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

III. PRODUCTION AND PHOTOSYNTHESIS EFFICIENCIES OF PHYTOPLANKTON**

ABSTRACT: In mesotrophic Lake Majcz Wielki the photosynthetic production (^{14}C), between April and October 1977, was 65 g $C_{ass} \cdot m^{-2}$, the maximal daily one was 500 mg $C_{ass} \cdot m^{-2}$ photosynthesis efficiency (in relation to PHAR) up to 0.31%, and the daily P : B coefficient up to 2.2. In remaining lakes, of a more advanced trophic state, these values were between 213 (Lake Jorzec) and 108 g $C_{ass} \cdot m^{-2}$ (Lake Zełwążek), and between 4491 and 1400 mg $C_{ass} \cdot m^{-2}$ day^{-1}, whereas the photosynthesis efficiency frequently exceeded 1%. Seasonal changes of photosynthesis its efficiency and the P : B ratio among others, depending on phosphorus concentration and the N : P ratios, were analysed.

KEY WORDS: Lakes, phytoplankton photosynthesis, nutrient ratio, daily P : B coefficient.

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Contents

1. INTRODUCTION, TERRAIN

The studies were conducted in lakes being a chain system of water bodies linked by a small watercourse of river Jorka of a mean flow at the mouth 200-500 l · $sec.^{-1}$, about 12 km long and a watershed of 63 km^2, which flows into Lake Tałty from the system of Great Masurian Lakes (Masurian Lakeland, Poland) (for the locality and map see Hillbricht-Ilkowska and Ławacz 1983, and Bajkiewicz-Grabowska - in press-a, b). These lakes are as follows (in the order of water runoff): Lake Majcz Wielki (area 1.74 km^2, max. depth 16.4 m, mean depth 6.0 m, dimictic, mesotrophic), Lake Inulec (area 1.61 km^2, max. depth 10.1 m, mean depth 4.6 m, polymictic, eutrophic), Głębokie Lake (area 0.46 km^2, max. depth 34.3 m, mean depth 11.8 m, dimictic, moderately eutrophic), Lake Zełwążek (area 0.12 km^2, max. depth 7.4 m, mean depth 3.7 m, polymictic, pond-type) and Lake Jorzec (area 0.41 km^2, max. depth 11.6, mean depth 5.5 m, dimictic, highly eutrophic). The morphometric relations, locality in the watershed, geological substrate and the land cover in the watershed of each lake, water retention, hydraulic and nutrient loading rates and point sources of pollution (Hillbricht-Ilkowska and Ławacz 1983, Planter, Ławacz and Tatur 1983, Bajkiewicz-Grabowska - in press-a, b, Ławacz et al. - in press) are the causes of differentiation of lakes in the past (Stasiak and Tatur - in press) and at present as regards the nutrient content, abundance and structure of various biota, including plankton (Spodniewska 1983, Węgleńska, Bownik-Dylińska and Ejsmont-Karabin 1983). The aim of the present paper is an estimation of the intensity of photosynthesis and its efficiency and the P : B ratio, as well as an analysis of seasonal changes in production and stratification according to concentration and ratio of basic nutrients.

2. METHODS

Phytoplankton production was estimated on the basis of measurements of assimilation of ^{14}C by phytoplankton in April, June, July, November 1976 and once a month between April and October 1977. The method of radioactive carbon ^{14}C was used (after Steemann Nielsen 1952, 1958, Goldman 1963, Vollenweider 1969). To each 100 ml bottle with unfiltrated lake water 1 ml of solution labelled sodium carbonate ($Na_2{}^{14}CO_3$) of a radioactivity 2 µCi was added and incubated in the lake at the depth 0.5-6 m or 0.5-5.0 m. The bottles were incubated 4 hours (from 10 a.m. to 2 p.m.) during the maximal solar radiation. At each depth there were three light and two dark bottles. The bottles were dark by being tightly wrapped in tin-foil. After the incubation, the water samples were fixed in 1 ml 4% formalin in order to inhibit the production and were taken to the laboratory. Not longer than three hours after the experiment water samples of a volume 20 ml were filtered on membrane filters 0.45 µm Millipore HAWOO 25. The filters were rinsed with 20 ml 0.1 n HCl to remove ^{14}C not embodied in algal cells and then dried at room temperature; the radioactivity of filters was determined in scintillation counter Beckman LS-355. This radioactivity was measured in scintillator being a mixture of 1000 ml of analytically pure toluene with 5 g PPO (2,5 diphenyloxazole pure) and 0.25 g POPOP (1,4-di/2/5-phenyloxazolylbenzene) (Turner 1972, Birks 1975). The radioactivity of filters was calculated with a 5-9% error. The number of impulses was calculated per µg C^{ass} per unit of time per surface area or volume unit (V o l l e n w e i d e r 1969). The isotope correction 1.06 was used according to the same author. Phytoplankton production was obtained by deducting the radioactivity in dark bottles from that in light bottles.

Total dissolved inorganic CO_2 was determined according to G o l t e r m a n and C l y m o (1969) by titrating water samples 0.05 n HCl in the presence of Tashiro index.

Daily production was calculated multiplying μg C^{ass} during the exposure by coefficient k (ratio of daily I_0 to I_0 for 4 hours), which is the ratio of incident radiation on lake surface area during a day to radiation during 4 hours of exposure in situ (S c h i n d l e r 1972).

Production (in mg or g C^{ass}) was expressed in two ways: per volume unit (l or m^3 of given horizon or average for trophogenic layer, i.e., 0-5 or 0-6 m) and time unit (hour, day), or per surface area unit (m^2) of this trophogenic layer and time unit (day, vegetation season) by integrating or by making the average of each series of measurements.

The photosynthesis efficiency was calculated as the ratio of C^{ass} to photosynthetically active radiation (PHAR), both values were expressed in $J \cdot m^{-2} \cdot day^{-1}$. It was assumed that 1 mg of C is 39.193 J (i.e., 9.361 cal). The daily P : B coefficient, i.e., production to biomass, was also estimated. Both values were given in carbon units assuming that carbon is 5% of fresh biomass of algae. The biomass data are after S p o d n i e w s k a (1983).

Incident solar radiation per surface area unit of water body is given in $J \cdot cm^{-2} \cdot min.^{-1}$. It was measured using the solarigraph of Moll-Gorczyński on the field station of the Institute of Meteorology and Water Management at Mikołajki, 10 km to the south-west from the area investigated. In order to calculate the photosynthesis efficiency, solar radiation active at the photosynthesis (PHAR) was assumed as 50% of incident solar radiation on the surface of the water body measured by the solarigraph minus about 10% (light reflected on water surface). Thus solar radiation active in the photosynthesis was estimated as about 45% of radiation measured by the solarigraph (S c h i n d l e r 1972, K e r e k e s 1977).

The transparency of water was measured using the Secchi disc in the vegetation season of 1976, twice a month between March and November, and in 1977, every month from April to October.

3. RESULTS

3.1. Estimation of total production during the vegetation season and seasonal dynamics

In both years of investigations the seasonal changes in phytoplankton production in the 0-6 m trophogenic layer were similar in the majority of lakes of Majcz Wielki-Jorzec system (Fig. 1). In all lakes examined the rate of ^{14}C assimilation by phytoplankton was higher in spring (April) and in summer (July, August). In other periods of vegetation season the rate of ^{14}C assimilation was much lower (Fig. 1). In lakes Inulec and Głębokie the spring production peak was higher than the summer one, whereas in Lake Jorzec the summer maximum of phytoplankton production was higher than the spring one, and was especially high in 1977. In Lake Majcz Wielki the production was the highest in spring of 1976 and in summer of 1977. These relations were similar in Lake Zełwążek.

As regards the assimilation of ^{14}C in successive years of investigations phytoplankton production was generally higher in the vegetation season of 1977 as compared with values obtained in analogous periods of 1976 (Fig. 1).

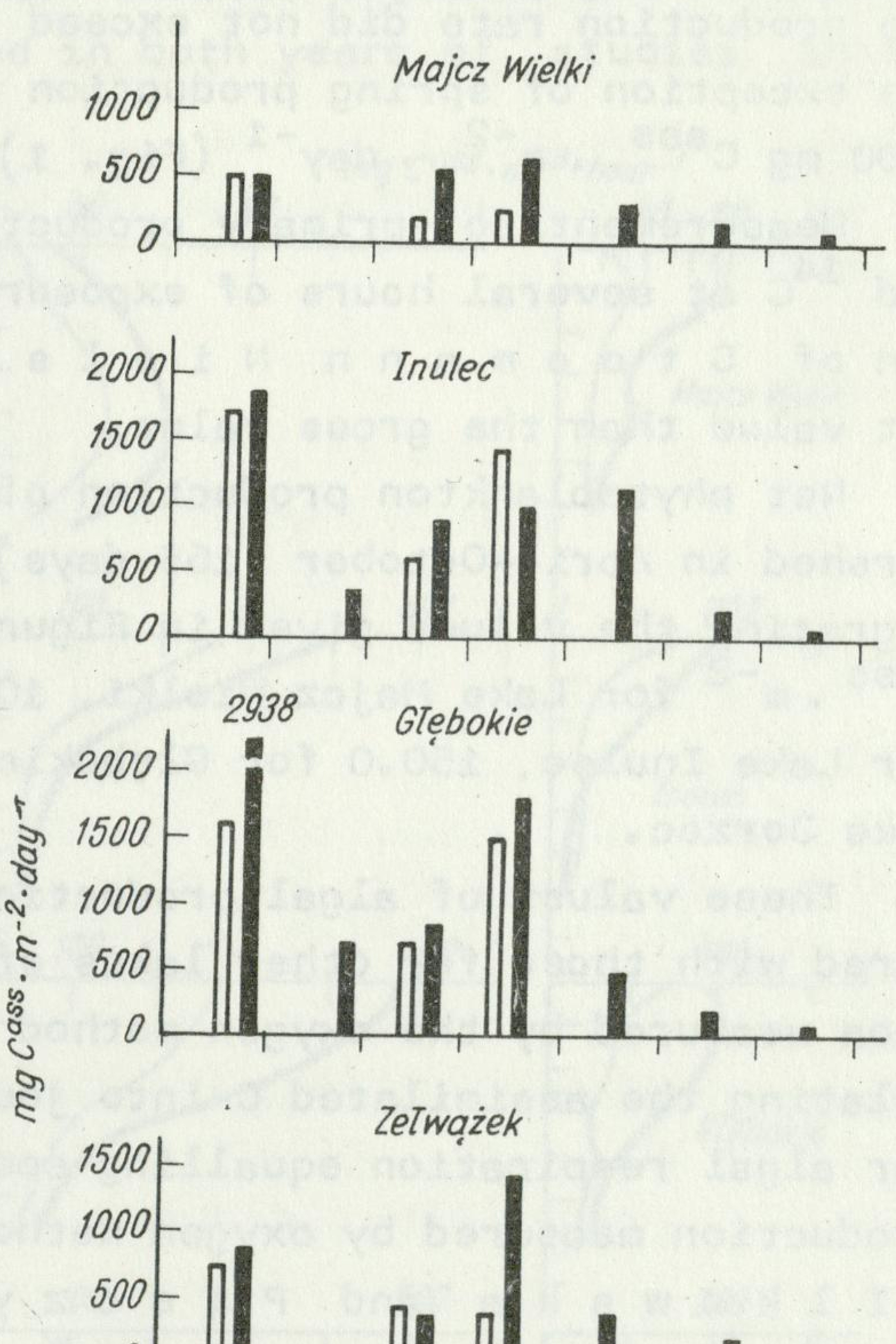

Fig. 1. Phytoplankton photosynthesis in r. Jorka lake system in 1976 (white bars) and 1977 (black bars)

In all periods of investigations Lake Majcz Wielki had the lowest primary production. The amount of assimilated ^{14}C exceeded only slightly 500 mg $C^{ass} \cdot m^{-2} \cdot day^{-1}$ at periods of peak production, i.e., in June and July, whereas in other months it was between 11 (November) and 276 mg $C^{ass} \cdot m^{-2} \cdot day^{-1}$ (August). The production was the highest in Lake Jorzec, which is the last one in the system of five lakes joined by r. Jorka. In periods of maximum production the amount of assimilated ^{14}C was between 1500 (April) and some 4500 mg $C^{ass} \cdot m^{-2} \cdot day^{-1}$ (July). In other lakes the production rate did not exceed 1800 mg $C^{ass} \cdot m^{-2} \cdot day^{-1}$, with the exception of spring production peak in Głębokie Lake - about 3000 mg $C^{ass} \cdot m^{-2} \cdot day^{-1}$ (Fig. 1).

Measurements of primary production by means of carbon labelled ^{14}C at several hours of exposure, consistently with the opinion of S t e e m a n n N i e l s e n (1977), are closer to the net value than the gross value.

Net phytoplankton production of lakes of the river Jorka watershed in April-October (165 days) in 1977 was calculated by integrating the values given in Figure 1, being respectively: 65 g $C^{ass} \cdot m^{-2}$ for Lake Majcz Wielki, 107.5 for Lake Zełwążek, 137.5 for Lake Inulec, 150.0 for Głębokie Lake and 212.5 g $C^{ass} \cdot m^{-2}$ for Lake Jorzec.

These values of algal production in lakes examined were compared with those for other lakes of the Masurian Lakeland (production measured by the oxygen method and given in calories) by calculating the assimilated C into joules. A correction was also made for algal respiration equalling some 20% gross production, i.e., production measured by oxygen method (K a j a k, H i l l b r i c h t - I l k o w s k a and P i e c z y ń s k a 1972).

During the study period the lowest production was in Lake Majcz Wielki, 2546 KJ $\cdot m^{-2}$ which was more than twice lower as that in the mesotrophic deep Lake Tałtowisko during a slightly longer period - 180 days (K a j a k, H i l l b r i c h t - I l k o w s k a and P i e c z y ń s k a 1972). The production was the highest in Lake Jorzec - 8256 KJ. Still, according to the same authors, it was lower than in the strongly eutrophic Mikołajskie Lake. In other lakes (Inulec, Zełwążek, Głębokie), despite considerable morphometric differentiation, first of all the chemical composition of water, the phytoplankton production values were similar being respectively: 4189 for Lake Zełwążek, 5388 for Lake

Inulec and 5878 KJ $\cdot$ m^{-2} for Głębokie Lake. However, these values were lower than those obtained in other eutrophic lakes of the Masurian Lakeland (Kajak, Hillbricht - Ilkowska and Pieczyńska 1972, Spodniewska and Hillbricht-Ilkowska 1973).

3.2. Stratification of primary production

In the most productive lakes: Inulec, Głębokie and Jorzec the production maxima were recorded in both years of studies in the surface water layers, i.e., 0-1 m (Fig. 2). Assimilation of ^{14}C fluctuated from over 100 to about 500 mg $C^{ass} \cdot m^{-3} \cdot h^{-1}$ in spring (April) and in summer (August).

A different type of photosynthesis stratification was observed in the least productive Lake Majcz Wielki (Fig. 2). The light inhibition of ^{14}C assimilation (about 20 mg C^{ass} m^{-3} $\cdot$ h^{-1}) was observed in surface water layers, whereas the maximal rate (about 80 mg C^{ass} $\cdot m^{-3}$ $\cdot h^{-1}$) - at the depth of 4-5 m at periods of both production

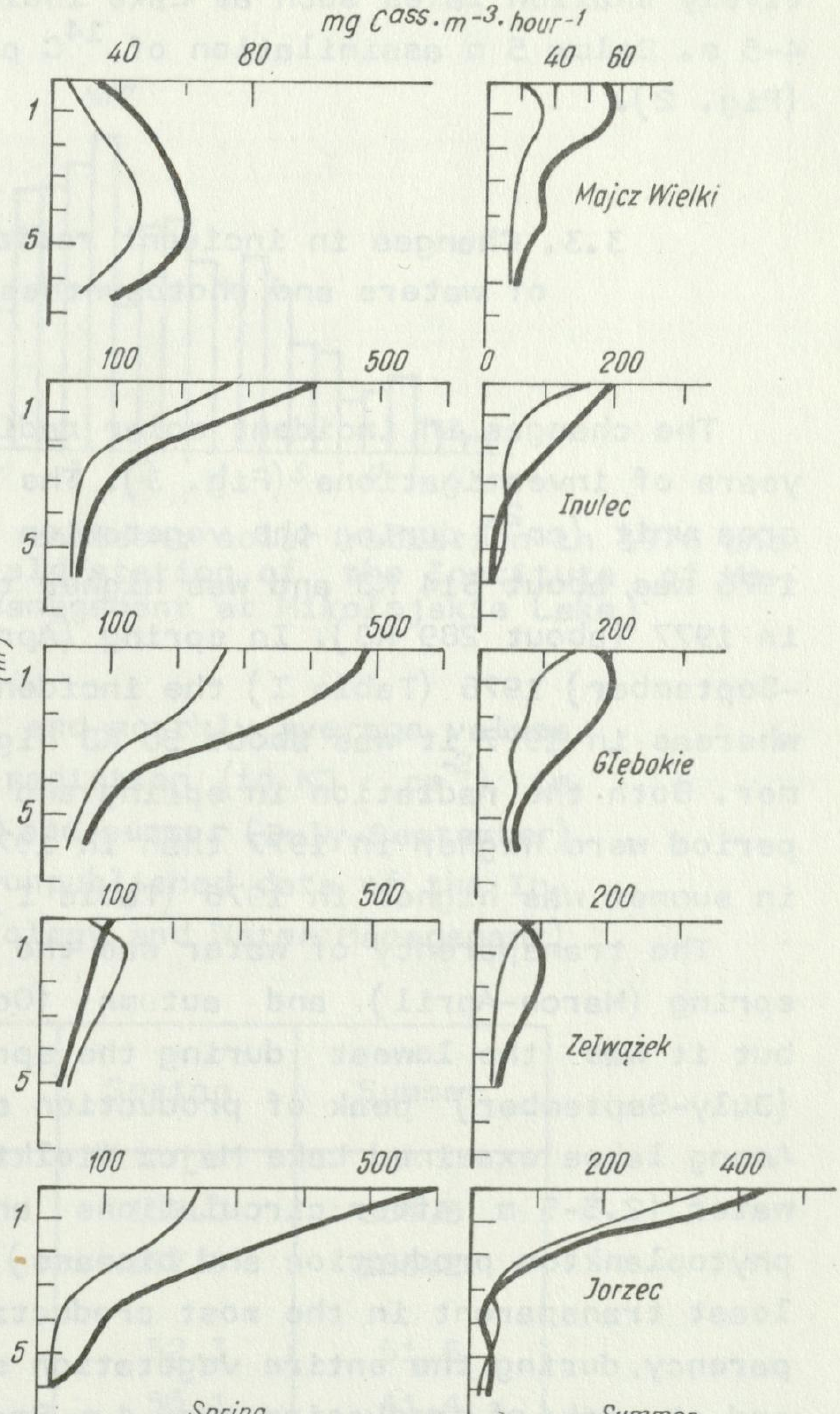

Fig. 2. Vertical changes of photosynthesis of phytoplankton in r. Jorka lake system in spring and summer 1976 (thin line) and 1977 (thick line)

peaks. Photosynthesis strafification in Lake Zełwążek was similar (Fig. 2).

According to F i n d e n e g g (1964) the character of vertical changes in intensity of photosynthesis describes better the trophic type of lake than the production calculated per surface area unit. The type of stratification observed in lakes: Inulec, Głębokie and Jorzec is characteristic of eutrophic lakes, whereas Lake Majcz Wielki has a stratification typical of mesotrophic water bodies. The thickness of production zone has changed during the vegetation season. In spring this layer reached 6 m in all lakes examined, whereas in summer, in highly productive and relatively shallow lakes such as Lake Inulec and Lake Jorzec it was 4-5 m. Below 5 m assimilation of ^{14}C practically equalled to zero (Fig. 2).

3.3. Changes in incident radiation, transparency of waters and photosynthesis efficiency

The changes in incident solar radiation were similar in both years of investigations (Fig. 3). The solar radiation per surface area unit (cm^2) during the vegetation period April-September in 1976 was about 314 KJ and was higher than in the analogous period in 1977 (about 289 KJ). In spring (April-June) and in summer (July--September) 1976 (Table I) the incident radiation was similar, whereas in 1977 it was about 50 KJ higher in spring than in summer. Both the radiation in spring and the monthly mean for this period were higher in 1977 than in 1976. But the solar radiation in summer was higher in 1976 (Table I).

The transparency of water was the highest (Fig. 4) after spring (March-April) and autumn (October-November) circulation, but it was the lowest during the spring (April-May) and summer (July-September) peak of production and biomass of phytoplankton. Among lakes examined Lake Majcz Wielki had the most transparent water (2.5-5 m after circulations and 2.5-3 m during peaks of phytoplankton production and biomass), whereas water was the least transparent in the most productive Lake Jorzec. Its transparency, during the entire vegetation season, did not exceed 1.5 m, and at peaks of production even 1 m. Small transparency of water in

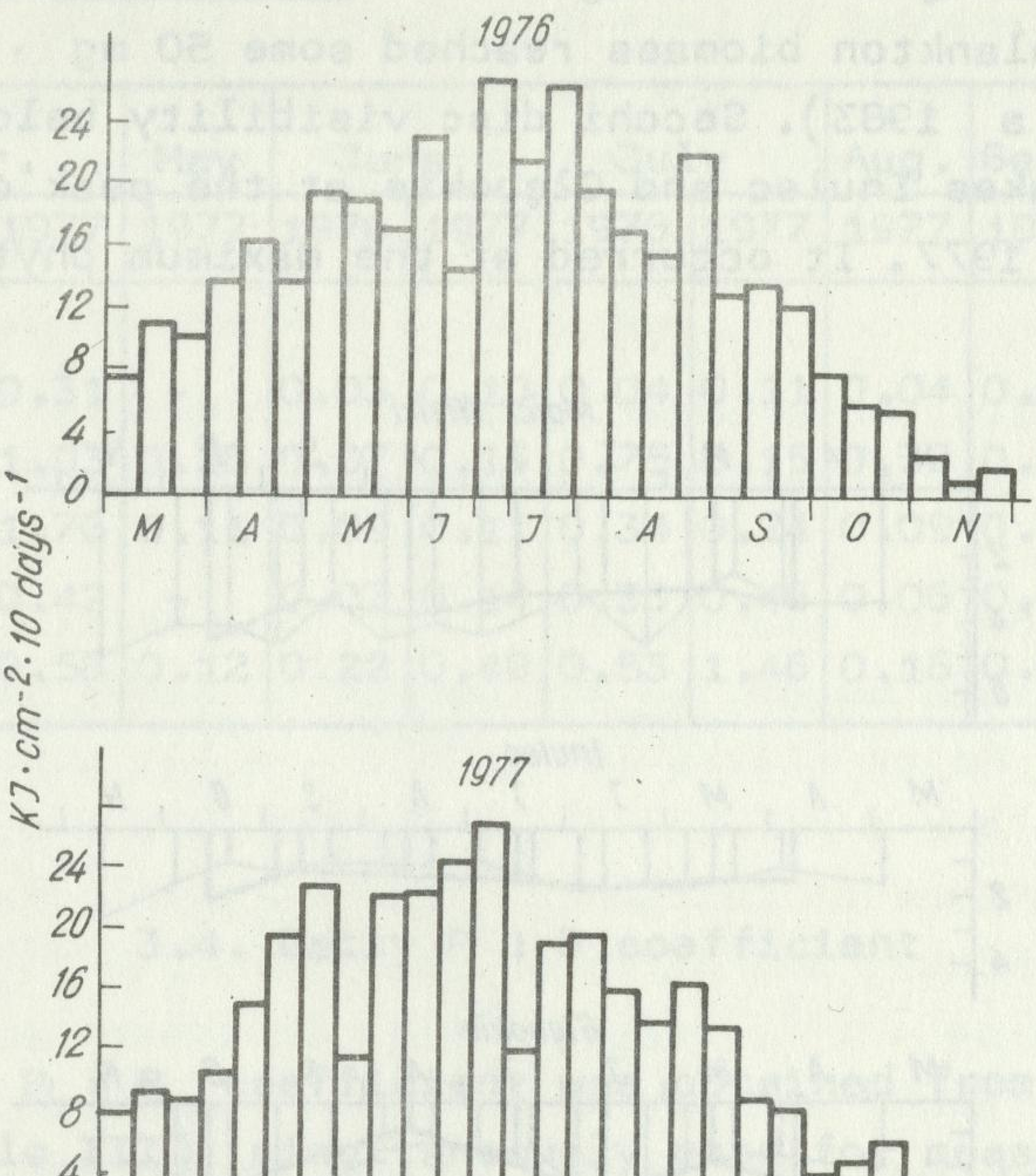

Fig. 3. Seasonal changes of incident solar radiation in 1976 and 1977 (unpublished data of field station of the Institute of Meteorology and Water Management at Mikołajskie Lake)

Table I. The total and monthly average values of incident solar radiation (in KJ · cm^{-2}) in spring (April–June) and summer (July–September) of 1976 and 1977 (unpublished data of the Institute of Meteorology and Water Management)

Incident radiation		Spring	Summer
Total	1976	157.0	154.5
	1977	167.9	125.2
Average	1976	52.3	51.5
	1977	56.1	41.4

this lake at the peak of summer stagnation was connected with intensive blooming of dinoflagellate Ceratium hirundinella O.F. Bergh. (phytoplankton biomass reached some 50 mg $\cdot l^{-1}$) (S p o d n i e w s k a 1983). Secchi disc visibility below 1 m was also recorded in lakes Inulec and Głębokie at the peak of summer stagnation (August) 1977. It occurred at the maximum phytoplankton biomass.

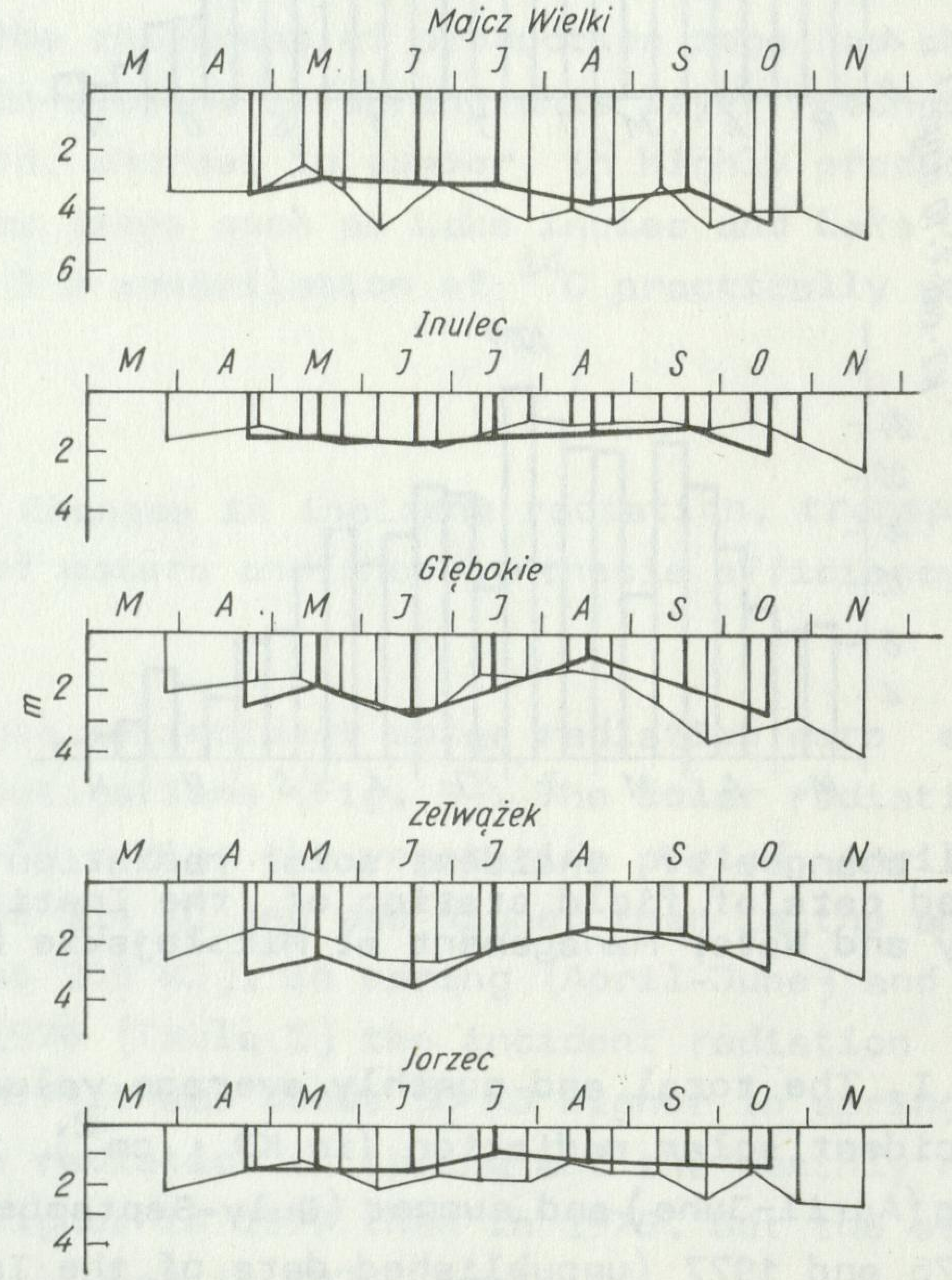

Fig. 4. Seasonal changes of the Secchi disc readings in r. Jorka lake system in 1976 (thin line) and 1977 (thick line)

Photosynthesis efficiency of phytoplankton of lakes of the river Jorka watershed (in per cents of radiation PHAR) attained almost 2% during the early spring production peak in lakes Inulec and Głębokie and attained 1.5% during the summer production maximum in Lake Jorzec (Table II). The maximal use of solar energy by the community of algae in lakes of river Jorka watershed approximated values recorded by T i l z e r et al. (1977) for phytoplanktonic communities in the strongly eutrophic stratified Mikołajskie Lake.

Table II. Efficiency of photosynthesis (in per cent of PHAR) of phytoplankton in r. Jorka lake system in 1976 and 1977

Lake	Apr.		May	June		July		Aug.	Sept.	Oct.	Nov.
	1976	1977	1977	1976	1977	1976	1977	1977	1977	1977	1976
Majcz Wielki	0.09	0.31	-	0.03	0.10	0.04	0.11	0.04	0.02	0.03	0.03
Inulec	0.05	1.93	0.28	0.07	0.13	0.75	0.15	0.38	0.08	0.09	0.02
Głębokie	0.39	1.76	0.11	0.09	0.11	0.34	0.24	0.09	0.05	0.09	0.12
Zełwążek	0.13	0.42	-	0.07	0.14	0.33	0.46	0.06	0.05	0.04	0.004
Jorzec	0.67	0.58	0.12	0.22	0.49	0.53	1.46	0.16	0.09	0.14	0.08

3.4. Daily P : B coefficient

The daily P : B coefficient was obtained from data taken on 8-10 dates (Table III) simultaneously used for measuring the assimilation of ^{14}C (in mg $C^{ass} \cdot m^{-3} \cdot day^{-1}$, on the average for the trophogenic layer and biomass of algae (in mg wet wt $\cdot m^{-3}$ of this layer) according to data of Spodniewska (1983). It was assumed that carbon is about 5% of wet weight of algae.

Table III. Daily P : B coefficient of phytoplankton in r. Jorka lake system in 1976 and 1977 (original data on production and biomass were transferred into mg C $\cdot l^{-1} \cdot day^{-1}$. Biomass data after Spodniewska 1983

Lake	Apr.		May	June		July		Aug.	Sept.	Nov.
	1976	1977	1977	1976	1977	1976	1977	1977	1977	1976
Majcz Wielki	0.48	-	-	0.40	0.29	0.73	2.23	0.15	0.20	0.02
Inulec	0.72	-	0.91	0.48	-	0.79	0.56	0.18	-	0.002
Głębokie	0.80	1.35	0.29	0.40	1.41	-	0.91	0.15	0.05	0.08
Zełwążek	0.98	-	-	2.07	-	0.21	0.77	0.13	0.07	0.004
Jorzec	0.62	0.57	-	0.49	-	0.61	1.95	0.04	0.33	0.04

The small number of data does not allow to analyse thoroughly the seasonal changes of the P : B coefficient. Still, it can be said that between August and November this coefficient was usually lower (0.002-0.33) (Table III), whereas in spring and early in summer (till July) it was higher (0.21-2.23). Values approximating 1.0 or more were observed in Lake Majcz Wielki in July (2.23), in Lake Inulec in May (0.91) in Lake Jorzec in July (1.95), i.e., once during the spring or summer production peak, whereas several times in lakes Głębokie and Zełwążek between April and July (Table III).

3.5. Relationship between production and nutrient concentration in water

As indicated in subchapter 3.1 the lowest production during the vegetation season in the series of lakes examined was recorded in Lake Majcz Wielki (65 g $C^{ass} \cdot m^{-2}$), which according to data of Planter, Ławacz and Tatur (1983) have low concentrations of inorganic forms of phosphorus (SRP-Soluble Reactive Phosphorus) and nitrogen (sum of $NO_3 + NH_4$), not exceeding 45 and 600 $\mu g \cdot l^{-1}$, respectively. In other lakes the concentration of nutrients and production were higher and Lake Inulec had the highest one (maximum SRP concentration at the bottom in summer reached 500 $\mu g \cdot l^{-1}$, whereas of N-NH_4 up to 2400 $\mu g \cdot l^{-1}$) with quite high production during the season, 137.5 g $C^{ass} \cdot m^{-2}$, but not the highest (e.g., as compared with Lake Jorzec, 212.5 g $C^{ass} \cdot m^{-2}$).

The relations among seasonal changes of SRP as a basic nutrient limiting the assimilation of ^{14}C is illustrated by data for three lakes: Inulec, Głębokie and Jorzec (Fig. 5) with sufficiently frequent SRP measurements and monthly production measurements between April and October 1977. The comparison of these data shows that the maximum spring production in all three lakes is simultaneous with the exhaustion of SRP from the winter resources both in the surface and near-bottom layer (spring circulation). But considering these three lakes examined, there is no close relationship between SRP concentration in the post-winter period and the production rate in spring. However, it is interesting that Głębokie Lake had the highest production in spring (about 400 mg $C^{ass} \cdot m^{-3} \cdot day^{-1}$) where at this time the weight ratio of inorganic forms N : P was 10, i.e., according to investigations of Vallentyne (1974) and Schindler (1977) is the best from the point of food requirements of algae.

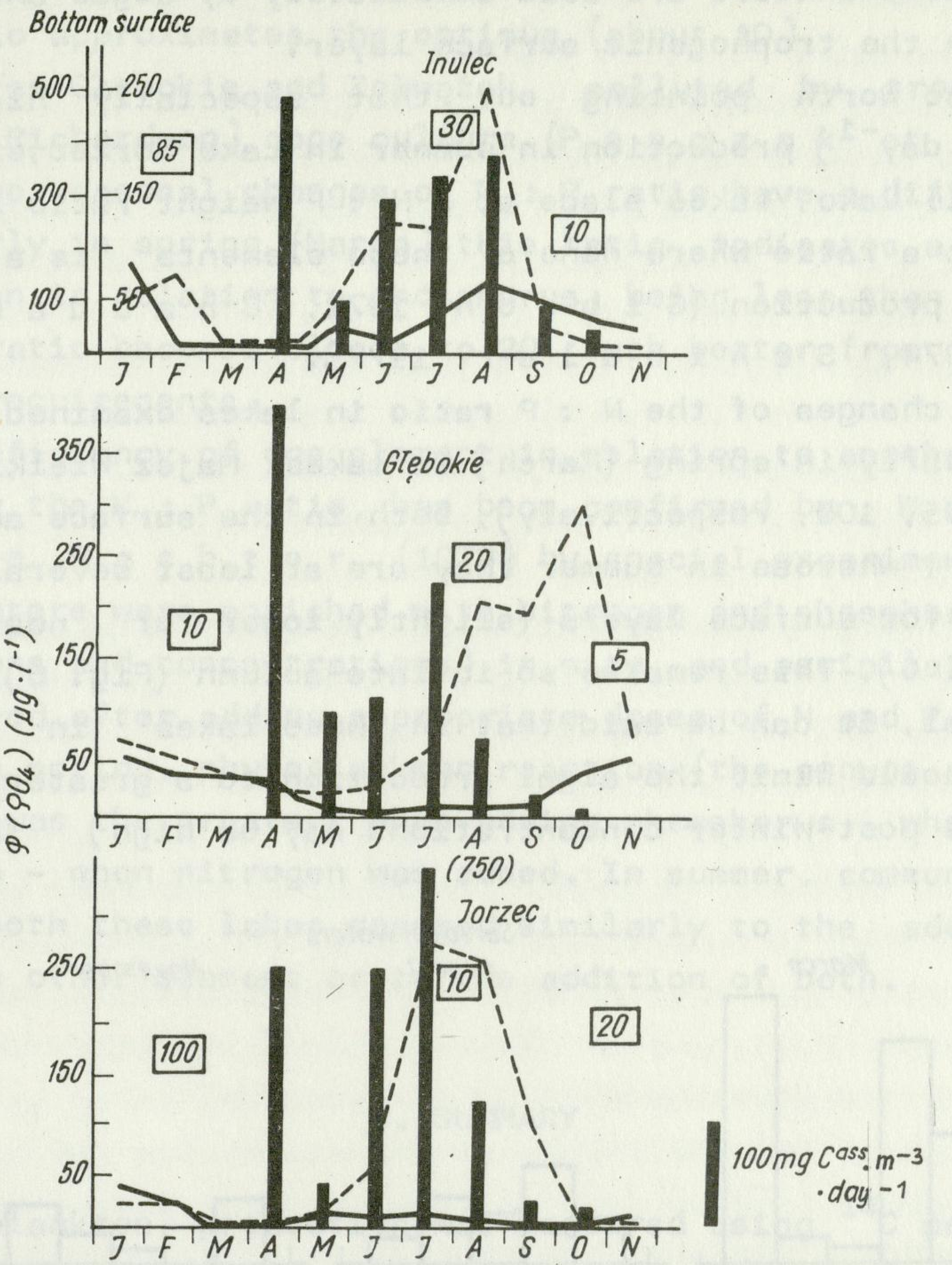

Fig. 5. Seasonal changes of phytoplankton photosynthesis (standing bars) in mg $C^{ass} \cdot m^{-3} \cdot day^{-1}$ in relation to the changes of phosphate concentration (in $\mu g \cdot l^{-1}$) in surface (continous line) and near-bottom (dashed line) water in three lakes of r. Jorka lake system

In frames: N : P weight ratio (phosphorus data after P l a n t e r, Ł a w a c z and T a t u r 1983)

Summer maximum of ^{14}C assimilation (July, August) in the above mentioned lakes usually co-occurs with faint or trace concentrations of SRP in surface layers, but with increasing concentration in the near-bottom layers (Fig. 5). As pointed out by E j s m o n t-K a r a b i n (1982), a relatively high production of algae in summer is mainly due to constant use of phosphorus excreted by zooplankton. This process in the main recycling mechanism of inorganic compounds in lake pelagial during summer, and the compounds excreted by zooplankters are used immediately by algae and do not accumulate in the trophogenic surface layer.

It is also worth pointing out that especially high (751 mg $C^{ass} \cdot m^{-3} \cdot day^{-1}$) production in summer in Lake Jorzec, similarly as in Głębokie Lake, takes place at a N : P weight ratio about 10, i.e., at such a ratio where none of these elements is a factor limiting the production (G i b s o n 1971, C h a u d a n i and V i g h i 1974, S c h i n d l e r 1977).

Seasonal changes of the N : P ratio in lakes examined show high values early in spring (March) in lakes: Majcz Wielki, Inulec, Jorzec (50, 85, 100, respectively), both in the surface and near-bottom layer, whereas in summer they are at least several times lower, 10-30 for surface layers (slightly lower for near-bottom layers) (Fig. 6). This remains so in late autumn (Fig. 6).

In general, it can be said that in these lakes in spring, phosphorus should limit the algal production to a greater extent (although its post-winter concentrations may be high) (Fig. 5),

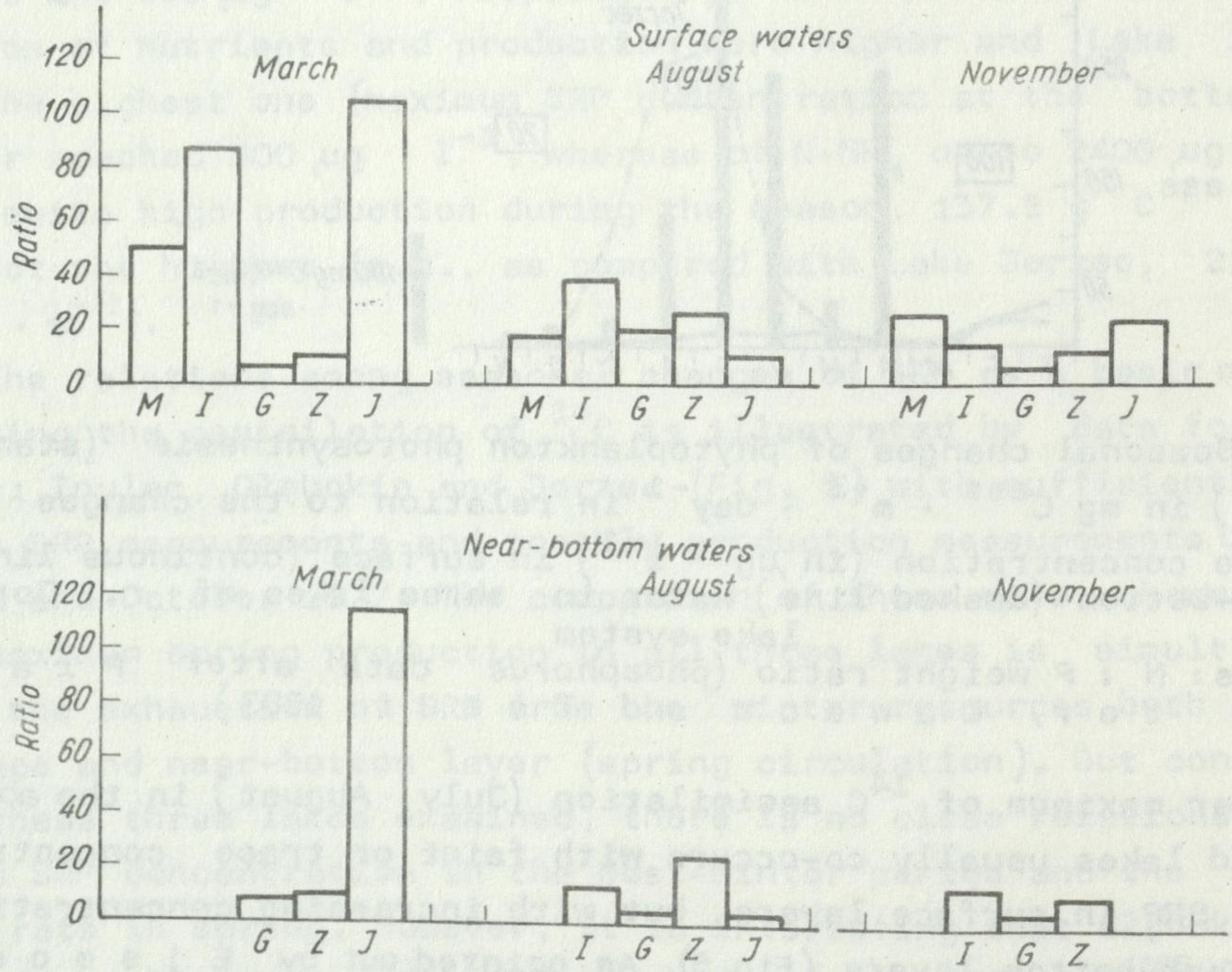

Fig. 6. The weight ratio of inorganic (nitrate and ammonium) nitrogen to phosphate phosphorus in surface and near-bottom waters in r. Jorka lake system in March, August and November 1976
M - Lake Majcz Wielki, I - Lake Inulec, G - Głębokie Lake, Z - Lake Zełwążek, J - Lake Jorzec

whereas, in summer, phosphorus is of lesser significance and the N : P ratio approximates the optimum (about 10).

In lakes Głębokie and Zelwążek, polluted by trout (Salmo gairdneri Richardson) cage culture (P e n c z a k et al. - in press), the seasonal changes of N : P ratio have a different character. Early in spring (March) this ratio indicates a deficiency of nitrogen in relation to phosphorus, being less than 10. In summer this ratio becomes closer to 20, much better from the point of algal requirements.

The deficiency of one element in relation to another, as reflected by the N : P ratio, has been confirmed by W o r o n i e c k a - d e W a c h t e r (1979) by special experiments, where surface waters were enriched with nitrogen and phosphorus (various combinations and concentrations) in situ, and assimilation of ^{14}C was measured after adding appropriate doses of N and P. In Lake Jorzec, in spring, phytoplankton reaction (the amount of assimilated ^{14}C) was the greatest when adding phosphorus, whereas in Głębokie Lake - when nitrogen was added. In summer, communities of algae in both these lakes reacted similarly to the addition of one or the other element or to the addition of both.

4. SUMMARY

Phytoplankton production was measured using ^{14}C method several times in 1976, and every month from April to October in 1977 in five lakes of river Jorka. In Lake Majcz Wielki the primary production was the lowest, between April and October (165 days) 1977 - 65 g $C^{ass} \cdot m^{-2}$ at maximal values in spring and summer about 500 mg $C^{ass} \cdot m^{-2} \cdot day^{-1}$ (Fig. 1). The maximal production in this lake was usually at the depth of 4-5 m, and especially in spring (light inhibition) (Fig. 2). The data point to the mesotrophic character of this lake.

In other lakes phytoplankton production in the same period in 1977 was about 2-3 times higher and was: in Lake Inulec 138 g $C^{ass} \cdot m^{-2}$ (max. about 500 mg $C^{ass} \cdot m^{-2} \cdot day^{-1}$), in Głębokie Lake 150 g $C^{ass} \cdot m^{-2}$ (max. about 3000 mg $C^{ass} \cdot m^{-2} \cdot day^{-1}$) in Lake Zełwążek 108 g $C^{ass} \cdot m^{-2}$ (max. about 1400 mg $C^{ass} \cdot m^{-2} \cdot day^{-1}$), in Lake Jorzec 213 g $C^{ass} \cdot m^{-2}$ (max. about 4500 mg $C^{ass} \cdot m^{-2} \cdot day^{-1}$) (Fig. 1). Maximum production in these lakes was frequent in sur-

face water layers (Fig. 2). The results obtained indicate the eutrophic character of lakes discussed.

The greatest transparency of water (Secchi disc visibility) was observed in Lake Majcz Wielki (to 5 m in periods following the circulation and to 3 m at peaks of phytoplankton production and biomass) (Fig. 4). The smallest transparency was observed at periods of maximal production in Lake Jorzec (about 1 m) and in lakes: Inulec and Głębokie at the peak of summer stagnation in 1977 (Fig. 4).

Photosynthesis efficiency of phytoplankton in relation to PHAR (assumed as 45% of incident solar radiation) (Fig. 3, Table I) during the spring production peak in lakes Inulec and Głębokie was about 2% and during the maximum summer production in Lake Jorzec about 1.5% (Table II). The lowest per cent of light energy was used by algae in Lake Majcz Wielki (max. 0.3%) (Table II).

The daily P : B coefficient, assuming that carbon is 5% of wet weight of algae, showed the highest phytoplankton activity in Lake Majcz Wielki, in July, at small phytoplankton density (about 2.2) (Table III). High photosynthesis activity of phytoplankton was also observed in Lake Inulec in May (about 1.0), in Lake Jorzec in July (almost 2.0), and in lakes Głębokie and Zełwążek almost 1.0, several times during the year (Table III).

The relation between phytoplankton production and the concentration of basic food compounds (nitrogen and phosphorus) in surface water showed that the highest production (about 400 mg $C_{ass} \cdot m^{-3} \cdot h^{-1}$) was in Głębokie Lake, when the weight ratio of inorganic forms N : P was about 10, i.e., the best from the point of food requirements of algae (Figs. 5, 6).

Summer maximum of phytoplankton production in eutrophic lakes examined occurs in the period of trace concentrations of phosphates in surface water (Fig. 5), which being consistent with results of investigations of E j s m o n t - K a r a b i n (1982) indicates that inorganic phosphorus compounds excreted by zooplankton are intensively used by phytoplankton.

An analysis of seasonal changes of N : P ratio in surface water of two eutrophic lakes - Inulec and Jorzec - show that in spring the phosphorus may limit the production (very high N : P), whereas the nitrogen - in lakes Głębokie and Zełwążek (N : P below 10) (Fig. 6). In summer, the ratio N : P is usually 10-30, i.e., closer to the optimum value about 10.

5. POLISH SUMMARY

Przeprowadzono pomiary produkcji fitoplanktonu (metodą ^{14}C) kilkakrotnie w 1976 r. oraz comiesięcznie w okresie kwiecień-październik w 1977 r. w 5 jeziorach rz. Jorki. Najniższą produkcję pierwotną stwierdzono w jeziorze Majcz Wielki, która w 1977 r. w okresie od kwietnia do października (165 dni) wynosiła 65 g $C^{ass}.m^{-2}$, przy wartościach maksymalnych dochodzących do ok. 500 mg $C^{ass}.m^{-2}$.doba^{-1} w okresie wiosennym i letnim (rys. 1). Maksymalne wartości produkcji w tym jeziorze występują zwykle na głębokości 4-5 m, a zwłaszcza wiosną (inhibicja świetlna) (rys. 2). Uzyskane dane wskazują na mezotroficzny charakter tego jeziora.

W pozostałych jeziorach produkcja fitoplanktonu w 1977 r. w tym samym okresie była od ok. 2 do 3 razy wyższa i wynosiła: w jeziorze Inulec 138 g C^{ass}. m^{-2} (maksymalna ok. 500 mg $C^{ass}.m^{-2}$.doba^{-1}), w Jeziorze Głębokie 150 g $C^{ass}.m^{-2}$ (maksymalnie ok. 3000 mg C^{ass}. m^{-2}.doba^{-1}), w jeziorze Zełwążek 108 g C^{ass}. m^{-2} (maksymalnie ok. 1400 mg C^{ass}. m^{-2}. doba^{-1}), w jeziorze Jorzec 213 g C^{ass}. m^{-2} (maksymalnie ok. 4500 mg C^{ass}. m^{-2}. doba^{-1}) (rys. 1). Maksymalne wartości produkcji stwierdzono w tych jeziorach bardzo często w powierzchniowych warstwach wody (rys. 2). Uzyskane wyniki wskazują na eutroficzny charakter omawianych jezior.

Największą przezroczystością wód (widzialność krążka Secchi'ego) cechowało się jezioro Majcz Wielki (do 5 m w okresach po cyrkulacji i do 3 m w okresach szczytów produkcji i biomasy fitoplanktonu) (rys. 4). Najniższą przezroczystość stwierdzono w okresach maksymalnej produkcji w jeziorze Jorzec (ok. 1 m) oraz w jeziorach Inulec i Głębokie w szczycie stagnacji letniej w 1977 r. (rys. 4).

Wydajność fotosyntetyczna fitoplanktonu w stosunku do PHAR (przyjętej jako 45% całkowitego promieniowania świetlnego) (rys. 3, tab. I) jezior dochodziła w czasie wiosennego szczytu produkcji w jeziorach Inulec i Głębokie do ok. 2% oraz osiągała wartości ok. 1,5% w czasie letniego maksimum produkcji w jeziorze Jorzec (tab. II). Najniższy procent energii świetlnej wykorzystywały glony w jeziorze Majcz Wielki (maksymalnie 0,3%) (tab. II).

Ocena dobowego współczynnika P : B (obliczonego przy założeniu, że węgiel stanowi 5% świeżej masy glonów) wykazała największą aktywność fitoplanktonu w lipcu w jeziorze Majcz Wielki, w którym zagęszczenie fitoplanktonu było niewielkie (ok. 2,2) (tab. III). Wysoką aktywność fotosyntetyczną fitoplanktonu stwierdzono również w jeziorze Inulec w maju (ok. 1,0), w jeziorze Jorzec w lipcu (blisko 2,0), zaś w jeziorach Głębokie i Zełwążek wartości bliskie 1,0 stwierdzono kilkakrotnie w ciągu roku (tab. III).

Analizując zależność produkcji fitoplanktonu badanych jezior od koncentracji podstawowych związków pokarmowych (azot i fosfor) w wodzie powierzchniowej wykazano, iż najwyższą produkcją (ok. 400 mg $C_{ass} \cdot m^{-3} \cdot godz.^{-1}$) odznaczało się Jezioro Głębokie w okresie gdy stosunek wagowy mineralnych form N : P wynosił ok. 10, czyli był najbardziej optymalny z punktu widzenia wymagań pokarmowych glonów (rys. 5, 6).

Letnie maksimum produkcji fitoplanktonu w badanych jeziorach eutroficznych występuje w okresie śladowych koncentracji fosforanów w wodach powierzchniowych (rys. 5), co - zgodnie z wynikami badań Ejsmont-Karabin (1982) - wskazuje na intensywne wykorzystanie przez fitoplankton uwalnianych przez zooplankton w procesie ekskrecji związków mineralnych fosforu.

Analiza zmian sezonowych stosunku N : P w wodach powierzchniowych 2 jezior eutroficznych - Inulec i Jorzec - wskazuje, że w okresie wiosennym czynnikiem limitującym produkcję może być fosfor (N : P bardzo wysokie), zaś w jeziorach Głębokie i Zełwążek azot (N : P poniżej 10) (rys. 6). W okresie letnim stosunek N : P wynosi na ogół 10-30, czyli jest bliższy optymalnej wartości równej ok. 10.

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