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VARIATION IN THE CONTENTS OF NITROGEN AND PHOSPHORUS IN THE HEATED WATER ECOSYSTEM OF THE KONIN LAKES

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ABSTRACT. The aim of the study was to determine changes in the trophic state of the Konin lakes heated water ecosystem. Changes in nitrogen and phosphorus content, Secchi disk visibility, and chlorophyll content were analyzed. The dominant form in the epilimnion was phosphorans and the organic fractions of the nutrients N and P. Phosphorans and ammonia nitrogen prevailed in the near-bottom layers and increased in the spring-summer period as oxygen deficits increased at the bottom. The deciding factor for eutrophication was nitrogen, the availability of which to phytoplankton was determined by the intensity of mineralization processes and denitrification. The short water retention time in the lakes restricted phytoplankton blooms. Phosphorus precipitation on calcite prevented lake eutrophication. The values of the TSI_{SD} and TSI_{Chl} indices were evidence of the mesotrophic status of lakes Licheńskie and Ślesińskie, while the TSI_{Ptot} index of phosphorus indicated a slightly higher degree of lake eutrophication.

Key word: HEATED WATERS, LAKE, EUTROPHICATION, NITROGEN, PHOSPHORUS, CHLOROPHYLL, WATER TRANSPARENCY

INTRODUCTION

The eutrophication of waters, accelerated by the inflow of nutrients from catchment areas are responsible for intense phytoplankton development and decreased water transparency in lakes. The consequence of the decomposition of organic matter and its increased sedimentation is that the oxygen content decreases in the meta- and hypolimnions (Vollenweider 1968, Hartmann 1977, Kajak 1983, Bajkiewicz-Grabowska 2002). These processes are especially intense in basins that receive post-cooling waters. The elevated temperature along with frequently changing hydrological conditions, such as water flow and lowered retention, leads to increased metabolism (Patalas 1970, Hillbricht-Ilkowska and Zdanowski 1988a, Zdanowski 1988, Zdanowski and Prusik 1994).

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The eutrophication process of lakes can be halted by the calcite precipitation of phosphorus. This phenomenon occurs in alkaline waters of a low trophic state, and it also decreases the availability of phosphorus to the phytoplankton (Golterman 1973, Zdanowski et al. 1988, Zdanowski 1994b, Nael 2001). This process can balance the annual load of phosphorus that lakes receive from catchments, and can even lower the trophic states of lakes heated by power plant post-cooling waters (Hillbricht-Ilkowska and Zdanowski 1988a). The aim of the current work was to determine the changes in the trophic state of the waters in the ecosystem of the Konin heated lakes.

MATERIALS AND METHODS

The Konin heated lakes system (Wielkopolsko-Kujawskie Lakeland), which is connected to the Warta River and Lake Gopło by the Warta-Gopło sailing canal (length 32 km), is located in a catchment area of 418 km^2 that is largely urbanized and transformed by energy generation and exploratory mining (Zdanowski 1994a, Socha and Zdanowski 2001). The surface waters of this area mainly flow in the Struga Biskupia River (mean flow 1.1 $m^3 s^{-1}$). Until recently, this river deposited a phosphorus load in excess of the critical limit into Lake Gopło (3.02 g m^{-2} $year^{-1}$) and the entire system (0.9 g m^{-2} $year^{-1}$; Hillbricht-Ilkowska and Zdanowski 1988a, Zdanowski 1994a). The phosphorus load deposited into the Konin system by the Struga Biskupia River in the 1995-2004 period was 0.8 g m^{-2} $year^{-1}$, which exceeded the unsafe load sixfold, while that deposited into the Warta-Gopło Canal was twofold that of the safe limit at 0.2 g m^{-2} $year^{-1}$. This is still a large load of phosphorus deposited into the Konin lakes in comparison to that of the previous study period.

In order to compare changes in the trophic status of the waters, Lake Licheńskie, the most heated of the system, Lake Ślesińskie, only heated in summer, and segments of the canals for power plant water uptake and discharge were chosen. Due to the short water retention time in the system (about 14 days during the summer period), and the resulting more intense water exchange in and among the lakes, the results of changes in the physicochemical parameters of the surface waters at these stations, in all probability, can be viewed as representative for the entire lake system.

Lake Licheńskie (52°19’ N, 18°20’ E), with a surface area of 147.6 ha and maximum and mean depths of 12.6 and 4.5 m, respectively, has been heated since

1958 and most intensely during the summer period (to 30°C). Water exchange in Lake Licheńskie occurs in the course of 3 to 5 days. Lake Ślesińskie (52°23' N, 18°19' E), with a surface area of 152.3 ha and a maximum and mean depth of 24.5 and 7.6 m, respectively, is a typical through lake. The surface layer temperatures of this lake do not exceed 28°C in the summer period, and water exchange occurred within 7-9 days. The water uptake and discharge canals, with a combined length of 26 km and a mean depth of 4 m, connect the various lakes of the system. Water flow in the canals (0.12-0.32 m s^{-1}) is regulated by four pumping stations and the water temperature in summer reached 35°C. The salinity of the waters of the studied lakes was bicarbonate-calcium. The electrical conductivity in the surface water layer ranged from 532 to 568 μS cm^{-1}, and at the near-bottom layer from 430 to 665 μS cm^{-1}, while the calcium contents was from 71.7 to 78.5 mg l^{-1} and from 60.1 to 91.1 mg l^{-1}, respectively, and that of bicarbonate ranged from 267.3 to 290.4 mg l^{-1} and from 231.8 to 415.0 mg l^{-1}, respectively. The mean pH value in the surface water layer was 8.4, while that of the near-bottom layer ranged from 7.2 to 8.6.

Samples for physicochemical analyses were taken monthly in the 1995-2004 period from the deep waters in the centers of the lakes from the surface (0.5 m) and near-bottom (0.5 m above the bottom) layers, and in the canals from the surface (0.5 m) layer. The physiochemical analyses of the water samples were performed with standard methods (Standard Methods 1980, Hermanowicz et al. 1999). Chlorophyll and pheophytin contents in the epilimnion were determined with the method by Lorenzen (1967). The amount of suspension in the epilimnion was determined by weight after the water samples were put through glass filters (45 μm) and dried to a constant weight at a temperature of 105°C. Water transparency in the lakes was determined with Secchi disk measurements.

The trophic status of the lake waters was evaluated based on Secchi disk visibility (SDV), total phosphorus concentrations (P_{tot}), and chlorophyll contents (Chl) that were performed in the summer (May-September). The results of these measurements were transformed to a common weight with the Carlson (1977) equation. The trophic state of the waters was determined with TSI_{SD}, TSI_{Ptot}, and TSI_{Chl} that describe trophic status on a three-stage scale: oligo-mesotrophic – < 40, mesotrophic – 40-60, and eutrophic – > 60. The actual values of lake loading were compared with Vollenweider's (1968) critical values, which identify permissible and unsafe phosphorus loads depending on mean lake depth. The results of the research performed in the 1995-2004 period were compared with previously published results (Korycka and Zdanowski 1976, Zdanowski et al. 1988, Zdanowski 1994a).

RESULTS

Nitrogen and total phosphorus and their mineral fractions dissolved in the water generally exhibited similar variability in the lakes of the complex and in the power plant uptake and discharge canals (Table 1). The dominant form of phosphorus was phosphoran (about 60%) and the organic fraction of nitrogen, which was an average of 80% of its content. The contents of nitrogen ammonia and nitrates did not exceed 0.10 and 0.08 mg l^{-1}, respectively, while that of phosphoran did not exceed 0.042 mg l^{-1} (Table 2). The content of total phosphorus correlated positively with the content of calcium, in both lakes Licheńskie ($r = -0.2986$ $P < 0.05$) and ($r = -0.3029$ $P < 0.05$).

TABLE 1

Contents (mean ± SD) of nitrogen and phosphorus (mg l^{-1}) in surface water layers in lakes Licheńskie and Ślesińskie and in the uptake and discharge canals in the 1995-2004 period

Parameter	Licheńskie Lake	Ślesińskie Lake	Konin Power Plant intake canal	Konin Power Plant discharge canal	Pątnów Power Plant discharge canal	Licheński Canal
N_{tot}	1.3 (±0.8)	1.3 (±0.8)	1.3 (±0,9)	1.3 (±0.8)	1.3 (±0.8)	1.3 (±0.7)
NH_4-N	0.09 (±0.05)	0.09 (±0.05)	0.09 (0.06)	0.09 (0.04)	0.11 (0.05)	0.11 (±0.10)
NO_3-N	0.24 (±0.23)	0.21 (±0.24)	0.20 (±0.22)	0.22 (±0.22)	0.28 (±0.28)	0.21 (±0.22)
NO_2-N	0.012 (±0.014)	0.010 (±0.015)	0.008 (±0.009)	0.010 (±0.011)	0.014 (±0.022)	0.016 (±0.019)
P_{tot}	0.089 (±0.035)	0.099 (±0.046)	0.085 (±0.040)	0.087 (±0.039)	0.096 (±0.038)	0.095 (±0.038)
PO_4-P	0.049 (±0.031)	0.059 (±0.035)	0.045 (±0.032)	0.045 (±0.032)	0.049 (±0.038)	0.062 (±0.032)

The ratio of the N:P content in the waters of Lake Licheńskie increased on average by 10 in spring and by 13 in summer, while in Lake Ślesińskie it fluctuated during the spring-summer period within the range of 11-13. Maximum concentrations of nitrates noted in the fall-winter period, and of ammonia from June to December (Fig. 1). This cycle of variation repeated annually and was analogous for the waters of both lakes. The mean contents of total nitrogen from the surface water layer of lakes Licheńskie and Ślesńskie decreased in the summer period during the last decade, while the content of total phosphorus increased (Fig. 2).

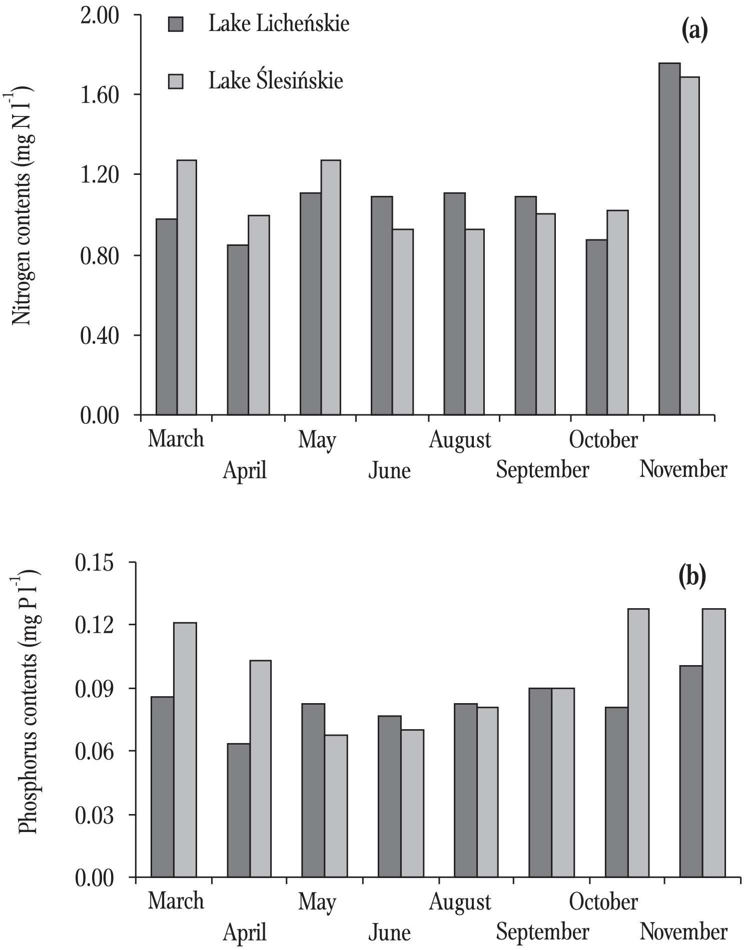

Fig. 1. Seasonal variation in the mean contents of nitrogen (a) and total phosphorus (b) in the surface water layers of lakes Licheńskie and Ślesińskie in the 1995-2004 period.

Higher concentrations of nitrogen and phosphorus were noted in the near-bottom water layers in lakes Licheńskie and Ślesińskie (Table 2). The contents of nitrogen and total phosphorus did not exceed 2.5 mg l^{-1} and 0.659 mg l^{-1}, respectively. The dominant form of phosphorus was phosphoran (80%), and of nitrogen – ammonia nitrogen (30-50%) and organic nitrogen (40- 60%). The content of phosphorans and ammonia increased in the spring-summer period along with increasing oxygen deficits near the bottom (Fig. 3).

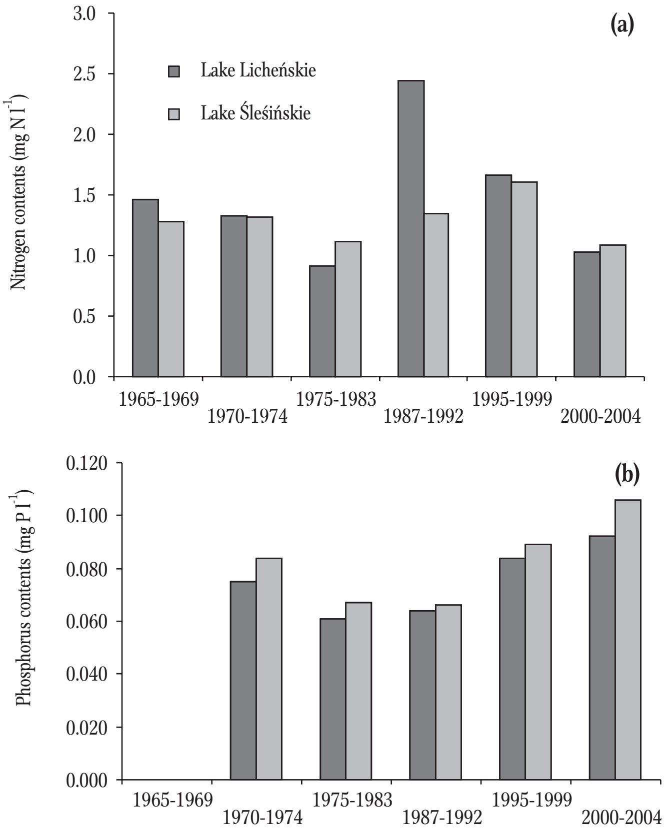

Fig. 2. Long-term changes in the mean contents of nitrogen (a) and total phosphorus (b) in the surface water layers of lakes Licheńskie and Ślesińskie.

TABLE 2

Contents (mean ± SD) of nitrogen and phosphorus (mg l^{-1}) in surface and near-bottom water layers in the summer (May- September) in lakes Licheńskie and Ślesińskie in the 1995-2004 period

	Lake Licheńskie		Lake Ślesińskie	
Parameter	surface	bottom	surface	bottom
N_{tot}	1.3 (±0.6)	2.3 (±1.3)	1.1 (±0.5)	2.5 (±0.5)
NH_4-N	0.10 (±0.04)	1.2 (±1.0)	0.08 (±0.05)	1.4 (±0.6)
NO_3-N	0.08 (±0.03)	0.11 (±0.7)	0.06 (±0.04)	-
NO_2-N	0.009 (±0.011)	0.074 (±0.174)	0.007 (±0.009)	0.029 (±0.059)
P_{tot}	0.083 (±0.036)	0.659 (±0.339)	0.099 (±0.031)	0.459 (±0.105)
PO_4-P	0.032 (±0.020)	0.525 (±0.263)	0.042 (±0.022)	0.374 (±0.086)

The mean contents of chlorophyll in the epilimnion of lakes Licheńskie and Ślesńskie were 22.7 and 15.8 μg l^{-1}. Maximum concentrations of this were noted

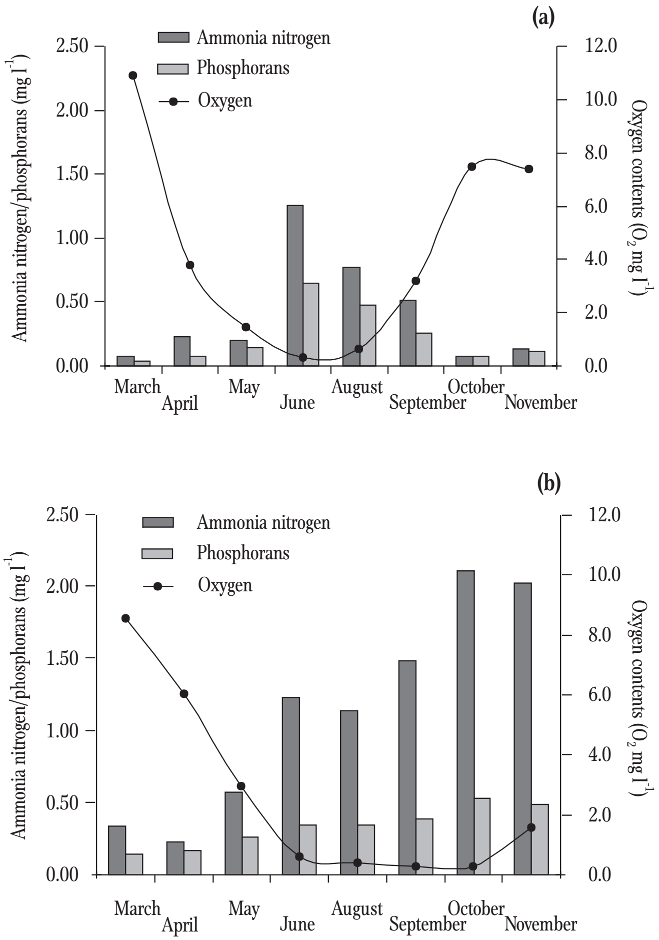

Fig. 3. Seasonal variation in the mean contents of ammonia nitrogen, phosphorans, and oxygen in the near-bottom layers of lakes Licheńskie (a) and Ślesińskie (b) in the 1995-2004 period.

usually in the spring. The summer maximum concentrations of chlorophyll occurred mainly in Lake Ślesińskie. Maximum transparency was noted in winter, while the minimum was recorded during the vegetation season from April to September. The least suspension and the highest transparency were noted in Lake Ślesińskie (Fig. 4).

The value of the TSI_{SD} and TSI_{Chl} indicators were evidence of the mesotrophic status of both lakes Licheńskie and Ślesńskie, while the phosphorus index TSI_{Ptot} indicated a slightly higher degree of eutrophication in the lake (Fig. 5). At the same time, a lower degree of eutrophication was noted in Lake Ślesńskie with regard to the trophic indicator

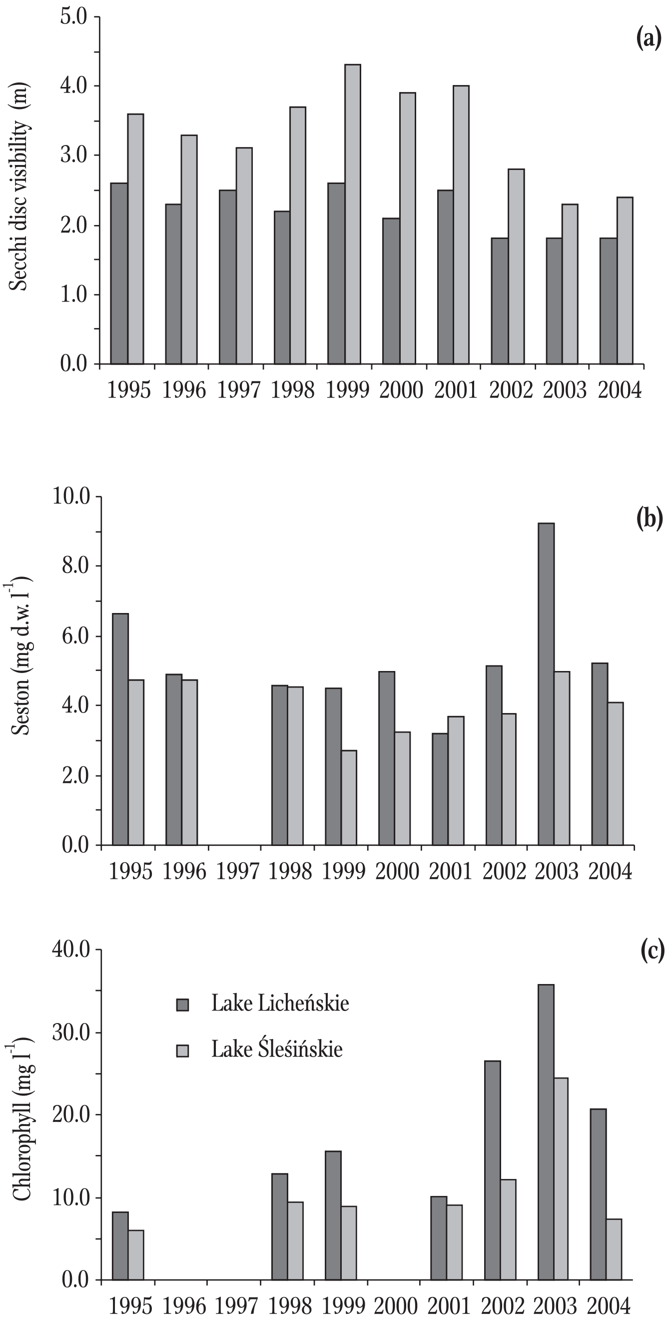

Fig. 4. Long-term changes in the mean values of Secchi disk visibility (a), seston (b), and chlorophyll contents (c) in lakes Licheńskie and Ślesińskie in the 1995-2004 period.

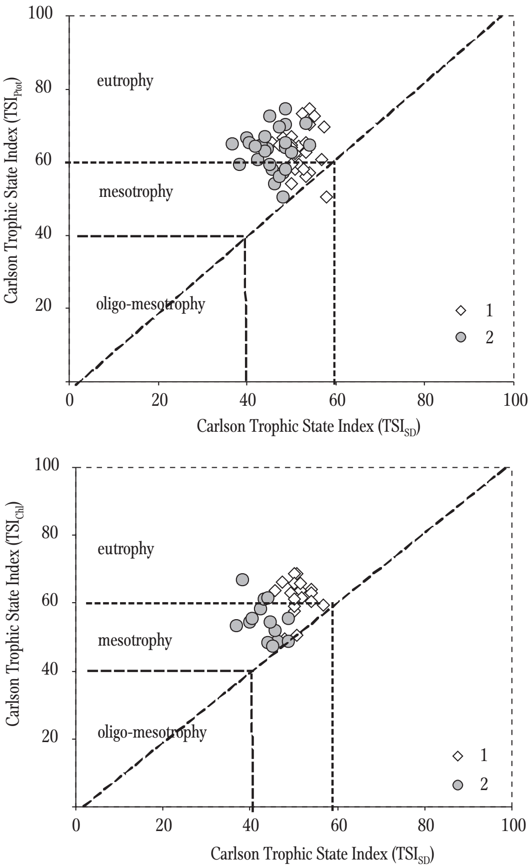

Fig. 5. Trophic state of lakes Licheńskie (1) and Ślesińskie (2) determined with the Carlson indices (TSI_{SD} TSI_{Ptot}, TSI_{Chl}) in the 1995-2004 period.

calculated based on Secchi disk visibility and the content of chlorophyll in comparison with that of Lake Licheńskie (U Mann-Whitney Test, $P < 0.05$).

DISCUSSION

The amounts of nitrogen and phosphorus in the lakes studied were typical of mesotrophic basins (Kajak 1983, Kufel 2000, 2001). The low ratio of N:P contents in the epilimnion of Lake Licheńskie indicated that the water was richer in phosphorus and the limiting role of nitrogen in the development of phytoplankton in the spring period. The insignificant increase of this ratio in the summer is evidence of the increased limitation of primary production by phosphorus. The availability of phosphorus for phytoplankton depended, above all, on the functioning of the carbonate arrangement. The sustained alkalinity of the water facilitated the precipitation of bicarbonate and the binding of phosphorus on calcite, apatite, and fluorapatite. This process could not only have equalized the significant loads of phosphorus introduced into the lake from the catchment area, but it could also have reduced the significant internal phosphorus loads in the epilimnion, which are directly available to phytoplankton (Hillbricht-Ilkowska and Zdanowski 1988b, Zdanowski et al. 1988). This mechanism is typical of clean mesotrophic lakes or river-lake systems, but also of lakes that are abundant in submerged vegetation (Avnimelech 1980, 1983, Zdanowski et al. 1992).

The increase in the phosphoran and ammonia content during the spring-summer period that more or less corresponded with the increasing oxygen deficit near the bottom is a typical phenomenon in eutrophic lakes (Korycka 1991, Bajkiewicz--Grabowska 2002). This process was more intense in Lake Ślesińskie and referred primarily to ammonia. External nutrient loading in lakes usually occurs at the highest intensity when the oxygen content near the bottom falls below 1 mg O_2 l^{-1} (Shaw and Prepas 1990, Thaler and Tait 1995, Wiśniewski 1995).

Generally, in recent years the contents of nitrogen in the lakes have declined while those of phosphorus have increased. Besides low water retention, which can halt the lake eutrophication process, one of the primary processes that impacts lake trophic status is denitrification. Additional precipitation of calcium carbonates probably immobilizes a significant portion of the phosphorus load flowing into the lakes with the waters of the Struga Biskupia River and the Warta-Gopło canal and part of the autochthonous pool of this element. Accelerated organic matter metabolism at higher temperatures and the short water retention period in the lakes limited phytoplankton blooms, while phosphorus precipitation facilitated progressing eutrophication of the lakes.

The higher phosphorus TSI_{Ptot} value probably stemmed from the occurrence of phosphorus bound with calcium in a form that is unavailable to phytoplankton. This form in Lake Licheńskie comprised an average of 25% of the entire pool, while in Lake Ślesińskie it was higher at an average of 47%. Co-precipitation and sedimentation, which was analogous to that demonstrated in other systems (Hillbricht-Ilkowska and

Simm 1988, Zdanowski et al. 1988, Zdanowski 1988, 2003, Hillbricht-Ilkowska 1994), depended on the intensity of water mixing in the system, including the flow rate forced by the uptake and discharge of post-cooling waters.

The intensity of the eutrophication process in the lakes was substantial in the first years of heating because of the increased water temperature and the exhaustion of internal peat resources. Progressive summer blooms and high phytoplankton biomass appeared (Zdanowski 1976). The decline in trophic status in the subsequent period was linked to sedimentation and the co-precipitation of phosphorus and calcium (Hillbricht-Ilkowska and Simm 1988, Zdanowski et al. 1988, Zdanowski 1988). Environmental alkalization currently still limits the potentially high eutrophication processes of the lakes.

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STRESZCZENIE

ZMIENNOŚĆ ZAWARTOŚCI AZOTU I FOSFORU W PODGRZANYCH WODACH EKOSYSTEMU JEZIOR KONIŃSKICH

Badano zmienność zawartości azotu i fosforu, widzialności krążka Secchiego oraz koncentracji chlorofilu. Oceniono na tej podstawie zmiany trofii wód w ekosystemie podgrzanych jezior konińskich. Azot i fosfor całkowity oraz ich mineralne frakcje rozpuszczone w wodzie charakteryzowała ogólnie podobna zmienność w jeziorach kompleksu i w kanałach poboru i zrzutu wody przez elektrownie (tab. 1). Dominującą formą fosforu były fosforany, a azotu – frakcja organiczna. Zawartość azotu amonowego i azotanowego nie przekraczała odpowiednio 0,10 i 0,08 mg l^{-1}, a fosforanów 0,042 mg l^{-1} (tab. 2). Stosunek zawartości N:P w wodach Jeziora Licheńskiego wzrastał przeciętnie z 10 w okresie wiosennym do 13 w okresie letnim, natomiast w Jeziorze Ślesińskim wahał się w okresie wiosenno-letnim w granicach 11-13 (rys. 1). Średnia zawartość azotu całkowitego w powierzchniowych warstwach wody Jeziora Licheńskiego i Ślesińskiego obniżyła się w ostatniej dekadzie, natomiast fosforu całkowitego – wzrosła (rys. 2). Większe koncentracje azotu i fosforu odnotowano w przydennych warstwach wody Jeziora Licheńskiego i Ślesińskiego (tab. 2). Zawartość fosforanów i amoniaku wzrastała w okresie wiosenno-letnim w miarę narastania deficytów tlenowych przy dnie (rys. 3). Maksymalne koncentracje chlorofilu odnotowano z reguły w okresie wiosennym, a największą przezroczystość wody zimą (rys. 4). Wartości wskaźników TSI_{SD} i TSI_{Chl} świadczyły o mezoeutrofii Jeziora Licheńskiego i Ślesińskiego, natomiast wskaźnik fosforowy TSI_{Ptot} – o nieco wyższym stopieniu zeutrofizowania jezior (rys. 5). Czynnikiem określającym stan trofii jezior był azot, którego dostępność zależała przede wszystkim od procesów mineralizacji materii organicznej i denitryfikacji. Przyspieszenie procesów rozkładu materii organicznej w wyższych temperaturach i niski czas zatrzymania wody w jeziorach ograniczały zakwity fitoplanktonu. Alkalizacja środowiska oraz wytrącanie fosforu na kalcycie zapobiegały obecnie, nadal potencjalnie dużym, możliwościom eutrofizacji jezior konińskich.