EKOLOGIA POLSKA (Ekol. pol.)	36	1–2	203–230	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

SPATIAL DISTRIBUTION OF THE ZOOPLANKTON AND ITS POPULATION FEATURES IN TWO LAKES OF DIFFERENT HEATED-WATER THROUGH-FLOW

ABSTRACT: Two lakes heated by power-plant cooling waters were studied: Lake Ślesińskie (stratified, heated temporarily, with a hot-water discharge through a spring-board) and Lake Gosławskie (polymictic, heated constantly, with an overflow-hot water discharge). In both the lakes there occurred considerable changes in zooplankton structure and functioning (earlier occurrence of summer forms, changed spatial distribution and species diversity of rotifer and crustacean communities) in relationship to the way of discharge of heated waters and lake morphometry.

KEY WORDS: Heated lakes, Rotatoria, Crustacea.

1. INTRODUCTION

Lake heating is the result of industrial processes, primarily the production of electricity. There has already been a rich literature dealing with the effect of a temperature rise on particular species making up the lake plankton communities. It is more difficult to assess the effect of water heating, which is always connected with changes in the lake water flow, and often also with chemical contamination, on whole lake ecosystems. As each group of organisms may respond to a temperature rise differently, and the groups are in addition interrelated in their existence, it is extremely difficult, as has been stressed by G o l t e r m a n (1976), to predict the possible response of a whole biocoenose. In this situation gathering data on the response of whole planktonic communities to water heating is valuable inasmuch as it may enable hydrobiologists to create a theory of this response by generalizing phenomena observed in various lakes. So the aim of such studies is to establish the range of changes taking place in biocoenoses under the influence of water heating and its impact on the functions of ecosystems.

However, the aim of the studies presented in this paper was first of all to determine the type of zooplankton reaction to the discharge mode (overflow or waterfall), forced thermal zonation and the associated mictic-condition zonation of lakes.

The studies were carried out on lakes Ślesińskie and Gosławskie, included in the 5 lake system, called the Konin Lake Complex (Fig. 1), situated in central Poland in a trough-like depression. Biological and environmental monitoring of 3 lakes of this system (Licheńskie, Mikorzyńskie and Ślesińskie) has been conducted since 1966 by the Inland Fisheries Institute in cooperation with the Institute of Ecology, Polish Academy of Sciences (Hillbricht-Ilkowska et al. 1988, Hillbricht-Ilkowska and Zdanowski 1988, Zdanowski et al. 1988).

In the initial period of power plant Konin operation, between 1958 and 1964, only Lake Pątnowskie was heated. Later on Lake Licheńskie was included in the cooling system. In the years 1969 and 1970, as a result of an increased volume of heated water

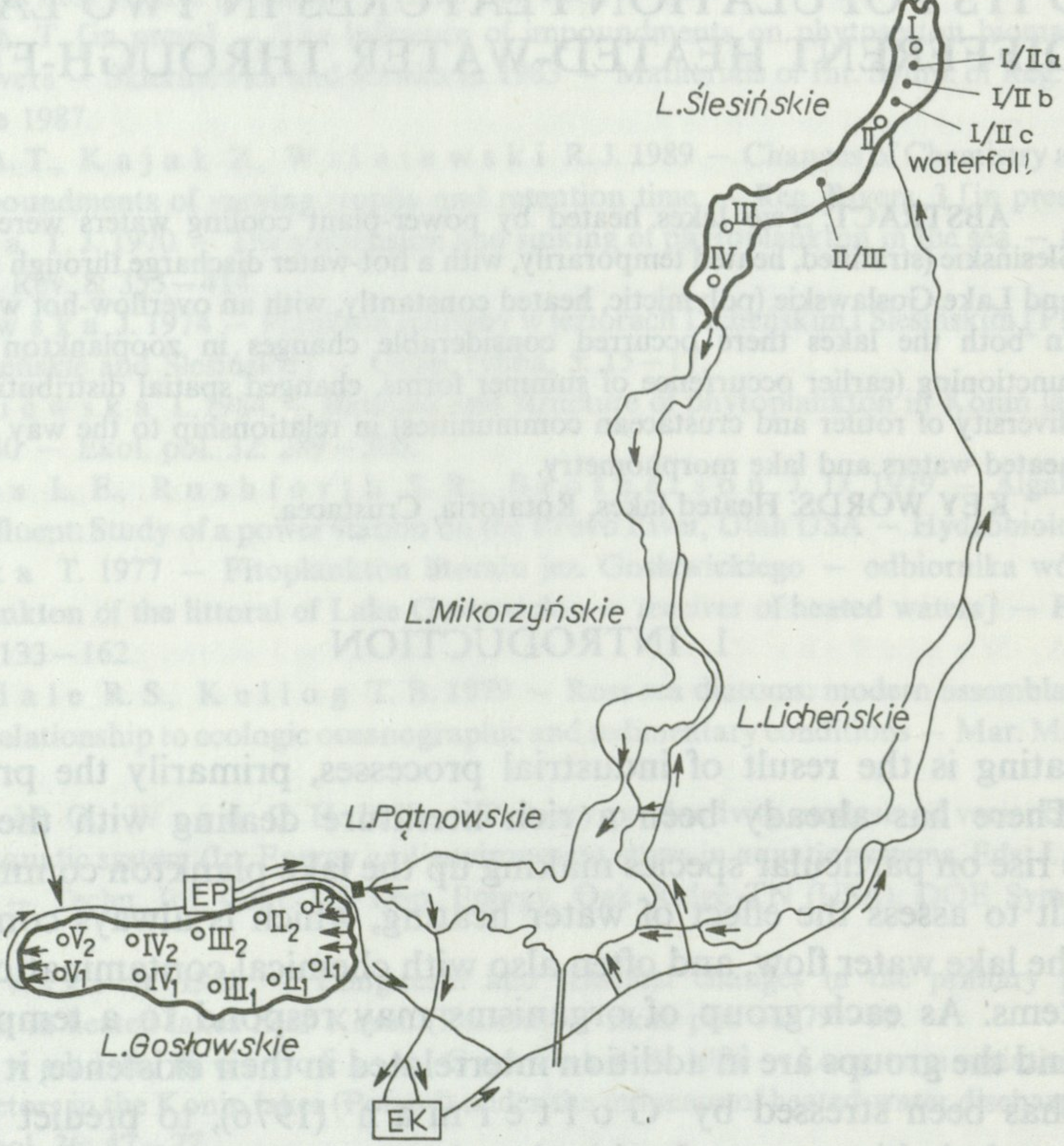

Fig. 1. Location of lakes Ślesińskie and Gosławskie in the Konin lake system, and the sampling stations on the two lakes

EK, EP — power plants, Roman numerals — sampling stations, arrows — water flow direction in the lakes (due to the construction of another power plant, Pątnów, EP – Fig. 1), further lakes were connected to the cooling system: in 1968 Lake Gosławskie began to receive heated water from the Pątnów power plant, and in June 1970 intensively heated waters from Lake Licheńskie began to flow through a canal to Lake Ślesińskie. Water temperature in the whole system rose by 4–6°C as compared with the temperature of unheated lakes (H i l l b r i c h t - I l k o w s k a and Z d a n o w s k i 1988a).

Within the series of studies carried out on the lakes enumerated above a number of papers have so far been published (e.g. P ó ł t o r a c k a 1968, P a t a l a s 1970, S o s n o w s k a 1974, H i l l b r i c h t - I l k o w s k a et al. 1976, Z d a n o w s k i 1976, H i l l b r i c h t - I l k o w s k a and Z d a n o w s k i 1978, S p o d n i e w s k a 1984) dealing with the effect of water heating on the physico-chemical properties of the water, primary production species composition and biomass of the phytoplankton, and species composition, biomass and production of the zooplankton.

2. AREA, MATERIAL, METHODS

Detailed, comprehensive [1] investigations were carried out in two lakes: Lake Ślesińskie in 1983 and Lake Gosławskie in 1984.

Lake Ślesińskie is a eutrophic, dimictic water body, with a maximum depth of 25.7 m and an average depth of 7.5 m. Its surface area is 148.1 ha. It seasonally (from May to October) receives heated waters from an intensively heated Lake Licheńskie, discharged in waterfall mode from a spring-board about 15 m high (Fig. 1). In 1983 the discharge was started on May 17. The hydraulic loading of the lake (the ratio between the circadian water volume carried by the canal and the total lake volume) (Hillbricht-Ilkowska and Simm 1988), calculated on the basis of records kept by the power plant staff, ranged from 6% in the initial period of discharge to 18% in summer. The temperature of discharged waters varied between 23–24°C in May-June and 26–28°C in July-August. Discharged heated waters move mainly towards the northern part of the lake. This flow does not find outlet in the canal and turns back towards the central part of the lake.

In the northern part of the lake a shallow station I was set up (Fig. 1). Station II was set up near the spring-board. Between these two station another three stations were set up (I/II a, b, c). In the southern part, most distant from the discharge site, a control station IV was established. Station III was located in a relatively shallow part of the lake between stations II and IV, and an additional station II/III – in a narrowing. During the discharge period water samples were also taken from the canal through which heated waters were discharged. Investigations were carried out on May 11 (6

[1] The following were studied: Secchi disk visibility, temperature, concentration of oxygen, basic nutrients (P and N), chlorophyll, abundance and structure of phyto- and zooplankton. The results have been presented in papers published in "Ekologia Polska" (H i l l b r i c h t - I l k o w s k a et al. 1988, H i l l b r i c h t - I l k o w s k a and Z d a n o w s k i 1988b, S i m m 1988, S t a ń c z y k o w s k a et al. 1988).

days before the starting of the discharging), on May 30 (12 days after starting of the discharging), and on July 28, after over two months' discharging of heated waters.

The temperatures, chemistry and the phytoplankton of both the lakes have been presented in detail in the paper by H i l l b r i c h t - I l k o w s k a and S i m m (1988). Discussed in this paper in only part of their data, significant for the description of the living conditions of the plankton.

As it follows from the above-mentioned studies, in the period preceding the starting of the discharging of heated waters from Lake Licheńskie the thermal conditions were at all the stations similar, indicating the beginning of a thermal stratification – the greater the depth, the more conspicuous the tendency (Fig. 2). Oxygen conditions were at all the stations similar, oxygen concentrations ranging from about 8.5 mg $\cdot$ l^{-1} at the surface to about 2 mg $\cdot$ l^{-1} in deeper layers of stations II, III and IV.

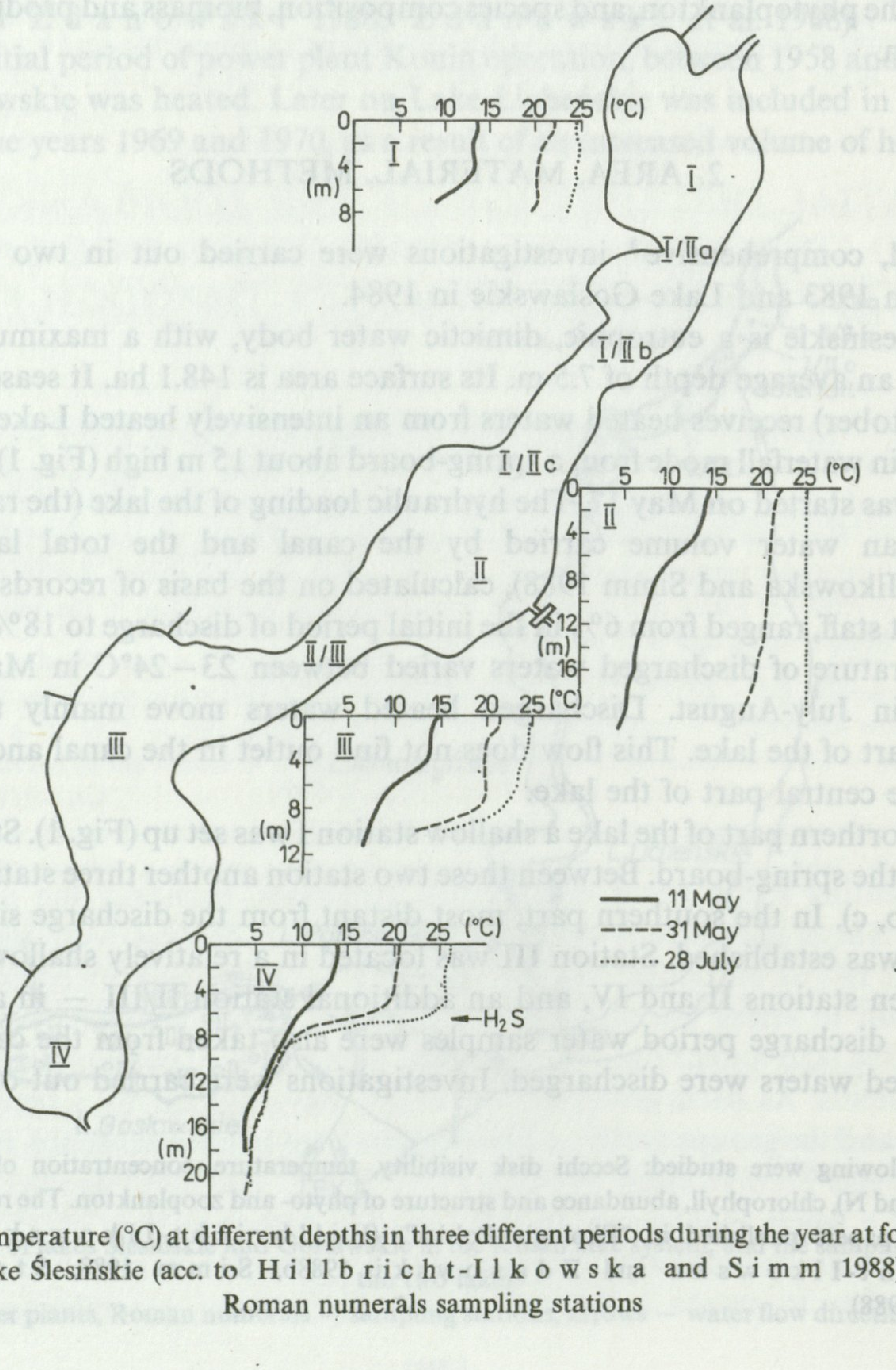

Fig. 2. Water temperature (°C) at different depths in three different periods during the year at four stations in Lake Ślesińskie (acc. to H i l b r i c h t - I l k o w s k a and S i m m 1988)
Roman numerals sampling stations

Following the starting of the discharge there began to occur marked temperature differences between lake parts. At the end of May at stations located near the discharge site and those farther on down the main flow (stations I and II) there was no thermal stratification, while at stations situated to the south of the near-discharge part, III and particularly IV a deeper stratification was found (Fig. 2). At station IV also a metalimnetic minimum oxygen content was recorded. But at other stations oxygen levels ranged from $7-10\ \mathrm{mg \cdot l^{-1}}$ at the surface to $5\ \mathrm{mg \cdot l^{-1}}$ at the bottom. This pattern still persisted in July. Station IV remained different, there occurred a strongly pronounced oxygen deficit at it, in the upper metalimnion and in almost the whole hypolimnion.

Prior to the starting of the discharge the biomass of the phytoplankton in the epilimnion was at the level of 4 to $10\ \mathrm{mg \cdot l^{-1}}$, and diatoms were then dominant. At the end of May and in July phytoplankton biomass was found to be low (below $4\ \mathrm{mg \cdot l^{-1}}$) at all stations, increasing from the shallow northern lake part towards the mid-lake. Diatoms continued to be dominant in the phytoplankton biomass, and there was a considerable proportion of blue-green algae which represented 30% of the phytoplankton biomass in July (S i m m 1988).

Zooplankton samples were collected in Lake Ślesińskie with a 5-litre Bernatowicz sampler, 10 litres from each depth analysed. The samples were taken at 2 m intervals, from surface to bottom at the main stations, and only at the depth of 2 m at the additional stations. On May 11 samples were only taken at the main stations. The samples then taken at the particular depths were pooled separately for the epi-, meta- and hypolimnion layers.

Lake Gosławskie is a pond-type, eutrophic, polymictic water body of a maximum (at a raised water level) depth of 4.5 m, and average depth of 3 m, and 378.9 ha in surface area. Heated waters of temperatures varying between 27 and 34°C are discharged into this lake during the whole year through several spillways on its eastern shore. The water retention time of the lake was estimated at about $2-3$ days (H i l l b r i c h t- -I l k o w s k a and S i m m 1988). The sampling stations were distributed along two transects more evenly (every 0.5 km), from the heated-water discharge site to the western part of the lake (Fig. 1). In 1974, samples were taken 3 times: on 12 April, 18 May and on 31 July. Ten-litre zooplankton samples taken at each station from the surface and the near-bottom layer were analysed separately.

Studies of the thermal and chemical conditions carried out simultaneously with the zooplankton studies (H i l l b r i c h t-I l k o w s k a and S i m m 1988) have demonstrated that Lake Gosławskie is characterized by a relatively uniform temperature fall gradient with increasing distance from the discharge site, and considerable vertical temperature variation (Fig. 3). Though the depth of the lake is not great, in the near-discharge part there persists a sharp temperature diversification, whereas in the western part even temperatures are found at all depths. This is proof that in its eastern part the heated waters constantly spread over the lake's surface, whereas in the more distant parts they are gradually mixed and cooled, thus diversifying the lake into its eastern, warmer part with a thermal gradient, and western — cooler, constantly mixed.

Despite the persistence of the above thermal pattern, there is no corresponding

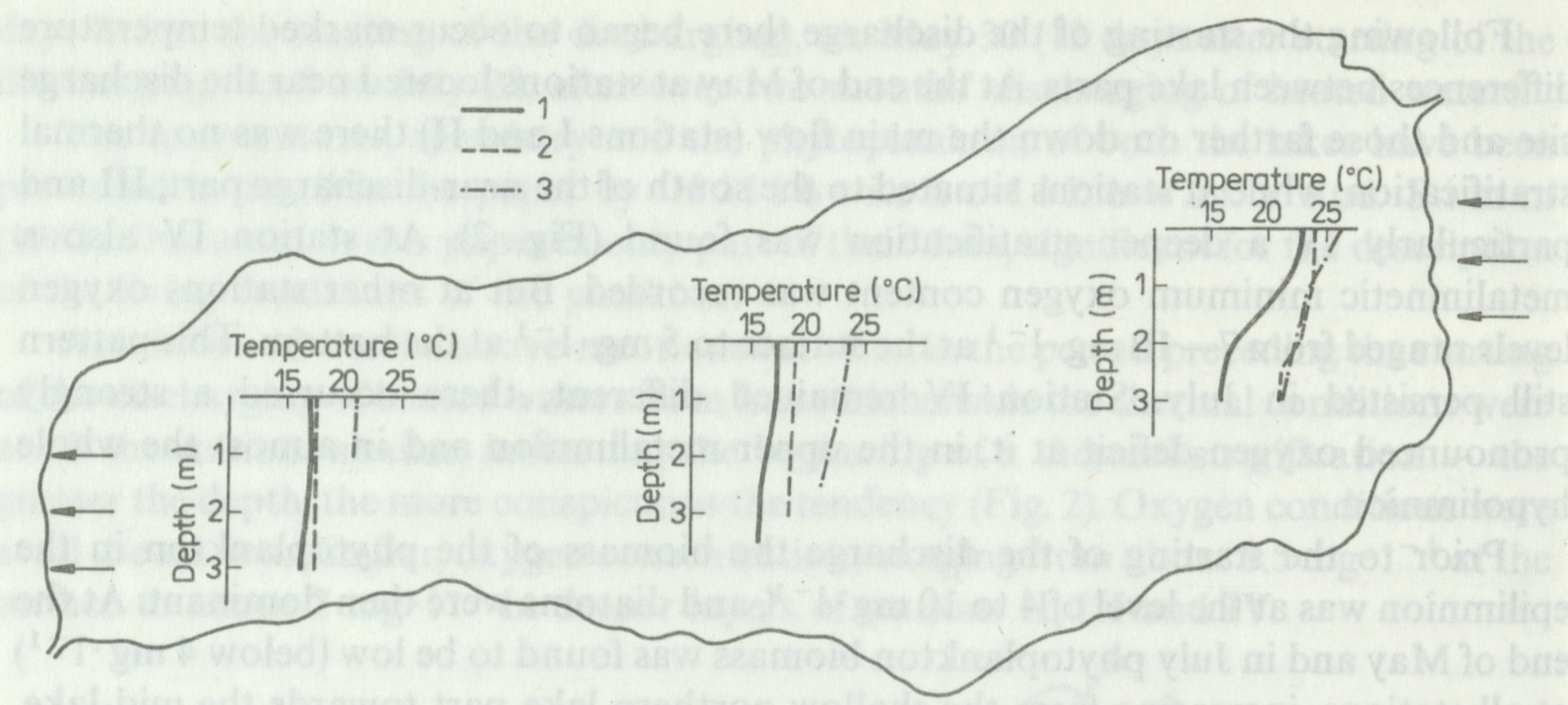

Fig. 3. Vertical water-temperature distribution in three parts of Lake Gosławskie estimated for three sampling dates (1–12 April, 2–18 May and 3–31 July, 1984) from data given in the paper by Hillbricht-Ilkowska and Simm (1988)
Arrows indicate directions of water discharge and intake

variation in oxygen-content which is similar at all depths, and only near the lake floor are lower oxygen concentrations found at some stations, yet never below 7 $mg \cdot l^{-1}$.

Throughout the study period the biomass of the phytoplankton in Lake Gosławskie was comparatively low, ranging from 0.6 to 2.7 $mg \cdot l^{-1}$, with no directional changes related to the distance from the discharge site, or depth in even the part close to the discharge site. In all the study periods dominant in the phytoplankton biomass were diatoms. In May and July green algae and blue-green algae occurred in relatively large numbers (Simm 1988).

Zooplankton samples taken from both the lakes were condensed by means of a plankton net (about 30 μ in mesh diameter) and fixed with 4% formalin. They were analysed according to Hillbricht-Ilkowska and Patalas (1967) and Bottrell et al. (1976). In each sample all Rotatoria and their eggs were counted by species, and so were all Crustacea, by species, developmental stages and eggs. For each crustacean species and stage the length of body of 50 individuals was measured.

The wet weight of rotifers was calculated on the basis of the relationship between body length and breadth, and body weight, described by Ruttner-Kolisko (1977a). Crustacean biomass was calculated from the relationship between body-length and weight, according to various references after Hillbricht-Ilkowska and Patalas (1967).

To determine changes in the species diversity of rotifers and crustaceans, the species diversity index according to Shannon and Weaver (Margalef 1957) was used:

$$D = -K \sum \frac{n_i}{n} \cdot \log_2 \frac{n_i}{n}$$

where: n_i – numbers of the i-th species, n – total numbers.

3. RESULTS

3.1. SPATIAL DISTRIBUTION OF THE ZOOPLANKTON OF LAKE ŚLESIŃSKIE WITH A WATERFALL HEATED-WATER DISCHARGE

3.1.1. Numbers and species structure of Rotatoria and Crustacea

In Lake Ślesińskie rotifers occurred in relatively small numbers, similar to those recorded for moderately eutrophic lakes. The maximum numbers recorded here was 2412 indiv. $\cdot l^{-1}$ (on 11 May at station IV). Following the starting of the discharge of heated waters there occurred a twofold reduction in rotifer numbers and clear inter-station variation (Fig. 4). In both May and July the richest in rotifers was station I, covered by the mixing effect of discharged waters but with a lower turbulence force due to a lower flow rate in this part of the lake. The higher numbers of rotifers at this station could have been the result of the gathering of individuals carried by the warm waters from the central part of the lake if the specific composition of the rotifer community had not been clearly different from that found at station II. For at station I there persisted a fairly high abundance of species which had been present there at an

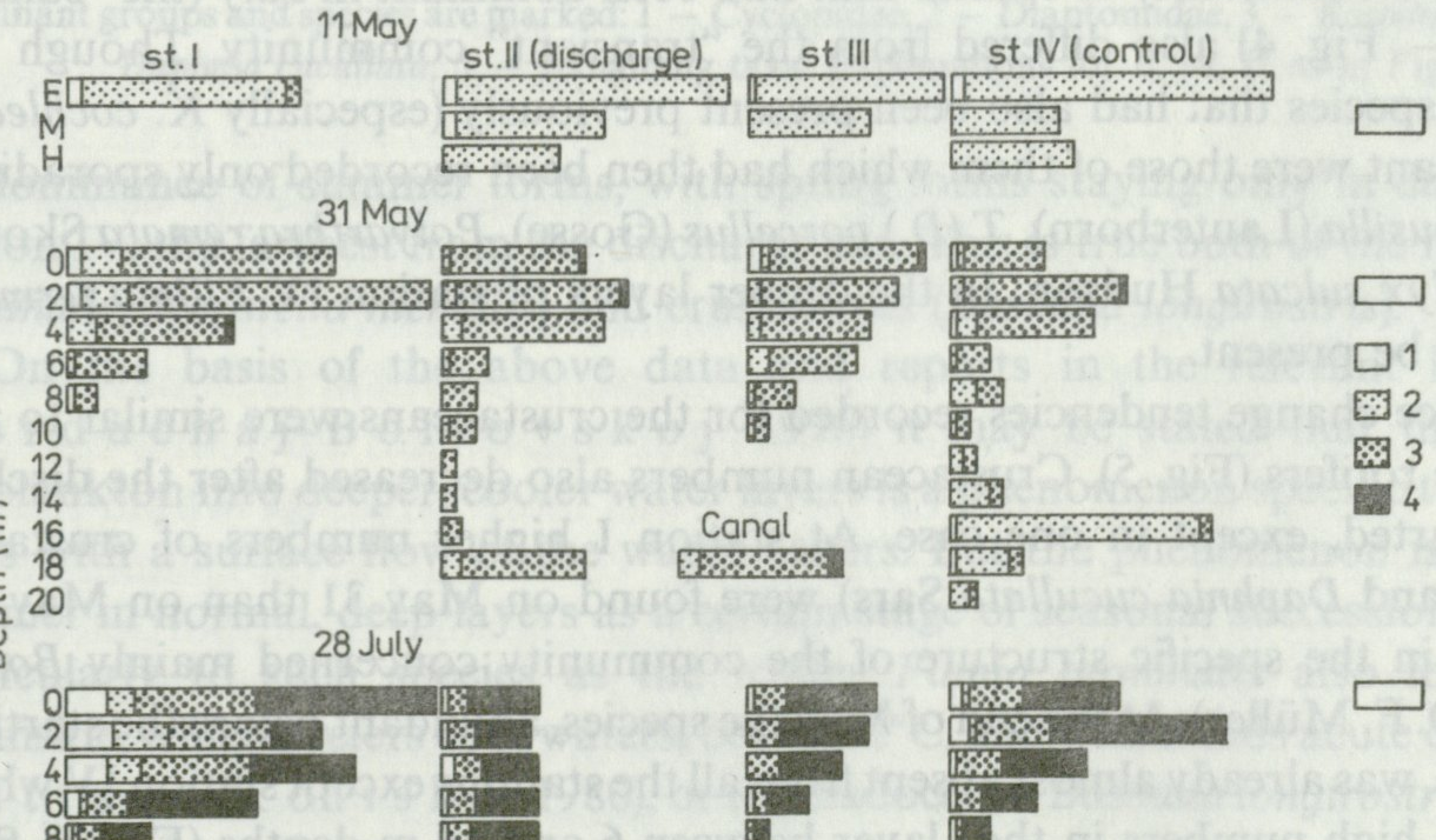

Fig. 4. Horizontal and vertical rotifer variation in Lake Ślesińskie (station location – Fig. 1) in three periods in 1983: before starting the discharge of hot waters (11 May) and during discharging (31 May and 28 July) Marked in the diagrams are numbers of rotifers of 4 seasonal communities: 1 – rotifers that were not dominant in any study period, 2 – "spring" community (*Keratella cochlearis* f. *typica*, *K. quadrata* Müller, *K. hiemalis*, *Conochilus unicornis* Rousselet, *Filinia terminalis*, *Polyarthra dolichoptera*), 3 – "transient" community (*K. cochlearis* f. *tecta*, *Synchaeta kitina*, *S. stylata*, *Polyarthra vulgaris* Carlin), 4 – "summer" community (*Polyarthra remata*, *Trichocerca pusilla*, *T. porcellus*, *Pompholyx sulcata*). E – epi, M – meta, H – hypolimnion

earlier time, while at the remaining stations an almost complete exchange of communities took place.

A clear vertical diversification of rotifers can also be seen, i.e., a decrease in numbers with growing depths at the shallow stations I and III, a drop in the upper layers and growth in the near-bottom layer at stations II and IV. In July a considerable reduction in rotifer numbers with increasing depths was recorded for three stations (I, III and IV). But at station II, near the spring-board, the level of numbers was uniform at all depths, and only at the bottom was it severalfold lower.

The dominance structure of the rotifers varied between the study periods, due to which it was possible to identify communities characteristic of these periods (Fig. 4). At the beginning of May six species of the "spring" community accounted for nearly 90% of the abundance of rotifers. About a dozen days after the starting of the discharge this community disappeared almost completely and was replaced by the community that was dominant in the canal carrying waters from Lake Licheńskie, called here the "transient" community (Fig. 4). So on May 31 dominant at all the stations covered by discharged waters and in the surface layer at station IV were the "summer" species: *Keratella cochlearis* f. *tecta* (Gosse) and *Synchaeta kitina* Rousselet. Species which had dominated there prior to the starting of the discharge (primarily *Keratella hiemalis* Carlin and *Filinia terminalis* (Plate)) stayed only in the meta- and hypolimnion of station IV. The community of species that had been dominant in July (the "summer" community — Fig. 4) also differed from the "transient" community. Though there stayed a few species that had also been present previously (especially *K. cochlearis* f. *tecta*), dominant were those of them which had then been recorded only sporadically: *Trichocerca pusilla* (Lauterborn), *T.* (*D.*) *porcellus* (Gosse), *Polyarthra remata* Skorikov and *Pompholyx sulcata* Hudson. In the deeper layers of station IV *Filinia terminalis* continued to be present.

Abundance change tendencies recorded for the crustaceans were similar to those found for the rotifers (Fig. 5). Crustacean numbers also decreased after the discharge had been started, except in one case. At station I higher numbers of crustaceans (Cyclopidae and *Daphnia cucullata* Sars) were found on May 31 than on May 11.

Changes in the specific structure of the community concerned mainly *Bosmina longirostris* O. F. Müller). At the end of May the species, abundant before the starting of the discharge, was already almost absent from all the stations except station IV where it was found in high numbers in the layer between 6 and 16 m depths (Fig. 5). Small, relatively, changes were found at station I which had earlier been found to be already clearly different because of the dominance of *Daphnia cucullata*. The species remained at that station also after the discharge had been started. In July, the decrease in numbers of the crustaceans at all the stations was accompanied by the disappearance of *Daphnia cucullata* from station I. Thus Cyclopidae and Diaptomidae dominated at all the stations, and the importance also increased of *Daphnia cristata* Sars and *Bosmina coregoni thersites* Poppe. Only at station IV from the depth of 8 m, was a different crustacean structure found, still with a high percentage of *Bosmina longirostris*.

The most conspicuous effect of the discharge of heated waters into Lake Ślesińskie was therefore a rapid change in the structure of the zooplankton towards a

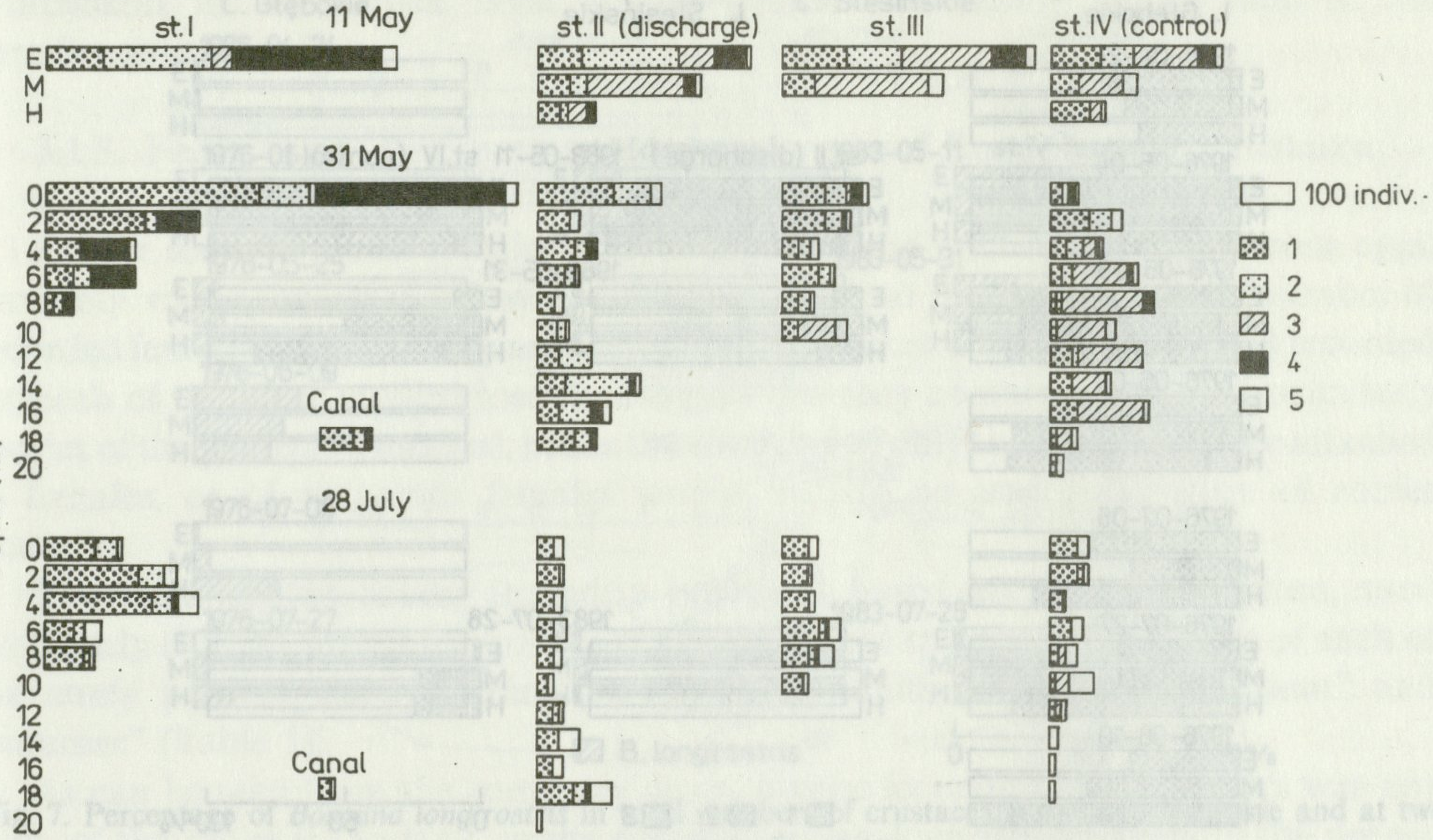

Fig. 5. Numbers of crustaceans at various depths and stations in Lake Ślesińskie before (11 May) starting the discharging and during continued heated-water discharge (31 May, 28 July)

Dominant groups and species are marked: 1 — Cyclopidae, 2 — Diaptomidae, 3 — *Bosmina longirostris*, 4 — *Daphnia cucullata*, 5 — remaining taxa. Explanations for E, M, H as in Figure 4

predominance of summer forms, with spring forms staying only in deeper layers of station IV, the farthest from the discharge site. This is true both of the rotifers (*Filinia terminalis, Keratella hiemalis*) and crustaceans (*Bosmina longirostris*).

On the basis of the above data and reports in the relevant literature (e.g. Morduchaj-Boltovskoj 1976) it may be stated that the "escape" of zooplankton into deeper, cooler water layers is a phenomenon specific to heated, deep lakes with a surface flow of the warm waters. But the phenomenon is often seen in summer in normal, deep layers as a certain stage of seasonal succession. This applies particularly to such species as the rotifer *Filinia terminalis* also found in Lake Ślesińskie, which prefers cool waters, below 12°C, and withstands acute oxygen deficits (Ruttner-Kolisko 1980), or the cladoceran *Bosmina longirostris* (Gulati 1978).

To find out to what extent the "escape" of zooplankton seen at station IV in Lake Ślesińskie corresponds to that observed in an unheated lake, the percentage of *Filinia terminalis* and of the "spring" community in the total numbers of rotifers at two stations in Lake Ślesińskie and in Lake Głębokie (Masurian Lakeland) have been set out for comparison. The composition of the "spring" community in Lake Głębokie corresponded to that found in Lake Ślesińskie (see Fig. 4). The surface area of L. Głębokie is 0.46 km^2, its maximum depth 34.3 m, and average depth 11.8 m. It is a through-flow, moderately eutrophic, elongate water body with two deep hollows (Węgleńska et al. 1983). It is similar to Lake Ślesińskie, but is not heated. It seemed that the lake would be very useful for comparisons.

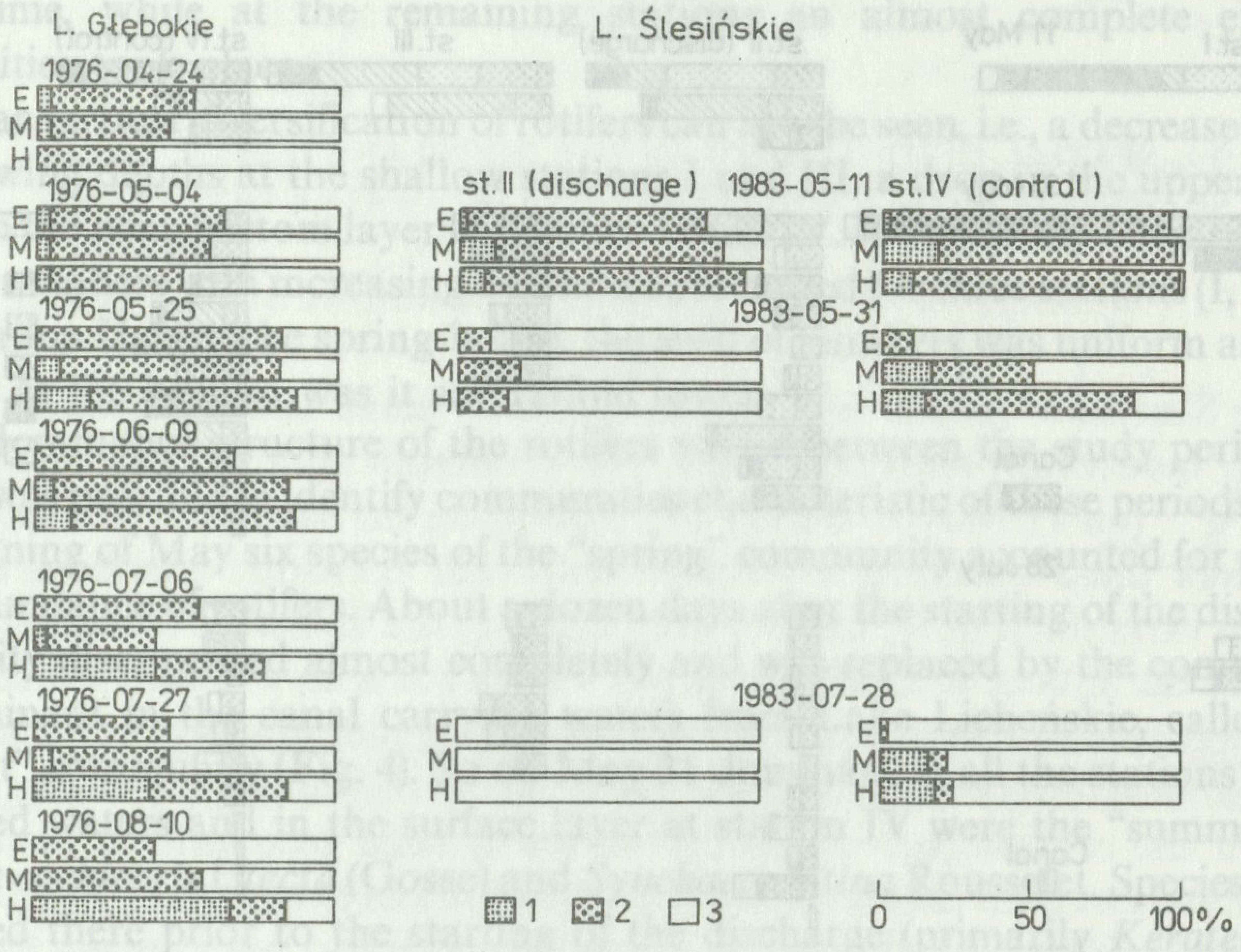

Fig. 6. Percentage of the "spring" community in total numbers of Rotatoria in Lake Głębokie in 1976 and in Lake Ślesińskie at the discharge and control stations in 1983

1 — *Filinia terminalis*, 2 — "spring" community (its composition is given in Figure 4), 3 — other rotifer species, E — epi, M — meta, H — hypolimnion

As can be seen from the summary (Fig. 6), in L. Głębokie the "spring" community was abundant in all layers in May and June, and only in July did the "escape" begin — the proportion of species from the "spring" community increased in the hypolimnion, but it decreased in the upper layers. So the phenomenon observed in L. Ślesińskie at the control station (IV) is natural also to unheated lakes, and what is different is that in L. Ślesińskie the "escape" started much earlier and was more rapid, for within the first dozen or so days of hot-water discharge the "spring" community in the epilimnion was reduced to 10% of the abundance of rotifers, while in L. Głębokie its proportion did not drop below 40% by the end of July (mainly owing to an abundant occurrence of *Keratella cochlearis* f. *typica* Gosse — a form replaced in L. Ślesińskie by *K. cochlearis* f. *tecta*, included in the "transient" community). At station II, near the spring-board, the "escape" phenomenon could not be seen at all. The starting of the heated-water discharge was followed by a rapid drop in abundance, then disappearance from the whole water column of all rotifer species found at this station in spring.

A similar summary has been presented for the crustaceans (Fig. 7), comparing variation in the percentage of *Bosmina longirostris* in the total numbers of crustaceans in both the lakes: Głębokie and Ślesińskie. In this case, too, the "escape" of the cold-water species *B. longirostris* occurred in L. Ślesińskie much earlier (31 May) than in L. Głębokie (at the end of July). Probably due to an isolation of the upper water layers at station IV from the deeper layers, and persistence of very low temperatures (about 4.5°C — Fig. 2) in the hypolimnion, the percentage of *B. longirostris* in the deeper layers of this station was also at the end of July relatively high, while in the

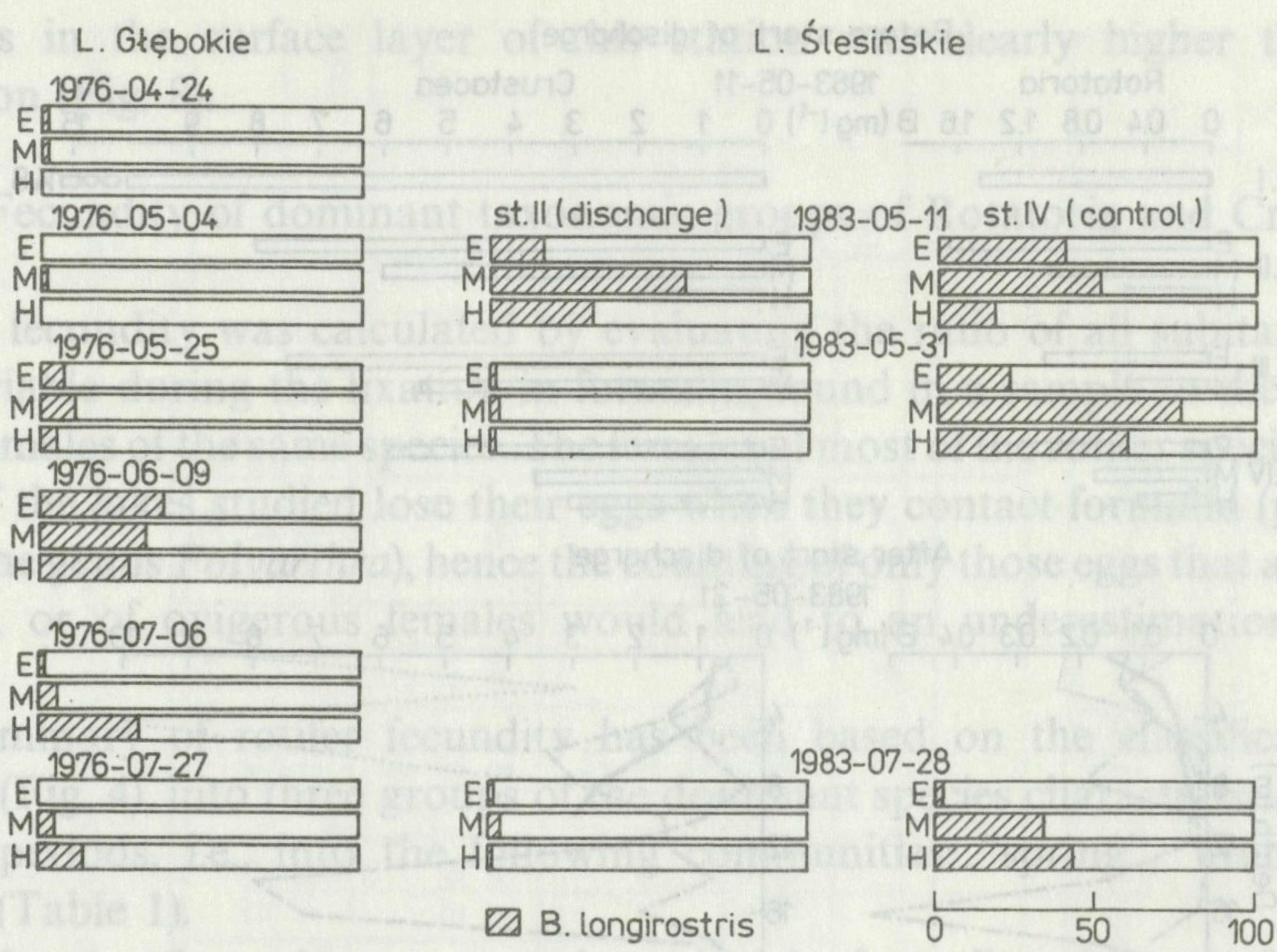

Fig. 7. Percentage of *Bosmina longirostris* in total numbers of crustaceans in Lake Głębokie and at two stations in Lake Ślesińskie
E — epi, M — meta, H — hypolimnion

deeper layers of L. Głębokie in the same season its gradual decrease could already be noticed. As in the case of the "spring" rotifer community, at the near-discharge station *B. longirostris* almost disappeared immediately after the starting of the discharge.

The phenomenon specific to heated lakes would, therefore, be not so much the actual "escape" of the spring forms to unheated, deeper layers as its acceleration, and disturbance of the seasonal cycle at these stations, as the result of an intensive, deep mixing, which make this "escape" impossible. This could be seen at station II near the spring-board (Figs. 6, 7).

3.1.2. Zooplankton biomass

The biomass of the rotifers in Lake Ślesińskie (Fig. 8) was similar to that often found in eutrophic lakes. It was much higher before the starting of the discharge (11 May), not only because of the high rotifer numbers at that time (Fig. 4), but also because the "spring" community included rotifers of higher individual body weights than those found in summer communities. For this reason, the biomass assessed for the surface layer of all the stations was above the level of 1 $mg \cdot l^{-1}$. Following the starting of the discharge there occurred a reduction in numbers and replacement of species by smaller, summer forms (mainly *Keratella cochlearis* f. *tecta* and *Synchaeta kitina*), due to which rotifer biomass decreased considerably and did not usually exceed 0.2 $mg \cdot l^{-1}$. Only in deeper layers of station IV, where species of the "spring" community still occurred in large numbers, did it not exceed the level of 0.5 $mg \cdot l^{-1}$. In July another decrease in the biomass of rotifers was recorded, and the biomass peak in the near-bottom layer of station IV disappeared. It was only at station I that the biomass of the rotifer

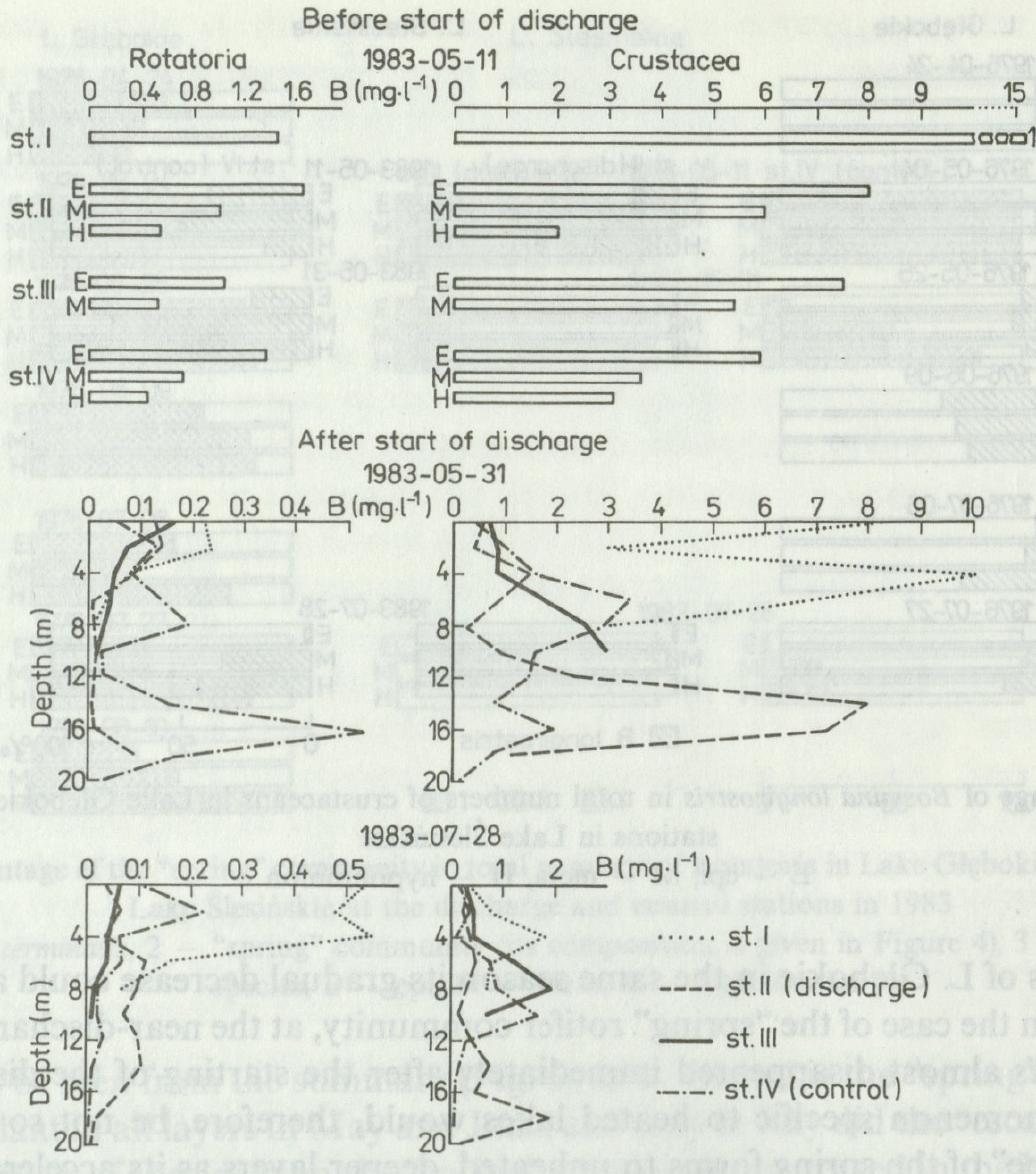

Fig. 8. Rotifer and crustacean biomass at different depths of four stations in Lake Ślesińskie
E — epi, M — meta, H — hypolimnion, B — biomass

community was, due to high numbers of the large-bodied rotifer *Asplanchna priodonta* Gosse, relatively high, above 0.5 mg $\cdot$ l^{-1} in the surface layer.

Crustacean biomass was also comparatively high in the period preceding the starting of the discharge, but very low in July (Fig. 8). The highest biomass quantities of crustaceans were recorded on May 11 at station I, due to higher crustacean numbers at this station and a high percentage of *Daphnia cucullata* at it. After the starting of the discharge the crustaceans continued to be abundant, and the proportion of *D. cucullata* continued to be high, and as a result, the crustacean biomass at this station was still considerably, almost threefold higher than at the remaining stations. This situation was no longer observed in July. In the period following the starting of the discharge a high crustacean biomass was also recorded at depths of 14 and 16 m of station II (close to the discharge). It consisted mainly of Diaptomidae. In the deeper layers of this station crustacean biomass was found to be nearly tenfold higher than in the surface layer. It may be presumed that the migration of crustaceans at this station into deeper layers may have been a direct effect of the warm waters discharged from the spring-board because three weeks earlier a converse situation was seen: the biomass of the crustaceans in the surface layer of this station was clearly higher than in the hypolimnion (Fig. 8).

3.1.3. Fecundity of dominant taxonomic groups of Rotatoria and Crustacea

Rotifer fecundity was calculated by evaluating the ratio of all subitaneous eggs, probably viable during the fixation in formalin, found in a sample to the number of recorded females of the same species. The females of most of the rotifer species recorded for both of the lakes studied lose their eggs when they contact formalin (particularly species of the genus *Polyarthra*), hence the counting of only those eggs that are attached to females, or of ovigerous females would lead to an underestimation of rotifer fecundity.

The summary of rotifer fecundity has been based on the classification, used previously (Fig. 4), into three groups of the dominant species characteristic of each of the study periods, i.e., into the following communities: "spring", "transient" and "summer" (Table 1).

As can be seen from the summary, in spring the fecundity of the rotifers was not high, of the range 0.25–0.44, in the epilimnion and it clearly dropped in the deeper layers. This decrease in fecundity with the depth in principle persisted also in the next study period. A conspicuous decrease in fecundity of the "spring" community in the meta- and hypolimnion was recorded at station IV where the community continued to occur in spite of the fact that the structure of the rotifer communities had changed considerably following the starting of the heated-water discharge. Thus the persistence of this community in the deeper layers at station IV seems to have been caused not so much by its intensive growth there as by its slower retreat from there. This very low fecundity of the "spring" community species in the deeper layers of station IV may also have had an effect on the numbers of the rotifers of this community, which were very low in July.

The fecundity of the rotifers of the "transient" community, brought in by the canal, was at the end of May lower than in Lake Ślesińskie, especially in comparison with station I. This regularity could still be seen in July. This may indicate that when they find themselves in better, relatively, thermal (a lower temperature than in the canal) and trophic (the highest phytoplankton biomass was found at station I) conditions, the rotifers brought in through the canal begin to multiply intensively owing to an increased fecundity.

The highest fecundity was recorded for rotifers of the "summer" community, this high level of fecundity was the result of the dominance in this period of three very fecund species: *Trichocerca pusilla, T.* (*D.*) *porcellus* and *Polyarthra remata.*

The number of eggs per cladoceran and copepod female (Table 2) throughout the study period was the highest at station I and the lowest at stations III and IV. Its maximum level, for all crustacean species, was recorded in spring (prior to the starting of the discharge). But in summer, crustacean fecundity was not very high, typical of moderately eutrophic lakes, and comparable to that found in other heated lakes of the Konin lake system (H i l l b r i c h t - I l k o w s k a et al. 1976). The greatest

Table 1. Fecundity of rotifers representing the following communities: "spring" (Sp), "transient" (T) and "summer" (Su) at 5 stations in Lake Ślesińskie in 1983 (for community compositon explanations see Figure 4)

Date	Layer	Station												Canal	
		I			II			III			IV				
		Sp	T	Su	Sp	T	Su	Sp	T	Su	Sp	T	Su	T	Su
11 May	epi-	0.28			0.25			0.30			0.44				
	meta-				0.13			0.12			0.22				
	hypo-				0.10						0.21				
31 May	epi-	0.20	0.67	3.75		0.36	1.00		0.51	1.58	0.37	0.46	2.66	0.32	1.81
	meta-					0.49	0.57		0.66	0.88	0.03	0.40			
	hypo-					0.29	0.13				0.11	0.40			
28 July	epi-	0.27	0.75	1.29		0.33	0.37		0.39	0.45	0.31	0.41	0.86	0.31	0.19
	meta-					0.27	0.39		0.49	0.83	0.11	0.67	0.75		
	hypo-					0.24	0.34				0.03	0.42	1.08		

Table 2. Fecundity (number of eggs per adult female) of dominant crustacean taxa at 5 stations in Lake Ślesińskie (including the near-discharge station — II and the control one — IV)

Taxon	Layer	11 May				31 May					28 July				
		st. I	st. II	st. III	st. IV	st. I	st. II	st. III	st. IV	canal	st. I	st. II	st. III	st. IV	canal
Cyclopoida	epi-	24.0	20.2	16.0	14.3	—	7.3	4.8	1.8	10.0	8.5	—	7.8	1.2	6.0
	meta-		26.1	20.3	18.1	—	10.1	—	—			—	6.0	5.3	
	hypo-		11.9		22.0		12.6		2.2			1.4		—	
Diaptomidae	epi-	16.3	11.1	4.8	4.8	—	—	2.2	1.4	—	—	—	1.3	—	—
	meta-		8.3	9.5	—		1.9	3.2	6.9			1.9	1.5	3.6	
	hypo-		—		—		3.8		—			3.8			
Daphnia cucullata	epi-	5.8	5.1	2.2	3.5	1.7	1.9	1.7	1.5	6.0	0.9	0.3	0.7	0.7	7.0
	meta-		3.5	1.0	—		2.1	4.7	2.1			0.7	2.9	2.6	
	hypo-		8.0		—		5.8		—			0.5		1.6	
Bosmina longirostris	epi-	6.2	4.2	2.2	3.1	—	—	—	1.1	—	—	—	—	0.5	—
	meta-		3.4	3.0	0.7		1.2		0.4			—	—	0.2	
	hypo-		2.2		4.5		—		0.4			—		0.3	
Bosmina coregoni	epi-	3.0	2.0	2.0	—	1.8	0.7	0.5	—	—	1.7	1.2	1.5	0.9	—
	meta-		1.0	2.3	—		—	—	—			2.0	1.3	—	
	hypo-		1.0		—		—		—			1.3		—	

changes during the study were observed in the case of *Bosmina longirostris*. Ovigerous females of this species could be found at all the stations before the starting of the discharge, whereas in other periods they were only recorded at station IV. However, as in the case of the "spring" community rotifers, following the start of the discharge of heated waters the fecundity of *B. longirostris* in the deeper layers of this station was found to be much lower than it had been in spring. Hence in this case, too, the abundance of this species in the meta- and hypolimnion of station IV was very low both at the end of May and in July. Characteristically, too, the fecundity of Cyclopoida and *Daphnia cucullata* was much higher among females brought in through the canal from L. Licheńskie than in females from the epilimnion of L. Ślesińskie.

3.2. SPATIAL DISTRIBUTION OF THE ZOOPLANKTON OF LAKE GOSŁAWSKIE WITH AN OVERFLOW DISCHARGE OF HEATED WATERS

3.2.1. Numbers and specific structure of Rotatoria and Crustacea

Zooplankton samples were analysed separately for surface and near-bottom layers of each station. A comparison of zooplankton numbers and species structure in both of these layers has revealed no regularity in zooplankton differences between them. For this reason, in all further summaries means values for both the water layers were used.

In Lake Gosławskie, typically a pond-like water body shallow and eutrophic, one could expect high numbers (of the range of several thousand individuals per litre), characteristic of such lakes, of small detritivorous rotifers (K a r a b i n 1983). The abundance of rotifers was not, however, high – on an average several hundred individuals per litre. The highest level of rotifer numbers was recorded in May when its maximum value was recorded at a comparatively cooler station IV_2 (1530 indiv. $\cdot l^{-1}$ – Fig. 9).

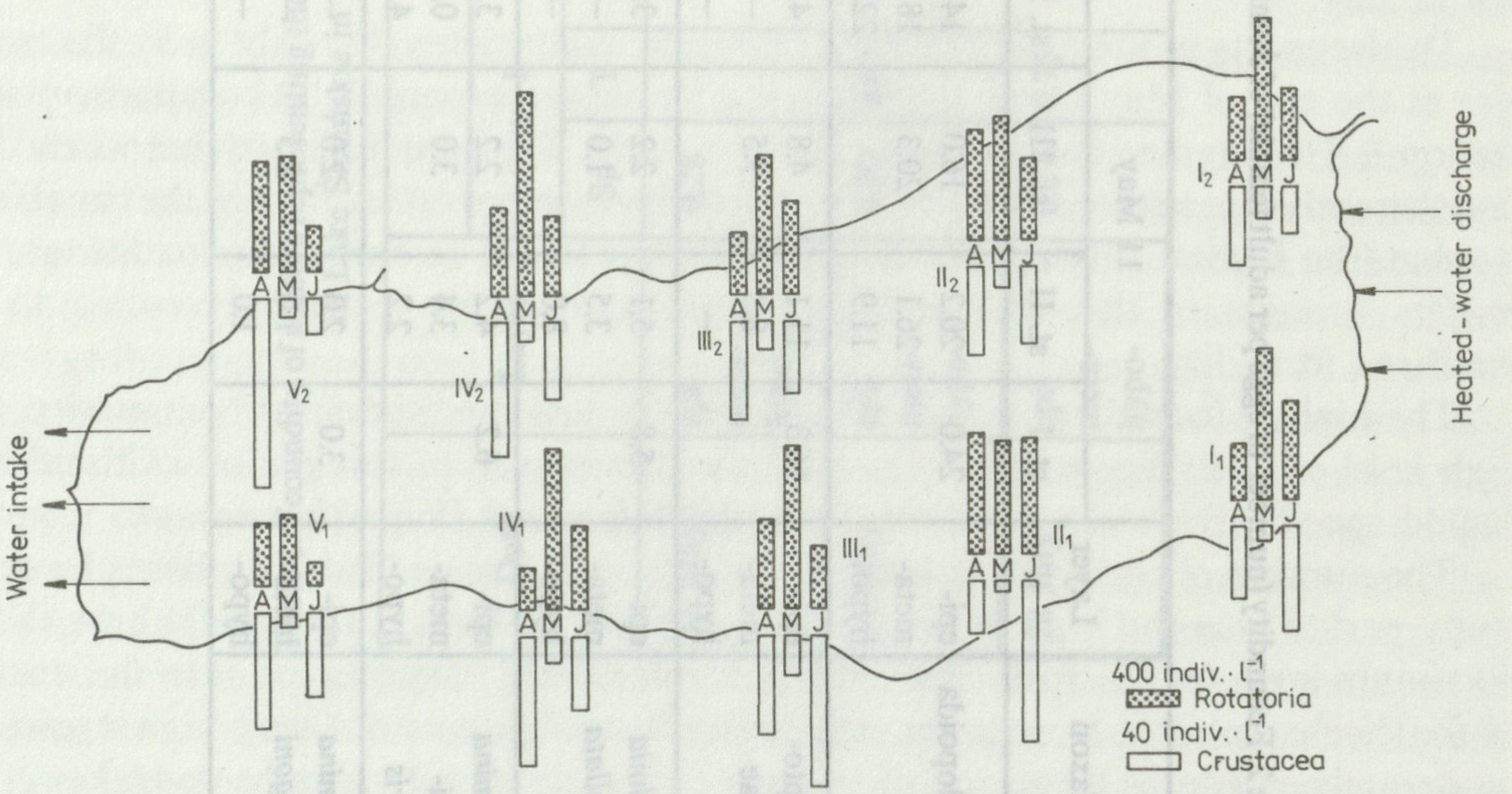

Fig. 9. Total abundance of Rotatoria and Crustacea at three sampling dates (A – 12 April, M – 18 May, J – 31 July, 1984) at particular stations in Lake Gosławskie

Crustacean numbers were also very low, between several to several score individuals per litre, and by contrast to rotifers they were much higher in April than in May. In July the abundance of the crustaceans rose again up to a level similar to that found in April.

Generally, neither the abundance nor species structure of rotifers or crustaceans in Lake Gosławskie showed spatial variation corresponding to the thermal diversification. A certain degree of directional spatial changes in crustacean numbers could only be observed in April. For the abundance of this community at cooler stations (IV, V) was clearly higher than at stations closer to the discharge site (Fig. 9). This may have been due to the dominance in that period of *Bosmina longirostris*, a species that prefers, as indicated by studies in Lake Ślesińskie (Figs. 5, 7), cooler waters.

The specific structure of the zooplankton in Lake Gosławskie was far less variable with time than in Lake Ślesińskie. As indicated by the comparison of the percentages of dominant species in the total numbers of rotifers and crustaceans (Fig. 10), the April community of both the taxonomic groups continued to be dominant also in other study periods. In the rotifer community it included mainly *Synchaeta kitina* and *Keratella cochlearis*. From May on the following were also present in it: *Trichocerca pusilla, Proalides* (probably *P. tentaculatus* Beauchamp, a species found in hypertrophic lakes)

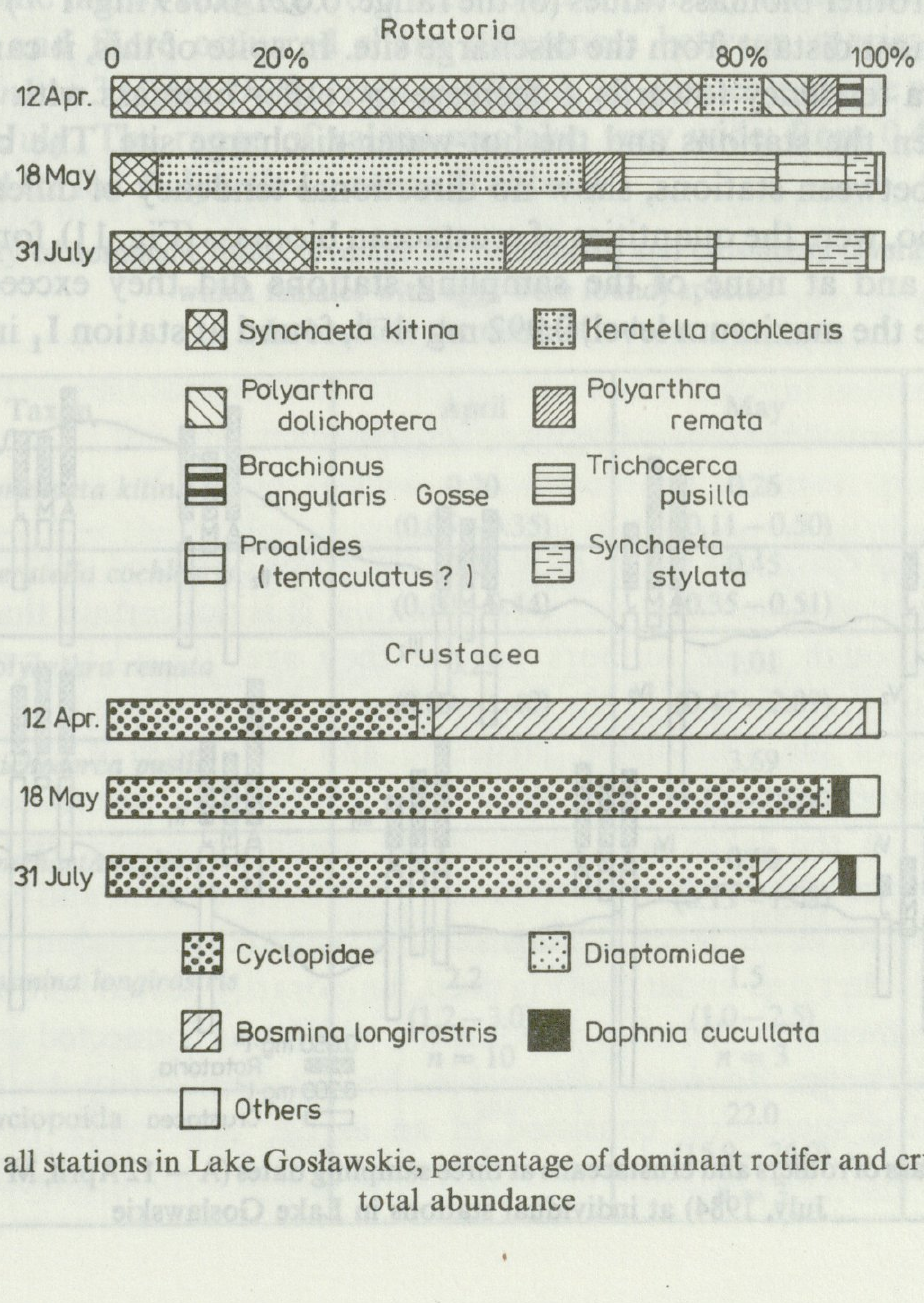

Fig. 10. Mean, for all stations in Lake Gosławskie, percentage of dominant rotifer and crustacean species in total abundance

and *Synchaeta stylata* Wierzejski. No new species appeared in significant numbers in July. A similar lack of more conspicuous seasonal changes was recorded for this lake during round-the-year studies carried out in 1978 (Ejsmont-Karabin and Węgleńska 1988).

The crustacean community at all the study dates consisted primarily of Cyclopoida. In April, dominant also was *Bosmina longirostris*, found also in July, although in smaller numbers. The species which joined the community in May was *Daphnia cucullata*.

Noteworthy is the fact that the April rotifer community resembled the summer rather than the spring communities in unheated lakes. The only spring species whose population declined here in later study periods was *Polyarthra dolichoptera* Idelson, but this species was not very numerous in April either (Fig. 10).

3.2.2. Zooplankton biomass

In Lake Gosławskie the biomass of the zooplankton was low in all the study periods. The highest rotifer biomass level was recorded in April, the maximum quantity having been recorded at station II_1, relatively close to the hot-water discharge site (Fig. 11). The lowest rotifer biomass values (of the range: 0.021-0.089 $mg \cdot l^{-1}$) were recorded at station V_1, most distant from the discharge site. In spite of this, it cannot be stated that there was a tendency towards a decrease in rotifer biomass with the increasing distance between the stations and the hot-water discharge site. The biomass levels, albeit varying between stations, show no directional tendency of differences.

Very low, too, were the quantities of crustacean biomass (Fig. 11), for in none of the study periods, and at none of the sampling stations did they exceed the level of 1 $mg \cdot l^{-1}$, while the maximum level, 0.992 $mg \cdot l^{-1}$, found at station I_1 in July, differed

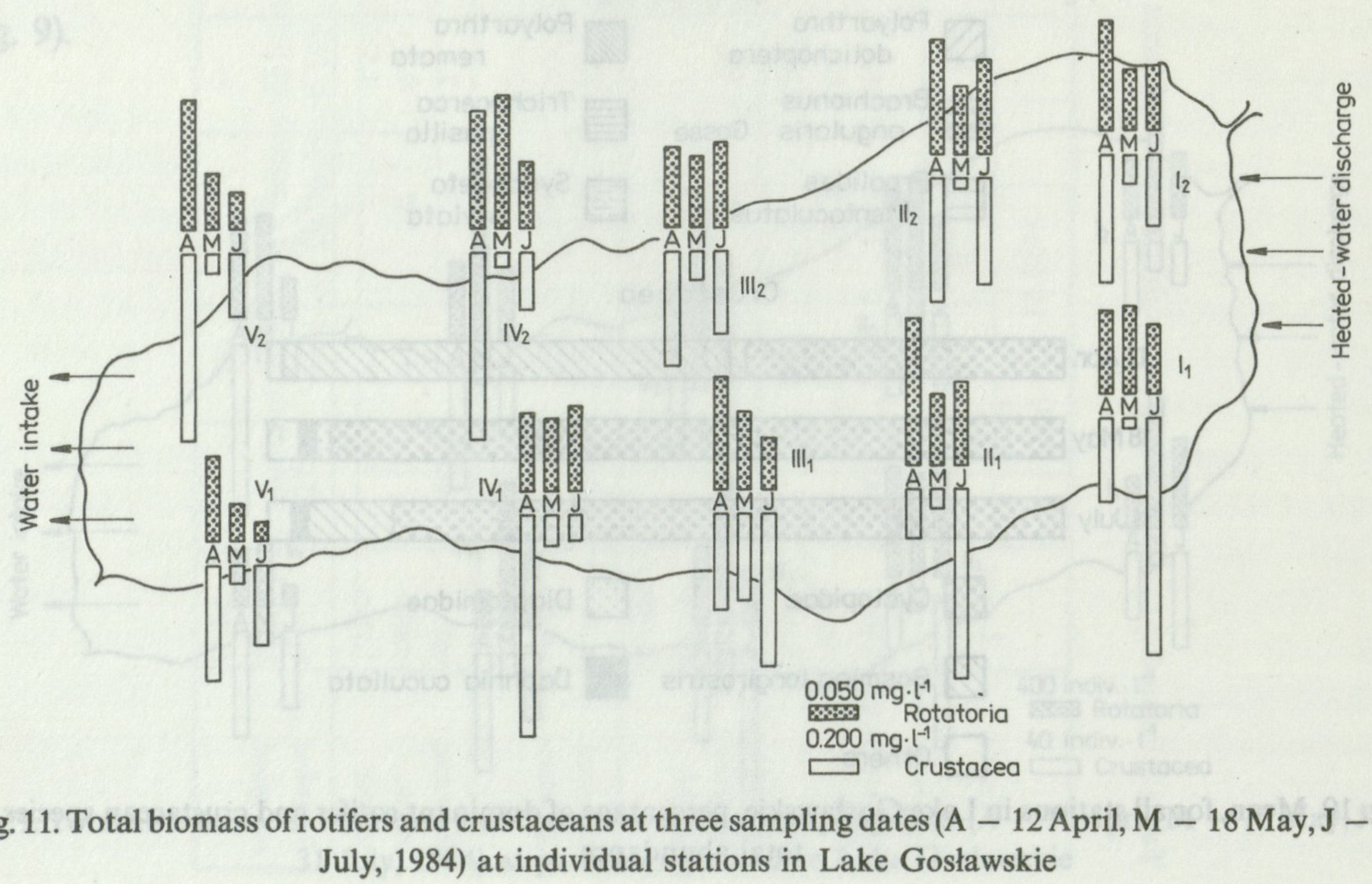

Fig. 11. Total biomass of rotifers and crustaceans at three sampling dates (A — 12 April, M — 18 May, J — 31 July, 1984) at individual stations in Lake Gosławskie

considerably from the values recorded for most of the remaining stations. The lowest biomass quantities were recorded in May (the average per station being 0.110 $mg \cdot l^{-1}$) when the youngest stages of Cyclopoida dominated. In the remaining months: in April (average per station = 0.544 $mg \cdot l^{-1}$) and in July (0.441 $mg \cdot l^{-1}$) they were much higher and, as in the case of numbers, only in April could a tendency be noticed towards higher biomass levels, increasing westwards in the direction of the cooler part of the lake (Fig. 11).

A comparison of the average, for the three study periods, values of zooplankton biomass at the particular stations I – V (0.40, 0.47, 0.47, 0.44 and 0.47 $mg \cdot l^{-1}$) has not revealed any directional zooplankton abundance changes either. Moreover, in this case the sharp differences, seen at the successive study dates, have disappeared.

3.2.3. Fecundity of the dominant taxonomic groups of Rotatoria and Crustacea

The fecundity of the rotifer species dominant in Lake Gosławskie (i.e. the ratio of all the eggs found in a sample to the number of females) clearly increased from month to month (Table 3). In April the fecundity of the three dominant species (*Synchaeta kitina, Keratella cochlearis* and *Polyarthra remata*) was similar and generally low (similar to that in eutrophic lakes), ranging from 0.20 to 0.26. In May these quantities increased considerably, and there occurred sharp differences between species (from 0.26 for *Synchaeta kitina* to 3.69 for *Trichocerca pusilla*). A yet greater increase was recorded for all species in July. The range of values was also very wide: from 0.48 for *Keratella cochlearis* to 4.02 for *Polyarthra remata* (Table 3).

Table 3. Fecundity of dominant rotifer (average for 10 stations) and crustacean (average for n stations at which females with eggs were found) species
In brackets the range of values

Taxon		April	May	July
Rotatoria $n = 10$	*Synchaeta kitina*	0.20 (0.05 – 0.35)	0.26 (0.11 – 0.50)	0.59 (0.17 – 0.94)
	Keratella cochlearis	0.26 (0.10 – 0.44)	0.45 (0.35 – 0.51)	0.48 (0.26 – 0.62)
	Polyarthra remata	0.23 (0.09 – 1.40)	1.01 (0.47 – 2.89)	4.01 (0.92 – 18.06)
	Trichocerca pusilla		3.69 (1.23 – 25.00)	3.20 (1.12 – 15.96)
	Synchaeta stylata		0.50 (0.13 – 1.08)	1.21 (0.32 – 4.33)
Crustacea	*Bosmina longirostris*	2.2 (1.2 – 3.0) $n = 10$	1.5 (1.0 – 2.5) $n = 3$	2.5 (1.5 – 3.0) $n = 3$
	Cyclopoida		22.0 (15.9 – 26.0) $n = 3$	20.0 (18.0 – 22.0) $n = 3$

Fecundity levels over 1.00, recorded for as many as three species (*Polyarthra remata, Trichocerca pusilla* and *Synchaeta stylata*), are very high, and rarely found in even eutrophic lakes. With such a high fecundity the production of these rotifers should also be very high. Studies of the extensive type do not make it possible to calculate the production of a rotifer community, but from estimates of the rate of egg development (D_e) at temperatures prevailing in Lake Gosławskie it can be estimated (with a considerable approximation) that in May and July the circadian $P:B$ for *Keratella cochlearis* would be: 0.3 and 0.4, respectively, and for *Synchaeta kitina* – 0.3 and 0.7. For more fecund species the $P:B$ ratio would be much higher: for *Trichocerca pusilla* (3.8 and 3.6, respectively) and *Polyarthra remata* (1.3 and 6.0). This means that the biomass of the latter two species would be doubled every several hours. Their biomass in Lake Gosławskie was not high, and it does not seem that it was higher immediately after the sampling. Sample taking lasted about 5 hours, during which time there ought to have occurred an increase in the biomass of the most fecund species along the direction of sample taking, from the western to the eastern parts of the lake. No such increase was seen. Furthermore, some time earlier in that lake a relative stability of rotifer numbers and biomass during the summer season had already been observed (Ejsmont-Karabin and Węgleńska 1988).

The plankton crustacean community found in Lake Gosławskie, represented primarily by *Bosmina longirostris* – dominant early in the spring, and Cyclopidae (mainly of the genus *Acanthocyclops*), was throughout the study period characterized by a relatively high fecundity, typical of eutrophic lakes (Table 3). The highest frequency of ovigerous females was found for *Bosmina longirostris*. In April, ovigerous females occurred at all the stations, but the stations did not differ significantly in the fecundity of this species.

4. DISCUSSION

In the two lakes described in this paper the effect was observed of two phenomena: artificially accelerated water flow and water heating. It is not certain that their effects are synergic, although some authors believe they are (Golterman 1976). Nevertheless, the effect of both of the factors had to be considered jointly.

Observations of the abundance, structure and fecundity of the zooplankton indicate that higher water temperatures, due to heating, combined with their accelerated flow in the lakes considered bring about primarily two phenomena: changes in the course of the seasonal succession of the zooplankton and an acceleration of the cycle of matter in the lakes. Changes in the seasonal succession, although they occur in both the lake types under study (a deep, temporarily heated lake, and a shallow one, heated permanently), differed in their nature, which was connected with the way of heated-water discharge. In Lake Ślesińskie, heated from May to October, the disturbance in the succession consisted in an earlier occurrence of the summer communities in the surface layers of all the stations, and in a simultaneous destruction of the natural stratification in the occurrence of zooplankton species at different depths at stations located closer to the site of heated-water discharge. Until the discharge started, the course of succession had been similar to that in unheated lakes. After the starting of the discharge, and most likely displacement of the spring forms by the summer zooplankton community brought in through the canal from Lake Licheńskie, the native community of Lake Ślesińskie persisted only in the deeper layers of the station located the farthest from the discharge site. As a result of the surface flow of the heated waters at this station, a sharp thermal gradient and water stratification still occurred there in July, enabling the spring forms to stay in the meta- and hypolimnion.

At stations located within the range of action of the discharge across their depth water mixing, disturbed stratification and thereby loss of the communities present in summer in the hypolimnion of many deep, eutrophic lakes (cold-water or eurythermic rotifer species enduring considerable oxygen deficits — Ruttner-Kolisko 1977b), as well as intensified competition, due to the fact that vertical separation of species is impossible, should lead on to a reduced specific diversity of the zooplankton due to a reduced spatial heterogeneity (Pianka 1974). Such a reduction in community diversity of rotifers and crustaceans has indeed been found at station II, mixed to the bottom in comparison with stratified station IV (Table 4). However, in spite of the fact that following the starting of the discharge stratification disturbance in all cases brought about a decrease in species diversity, the decrease was relatively small, and besides, the Species Diversity Index values for both stations were relatively high. This may indicate that the environment still offers a wide variety of possibilities, probably trophic, because other factors, particularly a lack of habitat stability (due to a high through-flow rate) ought to lead on to the reverse situation — species diversity decrease.

Seasonal-succession changes seen in a shallow Lake Gosławskie which has been heated round-the-year for a dozen or so years were of a different nature. The difference in succession was in this case manifested by a considerable reduction, or even absence of the phenomenon of spring species replacement by summer species during the summer period. For the rotifer community seen at the beginning of spring (in April) little differed in its composition from the summer community. In the crustacean

Table 4. Comparison of the Species Diversity Index value (H_b) calculated from the biomass of rotifer and crustacean communities for two stations in Lake Ślesińskie: II — near the discharge site, mixed to the bottom from May 31, and IV — the control one, with a strong thermal stratification

Date	Rotatoria		Crustacea	
	st. II	st. IV	st. II	st. IV
11 May	2.581	2.380	2.133	2.205
31 May	2.763	3.005	1.742	2.078
28 July	2.874	3.369	2.394	2.648

community the cladoceran *Bosmina longirostris* present in the spring, relatively sensitive to thermal shocks (V a n U r k 1975), was ousted, as early as May, by Cyclopidae which clearly better withstand higher temperatures. Lake Gosławskie has been heated for so many years that it is probable that the reduced variation in the zooplankton specific composition in summer may be an established, peculiar to this lake, succession caused by higher water temperatures, and particularly a lack of ice cover.

Characteristically, small water temperature differences, of several degrees, do not seem to play a significant role in the spatial distribution of the zooplankton. This becomes clear if the fact is taken into account that the temperatures recorded in both the lakes in July are also near the range of optimum temperatures for the growth of most of the species found there, and in no circumstance could they be lethal. For, as indicated by v a n U r k's (1979) studies, only temperatures above 30°C, and only under thermal shock conditions, cause a considerable mortality growth of the crustacean zooplankton. Studies of the survivorship of rotifers at high temperatures, carried out by H o r k a n et al. (1977) also confirm that temperatures of the range of 20 – 25°C should not be lethal for the summer forms of rotifers. It may therefore be presumed that the starting of the discharge of heated waters into Lake Ślesińskie may have brought about drastic changes in zooplankton structure (a rapid rise of water temperature and arrival of zooplankton communities new to this lake and to the season). In Lake Gosławskie the changes would occur slowly, or, which seem more likely, following the heating of the waters of this lake for over a dozen years, the changes are a seasonal succession peculiar to it.

Observable differences in the horizontal distribution of the zooplankton can therefore be attributed to differences in the food supplies available at the various stations. This is conspicuous in Lake Ślesińskie, where at station I with a clearly higher phytoplankton abundance considerably higher (than at other stations) zooplankton numbers were also recorded (Figs. 4, 5).

This phenomenon does not, however, occur in Lake Gosławskie, where no directional diversification could be seen in the horizontal distribution of the phytoplankton (S i m m 1988). Observable differences in zooplankton abundance between stations may be of a fortuitous nature, caused by the water flow direction in this lake and occurrence of local density gradients of the suspension carried by waters. An exception here is the distribution of *Bosmina longirostris* in April, clearly affected by the temperature.

Another phenomenon observed in both lakes, though more conspicuous in Lake Gosławskie, is a comparatively high fecundity of most zooplankton species during the period of intensive heating of the lake waters. This high fecundity of the zooplankton can be ascribed to the continuous input of food, with the warm waters discharged, which increases further as a result of the acceleration of the nutrient cycle by higher temperatures. Such a supposition seems to be confirmed by the fact that zooplankton fecundity is higher in Lake Ślesińskie than in the canal carrying heated waters. When there is much food, the rate of egg laying can be higher than the rate of their development, which can lead to egg accumulation. A phenomenon of this kind is often observed in cultures (G. A. Galkovskaja — personal communication). Thus, the extremely high fecundity of the dominant rotifer species in Lake Gosławskie may be the result of such an accumulation of eggs.

High temperatures can also be a significant cause of such a high fecundity level. According to E d m o n d s o n (1965), the thermal factor increases the reproductive rate (eggs · female^{-1} · day^{-1}) more than other factors. Likewise, G a l k o v s k a j a and M i t j a n i n a (1983) have found that of the agents they studied: light, food and temperature, temperature had the strongest effect on the number of eggs laid by a *Brachionus calyciflorus* (Pall.) female during her life.

One other noteworthy factors is the low stability of the environment with a high through-flow rate. A lack of environmental stability may prevent (P i a n k a 1974) a population from being saturated with individuals, and thereby intensify selection through rapid reproduction (*r*-selection).

Such *r*-selected populations as a rule have wide tolerance limits and relatively large niches, which is confirmed by the absence from both the lakes of narrow-specialization species (e.g. of the family Gastropodidae among rotifers).

Thus, the high fecundity of the zooplankton can be explained in several ways and there are probably several factors acting simultaneously.

Though the fecundity is so high, the abundance of the zooplankton is relatively low. The low level of zooplankton numbers also when their production is high indicates that the mortality of this community should also be very high. It is, however, difficult to point out the causes of such an intensive elimination of the zooplankton. In principle it should not be a high temperature as far as a direct effect is concerned. It is likely, however, that temperature can increase the natural mortality of the zooplankton by accelerating the life cycle, that is to say, shorten the individual life-span.

It does not seem likely, either, that a high-rate through-flow of waters, or even water discharge from a spring-board can cause such a high mortality of the zooplankton. Evidence can be sought here in an analysis of the proportion of dead individuals in a rotifer population (i.e. dead and living individuals counted together). Such an analysis was made possible by the recording of dead rotifers found in each of the samples examined. No depth-dependent directional changes in the percentage of dead individuals were found, so in the analysis average values for the whole water column were used (Table 5). As can be seen from the summary, station II (the closest of all to the discharge site), where an exceptionally high mortality could be expected, was not characterized by a higher percentage of dead individuals than were other stations.

Table 5. Percentage of dead and damaged individuals in the rotifer community (average per water column) in Lake Ślesińskie prior to the starting of heated-water discharge (11 May) and during discharging (31 May, 28 July)

Date	St. I	St. II near discharge	St. III	St. IV control
11 May	9	10	9	9
31 May	9	8	5	12
28 July	14	21	29	30

Higher mortality cannot be ascribed to the predation by invertebrates, either. For the predators occurred in both the lakes in rather small numbers, and moreover, Cyclopoida, which were dominant among them, were mainly represented by non--predatory, juvenile stages.

Another cause could be a high fish pressure. In the lakes of the Konin lake system there has indeed been a decrease in catches of valuable, i.e., large fish in favour of small fish, as the roach, bream and white bream (R o b a k 1985). A high fecundity was, however, recorded for very small rotifers which could be eaten intensively only by planktivorous fish (filter-feeders). The above-enumerated fish species are considered visual predators (L a z a r r o — in press). A high fish pressure could thus be an explanation only in the case of Lake Gosławskie, since 1973 stocked with the bighead carp and silver carp, that is, planktivorous fish. The effect of these two fish species can perhaps account for the difference in rotifer fecundity (and mortality) between lakes Ślesińskie and Gosławskie.

An additional cause could perhaps be a higher mortality of embryos at high temperatures, as a higher mortality could favour egg infection by bacteria and fungi. It has been known from the authors' own studies and from B a k e r ' s (1979) communication that it is very difficult to keep the eggs of many rotifer species in culture till the hatching because of their being attacked by bacteria and fungi.

From the above it follows that also in the case of a higher zooplankton mortality in heated lakes possible effects of many agents can be suggested. The causes of both a higher fecundity and mortality are most likely complex, and there coincide several factors acting in the same direction.

Changes in zooplankton structure and numbers caused by the inclusion of Lake Lukom'skoe in a cooling system, observed by M i t r a c h o v i č et al. (1983), were very similar to those presented in this paper. A decrease in abundance was observed in all communities, particularly in rotifers. At the same time *Chydorus sphaericus* (O. F. Müller) disappeared from the zooplankton, whereas the importance increased of species from the genera *Synchaeta* and *Polyarthra*.

Noteworthy is the fact that neither in Lake Lukom'skoe nor in either of the two lakes described in this paper was a dominance recorded during high temperatures of bacterio-detritivorous rotifer species as high as in unheated eutrophic lakes. For in addition to detritivorous species, as *Keratella cochlearis* and *Pompholyx sulcata* the following were dominant: *Synchaeta kitina, S. stylata* and *Polyarthra remata,* that is, small forms but herbivorous, as well as species of the genus *Trichocerca* considered omnivorous (D u m o n t 1977). This should favour faster sedimentation of the detritus less used by the zooplankton. Thus, an increased detritus sedimentation rate may be added to the factors described by H i l l b r i c h t - I l k o w s k a and S i m m (1988) as responsible for high nutrient concentrations in the near-bottom layer of Lake Ślesińskie, such as seston entrainment by water motion and release by bottom sediments.

In summing up it seems that the factors controlling the standing crop and functioning of zooplankton communities in heated lakes are higher temperatures and the mictic state brought about by the discharge of heated waters. In addition to factors common to both lakes but caused directly or indirectly by higher temperatures, as an earlier occurrence of the summer zooplankton communities, or their higher, relatively, fecundity, there are also considerable differences between them, dependent on the mode of heated-water discharge. For seasonal heating of Lake Ślesińskie causes rapid changes in zooplankton structure following the starting of the discharge, and high zooplankton variation in the next period; it also increases the horizontal diversity of habitats, and thereby also the structure of plankton communities, by changing particular parts of a lake into mixed and stratified zones. All-the-year and long-term heating of Lake Gosławskie, and the overflow mode of heated-water discharge favour narrow variation, spatial and temporal, in its zooplankton. In both cases the discharge of heated waters brings about considerable changes in the structure and functioning of the zooplankton, but the direction of the changes is different in each of the lakes.

5. SUMMARY

In two lakes of the Konin lake system the response was studied of the zooplankton to the discharge of heated waters into them. The lakes under study differed in respect of the way of heated-water discharge and morphometry: a deep and dimictic Lake Ślesińskie (heated seasonally) and a polymictic Lake Gosławskie, heated constantly (Fig. 1).

In Lake Ślesińskie heating and mixing to the bottom involved stations close to the discharge site; a station located the farthest from the heated-water discharge site retained thermal stratification (Fig. 2). But in Lake Gosławskie a uniform fall of temperature could be seen with increasing distance from the discharge site, as well as vertical temperature variation in the lake part near the discharge (Fig. 3).

Rotifer and crustacean numbers and biomass were in both of the lakes low (Figs. 4, 5, 8, 9, 11). The starting of heated-water discharge into Lake Ślesińskie resulted in the replacement in it of spring zooplankton species by a zooplankton community brought in from Lake Licheńskie with the water discharged through a canal (Fig. 4). The spring community persisted only in the meta- and hypolimnion at a station lying the farthest from the discharge site. It has been demonstrated, however, that such an "escape" of zooplankton into deeper layers at rising temperatures of the surface waters and formation of a thermal stratification is also found in unheated deep lakes (Figs. 6, 7). So the most significant change in the functioning of Lake Ślesińskie, as compared with unheated lakes, is an earlier change of the zooplankton structure into one that is typical of the summer period, and the making it impossible for the cold-water zooplankton to "escape" into deeper layers at stations mixed to the bottom by heated waters discharged from a spring-board. In Lake Ślesińskie, water mixing at the near-discharge station reduced the spatial diversification of the environment, and thereby the species diversity of the rotifer and crustacean communities in comparison to a thermically-stratified station. In spite of this, species diversity continued to be fairly high, indicating that the possibilities offered by the environment were still wide (Table 4).

In Lake Gosławskie, the disturbance of the seasonal succession typical of unheated lakes consited in an earlier (from April on) dominance of summer forms (Fig. 10). Directional thermal diversification of the waters in this lake was not accompanied by directional changes in zooplankton abundance and structure (Figs. 9, 11).

Rotifer and crustacean fecundity was in both the lakes high, especially in the period of the most intensive heating of the waters (Tables 1–3), being much higher in Lake Gosławskie. The possible causes of this high fecundity are considered.

Thus, in both the lakes studied the discharge of heated waters brings about great changes in zooplankton structure and functioning, but the direction of the changes is in each of them different.

6. POLISH SUMMARY

Badano reakcję zooplanktonu dwu jezior z systemu jezior konińskich na wprowadzanie do nich wód podgrzanych. Badania wykonano na jeziorach zróżnicowanych pod względem sposobu wprowadzania wód podgrzanych oraz morfometrii: głębokim i dymiktycznym Jeziorze Ślesińskim (podgrzewanym okresowo) oraz polimiktycznym, podgrzewanym stale Jeziorze Gosławskim (rys. 1).

W Jeziorze Ślesińskim podgrzaniu i wymieszaniu do dna uległy stanowiska przyzrzutowe; stanowisko najbardziej odległe od zrzutu wód ciepłych zachowało stratyfikację termiczną (rys. 2). W Jeziorze Gosławskim natomiast notowano równomierny spadek temperatury w miarę oddalenia od zrzutu oraz zróżnicowanie temperatur w pionie w przyzrzutowej części jeziora (rys. 3).

Liczebności wrotków i skorupiaków, jak też ich biomasy w obu jeziorach były niewysokie (rys. 4, 5, 8, 9, 11). Włączenie zrzutu ciepłych wód do Jeziora Ślesińskiego spowodowało wyparcie zeń wiosennych gatunków zooplanktonu przez zespół zooplanktonowy napływający kanałem z Jeziora Licheńskiego (rys. 4). Zespół wiosenny utrzymał się tylko w meta- i hypolimnionie stanowiska najbardziej oddalonego od zrzutu. Wykazano jednak, że taka „ucieczka" zooplanktonu do warstw głębszych w miarę wzrostu temperatury wód powierzchniowych i zakładania się stratyfikacji termicznej jest typowa również dla nie podgrzewanych głębokich jezior (rys. 6, 7). Najistotniejszą więc zmianą w funkcjonowaniu Jeziora Ślesińskiego w porównaniu z jeziorami nie podgrzewanymi jest wcześniejsza zmiana struktury zooplanktonu na typową dla okresów letnich oraz uniemożliwienie „ucieczki" chłodnolubnego zooplanktonu do warstw głębszych na stanowiskach mieszanych do dna przez zrzut wód podgrzanych z trampoliny. Wymieszanie wód stanowiska przyzrzutowego na Jeziorze Ślesińskim spowodowało zmniejszenie zróżnicowania przestrzennego środowiska i w efekcie niższą różnorodność gatunkową zespołów wrotków i skorupiaków w porównaniu ze stanowiskiem stratyfikowanym termicznie. Mimo to zróżnicowanie gatunkowe było nadal stosunkowo wysokie, świadcząc o szerokiej nadal ofercie środowiska (tab. 4).

W Jeziorze Gosławskim zachwianie naturalnej dla jezior nie podgrzewanych sukcesji sezonowej polegało na wcześniejszej (już od kwietnia) dominacji form letnich (rys. 10). Kierunkowemu zróżnicowaniu termicznemu wód tego jeziora nie towarzyszyły kierunkowe zmiany w obfitości i strukturze zooplanktonu (rys. 9, 11).

Płodność wrotków i skorupiaków w obu jeziorach była wysoka, zwłaszcza w okresie maksymalnego podgrzania wód (tab. 1–3) i znacznie wyższa w Jeziorze Gosławskim. Rozważane są ewentualne przyczyny tak wysokiej płodności wrotków.

W przypadku więc obu jezior wprowadzanie wód podgrzanych powoduje silne zmiany w strukturze i funkcjonowaniu zooplanktonu, lecz w każdym z badanych jezior zmiany te mają inny kierunek.

7. REFERENCES

1. Baker R. L. 1979 — Birth rate of planktonic rotifers in relation to food concentration in a shallow, eutrophic lake in western Canada — Can. J. Zool. 57: 1206–1214.
2. 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.
3. Dumont H. J. 1977 — Biotic factors in the population dynamics of rotifers — Arch. Hydrobiol. Beih. (Ergebn. Limnol.), 8: 98–122.
4. Edmondson W. T. 1965 — Reproductive rate of planktonic rotifers as related to food and temperature in nature — Ecol. Monogr. 35: 61–111.
5. Ejsmont-Karabin J., Węgleńska T. 1988 — Disturbances in zooplankton seasonality in Lake Gosławskie (Poland) affected by permanent heating and heavy fish stocking — Ekol. pol. 36: 245–260.

6. G a l k o v s k a j a G. A., M i t j a n i n a I. F. 1983 – Sposobnost' k partenogenetičeskomy vosproizvedeniju u kolovratki *Brachionus calyciflorus* Pallas pri wysokich temperaturach – Dokl. AN BSSR, 27: 184–186.

7. G o l t e r m a n H. L. 1976 – Some theoretical considerations of thermal discharge in shallow lakes – H_20 negende Jaargang, 1: 1–8.

8. G u l a t i R. D. 1978 – The ecology of common planktonic Crustacea of the freshwaters in the Netherlands – Hydrobiologia, 59: 101–112.

9. H i l l b r i c h t - I l k o w s k a A., E j s m o n t - K a r a b i n J., W ę g l e ń s k a T. 1988 – Long-term changes in the composition, productivity and trophic efficiency in the zooplankton community of heated lakes near Konin (Poland) – Ekol. pol. 36: 115–144.

10. H i l l b r i c h t - I l k o w s k a A., P a t a l a s 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.

11. H i l l b r i c h t - I l k o w s k a A., S i m m A. T. 1988 – Spatial pattern of temperature, oxygen and nutrient concentration in two lakes of different heated-water discharge systems – Ekol. pol. 36: 165–182.

12. H i l l b r i c h t - I l k o w s k a A., Z d a n o w s k i B., 1978 – Effect of thermal effluents and retention time on lake functioning and ecological efficiencies in plankton communities – Int. Revue ges. Hydrobiol. 63: 609–617.

13. H i l l b r i c h t - I l k o w s k a A., Z d a n o w s k i B. 1988 – Changes in lake ecosystems connected with the power-generating industry (the outline of problem); the Konin lakes (Poland) as the study sites – Ekol. pol. 36: 5–21.

14. H i l l b r i c h t - I l k o w s k a A., Z d a n o w s k i B., E j s m o n t - K a r a b i n A., W ę g l e ń s k a T. 1976 – Produkcja pierwotna i wtórna planktonu jezior podgrzanych [Primary and secondary production of plankton in heated lakes] – Rocz. Nauk roln. 97-H-3: 69-88.

15. H o r k a n J. P., G a l l u p D. N., N u r s a l l J. R. 1977 – Effects of thermal effluent upon the planktonic Rotifera – survival and egg production – Arch. Hydrobiol. Beih. (Ergebn. Limnol.), 8: 84–87.

16. K a r a b i n A. 1983 – Ecological characteristics of lakes in northeastern 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.

17. L a z a r r o X. (in press) – A review of planktivorous fishes: their evolution, feeding behaviour, selectivities and impacts – Hydrobiologia.

18. M a r g a l e f R. 1957 – Information theory in ecology – Gen. Syst. 3: 36–71.

19. M i t r a c h o v i č P. A., L a c h n o v i č V. P., B o j k o v a S. A. 1983 – Zooplankton ozera Lukom'skogo v uslovijach vlijanija TES – Gidrobiol. Ž. 19: 60–63.

20. M o r d u c h a j - B o l t o v s k o j F. D. 1976 – Vlijanie teplovych elektrostancij na fito- i zooplankton vodochranilišč na Volge (In: Sbornik dokladov simp. po issledovaniju vlijanija podogretych vod na termičeskij i biologičeskij režimy vodoemov) – Inst. Meteorologii i Gosp. Wodnej, Warszawa, 403–421.

21. P a t a l a s K. 1970 – Primary and secondary production in a lake heated by thermal power plant – Proc. of the 1970 annual Technical Meeting of the Institute of Environmental Sciences, Boston, 267–271.

22. P i a n k a E., 1974 – Evolutionary ecology – Harper and Row Publ., Ny-Evanston – San Francisco – London, 334 pp.

23. P ó ł t o r a c k a J. 1968 – Specific composition of phytoplankton in a lake warmed by waste water from a thermoelectric plant and lakes with a normal temperature – Acta Soc. Bot. Pol. 37: 297-325.

24. R o b a k S. 1985 – Charakterystyka zmian warunków siedliskowych i troficznych oraz połowów ryb w podgrzanych jeziorach konińskich [Description of changes in the habitat and trophic conditions, and in fish catches in heated lakes near Konin] – Ph. D. Thesis, Dept. of Hydrobiology, Inland Fisheries Institute, Olsztyn, 44 pp.

25. R u t t n e r - K o l i s k o A. 1977a – Suggestions for biomass calculations of planktonic rotifers – Arch. Hydrobiol. Beih. (Ergebn. Limnol.), 8: 71–76.

26. R u t t n e r - K o l i s k o A. 1977b — Population dynamics of rotifers as related to climatic conditions in Lunzer Obersee and Untersee — Arch. Hydrobiol. Beih. (Ergebn. Limnol.), 8: 88—93.
27. R u t t n e r - K o l i s k o A. 1980 — The abundance of distribution of *Filinia terminalis* in various types of lakes as related to temperature, oxygen and food — Hydrobiologia, 73: 169—175.
28. S i m m A. 1988 — Spatial distribution of the phytoplankton in two lakes in relation to the through-flow of heated waters — Ekol. pol. 36: 183—202.
29. S o s n o w s k a J. 1974 — Plankton roślinny w jeziorach Licheńskim i Ślesińskim [The phytoplankton of lakes Licheńskie and Ślesińskie] — Gosp. rybna, 5: 15—17.
30. S p o d n i e w s k a I. 1984 — Biomass and structure of phytoplankton in Konin lakes in the years 1976—1980 — Ekol. pol. 32: 289—306.
31. S t a ń c z y k o w s k a A., L e w a n d o w s k i K., E j s m o n t - K a r a b i n J. 1988 — The abundance and distribution of the mussel *Dreissena polymorpha* (Pall.) in heated lakes near Konin (Poland) — Ekol. pol. 36: 261—273.
32. V a n U r k G. 1979 — The effect of a temperature shock on zooplankton — Hydrob. Bull. 13: 101—105.
33. W ę g l e ń s k a T., B o w n i k - D y l i ń s k a L., E j s m o n t - K a r a b i n J. 1983 — Biotic structure and processes in the lake system of r. Jorka watershed (Masurian Lakeland, Poland). VI. Structure and dynamics of zooplankton — Ekol. pol. 31: 679—717.
34. Z d a n o w s k i B. 1976 — Wieloletnie zmiany w produkcji pierwotnej pelagialu jezior podgrzanych [Long-term changes of primary production in the pelagic zone of heated lakes] — Rocz. Nauk roln. 97-H-3: 123-139.
35. Z d a n o w s k i B., K o r y c k a A., G ę b i c k a A. 1988 — Long-term variation in habitat and trophic factors in the Konin lakes (Poland) under the influence of heated-water discharge and pollution — Ekol. pol. 36: 47—77.

(*Received 29 January 1987*)