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Anna HILLBRICHT-ILKOWSKA

Department of Hydrobiology,

Institute of Ecology, Polish Academy of Sciences,

Dziekanów Leśny (near Warsaw), 05-092 Łomianki, Poland

BIOTIC STRUCTURE AND PROCESSES IN THE LAKE SYSTEM OF R. JORKA WATERSHED (MASURIAN LAKELAND, POLAND)

XII. PRODUCTIVITY, STRUCTURE AND DYNAMICS OF LAKE BIOTA (A SYNTHESIS OF RESEARCH)*

ABSTRACT: A comparison of the primary production (^{14}C), its PHAR efficiency, daily P : B ratio, and the composition, biomass and dynamics of the phytoplankton, zooplankton and bacterioplankton, of the littoral and profundal benthos, as well as of the emergent and submerged vegetation of five lakes connected by the Jorka river indicates a consistent pattern of mesotrophic status in L. Majcz Wielki (deep, dimictic), of eutrophic status in L. Inulec and L. Jorzec (shallow, with a high internal and external loading), and of "mixotrophic" status in Głębokie L. (deep, dimictic) - originally mesotrophic, but at present enriched and polluted by an aquaculture (Salmo gairdneri Richardson).

KEY WORDS: Lake productivity, fish pressure, detritus, mesotrophic lake, eutrophic lake.

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Contents

1. INTRODUCTION

The aim of the present paper is a comparison and analysis of the most important biotic and dynamic features and the overall productivity level of five lakes forming a system of morphometrically and trophically different water bodies connected by a small watercourse (r. Jorka, 12 km long, maximum discharge 1850 $l \cdot sec^{-1}$), the watershed of which, 63 km^2 in surface area, represents part of a hilly, lakeland landscape, typical of the north-eastern regions of Poland and of the lakeland belt of the central European lowland.

The analysis will take into account information on tropho-ecological and biotic diversities, and on the occurrence of species and communities that are indicatory of lakes in a harmonious series from meso- to eutrophic status, with a particular consideration given to lakes of north-eastern Poland, studied on the basis of different sources (Hillbricht-Ilkowska et al. 1972, Spodniewska 1978, 1979, Kajak 1983). The object of analysis will also be the specific features peculiar to each of the lakes of the Jorka river and related to their morphometry, loading rates and direct impact of man. The present paper is entirely based on the results presented in the papers by Dusoge (1983), Ejsmont-Karabin, Bownik-Dylińska and Godlewska-Lipowa (1983), Godlewska-Lipowa (1983), Hillbricht-Ilkowska and Ławacz (1983), Ozimek (1983), Planter, Ławacz and Tatur (1983), Spodniewska (1983a), Stańczykowska, Lewandowski and Ejsmont-Karabin (1983), Szajnowski (1983), Węgleńska, Bownik-Dylińska and Ejsmont-Karabin (1983), Woroniecka-de Wachter (1983).

2. STUDY AREA

The river Jorka lake system begins with L. Majcz Wielki (A - 1.74 km^2, z_{max} - 16.4 m, $\tilde{z}$ - 6.0 m, dimictic, mesotrophic), the watershed of which shows conditions favouring the persistence, at present and in the past, of a mesotrophic status of the lake (many woodlands and areas without surface drainage, low population density, annual phosphorus loading not exceeding 0.08 g · m^{-2} lake surface area) (Hillbricht-Ilkowska and Ławacz 1983). P_{tot} concentrations are below or equal to 70 µg·l^{-1}; in spring there occurs a metalimnetic oxygen maximum (Planter, Ławacz and Tatur 1983), whereas the concentration of calcium in the bottom sediments comes up to 20% of dry wt, due to which the rates of P exchange in the sediment-water subsystem are very low (Planter and Wiśniewski - in press).

The next lake, L. Inulec (A - 1.61 km^2, z_{max} - 10.1 m, $\tilde{z}$ - - 4.6 m) is a very strongly eutrophic, shallow water body with the highest P_{tot} concentrations ($\leqslant$ 700 µg · l^{-1}) in the lake system under study, and with an invariably high percentage of Soluble Reactive Phosphorus ($\geqslant$ 50%). With a value of 0.08 g P · m^{-2} of the calculated annual P loading, this indicates a very high rate of internal loading from the bottom sediments (Hillbricht-Ilkowska and Ławacz 1983), which is favoured by a long-lasting oxygen deficit near the bottom, weak and moving thermic gradient above the bottom, and a very low sorption capacity of the bottom sediments (Planter and Wiśniewski - in press).

Głębokie L. (A - 0.46 km^2, z_{max} - 34.3 m, $\tilde{z}$ - 11.8 m, dimictic) receives over 1 g P · m^{-2} a year, 85% of which is derived from a rainbow trout (Salmo gairdneri) aquaculture (Hillbricht-Ilkowska and Ławacz 1983, Penczak et al. 1982). Combined with a long-term and sharply expressed thermic gradient, a high proportion of the unmixed layer (of the hypolimnion) in the lake volume, and a metalimnetic oxygen minimum in summer (Planter, Ławacz and Tatur 1983), this creates conditions which - according to Gliwicz's (1979) concept - accelerate the eutrophication of this lake. With the relatively high P_{tot} concentrations ($\leqslant 250\ \mu g \cdot l^{-1}$) this lake invariably shows a weight ratio of available N and P forms of the range 10-20 (that found for the other lakes being 30-100), that is, close to the optimum (≈ 10) as determined from the point of view of food requirements of the algae (Hillbricht-Ilkowska and Ławacz 1983).

The Jorka river drains Głębokie L., carrying its waters into the small, shallow, heavily overgrown L. Zełwążek (A - 0.12 km^2, z_{max} - 7.4 m, $\tilde{z}$ - 3.7 m), inputing with them a P_{tot} load of 0.81 g $\cdot m^{-2}$ (Hillbricht-Ilkowska and Ławacz 1983). From there the waters are carried on to L. Jorzec, located at the lowest level in the watershed (A - 0.41 km^2, z_{max} - 11.6 m, $\tilde{z}$ - 5.5 m), highly eutrophic, receiving discharge from watercourses polluted with wastes from settlements and arable lands (these dominating in the watershed), and with a high through-flow rate (water retention time ranging from 3 to 5 months). The annual P loading exceeds 1.0 g $\cdot m^{-2}$ (Hillbricht-Ilkowska and Ławacz 1983). Due to an early deforestation, agricultural use of the watershed (Stasiak and Tatur - in press) and a strong impact of the surface waters, the bottom sediments of this lake are distinguishable for high contents of Al, Si and of Fe in particular (up to 4% dry wt) (Planter, Ławacz and Tatur 1983), as a result of which the rates of P exchange between the sediments and the water are the highest in the lake system under study (Planter and Wiśniewski - in press).

3. INTEGRATED, AVERAGE AND/OR MAXIMAL VALUES OF THE INDICATORS OF LAKE PRODUCTIVITY AND ABUNDANCE OF THE BIOTA

All the basic indices, set up in Table I, of productivity and abundance of communities clearly indicate a mesotrophic status of

L. Majcz Wielki. This is evidenced by low T(rophic) S(tate)I(ndex) values (C a r l s o n 1977) estimated on S(ecchi) D(isc)readings ranging from 45 to 55 which are, according to C a r l s o n (1977), threshold values for meso- and eutrophic states, the lowest, in the lakes under study, values of primary production and biomass of planktonic algae, bacterioplankton, zooplankton and especially crustaceans (Table I). But this lake shows the highest density of submerged littoral vegetation which extends there to a depth of 6.0 m (O z i m e k 1983); this density is at least four times as high as that in the most fertile L. Inulec(Table I). Lake Majcz Wielki has a very abundant littoral benthos and a very high biomass of profundal benthos (about 232 g $\cdot$ m^{-2} wet wt) composed almost exclusively of Chaoborus flavicans (Meig.) larvae (93%), although the biomass of other benthos components, i.e., Oligochaeta and Chironomidae is also found to be the highest in the lake system under study (Table I). According to the view held by D u s o g e (1983), it is the highest biomass of Ch. flavicans larvae found in the lakes of northern Poland, and it may be due to temporary or local aggregation of these larvae. The high abundance of profundal benthos in this lake (even without the biomass of Ch. flavicans) should be the result of the absence of vast and long-term oxygen deficits at the bottom, whereas the large population of Dreissena polymorpha (Pall.) (Table I) - of the high calcium concentration in the sediments (up to 20% in dry wt)(P l a n t e r, Ł a w a c z and T a t u r 1983).

A high concentration of calcium in the sediments also determines a high contribution of Charophyta (about 53%) to the biomass of submerged vegetation, and indicates a mesotrophic nature of this lake in the light of the botanical typology of the lake littoral (O z i m e k 1983).

The quantitative indices of pelagial and profundal productivity of L. Inulec and L. Jorzec indicate a eutrophic status of these water bodies. The TSI is equal to 60 (Table I), i.e., peculiar to the status of advanced eutrophication, primary production amounts to 5443-8374 kJ $\cdot$ m^{-2}, mean phytoplankton biomass to about 8 mg$\cdot l^{-1}$ wet wt, and zooplankton biomass to 9-10 mg $\cdot$ l^{-1} wet wt (therein the biomass of rotifers above 1 mg $\cdot$ l^{-1} wet wt), whereas the abundance of the bacterioplankton ranges from 10 to $15 \cdot 10^6$ cells$\cdot ml^{-1}$ (Table I). The above values in general are characteristic of fertile lakes. The density of profundal and littoral benthos is typ-

Table I. Indicators of the overall productivity and abundance of the biota in r. Jorka lake system
Integrated or average values for the growing season (April-October)

Lake	Littoral: macrophytes $g \cdot m^{-1}$ dry wt for overgrown zone[1]: submerged	Littoral: macrophytes: emergent	Littoral: benthos[2] $g \cdot m^{-2}$ wet wt	Littoral: Dreissena polymorpha[3] $ind. \cdot m^{-2}$	Pelagial: photosynthesis[4] $kJ \cdot m^{-2}$	Pelagial: TSI (SD)[5]	Pelagial: phytoplankton[6] $mg \cdot l^{-1}$ wet wt	Pelagial: bacterioplankton[7] cells $\cdot 10^6$ in ml	Pelagial: protozoans[8] $mg \cdot l^{-1}$ wet wt	Pelagial: rotifers[8] $mg \cdot l^{-1}$ wet wt	Pelagial: crustaceans[8] $mg \cdot l^{-1}$ wet wt	Pelagial: total zooplankton $mg \cdot l^{-1}$	Benthos in central part $g \cdot m^{-2}$ wet wt
Majcz Wielki	200.2	no data	34.5	510	2546	44.1	2.1	5.5	0.21	0.50	2.56	3.4	231.5
Inulec	50.4	138.0	8.0	400	5388	60.0	8.0	14.7	0.60	1.22	7.81	9.6	11.0
Głębokie	39.6	34.0	20.5	280	5878	57.4	4.6	15.8	0.24	0.68	4.20	5.1	24.0
Zełwążek	4.0	129.0	9.5	175	4191	53.2	4.3	14.2	1.00	1.03	4.35	6.4	15.0
Jorzec	0.03	92.0	11.5	130	8328	60.0	7.5	9.8	0.55	1.76	7.42	9.7	6.5

[1]Acc. to Ozimek (1983) for submerged, and acc. to Szajnowski (1983) for emergent vegetation. [2]Data from Dusoge (1983). [3]Data from Stańczykowska, Lewandowski and Ejsmont-Karabin (1983). [4]Data from Woroniecka-de Wachter (1983). [5], [6]Data from Spodniewska (1983a). T(rophic) S(tate) I(index) acc. to Carlson (1979) on S(ecchi) D(isc) readings in summer. [7]Data from Godlewska-Lipowa (1983); average for epilimnion and two stations. [8]Data from Węgleńska, Bownik-Dylińska and Ejsmont-Karabin (1983); average biomass for epilimnion and stations.

ical of eutrophic lakes with oxygen deficits in the near-bottom layer (Table I).

The above two lakes clearly differ in the density of littoral vegetation (Table I). In L. Inulec the biomass of emergent vegetation (reeds) is found to be the highest in the lake system under study, amounting to 138 g $\cdot$ m^{-2}, while that found in L. Jorzec - to as little as 92 g $\cdot$ m^{-2} dry wt (Table I). According to S z a j n o w s k i ' s (1983) data, this difference results primarily from differences in the average shoot weight (4.39 and 3.03 g, respectively) rather than from a different density per m^2 of overgrown area (31.5 and 30.5 ind. $\cdot$ m^{-2}). L. Jorzec is practically devoid of submerged vegetation (Table I), the range of which does not go beyond 1.5 m (O z i m e k 1983).

The quantitative indices of pelagial and profundal productivity of the remainder of lakes, i.e., Głębokie and Zełwążek (the latter being fed with waters from the former) are clearly inconsistent from the point of view of the trophic status. Both lakes, and Głębokie L. in particular, show a high primary production (5878 kJ $\cdot$ m^{-2}), even higher than that found for the eutrophic L. Inulec (Table I); the summer TSI value amounts to 57.4 and is characteristic of the eutrophic status, while the very high numbers of the bacterioplankton (16 $\cdot$ 10^6 cells $\cdot$ ml^{-1}, the highest in the lakes under study) indicate a high fertility and/or a heavy pollution. Considering the high primary productivity indices and the abundance of heterotrophic bacteria, the biomass of the phytoplankton and that of the zooplankton seem to be particularly low, and in Głębokie L. attention is attracted by a low also biomass of rotifers and protozoans, practically of the range found for the mesotrophic L. Majcz Wielki (Table I). The high biomass of littoral and profundal benthos found in Głębokie L. makes it also similar to L. Majcz Wielki, probably because of similar oxygen conditions at the bottom in summer (P l a n t e r, Ł a w a c z and T a t u r 1983).

The above differences among the lakes reflected in the values of the overall productivity and abundance for the entire growing season are also illustrated with the maximal instantaneous values of the different trophoindicators, as well as the time of their occurrence (Table II). L. Majcz Wielki shows low and lowest values of the maximal daily photosynthesis (and consequently lowest efficiency of photosynthesis relative to photosynthetic active radiation, PHAR), whereas maximal algal biomasses are recorded in spring (Table II). The maximal daily P : B values (daily P : B ratio for the trophogenic layer) are the highest in this lake (2.23, Table II), which is proof of a higher relative rate of phytoplankton production in mesotrophic lakes (H i l l b r i c h t--I l k o w s k a 1977).

Table II. The maximal values of phytoplankton activity and biomass in r. Jorka lake system based on the data of S p o d n i e w s k a (1983) and W o r o n i e c k a - d e W a c h t e r (1983)

Lake	Photosynthesis				Biomass		Daily P:B ratio	
	$kJ \cdot m^{-2} \cdot day^{-1}$	time	efficiency (PHAR)	time	$mg \cdot l^{-1}$	time	ratio	time
Majcz Wielki	24.7	July	0.31	April	7.6	May	2.23	July
Inulec	74.3	April	1.93	April	31.0	August	0.91	May
Głębokie	117.2	April	1.76	April	11.6	August	1.41	June
Zełwążek	58.6	July	0.46	April[1] (July)	10.0	August	2.07	June
Jorzec	175.8	July	1.46	July	25.0	August	1.95	July

[1]The same value was noted in two months.

Most eutrophic, as judged from the maximal values of algal biomass and their being recorded in summer, are lakes Inulec and Jorzec (25.9 and 31.0 $\cdot l^{-1}$ wet wt, respectively, Table II); this level is 2-3 times as high as that adopted as a threshold level for algal blooms, and equal to 10 mg $\cdot l^{-1}$ wet wt (S p o d n i e w s k a 1979). In summer, a high algal biomass in L. Jorzec corresponds with a very high, the highest in the lake system under study, daily photosynthesis, as well as a high PHAR efficiency and daily P : B ratio (Table II).

In Głębokie L. attention is attracted by a high, relative to the other lakes, maximal value of daily photosynthesis and a relatively low maximal algal biomass recorded for the summer period (Table II). This indicates a tendency to a high photosynthetic activity of algae, with their biomass being relatively low. Due to this, the maximum daily P : B ratio for this lake (and L. Zełwążek) ranges from 1.5 to 2, being thus close to that for the mesotrophic L. Majcz Wielki (Table II).

The pelagic primary production of the lakes under study can be compared with the productivity of other lakes, including the Great Masurian Lakes investigated by Hillbricht-Ilkowska and Spodniewska (1969), Hillbricht-Ilkowska et al. (1972), Kajak, Hillbricht-Ilkowska and Pieczyńska (1972), Zdanowski (1976), after applying the appropriate corrections for the measurement method[1].

The net primary productivity of lakes such as deep and highly eutrophic Mikołajskie L. (Kajak, Hillbricht-Ilkowska and Pieczyńska 1972), or shallow lakes also highly eutrophic like L. Czarna Kuta (state prior to fertilization; Zdanowski 1976) is clearly higher than that of L. Jorzec, the most fertile lake in the river Jorka watershed, for it ranges from 9000 to 12 000 kJ $\cdot$ m^{-2} per growing season. A value similar to that found for L. Jorzec is recorded for L. Śniardwy, a large and moderately eutrophic water body, or L. Dgał Mały, a smaller one, but stratified and moderately eutrophic (about 7200-7600 kJ $\cdot$ m^{-2}). In the comparisons made by the above authors these lakes are considered moderately eutrophic. In general, it may be stated that the average productivity level of the r. Jorka lakes (except L. Majcz Wielki and L. Zełwążek), ranging from 5500 to 8500 kJ $\cdot$ m^{-2} per growing season, is rather similar to that recorded in moderately eutrophic lakes, like L. Śniardwy and L. Dgał Mały, mentioned above, or for instance L. Tałtowisko with meso-eutrophic characteristics, whose net primary production amounted to about 6300 kJ $\cdot$ m^{-2} (Hillbricht-Ilkowska and Spodniewska 1969).

Not forgetting that the above comparisons may be only approximate, one gets the impression that phytoplankton production in the lakes of the r. Jorka watershed is relatively lower than that of lakes of the similar trophic status, especially of larger lakes.

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[1] In the original studies primary production was measured by the oxygen method, so the result is gross production. To be able to compare this with the results obtained by using the ^{14}C method applied by Woroniecka-de Wachter (1983) (the result being close to net production), it is necessary to subtract about 20% representing the contribution of algal respiration to gross production. Used in the comparison were only harmonious, non-dystrophic lakes and those that are not subject to dystrophication, as well as the state of the particular lakes prior to their change due to different treatment (fertilization, fry introduction).

A particularly important diagnostic feature of the trophic state of lakes is the value of the summer phytoplankton biomass of the surface layers (S p o d n i e w s k a 1978, 1979). Algal biomass values found by S p o d n i e w s k a (1983b) in 43 lakes, differing in their trophic status and mixis, have been used by K a j a k (1983) for an analysis of the degree of lake eutrophication as measured by the summer total P concentration in the surface layer. K a j a k (1983) has suggested three classes: lakes of low, medium and high fertility with a specific range of total P concentration (see also H i l l b r i c h t - I l k o w s k a and Ł a w a c z 1983), different in dimictic lakes (with summer stratification) and in polymictic lakes (without stratification or with variable stratification in summer). Corresponding with these classes are ranges of biomass values of the phytoplankton (summer), zooplankton and profundal benthos, although it must be noted that the dispersion of the above parameters in a class is large, and the ranges for successive classes overlap.

On account of its summer phytoplankton biomass (2.6 mg $\cdot l^{-1}$ wet wt) (Table II) L. Majcz Wielki clearly belongs to the class of dimictic, low-fertility (range acc. to K a j a k 1983 - 0.39-7.84 mg $\cdot l^{-1}$ wet wt) lakes, while Głębokie L. (11.6 mg $\cdot l^{-1}$, Table II) - to medium-fertile lakes (range acc. to K a j a k 1983 - 6.59-29.37 mg $\cdot l^{-1}$ wet wt). Shallower lakes with a tendency to polymixis, or clearly polymictic lakes, like L. Inulec and L. Jorzec (31 and 25 mg $\cdot l^{-1}$, Table II) are within the range of medium-fertile, non-stratified lakes (range acc. to K a j a k 1983 - 9.8-68.7 mg $\cdot l^{-1}$ wet wt), and L. Zełwążek (10.3 mg $\cdot l^{-1}$ wet wt, Table II) belongs to low-fertility (range acc. to K a j a k 1983 - 1.3-27.5 mg $\cdot l^{-1}$ wet wt) lakes of this mictic group. The allocation of the r. Jorka lakes to the above classes in terms of the summer phytoplankton biomass is consistent and identical with their classification in terms of total P concentration (H i l l b r i c h t - I l k o w s k a and Ł a w a c z 1983), and on the whole it suggests that these lakes belong to low- or medium-fertility systems.

The mean values and ranges of zooplankton biomass (without protozoans) and of profundal zoobenthos in summer, which correspond with the lake groups distinguished on the basis of total P in K a j a k ' s (1983) classification, do not constitute a real gradient, because the dispersion is even larger than in the case of algal biomass, and to a considerable extent overlapping for the successive classes. However, noteworthy is the fact that the summer zooplankton biomass values (of the range of 9-10 mg · l^{-1} acc. to the data from W ę g l e ń s k a, B o w n i k - D y l i ń s k a and E j s m o n t - K a r a b i n 1983) recorded for L. Inulec and L. Jorzec are found among both medium- and high-fertility (in terms of total P) polymictic lakes (acc. to K a j a k 1983, the range for both these groups is 2.4-9 mg · l^{-1}), whereas those recorded for Głębokie L. (8.5 mg · l^{-1}) - among high-fertility dimictic lakes, and, finally, those for L. Majcz Wielki (5.3 mg · l^{-1}) among low and medium-fertility dimictic lakes.

Profundal benthos biomass values (leaving out the unusual quantity found in L. Majcz Wielki) recorded in summer in the r. Jorka lakes (6-24 g · m^{-2}) are found in lakes with a low, and in those with a medium content of phosphorus (K a j a k 1983).

A comparison of some indices of bacterioplankton abundance in the r. Jorka lakes, namely the annual average and total number of bacteria in one ml of surface water (Table I) with the corresponding values summarized by G o d l e w s k a - L i p o w a (1977) for lakes differing in their trophic status shows a similarity of values for meso- or mesoeutrophic lakes, like Majcz Wielki, Mamry, Tałtowisko (values around 5 · 10^6 cells · ml^{-1}). The range found in the other lakes of the r. Jorka (9.8-15.8·10^6 cells·ml^{-1}) is similar also for lakes like Mikołajskie, Nidzkie, Bełdany, i.e., deep and eutrophic. They are, however, clearly lower (even in polluted lakes, like Głębokie L. or L. Jorzec) than the values recorded by G o d l e w s k a - L i p o w a (1977) for heavily polluted lakes, like, e.g., L. Czarna Kuta (values of the range of 20.0-60.0 · 10^6 cells · ml^{-1}).

4. SPECIES- AND GROUP-COMPOSITION OF THE LAKE BIOTA

The basic feature common to all the r. Jorka lakes, found by S p o d n i e w s k a (1983a), is a relatively high nannoplankton biomass, expresed by both high (as a rule of the range of 50%) annual average and maximal values (Table III). Practically half the phytoplankton biomass of the r. Jorka lakes belongs to species of small algae (below 30 μm) which are found te be particularly abundant in both the eutrophic lakes, Inulec and Jorzec (annual

Table III. The occurrence of indicatory groups and species of algae in r. Jorka lake system. Average and maximal biomass (in mg · l^{-1} wet wt) in the epilimnion for the growing season (April-October) and the average percentage in total biomass. Data of S p o d n i e w s k a (1983a)

Lake	Nannoplankton ($\leqslant$30 µm)			Cyanophyta			Euglenophyta			Ceratium hirundinella (O.F.M.) Bergh.			Dinobryon sp. div.		
	average	maximal	%	average	maximal	%	average	maximal	%	average	maximal	%	average	maximal	%
Majcz Wielki	1.1	2.7 (June)	52	0.1	0.2	2	0.1	0.1	1	0.2	1.8	9	0.6	6.4	29
Inulec	4.0	19.3 (August)	50	1.9	10.7	24	0.1	0.5	1	0.7	6.1	9	0.1	0.9	1
Głębokie	2.2	7.0 (April)	49	1.2	8.5	25	0.15	2.7	3	0.3	2.3	6	0.3	3.8	6
Zełwążek	2.2	7.7 (May)	51	1.2	5.2	24	0.1	0.3	1	0.2	1.4	5	0.3	1.8	7
Jorzec	4.2	14.1 (July)	55	0.4	1.2	5	0.25	1.9	3	1.4	13.6	19	0.3	1.7	4

average value of the range of 4.0 mg wet wt · l^{-1}, and maximum summer values of the range of 14.0-19.0 mg wet wt · l^{-1}, Table III).

A comparison of the respective nannoplankton biomass values in S p o d n i e w s k a 's (1978, 1979) data from the Great Masurian Lakes investigated in the years 1973 and 1976, and from other lakes differing in phosphorus content (S p o d n i e w s k a 1983b) shows that the values found for L. Majcz Wielki are similar to those recorded in a group of deeper, mesoeutrophic lakes (i.e., of the range of 1.0-1.5 mg wet wt · l^{-1}, at least 40%), for both the eutrophic lakes, Inulec and Jorzec - to those in shallow, very fertile or polluted lakes (at least 10 mg wet wt · l^{-1}, about 50%), and for Głębokie L. and L. Zełwążek - to those in highly eutrophic lakes (of the range of 7-8 mg wet wt · l^{-1}, about 50%).

In mesotrophic lakes the percentage of the nannoplankton, and often also its abundance are particularly high in spring, hence maximal values are often recorded in this period.

Such a situation is found not only in L. Majcz Wielki - the most mesotrophic lake in the system analysed, but also in Głębokie L. and in L. Zełwążek (Table III).

Table III also contains data on the occurrence of groups or species known to be indicative of the trophic status, hence best documenting the biotic similarities and differences among the lakes studied.

According to R o s e n (1981) and S p o d n i e w s k a (1983b), species of the genus Dinobryon are more abundant in meso- or mesoeutrophic lakes, it is therefore understandable why the highest average and maximum values of their biomass, and of their percentage are recorded for L. Majcz Wielki (Table III). But attention is attracted by fairly high biomass levels of this group being found also in Głębokie L. (Table III). According to R o s e n (1981) and S p o d n i e w s k a (1983b), Euglenophyta are particularly numerous in very fertile or heavily polluted lakes, hence their absence from L. Majcz Wielki is obvious, and so are their fairly abundant occurrence and percentage in Głębokie L. and L. Jorzec which receive sewage (Table III).

As has been known, the numbers and proportion of blue-green algae in the phytoplankton biomass, as well as their species-composition, are a good diagnostic character indicative of the trophic status of a lake. The lowest blue-green algal biomass and percentage are found in the mesotrophic L. Majcz Wielki, whereas in the other lakes blue-green algae are more numerous, but their species composition varies (Table III). A composition most typical of an advanced eutrophication was found by S p o d n i e w s k a (1983a) in L. Inulec where blue-green algal biomass came up to 11 mg $\cdot$ 1^{-1}, and the dominant species was Oscillatoria agardhii Gomont (90%), and Aphanizomenon, Microcystis and Anabaena, that is, typical "hypertrophic" genera, were also abundant. Dominant among the blue-green algae of Głębokie L., the abundance of which is as high (Table III) as that in L. Zełwążek, is Gomphosphaeria lacustris Chodat, a species for which R o s e n ' s (1981) analysis of 1250 different Scandinavian lakes has revealed a tendency to occur in less productive environments. In L. Jorzec noticeable is a relatively low blue-green algal biomass several times lower than in the remaining lakes. Dominant in the summer phytoplankton of this lake is Ceratium hirundinella, a species that R o s e n (1981) considers characteristic of moderately eutrophic lakes. Spodniewska (1974) has demonstrated that it is this species that shows the strongest reaction to the eutro-

Table IV. Relative occurrence of Karabin's[1] "mesotrophic" and "eutrophic" groups of plankton crustaceans and rotifers in r. Jorka lake system (based on the data of Węgleńska, Bownik-Dylińska and Ejsmont-Karabin 1983) + low relative biomass, ++ high relative biomass

Group, species	Majcz Wielki	Inulec	Głębokie	Zełwążek	Jorzec
Group I - "mesotrophic"					
Conochilus hippocrepis Schrank	+	-	-	-	-
Bipalpus hudsoni Imhof	+	-	-	-	-
Polyarthra major Burhardt	+	-	-	-	+
Gastropus stylifer Imhof	+	-	+	+	-
Heterocope appendiculata (G. O. Sars)	+	-	-	-	-
Bosmina coregoni longispina (Leydig)	+	-	-	-	-
B. crassicornis crassicornis (Lillieborg)	+	-	-	-	+
Cyclops bohater Koźmiński	+	-	-	-	-
Daphnia hyalina (Leydig)	+	+	+	+	+
D. cristata G. O. Sars	+	+	+	+	+
D. cucullata G. O. Sars	+	++	+	++	++
Group II - "eutrophic"					
Brachionus angularis Gosse	-	+	+	+	++
Keratella quadrata Müller	-	+	+	+	+
Pompholyx sulcata Hudson	-	++	++	-	++
Chydorus sphaericus (O. F. Müller)	-	++	++	++	++
Diaphanosoma brachyurum (Lievin)	-	++	++	++	-
Keratella cochlearis tecta Gosse[2]	+	++	+	+	++
	(≪1)	(12.8)	(≪1)	(1.5)	(7.2)

[1]According to Karabin's (1982) classification based on the occurrence mainly in meso- or mesoeutrophic lakes (TSI $\leqslant$ 45--55 ("mesotrophic group") and/or in moderate and highly eutrophic lakes (TSI $\geqslant$ 55) ("eutrophic group"). Occurrence in terms of relative and/or absolute abundance or biomass. [2]In brackets relative abundance in plankton rotifers community, in per cent.

phication of Mikołajskie L., as evidenced by the elongation, from year to year, of its blooming period, and the increase in abundance.

Table V. Relative occurrence of indicatory species of protozoans in r. Jorka lake system (data of Bownik-Dylińska in Węgleńska, Bownik-Dylińska and Ejsmont-Karabin 1983)
+ low numbers, ++ high numbers

Species	Majcz Wielki	Inulec	Głębokie	Zełwążek	Jorzec
Oxybionts:					
Coleps hirtus Nitzsch	+	++	++	++	++
Tintinidium fluviatile Stein	++	+	+	+	+
Vorticella sp.	++	+	++	++	+
Stokesia vernalis Wenrich	++	+	++	++	+
Saprobionts:					
Saprodinium dentatum Lauterborn (polis.)	-	-	+	-	-
Colpidium colpoda Ehrenberg (^{B}mesos.)	-	-	-	-	+
Euplotes patella (O. F. Müller) (^{B}mesos.)	-	-	+	-	+
Metopus es (O. F. Müller) (polis.)	-	-	+	-	+

The relative abundance of selected zooplankton species (Tables IV, V) evidences in a summarized way the differences among the lakes in respect of their trophic status and effect of pollution. The bioindicative value has been utilized of various ciliate species (Table V), as well as Karabin's (1982) classification system relating to indicator groups of rotifers and crustaceans. This system is based on a detailed analysis of the biomass value of the various species of plankton crustaceans and rotifers in the summer zooplankton in 50 lakes of north-eastern Poland, differing in their trophic status (in terms of P_{tot} concentration), mixis and pollution. Karabin (1982) has distinguished three groups of species differing in their trophoindicative value: group I - with a tendency towards a greater abundance (in terms of relative and/or absolute biomass) in lakes with a TSI (SD) value below 45-50, that is, meso- and mesoeutrophic, group II - more abundant in lakes with a TSI (SD) value above 55, that is, moderately- and highly-eutrophic, and group III (the most numerous) - indifferent, that is, without a clear preference of a specific lake group, therefore without importance for the determination of the trophic status of a lake.

In general, group I species are found to occur (Table IV) only and/or in considerable numbers in L. Majcz Wielki, and in Głębokie L. except three species of Daphnia which occur in all lakes. Group II species are found primarily in lakes Inulec and/or Jorzec, or in all the lakes under study except L. Majcz Wielki.

In the case of ciliates a visible effect of pollution is evidenced by the presence of saprobiontic species in polluted lakes, that is, Głębokie L. (rainbow trout aquaculture) and L. Jorzec (receives farm sewage) (Table V). Conversely, species with a preference of mesotrophic waters with good oxygen conditions are on the whole more abundant in L. Majcz Wielki than in the other lakes. The ciliate Vorticella is found in larger numbers in both L. Majcz Wielki and Głębokie L. (Table V).

Changes in the three indices of the community structure also evidence the above differences among the lakes (Table VI). They are: the index of biomass diversity acc. to Margalef (Hb), calculated for crustaceans, and two ratios: predator biomass to non-predator biomass ratio ($B_p : B_{np}$), and Cyclopoida biomass to Calanoida biomass ratio ($B_{cycl} : B_{cal}$) which have been discussed in detail along with the calculation methods in W ę g l e ń s k a, B o w n i k - D y l i ń s k a and E j s m o n t - K a r a b i n (1983). Referred to crustacean biomass, the Hb index on the whole decreases in aquatic habitats changed due to a stress factor, including the trophic factor. Its usefulness in the description of structural changes in response to a stress factor has been demonstrated, e.g., by G i l j a r o v (1972); E j s m o n t - K a r a b i n et al. (1980) found its decrease in fertilized lakes. K a r a b i n (1982) has demonstrated the usefulness of this index, as well as of the other two indices in a description of structural changes in the zooplankton with progressing lake eutrophication. In general, the more advanced the eutrophication of a lake (in terms of P_{tot}, SD or phytoplankton biomass), the lower the Hb index, and the higher the $B_p : B_{np}$ and $B_{cycl} : B_{cal}$

Table VI. Biomass diversity index (Hb)[1] for crustaceans, and two indicators of trophic structure in the zooplankton: $B_p : B_{np}$, the ratio of predators' biomass to non-predators' biomass and $B_{cycl} : B_{cal}$, the ratio of cyclopoid biomass to calanoid biomass (in r. Jorka lake system); data from W ę g l e ń s k a, B o w n i k - D y l i ń s k a and E j s m o n t - K a r a b i n (1983)

Lake	Hb	$B_p : B_{np}$	$B_{cycl} : B_{cal}$
Majcz Wielki	1.8	0.53	0.6
Inulec	1.6	0.66	1.3
Głębokie	1.9	0.42	0.84
Zełwążek	1.6	0.63	0.88
Jorzec	1.5	0.67	1.4

[1] Acc. to G i l j a r o v (1972). Method of calculation in W ę g l e ń s k a, B o w n i k - D y l i ń s k a and E j s m o n t - K a r a b i n (1983).

ratios. In the lake system analysed, L. Majcz Wielki and Głębokie L. show a clearly higher (although only slightly) Hb (Table VI) than that found for the remaining lakes, and for L. Majcz Wielki additionally the lowest values of the other indices are found. The highest trophic-structural indices are found for both the eutrophic lakes - L. Inulec and L. Jorzec (Table VI).

The higher species diversity recorded in the mesotrophic lakes relative to the more eutrophic ones concerns not only the zooplankton, but also the zoobenthos, both littoral and profundal. In the littoral of Głębokie Lake D u s o g e (1983) recorded 9 taxa of Chironomidae, and in the littoral of the other lakes - 7-8; the distinctive taxon was Stictochironomus e.g. histrio (Fabr.). Greater differences are found in the profundal zone of lakes. The number of taxa found by D u s o g e (1983) in L. Majcz Wielki and in Głębokie L. was 4-5, and in the other lakes - 1-2. Tanytarsus e.g. gregarius Kieff. (a species known to be characteristic of a well-oxygenated bottom) and Ortocladinae are found only in the former lake, and present only in the latter lake are Cryptochironomus e.g. defectus (Kieff.) and Limnochironomus e.g. nervosus (Staeg.), while Chironomus f.l. anthracinus Zett. is present only in these two lakes.

5. SEASONAL PATTERN OF PLANKTON ABUNDANCE, AND THE DYNAMICS OF SESTON AND ITS ABIOTIC FRACTION

In the part studies carried out by G o d l e w s k a - L i p o w a 1983, S p o d n i e w s k a 1983a, and W ę g l e ń s k a, B o w n i k - D y l i ń s k a and E j s m o n t - K a r a b i n 1983 the seasonal dynamics of the particular plankton components was analysed in detail. On the basis of these analyses it is possible to dis-

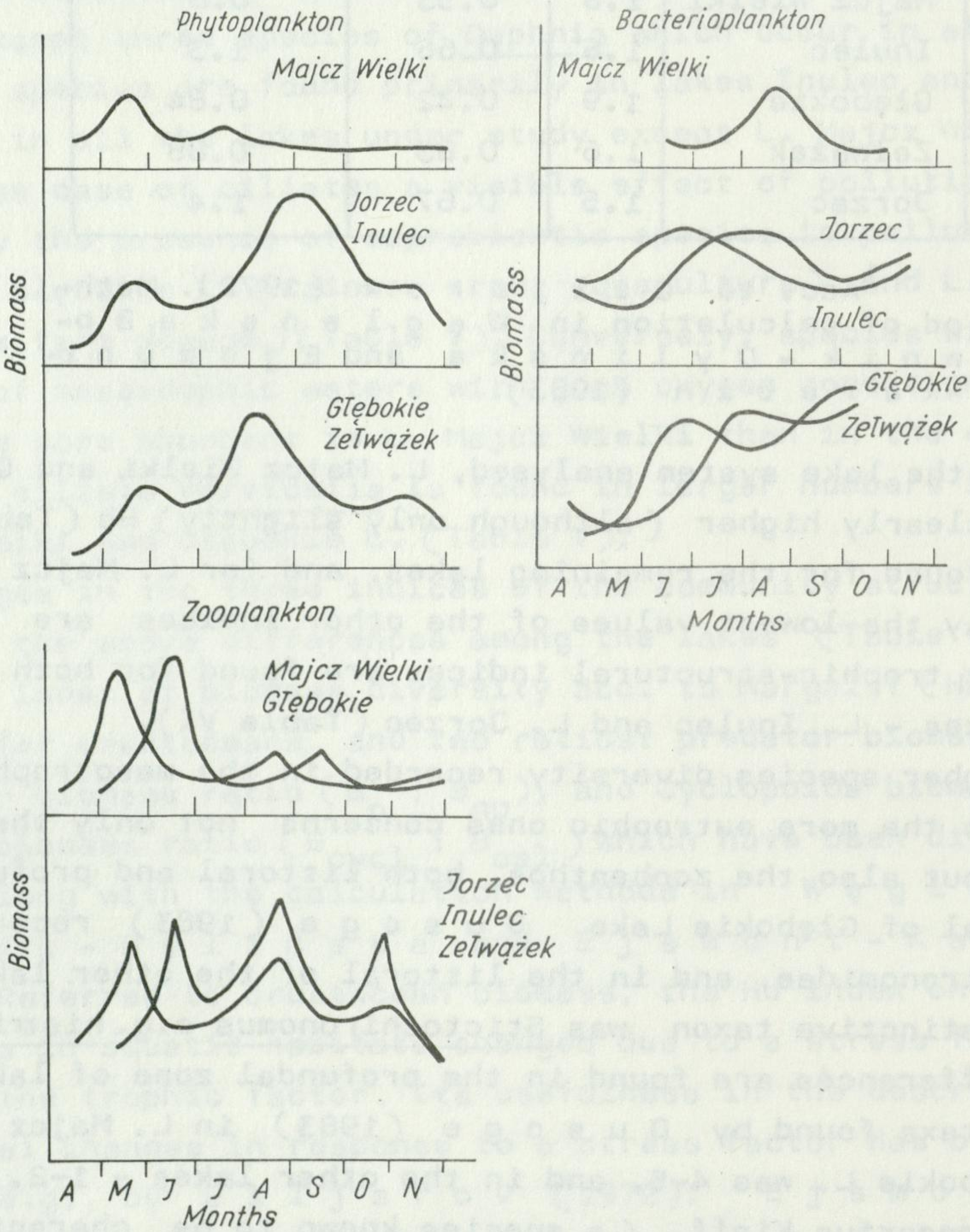

Fig. 1. Types of seasonal biomass dynamics of phytoplankton, bacterioplankton and zooplankton in r. Jorka lakes (acc. to G o d l e w s k a - L i p o w a 1983, S p o d n i e w s k a 1983a, W ę g l e ń s k a, B o w n i k - D y l i ń s k a and E j s m o n t - K a r a b i n 1983)

tinguish specific types of seasonal dynamics ignoring in this case the absolute quantities, as well as any secondary changes in abundance (secondary peaks or depressions), but taking into account the succession and times of successive abundance peaks, as well as their relative height (Fig. 1). Seasonal variations in abundance so smoothed indicate further differences among lakes, generally consistent with both the overall productivity level (Section 4) and the biotic structure (Section 5).

The type of dynamics of all the three plankton components (Fig. 1) analysed in L. Majcz Wielki is in general characterized by one clearly marked peak of abundance taking place in early spring (phytoplankton), early or late spring (various zooplankton groups) or summer (bacterioplankton). Such a "one-peak" type od dynamics of individual plankton components is most frequently encountered in low-fertility mesotrophic lakes. A different type of seasonal dynamics of the plankton is found in lakes Inulec and Jorzec: an abundance peak of the phytoplankton is recorded in spring (a smaller one) and then in late summer (very high), this being a typical situation found in fertile, eutrophic lakes; high levels of numbers of the bacterioplankton practically persist throughout the summer period (that is to say, a growth in abundance follows the spring phytoplankton bloom and continues until September), while the type of dynamics of the zooplankton varies considerably, showing many peaks and a tendency to grow in abundance in May-June, August and October. Individual abundance peaks may show a great variation, depending on the groups they concern (ciliates, rotifers or crustaceans) (cf. Węgleńska, Bownik-Dylińska and Ejsmont-Karabin 1983).

Noteworthy is, however, the type of abundance dynamics of the plankton in Głębokie L. and in L. Zełwążek which is connected with it. In the case of zooplankton this type clearly resembles that in L. Majcz Wielki, but the spring peak occurs slightly later. Though it is higher than the spring peak, the summer phytoplankton peak occurs earlier (end of July), hence the type of phytoplankton dynamics in these lakes shows intermediate features between the "mesotrophic type" (L. Majcz Wielki) and the "eutrophic type" (L. Inulec and L. Jorzec). The bacterioplankton invariably tends to grow in numbers from the beginning of summer until autumn, which seems to be the result of the fertilizing effect of the rainbow trout aquaculture. It is in the period from August to October that about

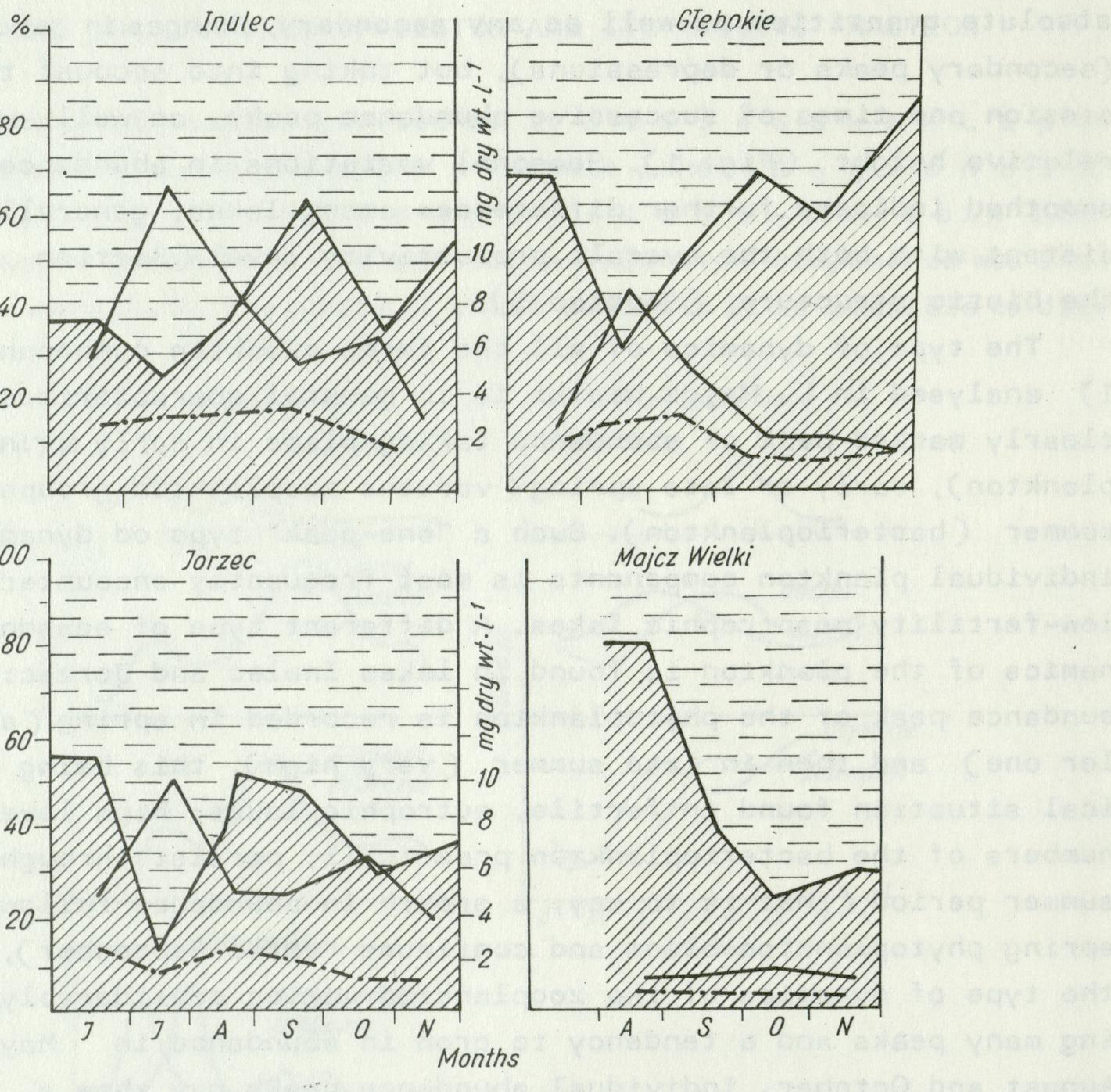

Fig. 2. Seston and bioseston dynamics ($mg \cdot l^{-1}$ dry wt) in surface layers of r. Jorka lakes in the period June-November, 1976, and the percentage of abioseston and bioseston in total seston (acc. to data from Godlewska-Lipowa 1983, Planter, Ławacz and Tatur 1983, Spodniewska 1983a, Węgleńska, Bownik-Dylińska and Ejsmont-Karabin 1983)
1- seston, 2 - bioseston, 3 - percentage of abioseston, 4 - percentage of bioseston

50% of the yearly load of nutrients is released by the culture population (Penczak et al. 1982).

Given the biomass dynamics of the phyto-, zoo- and bacterioplankton for the lakes analysed, and the dynamics and abundance of the seston evaluated by Planter, Ławacz and Tatur (1983) for the surface layers of four lakes in the r. Jorka watershed, it is possible to assess the abundance of the abioseston, that is, that part of seston which consists of: dead particulate organic matter, i.e., detritus of particle size above 0.4 µm, and mineral particles derived from the suspension brought into lakes by tributaries or arisen as a result of dust fall. Abioseston weight will, therefore, each time be the difference between the sum of the weights of the living seston fractions, and the total seston weight. As P l a n t e r, Ł a w a c z and T a t u r (1983) assessed the concentration of seston in dry weight, and the biomass of living fractions was assessed in wet weight, it was assumed that the dry weight represent 20% of the wet weight in bacterioplankton and 10% in phyto- and zooplankton.

According to Ostapenija et al. (1973), the weight of abioseston (calculated as mentioned above) and its dynamics show regular differences among the lakes of different trophic states. In high-productivity eutrophic lakes there is a higher percentage of the dead fraction of seston, especially immediately after periods of maximum algal biomass production and cumulation, than in low-productivity mesotrophic or mesoeutrophic lakes. In the lakes of the r. Jorka the dead seston fraction clearly dominates over the living fraction (Fig. 2), but in L. Majcz Wielki and Głębokie L. its proportion is smaller than in the two eutrophic lakes, Inulec and Jorzec.

6. EFFECT OF NATIVE FISH FAUNA PRESSURE AND OF FISH AQUACULTURE (SALMO GAIRDNERI) ON THE ABUNDANCE OF PLANKTON

The impact of planktonophagous stages (fry) or species (mainly Coregonidae) on zooplankton dynamics and abundance in general, and large-bodied species and crustacean stages in particular, has been commonly found not only under pond conditions (a very high predatory pressure of fish), but also in lakes, in all cases of a changed composition and/or abundance of native or introduced fish fauna (e.g., K e r f o o t 1981). This impact is often so strong that it overshadows changes connected with the eutrophication, regardless of the input of nutrients from outside the ecosystem (a review of the problem in H i l l b r i c h t - I l k o w s k a 1980).

In the lake system under study the fish may exert an influence in two ways: (1) as the effect of autochthonous ichthyofauna (a selective predator) on the occurrence of zooplankton (especially of crustaceans) in all the r. Jorka lakes, depending on the composition and numbers of the fish, and also (2) as the impact of faeces and rainbow trout metabolites, released from point-sources, i.e., aquaculture cages, which have a fertilizing effect on all the plankton components, and should affect their spatial distribution relative to the source of pollution. This is a particular case - Głębokie L.

According to P e n c z a k et al. (in press), fish catches (including non-coregonids) in the lakes of the r. Jorka are poor or very poor (Table VII), below the average for lakes in north-eastern Poland, estimated at 25-35 kg · ha^{-1}. An exception is Głębokie L., a typical "bleak" lake, where catches of rainbow trout run-aways from the cage aquaculture, as well as of regularly introduced bleaks are fairly high, amounting to 50 kg · ha^{-1}. It may be presumed that it is in this lake that the possible effect of planktonophagous fish on large-bodied crustaceans can be most significant. Among the members of the crustacean community most readily selected by this type of predator are large-bodied species,

Table VII. The yearly fish harvest (average for several years) in r. Jorka lake system, and the average summer abundance of daphnids and diaptomids

Data of P e n c z a k et al. (1982) and W ę g l e ń s k a, B o w n i k - D y l i ń s k a and E j s m o n t - K a r a b i n (1983)

Lake	Fish harvest (kg · ha^{-1})	Dominating species	Abundance of daphids[1] and diaptomids[2] (ind. · l^{-1})			
			D. c.	D. h.	D. cr.	Eudiaptomus
Majcz Wielki	no data[3]	no data	34	3	1.5	66
Inulec	19.4	bream	85	6	3	91
Głębokie	52.0	bleak trout (wild)	39	3	1	110.5
Zełwążek	12.8	tench	88	1	8	62
Jorzec	20.9	bream	84	3	3	72

[1]D(aphnia) c(ucullata), D. h(yalina), D. cr(istata). [2]Eudiaptomus gracilis and E. graciloides. [3]No exact data but fish harvest certainly below 15 kg · h^{-1}.

like daphnids and diaptomids. An analysis of their average numbers in the epilimnion of the r. Jorka lakes (W ę g l e ń s k a, B o w n i k - D y l i ń s k a and E j s m o n t - K a r a b i n 1983) did not reveal any significant differences that could be ascribed to limiting effect of fish predators (Table VII). Their possibly strongest effect in Głębokie L. has not been confirmed either, since the abundance of, e.g., diaptomids there is larger than in any other lake in the system considered. However, attention is attracted by the fact that the abundance of Daphnia cucullata in L. Majcz Wielki and in Głębokie L. in summer is over twice lower than in the other lakes (Table VII). This is true primarily of June when the abundance found in the two lakes does not exceed 80 ind. $\cdot$ l^{-1}, while in the other lakes it comes up to 260 ind. $\cdot$ l^{-1} (W ę g l e ń s k a, B o w n i k - D y l i ń s k a and E j s m o n t - K a r a b i n 1983). In addition to the many similar features of zooplankton structure the two lakes, L. Majcz Wielki and Głębokie L., also show a similar level of numbers of daphnids. A presumption may thus be ventured that this results from either similar trophic and morphometric features in both lakes, or a similar level of predation by planktonophagous fish (Głębokie L.) or by invertebrate predators (L. Majcz Wielki). The former cause seems less likely than the latter: though they have a lot in common as regards the structure and dynamics of zooplankton, the two lakes differ significantly in primary production and biomass, and in the composition of the phytoplankton (compare preceding sections). Daphnids are easy to notice, and are therefore readily selected by both eye-orientated fish (K e r f o o t 1981) and Chaoborus larvae (P a s t o r o k 1981). The effect of their selection may be more marked upon the most numerous species, like Daphnia cucullata, one of three daphnid species.

Set out in Table VIII are data illustrating the fertilizing effect of a point-input of organic matter and nutrients represented by the rainbow trout cage aquaculture in Głębokie L. In the vicinity of the cages at least 5 times higher bacterioplankton concentrations, with a clearly lower percentage of coccoid forms in favour of rod-like and stick-like forms, are found throughout the summer period. The concentration of phytoplankton is also higher, with a clearly pronounced dominance of Gomphosphaeria lacustris and Ceratium hirundinella. The presence of aquaculture cages has the weakest, and probably temporary, effect on the distribution of zooplankton groups, the most affected of which appear to be protozoans, followed by rotifers, crustaceans showing the smallest changes (Table VIII), that is to say, the strongest is the reaction of the zooplankters feeding almost exclusively on microbial biomass.

7. SUMMARY

As a result of wide-scope geochemical and hydrochemical studies, the main results of which have been presented in paper I of the present series (Hillbricht-Ilkowska and Ławacz 1983), and of detailed biological studies presented in further papers of the series, and dealing with five lakes and their watersheds located on a small watercourse (the Jorka river, about 12 km long) it can be stated that:

1. The lake located at the highest level in the watershed under study, i.e., L. Majcz Wielki, represents a system where the nature and impact of the watershed (at present and in the past), very low external loads of nutrients and absence of points of pollution determine a low productivity of the lake and its mesotrophic status. All the characteristics considered indicate a consistent pattern of a mesotrophic lake system: a low level of primary production, but a high daily P : B ratio, a low biomass of plankton components, but a high biomass of submerged vegetation (Characeae being dominant) and of littoral and profundal benthos (Tables I, III), a "flat" or one-peak type of dynamics of the plankton and its different components (Fig. 1), absence of blue-green algae from the phytoplankton and dominance of nannoplankton and species of the genus Dinobryon (Table III), the large species diversity of different biota (Tables IV, V), low $B_p : B_{np}$ and $B_{cycl} : B_{cal}$ ratios, and a high crustacean biomass diversity (Hb) (Table VI), the lowest percentage of abioseston in the summer seston (Fig. 2).

2. The richest (in terms of P content in the water), of the lakes discussed is the large, shallow L. Inulec whose contemporary eutrophic status seems to be the result of internal loading, the calculated value of which appears to be several times as high as the external input of nutrients. L. Inulec shows a consistent pattern of qualitative and quantitative properties of highly eutroph-

Table VIII. The effect of rainbow trout (S. gairdneri) aquaculture on the horizontal distribution of the plankton in Głębokie L. (r. Jorka lake system)
Selected data of G o d l e w s k a - L i p o w a (1983) S p o d n i e w s k a (1983a) and W ę g l e ń s k a, B o w n i k - D y l i ń s k a and E j s m o n t - K a r a b i n (1983) for August or July 1976[1] average for epilimnion

Elements compared	Stations close to cages	Stations 0.5 km from cages
Bacterioplankton		
mg · l^{-1} wet wt	16.9	5.5
per cent of cocci	12	50
Phytoplankton		
mg · l^{-1} wet wt	11.6	8.4
percentage of:		
Gomphosphaeria lacustris Chodat	71	45
Ceratium hirundinella (O. F. M.) Berg.	15	7
Zooplankton (ind. · l^{-1})		
protozoans	13600	8700
rotifers	400	280
crustaceans	500	350

[1] The data were chosen for August or for July, i.e., for the month in which the differences between two stations are the greatest. Acc. to P e n c z a k et al. (in press), in summer (from June to August) about 55% of the annual load of nutrients in faeces and urine is released directly to the lake.

ic systems. These are: a relatively high level of primary production, a high biomass of all plankton components, a low biomass of profundal benthos (Tables I, II), in the phytoplankton - a dominance of blue-green algae and their composition typical of the eutrophic systems (Oscillatoria agardhii, Microcystis, Aphanizomenon; Table III), a low biomass diversity index (Hb), and high $B_p : B_{np}$ and $B_{cycl} : B_{cal}$ ratios (Table VI), a high biomass of rotifers (Table I), with a dominance of Keratella cochlearis tecta, a good indicator of the eutrophic status (Table IV), a low diversity of the benthos, a high biomass of littoral emergent vegetation (Table I), a multi-peak seasonal plankton dynamics (Fig. 1), and a high percentage of abioseston in the seston (Fig. 2).

3. The remaining lakes of the r. Jorka watershed, which can be considered - relative to L. Majcz Wielki - more or less eutrophic, and markedly more fertile, represent a system of quantitative and qualitative trophic indices that is clearly inconsistent, that is to say, constitutes a mixture of characteristics known to be caused, or to occur more frequently in lakes trophically different. This is true primarily of Głębokie L. (and of L. Zelwążek which is connected with it hydrologically), and to a much lesser extent also of L. Jorzec. These lakes are exposed to the heaviest external load of nutrients derived from sources of pollution, and they also show distinct signs of organic pollution in the form of a higher percentage and biomass of Euglenophyta in the phytoplankton (Table III), larger numbers of polysaprobic ciliates (Table V), and in Głębokie L. - also a very high (the highest in the lakes considered) abundance of bacterioplankton (Tables II, VIII).

In Głębokie L. the direct point of pollution and enrichment (Table VIII) has exerted its influence for a relatively short time (the cage fish aquaculture has existed there since 1974), but according to Gliwicz's (1979) concept, the morphometric relations (a sharp thermic gradient, metalimnetic oxygen deficit in summer) act as a factor accelerating the increase of the productivity of this lake. Hence the lake in question, shows at present a definitely "mixotrophic" system, where a high primary productivity, even higher than in L. Inulec (Table I), is accompanied by a relatively low algal biomass (Table I), but a high percentage of nannoplankton, and a strongly marked dominance of the blue-green alga <u>Gomphosphaeria lacustris</u> (Table III), the tendency of which to occur nearer to the aquaculture cages (relative to a distant site; Table VIII), and in larger numbers from year to year in this lake, has been demonstrated by Spodniewska (1983a). The biomass of the zooplankton is relatively low (Table I), whereas its structure (Table IV) and dynamics (Fig. 1) rather typical of mesotrophic systems. Low, too, is the biomass of rotifers, while the index of crustacean biomass diversity (Hb) is high, the $B_p : B_{np}$ and $B_{cycl} : B_{cal}$ ratios being lower (Tables I, VI). The profundal benthos makes this lake similar, both quantitatively and qualitatively, to L. Majcz Wielki (Table I).

The conditions found in L. Jorzec show many features of a highly eutrophic system. They are the following: the highest primary production, a high phyto- and zooplankton biomass, but a low biomass of profundal benthos (Tables I, II), multi-peak seasonal dynamics (Fig. 1), and a high percentage of abioseston in the summer seston (Fig. 2). However, there are no blue-green algae in the phytoplankton of this lake, and dominant are algae of the genus Dinobryon (in late spring), and in summer - Ceratium hirundinella (Table I). The composition of the zooplankton is typical of eutrophic systems with a high biomass of rotifers, with numerous K. cochlearis tecta (Table IV). As it has been revealed by studies carried out in different years (W ę g l e ń s k a, B o w n i k-D y l i ń s k a and E j s m o n t - K a r a b i n 1983), an increase in numbers of rotifers is recorded in this lake.

4. A comparison of the mean values of phytoplankton biomass and production and of P_{tot} concentrations (H i l l b r i c h t-I l k o w s k a and Ł a w a c z 1983) of the lakes under study with the respective values found for other lakes (especially those of the group of the Great Masurian Lakes) indicates that the r. Jorka lakes can in general be included among low fertile or medium-fertile water bodies.

It may be presumed that factors, like the nature of the watershed (many forests, wooded and wetland areas, meadows) and low nutrient loads input with the surface runoff (H i l l b r i c h t-I l k o w s k a and Ł a w a c z 1983), a high-rate through-flow, especially in the lakes of the lower basin (e.g., L. Zełwążek and L. Jorzec), and the input of mineral matter (Al, Si, Fe) that can adsorb the nutrients (P in particular) and few (although significant) sources of pollution located in two lakes provide a specific natural background counteracting the rapid eutrophication of this lake system as a whole. This process should also be aided by the low pressure of the native fish fauna, as estimated from the poor or very poor catches. A sign of the weak pressure is the persistence in all the lakes of species of large-bodied crustaceans, including three Daphnia species, in numbers amounting to 200 ind. $\cdot l^{-1}$.

8. POLISH SUMMARY

W wyniku kompleksowych badań geochemicznych i hydrochemicznych, z których główne wnioski przedstawiono w pracy I niniejszego zbioru (Hillbricht-Ilkowska i Ławacz 1983), oraz szczegółowych badań biologicznych przedstawionych w dalszych pracach niniejszego zbioru a dotyczących 5 jezior usytuowanych na małym cieku (rz. Jorka, ok. 12 km długości) i ich zlewni stwierdza się, że:

1. Jezioro usytuowane najwyżej w badanej zlewni, jezioro Majcz Wielki jest układem, w którym oddziaływanie i charakter zlewni (aktualne i w przeszłości), bardzo niskie wartości dopływu pierwiastków biofilnych ze źródeł zewnętrznych oraz brak punktowych źródeł zanieczyszczeń stabilizują niską produktywność tego jeziora i jego status mezotroficzny. Wszystkie analizowane cechy wskazują na mezotroficzny charakter jeziora: niski poziom produkcji pierwotnej, ale wysoki dobowy współczynnik P : B, niska biomasa planktonu i jego komponentów, zaś wysoka biomasa makrofitów zanurzonych (dominują Characeae) oraz litoralowego i profundalowego bentosu (tab. I, III), „płaski" lub jednoszczytowy typ dynamiki planktonu i różnych jego komponentów (rys. 1), brak sinic w fitoplanktonie zaś dominacja nannoplanktonu i gatunków z rodzaju Dinobryon (tab. III), duża różnorodność gatunkowa różnych zespołów z gatunkami wskaźnikowymi (tab. IV, V), niskie wartości stosunku biomasy zooplanktonu drapieżnego do biomasy niedrapieżnego ($B_p : B_{np}$) oraz biomasy Cyclopoida do biomasy Calanoida ($B_{cycl} : B_{cal}$), zaś wysoki wskaźnik różnorodności biomasy skorupiaków (Hb) (tab. VI), najniższy odsetek abiosestonu w sestonie letnim (rys. 2).

2. Najbardziej zasobnym troficznie (o najwyższej koncentracji P ogólnego w wodzie) w omawianym systemie jest płytkie i rozległe jezioro Inulec, w którym czynnikiem powodującym współczesny status eutroficzny jest, jak się wydaje, intensywny dopływ fosforu ze źródeł wewnętrznych skalkulowany jako kilka razy przekraczający dopływ ze źródeł zewnętrznych. Jezioro Inulec wykazuje układ cech ilościowych i jakościowych właściwy jeziorom silnie eutroficznym. Są to: stosunkowo wysoki poziom produkcji pierwotnej, wysoka biomasa wszystkich komponentów planktonu, niska biomasa bentosu profundalowego (tab. I, II), w fitoplanktonie dominacja i typowy dla eutrofii skład sinic (Oscillatoria agardhii, Microcystis, Aphanizomenon; tab. III), niski wskaźnik różnorodności biomasy skorupiaków (Hb), zaś wysokie wartości wskaźników B_p : B_{np} i $B_{cycl} : B_{cal}$ (tab. VI), wysoka biomasa wrotków (tab. I) z dominacją dobrego wskaźnika eutrofii jakim jest Keratella cochlearis tecta (tab. IV), mała różnorodność gatunkowa bentosu, wy-

soka biomasa litoralowej roślinności wynurzonej (tab. I), wieloszczytowy charakter dynamiki sezonowej planktonu (rys. 1) i wysoki odsetek abiosestonu w sestonie (rys. 2).

3. Pozostałe jeziora kaskady rz. Jorki - które w stosunku do jeziora Majcz Wielki można uznać za mniej lub więcej eutroficzne i wyraźnie bardziej żyzne - prezentują układ ilościowych i jakościowych wskaźników trofii wyraźnie niespójny, tzn. stanowiący mieszankę cech, które - zgodnie z wiedzą - przypisuje się lub częściej spotyka w jeziorach odmiennych troficznie. Dotyczy to przede wszystkim Jeziora Głębokiego (i połączonego z nim hydrologicznie jeziora Zełwążek), w znacznie słabszym stopniu również jeziora Jorzec. Jeziora te eksponowane są na najsilniejszy dopływ pierwiastków biofilnych ze źródeł zewnętrznych, jakimi są źródła zanieczyszczenia, jak też wykazują wyraźne objawy zanieczyszczenia organicznego w postaci zwiększonego udziału i biomasy Euglenophyta w fitoplanktonie (tab. III), zwiększonej liczebności orzęsków polisaprobowych (tab. V), zaś w Jeziorze Głębokim również bardzo wysokiej (najwyższej w analizowanych jeziorach) obfitości bakterioplanktonu (tab. II, VIII).

Dopływ zanieczyszczeń (tab. VIII) do Jeziora Głębokiego oddziałuje względnie krótkotrwale (sadzowa hodowla istnieje od 1974 r.), ale stosunki morfometryczne (ostry gradient termiczny, metalimnetyczne minimum tlenowe w okresie letnim) stanowią w myśl koncepcji G l i w i c z a (1979) czynnik przyspieszający wzrost produktywności tego jeziora. Stąd jezioro to aktualnie wykazuje wyraźnie „miksotroficzny" układ, gdzie przy wysokiej produktywności pierwotnej, nawet wyższej niż w jeziorze Inulec (tab. I) istnieje względnie niska biomasa glonów (tab. I), ale wysoki odsetek nannoplanktonu oraz silnie zaznaczona dominacja sinicy Gomphosphaeria lacustris (tab. III), której tendencję do występowania bliżej sadzy hodowlanych (w porównaniu ze stanowiskiem oddalonym; tab. VIII), jak też liczniejsze występowanie z roku na rok w tym właśnie jeziorze wykazała S p o d n i e w s k a (1983b). Z kolei biomasa zooplanktonu jest stosunkowo niska (tab. I), zaś struktura (tab. IV) i dynamika (rys. 1) raczej typowa dla układów mezotroficznych. Również niska jest biomasa wrotków, zaś wysoki wskaźnik Hb oraz niższe wartości wskaźników $B_n : B_{np}$, $B_{cycl} : B_{cal}$ (tab. I, VI). Natomiast bentos profundalowy zarówno ilościowo jak i jakościowo upodobnia to jezioro do jeziora Majcz Wielki (tab. I).

Z kolei układ notowany w jeziorze Jorzec ma wiele cech wysoko eutroficznego systemu. Są to - najwyższa produkcja pierwotna, wysoka biomasa fito- i zooplanktonu, zaś niska bentosu profundalowego (tab. I, II), wieloszczytowy charakter dynamiki sezonowej (rys. 1) i wysoki odsetek abiosestonu w sestonie letnim (rys. 2). Jednakżę w składzie fitoplanktonu tego jeziora brak jest sinic, dominują natomiast glony z rodzaju Dinobryon (w okresie późnowiosennym), zaś w okresie letnim Ceratium hirundinella (tab. I). Skład zooplanktonu jest typowy dla układów eutroficznych, wysoka jest biomasa wrotków z licznie występującą K. cochlearis tecta (tab. IV), a jak wykazały badania prowadzone w różnych latach (W ę g l e ń s k a, B o w n i k - D y l i ń s k a i E j s m o n t - K a r a b i n 1983) notuje się wzrost obfitości wrotków, jak wiadomo dobrze reagujących na eutrofizację jezior (K a r a b i n 1982).

4. Z porównania średnich wartości biomasy i produkcji fitoplanktonu, jak też koncentracji P ogólnego (H i l l b r i c h t - I l k o w s k a i Ł a w a c z 1983) badanych jezior z innymi jeziorami (szczególnie z grupy Wielkich Jezior Mazurskich) wynika, że jeziora rz. Jorki należą ogólnie do mało lub średniożyznych. Można przypuścić, że takie czynniki, jak charakter zlewni (sporo lasów, zadrzewień, terenów zabagnionych i łąk) i niewielkie ładunki pierwiastków biofilnych dostarczane w spływie powierzchniowym (H i l l b r i c h t - I l k o w s k a i Ł a w a c z 1983), silna przepływowość jezior, szczególnie dolnego dorzecza (np. jezioro Zełwążek i jezioro Jorzec) i dopływ materii mineralnej (Al, Si, Fe) mogącej kompleksować związki troficzne (szczególnie P) i nieliczne (choć istotne) źródła zanieczyszczeń zlokalizowane w 2 jeziorach stanowią swoisty układ warunków naturalnych przeciwdziałający nadmiernej eutrofizacji tego kompleksu jeziornego jako całości. Współdziałać w tym powinna również słaba presja ichtiofauny, sądząc przynajmniej po niskich lub bardzo niskich odłowach. Objawem tej słabej presji jest utrzymywanie się we wszystkich jeziorach dużych gatunków skorupiaków, w tym 3 gatunków Daphnia w łącznej liczebności rzędu do 200 osobn. $\cdot l^{-1}$.

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