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VERTICAL DISTRIBUTION AND SEASONAL CHANGES IN THE NUMBER OF BACTERIOPLANKTON IN THE WATER OF LAKE HAŃCZA, PARTICULARLY IN THE PERIOD OF RESERVOIR SUMMER STRATIFICATION

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ABSTRACT

The paper presents the results of the study on seasonal changes in the number of bacterioplankton, its vertical distribution and morphological composition in the waters of the deepest Polish lake, Lake Hańcza (108.5 m deep). The research was performed from 1997 till 2000. Water samples were collected at a research station placed at a location where the lake depth was maximum, at monthly intervals from May to October. Water was sampled along the following depth profile: from 0-1 cm layer, at 0.3 m and at the depth of 1m, 2m, 5m, 10m, deeper down at 10m intervals towards the bottom. Bacteriological analyses were completed with measurements of selected physico-chemical parameters such as temperature, pH, oxygen, nitrogen and phosphorus contents. Obtained results with regards both to the number of bacterioplankton and its morphological structure, namely 68% for cylindrical rods forms, and physico-chemical assays confirmed the purity of Lake Hańcza. The vertical distribution of bacterioplankton was usually of a micro-zonal character, indicating the 'focal' distribution of organic and nutrient matter, with higher population reported at the surface (during summer stratification at 1-5 m depth) or in demersal water that can be attributed to organic matter of auto- or allochtonic origin accumulating there.

Key words: Bacterioplankton, lake, physico-chemical parameters.

INTRODUCTION

In natural, undisturbed water ecosystems it is natural to find stable groups of interrelated microorganisms. Any imbalance introduced into such systems by external factors triggers immediate reaction of the microorganisms. Qualitative and quantitative fluctuations in bacterioplankton biomass provide a very sensitive indicator of changes occurring in reservoirs [24]. The major parameters regulating the number and distribution of planktonic bacteria biomass are availability of organic nutrient substrates [11,16], particularly in oligotrophic reservoirs, predation that is most pronounced in eutrophic waters [8,22], concentration of mineral compounds, pH [18], and temperature [23]. In lake waters the number of bacterioplankton is also affected by inorganic nitrogen, phosphorus, and organic carbon content, as well as by the bacteria-phytoplankton correlation [27]. Usually, the highest number of bacterioplankton is reported when phytoplankton produces nutrients, namely in the spring, late summer, and early autumn [4,10]. The type of lake is also of significant importance. A complex analysis of lakes with different trophy levels confirmed that the number of bacteria in oligotrophic lakes is considerably lower than in contaminated eutrophic ones [14,16]. Quantitative distribution of micro-organisms is also determined by natural and climatic conditions, as well as by the season. It applies particularly to lakes of mild climates, where thermal layers occur and are inhabited by populations of various microorganisms. Both vertical and spatial distribution in lake waters is of significant importance for determining the current state of a lake and forecasting the direction of changes occurring therein.

The aim of the study was to determine vertical distribution, seasonal changes in the number of bacterioplankton and its qualitative composition in the waters of Lake Hańcza.

MATERIAL AND METHODS

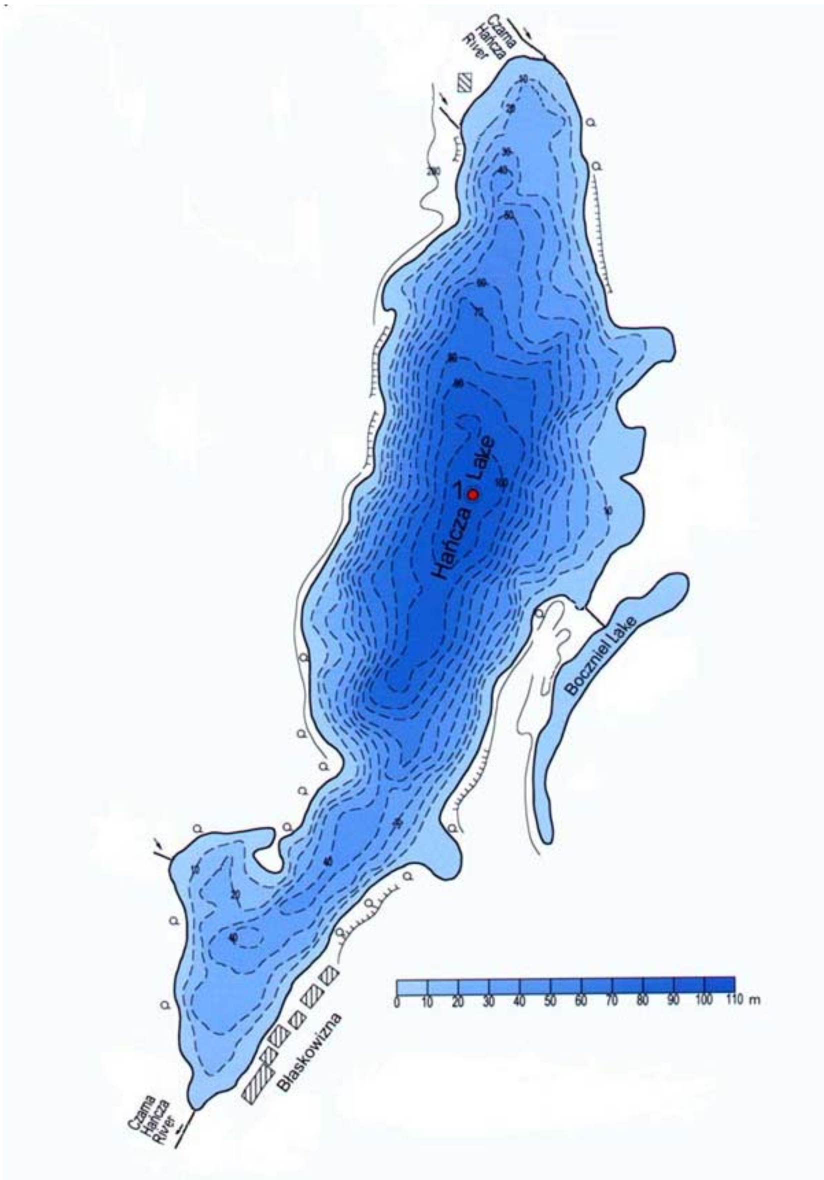
Lake Hańcza. Lake Hańcza is the deepest (108.5 m deep) gutter reservoir not only in Poland but also in the central part of European Depression. It has been recorded on the list of the purest lakes in Poland [2]. The lake surface area accounts for 311.4 ha. It has a volume of 120 364,100 m^3, while the maximum length and width correspond to 4525 m and 1175 m, respectively (see Table 1 for detailed morphometric and limnologic data). The reservoir is characterised by high banks of very steep slopes reaching the depth of 10 m. The lake is located far away from any industrial plants or buildings. It does not provide any water intakes. Direct sources of water pollution [2] have not been reported. High thickness of hypolimnion compared to epilimnion was reported for lake Hańcza. The water is greenish-blue and transparent up to 9 m [29]. The lake is known for high oxygen balance in the deeper layers. Due to its extraordinary natural, geographical, geological, and limnological value, the lake Hańcza has been established a protected reserve in 1963.

Table 1. Some morphometric data on Lake Hańcza, according to the Institute of Inland Fisheries after Ruhee-Stangenberg

Altitude a.s.l.	**229.0 m**
Latitude	**54° 16'**
Longitude	**22° 49'**
Basin	**Czarna Hańcza. Niemen. Bałtyk**
Water surface area	**311.4 ha**
Maximum depth	**108.5 m**
Mean depth	**38.7 m**
Volume	**120364.1 thoudands m^3**
Maximum length	**4525 m**
Maximum width	**1175 m**
Effective length	**4050 m**
Effective width	**1175 m**
Total coastline	**11750 m**
Total basin surface	**39.7 km^2**

Samples Collection. Water samples were collected at monthly intervals from May to October from 1997 till 2000. The samples were collected at the research station located at the deepest site of the lake (108.5 m, station 1 in Fig. 1). Collecting water samples followed a regular vertical pattern: 0-1 cm layer, the depth of 0.3 m, 1m, 2m, 5m, 10m, and finally at systematic 10m intervals down to the bottom. Demersal samples were collected ca. 20-30 cm above the bottom. Surface water samples (0-1 cm) were collected directly to sterile glass containers (V=300 cm^3) with a ground cork. The samples from deeper layers were collected with a Ruttner apparatus and placed in the glass containers of same type. The apparatus had to be used due to necessity of parallel water sampling for chemical analyses. While collecting water samples water temperature measurements with a mercurial thermometer fixed to a Ruttner apparatus were performed, as well as oxygen saturation, pH and visibility by means of a Secchi disk determined. The location of the measurement-control station had been determined as approximation of geographical position measurements by means of ScoutMaster GPS. After collecting the samples were transported in containers kept at 4-6°C to the laboratory where they were immediately analysed. The interval between collecting the samples and performing their analyses never lasted longer than 12 h.

Figure 1. Location of Hańcza Lake (1-water sampling site)



Microbiological analyses. Microbiological analyses consisted in determination of the number of planktonic bacteria by direct counting under a microscope. Membrane SYNPOR filters with pore diameter of 0.6 µm (Chemapol, Prague, Czech Republic) were used for the analyses. Microscopic samples on the membrane filters were prepared according to the technique described by Rodina (1968). Bacteria on the filters were counted in 30 visual fields of the microscope, at 12.5·100 magnification. All morphological forms were counted separately. The results were then recalculated into 1 cm^3 of water. The total number of planktonic bacteria in the investigated samples was calculated according to the formula described by Rodina (1968), i.e.:

$$K = \frac{S \times N}{s \times V}$$

where, the letters stand for:
S –filter working surface (μm^2);
s – surface of visual field of a microscope (μm^2);
N – mean number of bacterial cells in 1 visual field;
V – volume of water filtered (cm^3).

Physicochemical assays of Lake Hańcza water included determination of the following compound and elements content: ammonium nitrogen ($mgN\text{-}NH_4/dm^3$), nitrite nitrogen ($mgN\text{-}NO_2/dm^3$), nitrate nitrogen ($mgN\text{-}NO_3/dm^3$), organic nitrogen ($mgNorg/dm^3$), total nitrogen ($mgNtot/dm^3$), mineral phosphorus ($mgP\text{-}PO_4/dm^3$), organic phosphorus ($mgPorg/dm^3$), total phosphorus ($mgPtot/dm^3$), oxygen (mgO_2/dm^3), and last but not least water pH value. The measurements, compliant with Polish standards, were performed at the Institute of Environmental Protection, Suwałki, and at the Department of Water and Waste Technology of the University of Warmia and Mazury in Olsztyn.

RESULTS

Vertical and seasonal distribution of bacterioplankton (Tables 2,3, Figs. 2,3). In 1997, in Lake Hańcza pelagial waters (at station 1), the number of bacterioplankton ranged from $1.44 \cdot 10^6$ cells/1cm^3 in May at the depth of 108 m up to $8.44 \cdot 10^6$ cells/1cm^3 in July at the depth of 5 m. On average, for the whole aquifer, the lowest number of planktonic bacteria was reported for September, while the highest for July and August and amounted to $2.984 \cdot 10^6$, $4.212 \cdot 10^6$ and $4.151 \cdot 10^6$ of cells/1 cm^3, respectively.

Table 2. Total number of planktonic bacteria in the water of Lake Hańcza in 1997 at station 1 (in thousands of cells/cm^3)

Site	Depth [m]	1997					Mean value
		V	VI	VII	VIII	IX	
1	0	-	2377	4034	4056	4666	-
	0.3	5953	5124	3969	4557	4056	-
	1	4579	6236	3576	3903	4470	-
	2	5691	5844	3096	8003	2333	-
	5	3838	5103	8440	5430	3925	-
	10	3380	5909	6476	3947	4099	-
	20	3096	5168	4775	5364	3380	-
	30	2202	4666	4274	3118	2813	-
	40	-	2638	-	4536	2704	-
	50	2529	2464	3772	2638	2660	-
	60	2137	2508	4841	4056	2399	-
	70	2529	3009	3445	2813	2355	-
	80	1744	3009	3729	4928	2529	-
	90	1941	1788	2529	3467	1657	-
	100	1461	1832	-	3380	2006	-
	108	1440	2028	2006	2224	1697	-
	Mean value	**3037**	**3731**	**4212**	**4151**	**2984**	**3340**

Table 3. Total number of some morphological forms of planktonic bacteria in the water of Lake Hańcza in the years 1998-2000 at station 1 (in thousands of cells/cm^3). (C-cocci, R-rods, B-bacilli, T-total)

	1998																							
Depth [m]	V				VI				VII				VIII				IX				X			
	C	R	B	T	C	R	B	T	C	R	B	T	C	R	B	T	C	R	B	T	C	R	B	T
0	2555	1642	0	4197	1095	1095	182	2372	1460	1277	0	2737	2010	1825	0	3835	2007	1825	0	3832	2190	1830	365	4385
0.3	2920	2190	182	5292	1277	1095	182	2554	1825	1460	182	3467	2190	2007	365	4562	2007	1825	182	4014	1825	2007	182	4014
1	1825	2007	365	4197	2007	3103	365	5475	2737	2007	365	5109	1825	3650	547	6022	1642	3103	365	5110	2177	1825	182	4184
2	1277	2555	365	4197	1825	2920	182	4927	2555	2920	365	5840	1642	2190	182	4014	1460	2555	182	4197	1095	1642	0	2737
5	912	1825	182	2919	1460	2372	0	3832	1460	2007	0	3467	1277	1825	0	3102	912	1825	0	2737	912	1277	0	2189
10	730	1825	0	2555	912	1825	0	2737	1095	1825	0	2920	912	1642	0	2554	730	1277	0	2007	912	1095	182	2189
50	730	1277	0	2007	547	1277	0	1824	730	1095	0	1825	547	1095	0	1642	365	912	0	1277	365	730	0	1095
108	365	547	365	1277	365	547	365	1277	365	364	182	911	182	365	365	912	182	365	547	1094	0	547	365	912
Mean value	**1414**	**1734**	**182**	**3330**	**1186**	**1779**	**160**	**3125**	**1528**	**1619**	**137**	**3285**	**1323**	**1825**	**182**	**3330**	**1163**	**1711**	**160**	**3034**	**1185**	**1369**	**160**	**2713**
%	42	52	6	100	38	57	5	100	47	49	4	100	40	55	5	100	38	57	5	100	44	50	6	100
	1999																							
0	910	217	58	1185	621	347	0	968	1344	318	9	1671	3251	2587	43	5881	2110	405	58	2573	636	1055	304	1995
0.3	1170	633	116	1919	882	2847	43	3772	549	621	29	1199	188	231	15	434	1922	217	15	2154	1460	694	202	2356
1	390	1228	4	1622	910	1402	29	2341	737	434	29	1200	838	5722	275	6835	853	405	29	1287	607	1050	173	1830
2	376	1633	29	2038	694	665	29	1388	535	535	29	1099	376	4855	101	5332	1113	246	43	1402	593	1228	86	1907
5	1662	462	58	2182	506	672	15	1193	361	87	0	448	419	737	72	1228	448	406	29	883	434	2009	145	2588
10	795	708	87	1590	549	1382	0	1931	506	260	9	775	983	1705	58	2746	1113	4248	867	6228	896	390	58	1344
50	1893	882	116	2891	621	723	0	1344	607	145	29	781	665	448	72	1185	751	462	29	1242	607	1358	87	2052
108	332	838	29	1199	737	882	15	1634	332	145	15	492	491	535	29	1055	1315	361	188	1864	376	305	101	782
Mean value	**941**	**825**	**62**	**1828**	**690**	**1115**	**16**	**1821**	**621**	**318**	**19**	**958**	**901**	**2103**	**83**	**3087**	**1203**	**844**	**157**	**2204**	**701**	**1011**	**145**	**1857**
%	52	45	3	100	38	61	1	100	65	33	2	100	29	68	3	100	55	38	7	100	38	54	8	100

Table 3. cont.

	2000																							
0.3	378	850	15	1243	667	697	71	1435	2185	3119	76	5380	1184	1401	98	2683	1942	1826	82	3850	1102	1324	26	2452
1	929	1044	18	1991	826	823	68	1717	1749	1899	161	3809	1362	1396	87	2845	2234	1891	68	4193	1422	1434	34	2890
2	994	767	23	1784	956	777	56	1789	1731	2789	101	4621	1332	1524	109	2965	2747	2806	30	5583	1064	1142	30	2236
5	1235	1278	15	2528	638	505	64	1207	2426	2158	94	4678	1467	1430	60	2957	1930	1928	53	3911	1894	1924	30	3848
10	769	815	37	1621	773	726	60	1559	2022	2256	101	4379	1362	1692	79	3133	2067	2320	82	4469	1187	1300	34	2521
30	616	627	34	1277	1578	1521	45	3144	1786	1599	108	3493	1395	1104	49	2548	1882	2070	48	4000	2206	2085	30	4321
50	399	768	48	1215	1262	1352	68	2682	1630	2326	192	4148	1391	1359	60	2810	1702	1699	82	3483	1199	1303	30	2532
70	550	675	26	1251	-	-	-	-	1882	1856	79	3817	1319	2085	64	3468	2447	2468	60	4975	1446	1454	30	2930
108	929	1055	30	2014	1195	1352	40	2587	992	1364	94	2450	1301	1328	26	2655	2698	2572	94	5364	1271	1377	37	2685
Mean value	**755**	**875**	**27**	**1658**	**987**	**969**	**59**	**2015**	**1823**	**2152**	**112**	**4086**	**1346**	**1480**	**70**	**2896**	**2183**	**2176**	**67**	**4425**	**1421**	**1483**	**31**	**2935**
%	45	53	2	100	50	46	4	100	44	53	3	100	47	51	2	100	49	49	2	100	48	51	1	100

Figure 2. Vertical changes of temperature, oxygen saturation and number of planktonic bacteria (thousands of cells/ 1 cm^3 of water) in the water of Lake Hańcza (at station 1) during summer stratification of the lake in 1997 and 1998. A – temperature, B – oxygen, C – planktonic bacteria

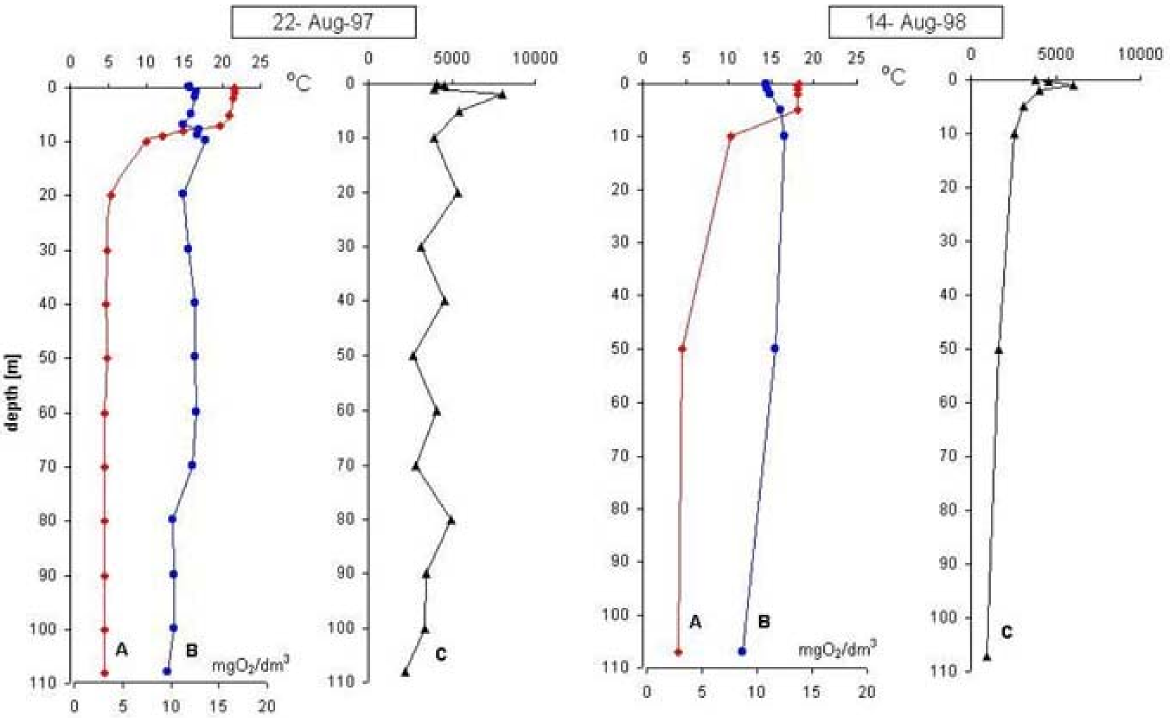
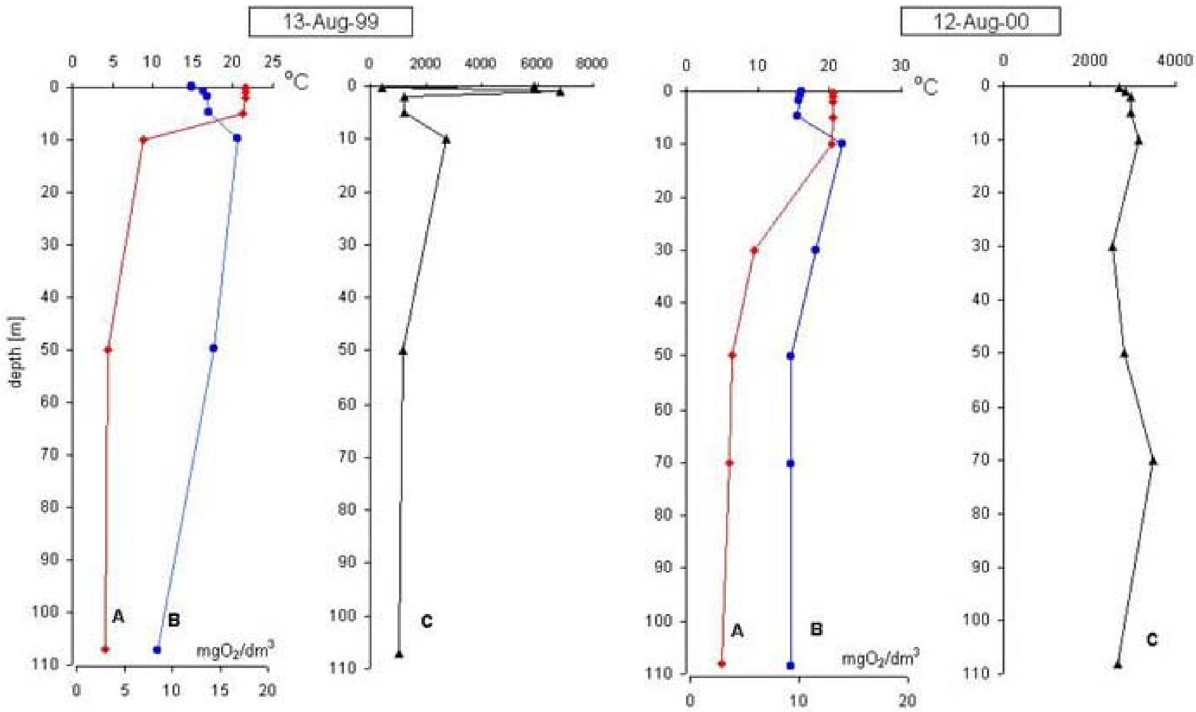


Figure 3. Vertical changes of temperature, oxygen saturation and number of planktonic bacteria (thousands of cells/ 1 cm^3 of water) in the water of Lake Hańcza (at station 1) during summer stratification of the lake in the years 1999 and 2000. A – temperature, B – oxygen, C – planktonic bacteria



During summer stratification, a characteristic vertical distribution of bacterioplankton was observed, characterised by higher numbers identified respectively in the upper and lower layer of epilimnion where it was smaller than $8.00 \cdot 10^7$, and $5.5 \cdot 10^7$ cells/1 cm^3. With depth, rapid changes in the number of such bacteria were observed within the hypolimnion layer (10-100 m), with a descending tendency at the bottom.

In the years 1998-2000 the number of planktonic bacteria varied from $4.34 \cdot 10^5$ of cells/1 cm^3 to $6.835 \cdot 10^6$ of cells/1 cm^3. Their lowest number was reported in August 1999 at the depth of 0.3 m, while the highest one was found the same month at the depth of 1 m. On average, the lowest number of these bacteria was reported in 1999, while the highest one in 1998 when it amounted to $1.959 \cdot 10^6$ and $3.136 \cdot 10^6$ of cells/1 cm^3, respectively.

In the period of summer stratification, the maximum number of bacterioplankton was noted at a depth of 1 m in 1998 and 1999 (6022 and 6835 of cells/1cm^3, respectively), and in the hypolimnion layer at 70 m in 2000 (3468 of cells/1cm^3). From May to September 1998, the mean number of planktonic bacteria slightly varied from $3.034 \cdot 10^6$ to $3.330 \cdot 10^6$ cells/1 cm^3. A higher fall in their number below 2713 cells/1 cm^3 was reported not sooner than in October. In 1999, the lowest mean number of bacterioplankton in the entire aquifer was observed in July and the highest in August ($9.58 \cdot 10^5$ and $3.087 \cdot 10^6$ cells/1 cm^3); while in 2000 the respective values were reported in May (lowest) and in July and September (highest) when they reached $1.658 \cdot 10^6$,$4.086 \cdot 10^6$ and $4.425 \cdot 10^6$ cells/1 cm^3, respectively. In the years 1998 and 1999 surface water (0-1 cm) were usually less abundant in these bacteria, while at the depths of 03-1.0 and 2.0 m their number increased several times. In 2000, a vertical stratification of bacterioplankton was more of a micro-zonal character, though the number of these bacteria was also lower in the surface water than at the depth of 0.3 m. Only in July their number was higher in the layer of surface water. Occasionally, a higher number of bacterioplankton was reported in the near bottom waters.

Qualitative composition of bacterioplankton (Table 3). Qualitative composition of bacterioplankton was determined in the years 1998-2000. Three morphological forms of such micro-organisms were identified: cocci, rods, and bacilli. Cylindrical rods forms prevailed and constituted from 33 % to 68 % of the total bacterioplankton number in July 1999 and August 1999, respectively. The cocci ranged from 29 % to 65 % (August 1999 and July 1999), while the bacilli – from 1 % to 7-8 % of the total planktonic bacteria number in June 1999 and October 2000 and in September and October 1999, respectively. Neither a correlation was found between the number of particular morphological forms of these bacteria and the season, nor any regularity in their vertical concentration was observed in particular months of the experimental period. Occasionally, a higher number of bacilli was reported in near bottom water.

Thermal-oxygen relations (Figs. 2, 3). In the summers of the experimental period, a clear thermal stratification of the lake was observed. In August of 1997, 1998 and 2000, warm epilimnion reached 5 m, and in 1999 it went down to 7 m. The temperature fluctuated in this water layer and the following values were recorded in middle-August of the 3 consecutive years 1997, 1998, 1999: 21.6-19.6°C (22nd August), 18.1°C (14th August), and 21.6-21.3°C (13th August). Below a metalimnion layer of a thickness of several meters and mean temperature gradient of ca. 3°C/m occurred. In the cold hypolimnion temperature decreased gradually from 8.3°C, 8.0°C, and 9.5°C at the respective depths of 12 m , 11 m and 10 m (1997 and 1998, 1999 and 2000), to 4.3°C in the near bottom water. Spring circulation was reported to begin in April or May, while autumn circulation in September, October or November. Measurements of oxygen saturation at the depth of 50 m yielded 6.5 mg and 16.1 mg O_2/dm^3 in October 2000 and spring 1999, respectively. In spring and autumn the oxygen saturation was approximately equal at all analysed depths, with a descending tendency at the bottom at (depth of 107 m (Figs. 2,3). During summer stagnation, the oxygen saturation in epilimnion did not fall below 8.5 mg/dm^3. Moreover, a higher concentration of this element equal to 12.5/dm^3 and 16.9 mg/dm^3, dated to 14th August 1998 and 13th August 1999, respectively, was reported in the lower part of thermal jump, i.e. in the water layer from 10 m depth.

The content of hydrogen ions (Table 4). The reaction of Lake Hańcza water was neutral or slightly alkaline and its pH ranged from 7.35 to 8.70. A higher pH in the upper layers was reported. Values of this parameter decreased with depth.

Table 4. Some physico-chemical data on the water of Lake Hańcza in 1997, 1999, and 2000

Season of the year	SPRING					SUMMER					AUTUMN				
Site - depth	Lake														
	1-0.3	1-5	1-10	1-50	1-108	1-0.3	1-5	1-10	1-50	1-108	1-0.3	1-5	1-10	1-50	1-108
	1997														
Temperature °C	9.6	8.8	7.4	4.7	4.3	21.6	20.8	10.0	4.9	4.4	15.2	15.1	12.5	4.9	4.3
Oxygen mg O_2/dm^3	10.8	11.3	10.6	11.0	10.8	9.5	9.6	10.1	10.3	9.7	9.4	9.8	9.5	9.4	9.0
pH	7.45	7.35	7.35	7.35	-	8.65	8.7	8.4	7.75	-	8.4	8.55	8.25	7.75	-
	1999														
Ammonium nitrogen mgN-NH4/dm^3	0.010	0.01	0.0	0.0	0.040	0.0	0.007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01
Nitrite nitrogen mgN-NO2/dm^3	0.007	0.010	0.020	0.010	0.070	0.010	0.020	0.092	0.010	0.010	0.005	0.002	0.0	0.002	0.002
Nitrate nitrogen mgN-NO3/dm^3	0.021	0.110	0.250	0.300	0.301	0.060	0.050	0.004	0.240	0.318	0.014	0.018	0.025	0.035	0.041
Organic nitrogen mg/dm^3	0.220	0.230	0.220	0.250	0.300	1.010	0.800	0.750	0.900	0.840	0.616	0.615	0.502	0.448	0.448
Total nitrogen mg/dm^3	0.248	0.36	0.49	0.56	0.711	1.08	0.877	0.846	1.15	1.168	0.635	0.635	0.527	0.485	0.501
Mineral phosphorus mg P-PO_4/dm^3	0.002	0.002	0.002	0.005	0.008	0.03	0.04	0.044	0.033	0.046	0.018	0.012	0.024	0.022	0.028
Organic phosphorus mg/dm^3	0.025	0.033	0.032	0.022	0.04	0.033	0.028	0.045	0.033	0.024	0.032	0.02	0.015	0.048	0.029
Total phosphorus mg/dm^3	0.027	0.035	0.034	0.027	0.048	0.063	0.068	0.089	0.066	0.07	0.05	0.032	0.039	0.07	0.057
Temperature °C	4.7	4.1	3.9	3.8	4.0	21.6	21.3	4.4	4.4	4.1	9.4	9.4	9.4	4.8	4.4
Oxygen mgO_2/dm^3	9.8	13.4	13.2	16.1	14.3	12.1	13.8	16.9	14.4	8.3	10.72	9.9	9.9	8.48	6.72

Table 4. cont.

	2000														
Ammonium nitrogen mgN-NH4/dm^3	0.01	0.01	0.0	0.0	0.03	0.0	0.008	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0
Nitrite nitrogen mgN-NO2/dm^3	0.008	0.01	0.01	0.01	0.008	0.002	0.003	0.0006	0.001	0.0	0.0	0.0	0.0	0.0	0.0
Nitrate nitrogen mgN-NO3/dm^3	0.222	0.331	0.61	0.349	0.352	0.206	0.091	0.222	0.109	0.325	0.064	0.076	0.058	0.307	0.273
Organic nitrogen mg/dm^3	0.55	0.55	0.56	0.45	0.42	0.56	0.66	0.56	0.6	0.67	0.56	0.56	0.504	0.392	0.448
Total nitrogen mg/dm^3	0.79	0.901	1.18	0.809	0.81	0.768	0.762	0.7826	0.73	0.995	0.624	0.636	0.562	0.699	0.721
Mineral phosphorus mg P-PO_4/dm^3	0.004	0.003	0.003	0.003	0.001	0.009	0.058	0.01	0.018	0.025	0.018	0.028	0.03	0.016	0.03
Organic phosphorus mg/dm^3	0.029	0.06	0.057	0.036	0.044	0.066	0.032	0.068	0.045	0.038	0.027	0.02	0.018	0.014	0.012
Total phosphorus mg/dm^3	0.033	0.063	0.06	0.039	0.045	0.075	0.09	0.078	0.063	0.063	0.045	0.048	0.048	0.03	0.042
Temperature °C	15.8	15.3	6.2	4.0	4.2	20.5	20.3	20.2	6.4	4.9	10.2	10.1	10.3	4.2	4.3
Oxygen mg O_2/dm^3	10.9	11.63	12.08	11.74	11.46	10.24	9.92	13.92	9.92	9.28	10.72	10.88	10.88	10.72	6.56

The content of ammonia, nitrite, nitrate, and total nitrogen (Table 4). The content of ammonia nitrogen changed within the values limited by the detectable limit, i.e. less than 0.001 mg $N\text{-}NH_4/dm^3$, and the value of 0.040 mg $N\text{-}NH_4/dm^3$. Such values were found in most of samples in all experimental seasons of 1999 and 2000, and in spring for 108-m deep water, respectively. The content of nitrite nitrogen ranged from the detectable threshold value of 0.001 mg $N\text{-}NO_2/dm^3$ recorded in the 10-m water layer in October 1999, regardless the depths in autumn, and in water at the depth of 50 and 108 m in August 2000, to the maximum of 0.092 mg $N\text{-}NO_2/dm^3$ measured in water at 10 m depth in August 1999. The content of nitrate nitrogen varied from 0.004 mg $N\text{-}NO_3/dm^3$ in 10 m deep water, in August 2000, up to 0.352 mg $N\text{-}NO_3/dm^3$ at the depth of 108 m in spring 2000, whereas the total nitrogen content changed between 0.248 mg N_{tot}/dm^3 at a depth of 0.3 m (April 1999) to 1.168 mg N_{tot} $/dm^3$ at the depth of 108 m in summer 1999. In spring and winter 1999 and 2000, higher concentrations of ammonia nitrogen were found in the near bottom water, while in summer – at 5 m depth. The contents of nitrite and nitrate nitrogen in the examined samples of Lake Hańcza waters demonstrated regularity neither in the vertical, nor in the seasonal distribution, though the total nitrogen content tended to increase with depth.

The content of mineral and total phosphorus (Table 4). Over the research period the mineral phosphorus content ranged from 0.001 mg $P\text{-}PO_4/dm^3$ (108 m depth in spring) up to 0.046 mg $P\text{-}PO_4/dm^3$ in August 1999. The content of organic phosphorus varied between 0.012 mg P_{org}/dm^3 at the depth of 108 m in autumn 2000, up to 0.068 mg P_{org}/dm^3 at the 10 m depth in August 2000. Total phosphorus content varied between 0.027 mg P_{tot}/dm^3 found at 0.3 and 50 m depth in spring 1999, to 0.089 P_{og}/dm^3 at 10 m depth in August 1999. Slightly higher concentrations of the examined forms of phosphorus were reported regularly for demersal layers of water, and occasionally, depending on the season and year of the study, also for the surface layers.

Statistical analysis of the results (Table 5) of bacterioplankton and water temperature points to a high or even very high correlation for the samples collected in 1997 (r_{xy}=0.549) and 1998 (r_{xy}=0.857). A weak positive correlation was also observed between the number of planktonic bacteria and oxygen saturation in the waters of Lake Hańcza during summer lake stratification in 1996 (r_{xy}= 0.228) and 1998 (r_{xy}= 0.184). What is more, a negative correlation was found between the number of bacterioplankton and depth, namely r_{xy}= -0.545, r_{xy}= -0.792 and r_{xy}=-0.362 in 1997, 1998, and 1999, respectively. It may be explained by lower oxygen saturation, lower temperature and usually lower content of easily-available organic matter inhibiting development of micro-organisms in the deeper layers of water.

Table 5. Correlation coefficient between temperature (X_1), oxygen saturation (X_2), and depth (X_3) versus the number of bacterioplankton for the examined habitat of Lake Hańcza

X	Site-1			
	Numer of bacteria (y)			
	Year			
	1997	1998	1999	2000
Temperature, X_1	0.549	0.857	0.344	0.028
Dissolved oxygen, X_2	0.228	0.184	0.092	0.043
Depth, X_3	-0.546	-0.792	-0.362	0.023

DISCUSSION

The obtained results of physico-chemical analyses for Lake Hańcza waters proved that all the investigated water samples meet the standards specified in the Directive of Minister for Environmental Protection, Natural Resources and Forestry dated November 5, 1999 (on classification of waters and requirements to be met by waste introduced into water and soil regarding $N\text{-}NH_4$, $N\text{-}NO_2$, $N\text{-}NO_3$, N mineral phosphorus, total phosphorus and oxygen contents) and correspond to I class purity waters. The number of bacterioplankton differed highly both with regards to water and individual months of the experimental period.

The total number of planktonic bacteria in Lake Hańcza, namely $4.34 \cdot 10^5$-$8.44 \cdot 10^6$ cells/1 cm^3, was found to be slightly lower in comparison to other lakes of a similar trophic status [9,11,17,28]. Throughout the experimental period (1997-2000) a remarkable variability was observed in the number of such bacteria occurring in the lake; it seems typical for pure waters as other research supports [6,17]. A significant impact on the number, structure and variability of bacterioplankton has been ascribed to the content and availability of organic matter [3,8,21,27]. In the pure, protected Lake Hańcza, surface flows from the basin or products of other micro-organism metabolism provide the main source of biogenes. In lakes with a low trophy, algae and associated numerous zooplankton [13] are considered to be the main reservoir of organic matter [19], especially in the blooming period [7,21]. Bacteriocytic organisms [8,14,16] can be also responsible for modifying the number of planktonic bacteria.

The enumerated factors may, to a high extent, evoke an influence on considerable quantitative and qualitative diversity of bacterioplankton reported for particular research seasons, as well as its vertical distribution in the water of Lake Hańcza. Usually, throughout the experimental period, lower numbers of bacterioplankton were reported in the surface water layer (0-0.3 m) that could be related to bactericidal activity of UV radiation [14,17]. In the period of summer stratification of the lake, higher concentrations of these bacteria were usually noted at depths of 2, 5 or 10 m. An increase in the planktonic bacteria content observed in the lower layer of warm trophogenic zone, is typical for lake stratification due to an increase in water density gradient, water temperature, and accumulation of organic matter in this part of a lake. Świątecki [25] has reported that with a temperature increased by 10°C, the number of planktonic bacteria doubles, on average. Higher number of bacterioplankton in summer months at specific depths and the whole capacity of Lake Hańcza may also be related to development and atrophy of phyto- and zooplankton that provides nutrients to bacterioplankton [12,17]. Well-documented decrease in bacterioplankton number down the depth of Lake Hańcza, is characteristic for oligotrophic lakes [9]. Similar regularity was reported by Niewolak and Kaczor [17] in oligotrophic Lake Wukśniki, where such a phenomenon was observed and explained by the lack of higher concentration of detritus in these water layers. In other lakes [9,15], higher concentrations of bacteria are usually reported in the over-sediment layer of water. In Lake Hańcza, the phenomenon was reported to occur a few times, namely in June 1997, June and September 1999, and May and September 2000.

In the experimental seasons, a higher number of bacterioplankton was reported in spring, which most likely resulted from the surface flows to the lake, and in summer that was attributed to the increased availability of organic matter content due to development and atrophy of other groups of organisms. The distinctive decrease in the number of planktonic bacteria in autumn can be explained by decreasing temperature and content of available organic matter, and/or by the pressure of bacteriocytic organisms [8,12,13,24]. Factors that determine the number of bacterioplankton also affect its morphological composition. The size of bacteria may provide a good indicator for the state of an ecosystem [1]. Lake Hańcza is dominated by a form of cylindrical rods which constitute from 33% to 68% of total bacterioplankton. A similar structure of these bacteria occurs in other Mazurian Lakeland [25,26,8]. The percentage of cocci, ranging between 29 and 69%, was also of significant importance. According to Godlewska-Lipowa [5], spherical forms of bacteria dominate in lakes with a low trophy, and the number of cylindrical bacteria tends to increase with an increased trophy. Lakes were less abundant in cylindrical forms of bacilli, which demonstrated insignificant concentration (lower than 8%) only at the bottom of the aquifer.

CONCLUSIONS

1. The results of physico-chemical analyses proved purity of the waters of Lake Hańcza.
2. The determined number of bacterioplankton, as well as its morphological structure, namely prevailing content of cylindrical rod forms, also support water purity in Lake Hańcza.
3. Over the experimental period vertical distribution of planktonic bacteria usually demonstated micro-zonal character indicating a 'focal' distribution of organic and mineral matter.
4. Higher number of bacterioplankton was reported in surface or near bottom water of the lake, which may be attributed to organic matter of auto- or allochtonic origin accumulating in the zones.

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