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PURITY OF WATER IN CHOSEN LAKES IN THE NORTH-EASTERN PART OF TUCHOLSKIE FORESTS

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Sumary. Parameters of water listed in the basic monitoring of lakes were determined in lakes situated in the north-eastern part of the Tucholskie Forests. Physicochemical parameters and sanitary purity of water (*E. coli*) were estimated. Classification of the lakes to appropriate classes of purity was performed on the basis of current Polish standards and recommendations for water analysis of lakes. Waters of lakes Borzechowskie, Niedackie and Wygonin were categorized in the second class of purity, and those of lakes Czechowskie, Wielki Ocypel, Struga and Wielkie – in the third class of purity.

Key words: monitoring of lakes, class of water purity, classification of lakes, Tucholskie Forests

INTRODUCTION

Tucholskie Forests is one of the biggest Polish complex of forests that covers approximately 4500 km^2. This area is rich in both hilly terrain covered by pine forests (approx. 77%) and lakes that encompass almost 5% of forest area. There are numerous subglacial channels across the region, from north to south and from east to west. The area is also rich in other kinds of lakes, such as post-glacial potholes and small ponds as well as flat lakes. The lakes of Tucholskie Forests are characterised by different levels of trophy and water purity.

The aim of this study was estimation of standard physicochemical parameters applied in basic monitoring of lakes. These parameters were determined in the water of lakes Borzechowskie, Czechowskie, Niedackie, Wygonin, Wielki Ocypel, Wielkie, Struga. The first three lakes are situated in the north-western subglacial channel, lake Wygonin lies in the north-eastern subglacial channel, while lakes Ocypel, Wielkie and Struga belong to the group of flat lakes. All studied lakes, except Borzechowskie and Wygonin, are typical flow-through lakes.

MATERIALS AND METHODS

The analysis of parameters of waters was conducted in spring (March) and summer stagnation (September) of 2008. Investigation of water in spring was performed during a time interval when temperature of water and concentration of oxygen were constant from surface to bottom. Water samples were collected at the deepest point of each lake, one meter below the surface and one meter above the bottom of the lake. The deepest point of each lake was determined using a sonic sounder. Transparency of waters was measured with Secchi discs. Analysis of physicochemical parameters was performed strictly according to the Polish standards and recommendations for water analysis of surface water reservoirs including lakes [Kudelska *et al*. 1994, Hermanowicz *et al.* 1999].

Water samples were analysed for oxygen concentration, chemical (CODCr) and biochemical oxygen demand (BOD) and oxidability (CODMn), content of phosphates, total phosphorus, mineral and ammonium nitrogen, nitrates, total nitrogen, chlorides, sulphates, specific electrolytic conductivity, chlorophyll, weight of dry residue, transparency of water, pH index and sanitary purity of water (*E. coli*). The results were averaged from the spring and summer data. Morphometric and batymetric parameters of the lakes were taken from Choiński [1991] and Jańczak [1997] or determined in the present study.

RESULTS AND DISCUSSION

All studied lakes belong to deep lakes and showed direct stratification of waters during the summer stagnation. The range of basic physicochemical parameters of water of studied lakes is presented in Tables 1 and 2.

The largest and deepest lake was Borzechowskie, covering an area of 237.7 ha (max. length 5130 m, max. width 1010 m, max. depth 43 m, mean depth 11.0 m). In the case of lake Borzechowskie, samples of water were collected at two sites: site 1 in the central part of the lake, and site 2 in the northern part of the lake. At site 1 the epilimnion came up to 8 m and dissolved oxygen concentration fluctuated between 16.7 and 12.9 mg O_2 dm^{-3}. In the metalimnion a sharp thermal gradient existed (> 2.2°C/m) and the metalimnetic minimum of oxygen concentration (3.6 mg O_2 dm^{-3}) was observed at a depth of 9 m. At the top of the hypolimnion oxygen concentration increased to 6 mg, but below 22 m its concentration decreased to 1.5 mg O_2 dm^{-3}. At site 2 the epilimnion

Table 1. Physicochemical parameters of waters of lakes Borzechowskie, Czechowskie and Niedackie

Index		Borzechowskie I, 24.5 m			Borzechowskie II, 30 m			Czechowskie, 32 m			Niedackie, 30m		
		III	IX	score	III	IX	score	III	IX	score	III	IX	score
Temperature, °C	S B	3.7 3.5	19.1 7.5		3.6 3.5	19.7 6.7		4.0 3.9	20.2 6.4		3.9 3.8	19.6 6.9	
Oxygen, mg O_2dm^{-3}	S B	14.8 14.7	14.7 1.55		12.9 13.0	14.9 2.27		15.7 15.7	12.2 1.07		14.7 13.8	14.0 1.55	
Mean, % saturation of oxygen of hypolimnion			33.5	2		31.9	2		18.9	3		26.7	2
Oxidability, mg O_2 dm^{-3}	S B		4.16	1		5.46	1		5.3	1		2.73	1
Chemical oxygen demand, mg O_2 dm^{-3}	S B		10.48	1		4.36	1		5.12	1		10.78	1
Biochemical oxygen demand, mg O_2 dm^{-3}	S B		6.37	3		6.8	3		8.0	4		6.3	3
Phosphate, mg P dm^{-3}	S B	0.043 0.017	0.034 0.239	3	0.017 0.014	0.017 0.278	1	0.003 0.005	0.045 0.375	1	0.008 0.001	0.010 0.298	1
Total phosphorus, mg P dm^{-3}	S B	0.045	0.086	2	0.075	0.159	2	0.103	0.118	4	0.09	0.295	3
Mineral nitrogen, mg N dm^{-3}	S B	0.460 0.381	0.202 0.339	1	0.471 0.436	0.133 0.310	2	0.213 0.287	0.0045 0.760	2	0.204 0.192	0.209 0.300	2

Ammonium nitrogen, mg N dm^{-3}	S B	0.240 0.228	0.019 0.139	1	0.299 0.236	0.033 0.259	2	0.033 0.08	0.006 0.531	1	0.069 0.043	0.026 0.139	1
Total nitrogen, mg N dm^{-3}	S B	0.38	0.270	1	0.328	0.352	1	0.242	0.163	1	0.269	0.285	1
Specific electrolytic conductivity, µS cm^{-1}	S B	415 433	402 410	4	439 435	395 441	4	407 424	359 454	4	355 349	308 352	4
Chlorophyll *a*, mg m^{-3}	S B	15.9	38.3	4	17.9	37.1	4	8.2	132.2	4	8.7	20.48	2
Weight of dry residue, mg dm^{-3}	S B	6.1	11.7	3	6.3	12.1	3	2.6	3.6	1	2.3	6.4	2
Transparency of water, m	S B	3.9	2.7	2	3.9	3.1	2	2.8	3.4	2	4.1	4.5	1
Sanitary purity (*E. coli*)	S B	<100	<100	2	<100	<100	2	<100	<100	2	<10	<10	1
Nitrate, mg dm^{-3}	S B	0.220 0.153	0.183 0.200		0.172 0.203	0.100 0.154		0.180 0.207	0.039 0.229		0.145 0.149	0.183 0.161	
pH	S B	7.4 7.5	7.5 7.1		7.0 7.6	7.3 7.2		8.2 8.2	7.6 7.2		7.7 7.6	7.2 7.0	
Chloride, mg dm^{-3}	S B	8.79 10.99	15.4 15.6		9.8 10.9	15.6 16.1		6.7 6.0	9.7 9.7		3.8 4.6	7.3 9.2	
Sulphate, mg dm^{-3}	S B	16.08 16.51	28.33 31.00		16.02 17.47	23.00 24.56		18.31 17.59	43.11 33.56		14.10 11.81	42.22	
Average scores class				2.1 II			2.1 II			2.2 III			1.8 II

Table 2. Physicochemical parameters of waters of lakes Ocypel, Wielkie, Struga, Wygonin

Index		Ocypel, 36 m			Wielkie, 16 m			Struga, 20 m			Wygonin, 22 m		
		III	IX	score	III	IX	score	III	IX	score	III	IX	score
Temperature, °C	S B	4.0 4.0	20.6 6.1		4.1 4.1	20.1 6.7		5.0 4.8	19.7 5.9		4.1 3.9	20.8 9.5	
Oxygen, mg O_2 dm^{-3}	S B	12.5 12.1	12.8 0.62		13.1 13.1	13.6 0.1		13.7 14.0	12.7 0.1		14.3 14.0	13.2 2.89	
Mean, % saturation of oxygen of hypolimnion			21.8	2		18.9	3		10.2	3		49.1	1
Oxidability, mg O_2 dm^{-3}	S B		6.5	1		4.4	1		5.6	1		6.37	1
Chemical oxygen demand, mg O_2 dm^{-3}	S B		13.7	1		13.7	1		11.64	1		6.72	1
Biochemical oxygen demand, mg O_2 dm^{-3}	S B		9.3	3		9.9	3		9.4	3		8.3	3
Phosphate, mg P dm^{-3}	S B	0.202 0.359	0.061 0.441	3	0.496 0.491	0.156 1.855	4	0.137 0.186	0.038 0.712	4	0.047	0.076	3
Total phosphorus, mg P dm^{-3}	S B	0.121	0.264	3	1.11	0.152	4	0.288	0.111	3	0.695	1.386	4
Mineral nitrogen, mg N dm^{-3}	S B	0.756 0.861	0.207 1.828	3	1.221 1.173	0.618 4.325	4	0.579 0.712	0.608 2.45	3	0.309 0.354	0.233 0.493	2
Ammonium nitrogen, mg N dm^{-3}	S B	0.454 0.582	0.019 1.589	3	0.792 0.798	0.525 4.11	3	0.147 0.245	0.498 2.33	3	0.202 0.205	0.006 0.212	2

Total nitrogen, mg N dm^{-3}	S B	0.541	0.328	1	0.67	0.402	1	0.551	0.569	1	0.218	0.262	1
Specific electrolytic conductivity, µS cm^{-1}	S B	387 386	298 403	4	415 410	288 456	4	359 331	354 421	4	174 175	169 182	1
Chlorophyll *a*, mg m^{-3}	S B	25.3	52.5	4	35.4	46.4	4	35.9	42.1	4	8.1	8.7	2
Weight of dry residue, mg dm^{-3}	S B	7.2	15.1	3	10.6	13.5	3	10.2	12.7	3	2.1	2.6	1
Transparency of water, m	S B	1.8	1.1	3	1.4	0.6	3	1.2	1.3	3	4.7	2.9	2
Sanitary purity (*E. coli*)	S B	<100	<100	2	<100	<10	2	<100	<10	2	<10	<10	1
Nitrate, mg dm^{-3}	S B	0.302 0.279	0.188 0.239		0.429 0.375	0.093 0.215		0.432 0.467	0.110 0.122		0.107 0.149	0.227 0.281	
pH	S B	7.8 7.7	7.5 7.3		7.7 7.8	8.33 7.5		7.9 7.8	7.2 7.2		7.6 7.3	7.4 7.1	
Chloride, mg dm^{-3}	S B	1.09 1.37	5.86 6.29		4.94 7.69	6.19 3.8		3.29 6.59	8.6 6.54		5.0 5.4	7.8 2.7	
Sulphate, mg dm^{-3}	S B	17.32 19.94	23.89 21.33		25.36 25.90	29.56 41.44		20.84 21.81	33.44 40.67		35.48 35.00	35.56 29.33	
Average scores class				2.6 III			2.6 III			2.7 III			1.8 II

came up to 8 m and the concentration of oxygen was rather constant up to 7 m. In the metalimnion concentration of oxygen decreased from 13.9 to 5.5 mg O_2 dm^{-3} at a depth of 10 m and was rather constant up to 16 m. Below 16 m, O_2 concentration declined up to 2.3 at a depth of 28 m. Oxidability of 4.14 mg O_2 dm^{-3} was compared with values of 3.8 mg O_2 dm^{-3} [Jańczak 1997], while conductivity of water (421 μS cm^{-1}) was much higher than 260 μS cm^{-1} [Jańczak 1997]. On the other hand, the same pH index of 7.4 was observed, concentrations of sulphates and chlorides were comparable – 22 [Jańczak 1997] vs. 23.2 mg dm^{-3} and 15 vs. 12.7 mg dm^{-3} in our study, respectively. Lake Borzechowskie was of the II class of water purity.

The second lake, Niedackie, occupies an area of 115.3 ha with max. length of 2200 m, max width of 710 m, max. depth of 30 m and mean depth of 9.3 m. The epilimnion came up to 10 m, but the metalimnion was shallow between 10 and 12 m. The curve of oxygen concentration in the water had a stepped shape. Oxygen concentration was constant from the surface down to 5 m (approx. 14 mg O_2 dm^{-3}), and below that depth it decreased to 9.5 mg O_2 dm^{-3} at a depth of 7 m and was constant down to 10 m. Further down O_2 concentration decreased to 4.6 mg O_2 dm^{-3} and was constant to 15 m, and then declined to 1.55 mg O_2 dm^{-3} at 26 m. Oxidability 2.7 mg O_2 dm^{-3} was little higher than 2.1 [Jańczak 1997]. Conductivity of water was 341 μS cm^{-1} and was much higher than 200 μS cm^{-1} [Jańczak 1997]. pH index was the same – 7.4, concentrations of sulphates and chlorides were little lower – 22.7 vs. 30.0 mg dm^{-3} and 6.2 vs. 10.0 mg dm^{-3}, respectively, than those cited by Jańczak [1997]. Lake Niedackie was classified in class II of water purity.

Lake Wielki Ocypel (114 ha) covers an area similar to that of lake Niedackie and has length of 1705 m, max. width of 1090 m, max. depth of 40 m, and mean depth of 6.7 m. In the epilimnion the temperature of water was rather constant (19.4–20.1^{o}C) as well as oxygen levels between 2 and 6 m of depth. Under surface (1–2 m) oxygen concentration was 3 mg O_2 dm^{-3} and higher than at the third meter of depth. Below 6 m sharp thermic and oxygen gradients were observed, temperature dropped very quickly down to 9.2^{o}C at 10 m of depth and oxygen from 14 to 3.8 mg O_2 dm^{-3}. At a depth of 11 m an increase of temperature to 11^{o}C and an increase in concentration of oxygen to more than 1 mg was found. Next, the temperature declined to 7^{o}C at a depth of 13 m. In the hypolimnion the temperature changed in the range from 7 to 6.1^{o}C at 35 m of depth. Below 20 m the concentration of oxygen was less than 1.7 mg O_2 dm^{-3} and below 26 m it was less than 1 mg O_2 dm^{-3}. Oxidability was 6.5 mg O_2 dm^{-3} and was higher than 2.9 [Jańczak 1997], as well as conductivity – 368 vs. 200 μS cm^{-1} cited by Jańczak [1997]. However, lower concentrations of sulphates (20.6 mg dm^{-3}) and chlorides (3.6 mg dm^{-3}) were found compared to Jańczak [1997] – 30 and 9 mg dm^{-3}, respectively. Lake Wielki Ocypel was of the III class of water purity Lake Czechowskie (Trzechowskie) occupies an area of 84.2 ha, and has a max. length of 2200 m, max. width of 710 m, max. depth of

32 m and mean depth of 8.3 m. The epilimnion came up to 8 m. Below that depth the temperature of water decreased to 10.7°C at 9 m and next increased to 13.8°C at 10 m. At the depth of 11 m the temperature of water was 11.4°C and next decreased to 7.5 and to 6.4°C at 31 m. Oxygen concentration did not change up to 7 m. Below 7 m it decreased to 3.3 mg O_2 dm^{-3} (at 12 m) and systematically declined to less than 2 mg O_2 at 26 m below dm^{-3} and 1 mg O_2 dm^{-3} only at 31 m. Oxidability was 5.3 mg O_2 dm^{-3}, i.e. higher than that 3.8 mg O_2 dm^{-3} [Jańczak 1997], as well as conductivity – 411 vs. 250 µS cm^{-1}. Also pH index was little higher – 7.8 vs. 7.5. Sulphate and chloride concentrations were lower – 28.1 vs. 36.0 mg dm^{-3} and 8.0 vs. 12.0 mg dm^{-3}, respectively.

Lake Wygonin has an area of 67.5 ha, max. length of 2200 m, max. width of 470 m, max. depth of 24.8 m, and mean depth of 6.4 m. Temperature and dissolved oxygen fluctuated between 20.3–19.1°C from the surface to 8 m and between 15.2 and 13.1 mg O_2 dm^{-3} from the surface to 10 m, respectively. Thickness of the metalimnion was high (approx. 6 m) and concentration of oxygen declined to 8.9 mg at a depth of 14 m. The oxygen concentration near the bottom was 2.9 mg O_2 dm^{-3}. It was the highest value of oxygen concentration near the bottom within this group of studied lakes. Oxidability (6.4 3 mg O_2 dm^{-3}) was higher than that of 3.9 [Jańczak 1996], as well as conductivity of water – 175 vs. 140 µS cm^{-1}. pH index was 7.3 while in Jańczak's [1997] work it was 8.0. Sulphates concentration was higher – 33.84 vs. 7 mg dm^{-3}, but concentrations of chlorides was comparable (6.25 vs. 7.7 mg dm^{-3}). Lake Wygonin was in class II of water purity.

Lake Wielkie – area of 46.0 ha, max. length 1100 m, max. width 600 m, max. depth 17.5 m, mean depth 8.9 m. Temperature of water fluctuated between 20.1 at the surface and 17.1°C at 6 m, and concentration of oxygen was constant (approx. 15.2 mg O_2 dm^{-3}). Metalimnion was only 2 m thin. At 7 m of depth oxygen concentration was 3.4 mg O_2 dm^{-3} and below 12 m less than 1.5. Oxidability vs. 2.8 mg O_2 dm^{-3} and conductivity 392 vs. 330 µS cm^{-1} were in accord with the results of Jańczak [1997]. pH =7.8 was little lower than the value reported by Jańczak [1997] (pH 8.1). Concentrations of sulphates were higher 28.31 vs. 19.0 mg dm^{-3}, while the concentration of chlorides was lower – 5.65 vs. 14 mg dm^{-3}. Lake Wielkie was in class III of water purity.

Lake Struga – area of 21.9 ha, max. length 762 m, max. width 400 m, max depth 24.5 m, mean depth 6.2 m, was classified in the third class of water purity. Temperature of water changed from 19.7 at the surface to 17.3°C at 5 m depth. Oxygen concentration was constant to a depth of 4 m only, and changed in the metalimnion from 12.7 to 4.1 mg O_2 dm^{-3}. At 8 m of depth an increase of temperature from 11.8 to 13.2°C and an increase in concentration of oxygen from 4.1 to 8.1 mg O_2 dm^{-3} were found. However, at 9 m of depth decreases of temperature from 13.2 to 7.5°C as well as a decrease in oxygen concentration from 8.1 to 1 mg O_2 dm^{-3} were observed. Temperature of the hypolimnion changed from 7.5 to 5.9°C at 19 m depth, but oxygen concentration was low and dropped below 12 m

(< 1 mg O_2 dm^{-3}). Three meters above the bottom oxygen concentration was not measurable. Oxidabilities values were similar (5.6 vs. 6.0 mg O_2 dm^{-3}), whereas conductivity was little higher – 366 vs. 310 μS cm^{-1} [Jańczak 1997]. Concentration of sulphates was 28.9 vs. 22.0 mg dm^{-3} and chlorides 6.3 vs. 14.0 mg dm^{-3}, respectively.

During the last 25 years anthropogenic activities, e.g. tourist pressure and domestic sewage discharge, altered the trophic status of the investigated lakes. These problems especially concern lakes Borzechowskie and Ocypel, because many private houses and resort centres located in close proximity of the lake worsened water quality. In the case of lakes Wielkie and Struga eutrophication problems are connected with agricultural pressure caused by the application of large quantities of fertilisers and agrochemicals in the fields. High conductivity, reflected by a high level of mineral substances in the water in all studied lakes except lake Wygonin, classified these lakes to the III class of water purity. Low values of chemical oxygen demand and biochemical oxygen demand indicated low level of organic materials in the water of the studied lakes (classes I and II of water purity).

On the basis of estimated parameters of physicochemical analysis of waters, lakes Borzechowskie, Niedackie and Wygonin were categorised to the second class of purity, while lakes Czechowskie, Ocypel, Struga and Wielkie – to the third class of purity.

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CZYSTOŚĆ WÓD WYBRANYCH JEZIOR W PÓŁNOCNO-WSCHODNIEJ CZĘŚCI BORÓW TUCHOLSKICH

Streszczenie. Określono parametry stosowane w podstawowym monitoringu jezior położonych w północno-wschodniej części Borów Tucholskich. Oszacowano parametry fizykochemiczne wód oraz ich czystość sanitarną. Zaklasyfikowano jeziora do odpowiednich klas czystości na podstawie punktacji uzyskanej po oznaczeniu parametrów wg Norm Polskich. Wody jezior Borzechowskie, Niedackie, Wygonin były w II klasie czystości, natomiast wody jezior Czechowskie, Ocypel, Struga, Wielkie w III klasie czystości.

Słowa kluczowe: monitoring jezior, klasy czystości wód, klasyfikacja jezior, Bory Tucholskie