J. Elementol. 2007, 12(4): 347–360

CAUSES OF LOADING THE WATER OF THE EUTROPHIC LAKE JAGIEŁEK WITH NITROGEN AND PHOSPHORUS COMPOUNDS UNDER THE METEOROLOGICAL CONDITIONS OF OLSZTYN LAKELAND

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Abstract

The causes of the eutrophication of Lake Jagiełek, situated around 6 km south-west of Olsztyn, were investigated in the hydrological years 1998-2004. The catchment area of this water body is situated in the watershed zone of the Łyna and Pasłęka rivers. The lake is subject to advanced eutrophication. As regards precipitation amount, the analysed period consisted of three dry years, two normal years and one wet year. Due to the occurrence of three successive dry years and higher evaporation resulting from increased air temperatures (by 0.5°C on average), the lake shallowed with periodic exposure of bottom sediments in the shoreline zone. The periodic exposure and inundation of sections of the lake bottom has led to intense mineralization of bottom sediments. This process contributes to secondary contamination of surface water with mineral substances, mainly nitrogen and phosphorus compounds. The investigated water body is situated in a watershed zone and is characterised by low and stable electrolytic conductivity (113 $\mu S \cdot cm^{-1}$ on average) and low pH of water (6.72 on average) which periodically reaches 4.70. The concentration levels of biogenic elements (nitrogen and phosphorus compounds) are subject to seasonal fluctuation. Relatively high concentrations of $N\text{-}NO_3$ (1.25 mg dm^{-3} on average) were observed in the winter and spring, while low levels of this compound (0.18 $mg \cdot dm^{-3}$ on average) were reported in the summer and autumn. $P\text{-}PO_4$ concentrations were marked by a growing trend from 0.26 $mg \cdot dm^{-3}$ on average in the spring to 0.70 $mg \cdot dm^{-3}$ on average in the summer. A high water load with biogenic elements, whose concentrations significantly exceeded the allowable and dangerous levels of N and P according to Vollenweider's criteria, speeded up the eutrophication process and stimulated the gradual self-decline of the entire ecosystem. The restoration of ecological balance in the surveyed

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ecosystem should rely on the seasonal nature of climatic and hydrological factors characteristic of the examined area, and should involve the re-introduction of the water body into the horizontal water circulation system.

Key words: lake, eutrophication, precipitation, biogenic elements, nitrogen, phosphorus.

PRZYCZYNY OBCIĄŻENIA WÓD ZEUTROFIZOWANEGO JEZIORA JAGIEŁEK ZWIĄZKAMI AZOTU I FOSFORU NA TLE WARUNKÓW METEOROLOGICZNYCH POJEZIERZA OLSZTYŃSKIEGO

Abstrakt

Przyczyny eutrofizacji jeziora Jagiełek, położonego ok. 6 km na południowy zachód od Olsztyna, badano w latach hydrologicznych 1998–2004. Zlewnia zbiornika jest położona w strefie wododziałowej rzek Łyny i Pasłęki. W zbiorniku stwierdzono zaawansowany stopień eutrofizacji wód. Pod względem ilości opadów, w analizowanym okresie wyróżniono 3 lata suche, 2 normalne i jeden rok wilgotny. Wystąpienie w krótkim okresie kilku lat suchych oraz wzrost parowania w wyniku podwyższenia temperatury powietrza (średnio o 0,5°C) spowodowały wypłycenie jeziora, z okresowym odsłanianiem osadów dennych w jego strefie przybrzeżnej. Skutkiem okresowego odsłaniania i zatapiania części dna zbiornika jest intensywna mineralizacja osadów dennych. Powoduje to wtórne zanieczyszczenie wód powierzchniowych składnikami mineralnymi, głównie związkami azotu i fosforu. W zbiorniku zlokalizowanym w strefie wododziałowej wykazano niskie i stabilne wartości przewodnictwa elektrolitycznego (średnio 113 $\mu S \cdot cm^{-1}$), niski odczyn wody (średnio pH 6,72), osiągający okresowo pH 4,70 oraz sezonową cykliczność stężeń biogenów (związków azotu i fosforu). Stosunkowo wysokie stężenia $N\text{-}NO_3$ (średnio 1,25 mg dm^{-3}) występowały w okresie zimowo-wiosennym, a niskie (średnio 0,18 $mg \cdot dm^{-3}$) w okresie letnio-jesiennym. Stężenia $P\text{-}PO_4$ wykazywały tendencję wzrastającą od średnio 0,26 $mg \cdot dm^{-3}$ wiosną do średnio 0,70 $mg \cdot dm^{-3}$ latem. Duże obciążenie wody substancjami biogennymi, przekraczające wielokrotnie dopuszczalne i niebezpieczne poziomy N i P, przyśpieszyło eutrofizację wody i spowodowało ewoluowanie całego ekosystemu w kierunku stopniowej samolikwidacji zbiornika. Odtworzenie równowagi ekologicznej w badanym ekosystemie, powinno opierać się na sezonowości zjawisk klimatycznych i hydrologicznych występujących w regionie przy ponownym włączeniu zbiornika w poziomy obieg wody.

Słowa kluczowe: jezioro, eutrofizacja, opady, biogeny, azot, fosfor.

INTRODUCTION

Every natural water body and its catchment area form a landscape system where water is the main means of transport and exchange of matter between ecosystems. The physical and geographical characteristics of the catchment area determine both the rate at which matter is transported to the water body as well as the volume of the accumulated substances. Situated at the lowest point in the surrounding area, a water body is the accumulation centre of energy and matter migrating from the catchment (WINTER 2001). Therefore, the catchment area plays a vital role in regulating the process of lake degradation (GLIŃSKA-LEWCZUK 2002, 2005., KOC et al. 1996, KOC, SZYMCZYK 2001).

The morphological parameters of a water body remain in a close relationship with the physical and geographical characteristics of its catchment area (BAJKIEWICZ-GRABOWSKA 1999, GLIŃSKA-LEWCZUK 2005), and they determine the intensity of biogeochemical changes taking place in this body of water (GLIŃSKA-LEWCZUK 2002). Subject to the individual susceptibility of a lake to external influences and to the supply of biogenic elements from the catchment area, clear changes in the physical and chemical properties of water are observed (BAJKIEWICZ-GRABOWSKA 1999, GLIŃSKA-LEWCZUK 2005). The inflow of excessive quantities of nutrients from the catchment into the water body leads to an ecological unbalance. The majority of Polish lakes, in particular water bodies with a small area of several hectares, are characterised by high water fertility which leads to their degradation, overgrowth and disappearance (JĘDRYKA, MACIEJEWSKI 2007). This process is visibly accelerated when the supply of groundwater to the water body is inhibited, a situation which is commonly noted in reclaimed areas. The change in the existing water relations, observed when a part of the catchment is excluded from the process of supplying matter to the water body and when water outflow is blocked, decreases the proportion of allochtonic substances in favour of autochtonic substances in the matter circulation cycle in an aquatic ecosystem.

As regards water bodies situated in a watershed zone, the amount and intensity of precipitation and meltwater input are important factors which determine the physical and chemical properties of water (WEGENER et al. 2007). Although precipitation contributes to surface water pollution (SAPEK 1998), it has a minor effect on water bodies in a watershed zone as regards their pH reaction and electrolytic conductivity which is marked by low ion concentration, in particular ions which are typical of the chemical denudation of the lithosphere, such as carbonates, calcium and others (KOC et al. 2003).

The objective of this study was to identify the factors and causes which have contributed to the strong degradation and the gradual decline of a small lake with the historical name of Jagiełek, situated in the watershed zone of the Łyna and Pasłęka rivers in the Olsztyn area.

MATERIALS AND METHODS

Research site. The topographic catchment of Lake Jagiełek covers an area of 210 hectares. It is situated within the administrative boundaries of the Stawiguda commune, around 6 km south-west of Olsztyn (Fig. 1). The catchment area is located in the watershed zone of the Łyna and Pasłęka

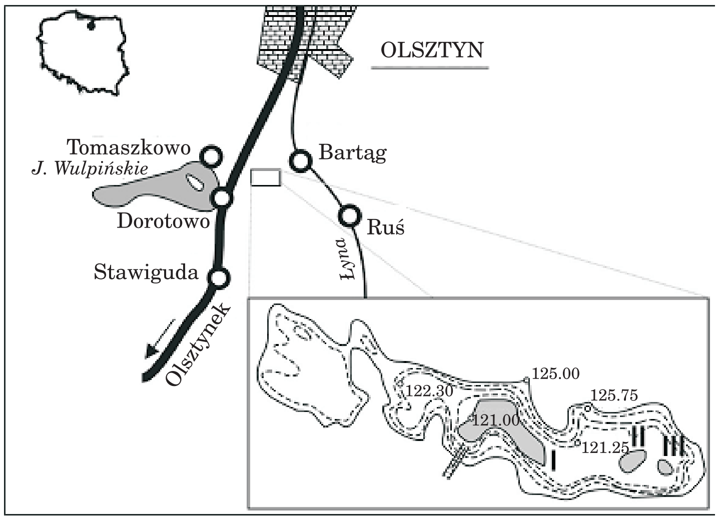

Fig. 1. Location and the contemporary (121,00 m a.s.l.) and former (125,00 m a.s.l.) reach of water table area of Jagiełek Lake

Rys. 1. Lokalizacja i zasięg obszarowy współczesnego (121,00 m n.p.m.) i dawnego jeziora Jagiełek (125,00 m n.p.m.)

rivers. It is an undulating moraine upland area situated at an altitude of 120 to 141 m above sea level. Soil in the catchment area consists of Quaternary deposits in the form of boulder clay with glacial and fluvioglacial sand and gravel interbedding. It comprises impermeable and weakly permeable deposits of boulder clay and slime with silty and loamy sand layers. Sand and gravel layers of glacial origin occur locally on the surface. The catchment comprises mostly soil of quality class V and VI, while class IV soil occupies only a small part of its area. The catchment area features a forest complex comprising mostly uneven-aged pure pine and pine-birch tree stands.

Jagiełek is a remnant of a postglacial lake with features characteristic of a ground moraine body of water. It presently consists of three small but strongly overgrown water bodies – the deepest points of the former postglacial lake (Fig. 2). The largest region occupies an area of 1.27 hectares and it is the only site where the surface water table is maintained throughout the year. The remaining two bodies of water, with an area of 0.24 and 0.09 hectares respectively, are periodically filled with water, mainly in the spring. The present water table level reaches 121 m above sea level on average, with annual amplitude of around 1.70 m. The water table was originally found at 125.00 m above sea level, indicating that the former water body had an area of 25.47 hectares. An analysis of Schroetter's general map of 1803 in the 1: 50 000 scale has shown that those water bodies had been connected in the early 19th century, and that the

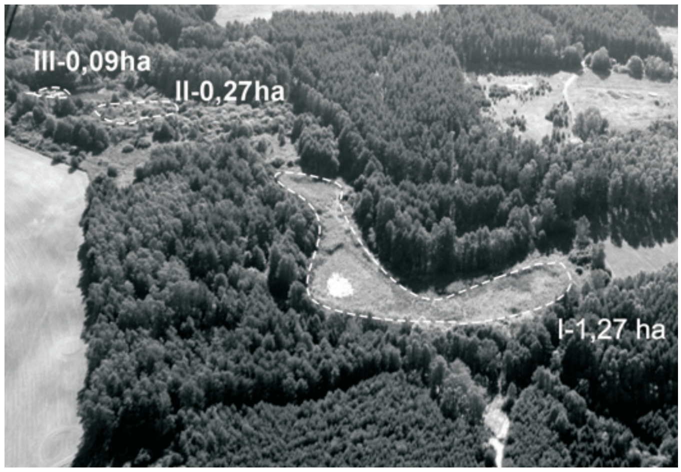

Fig. 2. View on three overgrowing reservoirs of the Jagielek lake, aerial photo. September 2004

Rys. 2. Widok na zarastające akweny jeziora Jagiełek, zdjęcie lotnicze – wrzesień 2004

water table of a lake with the Prussian name of *Jagiellen See* was approximately 5.25 m higher than today (Fig. 3). In addition to a decline tendency observed in most natural water bodies, the decrease in the water table area and the lake's capacity has resulted mainly from reclama-

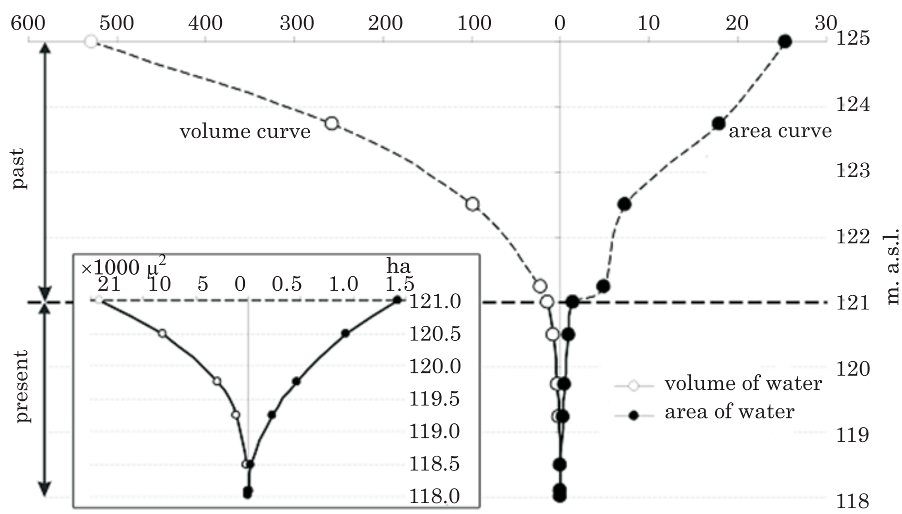

Fig. 3. Volume and area curves of Jagiełek Lake presenting maximal reach (in approximately 1800) and contemporary (2004) water table

Rys. 3. Krzywa powierzchni i pojemności jeziora Jagielek obrazująca maksymalny zasięg zbiornika (ok. 1800 r.) oraz współczesny (2004 r.)

tion works conducted between the two World Wars as well as in the 1960s.

Jagiełek was initially supplied with infiltration and ground water from the catchment with an area of 210 hectares. Water was flowing out of the lake via a canal on the southern side in the direction of Lake Wulpińskie. In the early 1960s, a drainage system was build in the western part of Jagiełek's catchment, but the lake was excluded from the drainage network. As a result, the groundwater level in the lake's vicinity was lowered by around 1 m. The above reduced the area of the groundwater source to 82.16 hectares. Jagiełek developed a quick and short-term response to intense supply of water (mostly meltwater) in the form of high water levels, long-term lowering of the water table which exposed bottom sediments in the summer and autumn low-flow periods. Jagiełek's catchment is a farming area, but the water body is surrounded by a young coniferous forest planted at the turn of the 1960s and 1970s.

Analysis methods. The study to determine the causes of eutrophication of Lake Jagiełek was conducted in Tomaszkowo near Olsztyn in the hydrological years 1998–2004. Water samples were taken once a month only from the largest water body (there is no access to the remaining two water bodies), in accordance with the generally applied methods (HERMANOWICZ et al. 1999). The following determinations were made: ammonium nitrogen ($N\text{-}NH_4$) – by colorimetry with Nassler's reagent, nitrate nitrogen ($N\text{-}NO_3$) – by colorimetry with phenoldisulfonic acid, nitrite nitrogen ($N\text{-}NO_2$) – by colorimetry with phenoldisulfonic acid. Mineral nitrogen was determined as the sum of the above nitrogen forms. Total phosphorus and phosphate concentrations were determined by colorimetry after mineralization with ammonium molybdate and tin chloride as the reducing agent.

Sampling was accompanied by observations of water level in Lake Jagiełek. Meteorological data were provided by from the meteorological station of the University of Warmia and Mazury in Olsztyn, situated at a distance of approximately 300 m from the lake. The mean total annual precipitation in the investigated period for the Olsztyn area was 570.5 mm (Fig. 4). According to KACZOROWSKA'S criterion (1962), the two years (1996 and 1997) preceding the investigated period were classified as normal years as regards precipitation amount, while the analysed period comprised 3 dry years (1999 – 497 mm, 2000 – 474 mm, 2003 – 478 mm), 2 normal years (1998 – 534 and 2001 – 591 mm) and one wet year (2004 – 696 mm). The average air temperature in the surveyed period was 7.8°C, marking an increase of 0.5°C from the long-term average for 1961–2004. Dry and warm years were predominant in the analysed six-year period.

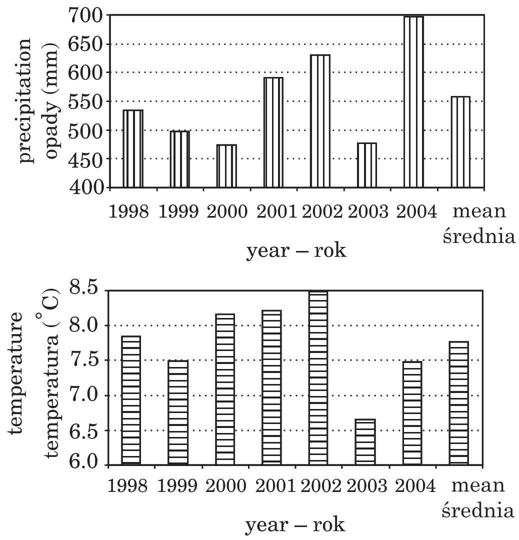

Fig. 4. Variability of precipitation sums in Tomaszkowo in hydrological years 1998–2004
Rys. 4. Zmienność opadów i temperatur w Tomaszkowie
w latach hydrologicznych 1998–2004

RESULTS AND DISCUSSION

The drainage reclamation works conducted in the catchment area of Jagiełek lake minimised the catchment's role as the main supplier of residual substances from farming production. Due to an estimated 40% reduction of the water body's alimentation area and the predominance (60%) of interior areas without an outflow, it should be assumed that the intensity of biogeochemical processes in this ecosystem relies mostly on autochtonic mineral and organic matter (Table 1). The quality of water in Lake Jagiełek is subject to seasonal variation, which is a characteristic feature of strongly eutrophic aquatic environments. The physical and chemical properties of water, presented in Table 1, are indicative of significant changes in the chemical composition of water in the body, mainly mineral forms of nitrogen and phosphorus and, in particular, nitrate nitrogen for which the coefficient of variation reached 245%.

The short-term migration of substances, which is also due to the water body's location in a watershed zone, results in stable and low electrolytic conductivity reaching 113 $\mu S \cdot cm^{-1}$ on average as well as periodically acidic pH of water (6.72 on average) which drops to 4.70.

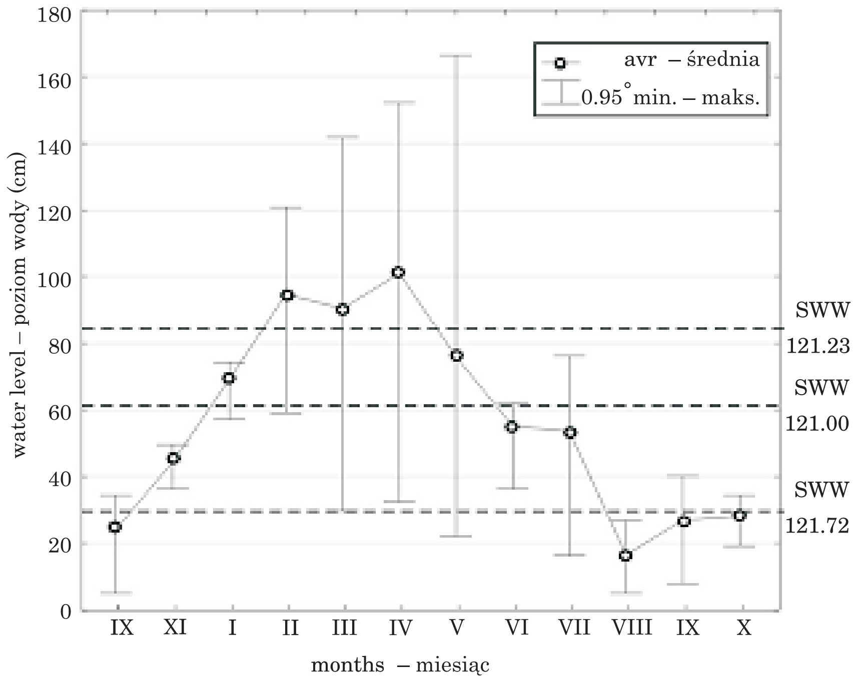

Fig. 5. Changes in water level in Jagiełek lake over the period of one hydrological year. Symbols of SWW, SSW, SNW denote limits of high, medium and low water

Rys. 5. Zmiany położenia lustra wody w jeziorze Jagiełek w ciągu roku hydrologicznego. Symbole SWW, SSW, SNW oznaczają granice stref stanów wody, odpowiednio: średnią wysoką wodę, średnią wodę i średnią niską wodę

Natural processes leading to the overgrowth and silting-up of the water body are caused by the closed cycle of water-contained matter due to the blockage of the surface outflow from the lake. In this environment, meteorological parameters which determine, among others, the circulation rate of water and water-contained matter play a very important role, as demonstrated by the water level amplitude which is 3.5 times higher (170 cm) than in most lakes of the region. The lowest water level was observed in 2003 (amplitude of only 29 cm) which was the driest and the coolest year, while the highest water level (amplitude of 137 cm) were recorded in 1998 which was marked by normal precipitation totals and temperatures approximating the long-term average. The absence of a significant rise in water levels in a wet year, preceded by a dry year, is indicative of a drastic drop in groundwater levels which were supplemented at the expense of lake filling. An analysis of the annual water levels shows two distinctive periods: a period marked by an abundance of water, observed between March and May, due to the melting of the snow and ice cover and soil thawing, and the summer period marked by low water levels (Fig. 5).

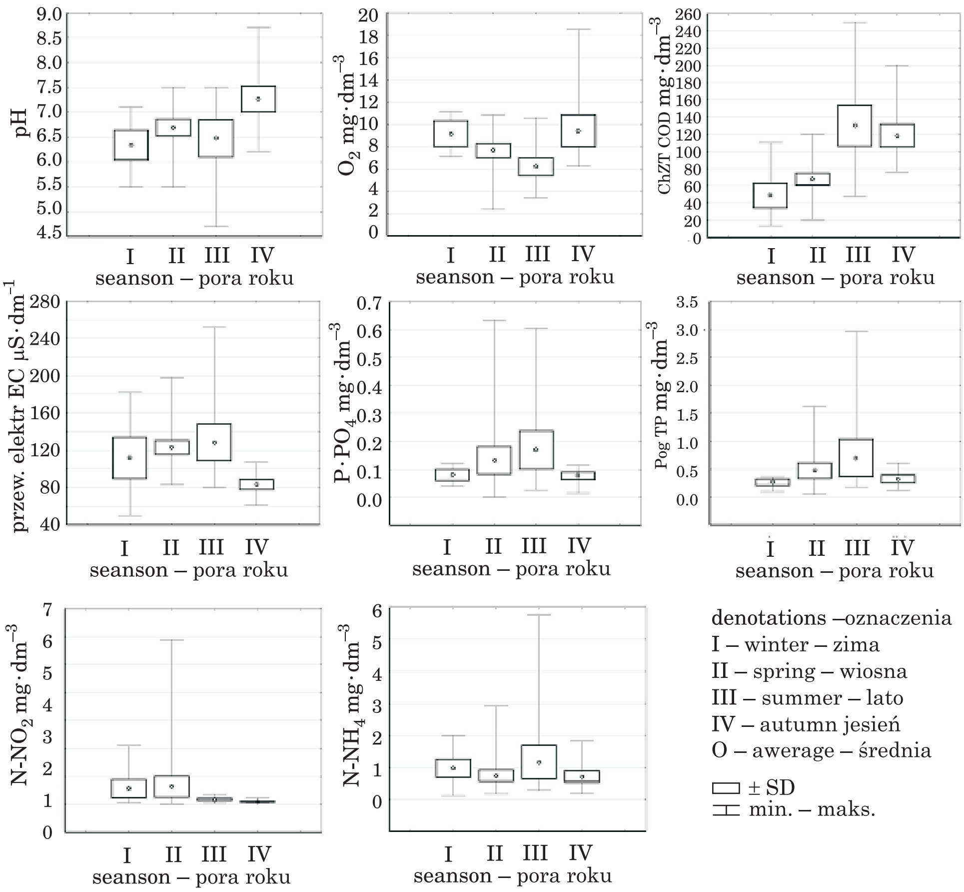

Fig. 6. Seasonal variability of physico-chemical parameters of water in Jagielek lake in the study period of 1998–2004

Rys. 6. Zróżnicowanie sezonowe właściwości fizykochemicznych wody jeziora Jagiełek w wieloleciu 1998–2004

In the spring period of high water, oxygen reserves are supplemented after the oxygen deficit in the winter. Yet both seasons have a significant impact on N-NO_3 concentrations. The highest levels (5.88 mg·dm^{-3}) of nitrate nitrogen are reported in the winter, probably due to a limited rate of phytosorption of nitrogen released in the process of biochemical change (Fig. 6). The lowest concentrations of this nitrate form were observed in the summer and autumn months – 0.18 and 0.10 mg·dm^{-3} respectively, during which substantial quantities of this component were absorbed by plants. Between 1998 and 2004, the N-NO_3 concentrations in the water of the investigated lake were similar to N-NH_4 concentration levels. In the discussed period of study, the concentration of ammonium nitrogen (N-NH_4) in water ranged from 0.11 mg·dm^{-3} in a normal year (2002) to 5.76 mg·dm^{-3} in a wet year (2004). The high N-NH_4 concentration in water in the wet year (autumn) resulted from organic matter mineralization in the summer, and was supported by relatively high temperatures, very low water levels over a period of several preceding years as well as higher precipitation totals which caused ammonium ions from decomposing sediments to be deposited in the water body, thus contributing to secondary contamination (Fig. 7).

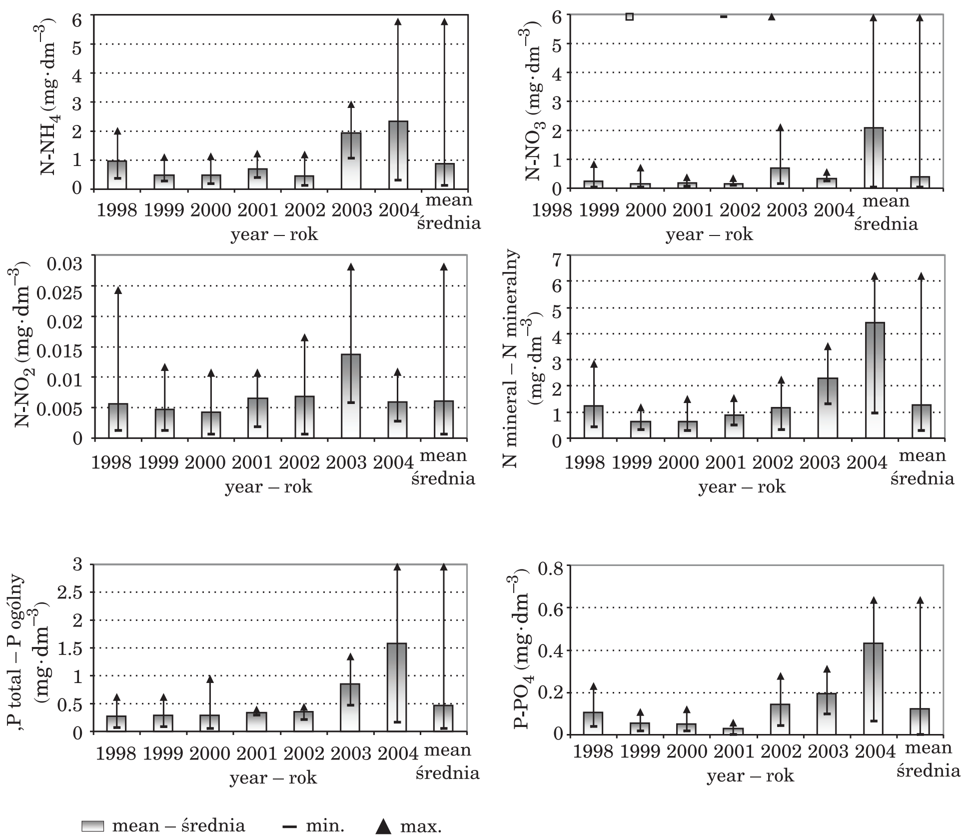

Fig. 7. Changes in mineral forms of nitrogen and phosphorus in Jagiełek Lake water in hydrological years 1998–2004

Rys 7. Zmienność stężenia mineralnych form azotu i fosforu w wodzie jeziora Jagiełek w latach hydrologicznych 1998–2004

From among the discussed nitrogen forms, nitrate nitrogen ($N\text{-}NO_2$) was marked by the smallest fluctuation in concentration levels (from 0.0006 to 0.0028 $mg \cdot dm^{-3}$). Changes in the concentration of nitrate nitrogen in surface layers could be due to the small area of the water body which is characterised by high sedimentation and a high content of anaerobic products of the sediment transformation process (Koc et al. 1996). Higher $N\text{-}NO_2$ concentrations in the lake were observed in the spring which could be due to a lower rate (at lower temperatures) of biochemical change of nitrogen and the extended duration of the first stage of nitrification.

The concentration of mineral nitrogen in Lake Jagiełek clearly indicates that this biogenic element posed the highest load on the investigated water body in the wet year (2004), preceded by drier years (Fig. 7). The above implies that the nitrogen accumulated in bottom sediments was released, leading to secondary contamination of surface waters, which was additionally aided by low water levels.

The high content of phosphorus compounds in shallow water bodies with a limited supply from the catchment is usually ascribed to sediment resuspension. An analysis of seasonal fluctuations in phosphorus concentration in water and hydrometeorological conditions in the investigated period supported this possibility.

The increase in total phosphorus concentrations (0.70 $mg \cdot dm^{-3}$) during low water periods in the summer was statistically significant in comparison with other periods due to the possibility of bottom sediment stim-

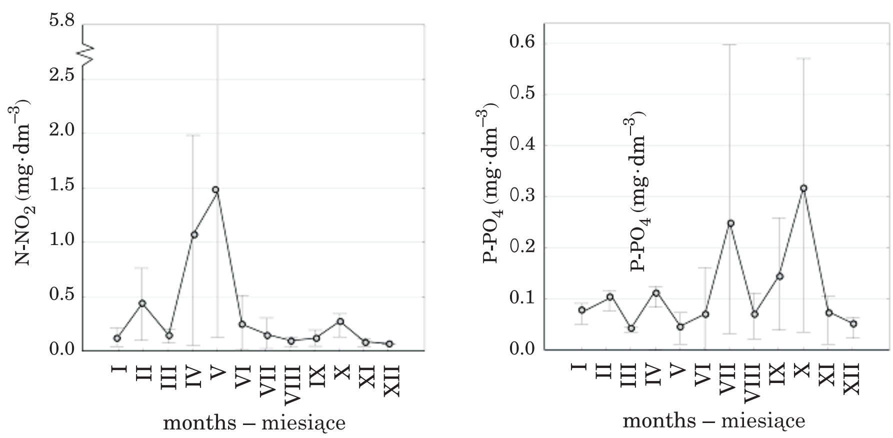

Fig. 8. Monthly changes in the concentrations of $N\text{-}NO_3$ and $P\text{-}PO_4$ in Jagiełek Lake water in a hydrological year from the period of 1998–2004. Vertical bars indicate ranges of minimal and maximal concentrations

Rys. 8 Zmiany stężeń $N\text{-}NO_3$ i $P\text{-}PO_4$ w wodzie jeziora Jagiełek w ciągu roku hydrologicznego na podstawie comiesięcznych wyników badań z okresu 1998–2004. Pionowe słupki oznaczają zakresy minimalnego i maksymalnego stężenia ulation by the wind. In the winter, when the insulating ice cover prevented water movement caused by wind, total phosphorus concentration reached 0.26 $mg \cdot dm^{-3}$. During that period, when the sorption of this element by plants was limited, phosphorus precipitation and its accumulation in bottom sediments increased. Yet in view of the significant rise in water levels in the spring, accompanied by higher phosphorus concentrations in water, it can be assumed that the dilution effect was supported by phosphorus desorption from sediments and the supply of phosphorus in melt and precipitation water. The nature of the annual changes in phosphorus concentration in Lake Jagiełek differed from the changes reported in respect in nitrate levels. While $N\text{-}NO_3$ concentration levels were high in the winter and spring, the concentration of $P\text{-}PO_4$ in Jagiełek was marked by a rising trend in the spring, summer and autumn (Fig. 8).

The dynamics of changes in concentration levels of total phosphorus and its soluble forms ($P\text{-}PO_4$) was influenced by hydrometeorological conditions in particular years of the experimental period. The dominance of dry years in the discussed period has led to a significant drop in groundwater levels which, in turn, intensified the release of nitrogen and phosphorus compounds from bottom sediments into the water. For this reason, the highest concentrations of both total phosphorus (2.96 $mg \cdot dm^{-3}$) and $P\text{-}PO_4$ (0.66 $mg \cdot dm^{-3}$) were noted in the last year (2004) of the investigated period (Fig. 7).

Table 1
Tabela 1

Assessment of the catchment of Jagiełek lake as a source of the matter to the lake
Ocena zlewni jeziora Jagiełek jako dostawcy materii do zbiornika przed melioracją i po melioracji

Property of the catchment Cecha zlewni	Unit Jednostka	Before reclamation Przed melioracjami	After exclusion from the drainage supply Po wyłączeniu z zasilania wodami drenarskimi
Powierzchnia zlewni jeziora	ha	210.00	82.16
Powierzchnia jeziora	ha	25.47	1.60
Ohle's index Wskaźnik Ohlego	%	8.4	51.3
Balance type of a lake Typ bilansowy jeziora	-	flown - through przepływowe	outflowless bezodpływowe
Share of depressions Obszary bezodpływowe	%	45	61
Land use Użytkowanie ziemi	-	arable lands and forest rolniczo-leśna	forest and arable land leśno-rolnicza

Regardless of the season, the water body was characterised by excessive unitary water load with biogenic elements whose concentrations were significantly above the allowable and dangerous levels of N and P according to Vollenweider's criteria (1968), a fact which stimulated the gradual self-decline of the ecosystem (Fig. 2). As shown on the example of the investigated body of water, the proper functioning of an aquatic ecosystem in a strongly drained environment of a watershed zone requires revitalisation despite the limited role played by the catchment as the source of biogenic elements. The restoration of ecological balance in the surveyed ecosystem should rely on the seasonal nature of climatic and hydrological factors characteristic of the examined area, and should involve the re-inclusion of the water body into the horizontal water circulation system. The progressive eutrophication of the lake could be inhibited by increasing landscape diversity and improving the water balance of the catchment.

Table 2
Tabela 2

Physico-chemical properties of water in Jagiełek Lake located near Tomaszkowo in the period of 1998–2004
Właściwości fizykochemiczne wody w jeziorze Jagiełek k. Tomaszkowa w latach 1998–2004

Parameter Wskaźnik	Average Średnia	Median Mediana	Range – Zakres		25% Quartile	75% Quartile	cv (%)
			minimum	maximum			
pH	6.72	6.88	4.70	8.70	6.22	7.30	12
Diss. oxygen O_2 mg · dm^{-3}	7.87	7.65	2.38	18.50	6.32	9.37	38
Temperature °C	13.01	13.90	0.50	29.00	5.50	18.70	65
COD, ChZT mg · dm^{-3}	90.63	80.00	13.50	250.00	53.00	104.00	59
SEC µS · cm^{-1}	112.89	106.00	50.00	252.00	90.00	133.00	35
N-NO_2 mg · dm^{-3}	0.006	0.004	0.001	0.028	0.003	0.007	97
N-NO_3 mg · dm^{-3}	0.39	0.13	0.03	5.88	0.08	0.32	245
N-NH_4 mg · dm^{-3}	0.87	0.51	0.11	5.76	0.35	1.08	112
N_{min} mg · dm^{-3}	1.27	0.92	0.28	6.19	0.49	1.40	105
P-PO_4 mg · dm^{-3}	0.12	0.07	0.00	0.63	0.04	0.12	121
TP Pog mg · dm^{-3}	0.47	0.30	0.05	2.96	0.17	0.45	122

CONCLUSIONS

1. The main cause of intensive geochemical changes leading to eutrophication, hypertrophy and disappearance of water bodies in a watershed zone are the adverse changes in water relations resulting from the lowering of groundwater levels and the exclusion of water bodies from the active system of horizontal water circulation.

2. The example of Lake Jagiełek situated in the Olsztyn Lakeland indicates that the dynamics of biochemical changes in the illustrated ecosystem is determined by meteorological conditions observed in the period of many years as well as in the course of a single year. Drainage reclamation works conducted in the catchment area of Lake Jagiełek inhibited groundwater supply, contributed to the shallowing of the lake and decreased its surface nearly 30-fold, as a result of which the water level became strongly dependent on meteorological conditions.

3. The investigated water body, located in a watershed zone, is marked by stable and low electrolytic conductivity of 113 $\mu S \cdot cm^{-1}$ on average as well as low water pH which periodically reaches 4.70. The above is indicative of short-term migration of precipitation water from the catchment.

4. In an annual cycle, the concentration levels of biogenic elements in Lake Jagiełek were characterised by seasonal fluctuations which differed for every analysed substance. While $N\text{-}NO_3$ concentrations were relatively high (1.25 $mg \cdot dm^{-3}$ on average) in the winter and spring and low in the summer and autumn ((0.18 $mg \cdot dm^{-3}$ on average), $P\text{-}PO_4$ concentrations were marked by a growing trend from 0.26 $mg \cdot dm^{-3}$ on average in the spring to 0.70 $mg \cdot dm^{-3}$ on average in the summer low-flow period.

5. The dynamics of changes in water resources in the investigated lake (amplitude of 170 cm) was due to significant differences in the supply of precipitation water which had a pronounced effect on biogeochemical processes in the ecosystem, mainly sedimentation and resuspension of mineral forms of phosphorus. The precipitation water deficit observed in 1998-2004 significantly lowered the water level in the lake which, consequently, led to organic matter mineralization in bottom sediments and to the release of nutrients into the water. The highest concentrations of mineral forms of nitrogen and phosphorus compounds in the lake were observed in the wet year preceded by two drier years.

6. A high water load with biogenic elements whose concentrations significantly exceeded the allowable and dangerous levels of N and P according to Vollenweider's criteria, speeded up the eutrophication process and stimulated the gradual self-decline of the entire ecosystem.

7. The restoration of ecological balance in the surveyed ecosystem should rely on the seasonal nature of climatic and hydrological factors characteristic of the examined area and should involve the re-introduction of the water body into the horizontal water circulation system.

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