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The effect of pulverising aeration on changes in the oxygen and nitrogen concentrations in water of Lake Starzyc

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Abstract

Due to poor ecological status of Lake Starzyc, lake restoration measures were undertaken in 2003 to improve aerobic conditions of near-bottom waters and to decrease phosphorus concentrations. To do this, a wind-driven pulverising aerator was installed in the lake. The aim of this study was to analyse variability of oxygen and nitrogen concentrations in lake water near the aerator in the third year of its operation and later on in the three-year-long period of the years 2008–2010. It was found that concentrations of ammonium-nitrogen, nitrate-nitrogen and dissolved oxygen near the aerator did not differ from those in sites 4 and 5, which evidenced similar abiotic conditions in analysed waters. Higher concentrations of dissolved oxygen and lower concentrations of nitrate-nitrogen were found in the years 2008–2010 than in 2005.

Key words: *ammonium-nitrogen, lake, nitrate-nitrogen, oxygen, pulverising aerator*

INTRODUCTION

Worsening recently ecological status of lakes forces the need of their restoration. Selection of appropriate method of restoration and the recovery of previous chemical and biological features of eutrophied ecosystem is extremely difficult. Habitat conditions of a water body are affected by the character of its catchment, urbanization and land management [LOSSOW 2000]. Lake restoration may be performed by several methods applied at the same time. Most effective are those, which are associated with the removal of bottom sediments (a store of phosphorus compounds) [WETZEL 2001] or hypolimnetic waters (low concentrations of dissolved oxygen in water and high nutrient concentrations) [KACZOROWSKA, PODSIADŁOWSKI 2012; KOSTECKI 2012]. Negative effects of processes taking place in the hypolimnion of eutrophic lakes may be limited by the aeration of near-bottom waters [PREMAZZI *et al*. 2005]. Improvement of ecological status of lake waters may be achieved based on various technical solutions like phosphorus inactivation. This method consists in the precipitation of inorganic phosphorus compounds by chemical coagulants based on aluminium (PAX 18) or iron (PIX 113) compounds [SOBCZYŃSKI, JONIAK 2010].

One of the technologies used to restore lakes is the method of mechanically- or wind-driven pulverising aeration [KONIECZNY 2004; OSUCH, PODSIADŁOWSKI 2012]. Compressed air systems are used to aerate open waters. In favourable conditions (oxygen deficit, low temperature, great water depth) the bubbles of compressed air deliver 5% of dissolved oxygen to water at maximum [LOSSOW, GAWROŃSKA 2000]. The first lake destratification with wind-driven air compressor was performed in Lake Starodworskie in Olsztyn in the years 1986–1987 and results of this method were considered good [KONIECZNY 2013].

Pulverising aerator uses wind energy to suck near-bottom water and disperse it to enable efficient gas exchange. Water is taken up through hoses due to rotation of a paddle wheel (water is pulverised

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through dispersion) driven by wind engine and so aerated is gravitationally returned to the hypolimnion. The devise is fully autonomic and does not need energy supply [KONIECZNY, PIECZYŃSKI 2006; MATKOWSKI, PODSIADŁOWSKI 2004].

Pulverising aerators have been installed across Poland since 2001. One of them was set up in Lake Starzyc in April 2003. The lake is a shallow, polymictic water body situated in the buffer zone of the Iński Landscape Park. North-west of the lake, near the outlet of lake waters, there is the town of Chociwel (Zachodniopomorskie Province) [WESOŁOWSKI *et al.* 2011a].

Water quality is affected by pollutants deposited in bottom sediments, rainfall waters and inflows, which deliver large amounts of nutrients [WIOŚ 2011]. Lake is fed by waters from reclamation ditches (inflows I and II) and from reclamation canal from Kamienny Most (inflow II). Inflows I and III deliver waters from abandoned agricultural lands, mainly from the former state farm and inflow II – water from Kamienny Most. Water outflow from the lake is realised through the Krąpiel River, which is a tributary of the Ina River. Therefore, Lake Starzyc is a throughflow lake. Chociwel has a new domestic waste water treatment plant since 1990. Previous treatment plant, built by Germans was modernised and developed, which markedly limited waste water input to the lake. More than 60% of the total catchment basin is covered by agricultural lands previously managed by the State Farm Starzyc [WESOŁOWSKI *et al.* 2011a].

The aim of presented studies was to assess the variability of water aeration and nitrogen content in water of Lake Starzyc during its aeration in the years 2005 and 2008–2010.

MATERIAL AND METHODS

Analyses of water quality in Lake Starzyc were made since April till October during six years in the surface (0.5 m below water table) and near-bottom (1 m above the bottom) layers. Two time periods: the years 2005 and 2008–2010 were selected for comparative analyses. Because of no statistically significant differences in the concentration of ammonium-nitrogen among all sampling sites and of nitrate-nitrogen among most sampling sites, discussion was limited to three sites – one near the aerator and two situated 200 m (site 4) and 150 (site 5) apart from the aerator (Fig. 1). Water depth in sampling sites was similar and equal 5.0 m (site 4), 4.7 m (site 5) and 4.5–5.0 m (aerator A).

Because of negative consequences of water pollution, pulverising aerator was situated in the central part of Lake Starzyc (photo 1). The aerator is 8 m high, raft diameter is 10 m and water output is 200–800 $m^3 \cdot day^{-1}$, which theoretically should increase water aeration by several times [MATKOWSKI, PODSIADŁOWSKI 2004].

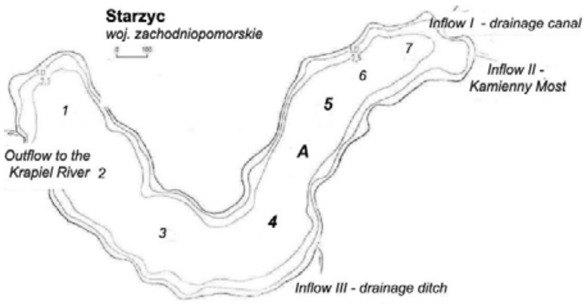

Fig. 1. Location of sampling sites (*1–7*) in Lake Starzyc (Zachodniopomorskie Province), *A* = aerator; source: own elaboration

Photo 1. Wind-driven pulverising aerator (photo *A. Brysiewicz*)

Water samples were taken with immersed pump Gigant made by Gomor-Technik. Oxygen concentration (g $O_2 \cdot m^{-3}$) in water was determined with multi-parameter meter Multi 3400 by WTW equipped with oxygen probe Cellox 323. Electrolytic conductivity was measured ($\mu S \cdot cm^{-1}$) with conductivity meter Tetragon 325. Concentrations of ammonium-nitrogen (g $NH_4^+ \cdot m^{-3}$) and nitrate-nitrogen (g $NO_3^- \cdot m^{-3}$) were determined with multiparameter photometers LF 205 and LF 305 made by SLANDI.

Results of analyses of nitrogen compounds and dissolved oxygen in relation to site (factor I) and time periods (factor II) were statistically processed with the analysis of variance. Tukey HSD test was used at significance level $\alpha = 0.05$. Linear correlation between dissolved oxygen and concentrations of nitrogen compounds for O_2 concentrations >2 $mg \cdot dm^{-3}$ was also estimated.

RESULTS AND DISCUSSION

Eutrophication of waters in Poland proceeds in both lakes and rivers. Still debated is the problem of nutrient distribution in water layers and estimation of their sources [ILNICKI 2014]. One of the methods to intensify nutrient immobilisation in bottom sediments is artificial aeration. A decrease of $P\text{-}PO_4$ and TP concentrations was noted as a result of aeration of near-bottom waters [SIWEK *et al.* 2014]. Positive results were obtained when studying phosphorus inactivation

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in relation to aeration of near-bottom layers of Lake Przesiecko [PODSIADŁOWSKI 2008].

Performed analyses of water quality in Lake Starzyc revealed higher concentrations of inorganic nitrogen in near-bottom than in surface water layer. The reverse relationship was found for dissolved oxygen [WESOŁOWSKI *et al*. 2011a]. After plant and animal die-off, their biomass is oxidised according to mechanism dependent on the availability of electron acceptors (oxygen, nitrates, sulphates) and specific microorganisms. During aerobic organic matter decomposition, nitrogen is primarily released in a form of ammonium ions or ammonia, depending on pH of the surrounding habitat [DOJLIDO 1995; VAN LOON, DUFFY 2007]. WESOŁOWSKI *et al*. [2011a] reported that in the years 2005 and 2008–2010, pH in both water layers varied between 7.29 and 8.41, at which ammonium ions are prevailing. Proceeding ammonification and later nitrification markedly decrease the concentration of dissolved oxygen in near-bottom water. Organic matter decomposition is accompanied by the transformation of sulphur compounds. Oxygen is consumed to oxidise sulphides to sulphates Aeration of near-bottom water layers with pulverising aerator may accelerate mineralisation of organic matter and increase the uptake of nitrates and ammonium ions by aquatic plants [GAŁCZYŃSKA 2012].

Significant differences in the concentration of dissolved oxygen in both analysed water layers were found between the two study periods (Figs 2 and 3). Significantly higher and more diverse concentrations of dissolved oxygen were noted in the years 2008–2010 than in the year 2005. In the site near aerator, the concentration of oxygen did not differ from that recorded in neighbouring sites 4 and 5.

Increasing concentration of dissolved oxygen through aeration of near-bottom waters may lead to oxidation of organic matter in the process of ammonification. If dissolved oxygen concentration exceeds 2 mg·dm^{-3}, nitrate-nitrogen is generated in the process of nitrification. Under anaerobic conditions this form of nitrogen undergoes denitrification and decreases the concentration of nitrate-nitrogen.

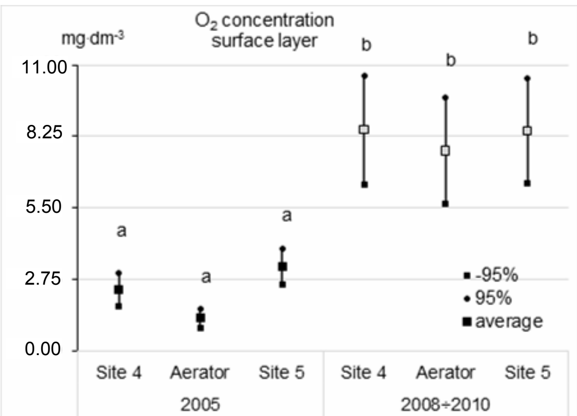

Fig. 2. Concentration of dissolved oxygen in surface water of Lake Starzyc; source: own study

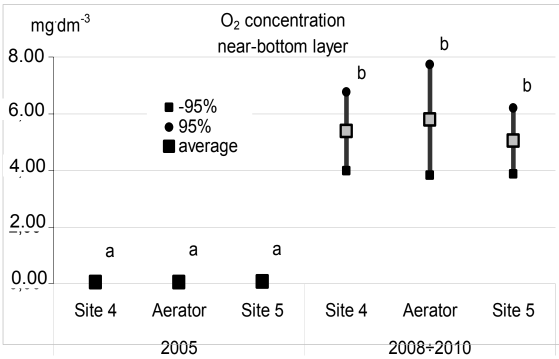

Fig. 3. Concentration of dissolve oxygen in near-bottom water of Lake Starzyc; source: own study

The source of ammonium-nitrogen is in the inflow of waters from catchment basin polluted by inorganic and organic nitrogen compounds and in decomposition of aquatic plants and animals, which is dependent on oxygen concentration in water [ZBIERSKA *et al*. 2002]. Indices of water quality parameters in sampling sites of Lake Starzyc are affected by water input from reclamation ditch No III [WESOŁOWSKI *et al*. 2011a]. However, due to lower concentration of ammonium-nitrogen in water from the ditch (0.24 mg·dm^{-3}) than in site 4 (0.32 mg·dm^{-3}) [WESOŁOWSKI *et al*. 2011a], the effect of this source may be considered insignificant. No significant differences in the concentration of ammonium-nitrogen were found in waters from sites 4, 5 and near aerator in both water layers and study periods (Figs 4 and 5).

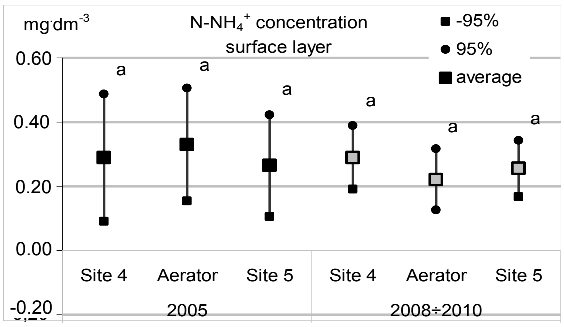

Fig. 4. Concentration of ammonium-nitrogen in surface water of Lake Starzyc; source: own study

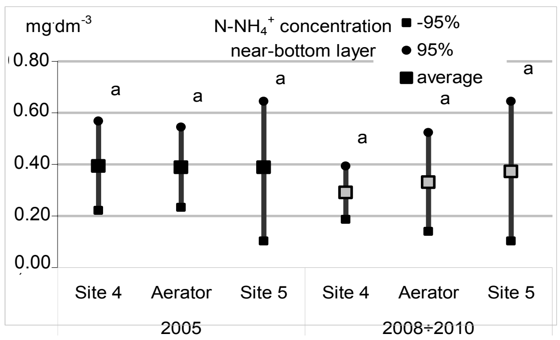

Fig. 5. Concentration of ammonium-nitrogen in near-bottom water of Lake Starzyc; source: own study

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Linear correlation between the concentration of dissolved oxygen and ammonium nitrogen showed that ammonification in surface water proceeded better near the aerator than in sites 4 and 5 (Tab. 1). The relationship was insignificant for near-bottom waters. Final effect of aerator activity since 2005 till 2010 consisted only in the decrease of ammonium-nitrogen variability in surface waters in the years 2008–2010.

Table 1. Linear correlation between the concentration of dissolved oxygen and nitrogen compound in water

Location	Parameter	$N\text{-}NH_4^+$		$N\text{-}NO_3^-$	
		layer			
		surface	near-bottom	surface	near-bottom
Site 4	equation	$y_{O2} = 7.20 - 2.56x$	$y_{O2} = 6.85 - 5.11x$	$y_{O2} = 8.07 - 21.92x$	$y_{O2} = 4.71 + 13.77x$
	r	–0.128	–0.377	–0.421	0.438
	p	0.707	0.404	0.177	0.326
Aerator	equation	$\mathbf{y_{O2} = 10.77 - 13.70x}$	$y_{O2} = 7.48 - 5.15x$	$y_{O2} = 6.99 + 0.10x$	$\mathbf{y_{O2} = 4.53 + 28.54x}$
	r	**–0.871**	–0.506	0.002	**0.957**
	p	**0.005**	0.247	0.997	**0.001**
Site 5	equation	$y_{O2} = 6.42 - 2.20x$	$y_{O2} = 5.08 - 1.12x$	$y_{O2} = 7.02 - 9.84x$	$y_{O2} = 5.18 - 3.54x$
	r	-0.093	–0.218	–0.424	–0.437
	p	0.751	0.604	0.131	0.279

Explanations: r – correlation coefficient, p – probability. Source: own study.

Changes of nitrate-nitrogen concentrations in water depend on the rate of microbially-mediated transformation of nitrogen compounds, their assimilation and on their load from the catchment and atmospheric precipitation [DURKOWSKI *et al.* 2009; GAŁCZYŃSKA *et al.* 2011; ZBIERSKA *et al.* 2002]. Higher concentration of nitrate-nitrogen in water of the reclamation ditch (0.62 mg·dm^{-3}) than in water of site 4 (0.12 mg·dm^{-3}) [WESOŁOWSKI *et al.* 2011a] may affect nitrate balance in this sampling site. Analyses of nitrate concentrations in sites 4 and 5 and in surface water near the aerator indicates that a significant decrease of nitrate-nitrogen concentrations in the years 2008–2010 compared with 2005 was only true for site 5 (Fig. 6).

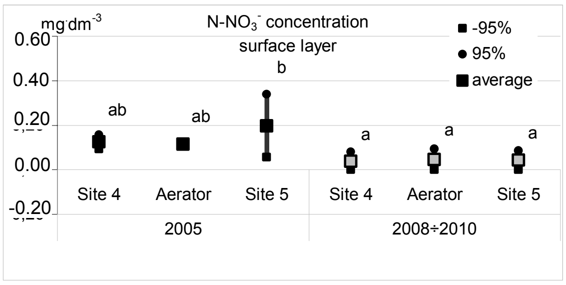

Fig. 6. Concentration of nitrate-nitrogen in surface water of Lake Starzyc; source: own study

There were no differences in the concentration of nitrate-nitrogen in near-bottom water between the two compared study periods but variability of concentrations was higher there than in the surface layer (Fig. 7). Variability of nitrate-nitrogen concentrations in both water layers was lower in 2008–2010 than in 2005. Under anaerobic conditions nitrates and sulphates play a role of electron acceptors.

Linear correlation between the concentration of dissolved oxygen and nitrate-nitrogen indicates that in

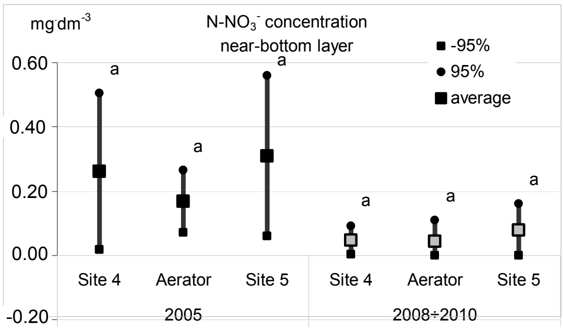

Fig. 7. Concentration of nitrate-nitrogen in near-bottom water of Lake Starzyc; source: own study

near-bottom layer near aerator an increase in nitrate concentrations was not accompanied by a decrease in dissolved oxygen concentration. Such a tendency was observed only for site 4 (Tab. 1).

As already mentioned, the functioning of pulverising aerator is based exclusively on wind energy, which does not pollute atmosphere, surface and ground waters. Moreover, the aerator operates silently so it does not make noise in the surrounding [DONDAJEWSKA 2013]. KONIECZNY [2004] when studying Lake Barlineckie found increased saturation of water with oxygen in the effect of pulverising aeration. In the present study it was observed that aerator did not operate at all on windless sunny days when air temperature exceeded 25^{n}C [WESOŁOWSKI *et al.* 2011b]. Summer season is the period of increased oxygen deficits, therefore, work of the aerator should be most efficient in this time period. A lack of the effects of pulverising aerators on lake waters was confirmed by RABAJCZYK and JÓŹWIAK [2008] and RABAJCZYK [2010; 2011]. The authors concluded that aeration did not bring expected effects. Anaerobic conditions, decreasing pH, altered ionic composition of water and consequently secondary water pollution may appear as a result of insufficient oxygen delivery to waters.

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Moreover, bottom sediments of Lake Kielce were most polluted in heavy metals in sites 1, 2 and 5 within the range of working zone of aerator [RABAJCZYK *et al*. 2011]

CONCLUSIONS

1. Concentrations of ammonium-nitrogen, nitrate-nitrogen and dissolved oxygen in water near aerator did not differ from those in sites 200 m (site 4) and 150 m (site 5) apart, which indicated similar abiotic conditions in studied waters.

2. Higher concentration of dissolved oxygen and lower concentration of nitrate-nitrogen in the years 2008 – 2010 compared with that in 2005 was probably a result of decreased input of organic matter and parallel inactivation of phosphorus in this lake.

3. Based on own observations it was found that in summer at a lack of wind energy, mainly on sunny days, the aerator situated in the lake did not operate at all.

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Piotr WESOŁOWSKI, Adam BRYSIEWICZ

Wpływ aeratora pulweryzacyjnego na zmiany stężenia tlenu i związków azotu w wodzie jeziora Starzyc

STRESZCZENIE

Ze względu na słaby stan ekologiczny jeziora Starzyc podjęto w 2003 r. działania rekultywacyjne, których celem była poprawa stanu natlenienia wód przydennych i obniżenie koncentracji związków fosforu. W tym celu zainstalowano na jeziorze aerator pulweryzacyjny z napędem wietrznym. Celem pracy była analiza zmienności stężenia tlenu i związków azotu w wodzie jeziora Starzyc w sąsiedztwie aeratora pulweryzacyjnego w trzecim roku jego działania (2005) oraz w kolejnych latach w trzyletnim okresie (2008–2010). Ustalono, że stężenie azotu amonowego i azotanowego (V) oraz tlenu rozpuszczonego w wodzie w punkcie w pobliżu aeratora nie różniło się od wartości pomiarów tych wskaźników w punktach 4 i 5, co świadczy o zbliżonych warunkach abiotycznych charakteryzujących badane wody. Stwierdzono większe stężenie tlenu rozpuszczonego w wodzie, a mniejsze stężenie azotu azotanowego (V) w latach 2008–2010 w porównaniu z 2005 r.

Słowa kluczowe: *aerator pulweryzacyjny, azot amonowy, azot azotanowy (V), jezioro, tlen*

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