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EFFECT OF THE FOUNTAIN-BASED WATER AERATION SYSTEM ON PHYTOPLANKTON GROWTH IN A URBAN LAKE

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Abstract. This phytoplankton study was conducted from May to September 2002, 2003 and 2005 during fountain-based water aeration in the pelagial of Jeziorak Mały urban lake in Poland. Differences in the abundance and biomass of phytoplankton groups (cyanobacteria, diatoms, chlorophytes, dinoflagellates, chrysophytes and cryptomonads) related to physico-chemical water parameters were analyzed at the fountain and in the lake centre. Fountain water-mixing changed phytoplankton growth likely by decreasing water temperature, oxygenation and nutrient concentrations. These induced a disturbance in the cyanobacteria and stimulated growth of phytoplankton groups in the water column. High phytoplankton abundance at 1 m depth at the fountain could relate with phytoplankton sinking in the water column. This additional water mixing also intensified sedimented organic matter decomposition, thus enhancing nutrient uptake by phytoplankton. These results are important for future shallow urban lake management.

Key words: lake, restoration, fountain, phytoplankton, nutrients

INTRODUCTION

Water eutrophication generates many problems in lake water quality [Bernhardt 1987, Reynolds 2003]. This is especially important in shallow urban lakes which are susceptible to a degradation, therefore restorative measures to minimize these negative effects have been implemented in many lakes [Bernhardt 1987, Schrenk-Bergt *et al.* 2004, Kleeberg *et al.* 2013]. Artificial aeration and increased mixing of bottom water-layers have been applied worldwide since 1953 [Steinberg 1983, Barbiero *et al.* 1996, Visser *et al.* 1996], and this system has also been functioning in Polish lakes [Rybak 1985, Lossow *et al.* 1998, Chudyba 1992, Lossow *et al.* 2004, Bańkowska 2007]. The response of cyanobacteria and other phytoplankton groups to this artificial aeration and restratification was quite variable. For example, some authors have reported the increase in total algal abundance and biomass [Woo-Myung and Bochmul 2004, Gafsi *et al.* 2009, Toffolon and Serafini 2013].

Lake Jeziorak Mały is a eutrophic lake with cyanobacteria dominating the phytoplankton. Protective-restoration measures, including fountain-based water aeration, were applied to protect and improve its water quality there. It is hypothesized that fountain-based water aeration by water-mixing would change environmental conditions and would affect phytoplankton growth. The aim of this paper was to determine the effect of mixing on the abundance, biomass and taxonomical structure of phytoplankton during fountain'activity in Lake Jeziorak Mały.

MATERIALS AND METHODS

Jeziorak Mały is a shallow eutrophic (mean depth 3.4 m) urban lake covering 26 ha in the Masurian Lakeland (North-Eastern Poland, Fig. 1). For many decades this lake was receiving municipal sewage from the town of Iława. Based on the studies

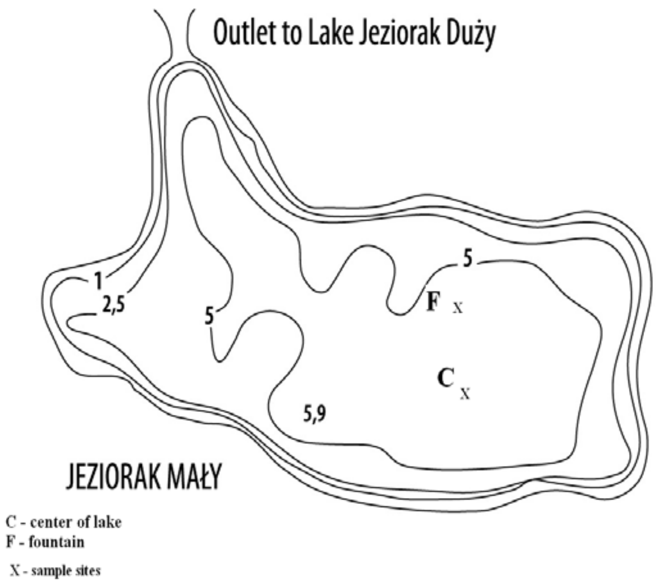

Fig. 1. Morphometric map of Lake Jeziorak Mały

on phytoplankton conducted in 1978 this lake was designated polytrophic [Spodniewska 1986]. Innovations to improve the lake's water quality began in 1997, and are still ongoing. The most important of these were the installation of separators for storm water pre-treatment and a fountain-based water aeration system. This fountain installation (which was established by Iława city water management authorities) now has two purposes: to improve the water quality and to increase aesthetic and scenic tourism value of Lake Jeziorak Mały. The fountain covered both the shore-line and the deeper part of the lake, and subsequent aeration transformed de-oxidized waters from the bottom layer of the 5 m deep lake-bed to oxygenated water by shooting it 16 m above the surface and then spraying it over a 30 m lake cascade area. The fountain is driven by a deep pump with 11 KWh power and maximum flow rate of 80 m^3 h^{-1}, with a water output volume of 0.14 m^3 [GRUNDFOS 1997]. The water should be artificially aerated by 11136 hours (about 464 days) to pass the whole volume of lake.

Phytoplankton samples were collected once a month from May to September in 2002–2003 and 2005 in two sites in the pelagial (C – center of the lake and F – the fountain) with a 5-liter plankton sampler (Toń) which provided samples every 1 m at the distance from the surface to the depth of 4 m. The samples were sieved through a 25 μm mesh plankton net, and then preserved with Lugol's solution and a 4% formaldehyde solution. Basic physical and chemical water parameters were measured directly at sampling sites. Water temperature and oxygen content were measured in the water column, using HANNA Instruments HI 9143 oxygen meter. Dissolved ions of Fe, PO_4, Ca, Si as well as N_{tot} were analyzed in the laboratory using Spectroquant Merck tests with NOVA 400 spectrophotometer.

The following groups of phytoplankton were analyzed in this study: cyanobacteria, diatoms, chlorophytes, dinoflagellates, chrysophytes and cryptomonads. Qualitative and quantitative determinations of phytoplankton were done with an Alphaphot YS2 Nikon optical microscope. The samples were sedimentaed in a 1 ml plankton chamber and then the specimens were counted in this chamber, and their numbers were converted into 1 dm^3. Algae biomass was calculated for biovolume by comparing the algae with their geometric shapes [Rott 1981]. The abundance of the algal groups was correlated with physical and chemical water parameters. Because the data were not normally distributed, non-parametric methods were used. These relationships were confirmed by calculating Spearman's rank correlation coefficient by Statistica version 8.

RESULTS

During the study, lower mean water temperature and oxygen content were recorded at the fountain compared to the lake centre (18.9°C and 19.4°C; 5.6 mg O_2 dm^{-3} and 6.3 mg O_2 dm^{-3}, respectively). In addition, lower PO_4, N_{tot}, Ca and Si concentrations were also recorded at the fountain. In the surface layer the concentration of nutrients and dissolved oxygen was higher than in the lake center (Table 1). Higher total phytoplankton abundance and biomass (as well as of all taxonomic groups) were registered at the fountain as compared to the lake centre; with values of 50.597 and 50.405 ind. dm^{-3} and 125.9 and 103.7 mg 10^{-3} dm^{-3}, respectively. Phytoplankton abundance and biomass was dominated by cyanobacteria. Higher their percentage was recorded at the fountain than in the lake centre (Table 2). Cyanobacteria was dominated by *Planktolyngbya brevicellularis* Cronberg & Komárek (87.5% of the total phytoplankton abundance) [Zębek 2014]. In diatoms the most abundant was *Fragilaria delicatissima* (W. Smith) Lange--Bertalot, while the highest biomass was recorded for *Rhizosolenia* cf. *eriensis* O. Zacharias. In addition, the following dominants were noted among the phytoplankton groups: (1) *Chlamydomonas* spp. in chlorophytes; (2) *Peridinium inconspicuum* Lemm. in dinoflagellates, (3) *Dinobryon* spp. in chrysophytes and (4) *Cryptomonas erosa* Ehrenberg in cryptomonads.

Table 1. Physical and chemical water parameters (mean ±standard deviation) in the pelagial of Lake Jeziorak Mały (mean values in 2002, 2003 and 2005)

Parameters	Lake'centre (C)	Fountain (F)
Water temperature (^{o}C)	19.4 ±4.69	18.9 ±5.1
Oxygen content (mg O_2 dm^{-3})	6.32 ±4.91	5.57 ±4.76
Orthophosphates (mg PO_4^{-3} dm^{-3})	0.41 ±0.19	0.37 ±0.15
Total nitrogen (mg N dm^{-3})	3.0 ±3.8	2.8 ±1.6
Iron (mg Fe dm^{-3})	4.76 ±0.80	4.85 ±0.82
Calcium (mg Ca dm^{-3})	99 ±57	93 ±47
Silicon (mg Si dm^{-3})	0.84 ±0.41	0.72 ±0.21

Table 2. The statistically significant correlations between phytoplankton group abundance and physico-chemical water parameters ($p < 0.05$) in the pelagial of Lake Jeziorak Mały

Algal groups Physico-chemical water parameters	Lake's centre (C)			Fountain (F)	
	T	O_2	Fe	T	PO_4
Cyanobacteria			$r = 0.39$	$r = 0.41$	$r = -0.31$
Diatoms		$r = 0.36$			
Dinoflagellates	$r = 0.37$			$r = 0.48$	
Chrysophytes				$r = 0.38$	$r = -0.54$
Cryptomonads				$r = 0.41$	$r = -0.36$

Some correlations between phytoplankton group abundance and physico-chemical water parameters were statistically significant (Table 2). In the lake centre, cyanobacteria was positively correlated with Fe ($r = 0.39$); diatoms with oxygen content ($r = 0.36$); and dinoflagellates with water temperature ($r = 0.37$). Moreover, at the fountain site, cyanobacteria, dinoflagellates, chrysophytes and cryptomonads had positive correlation with water temperature ($r = 0.41, 0.48, 0.38, 0.41$, respecti-

Table 3. Abundance and biomass of phytoplankton groups in the pelagial of Lake Jeziorak Mały (mean values in 2002, 2003 and 2005)

Algal groups	Lake's centre (C)		Fountain (F)	
	ind. dm^{-3} (%)	mg x 10^{-3} dm^{-3} (%)	ind. dm^{-3}(%)	mg x 10^{-3} dm^{-3} (%)
Cyanobacteria	50405 (90.76)	84.4 (81.39)	50597 (85.53)	96.9 (76.96)
Diatoms	3750 (6.75)	5.6 (5.40)	6793 (11.48)	9.5 (7.55)
Chlorophytes	372 (0.67)	0.5 (0.48)	426 (0.72)	0.7 (0.56)
Dinoflagellates	405 (0.73)	10.0 (9.64)	527 (0.89)	13.8 (10.96)
Chrysophytes	291 (0.52)	0.6 (0.58)	329 (0.56)	1.9 (1.50)
Cryptomonads	311 (0.57)	2.5 (2.51)	484 (0.82)	3.1 (2.47)
Total phytoplankton	55535	103.7	59156	125.9

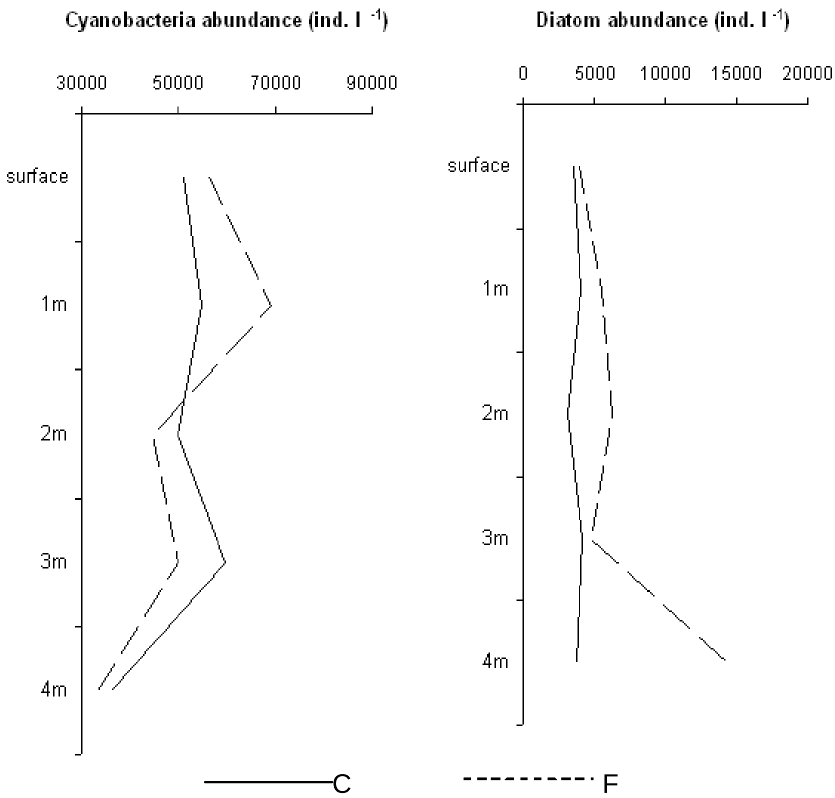

Fig. 2. Cynaobacteria and diatom abundance in the water column in the lake centre (C) and at the fountain (F) of Lake Jeziorak Mały (mean values in 2002, 2003 and 2005)

Table 4. Physical and chemical water parameters in the water column in the pelagial of Lake Jeziorak Mały (mean values in 2002, 2003 and 2005)

Lake's centre (C)							
	T	PO_4	N_{tot}	O_2	Fe	Ca	Si
Surface	22.3	0.31	2.2	9.68	5.01	83	0.57
1 m	22.0	0.56	2.7	9.62	5.00	100	0.60
2 m	20.6	0.43	2.3	6.51	4.90	113	1.01
3 m	16.8	0.39	2.2	3.71	4.37	128	0.87
4 m	15.3	0.48	2.9	2.07	4.00	73	0.93
Fountain (F)							
	T	PO_4	N_{tot}	O_2	Fe	Ca	Si
Surface	21.9	0.37	2.4	10.08	4.45	145	0.75
1 m	21.7	0.48	2.2	8.82	4.60	100	0.60
2 m	19.3	0.34	2.4	5.22	4.88	93	0.58
3 m	16.7	0.34	2.8	2.64	5.13	67	0.69
4 m	14.7	0.32	4.1	1.08	4.94	66	0.86

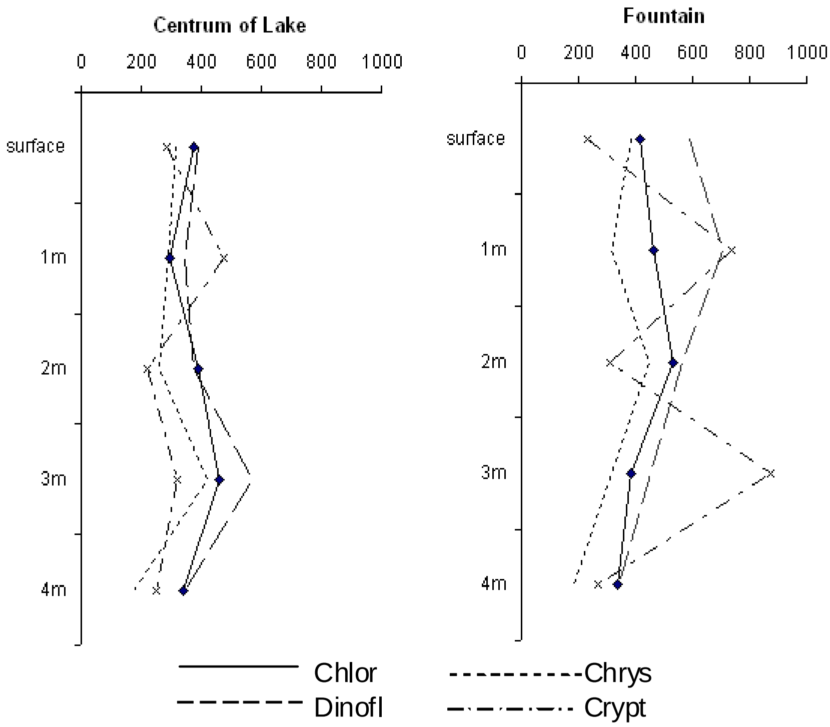

Fig. 3. Phytoplankton group abundance (Chlor – chlorophytes; Dinofl – dinoflagellates; Chrys – chrysophytes and Crypt – cryptomonads) in the water column in the lake centre (C) and at the fountain (F) in Lake Jeziorak Mały (mean values in 2002, 2003 and 2005)

vely). The negative correlations were found between cyanobacteria, dinoflagellates and cryptomonads and PO_4 (r = –0.31, –0.54, –0.36, respectively).

In the studied lake both water temperature and oxygenation decreased with the depth in the water column: (1) water temperature was noted 15.3°C in the lake centre (C) and 14.7°C at the fountain (F); and (2) oxygen content was 2.07 mg O_2 dm^{-3} (C) and 1.08 mg O_2 dm^{-3} (F) at 4 m depth. While higher orthophosphate levels was found at 4 m depth in the lake centre than at the fountain (Table 3).

The highest cyanobacterial abundance was recorded at 1 m depth at the fountain with maxima of 69,269 ind. dm^{-3}, and at 3 m depth in the lake centre with 59,839 ind. dm^{-3}. Although insignificant changes in diatom abundance were found in the water column in the lake centre with its maximum 4207 ind. dm^{-3} at 3 m depth at the highest calcium concentration. While the maximum fountain diatom abundance of 14348 ind. dm^{-3} was registered at 4 m depth (Fig. 2, Table 4). High chlorophyte and chrysophyte abundances were noted at 2 m depth and dinoflagellates at 1 m depth at the fountain (Fig. 3).

DISCUSSION

Lake Jeziorak Mały has similar conditions to those found in other polimictic urban lakes [Mischke and Nixdorf 2003], thus the studied lake has high risk of eutrophication. Changes in physico-chemical water parameters were observed after the fountain began to function: with lower oxygen content, nutrient concentrations and water temperature recorded at the fountain comparing to the lake centre (Table 1). Improved water aeration led to changes in orthophosphate and nitrogen concentrations as reported by Rybak [1985], Bürgi and Stadelmann [2002] and Zębek [2014]. The intensive water mixing during fountain activity and other restorative works changed phytoplankton growth conditions. Water aeration favoured diatom and dinoflagellate growth, and concurrent increase in phytoplankton abundance and biomass confirmed artificial aeration results reported by Rybak [1985] and Bürgi and Stadelmann [2002]. This phenomenon is also related to increased stress-tolerant phytoplankton species [Reynolds 1984]. These stress-strategists included genera from *Fragilaria* spp. and *Cryptomonas* spp. Phytoplankton in this study was dominated by species typical in eutrophic artificially aerated lakes including; *Plaktolyngbya brevicellularis*; *Fragilaria delicatissima,* genus *Chlamydomonas* spp.*, Peridinium inconspicuum*; *Dinobryon* spp. and *Cryptomonas erosa* [Schrenk-Bergt *et al.* 2004, Zębek 2014].

Similar to reports from other eutrophic lakes described by Schrenk-Bergt *et al.* [2004], in this lake cyanobacterial dominance registered 85–90% in the pelagial. The diatom and dinoflagellate share in total phytoplankton abundance and biomass increased after artificial aeration [Zębek 2014], while cyanobacterial decreased which is in agreement of other reports [Huisman *et al.* 2004]. Approximately 5% less cyanobacteria was recorded in the studied lake at the fountain comparing to the lake centre, and higher proportions of all phytoplankton groups, except cryptomonads, were recorded at the fountain (Table 3). This indicates that the restorative work and water aeration promoted environmental conditions which induced changes in phytoplankton structure. In addition, cyanobacteria, dinoflagellate, chrysophyte and cryptomonad growth could be stimulated by water temperature; which was indicated by the positive correlations between these parameters. Moreover, the positive correlation between algal group abundance and nutrients in the lake centre indicated that the iron content in the higher nutrient sources stimulated increased cyanobacterial growth there than at the fountain site [Zębek 2014].

Although cyanobacterial abundance was reduced by the environmental stress (decreased water temperature and strong water mixing), these factors did not stress other taxonomic groups which increased theirs abundance and biomass. In the studied lake, phytoplankton released more oxygen, intensifying their assimilation; as suggested in "Intermediate Disturbance Hypothesis" [Padisak *et al*. 1993]. The fountain activity promoted slightly lower water temperature and higher oxygenation at the fountain comparing to the lake centre (Table 4). The lower oxygen content noted at the fountain's base intensified the organic matter decomposition [Zębek 2014]. Decreased water-column PO_4 was recorded during artificial aeration [Lossow *et al.* 1998]. This is attributed to cyanobacterial and algal phosphorus assimilation during water aeration; and it was indicated by the negative correlation between phytoplankton abundance and nutrients. High cyanobacteria and dinoflagellate abundance recorded at 1 m depth at the fountain, and chlorophytes and chrysophytes at 2 m, suggests phytoplankton sinking caused by fountain-sprayed water on the surface layer (Figs. 2, 3). This agrees with reports from similar lakes [Huisman *et al.* 2004]. This phenomenon in cyanobacteria may also be related to their buoyancy regulated by such factors like water temperature and nutrient availability [Reynolds *et al.* 1987]. In this study, highest PO_4 concentration was recorded at 1 m depth at the fountain site (Table 3). Cryptomonads and chrysophytes may nouirsh in a mixotrophic way, and they may assimilate suspended organic matter at this depth [Tas *et al.* 2010]. High diatom abundance at 4 m depth at the fountain is related to their sinking through the thermocline to the lake bed, and to increased water turbulence altering the sedimentation rate.

CONCLUSION

Fountain operation altered phytoplankton growth conditions in Lake Jeziorak Mały, where; (1) water-mixing increased water aeration; (2) its implementation decreased water temperature and lowered lake-bed nutrient concentration; (3) it's deep-water discharge increased surface nutrients content and stimulated preferential phytoplankton growth over other taxonomic groups; (4) algae sank in the water column and (5) water mixing intensified sedimentated organic matter decomposition, thus enhancing phytoplankton nutrient uptake.

Results of this study indicate that benefits derived from fountain installation may be used in planning lakes and reservoir restoration programs, which may be implemented especially in the case of urban shallow lakes.

REFERENCES

Bańkowska A., 2007. Performance evaluation of the BIO-HYDRO structures in recultivation of the Ełckie Lake. Prz. Nauk. Inż. Kszt. Środ. 38, 21–28. Retrieved from http://iks_pn.sggw.pl/z38/art4.pdf.

Barbiero R.P., Speziale B.J., Arshby S.L., 1996. Phytoplankton community in a lake subjected to artificial circulation. Hydrobiologia 331, 109–120.

Bernhardt H., 1987. Strategies of lake sanitation. Shweiz. Z. Hydrol. 49(2), 202–219.

Bürgi H., Stadelmann P., 2002. Change of phytoplankton composition and biodiversity in Lake Sempach before and during restoration. Hydrobiologia 469, 33–48.

Chudyba H., 1992. Zmiany struktury fitoplanktonu w trakcie sztucznego napowietrzania Jeziora Długiego w Olsztynie. Acta Acad. Agric. Tech. Olst.19, 131–149.

Gafsi M., Kettab A., Benmamar S., Benziada S., 2009. Comparative studies of the different mechanical oxygenation systems used in the restoration of lakes and reservoirs. J. Food Agric. Environ. 7(2), 815–822.

GRUNDFOS, 1997. Fountain activity scheme (records).

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.

Kleeberg A., Herzog C., Hupfer M., 2013. Redox sensitivity of iron in phosphorus binding does not impede lake restoration. Water Res. 47(3), 1491–1502.

Lossow K., Gawrońska H., Jaszczułt R., 1998. Attempts to use wind energy for artificial destratification of Lake Starodworskie. Pol. J. Environ. Stud. 7, 221–227.

Lossow K., Gawrońska H., Łopata M., Jaworska B., 2004. Selection criteria for restoration method on Lake Suskie. Limnol. Rev. 4, 143–152.

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.

Padisak J., Reynolds C.S., Sommer U., 1993. Intermediate disturbance hypothesis in phytoplankton ecology. Developments in Hydrobiology 81. Kluwer Academic, Dordrecht, The Netherlands.

Reynolds C.S., 1984. Phytoplankton periodicity: The interactions of form, function and environmental variability. Freshwat. Biol. 14, 111–142.

Reynolds C.S., Oliver R.L., Walsby A.E., 1987. Cyanobacterial dominance: The role of buoyancy regulation in dynamic lake environments. New Zeal. J. Mar. Fresh. 21(3), 379–390.

Reynolds C.S., 2003. The development of perceptions of aquatic eutrophication and its control. Ecohydrol. Hydrobiol. 3(2), 149–163.

Rott E., 1981. Some results from phytoplankton counting intercalibrations. Shweiz. Z. Hydrol. 43, 34–62.

Rybak M., 1985. Some ecological effects of artificial circulation on the phytoplankton. Hydrobiologia 122(1), 89–96.

Schrenk-Bergt C., Krause D., Prawitt O., Lewandowski J., Steinberg C.E.W., 2004. Eutrophication problems and their potential solutions in the artificial shallow Lake Altmühlsee (Germany). SQ 21, 73–86.

Spodniewska I., 1986. Planktonic blue-green algae of lakes in North-Eastern Poland. Ekol. Pol. 34(2), 151–183.

Steinberg C., 1983. Effects of artificial destratification on the phytoplankton populations in a small lake. J. Plankton Res. 5, 855–864.

Taş B., Gönülol A., Taş E., 2010. Seasonal dynamics and biomass of mixotrophic flagellate Dinobryon Sertularia Ehrenberg (Chrysophyceae) in Derbent Reservoir (Samsun, Turkey). Turk. J. Fish. Aquat. Sci. 10, 305–313.

Toffolon M., Serafini M., 2013. Effects of artificial hypolimnetic oxygenation in a shallow lake. Part 2: Numerical modeling, J. Environ. Manage. 114, 530–539.

Visser P.M., Ibelings B.W., Veer B., Koedod J., Mur L.R., 1996. Artificial mixing prevents nuisance blooms of the cyanobacterium *Microcystis* in Lake Nieuwe, the Netherlands. Freshwat. Biol. 36, 435–450.

Woo-Myung H., Bomchul K., 2004. The effect of artificial destratification on phytoplankton in a reservoir. Hydrobiologia 524, 229–239.

Zębek E., 2014. Response of cyanobacteria to the fountain- based water aeration system in Jeziorak Mały urban lake. Limnol. Rev. 14(1), 49–58.

REAKCJA FITOPLANKTONU NA NAPOWIETRZANIE WÓD METODĄ FONTANNY W ŚRÓDMIEJSKIM JEZIORZE JEZIORAK MAŁY

Streszczenie. Badania fitoplanktonu prowadzono od maja do września w latach 2002, 2003 i 2005 podczas napowietrzania wód metodą fontanny w pelagialu jeziora Jeziorak Mały (Polska). W pracy analizowano zróżnicowanie liczebności i biomasy grup fitoplanktonu (sinice, okrzemki, zielenice, bruzdnice, złotowiciowce i kryptofity) w zależności od zmian fizyczno-chemicznych parametrów wody na stanowiskach przy fontannie i w centrum jeziora. Mieszanie wód na skutek działania fontanny zmieniło warunki rozwoju fitoplanktonu poprzez spadek temperatury wody, natlenienia i koncentracji nutrientów. Zjawisko to spowodowało zaburzenia w sezonowej dynamice sinic i w słupie wody, a stymulowało rozwój pozostałych grup fitoplanktonu. Działanie fontanny przyczyniło się także do zjawiska sinkingu, o czym świadczą duże liczebności fitoplanktonu na 1 m głębokości. Dodatkowo mieszanie wód zintensyfikowało także procesy rozkładu materii organicznej, podczas którego fitoplankton uczestniczył w pobieraniu nutrientów z wody. Uzyskane wyniki powinny być uwzględnione w procesie zarządzania płytkimi zbiornikami eutroficznymi o zurbanizowanej zlewni przy planowaniu zabiegów rekultywacyjnych.

Słowa kluczowe: jezioro, rekultywacja, fontanna, fitoplankton, nutrienty