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Changes in the concentration of selected water quality parameters in Lake Starzec in the vegetation periods

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Abstract

Studies were carried out in the years 2008–2010 in Lake Starzyc, zachodniopomorskie voivodship. The aim was to determine differences in the concentrations of selected water quality parameters between particular months of the vegetation seasons 2008–2010. Monthly mean concentrations of dissolved oxygen between April and October were by 1.91 g $O_2 \cdot m^{-3}$ higher in surface than in near-bottom water layer. Differences in the concentration of dissolved oxygen were also noted between particular months. Recorded concentrations fell within the range required for lake waters of the first and second water quality. Concentrations of mineral nitrogen in the years 2008–2010 corresponded to those of the third class of water quality and phosphorus concentrations exceeded this standard. Concentrations of ammonium ions did not exceed the values permitted for the second water quality class.

Key words: *ammonium ions, dissolved oxygen, inflow and outflow waters, Lake Starzyc, mineral nitrogen, phosphorus*

INTRODUCTION

Lakes in Poland are a valuable element of natural environment positively affecting micro-climate and sanitary conditions. Their natural hydro-geochemical character is often modified by human impact which accelerates eutrophication [HILL *et al.* 2000]. Changes resulting from human activity are complex and usually hard to reverse. This is particularly visible in lakes situated in the catchment basins with intensive agriculture which is an important source of water pollution by nitrogen and phosphorus [DURKOWSKI 2004; ŁAWNICZAK, ZBIERSKA 2007; ZBIERSKA *et al.* 2002]. Lake eutrophication is the most common reason of disturbances in aquatic ecosystems hence posing a threat to biodiversity of freshwater habitats [HILLBRICHT-ILKOWSKA 1989]. Eutrophication means an excessive production of organic matter in water [STARMACH *et al.* 1978], which may result in many adverse effects like: algal blooms, worsening photic conditions in the littoral zone and the deficit of dissolved oxygen. Protecting lakes from advanced eutrophication may be achieved mainly by the limitation or elimination of nutrient inputs from surrounding catchment basin. Water Framework Directive valid in Poland since its access to the European Union obliges Poland to achieve at least good ecological status in all water bodies, including lakes, till the year 2015 [GODLEWSKA, ŚWIERZOWSKI 2004].

The aim of this study was to determine the differences in the concentrations of selected water quality parameters in Lake Starzyc between particular months of the vegetation seasons 2008–2010.

STUDY OBJECT AND METHODS

Lake Starzyc is situated in northern Poland. It is a medium-size water body (surface area 59.2 ha), relatively shallow (maximum depth 6.1 m) of diverse shoreline. The lake is fed with water from a reclamation canal (input I), from Lake Kamienny Most (input II) and from a reclamation ditch (input III). Water from the lake ouflows to the Krąpiel River – a tributary to the Ina River (Fig. 1). Lake Starzyc is situated within the borders of the town and commune Chociwel, which has been served by sewage treatment plant since 1997. Diverse rush communities surround the lake [WESOŁOWSKI *et al*. 2007].

Two water samples for chemical analyses were taken from the surface (0.5 m depth) and near-bottom (1.0 m above the bottom) layer in each of the five sampling sites distributed along the lake (Fig. 1). Water depth in particular sampling sites was similar and reached: 5.0, 4.8, 4.9, 5.0 and 4.7 m in sites 1 to 5, respectively. Water samples were also taken from the inflows and outflow (Fig. 1). Obtained results were presented as mean values and subjected to statistical processing with the STATISTICA 8 software. Water samples were taken with an immersed pump Gigant made by Geomor-Technik. Dissolved oxygen was determined with the multiparameter analyser Multi 3400 WTW equipped with oxygen probe Callox 323. Soluble phosphates were determined with the WTW compact PC photometer and ammonium ions and nitrates – with the multiparameter photometer type LF 205 and LF 300 made by Slandi.

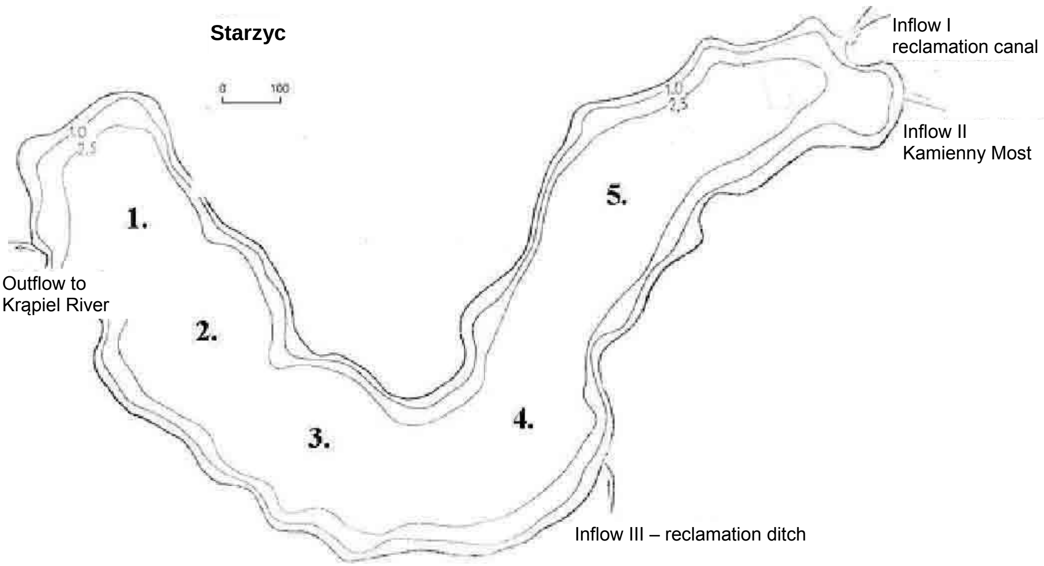

Fig. 1. Spatial distribution of sampling sites (1.–5.) in Lake Starzyc

RESULTS AND DISCUSSION

Monthly mean concentrations of dissolved oxygen between April and October of the years 2008–2010 were significantly higher in surface (8.15 g $O_2 \cdot m^{-3}$) than in near-bottom (6.24 g $O_2 \cdot m^{-3}$) water (Tab. 1 and Fig. 2). The highest mean concentration of oxygen was recorded in April – 12.46 g $O_2 \cdot m^{-3}$ and 10.48 g $O_2 \cdot m^{-3}$ in surface and near-bottom water, respectively. In May, July and August the concentrations of oxygen were lower; for example in May it was 5.47 g $O_2 \cdot m^{-3}$ in surface and 4.18 g $O_2 \cdot m^{-3}$ in near-bottom water. The differences were also observed between years. In 2009, oxygen concentration

Table 1. Concentrations of oxygen (g $O_2 \cdot m^{-3}$) in water of Lake Starzyc in particular months of the years 2008–2010

Years	Water layer	Months							Mean for April–October
		IV	V	VI	VII	VIII	IX	X	
		g $O_2 \cdot m^{-3}$							
2008	surface	13.07	6.61	9.22	8.74	8.66	10.64	8.97	9.42
	bottom	11.77	4.56	5.69	6.94	6.97	7.61	8.80	7.48
2009	surface	10.73	4.11	8.55	7.12	6.22	3.51	3.62	6.27
	bottom	7.05	2.93	6.52	3.36	3.76	3.47	3.62	4.39
2010	surface	13.57	5.68	11.36	7.85	7.46	7.56	7.84	8.76
	bottom	12.62	5.04	6.82	5.98	6.89	5.41	5.61	6.91
Mean for the years 2008–2010	surface	12.46	5.47	9.71	7.90	7.45	7.24	6.81	8.15
	bottom	10.48	4.18	6.34	5.43	5.87	5.50	6.01	6.26

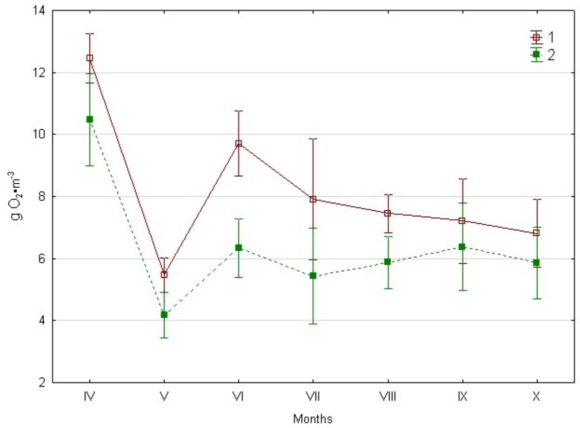

Fig. 2. ANOVA of the mean oxygen concentrations in Lake Starzyc (April–October of the years 2008–2010); *1* – surface layer, $F(6, 140) = 17.047$, $p = 0.00000$; *2* – near-bottom layer, $F(6, 140) = 11.621$, $p = 0.00000$;

was lower than in 2008 and 2010. Mean concentration for the period April–October was 6.27 g O_2·m^{-3} in surface and 4.39 g O_2·m^{-3} in near-bottom layer in this year (Tab. 1). ANOVA showed statistically significant differences between particular months. Highly significant differences of oxygen concentration in both layers were found between April and May (Fig. 2).

Observed phenomena one may explain by *i.a.* relatively high surface water temperature (above 20°C) in the year 2009. KUBIAK *et al*. [2006] demonstrated that oxygen concentrations in water bodies decreased with increasing temperature of surface water. The content of oxygen noted during the study period was appropriate for fish growth. This may be confirmed by results of a test fish harvesting made in 2009 by Polish Angling Association, Circle No 6 in Chociwel. The following fish species were caught in Lake Starzyc: perch-pike (*Stizostedion lucioperca*), tench (*Tinca tinca*), carp (*Cyprinus carpio*), bream (*Abramis brama*), pike (*Esox lucius*), roach (*Rutilus rutilus*), perch (*Perca fluviatilis*), bleak (*Alburnus alburnus*) and in small amounts eel (*Anguilla anguilla*). Oxygen concentrations found in Lake Starzyc in the years 2008–2010 fell within the range required of lakes in the first and second water quality class [KUDELSKA *et al*. 1994].

Results of analyses of ammonium ions (NH_4^+), mineral nitrogen (NO_3^- + NH_4^+) and phosphate-phosphorus (P-PO_4^{3-}) were compared with the threshold values given in recommendations for lake monitoring by the State Inspectorate of Environmental Protection to classify lake water quality [KUDELSKA *et al*. 1994]. Mean for the years 2008–2010 concentrations of ammonium ions were 0.27 g NH_4^+·m^{-3} in the surface and 0.33 g NH_4^+·m^{-3} in near-bottom layer (Tab. 2). The highest concentrations of these ions in both layers were noted in April and October (Tab. 2). For example, mean concentrations of ammonium ions in April were 0.56 g NH_4^+·m^{-3} in the surface and 0.74 g NH_4^+·m^{-3} in near-bottom layer. The lowest concentrations were found in June, July and August. In June, the concentration of ammonium ions in the surface layer was 0.10 g NH_4^+·m^{-3} and that in near-bottom layer was 0.11 g NH_4^+·m^{-3}. Noteworthy, in June, July and September of the years 2008 and 2009 (but not of 2010) there were no differences in the concentration of ammonium ions between surface and near-bottom layer (Tab. 2). The differences were, however, found between particular years. The highest concentrations were noted in 2008 and 2010. Monthly mean concentrations for the period April–October ranged from 0.31 to 0.36 g NH_4^+·m^{-3} in surface water and from 0.40 to 0.43 g NH_4^+·m^{-3} in near-bottom layers. Means for the same period of 2009 were similar in both layers of water (0.15 g NH_4^+·m^{-3}, Tab. 2). ANOVA showed statistically significant differences between April and June and a lack of such differences among April, September and October (Fig. 3).

Mean concentrations of ammonium ions in the years 2008–2010 attributed waters of Lake Starzyc to the first and second class of water quality [KUDELSKA *et al*. 1994].

Mean concentrations of mineral N in the period April–October of the years 2008–2010 were 0.51 g·m^{-3} in surface waters and 0.68 g m^{-3} in near-bottom layers

Table 2. Concentrations of ammonium nitrogen (g NH_4^+·m^{-3}) in water of Lake Starzyc in particular months of the years 2008–2010

Years	Water layer	Months							Mean for April–October
		IV	V	VI	VII	VIII	IX	X	
		g NH_4^+·m^{-3}							
2008	surface	1.34	0.14	0.10	0.10	0.10	0.14	0.62	0.36
	bottom	1.84	0.10	0.10	0.10	0.10	0.10	0.64	0.43
2009	surface	0.10	0.12	0.10	0.10	0.16	0.10	0.37	0.15
	bottom	0.12	0.13	0.11	0.10	0.11	0.11	0.37	0.15
2010	surface	0.23	0.45	0.10	0.13	0.12	0.76	0.35	0.31
	bottom	0.25	0.57	0.13	0.45	0.26	0.76	0.41	0.40
Mean for the years 2008–2010	surface	0.56	0.24	0.10	0.11	0.13	0.33	0.45	0.27
	bottom	0.74	0.27	0.11	0.22	0.16	0.32	0.47	0.33

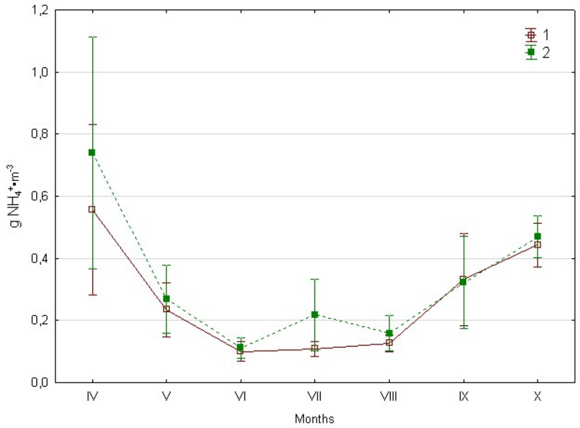

Fig. 3. ANOVA of the mean ammonium ion concentrations in Lake Starzyc (April–October of the years 2008–2010); *1* – surface layer, $F(6, 140) = 8.6630$, $p = 0.00000$; *2* – near-bottom layer, $F(6, 140) = 7.2751$, $p = 0.00000$; explanations as in Table 1.

(Tab. 3). Higher concentrations of mineral N were found in near-bottom than in surface layer of the study lake, similarly to those of ammonium ions. The highest mean concentrations of mineral N in the vegetation period were noted in the year 2008 – 0.66 g·m^{-3} and 0.83 g·m^{-3} in surface and near-bottom layers, respectively. Concentrations of mineral N in the years 2009 and 2010 were lower, particularly in 2010 they amounted 0.37 g·m^{-3} in the surface and 0.50 g·m^{-3} in near-bottom layers (Tab. 3). There were significant differences in the concentration of mineral N among months. The highest mean concentration of mineral N for the years 2008–2010 was noted in April (0.79 g·m^{-3} and 1.22 g·m^{-3} in surface and near-bottom layer, respectively) and in October (0.82 g·m^{-3} and 0.84 g·m^{-3}, respectively). Lower concentrations were found in August (0.31 g·m^{-3} in surface and 0.41 g·m^{-3} in near-bottom layers, Tab. 3). Highly significant differences were recorded in the concentration of mineral N in both layers between April and May, June, July and August. There were no such differences in surface waters between April and October (Fig. 4). Mean concentrations of mineral N qualified waters of Lake Starzyc to the third class of lake water quality from May till September and above this class in April and October [KUDELSKA *et al*. 1994].

Table 3. Concentrations of mineral nitrogen (g N-min·m^{-3}) in water of Lake Starzyc in particular months of the years 2008–2010

Years	Water layer	Months							Mean for April–October
		IV	V	VI	VII	VIII	IX	X	
		N_{min} (NO_3^-+NH_4^+)							
2008	surface	1.43	0.28	0.30	0.50	0.31	0.55	1.23	0.66
	bottom	2.16	0.21	0.61	0.64	0.30	0.64	1.26	0.83
2009	surface	0.44	0.63	0.46	0.40	0.51	0.26	0.86	0.51
	bottom	0.72	1.01	0.65	0.83	0.67	0.29	0.85	0.72
2010	surface	0.51	0.55	0.28	0.14	0.12	0.77	0.36	0.39
	bottom	0.79	0.68	0.11	0.46	0.27	0.78	0.41	0.50
Mean for the years 2008–2010	surface	0.79	0.49	0.35	0.35	0.31	0.53	0.82	0.52
	bottom	1.22	0.63	0.46	0.64	0.41	0.57	0.84	0.68

Mean concentrations of phosphorus were differentiated among months (Tab. 4). Higher P concentrations (means of the years 2008–2010) were found in lake water in September and October and lower – in April, May, June, July and August. There were no differences in P concentrations between the years 2008 and 2009 while in 2010 these concentrations were more than two times higher than in the two previous years. ANOVA showed statistically significant differences in P concentrations in both water layers between spring (April, May) and summer–autumn (June to October). Moreover, there were significant differences in P concentrations in surface layer between spring–summer (April to August) and autumn (September, October) (Fig. 5).

Mean concentrations of phosphorus in 2010 were 0.16 and 0.23 g P·m^{-3} in surface and near-bottom layer, respectively, which qualified waters of Lake Starzyc to non-standard water quality class [KUDELSKA *et al*. 1994]. Lower P concentrations in

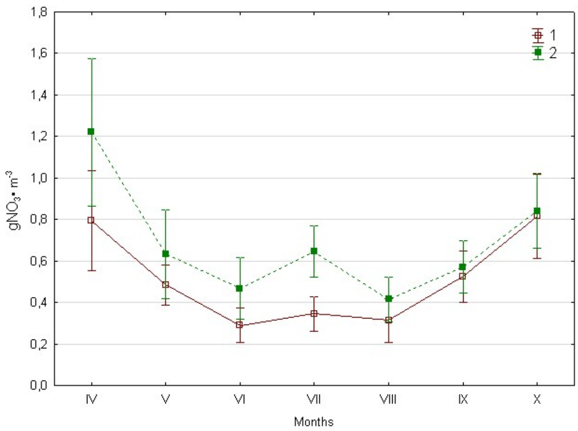

Fig. 4. ANOVA of the mean concentrations of mineral nitrogen in Lake Starzyc (April–October of the years 2008–2010); *1* – surface layer, $F(6, 140) = 9.8201$, $p = 0.00000$; *2* – near-bottom layer, $F(6, 140) = 8.4508$, $p = 0.00000$; explanations as in Table 1.

Table 4. Concentration of phosphorus (g P·m^{-3}) in water of Lake Starzyc in particular months of the years 2008–2010

Years	Water layer	Months							Mean for April–October
		IV	V	VI	VII	VIII	IX	X	
		g P·m^{-3}							
2008	surface	0.02	0.03	0.03	0.04	0.10	0.18	0.06	0.07
	bottom	0.02	0.03	0.12	0.07	0.10	0.17	0.06	0.08
2009	surface	0	0.01	0.07	0.09	0.06	0.11	0.09	0.06
	bottom	0	0.02	0.11	0.12	0.07	0.14	0.14	0.09
2010	surface	0.01	0.05	0.14	0.06	0.19	0.26	0.39	0.16
	bottom	0.02	0.12	0.21	0.27	0.29	0.28	0.39	0.23
Mean for the years 2008–2010	surface	0.01	0.03	0.08	0.06	0.12	0.18	0.18	0.09
	bottom	0.01	0.06	0.15	0.15	0.15	0.20	0.20	0.13

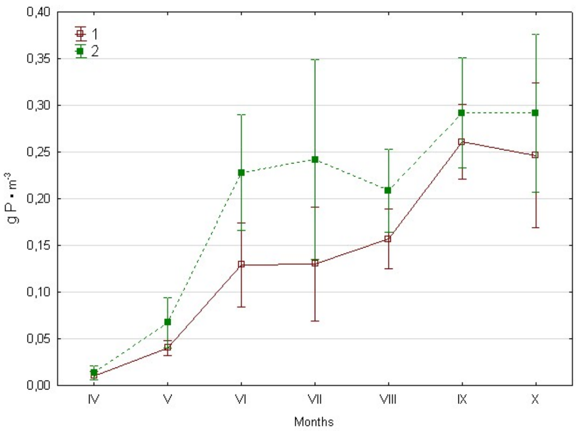

Fig. 5. ANOVA of the mean phosphorus concentrations in Lake Starzyc (April–October of the years 2008–2010); *1* – surface layer, $F(6, 140) = 18.556$, $p = 0.00000$; *2* – near-bottom layer, $F(6, 140) = 12.618$, $p = 0.00000$; explanations as in Table 1.

the years 2008–2009 may be explained by the fact that commune authorities applied a coagulant (PIX 113 containing 43% of iron sulphate and 1% of sulphuric acid) over the whole lake area.

In general, water quality in Lake Starzyc largely depends on nutrient concentrations in the inflows (Tab. 5) which differed during the study period. The highest concentrations of mineral N were found in the inflow I (3.69 g N-min·m^{-3}) and III (3.00 g N-min·m^{-3}), the lowest – in the inflow II (1.25 g N-min·m^{-3}). Phosphorus concentrations were higher in the inflow I (0.37 g P·m^{-3}) and lower in the inflows II and III (0.25–0.27 g P·m^{-3}). Mean nutrient concentrations over the three study years exceeded the permissible values for lake waters [KUDELSKA *et al*. 1994]. Low concentrations of ammonium ions found in three inflows (0.23–0.29 g NH_4^+·m^{-3}) qualified their waters to the second class of lake water quality. Low concentra-

Table 5. Concentrations of mineral nitrogen, (N-min), NH_4^+ and P (g·m^{-3}) in the inflows to and outflow from Lake Starzyc to the Ina River from April till October of the years 2008–2010

Months	Inflow I (reclamation canal)			Inflow II (Kamienny Most)			Inflow III (reclamation ditch)			Outflow to the Ina River		
	N-min	NH_4^+	P	N-min	NH_4^+	P	N-min	NH_4^+	P	N-min	NH_4^+	P
1	2	3	4	5	6	7	8	9	10	11	12	13
2008												
IV	1.07	0.17	0.10	2.24	0.29	0.00	0.78	0.27	0.22	1.01	0.91	0.06
V	1.29	0.34	0.30	2.70	0.41	0.09	3.11	0.13	0.09	0.92	0.42	0.09
VI	5.59	0.19	0.28	2.62	0.51	0.10	4.17	0.43	0.08	2.57	0.81	0.19
VII	9.37	0.19	0.03	1.22	0.04	0.05	2.56	0.51	0.03	1.10	0.01	0.04
VIII	8.11	0.09	0.05	2.18	0.19	0.18	3.42	0.21	0.14	1.06	0.15	0.03
IX	9.43	0.55	0.03	1.20	0.05	0.15	1.29	0.24	0.22	1.29	0.49	0.07
X	1.58	0.07	0.08	2.33	0.79	0.02	0.64	0.14	0.03	0.29	0.08	0.01
Mean for April–October	5.21	0.23	0.12	2.07	0.33	0.08	2.28	0.28	0.12	1.18	0.41	0.07
2009												
IV	0.39	0.28	0.07	0.49	0.39	0.02	0.59	0.29	0.03	0.34	0.24	0.01
V	1.13	0.26	0.05	0.66	0.56	0.08	0.51	0.41	0.20	0.83	0.59	0.06
VI	0.59	0.37	0.71	0.42	0.32	0.37	0.53	0.43	0.26	0.49	0.39	0.09
VII	2.97	0.29	0.07	1.54	0.38	0.50	2.47	0.43	0.42	8.34	0.33	0.08
VIII	3.85	0.30	1.24	2.51	0.30	1.10	3.08	0.46	0.27	0.62	0.39	0.09
IX	6.59	0.26	1.48	0.15	0.05	1.06	0.19	0.09	0.53	0.31	0.21	0.02
X	10.70	0.05	1.37	1.71	0.14	0.53	1.26	0.40	0.55	1.17	0.44	0.04
Mean for April–October	3.75	0.26	0.71	1.07	0.31	0.52	1.23	0.36	0.32	1.73	0.37	0.06

cont. Tab. 5

1	2	3	4	5	6	7	8	9	10	11	12	13
2010												
IV	1.46	0.28	0.02	0.96	0.05	0.01	6.30	0.25	0.01	0.50	0.37	0.00
V	1.30	0.49	0.04	0.27	0.18	0.02	0.51	0.42	0.01	0.29	0.20	0.03
VI	1.16	0.12	0.38	0.27	0.11	0.33	14.62	0.05	0.44	0.29	0.12	0.14
VII	1.77	0.20	0.20	2.15	0.60	0.26	6.09	0.07	0.52	0.07	0.06	0.16
VIII	1.80	0.06	0.31	0.14	0.11	0.13	10.59	0.11	0.29	0.10	0.10	0.27
IX	7.10	0.09	0.39	0.19	0.18	0.37	0.18	0.18	0.32	0.59	0.58	0.30
X	0.10	0.09	0.63	0.37	0.36	0.31	0.21	0.21	0.68	0.42	0.39	0.60
Mean for April–October	2.10	0.19	0.28	0.62	0.23	0.20	5.50	0.18	0.32	0.32	0.26	0.21
Mean for the years 2008–2010	3.69	0.23	0.37	1.25	0.29	0.27	3.00	0.27	0.25	1.08	0.35	0.11

tions of mineral N and ammonium ions (but not phosphates) were noted in the outflow to the Ina River (Tab. 5).

To sum up, mean nutrient concentrations in the years 2008–2010 qualified water in Lake Starzyc to non-standard class of water quality (due to the concentrations of mineral N and phosphorus) or to the first and second class (due to the concentration of ammonium ions).

The improvement of water quality depends mainly on the elimination of nutrients from the inflow I (reclamation canal) and III (reclamation ditch).

CONCLUSIONS

1. During the study period 2008–2010 the concentration of dissolved oxygen was higher in the surface than in near-bottom water layers.

2. In the same period, higher concentrations of dissolved oxygen were noted in April (12.46 g $O_2 \cdot m^{-3}$ and 10.48 g $O_2 \cdot m^{-3}$ in the surface and near-bottom layer, respectively) than in May, July and August. For example, in May the O_2 concentrations were 5.47 g $O_2 \cdot m^{-3}$ in surface water and 4.18 g $O_2 \cdot m^{-3}$ in near-bottom water. In the year 2009, due to high temperatures of lake water, oxygen concentrations in respective layers were lower than in 2008 and 2010.

3. Mineral nitrogen concentrations recorded in the period 2008–2010 qualified lake waters to the third class of water quality, those of phosphorus were non-standard and concentrations of ammonium nitrogen – to the first and second class.

4. Concentrations of mineral N and phosphorus in the inflows to the lake exceeded the values allowable for lake waters while the concentrations of ammonium ions fell within the second class of water quality. Moreover, low concentrations of mineral N and ammonium (but not phosphorus) ions were noted in waters flowing out to the Ina River.

5. The improvement of water quality in Lake Starzyc depends mainly on the estimation of pollution sources for the inflows to that lake.

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Zmiany stężenia wybranych wskaźników jakości wody w jeziorze Starzyc w okresach wegetacyjnych

STRESZCZENIE

Słowa kluczowe: *fosfor (P), jezioro Starzyc,* NH_4^+, *N-min., tlen* (O_2), *wody dopływowe i odpływowe*

Badania przeprowadzono w latach 2008–2010 na jeziorze Starzyc, w województwie zachodniopomorskim. Celem pracy było określenie różnic wartości stężenia wybranych wskaźników jakości wody w jeziorze Starzyc w poszczególnych miesiącach okresów wegetacyjnych w latach 2008–2010. Stwierdzono, że średnie miesięczne stężenia tlenu w wodzie za okres IV–X były o 1,91 g $O_2 \cdot m^{-3}$ większe w warstwie powierzchniowej w porównaniu ze stwierdzonymi w warstwie naddennej. Ponadto odnotowano różnice w zawartości tlenu w wodzie jeziora w poszczególnych miesiącach. Stwierdzone wartości stężenia tlenu w wodzie jeziora Starzyc mieszczą się w zakresie wymaganym dla wód jeziorowych pierwszej i drugiej klasie czystości. Stwierdzono także, że stężenie azotu mineralnego w wodzie jeziora Starzyc za okres 2008–2010 odpowiada wartościom dopuszczalnym dla trzeciej klasy czystości wód jeziorowych, a fosforu przewyższają te wartości, natomiast stężenie jonów amonowych nie przekracza wartości dopuszczalnych dla drugiej klasy czystości.