer pH values to the control year (1970) values. Total nitrogen was found to have generally dropped to values similar to those recorded in the control year, whereas phosphorus concentration was found unchanged or raised (Fig. 1).

A decrease in rotifer numbers and biomass after the cessation of fertilization was only recorded in Lake Smolak, the poorest one in the control year. In the other lakes no clear decrease in rotifer numbers could be seen, with only a slight decrease in biomass (Figs. 2, 4). No directional changes in numbers and biomass were found in the case of crustaceans (Figs. 3, 5). In none of the lakes under study (despite clear changes from year to year in lakes Smolak and Piecek) did the rotifers (Fig. 6) or crustaceans (Fig. 7) recover the initial state of their specific structure. The response of crustaceans to the cutting-off of part of the external nutrient input was always weaker than that of rotifers.

In lakes Smolak and Piecek inorganic fertilization caused changes in the proportions of rotifer and crustacean ecological groups, i.e., a growth in importance of the group indicative of eutrophy (Figs. 8, 9). Cessation of fertilization caused a decrease in the percentage of rotifer species typical of eutrophy, but the crustaceans did not show a response of this type.

Due to fertilization-caused changes in the zooplankton species structure, the lower the lake trophic state prior to fertilization, the greater the changes, the similarity of the zooplankton communities (as expressed with the percentage similarity of community (*PSc*)) increased considerably and then decreased slightly after the cessation of fertilization (Figs. 10, 11), although six years after the last treatment with fertilizers it was still higher than in the control year.

Fertilization-caused changes in the trophical structure of rotifers and crustaceans appeared to be more significant in lakes with a lower original pH (Smolak and Piecek), whereas greater changes following the cessation of fertilization were recorded in the dimictic Lake Dgał Mały (Figs. 12, 13).

The cutting-off of part of the nutrient input to the water bodies under study caused changes in the specific and trophic structure of the zooplankton, indicating a slight fall of the trophic state of the lakes studied. The intensity of this response was the same as the intensity of the response of the zooplankton of these lakes to fertilization. However, the changes did not result in a complete recovery of the communities to a state of numbers and structure identical with that recorded in the control year, before inorganic fertilization was started.

7. POLISH SUMMARY

W latach 1975 – 1980 objęto badaniami zooplankton letni 4 jezior: Smolak, Piecek, Dgał Mały i Czarna Kuta. Jeziora te, o różnej morfometrii oraz początkowo trofii (tab. I), były nawożone NPK w latach 1971 – 1974, natomiast w 1975 r. nawożenia zaniechano. Zaprzestanie nawożenia nie spowodowało spadku letnich wartości pH w 2 jeziorach pierwotnie dystroficznych (Smolak i Piecek) do wartości z roku kontrolnego (1970). Natomiast zanotowano na ogół spadek koncentracji azotu ogólnego do wartości zbliżonych do notowanych w roku kontrolnym oraz brak zmian bądź wzrost koncentracji fosforu ogólnego (rys. 1).

Spadek liczebności i biomasy wrotków po zaprzestaniu nawożenia zanotowano jedynie w najuboższym w roku kontrolnym jeziorze Smolak. W pozostałych jeziorach, przy pewnym spadku biomasy, nie notowano wyraźnego spadku liczebności wrotków (rys. 2, 4). Żadnych kierunkowych zmian nie zanotowano natomiast w przypadku liczebności i biomasy skorupiaków (rys. 3, 5). W żadnym z badanych jezior (mimo wyraźnych zmian w kolejnych latach w jeziorach Smolak i Piecek) nie nastąpił też powrót do stanu wyjściowego pod względem struktury gatunkowej zarówno wrotków (rys. 6), jak i skorupiaków (rys. 7). Przy tym reakcja skorupiaków na odcięcie części zewnętrznego dopływu pierwiastków biofilnych była zawsze słabsza niż reakcja wrotków.

Nawożenie mineralne spowodowało w jeziorach Smolak i Piecek zmiany udziału grup ekologicznych wrotków i skorupiaków, tzn. wzrost znaczenia grupy charakterystycznej dla eutrofii (rys. 8, 9). Zaprzestanie nawożenia wywołało spadek udziału gatunków typowych dla eutrofii w przypadku wrotków, nie notowano natomiast tego typu reakcji w przypadku skorupiaków.

Zmiany struktury gatunkowej zooplanktonu, tym silniejsze im niższa była trofia zbiorników przed nawożeniem, spowodowały, że pod wpływem nawożenia podobieństwo zespołów zooplanktonowych (wyrażone wskaźnikiem procentowego podobieństwa zespołów (*PSc*)) badanych jezior silnie wzrosło, by zmniejszyć się nieco po zaprzestaniu nawożenia (rys. 10, 11), aczkolwiek jeszcze po 6 latach od ostatniego zabiegu nawożenia utrzymuje się ono na poziomie znacznie wyższym niż w roku kontrolnym.

Istotniejsze zmiany w strukturze troficznej wrotków i skorupiaków wywołane nawożeniem notowano w jeziorach o niskim pierwotnie pH (Smolak i Piecek). Istotniejsze zmiany po zaprzestaniu nawożenia wystąpiły w dymiktycznym jeziorze Dgał Mały (rys. 12, 13).

Odcięcie części dopływu pierwiastków biofilnych do badanych zbiorników wodnych spowodowało zmiany w strukturze gatunkowej i troficznej zooplanktonu świadczące o niewielkim spadku trofii badanych jezior. Przy tym reakcja była tym silniejsza, im silniejsza była reakcja zooplanktonu tych jezior na nawożenie. Zmiany te nie spowodowały jednak powrotu zespołów zooplanktonowych do stanu ich obfitości i struktury identycznego jak notowany w roku kontrolnym, przed rozpoczęciem nawożenia mineralnego.

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