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POLLUTION DEGREE AND SANITARY STATE INDICATOR BACTERIA AS THE INDICATORS OF THE PURITY OF LAKE HAŃCZA WATERS

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BAKTERIE WSKAŹNIKOWE STOPNIA ZANIECZYSZCZENIA I STANU SANITARNEGO JAKO INDYKATORY CZYSTOŚCI WÓD JEZIORA HAŃCZA

W pracy przedstawiono wyniki badań sanitarno-bakteriologicznych wód jeziora Hańcza, jego dopływów i odpływu. Badania prowadzono w latach 1998–2000 od kwietnia do października na 9 stanowiskach usytuowanych na jeziorze (pelagial, wody przybrzeżne, strefa ekotonalna), 4 stanowiskach usytuowanych na dopływach (rzeka Czarna Hańcza, Stara Hańcza, dopływ „Spod Przełomki" i z jeziora Boczniel) oraz jednym na rzece Czarnej Hańczy odpływającej z jeziora Hańcza. Bakteriologicznymi wskaźnikami były bakterie TVC 22°C i 37°C, bakterie TC, FC, i FS. W wodzie jeziora Hańcza i w wodzie odpływu liczby badanych bakterii wskaźnikowych były najczęściej typowe dla czystych wód powierzchniowych (I klasa czystości). W wodzie cieków dopływających do jeziora Hańcza liczby oznaczanych drobnoustrojów były znacznie wyższe niż w wodzie jeziora i odpowiadały przeważnie wartościom typowym dla wód nieznacznie zanieczyszczonych (II klasa czystości) i wyraźnie zanieczyszczonych (III klasa czystości). W całym okresie badawczym wyższe liczebności bakterii wskaźnikowych stwierdzano zazwyczaj w miesiącach letnich, sporadycznie więcej było ich w innym okresie. Wzrost ich liczebności w kolejnych latach badań w wodzie na wyznaczonych stanowiskach może wskazywać na coraz intensywniejsze oddziaływanie czynników allochtonicznych na wody jeziora Hańcza.

Summary

This paper presents the results of a sanitary and bacteriological study of Lake Hańcza and its influents and an outflow. The study was conducted from April to October in the years 1998–2000, at 9 sites situated on the lake (pelagic zone, near-shore waters, ecotonal zone), 4 sites situated on the influents (the Czarna Hańcza and Stara Hańcza Rivers, the Spod Przełomki stream and the stream flowing from Lake Boczniel) and one situated on the Czarna Hańcza River, which flows out of Lake Hańcza. Total Viable Count at 20°C (TVC 20°C) and Total Viable Count at 37°C (TVC 37°C) were used as indicators of pollution, while Total Coli (TC), Faecal (thermotolerant) Coli (FC) and Faecal *Streptococcus - Enterococcus* (FS) – as indicators of the sanitary state. The indicator bacteria number in the waters of Lake Hańcza and in the outflowing waters were usually typical of clean surface waters (purity class I). The bacteria number in the water inflowing to Lake Hańcza was much higher than that measured in the water of the lake and was usually similar to the values typical of slightly polluted (purity class II) and heavily polluted waters (purity class III). Throughout the study period, higher indicator bacteria numbers were measured in summer months; in other periods a higher number was found only sporadically. Its increase in subsequent years of study in the water at the established sites may be an indication of the increasing effect of allochtonic factors on the waters of Lake Hańcza.

INTRODUCTION

A number of clean or only slightly polluted oligotrophic lakes in Poland and around the world are decreasing each year. Their eutrophication is largely affected by growing anthropopressure and, linked with it, the expansion of agriculture, industry, urbanization and tourism. Bacteria can be considered a good parameter for a quick diagnosis and assessment of any adverse changes occurring in aquatic ecosystems and for taking protective measures. The sanitary state and degree of pollution of a lake can be reflected in the number of bacteria which permanently live as saprophytes in the digestive tract of humans and higher animals. Their presence in water is an indicator of it being polluted with faeces and of a potential simultaneous occurrence of other pathogens from sick individuals. Bacteria, referred to as sanitary indicators, constitute a large group which include: total coliforms, faecal (thermotolerant) coliforms, faecal streptococci and anaerobic sulphite-reducing spore forming bacteria (*Clostridium perfringens*) [1]. This study aimed at examining the sanitary and bacteriological state of Lake Hańcza – the deepest in Poland – its influents (the Czarna Hańcza and Stara Hańcza Rivers, the Spod Przełomki stream and the one from Lake Boczniel) and that of the Czarna Hańcza River, which is the lake's outflow. Although a nature reserve, the lake is not free from auto- or allochtonic pollution which results from the fact that the protective zone around the lake is not wide and the bans introduced around it do not include the flow of sewage from villages situated within the lake drainage area or flowing into it along small streams and the Czarna Hańcza River [10].

STUDY AREA

Lake Hańcza is situated in the highest, north-eastern part of the Wschodnio-Suwalskie Lake District in the upper part of the Czarna Hańcza River (Fig. 1). It is a long, narrow post-glacial channel lake, the deepest one of this type in Poland and in the middle part of the European Lowlands. It has high, steep banks, with numerous boulders, with high embankments falling steeply 10 m below the water surface. The vegetation of the lake is scarce; the bottom is furrowed with ditches, holes and steep ravines. Lake Hańcza is a dimictic lake with thermal stratification of a positive heterograde type, with an increase in oxygen content in metalimnion and absence of deficit near the bottom [4, 9, 10]. Its characteristic feature is a high hypolimnion-to-epilimnion thickness ratio; the water is greenish-blue in color, its transparency reaches 9 m [26]. The lake is far from any industrial plants, urban areas and there are no water intakes or direct registered sources of pollution. The lake is supplied by the Czarna Hańcza River and several small streams, which are active mainly during periods of intensive rainfalls which collect waste material from cattle grazing on nearby pastures and meadows and from the few households. Because of its high natural, geological and limnological value, it has been a reserve since 1963 and in 1976 it was included in the Suwalski Landscape Park. Some of the morphometric data for the lake are given in Table 1.

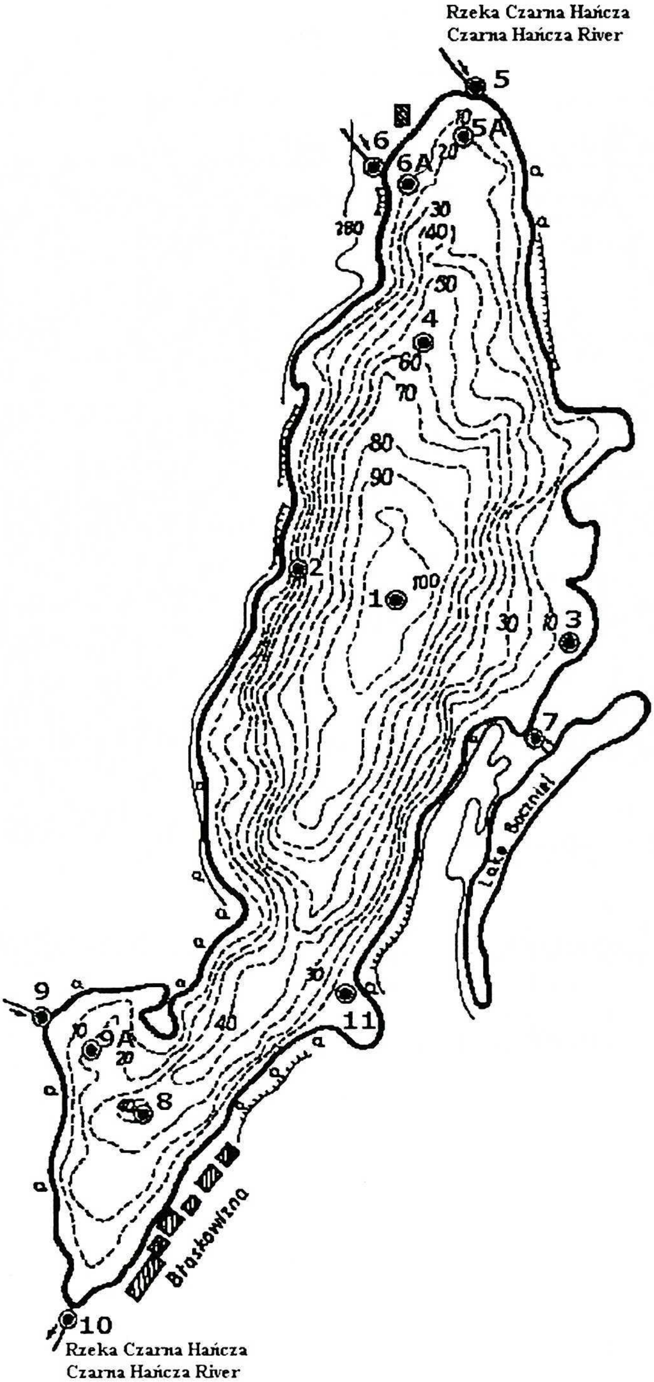


Fig. 1. Location sketch of the Hańcza Lake (1, 2, 3...11 – water sampling sites)

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
Maxim um depth	108.5 m
Mean depth	38.7 m
Volume	120 364 100 m^3
Maximum length	4525 m
Maximum width	1175 m
Effective length	4050 m
Effective width	1175 m
Total coastline	11 750 m
Total basin surface	39.7 km^2

MATERIALS AND METHODS

Sample taking. Samples were taken on days one month apart from each other from April to October in the years 1998–2000. Three sites were selected for sample taking in the pelagic zone (site 1, 4, and 8), three in the near-shore zone (sites 2, 3, 11) of Lake Hańcza and three in the area where the inflowing waters mix with the lacustrine waters (sites 5A, 6A, 9A). Additionally, four sites were selected on the streams flowing into the lake (sites 5, 6, 7, 9) and one – on the Czarna Hańcza River, which flows out of it (site 10). The sites in the pelagic zone were situated close to the deepest places in Lake Hańcza (108.5 m, 50 m and 40 m), and the sites in the near-shore zone were situated on the eastern and western side of the littoral zone. The sampling sites in the mixing zone of the inflowing waters with the lacustrine waters were situated several meters away from the estuaries of the streams to the lake. The sites on the streams flowing into the lake were situated about 100 m from the estuary. The site on the Czarna Hańcza River, flowing out of the lake, was situated about 10 m away from it. The geographic position of the sampling sites was earlier established as an approximation of the geographic position measurements done with a ScoutMaster GPS device according to the GPS (Global Position System) standards. Samples of water were taken from the surface layer (0.3 m) and in the pelagic zone of Lake Hańcza – additionally at the depth of 0–1 cm and 1, 2, 5, 10, 20, 30, 50 and 108 m. Samples of surface water (0–1 cm and 0.3 m) were taken directly to sterile 250 cm^3 glass vessels, samples from deeper and demersal layers (0.3–0.5 m above the bottom) with a 2 dm^3 Ruttner apparatus to similar vessels. A total of 543 samples of water were taken during the study period. The samples to be examined microbiologically were immediately placed in thermobags with inserts, enabling them to be cooled down to 4–6°C. No more than 12–18 hours passed between the times of sample taking to the analyses.

Microbiological examination. Bacteriological analyses comprised the following:

1. Total viable counts (CFU/1 cm^3) of psychrophilic bacteria on broth agar after 72 h incubation at 22°C (TVC 22°C);
2. Total viable counts (CFU/1 cm^3) of mesophilic bacteria on broth agar after 24 h incubation at 37°C (TVC 37°C);
3. Total number (MPN/100 cm^3) of coliforms (TC) on Eijkman medium after 48 h incubation at 37°C;
4. Number (MPN/100 cm^3) of faecal (thermotolerant) coliforms (FC) on Eijkman medium after 24 h incubation at 44.5°C;
5. Number (MPN/100 cm^3) of faecal streptococci (FS) on Slanetz and Bartley medium after 72 h incubation at 37°C.

Each measurement was done in three simultaneous repetitions with the same sample of water. TVC 22°C and 37°C were measured according to the guidelines laid down in the relevant Polish Standard [21]. MPN/100 cm^3 TC, FC and FS were measured according to the guidelines laid down in the A.P.H.A. Standard Methods [1] and read out from Mc Crady's charts.

RESULTS

Indicator bacteria of the pollution level. TVC 22°C and TVC 37°C in the examined samples of water (pelagic zone, near-shore waters, ecotonal zone, the outflowing river) ranged from 15 cfu/cm^3 at site 1 in June 1998 to 4280 cfu/cm^3 at site 8 in August 2000 and from 1 cfu/cm^3 at site 2 and 8 in April 1999 to 1560 cfu/cm^3 at site 8 in June 2000, respectively. The number of TVC 22°C and TVC 37°C bacteria in the water of the streams which flow into Lake Hańcza was much higher than that found in Lake Hańcza itself and ranged from 85 cfu/cm^3 at site 7 in April 1998 and at site 9 in September 1999 to 89100 cfu/cm^3 at site 9 in September 2000 and from 25 cfu/cm^3 at site 7 in April 1998 and 1999 to 7850 cfu/cm^3 at site 5 in June 1999, respectively.

The TVC 22°C to TVC 37°C ratio (which enables the classification of water) ranged from 0.1 at site 4 in 2000 to 124 at site 8 in the same year of study. In the streams which flow into the lake it ranged from 0.04 at site 9 in 1999 to 2635 at site 6 in 2000. In most samples of water taken from Lake Hańcza and the streams flowing into and out of it, it was below 10. The lowest percentage of water samples with this ratio of the bacteria in the pelagic zone, near-shore zone and the river flowing out of the lake was found in 1998, (in 2000 in the inflowing streams) and the highest was in 2000 (in 1999 in the outflowing streams).

Indicator bacteria of the sanitary state. The sanitary bacteria number (TC, FC, FS) in the examined water samples taken from Lake Hańcza and from the Czarna Hańcza River, which flows out of the lake, ranged from < 3 to 1400 MPN/100 cm^3 at various sites, depths and during various study periods. The FC number in the examined water was the lowest and usually did not exceed 25 MPN/100 cm^3; FS were the most numerous, with the highest number recorded in October 1998, in May 1999 and in June 2000. The number of bacteria used as indicators of a sanitary state in the streams flowing into Lake Hańcza was significantly lower than in the lake itself. The TC ranged from 9 MPN/100 cm^3 of water at site 7 in April 1998 to 14000 MPN/100 cm^3 of water at site 5 and 9 in August 2000. The FC ranged from < 3 at various sites in various periods of study to 1400 MPN/100 cm^3 of water at site 5 in July and August 2000. The FS ranged from < 3 at site 6 in September 1999 to 14000 MPN/100 cm^3 of water at sites 5, 6 and 9 in October 1998 and July 1999, respectively. The FS in all samples of water taken from Lake Hańcza and from the inflowing and outflowing streams was usually higher than the FC, which indicates the animal origin of pollution. According to Geldreich [6] the FC/FS ratio which is lower than 0.7 (87.5% of samples of water taken from the streams flowing into Lake Hańcza and 85% of such samples from the Czarna Hańcza River which flows out of it) indicates the animal origin of the pollution, a ratio lying between 0.7 and 4.0 indicates a mixed origin (10% of samples of water taken from the streams flowing into Lake Hańcza and 15% of such samples from the Czarna Hańcza River which flows out of it), and a ratio above 4 (2.5% of samples of water taken from the streams flowing into Lake Hańcza) indicates a human origin.

Statistical analysis. In order to obtain information concerning potential differences between bacteria numbers at various sites and in various periods of study, a single factor analysis of variance (ANOVA) was conducted, verifying the hypothesis of the equality of means (H_0:$x_1 = x_2 = ... = x_5$) at the level of significance $\alpha = 0.05$, assuming that the variance for the numerousness of the bacteria groups under study are uniform. The uniformity of variance was tested with Levene's test. If the test proved significant, the hypothesis was rejected. Next, the Kruskal-Wallis test was applied, which is a non-parametric equivalent of the analysis of variance [23]. This paper presents only the general statistical relationships, which are shown below; the detailed results can be obtained from the authors.

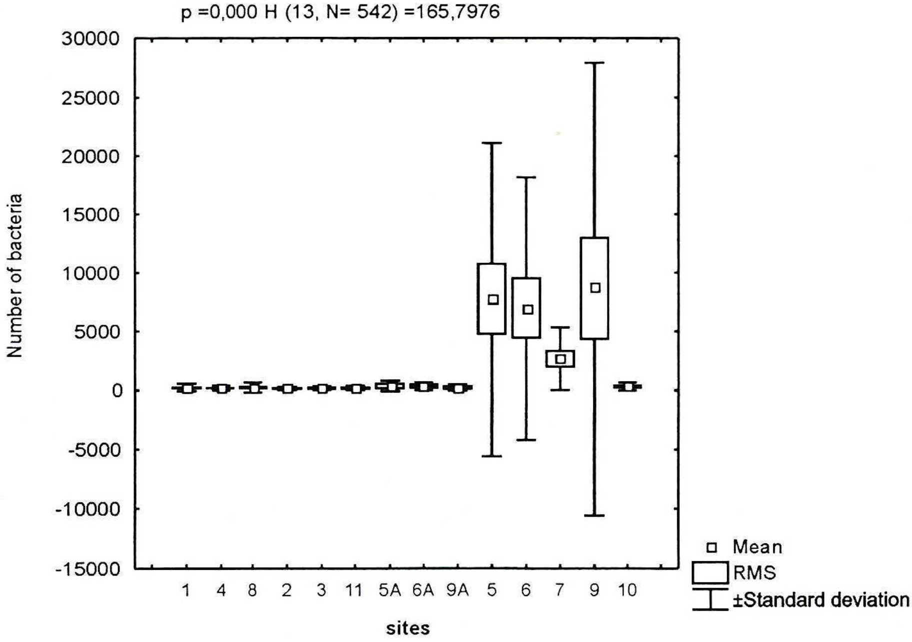
The mean numerousness of the bacteria used as indicators of the sanitary state in Lake Hańcza and in the inflowing and outflowing streams, measured at various sites, varied significantly from each other (except for the TVC 22°C and FS number at the sites situated only on the lake). Higher TVC 22°C, TVC 37°C and FC bacteria number in the lake water was found at sites 5A and 9A in the ecotonal zone, more TC and FC bacteria were found at sites 3 and 11, while more FS bacteria – at sites 1, 4, 8 and 11. The highest values for all the measured bacteria were found at sites 5 and 9 (the inflowing Czarna Hańcza River and the Spod Przełomki stream) (Fig. 2, 3).

Significant differences were found for particular months of study between mean numbers of the bacteria groups under study, except for the FC bacteria in the lake water and the FS bacteria in the water of inflowing streams. Their highest values were usually recorded in spring and summer (June, July, and August), only the TVC 22°C number was higher in September in the inflowing streams and that of FS was higher in October in the inflowing and outflowing streams.

The mean number of the indicator bacteria (except the TC bacteria) in particular years of study differed significantly. In the water of Lake Hańcza and in inflowing and outflowing streams it was found to increase in consecutive years of study. The highest mean numbers of the bacteria groups under study were found at the selected sites in 2000 (Fig. 4, 5), except the mean number of TC in the water of Lake Hańcza and FS in the waters of inflowing and outflowing streams, which were higher in 1998.

The bacteria used as indicators of the level of pollution and the sanitary state and the classification of surface waters. According to the latest Regulation by the Minister of Environmental Protection, concerning the classification of surface waters [22], TC and FC bacteria are used as microbiological indicators. The pelagic waters of Lake Hańcza, the near-shore waters, the inflowing zone water (ecotone) and the waters of the Czarna Hańcza River,

a)



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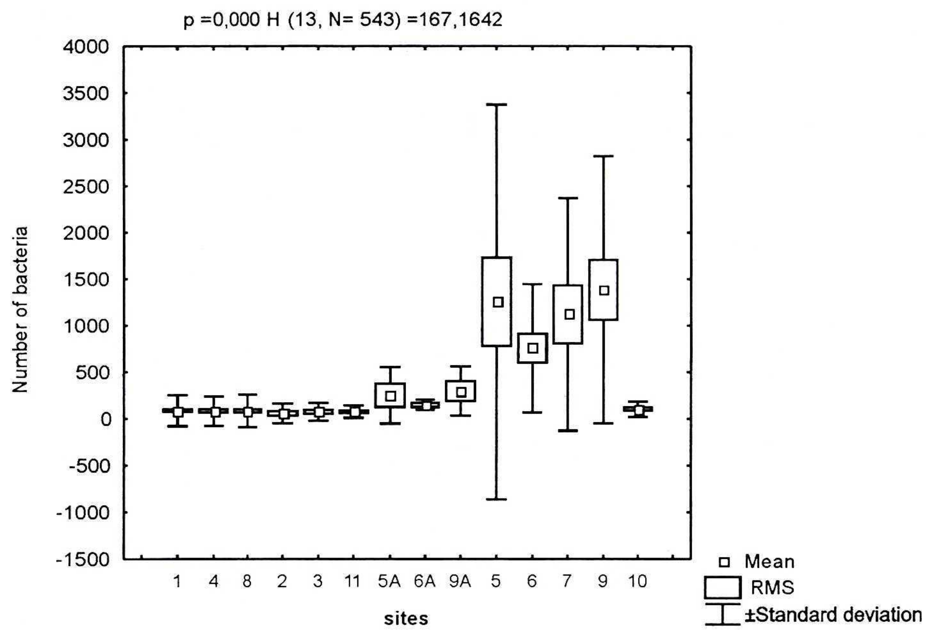
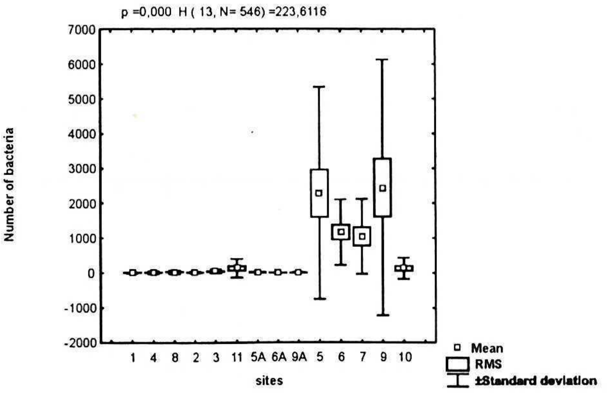


Fig. 2. Averages of numbers (± standard deviation and ± random mean square-RMS) of total viable counts (CFU/cm^3) on the broth agar at a) 22°C (TVC 22°C) and b) 37°C (TVC 37°C) in water on particular sites; independent variable (assembling) – sites; ANOVA test of Kruskal-Wallis ranges

a)



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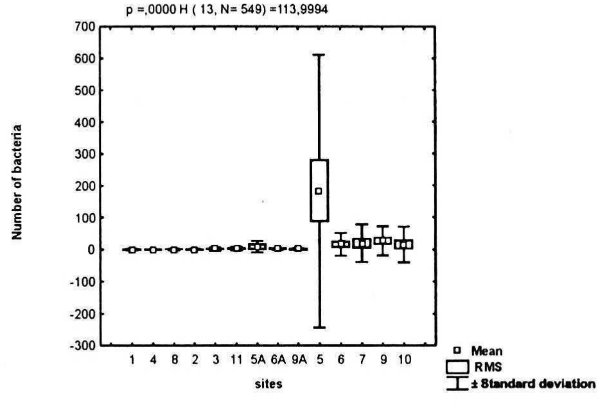

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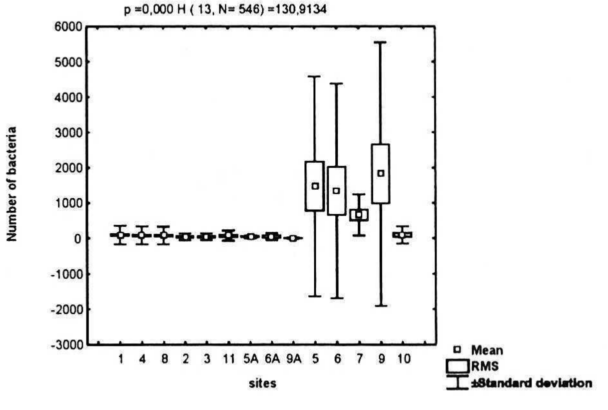
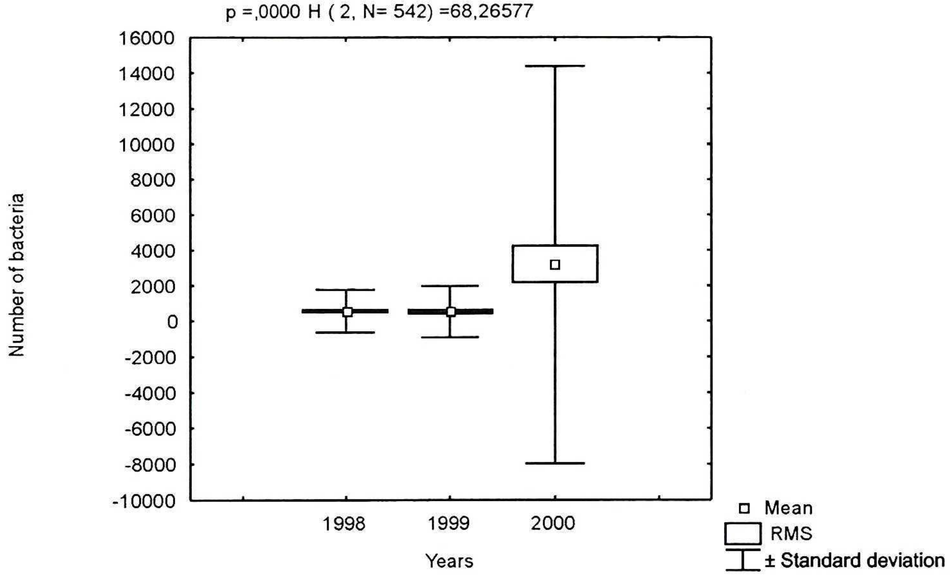


Fig. 3. Averages of number (± standard deviation and ± random mean square-RMS), (MPN/100 cm^3): a) total coliforms (TC), b) faecal (thermotolerant) coliforms (FC) and c) faecal streptococci (FS) in water on individual sites; independent variable (assembling) – sites; ANOVA test of Kruskal-Wallis ranges

a)



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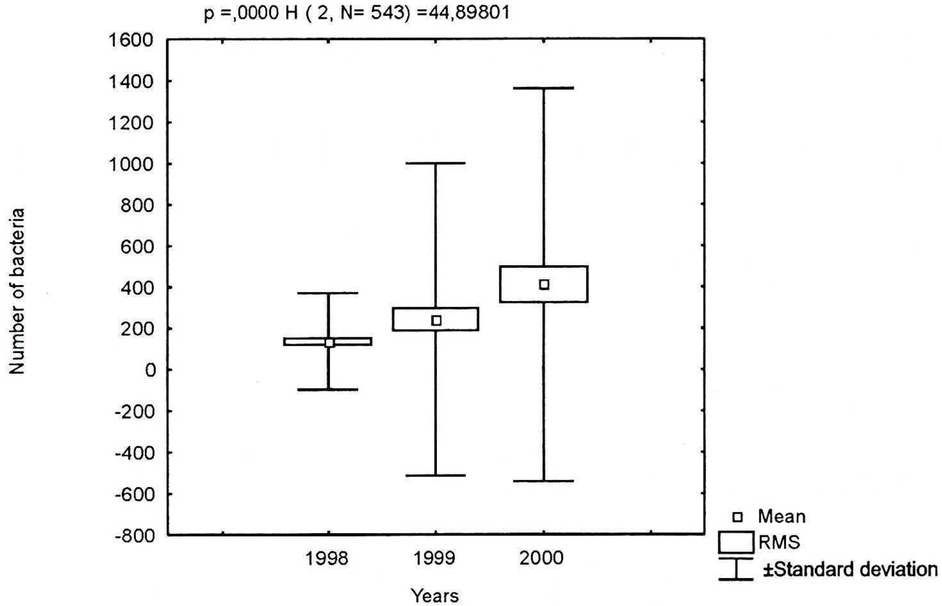
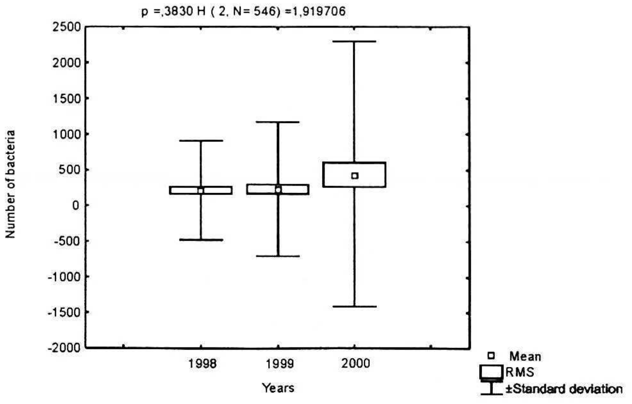


Fig. 4. Averages of numbers (± standard deviation and ± random mean square-RMS) of total viable counts (CFU/cm^3) on the broth agar at a) 22°C (TVC 22°C) and b) 37°C (TVC 37°C) in water on particular sites; independent variable (assembling) – years; ANOVA test of Kruskal-Wallis ranges

a)



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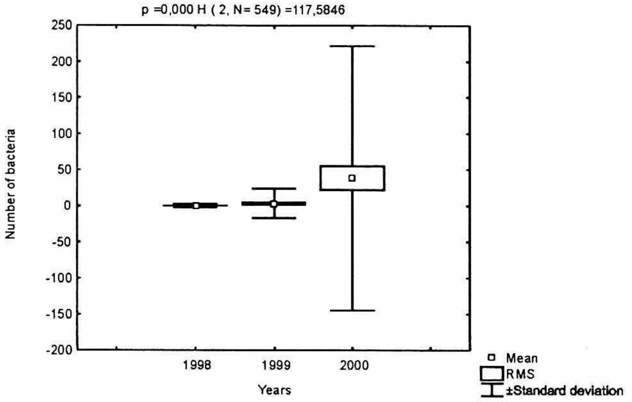

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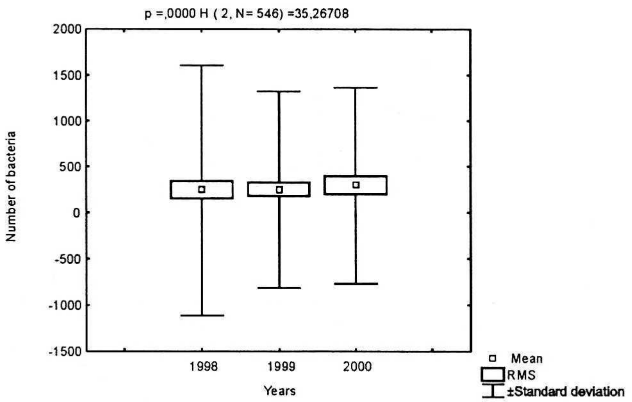

Fig. 5. Averages of number (± standard deviation and ± random mean square-RMS), (MPN/100 cm^3): a) total coliforms (TC), b) faecal (thermotolerant) coliforms (FC) and c) faecal streptococci (FS) in water on individual stations; independent variable (assembling) – sites; ANOVA test of Kruskal-Wallis ranges

Table 2. Bacteriological evaluation of water quality of the Lake Hańcza waters and its tributaries and outflow waters, according to the Minister of Environmental Protection dispositions from 2004 year, percent of water samples in the class

Water quality criteria		Class of water	Sites				
	(MPN/100 cm^3)		Pelagical waters (1, 4, 8)	Near-shore waters (2, 3, 11)	Ecotonal zone (5A, 6A, 9A)	Influents (5, 6, 7, 9)	Outflow (10)
			percent of water samples in the class.				
FC	20	1	99.2	96.6	98.7	64.4	90.0
	200	2	100	100	100	94.7	95.0
	2.000	3	100	100	100	100	100
	20.000	4	100	100	100	100	100
	>20.000	5	100	100	100	100	100
			(371)*	(58)	(18)	(76)	(20)
TC	50	1	95.7	81.0	100	7.6	70.0
	500	2	100	100	100	73.7	100
	5.000	3	100	100	100	3.9	100
	50.000	4	100	100	100	100	100
	>50.00	5	100	100	100	100	100
			(371)*	(58)	(18)	(76)	(20)

FC – the number of faecal (thermotolerant) coliforms (MPN/100 cm^3) on the Eijkman medium at 44.5°C after 24 h incubation,
TC – the number of total coliforms (MPN/100 cm^3) on the Eijkman medium at 37°C after 48 h incubation,
()* – number of samples investigated.

Table 3. Bacteriological evaluation of water quality of the Lake Hańcza waters and its influents and outflow waters, using criteria given by Cabejszek *et al.* [3], percent of water samples in the class

Bacteriological water quality criteria		Water quality	1998-2000 years													
			Pelagical waters			Near-shore waters			Ecotonal zone			Influents				Outflow
			sites													
Microorganisms	cfu/1 cm^3		1	4	8	2	3	11	5A	6A	9A	5	6	7	9	10
TVC 22°C[a]	< 300	A	82.4	85.8	84.4	90.0	80.0	77.8	66.7	66.7	66.7	10.0	15.0	12.5	10.0	65.0
	300 – 5.000	B	17.6	14.2	15.6	10.0	20.0	22.2	33.3	33.3	33.3	55.0	35.0	75.0	50.0	35.0
	5.000–10.000	C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	40.0	6.3	30.0	0.0
	> 10.000	D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	6.2	10.0	0.0
			(136)[c]	(113)	(122)	(20)	(20)	(18)	(6)	(6)	(6)	(20)	(20)	(16)	(20)	(20)
TVC 37°C[b]	< 200	A	91.2	90.3	94.3	95.0	95.0	94.4	66.6	83.3	50.0	20.0	25.0	37.5	15.0	85.0
	200– 1.000	B	8.1	8.8	4.9	5.0	5.0	5.6	33.4	16.7	50.0	55.0	50.0	12.5	40.0	15.0
	1.000– 5.000	C	0.7	0.9	0.8	0.0	0.0	0.0	0.0	0.0	0.0	15.0	25.0	50.0	40.0	0.0
	> 5.000	D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	5.0	0.0
			(136)[c]	(113)	(122)	(20)	(20)	(18)	(6)	(6)	(6)	(20)	(20)	(16)	(20)	(20)
Coli titre	> 1	A	100.0	100.0	100.0	95.0	100.0	95.0	83.3	83.3	83.3	60.0	80.0	90.0	75.0	90.0
	1–0.1	B	0.0	0.0	0.0	5.0	0.0	5.0	16.7	16.7	16.7	30.0	20.0	10.0	25.0	10.0
	0.1–0.01	C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0
	< 0.01	D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			(136)[c]	(113)	(122)	(20)	(20)	(18)	(6)	(6)	(6)	(20)	(20)	(16)	(20)	(20)
A – unpolluted, B – insignificantly polluted, C – distinctly polluted, D – heavily polluted																

Explanation [a] – total viable counts (CFU/1 cm^3) on broth-agar at 22°C after 72 h incubation,
[b] – total viable counts (CFU/1 cm^3) on broth-agar at 37°C after 24 h incubation,
[c] – the number of samples investigated.

which flows out of the lake (95.7%, 81.0%, 98.7% and 70.0%, respectively) can be classified in terms of their microbiological quality as purity class I. However, only 7.6% of waters of the inflowing streams could be classified as class I and 73.7% – as class II (Tab. 2).

According to the criteria of assessment of water purity, proposed by Cabejszek *et al.* [3], presented in Table 3, the number of the TVC 22°C and TVC 37°C bacteria as well as that of FC in most samples taken at the sites in the water of Lake Hańcza and the Czarna Hańcza River, which flows out of the lake, corresponded to the values adopted for unpolluted waters. The water of inflowing streams was usually slightly or considerably polluted.

DISCUSSION

The results of the sanitary and bacteriological examination of the waters of Lake Hańcza were compared to the criteria of water purity proposed by Cabejszek *et al.* [3] and to the data presented in the Regulation of the Minister of Environment Protection of 11 February 2004 [22]. These provided grounds for the conclusion that the number of bacteria used as indicators of the level of pollution (TVC 22°C and TVC 37°C) and of the sanitary state (TC, FC, FS) in the samples was typical of clean or slightly polluted waters, which included them in terms of their microbiological features as class I waters. The indicator bacteria number, similar to that in Lake Hańcza, was found by Niewolak and Kaczor [15] in the water of the oligotrophic Lake Wukśniki, and by Korzeniewska *et al.* [12, 13] and Niewolak [18] in the middle and southern part of Lake Wigry (except the Hańcza Bay, where the Czarna Hańcza River flows in). The mean number of TVC 37°C, TC and FC measured at particular sites in the waters of Lake Hańcza was significantly different from each other. The indicator bacteria number found in the near-shore zone (sites 2, 3, 11) was similar to that found in the pelagic zone of the lake. Only at site 11, situated close to the farm household, was a growth in TC and FS number observed (particularly in spring and summer). These bacteria, used as indicators of a sanitary state, may have made it to the lake with water flowing down into it from its shores, where manure had been stored, this being their potential source. Heufelder [8] found storm rainfalls to cause an increase in the FC number in the near-shore waters of Buttermilk Bay in the USA. Hunter and Mc Donald [11] noted a high concentration of FC bacteria in surface and drain waters flowing from a small area into a reservoir near the Yorkshire Dales in the UK, whose maximum values were recorded in summer, particularly during the stormy period. In the near-shore zone of Lake Hańcza, at site 11, the observed increase in the indicator bacteria number was only periodical and lower than expected. This situation may be linked to a specific character of the near-shore zone of the lake, which is overgrown with cane, playing the role of a biological filter and reducing the amount of pollution and the amount of sanitary and pollution indicator bacteria [25]. Only a slight increase in the indicator bacteria number was observed in the ecotonal zone of Lake Hańcza, at sites 5A, 6A and 9A, where the waters of the Czarna Hańcza, the Stara Hańcza and the Spod Przełomki stream mix with the lake waters. Judging by the TC and FC bacteria number, these waters could be classified as purity class I water in 98.7% of the samples. The number of the bacteria in those streams which flow into the lake was several times higher than the waters of Lake Hańcza and in the water of the Czarna Hańcza River, which flows out of it. This proves that while draining the area of forest, arable land and pastures, the water takes different types of pollution and carries a certain load of it to the lake. Korzeniewska *et al.* [13] and Niewolak [19, 20] found that the Czarna Hańcza River was transporting high loads of indicator bacteria flowing into the Hańcza Bay (the western part of Northern Plos of Lake Wigry). Similar results were obtained by Niewolak [16, 18] in the study of rivers and lakes in the Wigry National Park. The author showed that the Wiatrołuża River was strongly polluted bacteriologically, with the pollution coming from the waste which flowed into it from meadows, pastures, arable land or leaking cesspits. The pollution of rivers is also caused by cattle grazing in their drainage area. Such cattle were observed several meters away from the river bank and this fact was reflected in the results of tests, with an increased number of FC and FS bacteria. In a study of Canadian leisure lakes, Hendry and Toth [7] found an increase in FS and coliform bacteria number as a result of tourist activity and flowing of polluted streams into the lake. An increase in the number of all pollution and sanitary state indicator bacteria in Lake Hańcza, as well as in the inflowing and outflowing streams, was usually observed in spring and summer. Their increased number during these periods may have been caused by an increased amount of allochtonic pollution flowing into the lake; this hypothesis is corroborated by the TVC 22°C/TVC 37°C ratio, which in most samples was lower than 10. The bacteria may have entered the lake with the inflowing streams and surface waters flowing down to the lake from the neighboring agricultural area, particularly those adjacent to the southern part of the lake. The lake direct drainage area is dominated by arable land (69.3%), whereas forests (15.8%) and pastures and meadows (14.6%) account for less than half of the area [2]. Numerous authors have stressed that surface waters flowing down into the lake from agricultural areas, and pastures in particular, contain significant amounts of indicator bacteria, which provide evidence of strong pollution of water reservoirs – especially during periods of intensive rainfalls [5, 14, 17].

According to Geldreich [6], an FC/FS ratio can provide grounds for measurement of a pollution type. The ratio can be calculated when the bacteria number exceeds 100 MPN /100 cm^3 of water. In most samples taken from Lake Hańcza, the FS bacteria number was higher than that of FC bacteria. However, the ratio held true only for the waters in the inflowing streams and in the outflowing Czarna Hańcza River in July. In 87.5% of the water samples taken from the inflowing streams, it was lower than 0.7 – which may indicate the animal origin of the pollution, whereas in 10% of samples it ranged from 0.7 to 4.0, which indicates mixed pollution. This may suggest that the water was polluted by domestic and wild animals. Niewolak [18] states that a higher amount of pollution in protected rather than in open waters is a result of the increased presence of wild animals. Korzeniewska *et al.* [13] explain a higher FS bacteria number in the water of Lake Wigry by the effect of wild animals and water birds. When the Kruskal-Wallis ANOVA was conducted, it was found that significant differences exist between the mean number of the bacteria groups at various sites and in various years of study. The mean number of the indicator bacteria, except for the TC bacteria number in Lake Hańcza and the FS number in the inflowing and outflowing streams, increased in consecutive years of study, with the peak in 2000, which may indicate the growing effect of allochtonic factors on the lake waters.

CONCLUSIONS

1. The results of the sanitary and bacteriological examinations of the Lake Hańcza waters prove that they are clean or only slightly polluted, which confirms their classification as purity class I waters.

2. A low FC bacteria number and a high FS bacteria number were found in the Lake Hańcza waters, which indicate a dominating contribution of animal excrement in the pollution.
3. The influents (from the Czarna Hańcza and Stara Hańcza rivers, the Spod Przełomki stream and Lake Boczniel) contained 10 times more bacteria which are the subject of this study; the level of sanitary and bacteriological pollution was higher than in the lake itself. The FC/FS ratio, lower than 0.7 in most samples taken from the water of inflowing streams, indicated their contamination by animal excrement, mainly by wild animals.
4. The mean number of pollution and sanitary state indicator bacteria usually increased in consecutive years of study (it was the highest in 2000), which may indicate an increasing effect of allochtonic factors and necessitate that the agricultural, forest and fisheries economy, together with tourist activities, should be subordinated to the protection of this unique reservoir.

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