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Sanitary and Bacteriological Survey of an Artificially Aerated Eutrophic Lake Starodworskie, Poland

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Abstract

This paper presents the results of sanitary and bacteriological analyses of water and bottom sediments of an artificially aerated eutrophic Lake Starodworskie, Mazurian Lakeland, performed in 1986-1988. Analyses of water (in a vertical and horizontal profile) and of bottom sediments (from the 0-5 cm layer) were performed on five stations; samples were collected at monthly intervals: in 1986 when aeration was of low density; in 1987, when it was intensive; and in 1988, under the ice cover. The following indices were determined: TVC 20°C, TVC 37°C, TC, FC and FS. Numbers of micro-organisms belonging to these groups in water and bottom sediments were different in 1986 and 1987 and related to the intensity of aeration, distance from the lake shore, depth, and season, and atmospheric conditions. Bacteriological purity of water and bottom sediments was defined based on the usual water quality criteria, water suitability for recreational use, lake loading with organic matter easily decomposed by bacteria, and its loading with pollutants originating from humans and animals. The results suggest that the majority of water samples were clean or only slightly polluted, and loading of lake sediments with easily decomposed organic matter was relatively low, but they were fairly polluted with animal faeces. Pollution of water and of bottom sediments was higher in the first year of aeration than in the second one.

Keywords: Eutrophic lake, artificial aeration, water and bottom sediments, sanitary evaluation, indicatory micro-organisms, bacteria

Introduction

Increasing eutrophication and deteriorating sanitary and bacteriological quality of surface waters limit or even make impossible their use for recreation, water supply, fisheries, etc. This situation is connected with excessive discharge of domestic sewage and industrial pollution, as well as with an inflow of nutrients, pathogenic bacteria, viruses and other parasites from agricultural lands. Enrichment of surface waters with nutrients leads to massive blooms of blue-green algae, followed by secondary water pollution caused by the decay of these plants. Dead plants decompose using oxygen so that its resources in the hypolimnion become depleted and subsequent decomposition must take place almost exclusively in anaerobic conditions. Anaerobic decomposition of organic matter is very slow, and the intermediate products (ammonia, hydrogen sulphide, indol, scatol, organic acids) are toxic to the organisms which take place in the self-purification of water. In addition, this lack of oxygen excludes fish from deeper water layers. Polluted water can also potentially cause gastric problems, both in humans as well as domestic and wild animals. Counteractive measures are connected with the elimination of point and aerial sources of pollution, and in drastic cases with the need to undertake costly recultivation programmes. Lake aeration belongs to the latter group; it can be performed either with a lake destratification or aerating the hypolimnion layer so as not to destroy the natural thermal regime. Literature on the subject is fairly vast; mention can be made here of such works as McQueen et al. [16, 17], Osgord and Stiegler [22], Steinberg et al. [23, 24, 25], Toetz [27, 28], Thomdorfe and Boyd [29], and Visser et al. [30]. The majority of these papers deal with the effects of aeration on physico-chemical parameters of lake water, phyto- and zooplankton production as well as fish. Studies on the effect of lake and reservoir aeration upon sanitary and bacteriological characters are scarce and limited to a few papers only [4, 14, 16, 20, 21]. In the studies carried out on Lake St. George (Ontario, Canada) there were no differences in the numbers of saprophytic bacteria at the station where the hypolimnion was aerated compared to the control (with no aeration). There were also no differences as to

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the biochemical activity of the respective bacteria measured using an INT-formazan reduction technique [16]. It was found in the studies on Lake Mutek (Mazurian Lakeland, Poland) that whole lake aeration caused in the first year a noticeable deterioration of bacteriological water quality, this being caused by the passage of micro-organisms having sanitary importance from the bottom sediments to lake water. In subsequent years, however, water quality improved [14, 20, 21]. It is known from earlier data [4, 8] that long-term water mixing caused by aeration may decrease survival of indicatory bacteria and improve bacteriological quality of water.

The objective of these studies was to study the effect of aeration upon sanitary and bacteriological quality of eutrophic Lake Starodworskie, Olsztyn, Mazurian Lakeland. The lake was aerated with an aerator driven by wind force. It has been an experimental lake for a number of years – its recultivation is carried out by the Department of Water and Sewage Chemistry and Technology of the University of Agriculture and Technology in Olsztyn [7, 11, 12, 15].

Material and Methods

Lake under Study

Lake Starodworskie (Fig. 1) is located within the administrative boundaries of the town of Olsztyn in Mazurian Lakeland. It is small but fairly deep; its basin is cone-shaped. Basin slopes' angle is 20-25°. There is one deep place ("kettle" – 23.3 m). Lake area is 6.7 ha, water volume 549,900 m^3. The lake is partly surrounded with moraine hills overgrown with grass, with some houses here and there. There are also small gardens and a horse-riding school in the lake vicinity. The lake has no natural inflows, and the only outflow flows to the Łyna River catchment. The catchment area of the lake embraces 24 ha. This water body is characterized by considerable stability of water masses, so it has been classified as a eutrophic lake of bradymictic type [7, 11]. According to Lossow [11] "after a brief spring overturn, which usually embraces water masses down to 12 m depth, thermal and oxygen stratification rapidly sets in, with a shallow 3 m epilimnion in summer, and the thermocline at a depth of 8 m, and very stable hypolimnion with temperatures of 4-5°C. Autumn circulation is also very short, and the lake is quickly covered with ice." In 1950-1960 the lake received a discharge of wastes from the nearby pig farm which resulted in considerable pollution of its environment. Bradymictic character and considerable relative depth (0.0822) of the lake inhibit water mixing, so that in summer over 70% of the bottom surface was devoid of oxygen. In extreme cases oxygen disappeared from the whole lake, resulting in fish kills [12].

Lake Aeration

In 1986 and 1987 the lake was aerated with an air-compressor driven by wind force [14]. It was placed on one of the surrounding hills. Compressed air was directed to a MI

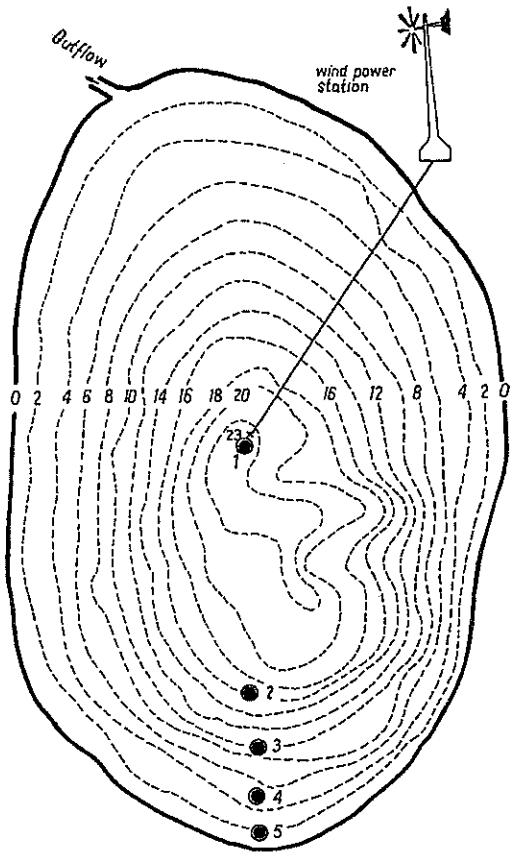


Fig. 1. Location sketch of Lake Starodworskie. 1, 2, 3, 4, 5 – water and bottom sediment sampling sites.

NIFLOX aerator produced by Multireaktor; it was placed in the deepest part of the lake. Aeration lasted from April 1986 till the end of 1987; the destratification method was used. Due to weak and irregular air supply (in 1986 only 13315 m^3 of oxygen were supplied to the lake bottom) in 1987 the system was modified in order to increase the amount of supplied oxygen (in 1987 oxygen supply was 18677 m^3). The latter amount was sufficient to cover 55-77% of the theoretical amount of oxygen needed to liquidate lake stratification and improve environmental conditions [7]. More technical details and data pertaining to the experiment and the resulting physico-chemical conditions in the lake are to be found in Lossow and Jaszczult [14].

Sampling

Water (from the experimental layers) and bottom sediment samples were collected from 5 stations located along the N-S axis running from the deepest part in the direction of the riding school. At station 1 water samples were collected from depths of: 0.3, 1.0, 2.0, 5.0, 10.0, 15.0, 20.0 and 22.0 m.; at station 2 from depths of: 0.3, 1.0, 2.0, 5.0, 10.0 and 15.0 m; at station 3 from depths of 0.3, 1.0, 2.0, 5.0 and 10.0 m, at station 4 from depths of: 0.3, 1.0, 2.0 and 5.0 m.; and at station 5 from depths of 0.3, 1.0 and 2.0 m. Samples were collected with a Ruttner sampler of 10 dm^3.

As soon as water samples had been collected, sediment samples were collected from the same station taking 0-5 cm layer. They were collected with a Kajak sediment sampler. Water samples were poured into 300 cm^3 sterile bottles with water-tight glass stoppers. Samples of bottom sediments were collected into 330 cm^3 sterile glass jars of the TWIST type. Water and sediment samples were transported to the laboratory and subjected to bacteriological analyses within 4 hours of collection. In the meantime all samples were stored at 4°C.

Microbiological Studies

Microbiological studies comprised the following analyses:

1. total bacteria counts on agar broth at 20°C (TVC 20°C) after 72 h incubation;
2. total bacteria counts on agar broth at 37°C (TVC 37°C) after 24 h incubation;
3. total coliforms (TC) on Eijkman medium at 37°C after 48 h incubation;
4. faecal coliforms (FC) on Eijkman medium at 44.5°C after 24 h incubation;
5. faecal streptococci (FS) on Slanetz and Bartley media at 37°C after 72 h incubation.

Total numbers of bacteria on broth agar at 20°C and 37°C were determined according to the methods generally used for the examination of drinking water. Total coliforms and faecal coliforms were determined using the most probable number method (MPN) based on sample solutions described in Standard Methods [2]. 10 cm^3, 1 cm^3, 0.1 cm^3 and 0.01 cm^3 of water and 10 g, 1 g, 0.1 g, 0.01 g, 0.001 g and 0.0001 g of bottom sediments were used each time – all solutions were in 3 parallel repetitions. Positive results for the presence of coliforms were checked on Endo medium, in a fermentation-test tube sample on lauryl-tryptose broth and in the preparations stained with Gram's method. Positive results for the presence of faecal streptococci were checked on m-Enterococcus Agar. Typical colonies which developed on this medium were transferred to a broth medium and determinations were made of their growth potential at 44.5°C at pH 9.6, in the presence of 6.5% NaCl and in milk with an addition of 0.01% methylene blue. Physiological NaCl solution was used as solvent. The most probable numbers of total coliforms and faecal streptococci were obtained from MacCrady's tables [18]. The results were

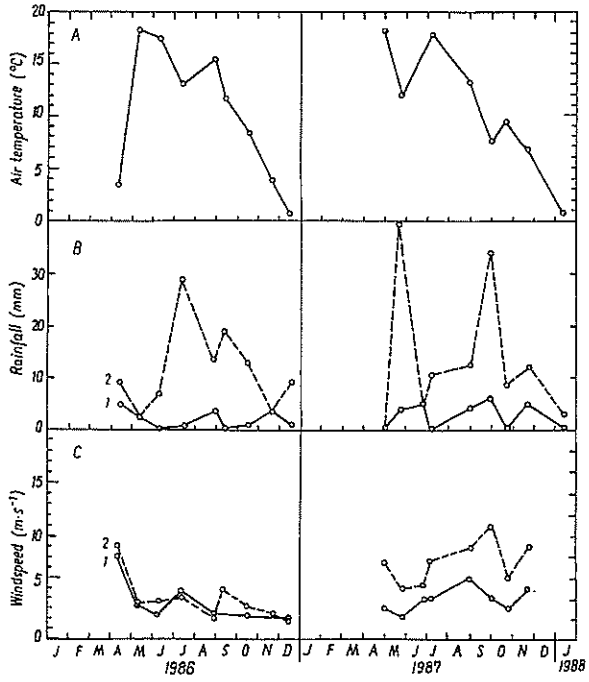


Fig. 2. Some meteorological data on the time of water and bottom sediment sampling from Lake Starodworskie. A – air temperature (°C) during water and bottom sediments sampling; B – rainfall (mm) during 2 days (1) and one week (2) before sampling; C – wind speed (in m · sec^{-1}) during 1 (1) and 2 (2) days before sampling.

Table 1. Mean (for study period) and range for the numbers of total viable counts at 20°C and 37°C in the water of Lake Starodworskie in 1986-1988.

Site*	Depth (m)	Number of samples		Total viable count at 20°C				Total viable count at 37°C			
				1986	1987	1988	1986-1988	1986	1987	1988	1986-1988
				(CFU · 1 cm^{-3})							
1	22	60	A	132	70	40	81	193	25	20	79
			B	0–1,300	3–2,200	–	0–2,200	10–2,970	3–300	–	3–2,970
2	15	52	A	200	178	53	144	169	44	36	83
			B	5–2,150	5–2,000	–	5–2,150	10–3,050	6–285	–	6–3,050
3	10	43	A	212	132	87	144	133	43	46	74
			B	12–1,500	8–3,100	–	8–3,100	4–1,150	2–245	–	2–1,150
4	5	32	A	151	142	37	160	115	186	12	104
			B	5–870	33–1,250	–	5–1,250	10–1,100	6–830	–	6–1,100
5	2	17	A	264	177	29	157	275	248	9	177
			B	15–960	21–780	–	15–960	23–1,400	20–750	–	9–1,400

* – See Figure 1

Table 2. Ratio of TVC 20°C : TVC 37°C in the water of Lake Starodworskie in 1986 and 1987.

	1986		1987	
	Number of samples	Percent	Number of samples	Percent
Total	204	100	221	100
≤ 10	198	97,1	212	95,9
> 10	6	2,9	9	4,1

recalculated to 1 (TVC 20°C and TVC 37°C) or 100 cm^3 (TC, FC, FS) of water or 1g of fresh sediment weight (all bacteria groups).

Meteorological observations were performed by the Department of Meteorology of the University of Agriculture and Technology, at a nearby station in Tomaszkowo near Olsztyn. They comprised measurements of air temperature, sum of precipitation for the period 2 and 7 days before lake sampling, and wind force 1 and 2 days before sampling.

Results

Meteorological Observations

The results of meteorological observations for the period April, 1986 – January, 1988 are presented in Fig. 2. Average air temperature on sampling days varied from 0°C in December, 1986 and 0.4°C in January, 1988 to 18°C in April, 1987 and 18.2°C in May, 1986. The sum of rainfall on 2 days before sampling reached 5 mm in April, 1986 and 6.1 mm in November, 1987, while it was 34.5 mm in July, 1986, 40 mm in May and 33 mm in September, 1987 for the period of 7 days before sampling. Wind speed on the day before lake sampling was maximally 8 m · sec^{-1} in April, 1986 and 5.7 m · sec^{-1} in August 1987. The highest wind speed two days before sampling did not exceed 10 m · sec^{-1} in April, 1986 and 11 m · sec^{-1} in September, 1987.

Microbiological Studies

Total Viable Counts and Enteric Bacteria Concentration in Lake Water

Numbers and horizontal distribution. Total bacteria counts in the lake water, determined on broth agar in 20 and 37°C (subsequently called TVC 20°C and TVC 37°C respectively) ranged from 0 to 3100 CFU · 1 cm^{-3} and from 1 to 3050 CFU · 1 cm^{-3} respectively, depending on the station, depth, year of studies [1986, 1987, 1988], season and atmospheric conditions. There were usually less bacteria in 1987, more in 1986. In winter 1988 (under the ice cover) bacteria numbers were relatively small. Generally speaking, average bacteria numbers were lower in water at station 1 and higher at stations 2-5 (Tab. 1). TVC 20°C to TVC 37°C ratio was less than 10 in 95.9-97% of the samples, and higher than 10 only in 2.9-4.1% of the samples (Table 2).

Total coliforms (TC), faecal coliforms (FC) and faecal streptococci (FS) in water collected from Lake Starodworskie did not exceed 1400 MPN · 100 cm^{-3} in 1986 and 460, 210 and 1400 MPN · 100 cm^{-3}, respectively, in 1987. In winter 1988 (under the ice) numbers of these bacteria reached 11, 13 and 5 MPN · 100 cm^{-3}. Frequently water samples did not contain these bacteria at all. Average TC for the whole period of studies was lowest at station 1 and highest in water collected from station 2. FC were less numerous in water at stations 3, 4 and 5 and more so at stations 1 and 2, while FS were less numerous at stations 2, 3 and 5 and more numerous at stations 1 and 4 (Table 3). The FC to FS ratio was less than 0.7 in 70% of the samples, from 0.7 to 4.0 in 22% of the samples, and higher than 4.0 in 7-8% (Table 4).

Vertical stratification. Vertical distribution of the indicatory bacteria in Lake Starodworskie was fairly diversified at particular sampling stations. Near-bottom water always or almost always contained more of these bacteria than the upper layers. It is very difficult to present all the results for all sampling stations, so Figs. 3 and 4 present

Table 3. Mean (for study period) and range for the numbers of total coliforms, faecal coliforms and faecal streptococci in the water of Lake Starodworskie in 1986-1988.

Site*	Depth (m)	Number of samples		Number of total coliforms				Number of faecal coliforms				Number of faecal streptococci			
				1986	1987	1988	1986-1988	1986	1987	1988	1986-1988	1986	1987	1988	1986-1988
				(MPN · 100 cm^{-3})											
1	22	60	A	228	21	4	84	54	19	13	29	275	392	3	223
			B	0–1,400	0–93	–	0–1,400	0–1,400	0–93	–	0–1,400	0–1,400	0–14,000	–	0–14,000
2	15	52	A	387	8	11	135	92	20	4	39	205	150	4	120
			B	0–1,400	0–240	–	0–1,400	0–1,100	0–210	–	0–1,100	0–1,400	0–2,800	–	0–2,800
3	10	43	A	284	6	4	98	29	12	5	15	196	166	5	122
			B	0–1,400	0–43	–	0–1,400	0–240	0–93	–	0–240	0–1,400	0–1,400	–	0–1,400
4	5	32	A	308	12	4	108	33	9	0	14	185	302	3	163
			B	0–1,400	0–43	–	0–1,400	0–420	0–43	–	0–420	0–1,400	0–1,400	–	0–1,400
5	2	17	A	323	21	1	115	29	13	0	14	209	103	0	104
			B	9–1,400	0–460	–	0–1,400	0–150	0–93	–	0–150	4–1,400	0–1,700	–	0–1,700

* – See Figure 1.

Table 4. Percentage distribution of values of ratio FC : FS in the water and bottom sediments of Lake Starodworskie in 1986-1987.

FC : FS ratio	Water		Bottom sediments	
	Years			
	1986	1987	1986	1987
< 0.7	139 (71.0)	150 (69.8)	19 (54.3)	26 (89.6)
0.7 – 4.0	44 (22.4)	47 (21.8)	8 (22.85)	1 (3.5)
> 4.0	13 (6.6)	18 (8.4)	8 (22.5)	2 (6.9)
Total	196[a] (100)[b]	215 (100)	35 (100)	29 (100)

[a, b] – Number and percent (in brackets) of samples investigated

– as an example – vertical distribution of TVC 20°C at the deepest station (station 1). These bacteria are usually regarded as an index of water environment loading with easily decomposed organic matter. In April 1986, when aeration commenced, vertical distribution of these bacteria showed maximal numbers at a depth of 2 m, in May, June and July there were more or less the same numbers found in the whole water column except the near-bottom layer, where they were higher. In August, September and October these numbers became more diversified, with higher levels noted down to a depth of 2 m, while in November and December they again became more or less uniform in the water column. In 1987 vertical distribution of TVC 20°C was more diversified than in 1986. Higher values were usually observed at depths of 1-2 m, 5-10 m and near bottom. In winter 1988 (under the ice) higher numbers of these bacteria were found at 2 m, 10m and near bottom (Figs. 3 and 4).

Seasonal variations. Seasonal variations of indicatory bacteria numbers in 1986 were more or less similar at all sampling stations (Fig. 5-9), with peaks in May (TVC 20°C and 37°C), and in July, September and December (TC, FC, FS), rare in other months. In 1987 maximal numbers were observed in June and November (TVC 20°C), July and November (TVC 37°C), September and November (TC), May, June, July, August and November (FC), and June and September (FS) depending on the station.

Numbers of indicatory micro-organisms and pollution. TVC 20°C and TVC 37°C in water collected from Lake Starodworskie in the study period did not differ much from the values accepted [3] for clean surface waters (Table 5). Only a small percentage of the samples was classified as slightly or noticeably polluted. On the other hand, faecal coliforms reached the values accepted [3] for slightly or noticeably polluted waters (detailed data on faecal coliforms can be obtained from the authors), and in 1987 even as high as those notices in strongly polluted ones. How-

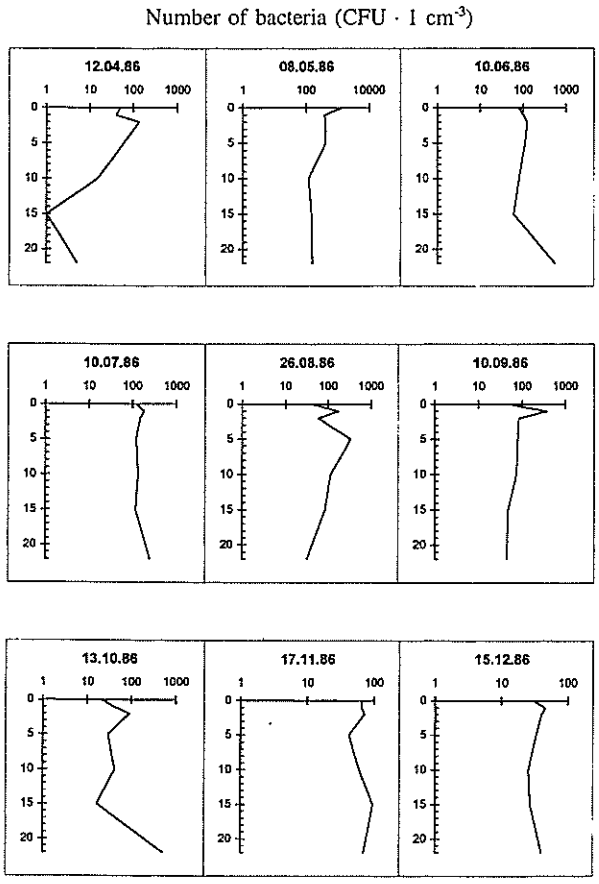


Fig. 3. Vertical stratification of total viable count at 20°C in Lake Starodworskie at site 1 in 1986.

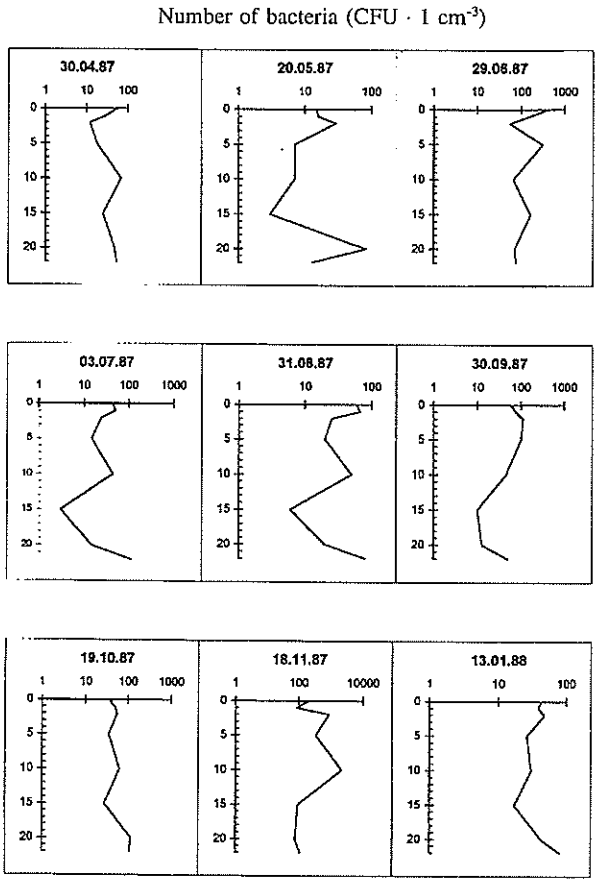


Fig. 4. Vertical stratification of total viable count at 20°C in Lake Starodworskie at site 1 in 1987.

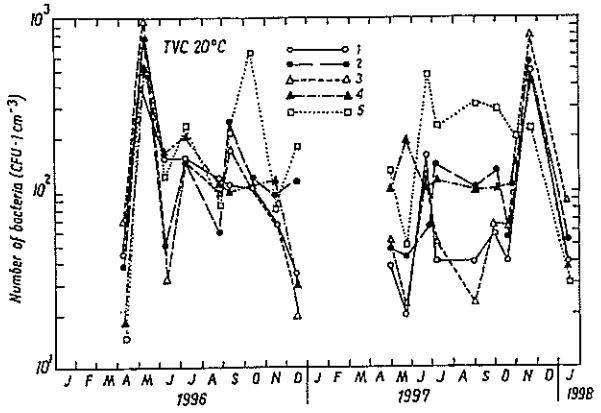


Fig. 5. Seasonal changes in number of total viable count at 20°C (average for total column) in Lake Starodworskie. 1, 2, 3, 4, 5 – sampling site.

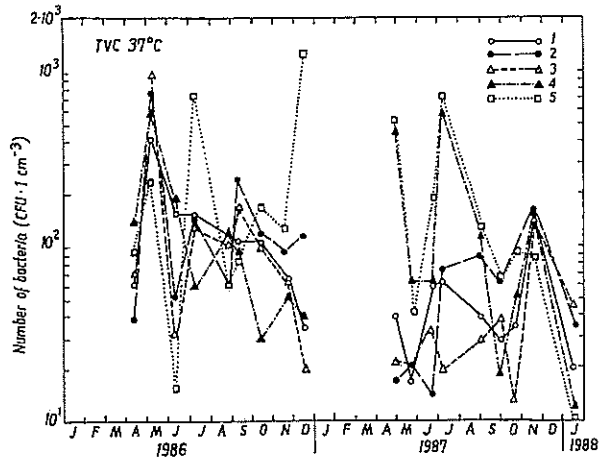


Fig. 6. Seasonal changes in number of total viable count at 37°C (average for total column) in Lake Starodworskie. Denotation as in Figure 5.

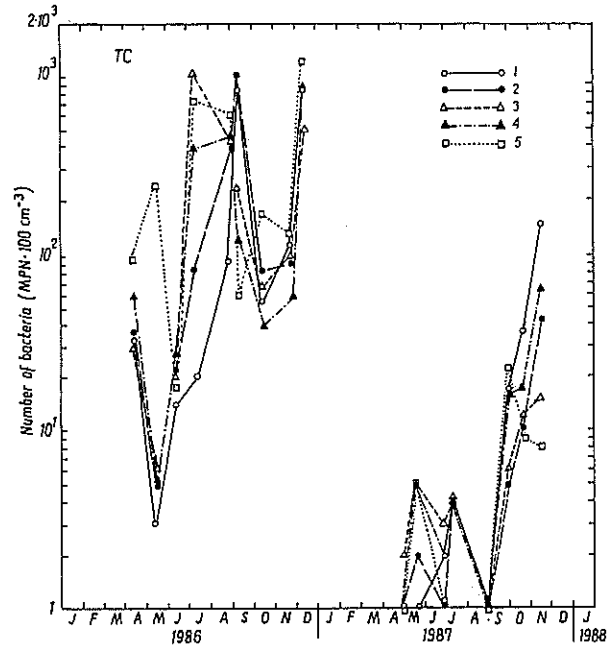


Fig. 7. Seasonal changes in number of total coliforms (average for total column) in Lake Starodworskie. Denotation as in Figure 5.

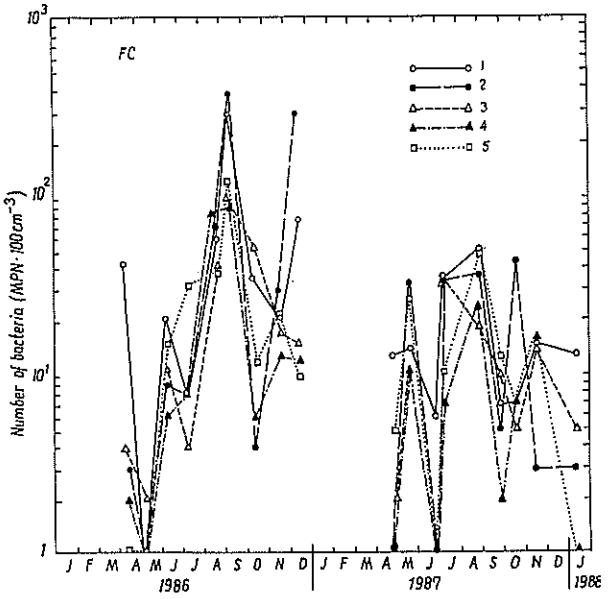


Fig. 8. Seasonal changes in number of faecal coliforms (average for total column) in Lake Starodworskie. Denotation as in Figure 5.

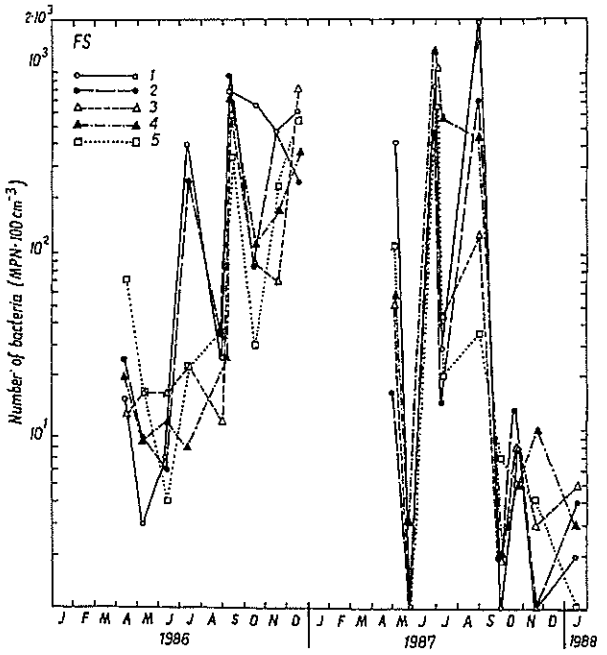


Fig. 9. Seasonal changes in number of faecal streptococci (average for total column) in Lake Starodworskie. Denotation as in Figure 5.

ever, according to the data of the US Department of the Interior Federal Water (..) [6] only some water samples contained TC and FC exceeding maximal levels permissible for waters used for recreation (Table 6). The percentage of these samples was lower in 1986 and higher in 1987. Comparison of TVC 20°C and FC given in Table 7 with the data presented by Albinger [1] suggests low loading of Lake Starodworskie with easily decomposed organic matter and its relatively high loading with faecal pollution.

Total Viable Count and Enteric Bacteria Concentration in Bottom Sediments

Numbers and horizontal distribution. All groups of indicatory bacteria were 10^3 to 10^4 times more numerous in the bottom sediments of Lake Starodworskie compared to water. TVC 20°C and TVC 37°C in 1986 ranged from 5×10^3 to 571×10^3 and from 6×10^3 to 8×10^5 CFU · g^{-1} wet wt, respectively, while in 1987 the respective numbers ranged from 9.75×10^3 to 22×10^5 and from 15×10^3 to 21×10^5 CFU · g^{-1} wet wt. In winter 1988 (under the ice) these numbers ranged, respectively, from 26×10^3 to 85×10^3 and from 30.6×10^2 to 118×10^3 CFU · g^{-1} wet wt. In the whole study period these bacteria were, on average, less numerous in the bottom sediments at station 4 (TVC 20°C) or 1 and 5 (TVC 37°C), and more numerous at stations 1, 2, 3 and 5 (TVC 20°C) or 2, 3 and 4 (TVC 37°C) (Table 8).

Table 5. The anaysis of bacteriological water quality of Lake Starodworskie, using criteria given by Cabejszek et al. [3].
A – unpolluted, B – insignificantly polluted, C – distinctly polluted, D – heavily polluted, percent distribution of samples relevant to the given class.

Bacteriological water quality criteria		Water quality	Years	
Microorganisms	Number of cells (CFU · 1 cm^{-3})		1986	1987
Total viable count at 20°C	< 300	A	86.9	92.4
	> 300 - 5,000	B	13.1	7.6
	> 5,000 - 10,000	C	0.0	0.0
	> 10,000	D	0.0	0.0
			(206)* 100	(224) 100
Total viable count at 37°C	< 200	A	81.1	88.3
	> 200 - 1,000	B	15.6	11.7
	> 1,000 - 5,000	C	5.3	0.0
	> 5,000	D	0.0	0.0
			(207) 100	(222) 100
Coli titre	> 1	A	73.9	46
	< 1 - 0.1	B	17.8	39.4
	< 0.1 - 0.01	C	8.3	3.5
	< 0.01	D	0.0	11.1
			(207) 100	(226) 100

* – Number of samples investigated

TC, FC and FS numbers in the bottom sediments of Lake Starodworskie in 1986 did not exceed 14×10^4, 14×10^4 and 7.5×10^2 MPN · g^{-1} wet wt. respectively, and in 1987 – 15×10^3, 15×10^3 and 14×10^5 MPN · g^{-1} wet wt. In 1987 these bacteria were often not found at all. In winter 1988 (under the ice) TC and FC numbers did not exceed 7.5×10^2 and 45×10^3 MPN · g^{-1} respectively, while FC were not found in the bottom sediments. On the average for the whole study period these bacteria were the least numerous in the bottom sediments at station 3 (TC, 2 and 5 (FC) or 3 and 4 (FS), and the most numerous at station 2 (TC), 4 (FC) or 1 (FS) (Table 9). FC to FS ratio in 1986 was less than 0.7 in 54.3% of the samples, from 0.7 to 4.0 in 22.8%, and higher than 4.0 in 22.5% of the sediment samples. In 1987 this ratio was lower than 0.7 in 89.6% of the samples, from 0.7 to 4.0 in 3.5% and higher than 4.0 in 6.9% of the samples (Table 4).

Seasonal variations. Seasonal variations in the numbers of indicatory bacteria in bottom sediments of Lake Starodworskie are presented in Figs. 10-14. TVC 20°C reached maximal levels in 1986 in May or June, August or September, and November or December; and in 1987 in June, September and November, exceptionally (station 2) also in other periods. TVC 37°C reached maximal levels in 1986 in June or July, September and November, and/or December; in 1987, in April, June or July and August and November. TC peaks in 1986 were observed in June and/or July, August, November and/or December, while in 1987 in April, June, and/or July and November or December. FC reached maximal levels in 1986 in May and/or June, in August and/or September, and in November or December. In 1987 they were noted in April and/or May, in June

Table 6. Analysis of bacteriological water quality of Lake Starodworskie using criteria given by U.S. Department of the Interior Federal Water Pollution Control Administration [6], as the percent distribution of samples relevant to the given criteria.
I – primary contact, II – secondary contact

Years	Number of samples investigated	Bacteriological water quality standards						
		Total coliforms MPN · 100 cm^{-3}			Number of samples investigated	Faecal coliforms MPN · 100 cm^{-3}		
		Recreational		Public water supply		Recreational		Public water supply
		I 1,000	II 5,000	10,000		I 200	II 1,000	2,000
1986	209[a] (100)[b]	166 (81,0)	204 (100)	204 (100)	208 (100)	193 (192,8)	205 (98,5)	208 (100)
1987	225 (100)	224 (99,6)	225 (100)	225 (100)	216 (100)	215 (99,5)	216 (100)	216 (100)

[a] – Number of samples
[b] – Percent of samples

Table 7. The analysis of water quality of Lake Starodworskie using criteria given by Kavka [9] and Kohl [10] after Albinger [1]. Percent distribution of samples to the given class.

Water quality criteria		Water quality level[3]	1986						1987						1986-1987
			Site*												
Micro-organisms	Number of bacteria		1	2	3	4	5	1-5	1	2	3	4	5	1-5	
TVC 20°C[1]	< 500	1	95.7	91.2	87.5	94.5	86.2	91.7	97.2	92.8	97.8	97.2	94.5	96.2	94.1
	>500- 1,000	2	2.8	5.3	6.3	5.5	13.8	5.8	1.4	4.8	2.2	2.8	5.5	2.8	4.2
	>1,000- 10,000	3	1.5	3.5	6.2	0	0	2.5	1.4	2.4	0	0	0	1.0	1.7
	>10,000- 50,000	4	0	0	0	0	0	0	0	0	0	0	0	0	0
	>50,000-100,000	5	0	0	0	0	0	0	0	0	0	0	0	0	0
	>100,000-750,000	6	0	0	0	0	0	0	0	0	0	0	0	0	0
	>750,000	7	0	0	0	0	0	0	0	0	0	0	0	0	0
			(71)[4]	(57)	(48)	(36)	(29)	(241)	(72)	(42)	(45)	(36)	(18)	(213)	(474)
FC[2]	0.1- 0.10	1	24.6	14.5	17.4	9.4	10.2	16.6	25.4	37.8	40.0	41.1	27.8	33.9	24.9
	>0.10- 1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	>1- 10	3	29.0	38.2	41.3	56.2	61.5	42.3	32.4	22.7	33.3	29.5	33.3	29.9	36.4
	>10- 50	4	31.9	21.8	30.5	18.8	23.0	26.1	35.2	84.0	24.5	29.5	33.3	31.7	28.8
	>50- 100	5	7.2	7.3	4.3	9.4	2.6	6.2	5.6	3.8	2.2	0	5.6	3.6	5.8
	>100-1,000	6	5.8	14.5	6.5	6.2	2.7	7.5	1.4	1.7	0	0	0	0.9	4.3
	>1,000	7	1.5	3.7	0	0	0	1.3	0	0	0	0	0	0	0.8
			(69)	(55)	(46)	(32)	(39)	(241)	(71)	(53)	(45)	(34)	(18)	(221)	(462)

* – See Figure 1

[1] – Total viable count at 20°C (saprophytic bacteria as CFU · 1 cm^{-3} water)

[2] – Number of faecal coliforms (MPN · 100 cm^{-3} warter)

[3] – Degree of loading with organic substances, which can be well decomposed by bacteria (TVC 20°C) and degree of loading with faecal substances (FC): 1 – very little, 2 – little, 3 – moderate, 4 – moderate high, 5 – high, 6 – very high, 7 – extreme high

[4] – In brackets number of samples investigated.

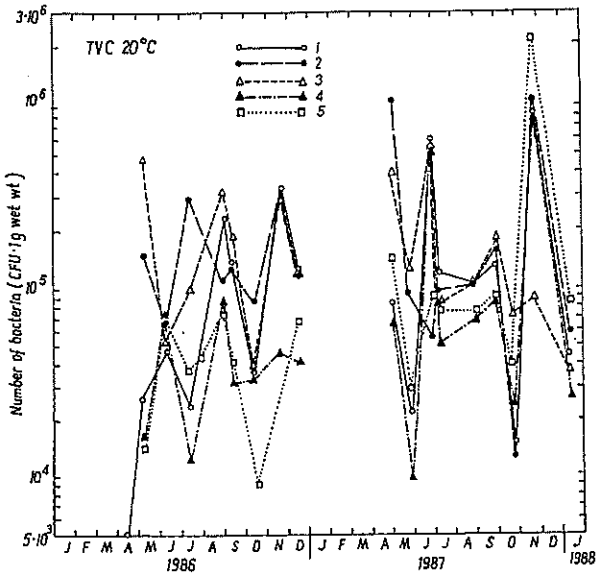


Fig. 10. Seasonal changes in number of total viable count at 20°C in bottom sediments (0 – 5 cm layer) of Lake Starodworskie. Denotation as in Figure 5.

or July, and in October and/or November. At sampling stations 2 and 4 the maximum was observed also in winter 1988 (under the ice). FS were more numerous in 1986 in July or August and in the period from September to December, while in 1987 – from June to September.

TVC 20°C and FC numbers and the degree of bottom sediment loading with organic substances which can be well decomposed by saprophytic bacteria, and the degree of loading with faecal substances. Comparison of TVC 20°C and FC numbers in the bottom sediments of Lake Starodworskie with the literature data and the data presented by Kavka [9], Kohl [10] as modified by Albinger [1] and presented in Table 10, suggests that bottom sediments in this lake are little loaded with organic matter which can be easily decomposed by saprophytic bacteria, are moderately and/or highly loaded with animal faeces.

Discussion

Total Viable Counts and Enteric Bacteria Concentrations in Lake Water

TVC 20°C (usually regarded as an index of loading with organic matter easily decomposed by saprophytic bacteria) in the water of Lake Starodworskie was typical of clean or

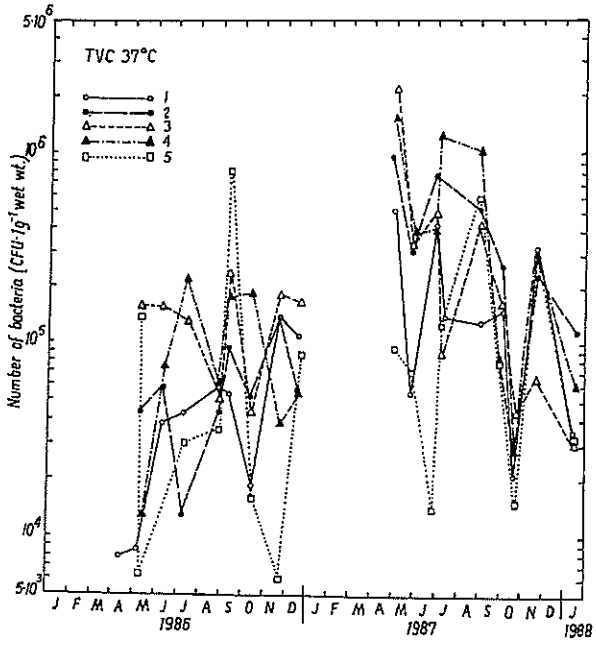


Fig. 11. Seasonal changes in number of total viable count at 37°C in bottom sediments (0 – 5 cm layer) of Lake Starodworskie. Denotation as in Figure 5.

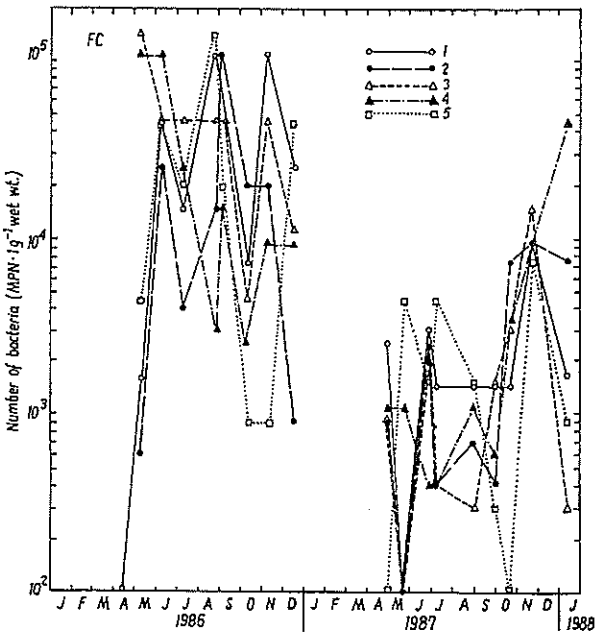


Fig. 13. Seasonal changes in number of faecal coliforms in bottom sediments (0 – 5 cm layer) of Lake Starodworskie. Denotation as in Figure 5.

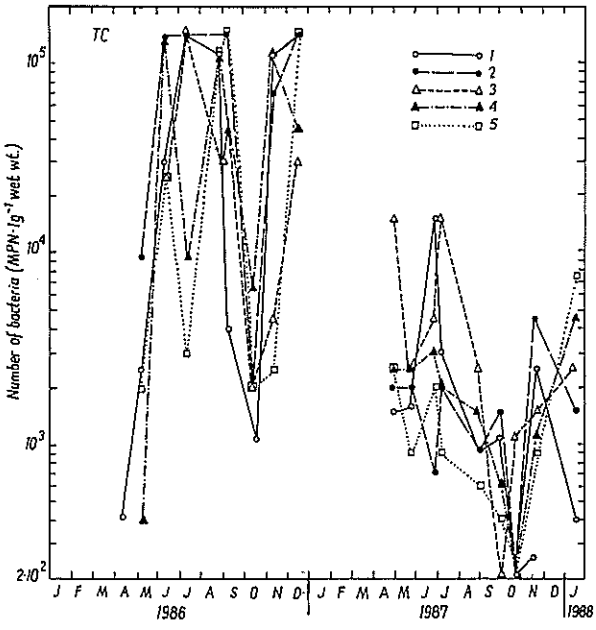


Fig. 12. Seasonal changes in number of total coliforms in bottom sediments (0 – 5 cm layer) of Lake Starodworskie. Denotation as in Figure 5.

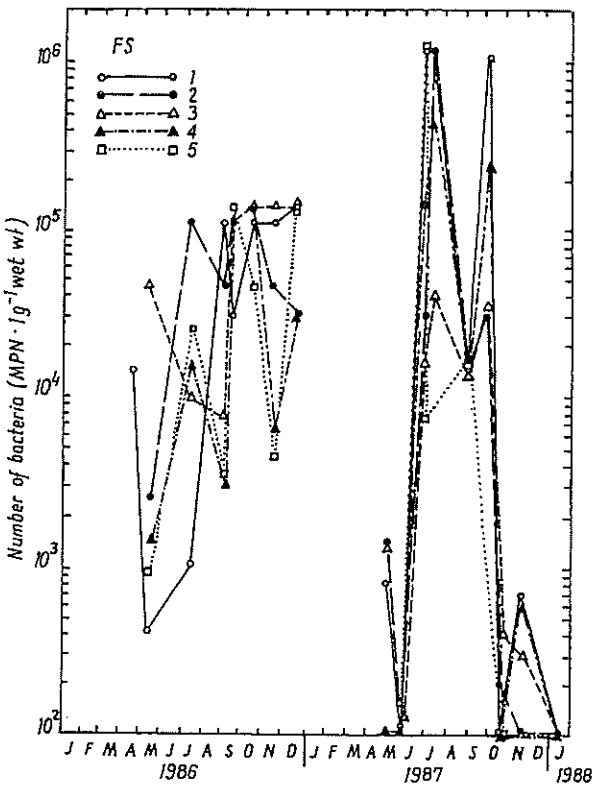


Fig. 14. Seasonal changes in number of faecal streptococci in bottom sediments (0 – 5 cm layer) of Lake Starodworskie. Denotation as in Figure 5.

only slightly polluted lakes of the Mazurian Lakeland [18]. Differences observed in the numbers of these bacteria in 1986 and 1987 might have resulted from different content of organic matter produced *in situ* within the lake. In 1986, when lake aeration was less intensive while there were long periods of windless weather, it was not possible to fully liquidate thermal stratification [7], so that algae development in the trophogenic layer was not disturbed to any greater extent. As a result, TVC 20°C reached higher levels as these bacteria used substances excreted by live algae

Table 8. Mean (for study period) and range for the numbers of total viable counts at 20°C and 37°C in bottom sediments of Lake Starodworskie in 1986-1988.

Site*	Depth (m)	Number of samples		Total viable count at 20°C				Total viable count at 37°C			
				1986	1987	1988	1986-1988	1986	1987	1988	1986-1988
				(CFU · 1 g^{-1} wet wt.)							
1	22	9	A	105,410	239,690	45,000	130,030	52,770	221,000	35,000	102,920
			B	5,000–326,000	15,000–840,000	–	5,000–840,000	7,700–140,000	21,000–525,000	–	7,700–525,000
2	15	8	A	156,440	315,190	58,000	176,540	61,490	420,125	118,000	199,870
			B	67,500–32,000	12,500–1,000,000	–	12,500–1,000,000	13,400–134,000	28,000–990,000	–	13,400–990,000
3	10	8	A	195,730	193,625	36,000	141,785	140,125	464,500	30,600	211,740
			B	38,000–471,000	70,000–400,000	–	36,000–471,000	43,000–237,000	44,000–2,100,000	–	30,600–2,100,000
4	5	8	A	41,720	219,340	26,000	95,690	102,250	583,750	60,000	248,670
			B	12,150–85,000	9,750–900,000	–	9,750–900,000	13,000–220,000	28,000–1,250,000	–	13,000–1,250,000
5	2	8	A	44,625	341,660	85,000	157,090	139,325	159,690	33,000	110,670
			B	9,000–68,500	29,250–2,200,000	–	9,000–2,200,000	6,000–800,000	15,000–600,000	–	6,000–800,000

* – See Figure 1

Table 9. Mean (for study period) and range for the numbers of total coliforms, faecal coliforms and faecal streptococci in bottom sediments of Lake Starodworskie in 1986-1988.

Site*	Depth (m)	Number of samples		Number of total coliforms				Number of faecal coliforms				Number of faecal streptococci			
				1986	1987	1988	1986-1988	1986	1987	1988	1986-1988	1986	1987	1988	1986-1988
				(MPN · 1 g^{-1} wet wt.)											
1	22	9	A	59,780	3,200	400	21,130	39,900	2,625	1,600	14,710	64,410	489,600	0	184,670
			B	400 - 140,000	0 - 15,000	-	0 - 140,000	0 - 110,000	0 - 9,500	-	0 - 110,000	400 - 140,000	0 - 140,000	-	0 - 1,400,000
2	15	8	A	97,250	1,700	1,500	33,480	25,690	2,740	7,500	11,975	73,210	184,590	0	85,930
			B	3,500 - 140,000	0 - 4,500	-	0 - 140,000	600 - 110,000	0 - 9,500	-	0 - 110,000	2,500 - 140,000	0 - 1,400,000	0	0 - 1,400,000
3	10	8	A	39,5000	5,260	2,500	15,750	47,625	2,890	300	16,940	84,570	13,390	0	32,650
			B	2,000 - 140,000	0 - 3,000	-	0 - 140,000	4,500 - 140,000	0 - 15,000	-	0 - 140,000	7,500 - 140,000	2,500 - 40,000	-	0 - 40,000
4	5	8	A	58,300	1,650	4,500	21,480	35,560	2,210	45,000	27,590	43,700	50,830	0	31,510
			B	400 - 140,000	0 - 3,000	-	400 - 140,000	2,500 - 110,000	400 - 9,500	-	2,500 - 110,000	1,400 - 140,000	0 - 45,000	-	0 - 45,000
5	2	8	A	58,125	1,025	7,500	22,220	32,040	2,475	900	11,800	51,270	178,870	0	76,670
			B	2,000 - 140,000	0 - 2,500	-	0 - 140,000	900 - 140,000	0 - 7,500	-	0 - 140,000	900 - 140,000	0 - 1,400,000	-	0 - 1,400,000

* - See Figure 1,

and/or the products of algae decomposition. Higher loading of Lake Starodworskie with organic matter easily decomposed by saprophytic bacteria was also confirmed by BOD_5 levels, which were higher in 1986 than in 1987 [7]. Higher lake loading with easily decomposed organic matter and lower visibility of Secchi's disc [7] in 1986 compared to 1987, hence lower penetration of UV radiation in the water column, might have favoured higher survival of TVC 20°C, TC, FC and FS in 1986 than in 1987. In 1987, when the aeration was more intensive, algae development in the trophogenic layer was probably disturbed, this being reflected in an increase of visibility and a decrease of BOD_5. Lower numbers of TVC 37°C, TC and FC in 1987 could also have been connected with higher penetration of bactericidal UV radiation. Increased water temperature in the hypolimnion, to 11.8°C in 1986 and 10.0°C in 1987, although possibly affecting the survival of these micro-organisms, does not explain the differences in their numbers observed between 1986 and 1987. Also aeration by itself probably had no greater effect on the densities of these bacteria in water, also due to their microaeriphylic character. Higher numbers of indicatory bacteria in near-shore waters of Lake Starodworskie (station 5), and lower at the stations more distant from the shore (stations 2-5) might have been due to an inflow of pollution with surface run-offs. Moreover, in shallow waters the discussed micro-organisms can originate from detritus remnants and surface sediment layers as a result of waving, wind action, people walking along etc.

Table 10. The analysis of sediments quality of Lake Starodworskie using criteria given by Kavka [9] and Kohl [10] after Albinger [1]. Percent distribution of samples to the given class.

Water quality criteria		Bottom sediments quality level[3]	1986						1987						Average 1986-1987
			Site*												
Micro-organisms	Number of bacteria		1	2	3	4	5	1-5	1	2	3	4	5	1-5	
TVC 20°C[1]	< 500,000	1	100	100	100	100	100	100	77.8	77.8	100	77.8	88.9	84.5	92.2
	>500,000- 1,000,000	2	0	0	0	0	0	0	22.2	22.2	0	22.2	0	13.3	6.7
	>1,000,000- 10,000,000	3	0	0	0	0	0	0	0	0	0	0	11.1	2.2	1.1
	>10,000,000- 50,000,000	4	0	0	0	0	0	0	0	0	0	0	0	0	0
	>50,000,000-100,000,000	5	0	0	0	0	0	0	0	0	0	0	0	0	0
	>100,000,000-750,000,000	6	0	0	0	0	0	0	0	0	0	0	0	0	0
	>750,000,000	7	0	0	0	0	0	0	0	0	0	0	0	0	0
			(9)[4]	(9)	(9)	(9)	(9)	(45)	(9)	(9)	(9)	(36)	(9)	(45)	(90)
FC[2]	1- 10	1	11.1	0	0	0	0	2.4	11.1	11.1	11.1	0	22.2	11.1	7.0
	>10- 100	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	>100- 1,000	3	0	25.0	0	0	25.0	9.7	0	44.5	44.5	33.3	22.2	28.9	19.8
	>1,000- 5,000	4	11.1	12.5	12.5	25.0	12.5	14.6	78.8	44.4	33.3	44.5	44.5	48.9	32.6
	>5,000- 10,000	5	11.1	0	0	25.0	0	7.4	11.1	0	0	11.1	11.1	6.6	7.0
	>10,000-100,000	6	44.4	50.0	75.0	25.0	50.0	48.8	0	0	11.1	11.1	0	4.5	25.6
	>1,000,000	7	22.3	12.5	12.5	25.0	12.5	17.0	0	0	0	0	0	0	8.0
			(9)	(8)	(8)	(8)	(8)	(41)	(9)	(9)	(9)	(9)	(9)	(45)	(86)

* – See Figure 1

[1] – Total viable count at 20°C (saprophytic bacteria as CFU · 1 g^{-1} wet wt. sediments)

[2] – Number of faecal coliforms (MPN · 1 g^{-1} wet wt. sediments)

[3] – Degree of loading with organic substances, which can be well decomposed by bacteria (TVC 20°C) and degree of loading with faecal substances (FC): 1 – very little, 2 – little, 3 – moderate, 4 – moderate high, 5 – high, 6 – very high, 7 – extreme high

[4] – In brackets number of samples investigated.

At deeper stations possible effects of the bottom sediments are limited only to the near-bottom water layer and minimalized due to higher water volume having a diluting effect.

Vertical distribution of the discussed indicatory bacteria could have been connected with the bactericidal effect of UV radiation, uptake of the substances excreted by algae, uptake of algae decomposition products. In the case of TVC 20°C in 1986 these phenomena accounted for lower bacteria numbers in water collected from a depth of 0.3 m compared to that from 1-2 m depth. In 1987 the same also referred to water collected from 10 m depth. Algae development in the surface water layer limited penetration of UV radiation and their effect on bacteria to water layer of only 30 cm. Higher TVC 20°C in water collected from 10 m depth was due the fact that dead phytoplankton gathered there. Aeration of Lake Starodworskie did not fully liquidate thermal stratification. Water temperature at 10 m was never higher in summer than 10-11°C. Differences in water density (related to water temperature) also favoured bacteria gathering in this layer [19, 20, 21]. The increase of TVC 20°C (as well as of other indicatory bacteria) at the bottom is explained by their passage from bottom sediments due to the turbulence caused by aeration, sediment penetration by benthic organisms, convection water currents, and phenomena connected with methane fermentation. Also, animal organisms grazing in the water column might have had a modifying effect on the vertical distribution of micro-organisms.

Seasonal changes in the numbers of indicatory bacteria in Lake Starodworskie could be connected to rainfalls which brought in pollutants from the surrounding land, as well as with ice thawing and other aerial runoffs in spring, summer and autumn. Algae development and decay could also modify seasonal variations in bacteria numbers, and so could water turbulence caused by aeration. The relationship between atmospheric conditions and the numbers of indicatory bacteria is noticeable comparing temperature peaks on the days of sampling, or sum of precipitation during 7 days before sampling with TVC 20°C and numbers of some other bacteria groups. In 1986 a decrease of TVC 20°C and TVC 37°C in June and August was connected with the bloom of *Anabaena spiroides, Gleocapsa* sp., *Microcystis aeruginosa* and *Gomphosphaeria lacustris* [6]; some of these algae are known to be toxic. A decrease of TC and FC numbers in water at all sampling stations, and of FS numbers at stations 2, 3 and 5 in 1987 seems to confirm the hypothesis [8] that long-term mixing and

artificial destratification can improve bacteriological quality of water. This was confirmed also in the course of long-term studies on the effects of aeration in eutrophic Lake Mutek, Mazurian Lakeland [13, 20, 21, 26].

Total Viable Counts and Enteric Bacteria Concentrations in Lake Bottom Sediments

Considerably higher than in water were the numbers of the indicatory bacteria found in the bottom sediments of Lake Starodworskie, this being due to their sedimentation from the water column on animal and plant remnants. Bottom sediments adsorb dissolved organic and mineral substances, thereby condensing them to a degree sufficient for the development of even more required gastric bacteria [19]. Moreover, type of organic and mineral substance and qualitative composition of the authochthonic microflora of bottom sediments is different than in water column, this having an effect on the survival of indicatory bacteria. It has been stated [19] that bottom sediments have a positive effect on the survival of inflowing bacteria due to a neutralising action towards antagonistic environmental factors, or else due to different bottom microflora, enabling the gastric bacteria to compete for the available sources of carbon and energy more effectively than in water. In addition to this, low temperature at the bottom limits activity of antagonistic organisms. Due to the fact that survival of gastric bacteria (TC, FC, FS) decreases with increasing temperature (from 4°C upwards) [19], lake aeration and the resulting increase of temperature at the bottom, to 10°C in 1986 and 11°C in 1987, might have affected numbers of these micro-organisms in the bottom sediments of Lake Starodworskie. Usually lower TVC 20°C in the bottom sediments of Lake Starodworskie compared to other eutrophic lakes of Mazurian Lakeland [19] was due to a relatively low content of organic matter [7], amounting to only 1.8-18 % of dry weight. This was confirmed by the results on TVC 20°C in the bottom sediments of Lake Starodworskie compared to the data by Kavka [9], and Kohl [19] cited by Albinger [1]. Contrary to this, relatively high loading of the bottom sediments in Lake Starodworskie with TC, FC and FS suggests continuous pollution of this lake by animal faeces, possibly originating from the nearby riding school. This suggestion is also confirmed by FC to FS ratio lower than 0.7 in the majority of sediment samples.

Conclusions

1. TVC 20°C, TVC 37°C, TC, FC and FS numbers in the water of Lake Starodworskie were typical of clean or only slightly polluted surface waters.

2. Water at the stations located at a distance from the lake shore was less polluted with these bacteria than at the station located close to the lake shore.

3. Vertical distribution of TVC 20°C was usually characterized by lower levels of these bacteria in water collected from 0.3 m, and higher in samples collected from 1-2 m and at the bottom, and in 1987 also in those collected from 5 or 10 m depth. Near-bottom maximum was also observed for TVC 37°C, TC, FC and FS.

4. Seasonal variations in the numbers of indicatory bacteria were usually characterized by maximal values in May, September and November, exceptionally in other months. Peaks of bacteria numbers corresponded to peaks of the sum of precipitation during 7 days before sample collection, with minimal levels observed in June and August, when blue-green algae were blooming.

5. Lower TVC 20°C were found in Lake Starodworskie water in 1987 (second year of aeration), higher – in 1986 (first year of aeration); they correlated with organic matter content expressed in BOD_5.

6. All groups of indicatory bacteria were much more numerous in the bottom sediments of Lake Starodworskie than in its water.

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