LONG-TERM CYANOBACTERIAL DYNAMICS AS RELATED TO PHYSICOCHEMICAL WATER PARAMETERS IN A RESTORED URBAN LAKE

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Abstract

The aim of this study has been to determine the response of cyanobacteria to the lake protection and restoration measures implemented in the littoral zone of an urban lake called Jeziorak Mały. The first investigations were conducted in 1996 and were resumed in 1997-2003, 2005 and 2013, following the installation of a separator and the creation of stone accumulation sites. Long-term changes in phytoplankton cyanobacterial proportions, abundance and biomass were analyzed in relation to environmental conditions at the sites in the littoral zone (S – separator pipes, K – sites with stones and R – sites with macrophytes). Relationships between cyanobacteria and water chemistry variables were analyzed by calculating the Spearman's rank correlation coefficient, and then with canonical correspondence analysis (RDA). The results provided evidence that water temperature, total nitrogen and iron concentration (S, R), but also PO_4^{3-} in spring (S,K) were the principal factors affecting cyanobacterial development. There was a significant decrease in the share, abundance and biomass of cyanobacteria coinciding with a decrease in conductivity and PO_4^{3-} following the onset of lake restoration efforts. Changes in dominant species from the ones typical in hypertrophic lakes to those typically found in eutrophic lakes took place during the research. The modifications indicated a strong initial response of cyanobacteria to the restoration measures, but the situation stabilized in 2013, when cyanobacteria returned to their previous average levels. This suggests that the introduction of lake restortation measures contributed to the lake's improved water quality and they should be retained for efficient lake management in the future.

Keywords: protective and restoration procedures, cyanobacteria, nutrients, RDA.

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INTRODUCTION

Intensive urban and industrial development contributes to water eutrophication (BERNHARDT 1987), which is accelerated in those agglomerations in which domestic sewage and nutrient rich stormwater enter shallow lakes (GUZKOWSKA, GASSE 1990, WICHELEN et al. 2007). Excessive primary nutrient production causes massive growth of some algal species, particularly cyanobacteria, leading to algal blooms and inferior water quality (REYNOLDS 1978), as a result of which the ecological status of some lakes suffers (NAPIÓRKOWSKA--KRZEBIETKE et al. 2012). Mass cyanobacterial growth depends on water temperature, nutrient resources (particularly phosphorus and nitrogen), the degree of exposure to wind and water mixing, phosphorus resuspension from sediments and iron accessibility (MISCHKE, NIXDORF 2003, BERMAN-FRANK et al. 2007, EL-SAYED et al. 2010). Particular phytoplankton species, including cyanobacteria, have various requirements as regards physicochemical water parameters. According to PEŁECHATY, BURCHARDT (1998), bioindication is essential in this respect. A certain state of the natural environment or intensity of environmental factors create suitable conditions for the occurrence of a given species, characterized by a specific range of tolerance.

Eutrophication processes are effectively decelerated by reducing the inflow of nutrients, especially phosphorus, through lake basin restoration methods (BERNHARDT 1987, KLAPPER 2003, JEPPESEN et al. 2007, WICHELEN et al. 2007, MCDONALD, LEHMAN 2013), which include external protecting solutions in the lake's catchment area (LOSSOW 1998). In urbanized catchments lacking a sewer system with pipes for collecting superficial water and sewage water, polluted stormwater is often discharged directly into lakes (GUZKOWSKA, GASSE 1990). In order to protect water of urban lakes, separators are used for stormwater pretreatment, during which some amounts of the organic substances are removed.

Jeziorak Mały is a eutrophic lake, in which the phytoplankton is dominated by cyanobacteria. Certain protection and restoration measures have been implemented to improve the lake's water quality. Namely, separators for stormwater pre-treatment were installed and stone accumulation sites in the littoral zone were created. Our hypothesis was that these measures influenced the environmental conditions, thus affecting the littoral zone cyanobacteria development over the 16 years since they were started. The aim of this study has been to determine the response of cyanobacteria to the protection and restoration technologies applied in the littoral zone of Jeziorak Mały Lake. The study was conducted in 1996-2003, 2005 and 2013.

MATERIAL AND METHODS

Jeziorak Mały Lake is a typical, shallow (mean depth of 3.4 m), eutrophic urban lake. It lies in a temperate climatic zone, in the Mazurian Lake District, north-eastern Poland (Figure 1). Jeziorak Mały covers 26 ha and
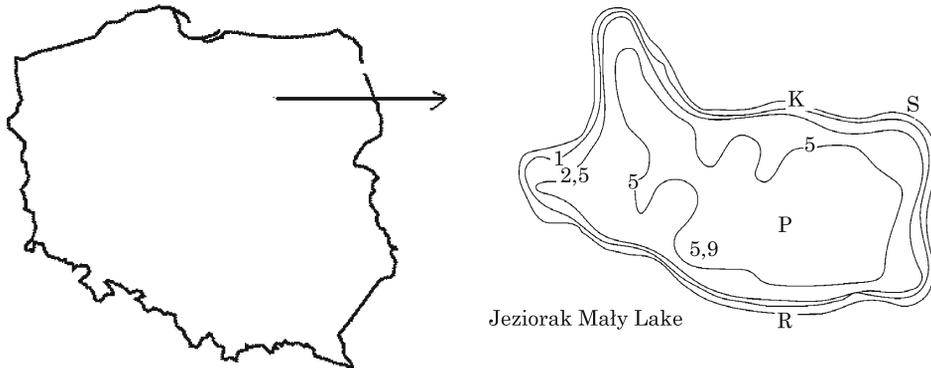

Fig. 1. A morphometric map of Jeziorak Mały Lake:
S – sites with pipes from separators which drain stormwater,
K – sites with stone accumulation created in 1997, *R* – sites with macrophytes, *P* – pelagic zone

connects to a much bigger lake, Jeziorak Duży (3,219 ha) through a narrow canal (4 m wide and 4 m deep). For decades, this lake had been receiving untreated municipal sewage from the town of Iława. Since 1991, the effluent has been treated at a local wastewater treatment plant. Efforts to improve the lake's water quality began in 1997. Since then, separators for the pretreatment of stormwater flowing to the lake have been installed in the littoral zone. The construction started in 1996 and consisted of the Unicon System lamella separators placed in the lake's littoral zone. Completed in the spring of 1997, the installation prevents untreated stormwater transfer to the lake. The separators comprise 16 blinder sections, 1200 mm diameter inlet and outlet pipes, and a 3200 l sedimentation tank to remove petroleum compounds, silt and sand in a separate rainwater sewer system. The petroleum derivatives separation efficiency is 97% at nominal discharge of 160 l s^{-1}. This stormwater pretreatment covers the 70 ha catchment area of Jeziorak Mały Lake (PUH EKOL 1995). The shores are partly concrete cast or reinforced with fascines, and most of the lake bed is covered with stones and gravel. Jeziorak Mały is an example of a lake submitted to a reversed littoral zone management system, with approximately 30% macrophytes and 70% concrete bank. The phytolittoral includes emerged macrophytes, mainly *Phragmites australis* (Cav.) Trin. ex Steud., *Scirpus lacustris* (L.) Palla, *Acorus calamus* L., and *Glyceria aquatica* (L.) Wahlb., and the bed is muddy and covered with decomposing plant debris.

Samples of phytoplankton were collected monthly from April to October

in 1996-2003, 2005 and 2013, at three sites located in the littoral zone of Jeziorak Mały (Figure 1).

The samples were taken from 1 m deep euphotic zone into a 10 l calibrated bucket (20 l at each site), poured through plankton net no 20 and preserved first in Lugol's solution and then in 4% formaldehyde solution. In total, 120 phytoplankton samples were tested. Basic physical and chemical water parameters were measured directly at the phytoplankton sampling sites. Water temperatures at $0.1^{\circ}C$ precision and oxygen content at 0.01 mg O_2 dm^{-3} accuracy, as indicated on an HI 9143 oxygen meter, were determined *in situ*, while the water pH and conductivity at 1-1500 μS cm^{-1} were assessed by CONMET 1. Orthophosphate (0.05-5.00 mg PO_4^{-3} dm^{-3}), total nitrogen (0.5-15 mg N dm^{-3}), iron (2.5-250 mg Fe^{3+} dm^{-3}) and chloride (2.5-250 mg Cl^- dm^{-3}) concentrations were measured in a laboratory using Spectroquant Merck tests on a NOVA 400 spectrophotometer.

Qualitative and quantitative determinations of phytoplankton were performed with an Alphaphot YS2 optical microscope at magnifications of 10x, 20x, 40x and 100x. Phytoplankton counts in 1 ml samples were determined in a planktonic chamber, in 5000 fields of vision at 200× magnification. Cyanobacterial biomass of 10 individuals of each planktonic and periphytic algal species was calculated by comparing algae to their geometric shape (ROTT 1981). Cyanobacterial abundance and biomass were correlated with water physical and chemical parameters using non-parametric methods because these data were not normally distributed. In order to reduce the number of variables, a forward selection procedure using the Monte Carlo test with 999 permutations ($p<0.05$) was applied. Relationships were confirmed by calculating the Spearman's rank correlation coefficient in a Statistica version 8 package, and then canonical correspondence analysis (RDA) was accomplished. This methodology was chosen after the DCA test had been conducted to estimate assemblages of cyanobacteria occurring in spring, summer and autumn, i.e. environmental variable relationships. Finally, the relationships were presented on a biplots graph using Canoco for Windows 4.5 software.

RESULTS

In terms of abundance, the phytoplankton in Jeziorak Mały Lake at all littoral zone sites (*S* – separator pipes, *K* – stones and *R* – macrophytes) was dominated by cyanobacteria, ranging from 75% (K) to 76% (S). Analogously to the results concerning abundance, cyanobacteria had the highest share in the total phytoplankton biomass, varying from 48% to 60%. The highest mean cyanobacterial abundance (27,378 ind. cm^{-3}) was noted at the sites with macrophytes, while the lowest one (23,642 ind. cm^{-3}) was determi-

ned at the sites with stones. The highest biomass was recorded at the separator pipes (0.0427 mg cm^{-3}) and the lowest one was at the sites with stones (0.0292 mg cm^{-3}). The following physicochemical water parameters were recorded:

1) the sites at the separators had the lowest pH and mean water temperature of 16.8°C, and the highest water electrolytic conductivity (577 µS cm^{-1}), total nitrogen (3.7 mg N dm^{-3}) and chlorides (47 mg Cl$^-$ dm^{-3});

2) the sites with stones had the highest mean orthophosphates at 0.52 mg PO$_4^{3-}$ dm^{-3} and iron at 4.36 mg Fe^{3+} dm^{-3};

3) the sites with macrophytes were determined to have the highest pH and water temperature of 19.0°C, with the lowest PO$_4^{3-}$, NT and Cl$^-$ and also the lowest oxygen at 7.13 mg O$_2$ dm^{-3} (Table 1).

Table 1

Abundance and biomass and physicochemical water parameters (mean± standard deviation) in the littoral zone of Lake Jeziorak Mały (means for 1996-2003, 2005 and 2013)

Parameters	Separators	Stones	Macrophytes
Abundance of cyanobacteria (ind. cm^{-3})	26277±50499	23642±67051	27378±59135
Proportion of cyanobacteria in the total phytoplankton abundance (%)	76	75	76
Biomass of cyanobacteria (mg cm^{-3})	0.0427±0.0747	0.0292±0.0578	0.0331±0.0496
Proportion of cyanobacteria in the total phytoplankton biomass (%)	60	48	51
Water temperature (°C)	16.4±3.8	18.8±5.0	19.0±4.8
Oxygen content (mg O$_2$ dm^{-3})	8.07±2.56	7.95±4.12	7.13±3.55
pH	8.80±1.03	8.84±0.90	8.94±0.83
Conductivity (µS cm^{-1})	577±277	466±183	415±197
Orthophosphates (mg PO$_4^{3-}$ dm^{-3})	0.40±0.38	0.52±0.50	0.22±0.20
Total nitrogen (mg N dm^{-3})	3.7±2.5	2.8±1.1	2.4±2.1
Iron (mg Fe^{3+} dm^{-3})	3.31±2.12	4.36±1.40	3.45±2.12
Chlorides (mg Cl$^-$ dm^{-3})	47±23	36±16	29±15

Some correlations between the cyanobacterial abundance and biomass versus the physical and chemical water parameters were statistically significant at N = 120, $p < 0.05$:

1) at the separators, there were positive correlations between cyanobacterial abundance and water temperature ($r = 0.59$), and between their biomass and water temperature, conductivity, Fe and NT ($r = 0.57$, $r = 0.42$, $r = 0.36$ and $r = 0.36$, respectively);

2) at the sites with stones, negative correlations were recorded between cyanobacterial biomass and conductivity ($r = -0.34$) and Fe ($r = -0.36$);

3) at the sites with macrophytes, there were positive correlations between cynaobacterial abundance and water temperature ($r = 0.32$), and also between their biomass and water temperature, Fe and TN ($r = 0.35$, $r = 0.39$ and $r = 0.25$, respectively).

The RDA analyses also showed significant relationships between cyano-bacterial abundance and biomass and 8 physicochemical water parameters at the sites in the littoral zone (Figure 2). In the sites with separators (S), cyanobacteria correlated with PO_4^{3-} and conductivity in spring, water temperature and NT in summer, and Fe^{3+} in autumn. Correlations were found between these prokaryotic organisms and PO_4^{3-} and conductivity in spring, water temperature and Fe^{3+} in summer and Cl^- in autumn at the sites with stones (K).

$\times$ - spring, ♠ - summer, ♦ - autumn, cond. – electrolytic conductivity, NT – total nitrogen
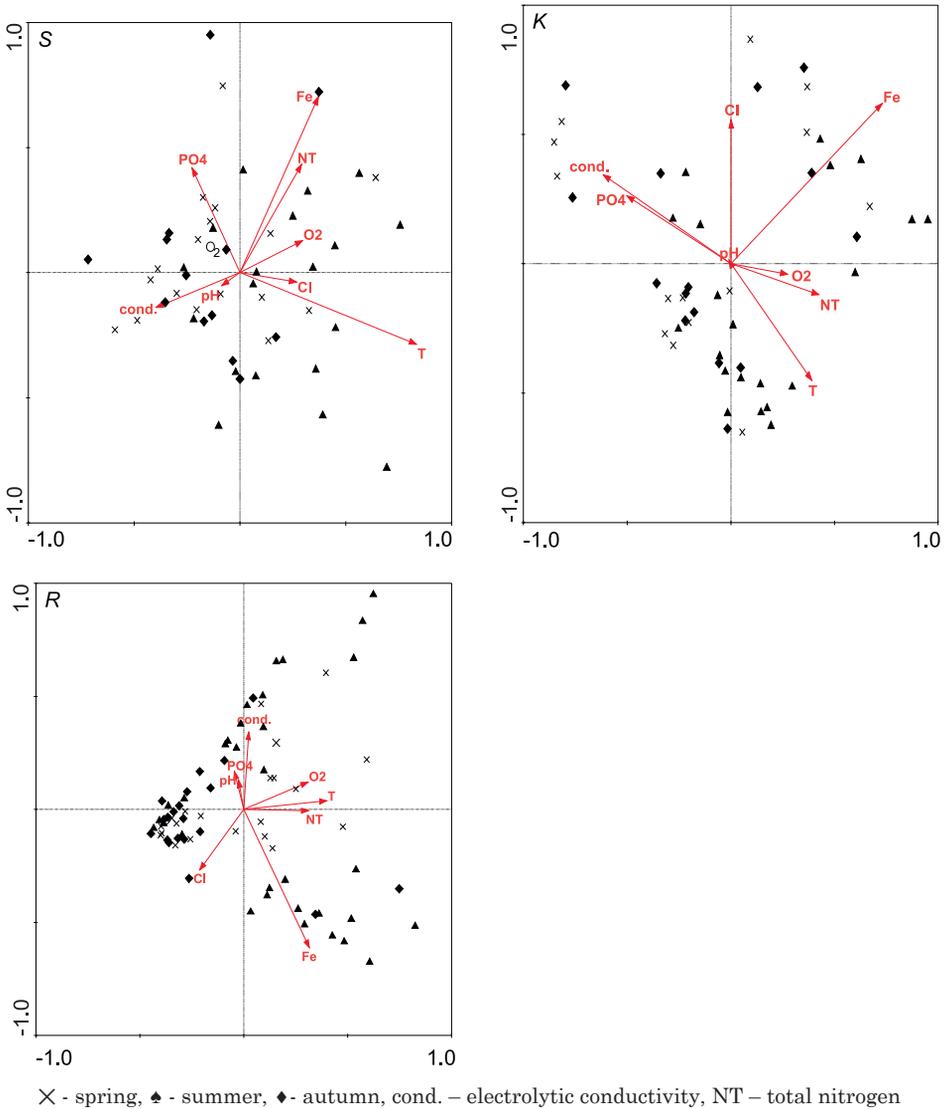
Fig. 2. Biplot of the canonical correspondence analysis (RDA) showing the relationships between abundance and biomass of cyanobacteria and the physicochemical water parameters in Jeziorak Mały Lake: S – separators, K – sites with stones, R – macrophytes

At the sites with macrophytes (R), cyanobacteria correlated with Fe^{3+} in summer and Cl^- in spring and autumn.

The highest contribution of cyanobacteria to the total phytoplankton abundance in 1996 ranged from 95% (S) to 97% (K). Afterwards, a significant decrease in their abundance was noted in 1997-1998, which was followed by an increase 1999-2003 and finally another decline in 2005 and 2013. The lowest cyanobacterial share (34%) was recorded in 2000 at the separators, while the 1997 statistics demonstrated a 37% share at the sites with stones and 41% at the sites with macrophytes. Similarly to the results on abundance, cyanobacterial biomass rapidly decreased after 1996, but high proportions of these organisms, ranging from 72% (K) to 86% (S), were determined in 2003. The lowest percentage of cyanobacteria in total phytoplankton was 10% in 2000 at the separators, 14% in 1997 at the sites with stones and 9% in 1998 at the sites with macrophytes (Figure 3). The highest abundance and
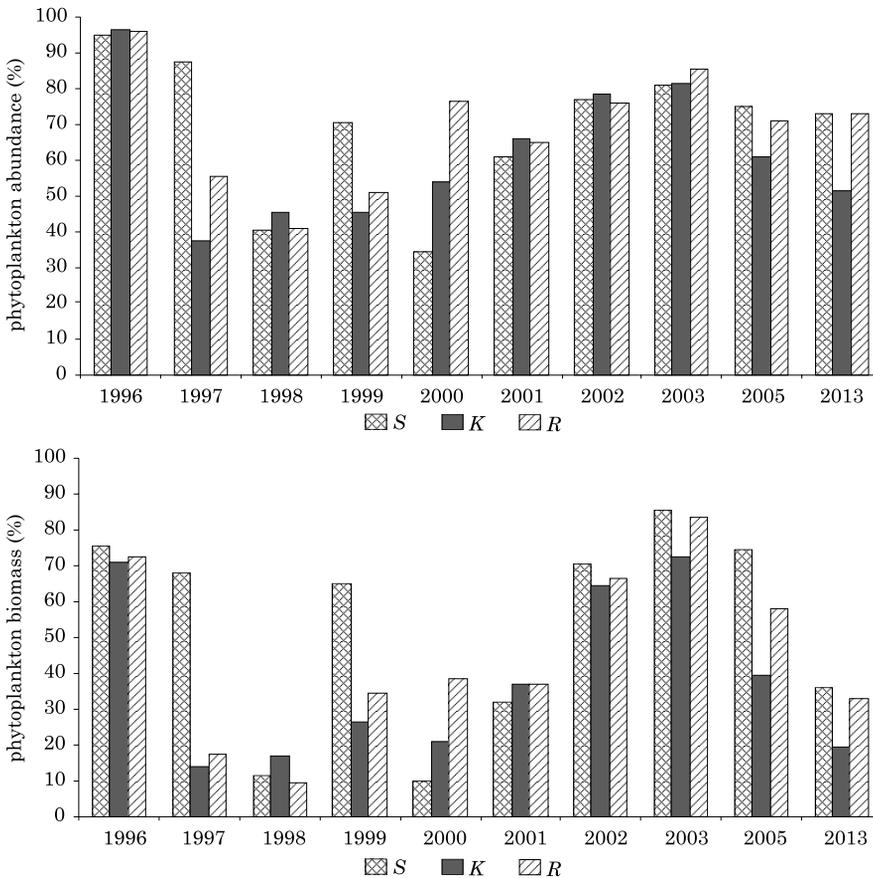

Fig. 3. The proportion of cyanobacteria in the total phytoplankton abundance and biomass in 1996-2003, 2005 and 2013 in the littoral zone of Jeziorak Mały Lake: S – separators, K – sites with stones, R – macrophytes

biomass of cyanobacteria were noted in 1996, and then a rapid decrease at all the sites occurred after 1997. The cyanobacterial abundance at the separators differed from that at the sites with stones and macrophytes: the former group of sites experienced a significant increase in the abundance and biomass of cyanobacteria in 1999 and 2003, which was accompanied by an elevated water temperature; meanwhile, at the other two types of sites, the abundance of cyanobacteria increased in 1998, 2001 and 2005, whereas the biomass increased in 2003 together with a PO_4^{3-} rise (K). Generally, a decrease in water conductivity at the separators and orthophosphates at the sites with stones occurred in 1997-2003, and the same water parameters scored higher at the sites with macrophytes in 2005 (Figures 4, 5).

Regarding their abundance, the cyanobacteria determined in Jeziorak Mały Lake in 1996 were dominated by *Limnothrix redekei* at all sites in the littoral zone; their share ranged from 95% at the separators to 96% at the sites with macrophytes. The proportion of this species decreased in the subsequent years, while the contribution of the following species rose: *Planktolyngbya brevicellularis* (the highest proportion of 84% at the separators in 1998), *Aphanizomenon gracile* (45% and 21% at the separators and stones, respectively, in 1999), *Planktothrix agardhii* (21% at the separators in 2013), and *Pseudanabaena limnetica* (20% at the sites with macrophytes in 2003).
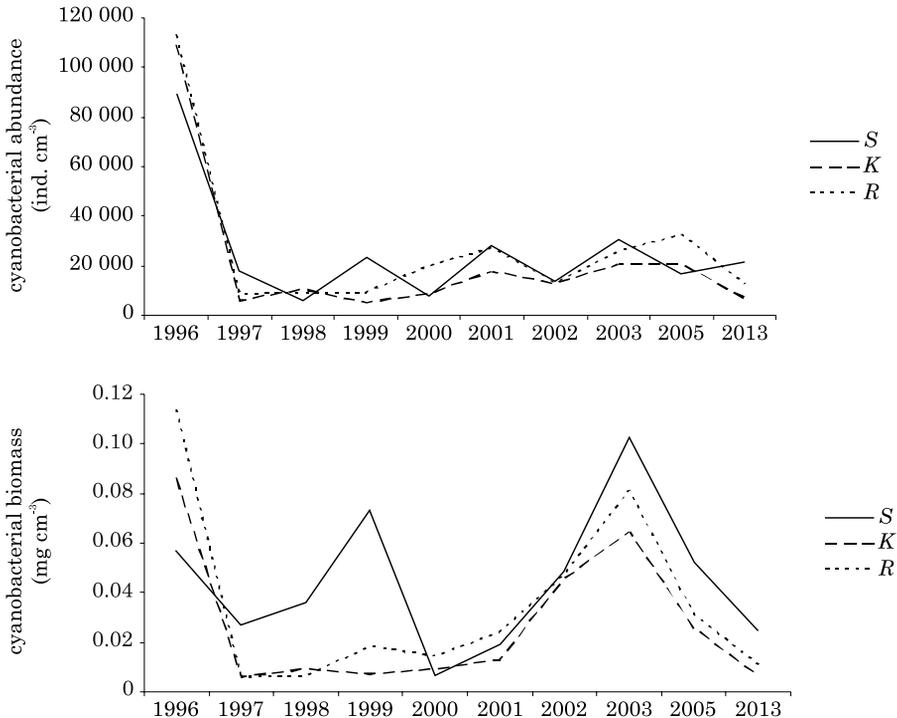

Fig. 4. Dynamics of cyanobacterial abundance and biomass 1996-2003, 2005 and 2013 in the littoral zone of Jeziorak Mały Lake: *S* – separators, *K* – sites with stones, *R* – macrophytes
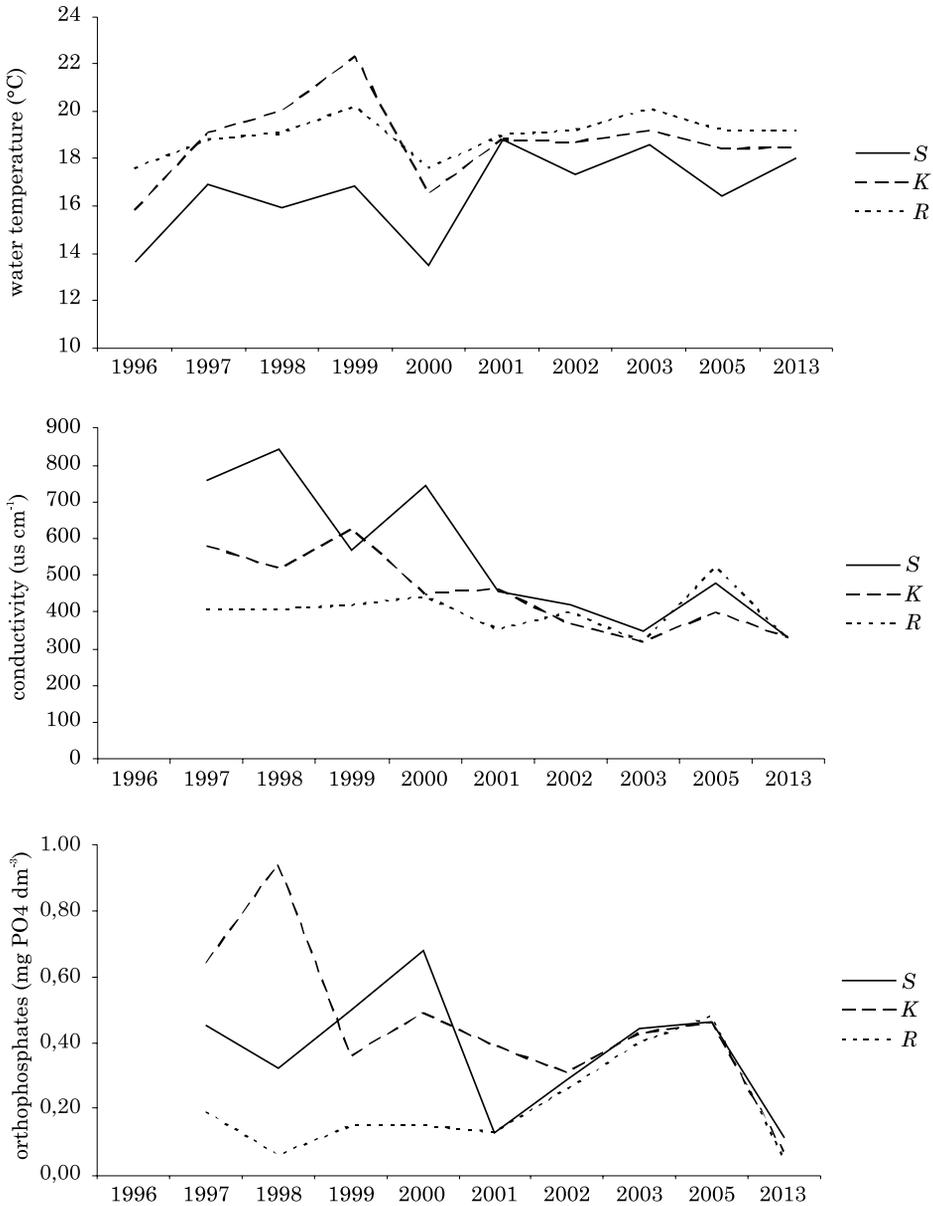
Fig. 5. Changes in water temperature, conductivity and orthophosphates in 1996-2003, 2005 and 2013 in the littoral zone of Jeziorak Mały Lake: *S* – separators, *K* – sites with stones, *R* – macrophytes

DISCUSSION

Jeziorak Mały Lake is a epitome of a shallow, eutrophized urban lake, where phytoplankton is dominated by cyanobacteria (Guzkowska, Gasse 1996, Mischke, Nixdorf 2003). Before implementing lake restoration measures, such as the installation of separators and the creation of stone accumulation sites in the littoral zone, phytoplankton and water quality determinations had indicated that the lake was polytrophic. Between 1960 and 1990, lake water in the pelagial was low in oxygen and the oxygen deficit near the lake bed often caused fish death (Jankowski 1966). Cyanobacterial blooms of *Anabaena*, *Aphanizomenon* and *Microcystis* genera occurred in the summer season of 1968 (Niewolak 1974), while a mass growth of *Planktothrix agardhii* (Gom.) Anagn. et Kom. was recorded in 1978 (Spodniewska 1986). At that time, the share of cyanobacteria in the total phytoplankton abundance was above 90%, being similar to that recorded in 1996 directly before resuming restoration measures (Zębek 2009). In contrast, their proportion was above 70% in the littoral zone in 1997-2003, 2005 and in 2013. Changes in water quality in urban lakes are often rapid and extreme because of inflows which vary in quantity, chemistry and seasonality. Elevated chemical parameter values have been recorded in such lakes, including conductivity, nutrients and chlorides, but also Pb, Cu, Zn, Cd heavy metals (Guzkowska, Gasse 1990, Sapek 2014, Szpakowska et al. 2014, Vincent, Kirkwood 2014, Zębek, Szwejkowska 2014). Similar dynamics of changes in cyanobacteria occurred in the pelagial zone, where the maximum share of these organisms was 98% in 1996 and 64% in 2005. This was also attributed to additional water mixing during the fountain activity (Zębek 2014).

In Jeziorak Mały Lake, differences in environmental conditions important for cyanobacterial growth were recorded at the sites with separator pipes, stones and macrophytes. In this study, the separators supported more varied environmental conditions than present at the other sites. Stormwater inflow through the separators decreased water temperature and pH, while increasing oxygenation, conductivity, NT and chlorides. Meanwhile, the highest PO_4^{3-} and Fe^{3+} were recorded at the sites with stones, and the highest water temperature and the lowest oxygen, NT and Cl^- occurred at sites with macrophytes, where there was muddy bottom and intensive organic matter decomposition. While the highest mean cyanobacterial abundance was found at the sites with macrophytes and the highest biomass was at the separators, their lowest abundance and biomass appeared at the sites with stones. The main reason was the variation of environmental conditions at the sites. The findings also suggests extremely strong influence of polluted stormwater flowing from the catchment, thus influencing cyanobacterial development, especially at the separators and the sites with stones. However, water temperature seems to be the most important factor determining cyanobacteria development in fertile lakes such as Jeziorak Mały (Zębek 2005), and their growth

depends on nutrient concentrations and specific iron, nitrogen and phosphorus concentrations (BURCHARDT et al. 2007). Apart from a suitable water temperature, cyanobacterial growth was stimulated by iron and total nitrogen concentrations at both the separators and macrophytes. The RDA analysis indicate differences in environmental requirements of cyanobacteria at the studied sites. The important factors regulating the growth of cyanobacteria are PO_4^{3-} and conductivity in spring as well as water temperature in summer at the separators and at the sites with stones. Moreover, NT stimulated their development at the separators and Fe^{3+} at the remaining sites in summer. In addition, chlorides limited the growth of cyanobacteria in spring at the sites with stones. This confirms the influence of stormwater effluents and stone accumulation on the cyanobacterial growth in the individual seasons.

The protection and restoration technologies implemented in Jeziorak Mały Lake, especially the separators and stone accumulation sites, contributed to long-term changes in cyanobacterial structure, abundance and biomass. The highest proportion (95%), abundance and biomass of cyanobacteria were recorded in 1996, before the aforementioned solutions were implemented. Many authors have reported dramatic changes in phytoplankton and water quality directly after lake restoration (HUISMAN et al. 2004, WOO-MYUNG, BOMCHUL 2004, OBERHOLSTER et al. 2007, JEPPESEN et al. 2007). Similarly to their results, a rapid decrease in cyanobacterial shares, abundance and biomass was verified in Lake Jeziorak Mały in 1997, immediately after the separators and other restoration measures had become operational. Increased cyanobacterial shares and abundance were noted in 1999-2003, before the final decrease in these parameters that took place in 2005 and 2013. Importantly, the above modifications in the phytoplankton growth were more dynamic and progressed more rapidly at the separators than at the other sites. Here, storm effluents from the catchment contributed to dramatic disturbance of lake water conditions, such as higher water fertility and changes similar to ones reported in other urban lakes (GUZKOWSKA, GASSE 1990, LOSSOW et al. 2004). The overall changes were related to variations in environmental conditions, especially water temperature, conductivity and PO_4^{3-}. In this study, there was a general decrease in conductivity and orthophosphates, while the high cynaobacteria biomass noted in 2003 was most likely due to the increased conductivity and orthophosphates in 2003 and 2005. After the introduction of restoration measures, the dominant species in cyanobacteria assemblages changed from *Limnothrix redekei*, typical of polytrophic waters with very high nutrient concentrations (WERNICKE, NICKLISH 1986, JÖBGEN et al. 2004), to *Planktolyngbya brevicellularis*, typically found in eutrophic waters (CRONBERG, KOMAREK 1994, ZĘBEK 2006). A high proportion of the total cyanobacterial abundance was also recorded for typical eutrophic species such as *Aphanizomenon gracile*, *Planktothrix agardhii* and *Pseudanabaena limnetica*. This suggests strong response of cyanobacteria to changes in environmental conditions caused by restoration and protection solutions implemented in the littoral zone of Lake Jeziorak Mały.

CONCLUSION

The introduction of restoration measures in the littoral zone of Lake Jeziorak Mały, and especially separator and stone accumulation effects, caused long-term changes in the cyanobacterial structure and dynamics. These changes were more dynamic and progressed more rapidly at the separators than at the other sites. This was related to the dramatic water disturbance caused by storm effluents from the catchment. The 1997-1998 period, following directly the installation of the lake restoration meausres, was very important for this lake because of the significant decrease in cyanobacterial proportion in abundance with a simultaneous decrease in conductivity and PO_4^{3-}. This indicates an extensive and rapid response of cynaobacteria to environmental changes in this system. This study highlights the stabilization of species in 2013, when cyanobacteria reached their previous, average levels, and it also shows that the introduction of protection and restoration solutions resulted in positive effects and contributed to the improved lake water quality. The fact that these restoration measures established in Lake Jeziorak Mały will certainly continue in the future underlines the great importance of appropriate lake restoration technologies applied to achieve efficient shallow urban lake management.

REFERENCES

BERNHARDT H. 1987. *Strategies of Lake Sanitation*. Shweiz. Z. Hydrol., 49(2): 202-219.

BERMAN-FRANK I., QUIGG A., FINKEL Z.V., IRWIN A.J., HARAMATY L. 2007. *Nitrogen-fixation strategies and Fe requirements in cyanobacteria*. Limnol Oceanogr., 52(5): 2260-2269. DOI: 10.4319/lo.2007.52.5.2260

BURCHARDT L., MARSHALL H.G., KOKOCIŃSKI M., OWSIANNY P.M. 2007. *Blooms of Aphanizomenon flos-aquae associated with historical changes occurring in Lake Świętokrzyskie, Poland*. Oceanol Hydrobiol. St., 36(1): 261-266.

CRONBERG G., KOMAREK J. 1994. *Planktic Cyanoprokaryotes found in South Swedish lakes during the XIIth International Symposium on Cyanophyte Research*, *1992*. Algolog. Stud., 75: 323-352.

EL-SAYED A.B., EL FOULY M.M., GHAZY S.M., EL SEMARY N.A., HASSOUB M.A. 2010. *Some growth metabolites of two cyanobacteria species as affected by mineral nutrition*. Nat. Sci., 8(12): 20-28.

GUZKOWSKA M.A.J., GASSE F. 1990. *Diatoms as indicators of water quality in some English Urban lake*. Freshwater Biol., 23: 233-250.

HUISMAN J., HHARPLES J., STROOM A.M., VISSER P.M., KARDINAAL W.E.A., VERSPAGEN, J.M.H., SOMMEIJER B. 2004. *Changes in turbulent mixing shift competition for light between phytoplankton species*. Ecology, 85(11): 2960-2970. DOI: 10.1890/03-0763

JANKOWSKI A. 1966. *Studies on thermal-oxygen conditions in the Lake Jeziorak*. Zesz. Nauk. Uniw. Mikołaja Kopernika w Toruniu, 16(2): 17-31.

JEPPESEN E., SONDERGAARD M., MEERHOFF M., LAURIDESEN T.L., JENSEN J.P. 2007. *Shallow lake restoration by nutrient loading reduction – some recent findings and challenege ahead*. Hydrobiologia, 584: 239-252. DOI: 10.1007/s10750-007-0596-7

JÖBGEN A.M., PALM A., MELKONIAN M. 2004. *Phosphorus removal from eutrophic lakes using periphyton on submerged artificial substrata*. Hydrobiologia, 528: 123-142.

KLAPPER H. 2003. *Techologies for lake restoration.* J. Limnol., 62(1): 73-90.

LOSSOW K. 1998. *Protection and restoration of lakes – theory and practice.* Idee Ekologiczne, 13(7): 55-71.

LOSSOW K., GAWROŃSKA H., ŁOPATA M., JAWORSKA B. 2004. *Selection criteria for restoration method on Lake Suskie.* Limnol. Rev., 4: 143–152.

MCDONALD K.E., LEHMAN J.T. 2013. *Dynamics of Aphanizomenon and Microcystis (cyanobacteria) during experimental manipulation of an urban impoundment.* Lake Reserv. Manage., 29(2): 103-115. DOI: 10.1080/10402381.2013.800172

MISCHKE U., NIXDORF B. 2003. *Equilibrium phase conditions in shallow German lakes: How Cyanoprokaryota species establish a steady state phase in late summer.* Hydrobiologia, 502: 123-132. DOI: 10.1007/978-94-017-2666-5_11

NAPIÓRKOWSKA-KRZEBIETKE A., PASZTALENIEC A., HUTOROWICZ A. 2012. *Phytoplankton metrics response to the increasing phosphorus and nitrogen gradient in shallow lakes.* J. Elem., 17(2): 289-303. DOI: 10.5601/jelem.2012.17.2.11

NIEWOLAK S. (1974). *Production of bacterial biomass on the water of the Iława Lakes.* Acta Hydrobiol., 16(1): 101-112.

OBERHOLSTER P.J., BOTHA A-M., CLOETE M.E. 2007. *Ecological implications of artificial mixing and bottom-sediment removal for a shallow urban lake, Lake Sheldon, Colorado.* Lakes Reser. Res. Manage., 12(2): 73-86. DOI: 10.1111/j.1440-1770.2007.00326.x

PEŁECHATY M., BURCHARDT L. 1998. *The problems of bioindication in the ecotone zone of lakes.* In: *Freshwater ecotones. Structure – genera – functioning.* RADWAN S. (ed.), UMCS, Lublin, pp. 99-106. (in Polish)

PUH EKOL 1995. *Separators of oils and petrols* (records).

REYNOLDS C.S. 1978. *IX. Ecology of aquatic organisms. 2. Algae and other plants. stratification in natural populations of bloom-forming blue-green algae.* Verh. Internat. Verein. Limnol., 20: 2285-2292.

ROTT E. 1981. *Some results from phytoplankton counting intercalibrations.* Shweiz. Z. Hydrol., 43: 34-62.

SAPEK B. 2014. *Calcium and magnesium in atmospheric precipitation, groundwater and the soil solution in long-term meadow experiments.* J. Elem., 19(1): 191-208. DOI: 10.5601/jelem.2014.19.1.597

SPODNIEWSKA I. 1986. *Planktonic blue-green algae of lakes in north-eastern Poland.* Ekol. Pol., 34(2): 151-183.

SZPAKOWSKA B., ŚWIERK D., GOŁDYN R., BARAŁKIEWICZ D. 2014. *Contents of Cu, Zn, Cd, Pb and Fe in rainwater effluents discharged to surface waters in the city of Poznań.* J. Elem., 19(3): 779-794. DOI: 10.5601/jelem.2014.19.2.522

VINCENT J., KIRKWOOD A.E. 2014. *Variability of water quality, metals and phytoplankton community structure in urban stormwater ponds along a vegetation gradient.* Urban Ecosystems. DOI: 10.1007/s11252-014-0356-1

WERNICKE P., NICKLISCH A. 1986. *Light/dark cycle and temperature – their impact on phosphate – limited growth of Oscillatoria redekei van Goor in semicontinuous culture.* Int. Rev. Gesamten. Hydrobiol., 71(3): 297-313.

WICHELEN J., DECLERCK S., MUYLAERT K., HOSTE I., GREENENS V., VANDEKERKHOVE J., MICHELS E., PAUWN N., HOFFMANN M., MEESTER L., VYVERMAN W. 2007. *The importance of drawdown and sediment removal for the restoration of the eutrophied shallow Lake Kraenepoel (Belgium).* Hydrobiologia, 584: 291-303. DOI: 10.1007/s10750-007-0611-z

WOO-MYUNG H., BOMCHUL K. 2004. *The effect of artificial destratification on phytoplankton in a reservoir.* Hydrobiologia, 524: 229-239.DOI: 10.1023/B:HYDR.0000036142.74589.a4

ZĘBEK E. 2005. *Qualitative and quantitative changes of blue-green algae in response to physicochemical water parameters in the urban lake Jeziorak Mały.* Oceanol Hydrobiol Stud., 34(1): 39-56.

ZĘBEK E. 2006. *Quantitative changes of Planktolyngbya brevicellularis, Limnothrix redekei and Aphanizomenon gracile in the annual cycle vs. physicochemical water parameters in the urban Lake Jeziorak Mały*. Oceanol. Hydrobiol. St., 35(1): 69-84.

ZĘBEK E. 2009. *Seasonal changes in net phytoplankton in two lakes with different morphometry and trophic status (northeast Poland)*. Arch. Pol. Fis., 17: 267-278; DOI: 10.2478/v10086-009-0019-7

ZĘBEK E. 2014, *Response of cyanobacteria to the fountain-based water aeration system in Jeziorak Mały urban lake*. Limnol. Rev., 14(1): 49-58. DOI: 10.2478/limre-2014-0006

ZĘBEK E., SZWEJKOWSKA M. 2014. *Influence evaluation pretreated storm water on analysis of cyanobacteria numbers in Jeziorak Maly urban lake at various precipitation rates*. Ochr. Środ., 36(1): 27-31. (in Polish)