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LONG-TERM AND SEASONAL CHANGES IN THE PRIMARY PRODUCTION AND DESTRUCTION IN HEATED LAKES NEAR KONIN (POLAND)*

ABSTRACT: Directional, long-term trends of changes in primary production and destruction in three heated lakes are characterized. The effect of environmental conditions has been estimated. Primary production has decreased as a result of lower water retention in lakes and smaller abundance of nutrients. Heated water is responsible for maintaining a high level of destruction.

KEY WORDS: Lake, thermal pollution, primary production, destruction, eutrophication.

1. INTRODUCTION

Studies on primary production in heated lakes of Konin surroundings were a part of complex hydrobiological and fishery research conducted since 1965 by the Inland Fisheries Institute in Olsztyn and Institute of Ecology, Polish Academy of Sciences at Dziekanów Leśny near Warsaw (Hillbricht-Ilkowska and Zdanowski 1988b). They were treated as an indicator of changes in trophic state and the effect of heating water, and also as an element characterizing the functioning of lakes under conditions of a changed thermal and hydrological regime after the lakes were included into the power plant cooling system (Patalas 1970, Zdanowski 1976, Hillbricht-Ilkowska and Zdanowski 1978).

For a relatively long time (1966–1983) studies on primary production were conducted on two out of five lakes of Konin surroundings, i.e., on the heated since 1958 Lake Licheńskie and Wąsosko-Mikorzyńskie (further on called Lake Mikorzyńskie) at first very little heated, belonging to the cooling system from 1970. Primary production was also investigated in the heated and polluted Lake Gosławskie between 1975 and 1978.

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The lakes examined differed in mixing, morphometry, natural trophic state, thermal and hydrological system, formed in each lake by a different kind and intensity of heated-water discharge. They were also loaded to a different degree with mineral and organic pollution from the catchment area (Korycka and Zdanowski 1976, Zdanowski and Korycka 1976, Hillbricht-Ilkowska and Zdanowski 1988b, Zdanowski et al. 1988).

Directional trends of changes in primary production are characterized for three heated lakes and the relations with changes of habitat conditions are estimated. Results of investigations in the years 1966 – 1973 have been used here (Patalas 1970, Hillbricht-Ilkowska et al. 1976, Zdanowski 1976, Hillbricht-Ilkowska and Zdanowski 1978).

2. AREA AND METHODS OF INVESTIGATIONS

Detailed environmental characteristics of lakes are given by Hillbricht-Ilkowska and Zdanowski (1988b) and Zdanowski et al. (1988).

Lake Licheńskie (surf. 153.6 ha, max. depth 13.3 m, mean depth 4.9 m) is a eutrophic morraine type water body having the highest fertility and phytoplankton abundance (Półtoracka 1968, Sosnowska 1974, in press, Korycka and Zdanowski 1976), heated the longest (1958), not freezing in winter, of mean summer temperature about 7°C higher than naturally. Discharge of heated water results in high degree of lake heating (up to 30°C in summer) and a very low water retention (about 5 days in summer). Stability of stratification temperature and oxygen contents is low. In summer there is a distinct oxygen deficit in near-bottom water layers (Zdanowski et al. 1988). The lake does not have submerged vegetation as a result of introduction of grass carp (*Ctenopharyngodon idella* Val.) in 1966/1967 (Wilkońska 1988). Only some parts on the littoral are overgrown by vegetation with floating leaves and *Najas marina* L.

Lake Gosławskie is a shallow, eutrophic water body (surf. 378.9 ha, max. depth 3.0 m, mean depth 1.3 m), heated since 1969, highly through-flow, of a very low average retention (about 2.5 days in summer), and water temperatures about 3°C higher than naturally (Hillbricht-Ilkowska and Zdanowski 1988b, Zdanowski et al. 1988). The Struga Biskupia stream carries into the lake considerable loads of mineral pollutants from brown coal mine, about 2.9 g $P \cdot m^{-2}$ per year (Hillbricht-Ilkowska and Zdanowski 1988b). In 1976 – 1979, the lake was stocked with silver carp (*Hypophthalmichthys molitrix* Val.), 53 – 65 indiv. $\cdot$ ha^{-1} per year. In 1977 – 1979, about 40 tons of this species were caught annually (Wilkońska 1988).

Lake Mikorzyńskie (surf. 245.3 ha, max. depth 38 m, mean depth 11.9 m) is a deep, mesotrophic, morraine type water body of a low trophic state. Heated rather poorly till 1969 in the southern part only. Northern parts of the lake had natural thermal conditions (Zdanowski and Korycka 1976). It was included into the power plant cooling system in 1970. Heated waters were introduced directly into the lake in its central part and indirectly from Lake Licheńskie through Lake Ślesińskie

(H i l l b r i c h t-I l k o w s k a and Z d a n o w s k i 1988b, Z d a n o w s k i et al. 1988). Water temperatures in summer increased in the lake by 4°C in relation to natural ones. Water exchange in summer is only in the epilimnion. It takes place during 7 days on the average and isolates the stable meta- and hypolimnion layers from the epilimnion (Z d a n o w s k i et al. 1988).

Studies on water chemistry showed that the lakes were more abundant in mineral components, electrolytic conductivity of water increased, water reaction was stabilized at the level of 8.4 on the average during the year; lakes were less abundant in nitrogen and phosphorus (Z d a n o w s k i et al. 1988). Water exchange unified also trophic conditions in the epilimnion of particular lakes.

Primary production in lakes was determined using the oxygen method of dark and light bottles in a water layer down to 5 m (every 1 m of depth). In Lake Gosławskie the production was investigated in the water layer down to the bottom. Samples were exposed in the lake for 24 hours. Oxygen was determined by the non-modified Winkler method with an accuracy to 0.05 mg $\cdot$ dm^{-3}. Gross production and destruction were expressed in mg $O_2 \cdot dm^{-3} \cdot day^{-1}$ or in g $O_2 \cdot dm^{-2} \cdot day^{-1}$ as a total for the layer from surface to the depth of 5 m, and for Lake Gosławskie down to the depth of 3 m. These values were calculated into calories using the converter 1 mg O_2 = 3.51 cal (14.696 J) (W i n b e r g 1960). Destruction rate was also expressed in values of absolute oxygen consumption or destruction percentage in gross production of trophogenic layer. Simultaneously measured were: water temperature, oxygen content in the vertical profile and water transparency by means of Secchi disc.

Furthermore, detailed production measurements were conducted in lakes Licheńskie and Mikorzyńskie in daily intervals, in the warmest summer periods of 1978 and 1983. These studies were linked with analogous observations of P a t a l a s (1970) and H i l l b r i c h t-I l k o w s k a and Z d a n o w s k i (1978) in 1966 and 1973.

In the season of 1978, and in summer of 1983, chlorophyll concentrations were also measured in the lake epilimnion. Samples of water were taken from the layer 0–5 m deep (in Lake Gosławskie to the depth of 3 m). After mixing the identical water volumes a subsample was taken, which was filtered through Whatman GF/C filter paper. The filters were dried, triturated and extracted with 90% acetone. Chlorophyll and phaeo-pigments concentrations were calculated from L o r e n z e n (1967) equation. Total concentrations of these two components are given here.

3. RESULTS

3.1. LONG-TERM CHANGES IN PRIMARY PRODUCTION AND DESTRUCTION IN HEATED LAKES LICHEŃSKIE AND MIKORZYŃSKIE

Studies in 1966–1969 allowed to determine the primary production changes under conditions of a changed thermal regime of Lake Licheńskie (P a t a l a s 1970, Z d a n o w s k i 1976, H i l l b r i c h t-I l k o w s k a and Z d a n o w s k i

Table 1. Production and destruction differentiation in spring and summer in lakes Licheńskie and Mikorzyńskie in 1966–1969, 1970–1975 and 1978–1983 (acc. to Patalas 1970, Zdanowski 1976, unpublished data, Hillbricht-Ilkowska and Zdanowski 1978, Robak 1985)

Lake	Period	Gross primary production ($g\ O_2 \cdot m^{-2} \cdot 24\ h^{-1}$)			Destruction ($g\ O_2 \cdot m^{-2} \cdot 24\ h^{-1}$)		
		1966-1969	1970-1975	1978-1983	1966-1969	1970-1975	1978-1983
Licheńskie	spring	6.0 0.8–10.2	4.0 1.6–9.6	4.4 3.9–5.1	2.8 1.6–4.3	2.2 0.6–7.8	4.3 1.4–8.2
	summer	6.2 2.6–8.6	4.7 2.5–9.2	4.7 2.1–8.3	5.5 0.7–8.8	4.2 1.1–7.6	4.8 2.0–8.2
Mikorzyńskie	spring	2.3 1.2–3.2	3.4 0.7–5.6	3.4 0.5–5.1	1.8 0.6–3.0	2.7 0.3–4.8	3.7 0.5–6.1
	summer	3.3 1.9–5.1	4.4 2.6–5.9	4.0 1.5–7.1	4.4 0.5–8.2	4.0 1.4–8.6	4.1 1.8–7.4

1978). Primary production in Lake Licheńskie, constantly heated during year, was then almost twice higher on the average than the production of not heated, static and poorer Lake Mikorzyńskie (Table 1). Apart from temperature, the stability of Lake Licheńskie was lower due to heated water discharge which is a factor increasing primary production, accelerating internal nutrient loading. Maximum primary production of this lake, although relatively high in the warmest period, shifted distinctly to spring and early summer periods as compared with the not heated lake.

Maximal production in trophogenic layer of Lake Licheńskie was usually recorded in the surface layer. Below the depth of 2 and sometimes 1 m the production rapidly decreased. Maximal production in Lake Mikorzyńskie was recorded at the depth of 1–2 m in summer and at the depth 0–1 m in spring-autumn period. The thickness of trophogenic layer of Lake Licheńskie was about 1 m smaller as compared with Lake Mikorzyńskie. These differences were consistent with water transparency and phytoplankton densities (Sosnowska 1974, 1984, Zdanowski and Korycka 1976). Maximal gross primary production ($P_{max.}$) in the trophogenic layer of Lake Licheńskie was 5.9 mg O_2 · dm^{-3} per day, and destruction 2.8 mg $O_2 \cdot dm^{-3}$ per day, whereas for Lake Mikorzyńskie – 1.9 and 3.5 mg $O_2 \cdot dm^{-3}$ per day, respectively (Zdanowski 1976). Production indices in the lakes examined in comparison with other lakes proved the higher degree of eutrophication of Lake Licheńskie (Zdanowski 1976).

Comparison of production and destruction (calculated per m^2 of lake surface) in Lake Licheńskie showed a decrease in gross production in spring and summer when all lakes in 1970 were included into the power plant cooling system (Table 1). It was quite considerable in spring. In the last periods of the investigations the changes in production were relatively small, and destruction rate increased mainly in spring periods, especially in the last stage of the investigations (Table 1). These changes could have been due to the greater inflow of allochthonic matter, when the big cooling system began to function each spring. In summer the destruction intensity was similar in particular periods of investigations (Table 1).

When Lake Mikorzyńskie was in 1970 included into the cooling system the production distinctly increased (Table 1). Gross production in spring increased on the average from 2.3 to 3.4 g $O_2 \cdot m^{-2}$ per day, and in summer from 3.3 to 4. 4 g $O_2 \cdot m^{-2}$. Changes in primary production in 1978 – 1983 were similar to those in the first years of lake heating (1970 – 1975). In Lake Mikorzyńskie destruction increased mainly in spring of the last period of the investigations, from 1.8 to 3.7 g $O_2 \cdot m^{-2}$ per day, on the average (Table 1). Destruction intensity did not change much in summer. Similarly as in Lake Licheńskie, higher destruction in spring could have been due to the inflow of allochthonic matter with the discharge water when the big cooling system began to function.

Mean percentage of destruction in gross production of the trophogenic layer in particular periods of the investigations did not change much in Lake Licheńskie (Table 2). Higher values of this coefficient indicate great efficiency of the utilization of production by animal organisms and probably high intensity of organic matter bacterial decomposition. These phenomena could have prevented the occurrence of burdensome algal blooms in the lake. In Lake Mikorzyńskie, very high destruction percentage in 1966 – 1969 decreased after lake heating slightly less than in Lake Licheńskie (Table 2). In summer, water mobility and heating of this lake stimulated more the production than the destruction.

Table 2. Mean respiration percentage in gross production in lakes Licheńskie and Mikorzyńskie in summer (June-September) of 1966 – 1969, 1970 – 1975 and 1978 – 1983 (acc. to Zdanowski 1976, unpublished data)

Period	L. Licheńskie	L. Mikorzyńskie
1966 – 1969	58	163
1970 – 1975	66	61
1978 – 1983	50	48

Changes in primary production and destruction in lakes were also estimated by comparing results of intensive 2-weekly investigations conducted in summer of 1966, 1973, 1978 and 1983. Primary production in Lake Licheńskie decreased distinctly after seven years of heating (Table 3). Fluctuations of primary production in 1973 and 1978 were smaller than in 1966. Maximal production in the trophogenic layer decreased from 4.0 – 5.2 to 1.2 – 2.4 mg $O_2 \cdot dm^{-3}$ per day. Respiration in gross production increased and so did water transparency, whereas phytoplankton biomass decreased quite considerably (Table 3). Nannoplanktonic forms were main dominants in the phytoplankton (Spodniewska 1984).

After 24 years of heating Lake Licheńskie had a higher gross production than in 1973 and 1978. It was, however, lower than in the first period of heating the lake (Table 3). These changes were similar as regards maximal production in the trophogenic layer,

Table 3. Mean epilimnion temperature (0 – 5 m), gross primary production, $P_{max.}$ [1], destruction [2], water transparency, phytoplankton and chlorophyll content in Lake Licheńskie in the summer of 1966, 1973, 1978 and 1983

Parameters	After 7 years of heating (1966)	After 14 years of heating (1973)	After 19 years of heating (1978)	After 24 years of heating (1983)	Sources
T (°C)	27.1 (26.2 – 28.5)	27.9 (26.3 – 28.8)	27.4 (25.8 – 28.8)	25.8 (24.9 – 26.7)	Patalas (1970), Sosnowska (1974), Hillbricht-Ilkowska et al. (1976), Zdanowski (1976), Hillbricht-Ilkowska and Zdanowski (1978), Spodniewska (1984), Robak (1985), Simm (1988a), A. Hillbricht-Ilkowska and B. Zdanowski (unpublished data)
Gross primary production ($g\ O_2 \cdot m^{-2} \cdot 24\ h^{-1}$)	7.9 (6.2 – 8.5)	3.9 (2.5 – 5.4)	4.1 (2.7 – 5.0)	5.0 (2.4 – 8.3)	
$P_{max.}$ ($mg\ O_2 \cdot dm^{-3} \cdot 24\ h^{-1}$) [1]	(4.0 – 5.2)	(1.3 – 2.4)	(1.2 – 2.2)	(1.6 – 3.7)	
Destruction (%) [2]	37 (29 – 46)	110 (41 – 170)	56 (38 – 88)	76 (51 – 136)	
Water transparency (m)	1.1 (1.0 – 1.2)	2.0 (1.8 – 2.4)	1.5 (1.2 – 2.2)	1.5 (1.1 – 2.0)	
Phytoplankton biomass, dominants ($mg \cdot dm^{-3}$)	80.1 green algae, diatoms, dinoflagellates	3.1 diatoms	3.7 green algae, diatoms, dinoflagellates (August)	1.5 (0.6 – 1.5) nannoplankton, green algae, blue-green algae, cryptophytes, dinoflagellates (end of July, beginning of August)	
Chlorophyll ($mg \cdot m^{-3}$)	lack of data	lack of data	10.2 (9.1 – 15.6)	11.3 (9.2 – 13.4)	

[1] Maximal primary production in the trophogenic layer. [2] Oxygen consumption in the trophogenic layer expressed as per cent of gross production.

Table 4. Mean temperature of epilimnion (0–5 m), gross primary production, $P_{max.}$ [1], destruction [2], chlorophyll content and Secchi disc visibility in Lake Mikorzyńskie in the summer of 1966, 1973, 1978 and 1983

Parameters	Control period (1966)	After 4 years of heating (1973)	After 9 years of heating (1978)	After 14 years of heating (1983)	Sources
T (°C)	(21.6) 21.0–22.0	(24.7) 23.7–25.7	(23.7) 22.6–24.3	(23.5) 22.6–23.9	Patalas (1970), Sosnowska (1974), Hillbricht-Ilkowska et al. (1976), Zdanowski (1976), Hillbricht-Ilkowska and Zdanowski (1978), Spodniewska (1984), Robak (1985), Simm (1988a), A. Hillbricht-Ilkowska and B. Zdanowski (unpublished data)
Gross primary production ($g\ O_2 \cdot m^{-2} \cdot 24\ h^{-1}$)	(3.7) 2.3–5.4	(4.7) 2.5–5.4	(3.6) 1.7–5.1	(5.0) 1.5–7.1	
$P_{max.}$ ($mg\ O_2 \cdot dm^{-3} \cdot 24\ h^{-1}$) [1]	1.1–2.2	1.6–2.1	0.7–2.0	1.2–3.0	
Destruction (%) [2]	(58) 22–71	(74) 29–100	(57) 38–81	(69) 54–81	
Water transparency (m)	(1.9) 1.7–2.1	(2.4) 1.9–3.0	(2.2) 1.2–2.8	(2.1) 2.0–2.1	
Phytoplankton biomass, dominants ($mg \cdot dm^{-3}$)	(2.7) blue-green algae, green algae (August)	5.1 diatoms (August)	7.1 nannoplankton, diatoms (August)	1.8 green algae, dinoflagellates (end of July, beginning of September)	
Chlorophyll ($mg \cdot dm^{-3}$)	lack of data	lack of data	(11.3) 8.4–20.1	(13.6) 11.1–17.8	

[1] Maximal gross primary production in the trophogenic layer. [2] Daily oxygen consumption in the trophogenic layer expressed as per cent of gross production.

but at summer stagnation peak, similar percentage of destruction in the production was still noticed, water transparency was similar and chlorophyll concentration relatively low. Phytoplankton biomass was lower than in the previous period of the investigations (Table 3).

In Lake Mikorzyńskie, fluctuations of gross and maximal production in the trophogenic layer were similar to the control period before heating and to the two first investigation periods after heating the lake (Table 4). Mean gross production increased in 1973 to 4.7 g $O_2 \cdot m^{-2}$ per day and exceeded that in Lake Licheńskie. In the last period of the investigations maximal gross and maximal production in the trophogenic layer continued to increase (Table 4). Mean production (5.0 g $O_2 \cdot m^{-2}$ per day) equalled that recorded in Lake Licheńskie. Water transparency, chlorophyll content and phytoplankton biomass did not change much. The percentage of blue-green algae in the biomass decreased after heating the lake, whereas that of diatoms and small nannoplanktonic forms increased (Table 4).

Water transparency in the lakes did not change much during the investigations. According to Spodniewska (1984) fluctuations of this index did not depend on phytoplankton abundance, but were conditioned by the changes in concentrations of the abioseston floating in the water column (flows). This was especially the case of flow-through lakes Gosławskie and Licheńskie.

A comparison of production value expressed in $kJ \cdot m^{-2}$ for vegetation periods in particular years of the investigations is an indicator of its directional changes (Table 5). Before heating Lake Mikorzyńskie had a twice lower production than Lake Licheńskie. Small differences in production in particular years depended on variability of meteorological factors and indicated a high production stability of the lakes under conditions of similar thermal and hydrological regime.

When all lakes had been included into the cooling system and the retention of lakes decreased considerably, production in Lake Licheńskie decreased and in Lake Mikorzyńskie – increased (Table 5). Production in Lake Licheńskie was similar and in some years slightly higher than in Lake Mikorzyńskie.

Table 5. Gross primary production ($kJ \cdot m^{-2}$) between May and September (150 days) in lakes Licheńskie and Mikorzyńskie in 1966–1969, 1973 and 1975–1978 and 1983 (data acc. to Patalas 1970, Zdanowski 1976, unpublished data, Hillbricht-Ilkowska and Zdanowski 1978, Robak 1985)

Lake	1966	1967	1968	1969	1973	1975	1978	1983
Licheńskie	16747	13398	15491	12979	10886	12979	9630	10886
Mikorzyńskie	8374	6699	7955	5862	10467	10048	6699	10886

3.2. PRIMARY PRODUCTION IN LAKE GOSŁAWSKIE

Production indices in Lake Gosławskie were typical of shallow, intensively mixed lakes (Table 6). Due to low water transparency, maximum production was only in the surface layer down to the depth of 0.5 m. Mean production in the vegetation season of

Table 6. The mean and range of changes of primary production and Secchi disc visibility in Lake Gosławskie in 1975–1978

Parameters	Mean and range
Gross primary production ($g\ O_2 \cdot m^{-2} \cdot 24\ h^{-1}$)	3.4 0.7–7.6
Destruction ($g\ O_2 \cdot m^{-2} \cdot 24\ h^{-1}$)	2.7 0.5–6.7
Gross production in the trophogenic layer $P_{max.}$ ($mg\ O_2 \cdot dm^{-3} \cdot 24\ h^{-1}$)	2.6 0.5–5.3
Destruction percentage in gross production (%)	60 9–200
Secchi disc visibility (m)	1.2 0.5–1.9

1975–1978 fluctuated between 0.5 to 5.3 mg $O_2 \cdot dm^{-3}$ per day. Its mean values for many years approximated those recorded in Lake Licheńskie. The production decrease in deeper water layers resulted in the fact that its total values under 1 m^2 of lake surface were lower than in the strongly heated Lake Licheńskie and less heated Lake Mikorzyńskie (Table 6). Destruction percentage in gross production in the trophogenic layer of Lake Gosławskie fluctuated similarly (about 60%) as in other lakes examined.

Primary production of Lake Gosławskie in the vegetation season of 1975–1978 was much lower than in other heated lakes (Table 7).

Table 7. Gross primary production in Lake Gosławskie in the vegetation period (April-October) in 1975–1978

Production	1975	1976	1977	1978
Gross primary production ($kJ \cdot m^{-2}$ per season)	7536	6699	7536	5861

3.3. SEASONAL CHANGES OF PRIMARY PRODUCTION IN LAKES

Comparison of changes in the chlorophyll concentrations and primary production in 1978 showed the dissimilarity of seasonal dynamics of these indices despite great similarity of the lakes as regards the abundance in nutrients. Different thermal and mictic conditions differentiated production in particular lakes (Table 8, Fig. 1).

A significant correlation of changes in the chlorophyll content and primary production (also $P_{max.}$ in the trophogenic layer) was recorded in the shallow, flow-through and less heated Lake Gosławskie and in static Lake Mikorzyńskie heated only in summer (Fig. 1). In these two lakes changes in the production correlated with water transparency. Its low values in Lake Gosławskie limited the production to a narrow water layer. Water flow in the lake maintained in the water column

Table 8. Seasonal changes in water temperature, retention and of indices of trophic state in lakes Licheńskie, Gosławskie and Mikorzyńskie in 1978 (acc. to S p o d n i e w s k a 1984, R o b a k 1985, H i l b r i c h t - I l k o w s k a and Z d a n o w s k i 1988b, Z d a n o w s k i et al. 1988, J. Sosnowska – unpublished data, B. Zdanowski – unpublished data)

Parameters	Lake		
	Licheńskie	Gosławskie	Mikorzyńskie
Temperature (°C)	22.4 8.0 – 29.9	18.4 0.6 – 26.6	19.2 5.7 – 25.4
Water exchange (in days)	4 3 – 5	3 1.5 – 4	9 5 – 22
Secchi disc visibility (m)	1.8 1.2 – 2.8	0.8 0.2 – 1.9	3.2 2.0 – 5.3
pH	8.4 8.1 – 8.6	8.4 8.2 – 8.5	8.4 7.8 – 8.6
PO_4-P concentrations ($mg \cdot dm^{-3}$)	0.038 0.017 – 0.106	0.036 0.009 – 0.093	0.026 0.013 – 0.030
Tot.-P concentrations ($mg \cdot dm^{-3}$)	0.069 0.050 – 0.106	0.076 0.056 – 0.100	0.063 0.053 – 0.087
Tot.-N concentrations ($mg \cdot dm^{-3}$)	0.71 0.46 – 1.06	1.02 0.26 – 1.76	0.73 0.49 – 0.92
N : P	12 5 – 21	13 4 – 20	12 8 – 15
Primary production ($g\ O_2 \cdot m^{-2} \cdot 24\ h^{-1}$)	4.6 2.1 – 8.1	2.6 1.7 – 3.8	2.5 0.5 – 4.7
P_{max} in trophogenic layer ($mg\ O_2 \cdot dm^{-3} \cdot 24\ h^{-1}$)	2.3 1.2 – 3.8	2.3 0.9 – 3.8	1.2 0.9 – 2.5
Chlorophyll ($mg \cdot dm^{-3}$)	12.1 2.4 – 27.5	21.7 6.1 – 37.3	10.4 0.6 – 23.6
Phytoplankton biomass ($mg \cdot dm^{-3}$)	5.9 2.4 – 12.0	6.4 3.9 – 10.2	10.4 0.1 – 11.7

considerable amount of abioseston. In Lake Mikorzyńskie, with a smaller water flow, the decrease in water transparency late in summer and in autumn converged with the highest production and chlorophyll concentrations (Fig. 1).

The effect of water heating was mainly visible in the warmest Lake Licheńskie by shifting the maxima of production and chlorophyll concentration to periods of lower water temperatures (Fig. 1). Low retention and water flow in summer limited the high phytoplankton abundance in this lake (S p o d n i e w s k a 1984, S o s n o w s k a – in press). Very low water retention of Lake Gosławskie limited nutrient accumulation rate, despite considerable inflow of mineral pollution and mass appearance of algae (S p o d n i e w s k a 1984, S i m m 1988a, 1988b, Z d a-

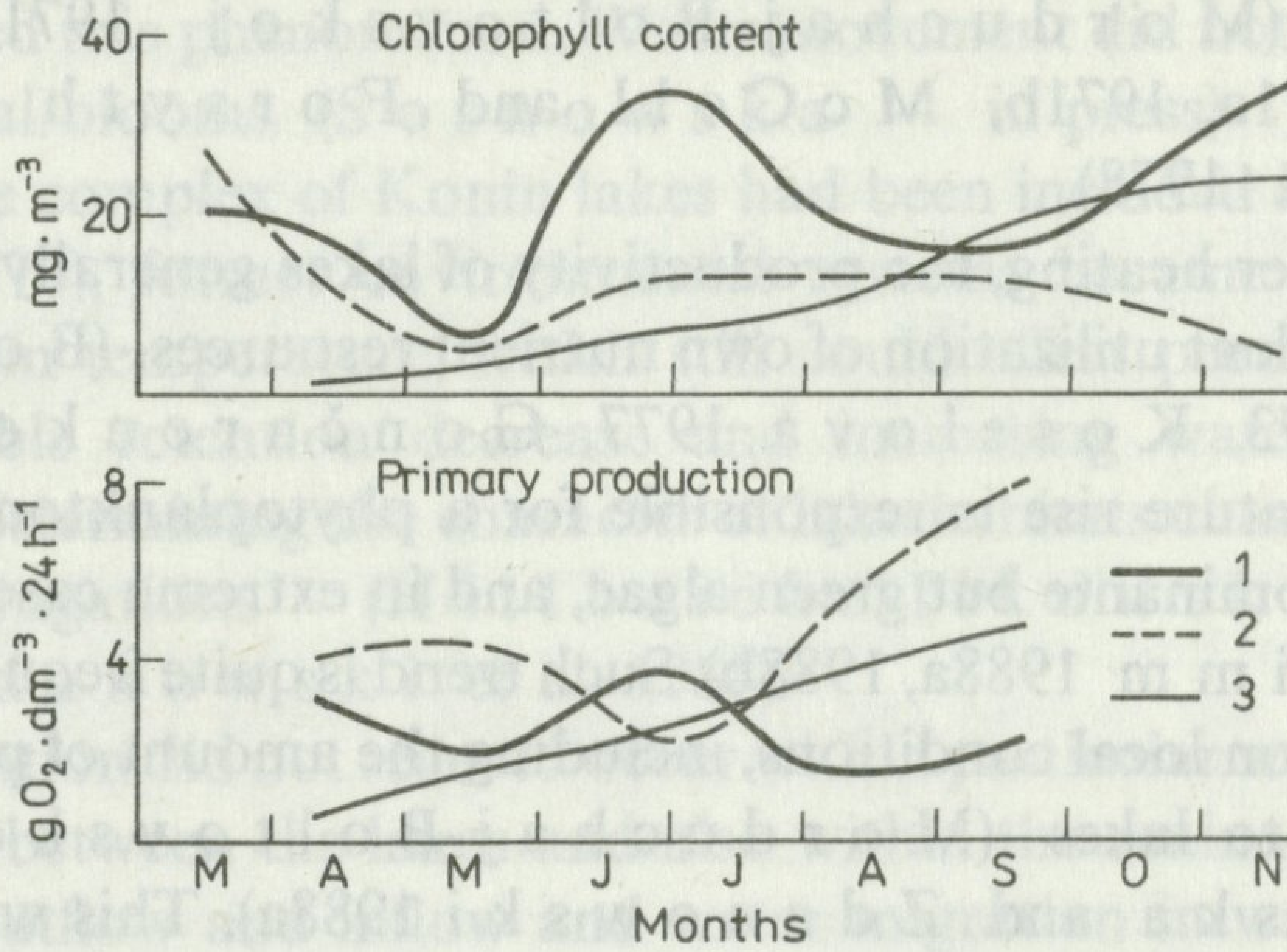

Fig. 1. Seasonal changes in chlorophyll content and primary production in lakes Gosławskie (1), Licheńskie (2) and Mikorzyńskie (3) in 1978

n o w s k i et al. 1988). Water turbidity was also high and spatial differentiation of the environmental conditions was low (H i l l b r i c h t - I l k o w s k a and S i m m 1988).

Production changes in Lake Mikorzyńskie depend less on the water temperature rise. Lower retention indirectly affects production, mainly by activation of nutrient loading in the lake. In spring of each year, when the big cycling begins to function, the lake obtains nutrient load from lakes Ślesińskie and Licheńskie (H i l l b r i c h t - I l k o w s k a and S i m m 1988, Z d a n o w s k i et al. 1988). Production and chlorophyll content increase in the lake late in summer and in autumn (Fig. 1). Deeper mixing of water, similarly as in natural dimictic lakes, activates the nutrient transport from deeper layers and may cause algal blooms. However, water flow in the lake decreases the primary production and at moderate heating prevents the occurrence of burdensome algal blooms. Gradually in summer diatoms no longer dominate but green algae, dinoflagellates and cryptophytes (S p o d n i e w s k a 1984, S i m m 1988a).

4. DISCUSSION

A change of natural thermal regime of water bodies caused by constant or periodical heated-water discharge by power plants is a factor changing both the structure and functioning of these ecosystems. Water temperature rise activates reactions at particular trophic levels, determines the succession trend of these communities, causes more efficient utilization of the own nutrient resources permanently kept in the bottom sediments, accelerates the hardly decomposing organic matter fraction. Thus changes caused by heating may concern biomass production of the communities, energy transfer by particular trophic levels (P a t a l a s 1970, H i l l b r i c h t - I l k o w s k a and Z d a n o w s k i 1978, 1988a). They also may accelerate the eutrophication, and in extreme cases result in secondary pollution of the water bodies (M o r d u c h a j-B o l t o v s k o j 1971, 1975, V i n o g r a d s k a j a 1971a, 1971b, M c C o l l and F o r s y t h 1973, P a s t e r n a k and K a s z a 1978).

As a result of water heating, the productivity of lakes generally increases which is also due to more efficient utilization of own nutrient resources (B o g a t o v a 1971, J a r o š e n k o 1973, K o s e l o v a 1977, G o n č a r e n k o and T a i r o v 1981). Water temperature rise is responsible for a phytoplankton succession where diatoms no langer dominante but green algae, and in extreme cases blue-green algae (C a i r n s 1971, S i m m 1988a, 1988b). Such trend is quite frequent in heated lakes, as it depends largely on local conditions, including the amount of pollution load from the catchment area to lakes (M o r d u c h a j-B o l t o v s k o j 1976, H i l l b r i c h t-I l k o w s k a and Z d a n o w s k i 1988a). This was observed in the first years of the investigations, when some Konin lakes were heated, the temperature rose and moderate water movement accelerated the internal nutrient loading of the lakes (P ó ł t o r a c k a 1968, P a t a l a s 1970, S o s n o w s k a et al. 1976, Z d a n o w s k i 1976, H i l l b r i c h t-I l k o w s k a and Z d a n o w s k i 1978, S o s n o w s k a – in press).

Changes in production of lakes at the time were characterized by deformation of the natural seasonal production cycle (Z d a n o w s k i 1976, H i l l b r i c h t-I l k o w s k a and Z d a n o w s k i 1978). Similarly as in other lakes, the vegetation period was longer (V i n o g r a d s k a j a 1971a, 1971b, G o n č a r e n k o and T a i r o v 1981), production higher, and great algal densities in winter-spring and autumn periods occurred more frequently (D e v j a t k i n 1971, V i n o g r a d s k a j a 1971a, 1971b, N o t o n 1975), or production at higher water temperature ranges was limited (M o r g a n and S t r o s s 1969, M c-N a u g h t and F e n l o n 1972). Heating of water usually limited the blooms of algae having a low thermal tolerance, but did not eliminate them from the habitat, so the frequent appearance of new representatives gave variety to qualitative phytoplankton composition (S o s n o w s k a 1974, in press).

With the increase of primary production in the lakes examined, destruction accelerated and so did the utilization of primary production by planktonic phytophagous animals (P a t a l a s 1970, H i l l b r i c h t-I l k o w s k a and Z d a n o w s k i 1987). These systems functioned quite satisfactorily and were relatively stable in longer research periods which under conditions of a similar thermal and hydrological regime protected the lakes examined against mass occurrence of algae and such bacterioplankton growth and destruction increase, which could result in oxygen deficits in the lake epilimnion (K o r y c k a and Z d a n o w s k i 1976, Z d a n o w s k i 1976, Z d a n o w s k i et al. 1988).

Under conditions of limited sewage inflow and low mineral pollution of lakes in the first period of the investigations the high secondary production efficiency at the gradually decreasing own food resources could lead to a decrease of the trophic state of the lakes examined (Z d a n o w s k i 1976, H i l l b r i c h t-I l k o w s k a and Z d a n o w s k i 1978, Z d a n o w s k i et al. 1988). At the time the lower water retention accelerated this phenomenon. Water movement did not help the occurrence of burdensome algal blooms (Sosnowska — in press).

When the whole complex of Konin lakes had been included into the power plant cooling system (1970), former environmental systems became more complex and different. Apart from temperature, which still could affect production in particular lakes, a considerable retention decrease and increasing water salinity were the significant factors determining the character of lake habitats changing in seasons and years of the investigations (Hillbricht-Ilkowska and Zdanowski 1988b, Zdanowski et al. 1988).

Changes in retention did not seem to occur within particular water bodies, but were probably quite big between the lakes and also within the drainage area of the lakes, including surface outflow and inflow and water migration in water-bearing ground layers. Undoubtedly, low water retention unified the lake as regards water quality, nutrient abundance or susceptibility of lakes to mineral pollution and eutrophication (Hillbricht-Ilkowska and Zdanowski 1988b, Zdanowski et al. 1988).

Despite the relatively great similarity of the lakes as regards water chemistry and average nutrient abundance, the dissimilarity of seasonal production dynamics was a result of specific thermal and hydrological conditions in each lake and the kind and intensity of food resources renewal (Hillbricht-Ilkowska and Simm 1988, Zdanowski et al. 1988). Of course, correlation between changes of environmental conditions or between particular habitat parameters and primary production were not simple. It seems that temperature rise activated the production to a greater extent in periods with natural lower water temperatures. During periods of maximal heating and low water retention high destruction level was maintained, low phytoplankton biomass and considerable utilization of primary production as a source of food (Hillbricht-Ilkowska and Zdanowski 1978, Spodniewska 1984, Hillbricht-Ilkowska et al. 1988, Simm 1988a, 1988b).

Decreasing nutrient abundance in heated lakes may be also the factor reducing production of the lakes examined (Zdanowski et al. 1988). Similar direction of changes has been also indicated by other authors (Schulte and Lackey 1973, Stuart and Standford 1978). The increasing salinity in the lakes examined, due to their mineral pollution by the inflow of mineral salts from the drainage area (post-mining waters, dusts from power plants), activated specific physico-chemical mechanisms. They maintained during the season an alkaline water reaction and intensive precipitation of phosphorus inflowing to lakes and some autochthonic part of this element in the form of soluble apatites unattainable for algae. Long-term heating of lakes, under conditions of small organic sewage inflow, also decreased the lake abundance in nitrogen compounds (denitrification), keeping the ratio of this element to phosphorus at a relatively low level (Zdanowski et al. 1988). Changes in lake abundance in phosphorus and nitrogen could deepen the earlier indications of decreasing trophic state in lakes examined.

5. SUMMARY

Directional, long-term trends of the primary production changes in the lakes of a changed thermal and hydrological regime are characterized. The studies were conducted between 1966 and 1983 on lakes of Konin surroundings: Licheńskie and Mikorzyńskie, and from 1975 also on Lake Gosławskie. Environmental conditions in the lakes are described in separate publications (H i l l b r i c h t - I l k o w s k a and Z d a n o w s k i 1988b, Z d a n o w s k i et al. 1988).

Studies conducted in 1966 – 1969 showed an almost twice higher production of heated Lake Licheńskie than of the unheated at that time Lake Mikorzyńskie (Z d a n o w s k i 1976). When in 1970, the whole complex of Konin lakes was included into the power plant cooling system, after heating of Lake Mikorzyńskie and a distinctly lower retention in all lakes examined, the production in Lake Licheńskie decreased in spring and summer, whereas in Lake Mikorzyńskie it increased (Table 1). The destruction in both lakes increased in spring. Mean percentage of destruction in Lake Mikorzyńskie decreased to the level recorded in Lake Licheńskie (Table 2).

Analogous trends in production changes were recorded when comparing results of 2-weekly investigations conducted in summer of 1966, 1973, 1978 and 1983 (Tables 3, 4) and total production in vegetation periods of particular years of investigations (Table 5). In the last periods of investigations primary production of Lake Licheńskie was similar or in some years slightly higher than that of Lake Mikorzyńskie. Water heating in both lakes maintained a high destruction intensity.

Lake Gosławskie had production indices typical of shallow, intensively mixed lakes (Table 6). Production of this water body in vegetation seasons of 1975 – 1978 was lower than in remaining lakes (Table 7).

Comparison of chlorophyll concentrations and primary production in lakes examined in 1978 showed different seasonal dynamics of these indicators despite a great similarity of lakes as regards water chemistry and nutrient abundance (Fig. 1, Table 8). Frequently different thermal and mixing conditions were the factors differentiating the production in particular lakes. The effect of heating was mainly visible in spring and early summer periods at lower water temperature ranges. The water flow in lakes decreased the primary production and prevented the occurrence of algal blooms.

6. POLISH SUMMARY

Scharakteryzowano kierunkowe, wieloletnie tendencje zmian produkcji pierwotnej w jeziorach o zmienionym reżimie termicznym i hydrologicznym. Badania prowadzono w latach 1966 – 1983 na jeziorach okolic Konina: Licheńskim i Mikorzyńskim, a od 1975 r. również na J. Gosławskim. Charakterystykę warunków środowiskowych w jeziorach podano w oddzielnych opracowaniach (H i l l b r i c h t - I l k o w s k a i Z d a n o w s k i 1988b, Z d a n o w s k i et al. 1988).

Badania prowadzone w latach 1966 – 1969 wykazały około 2-krotnie wyższą produkcję podgrzewanego w ciągu roku J. Licheńskiego w porównaniu do produkcji nie podgrzewanego w tym czasie J. Mikorzyńskiego (Z d a n o w s k i 1976). Po włączeniu w 1970 r. całego kompleksu jezior konińskich w system chłodzący elektrowni i po podgrzaniu J. Mikorzyńskiego, oraz wydatnym obniżeniu retencji wody we wszystkich badanych jeziorach, stwierdzono obniżenie produkcji w J. Licheńskim w okresie wiosennym i letnim, zaś wzrost w J. Mikorzyńskim (tab. 1). Destrukcja wzrosła w obu jeziorach w okresie wiosennym. Średni udział destrukcji w J. Mikorzyńskim obniżył się do wartości notowanych w J. Licheńskim (tab. 2).

Analogiczne tendencje zmian produkcji zanotowano porównując wyniki dwutygodniowych badań przeprowadzonych latem 1966, 1973, 1978 i 1983 r. (tab. 3, 4), jak również sumarycznej produkcji w okresach wegetacyjnych poszczególnych lat badań (tab. 5). Produkcja pierwotna J. Licheńskiego w ostatnich okresach badań była podobna lub w niektórych latach nieco wyższa od produkcji J. Mikorzyńskiego. Podgrzanie wody w obu jeziorach utrzymywało wysoką intensywność destrukcji.

J. Gosławskie cechowały wskaźniki produkcji typowe dla płytkich i intensywnie mieszanych jezior (tab.

6). Produkcja tego zbiornika w sezonach wegetacyjnych lat 1975–1978 była niższa w porównaniu do wartości notowanych w pozostałych jeziorach (tab. 7).

Porównanie zmian stężeń chlorofilu i produkcji pierwotnej w badanych jeziorach w 1978 r. wykazało odmienność sezonowej dynamiki tych wskaźników mimo dużego podobieństwa jezior pod względem składu chemicznego wody i zasobności jezior w związki biogenne (rys. 1, tab. 8). Czynnikami różnicującymi produkcję w poszczególnych jeziorach były często odmienne warunki termiczne i miktyczne jezior. Efekt podgrzania ujawniał się głównie w okresach wiosennych i wczesnoletnich w niższych zakresach temperatur wody. Przepływy wody w jeziorach obniżały produkcję pierwotną i zapobiegały występowaniu uciążliwych zakwitów glonów.

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