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Evaluation of Pollution and the Sanitary-Bacteriological State of Lake Wigry, Poland

Part I. Pelagic Waters of Lake Wigry

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Abstract

The paper presents the results of studies on the degree of pollution and the sanitary-bacteriological state of pelagic waters of Lake Wigry in northeastern Poland, 1994-1996. Thirteen sampling stations were selected in the most characteristic points of the lake. TVC 20°C and TVC 37°C were used as indicators of pollution, while TC, FC and FS served as indicators of the sanitary state. Pelagic waters in the north part of Lake Wigry showed a higher degree of pollution than waters in the middle and southwest part. As regards the north part, less polluted were Zadworze and Wapiennica bays, as was the middle point of this part, while Hańczańska Bay was more polluted than the other stations. Water in the middle part of the lake (stations Rosochaty Rog, Wysoki Wegiel, Zatoka Jastrzebia, Zatoka Bielańska) and in the southwest part (Plos Bryzglowski, Zatoka Slupianska, Zatoka Wigierki, Zatoka Uklei) was of good quality, showing exceptionally slight symptoms of pollution.

Keywords: Lake, National Park, pollution, sanitary evaluation, indicatory bacteria, recreation, bathing

Introduction

There are practically no papers dealing with the bacteriological quality of surface waters in Suwalki Lake District, regarding either lakes or rivers. The region is distant from bigger industrial centres of the country, possesses large areas of forests, and its population is fairly scarce, so it seems that its waters should be less exposed to anthropogenic pollution than in other regions. The only great source of pollution in this region are municipal sewage of Suwalki town (about 60,000 inhabitants). Until 1992 they were discharged to the Czarna Hancza River, which brought this pollution to Lake Wigry. This resulted in an increase of pollution and eutrophication of the north lake part, especially of Zatoka Hanczanska. The Czarna Hancza River, together with Lake Wigry, constitute one of the most beautiful water routes of the region: the so-called Suwalki - Augustow route. Beautiful landscapes and relatively high quality of waters in the region attract more and more tourists each year, both from Poland and from abroad. This potentially endangers the quality of the whole ecosystem of Lake Wigry. To undertake some preventive measures it is first necessary to know the current sanitary and bacteriological states of this lake. This paper presents the results of surveys on the occurrence of bacteria indicatory of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) in the pelagic waters of Lake Wigry in 3 consecutive annual cycles: 1994-1996. Along with sanitary and bacteriological studies of the Czarna Hancza River [14, 15] and of underground water [13], this paper represents part of a more complex study of bacteriological quality of surface and underground waters in Wigry National Park.

Materials and Methods

Lake Wigry (Fig. 1) is located in Wigry National Park, which was created in 1989. It is one of 41 lakes of the Park, and is the largest and deepest (Table 1). It is also ranked twelfth in size in Poland. According to Bajkiewicz-Grabowska [3], the direct catchment area of the lake is 94.3 km^2 and constitutes the central part of the park. The southwest part of the lake catchment area is formed by Augustowskie Hills, and the southeast by Frackowska Plain. Lake Wigry

represents 78% of total area of lake in the Park, and 87% of their volume. Czarna Hancza River is its major inflow. Lake Wigry also receives waters of the Wiatrołuża River, the latter collecting pollutants from an agricultural-forest catchment. Outflow from the lake is in its north part, the so-call Ploso Northern. It is a moraine part of the lake, with very well developed shoreline and a number of bays: Hanczanska (with the inflow of Czarna Hancza River), Północna (inflow of Wiatrołuża) and Wschodnia (outflow of the Czarna Hancza River). This part of Lake Wigry also receives inflow from Lake Leszczewek. Czarna Hancza and Wiatroluza rivers supply Lake Wigry with about 76.2 million m^3 of water annually, while inflow from Lake Leszczewek supplies some 1.8 million m^3. The northern part (called Ploso Northern) is connected to the middle lake part (called Ploso Middle) through a narrowing (called Szyja), while the middle part passes into western part (called Ploso Western), which is connected to the most ribbon-like part of Lake Wigry, a bay called Zatoka Wigierki, and indirectly also the other bay - Zatoka Uklei. The lowest water levels are observed usually in June, July and August, and then in January and February, the highest - in April (exceptionally in May) and frequently in December. Differences in water level range from 20 to 50 cm [3]. Surface inflows to Lake Wigry are characterized by 3 maxima in the annual cycle:

1) the main one, following spring thaw, usually in March (rarely in April),

2) a short one in winter, culminating in December or January, and

3) in October.

Water inflow to the lake decreases from April, reaching the minimum in August or September. The lake has a number of islands, some quite large. There are also many deep places, at some points 73 m. High shores are overgrown with coniferous forest. Water is relatively clean, of greenish colour. A decrease of oxygen content takes place in the hypolimnion during summer stagnation. Fish stock is

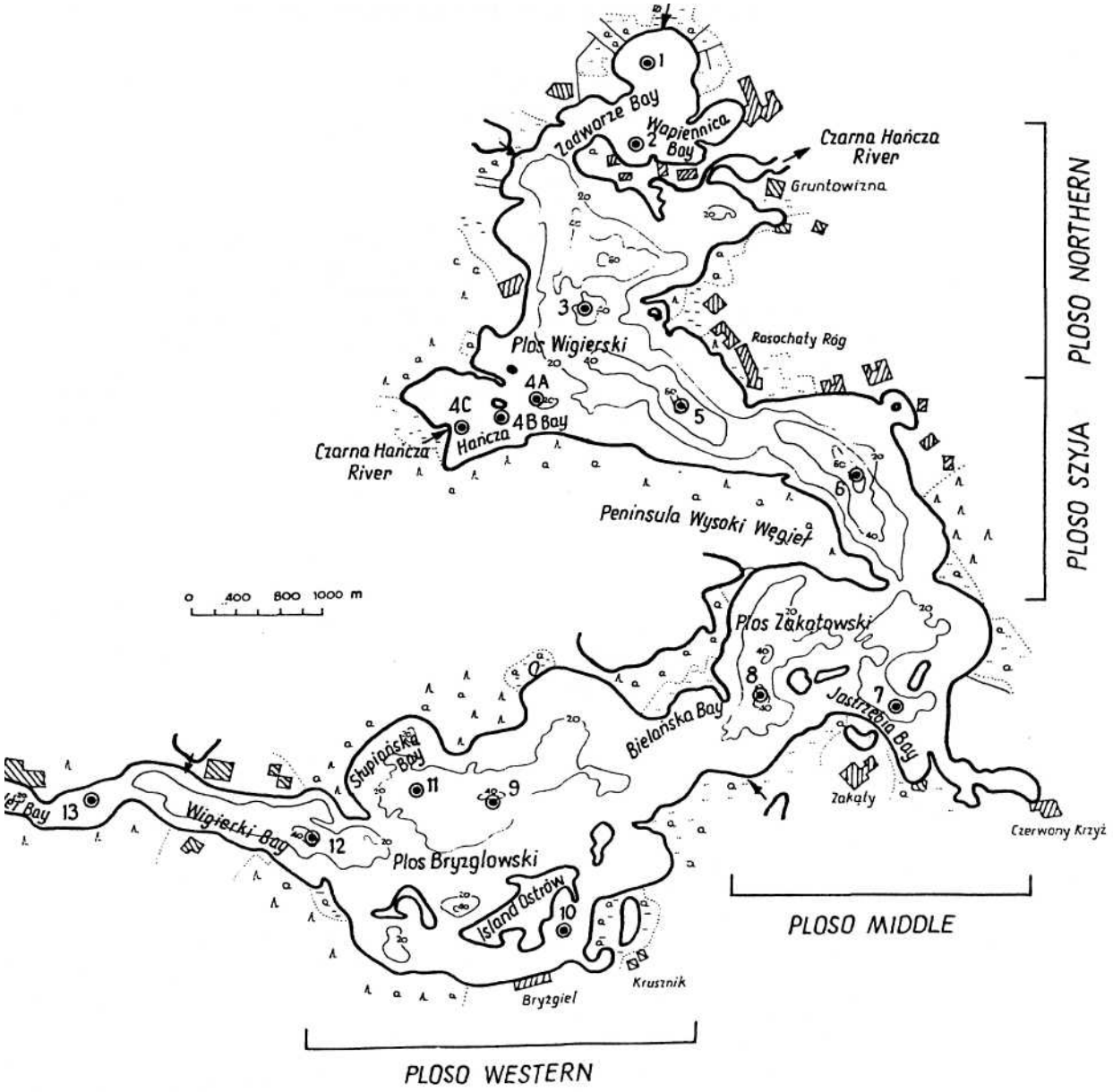

Fig. 1. Situational sketch of Lake Wigry. 1, 2, 3... 13 sites for collecting water samples.

Table 1. Some morphometric parameters of Lake Wigry after Stangenberg (according to the Inland Fisheries Institute in Olsztyn).

Geographic latitude	54°02.5'
Geographic longitude	23°04.4'
Height above sea level	131.9 m
Water surface area	2118.3 ha
Area of islands	68.4 ha
Maximal length	17500 m
Maximal breadth	3550 m
Maximal depth	73.0 m
Mean depth	15.4 m
Length of the shore-line: totally	72225 m
in this: of the lake	59850 m
of islands	12375 m
Lake volume (V)	336726.7 thousand m^3
Catchment basin Czarna Hańcza--Niemen	

very diversified (vendace, whitefish, bream, tench, perch, pike and more); there are also many animals, including beaver. Birds (falcon, great cormorant, swan, duck, coot etc.) find favourable conditions to nest among rich vegetation in the lake littoral, on the islands, and in the surrounding forest. There are also many recreation sites along the lake shores. Northeastern and southern parts neighbour residential areas and summer houses.

Sampling Sites

Taking advantage of the data collected in the research laboratory of Wigry National Park in Krzywe, and considering technical possibilities of collecting water samples in the lake and carrying bacteriological analyses in a reasonable time, 13 sampling stations were selected in the lake pelagial. They were usally located in the deepest point. The only exception are the stations in Zatoka Hanczanska, from the inflow of the Czarna Hancza river towards the middle part of the bay. A short characteristic of the sampling stations, number of collected samples and depth of sample collection are presented in Table 2.

Sampling Procedures

Water samples were collected in Lake Wigry from May 1994 till November 1996, at monthly intervals with the exception of winter months, when the lake was covered with ice. They were collected from 13 stations (Fig. 1). Samples were collected only once under the ice cover, in March 1995. Water samples were collected from depths of: 0.3 m (surface), 1.0 m, 2.0 m, 5.0 m, 10.0 m and then at 10 m intervals down to the bottom. At the water surface, samples were collected directly into sterile glass bottles. In deeper water layers and over the bottom (0.3-05 m above the bottom), a 10 1 Ruttner sampler was used. All water samples were poured into 300 ml sterile bottles with ground stoppers, and the the bottles were placed in dry ice, transported to the laboratory, and immediately taken for bacteriological analyses. There was never more than 18 h difference between sample collection and their analysis.

Bacteriological Methods

Bacteriological analyses comprised the following:

1. Total counts (CFU/1 ml) of psychrophilic bacteria in broth agar after 72 h incubation at 20°C (TVC 20°C),
2. Total counts (CFU/1 ml) of mesophilic bacteria in broth agar after 24 h incubation at 37°C (TVC 37°C),
3. Total number (MPN/100 ml) of total coliforms (TC) in Eijkman medium after 48 h incubation at 37°C,
4. Numbers (MPN/100 ml) of faecal coliforms (FC) in Eijkman medium after 24 h incubation at 44.5°C,
5. Numbers (MPN/100 ml) of faecal streptococci (FC) in Slanetz and Bartley medium with sodium azide and crys talline violet after 72 h incubation at 37°C.

TVC 20°C and TVC 37°C were determined according to

Table 2. Sites of water sampling

Lake part	Site (designation)	Depth (m)	Number of samples	Depth of sampling (m)
I. Ploso Northern	1. Zadworze Bay	12	4	0.3; 1.0; 5.0; 10.0/12.0
	2. Wapiennica Bay	15	5	0.3; 1.0; 5.0; 10.0; 15.0
	3. Plos Wigierski	60	9	0.3; 1.0; 5.0; 10.0; 20.0; 30.0; 40.0; 50.0; 60.0
	4. Hańczańska Bay			
	4A	10	4	0.3; 1.0; 5.0; 10.0
	4B	5	3	0.3; 1.0; 5.0
	4C	1	1	0.3
II. Ploso Szyja	5. Rosochaty Róg	60	9	0.3; 1.0; 5.0; 10.0; 20.0; 30.0; 40.0; 50.0; 60.0
	6. Wysoki Węgieł	60	9	0.3; 1.0; 5.0; 10.0; 20.0; 30.0; 40.0; 50.0; 60.0
III. Ploso Middle	7. Jastrzębia Bay	30	6	0.3; 1.0; 5.0; 10.0; 20.0; 30.0
	8. Bielańska Bay	40	7	0.3; 1.0; 5.0; 10.0; 20.0; 30.0; 40.0
IV. Ploso Western	9. Plos Bryzglowski	30	6	0.3; 1.0; 5.0; 10.0; 20.0; 30.0
	10. near Island Ostrów	20	5	0.3; 1.0; 5.0; 10.0; 20.0
	11. Słupiańska Bay	40	7	0.3; 1.0; 5.0; 10.0; 20.0; 30.0; 40.0
V. Wigierska Bay	12. Wigierki Bay	40	7	0.3; 1.0; 5.0; 10.0; 20.0; 30.0; 40.0
	13. Uklei Bay	15	5	0.3; 1.0; 5.0; 10.0; 15.0

Table 3. Mean (for study period) and range for the numbers of total viable counts at 20°C and 37°C in the water of Lake Wigry

Site*	Depth (m)	Number of samples	Total viable count at 20°C (CFU/1 ml)				Total viable count at 37°C (CFU/1 ml)			
			1994	1995	1996	1994-1996	1994	1995	1996	1994-1996
1	12	30 A	420	350	220	340	75	205	20	100
		B	50-730	25-1400	25-1525	25-1525	5-605	6-1535	3-98	3-1535
2	15	89 A	490	410	135	355	90	155	60	95
		B	70-1400	50-1400	35-950	35-1400	2-340	2-460	2-675	2-675
3	60	133 A	405	415	140	305	195	125	20	95
		B	75-1220	25-3170	10-1000	10-3170	1-1220	2-850	1-75	1-1220
4A	10	67 A	438750	720	210	144390	1410	70	35	510
		B	500-3680000	215-3800	50-1000	50-3680000	5-18000	10-250	5-165	5-18000
4B	5	40 A	323850	660	1960	81880	3200	125	180	815
		B	600-2690000	45-4500	170-21000	45-2690000	10-7400	15-275	30-1400	10-7400
4C	1	20 A	81630	1720	510	21270	10090	65	75	2575
		B	300-372000	400-9800	55-2020	55-372000	65-41000	5-320	20-210	5-41000
5	60	124 A	260	375	135	235	225	115	20	80
		B	70-1000	15-1670	5-710	5-1670	5-760	2-825	1-265	1-825
6	60	140 A	450	410	105	310	110	105	25	75
		B	20-5160	15-4000	5-380	5-5160	2-480	2-525	1-210	1-525
7	20	88 A	520	515	185	425	100	505	60	245
		B	25-6170	10-5330	40-955	10-6170	2-800	2-14200	5-220	2-14200
8	40	102 A	360	320	150	280	50	30	55	45
		B	65-2560	5-2520	25-475	5-2560	0-325	0-250	2-310	0-325
9	40	99 A	290	405	215	310	55	30	45	40
		B	65-1115	5-3450	15-325	5-3450	0-310	0-130	0-340	0-340
10	20	79 A	280	290	160	240	65	30	45	45
		B	75-485	3-670	25-490	3-670	0-550	0-135	0-225	0-550
11	20	93 A	380	300	160	270	35	25	70	40
		B	25-2800	2-1725	30-915	2-1800	0-240	0-145	2-800	0-800
12	40	117 A	540	395	150	360	75	35	30	45
		B	75-1200	3-1065	10-600	3-1200	0-850	0-675	0-140	0-850
13	15	82 A	400	310	305	340	45	20	60	40
		B	125-1720	20-3200	60-1275	20-3200	0-300	0-105	3-715	0-715

* See Figure 1.

the bacteriological procedure used for drinking water. The most probable number of TC, FC and FS was determined with the fermentation test-tube method and the dilution method according to Standard Methods [2]. Each time 10 ml, 1 ml, 0.1 ml and 0.01 ml of water were inoculated in 3 parallel repetitions. The results were obtained from Mac-Crady's tables. Physiologic NaCl solution was used as the diluent. Positive results for the presence of total coliforms in fermentation samples in Eijkman medium were checked in Endo medium, lauryl-tryptose broth, and in preparates stained with the Gram method. Positive results for the presence of faecal streptococci in Slanetz and Bartley medium were checked in m-Enterococcus Agar medium. Typical dark-red colonies which developed in this medium were transferred to broth medium, and their growing ability was determined in 44.5°C, at pH 9.6, in the presence of 6.5% NaCl, and additionally - in milk with an addition of 0.01% methylene blue. Dry media produced by DIFCO and MERCK were used in the study. The obtained values of microbiological indices of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) of lake water were related to the criteria adopted for the classification of surface waters [1, 4, 16] and for water used for recreation purposes [5, 17]. In total, 1343 water samples were analysed.

Results

Numbers of Bacteria Indicatory of Pollution and Sanitary State in the Pelagic Waters of Lake Wigry

Northern part of Lake Wigry. There were 4 areas distinguished in this part: the so-called Ploso Northern (North Middle section), Zatoka Hanczanska (Hanczanska Bay), a part which represented an elongation of Zatoka Hanczanska towards the east, to the peninsula (and a village) called Rosochaty Rog, and the so-called Ploso Szyja (Middle Neck section). From among these 4, the lowest degree of bacteriological pollution was observed in pelagic waters of Rosochaty Rog close to peninsula and village,

Table 4. Mean (for study period) and range for the number of total coliforms, faecal coliforms and faecal streptoccocci (enterococci) in the water of lake Wigry

Site*	Depth (m)	Number of samples	Number of total coliforms (MPN/100 ml)				Number of fecal coliforms (MPN/100 ml)				Number of fecal streptococci (enterococci) (MPN/100 ml)			
			1994	1995	1996	1994--1996	1994	1995	1996	1994--1996	1994	1995	1996	1994--1996
1	12	73 A	55	220	70	115	10	35	1	15	235	60	180	155
		B	< 3-460	3-1100	< 3-1100	< 3-1100	< 3-150	< 3-460	< 3-9	< 3-460	< 3-2400	< 3-1100	< 3-1400	< 3-2400
2	15	90 A	90	285	15	130	5	40	3	15	130	70	225	140
		B	< 3-1100	3-1400	< 3-150	< 3-1400	< 3-75	< 3-150	< 3-43	< 3-150	< 3-1100	< 3-1100	< 3-1400	< 3-1400
3	60	133 A	125	210	160	165	12	22	1	10	50	15	200	100
		B	3-1100	3-1400	< 3-1400	< 3-1400	< 3-93	< 3-240	< 3-23	< 3-240	< 3-460	< 3-120	< 3-1400	< 3-1400
4A	10	69 A	215	2755	120	1100	195	165	30	130	90	105	195	125
		B	23-1100	15-45000	4-1400	4-45000	< 3-2400	< 3-1400	< 3-240	< 3-2400	3-460	< 3-1500	< 3-1400	< 3-1500
4B	5	40 A	750	550	350	535	205	205	180	200	125	50	227130	73870
		B	20-4000	11-1400	< 3-460	< 3-4000	< 3-1100	< 3-1100	< 3-1100	< 3-1100	< 3-460	3-240	<3-1400000	<3-1400000
4C	1	20 A	535	335	940	600	230	345	215	275	275	1835	200090	5830
		B	43-2400	93-1100	< 3-4500	< 3-4500	3-1100	4-1100	< 3-1100	< 3-1100	3-1100	15-14000	<3-1400000	<3-1400000
5	60	126 A	43	220	13	95	15	23	5	15	23	13	245	105
		B	< 3-240	3-1400	< 3-93	< 3-1400	< 3-93	< 3-150	< 3-93	< 3-150	< 3-93	< 3-120	< 3-1400	< 3-1400
6	60	141 A	70	150	5	80	3	20	0	8	25	15	235	95
		B	< 3-460	3-1400	< 3-43	< 3-1400	< 3-9	< 3-110	< 3-4	< 3-110	< 3-150	< 3-93	< 3-1400	< 3-1400
7	20	88 A	55	95	5	55	30	50	0	30	25	20	210	75
		B	< 3-240	< 3-460	< 3-23	< 3-460	< 3-460	< 3-1100	< 3	< 3-1100	< 3-160	< 3-20	< 3-1400	< 3-1400
8	40	102 A	55	135	15	75	4	8	0	4	15	55	165	75
		B	< 3-460	< 3-1100	< 3-240	< 3-1100	< 3-23	< 3-93	< 3-4	< 3-93	< 3-120	< 3-1400	< 3-1400	< 3-1400
9	40	99 A	125	90	50	85	5	4	0	2	15	18	150	60
		B	<3-1100	< 3-1100	< 3-1100	< 3-1100	< 3-23	< 3-43	< 3-23	< 3-43	< 3-43	< 3-240	< 3-1400	< 3-1400
10	20	76 A	80	120	43	165	9	8	2	6	35	115	225	130
		B	3-1100	3-1100	< 3-460	< 3-1100	< 3-43	< 3-43	< 3-23	< 3-43	< 3-460	< 3-1100	< 3-1100	< 3-1100
11	20	94 A	115	25	15	50	8	3	0	3	50	20	145	95
		B	< 3-2400	< 3-240	< 3-240	< 3-2400	< 3-93	< 3-23	< 3-23	< 3-93	< 3-1100	< 3-460	< 3-1100	< 3-1100
12	40	118 A	140	40	15	60	4	6	0	3	22	60	145	75
		B	< 3-2400	< 3-460	< 3-240	< 3-2400	< 3-23	< 3-43	< 3-9	< 3-43	< 3-150	< 3-1100	< 3-1400	< 3-1400
13	15	82 A	120	65	15	65	3	15	0	6	27	27	120	60
		B	< 3-1100	< 3-450	< 3-93	< 3-1100	< 3-23	< 3-43	< 3	< 3-43	< 3-64	< 3-240	< 3-1400	< 3-1400

* See Figure 1.

(station 5), and in Ploso Szyja (station 6). Both stations are located over the deepest points. The highest degree of pollution was found in Zatoka Hanczanska (sampling stations 4A, 4B, 4C). Waters of Ploso Northern, with the bays Zadworze (station 1), Wapiennica (station 2) and Plos Wigierski (station 3) were clean or negligibly polluted (Tables 3 and 4). Numbers of TVC 20°C in this part ranged from a few to several thousand cells in 1 ml, depending on sampling date and depth. Average number for the whole water column was more or less similar at the there stations and did not exceed 355 CFU/1 ml, decreasing in the consecutive years of studies. Numbers of TVC 37°C were 2-3 times lower. Average value for the whole water column did not exceed 100 CFU/1 ml, increasing slightly in the consecutive years at stations 1 and 2, decreasing at station 3. Numbers of TC and FS did not exceed 1400, of FC - 460 MPN/100 ml, TC were less abundant at station 1, and more at stations 2 and 3, contrary to FC and FS, which were less numerous at stations 2 and 3 and more numerous at station 1. Average numbers of TC and FC increased in 1995 and decreased in 1996, while the average number of FS showed an opposite pattern, with lower numbers in 1995 and higher in 1996. In the annual cycle, higher numbers of indicatory bacteria were usually recorded in different summer months, rarely in other periods (Figs. 2-6).

TVC 20°C numbers in Zatoka Hanczanska waters (stations 4A, 4B, 4C) sometimes reached a few million CFU/1 ml, while of TVC 37°C - several thousand CFU/1 ml (100-1000 - fold more than at other stations in the north part of Lake Wigry). The average number of these bacteria decreased in consecutive years. As regards the bacteria indicatory of the sanitary state (TC, FC, FS), only FS attained higher numbers, whereas numbers of TC and FS did not exceed 2400 MPN/100 ml. These bacteria were usually more numerous at station 4C, close to the inflow of the Czarna Hancza River. Their average numbers either dec-

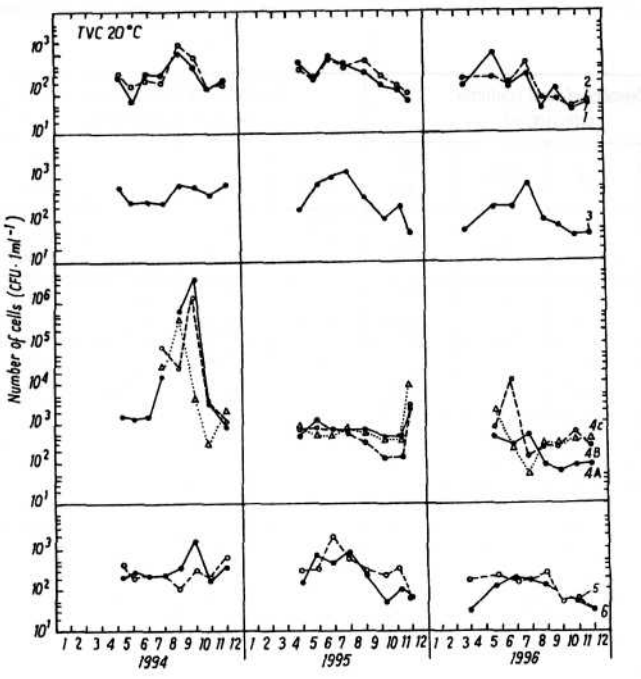

Fig. 2. Seasonal changes of the number TVC 20°C in pelagic waters of Lake Wigry on sites 1-6.

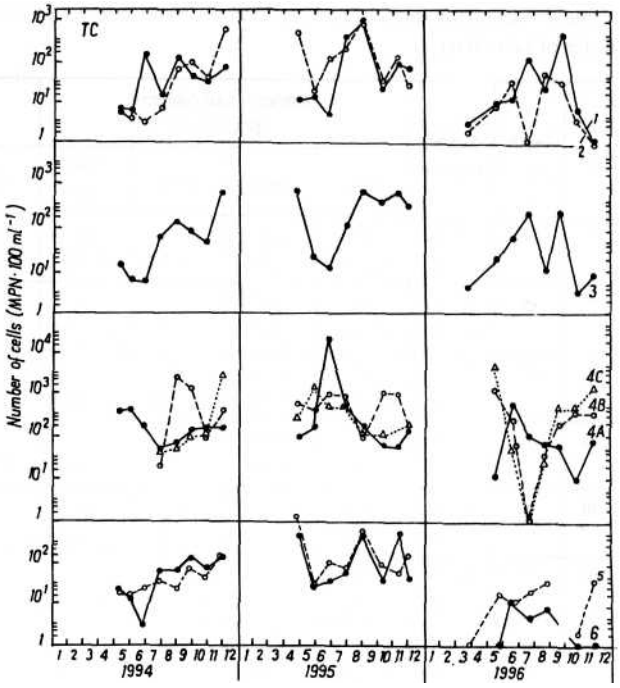

Fig. 4. Seasonal changes of the number TC in pelagic waters of Lake Wigry on sites 1-6.

reased or increased in consecutive years, depending on the station and bacterial group (Tables 3 and 4). TVC 20°C were numerous in autumn 1994 and 1995 and spring 1996, and TVC 37°C - in summer 1994 and spring 1995 and 1996. TC were more numerous in summer and spring, FC and FS in spring and autumn (Figs. 2-6).

Prolongation of Zatoka Hanczanska towards Polwysep (peninsula) and the village Rosochaty Rog, Ploso Szyja (station 5) was characterized by TVC 20°C numbers not exceeding 1670 CFU/1 ml, and TVC 37°C - less than 825 CFU/1 ml. Their mean numbers for the entire study period were 235 and 80 CFU/1 ml, respectively. Numbers of both groups decreased in consecutive years. TC and FS reached maximally 1400 MPN/100 ml, and FC - 150 MPN/100 ml. Bacteria belonging to the latter group were frequently totally absent from water samples. Their mean number was similar as at station 6 and in the southwestern part of Lake Wigry (stations 8-13) (Tables 3 and 4). Curves of annual variations in TVC 20°C and TVC 37°C numbers were similar to those in Plos Wigierski (station 3) or shifted in time (by a month) in relation to the latter. Curves of TC,

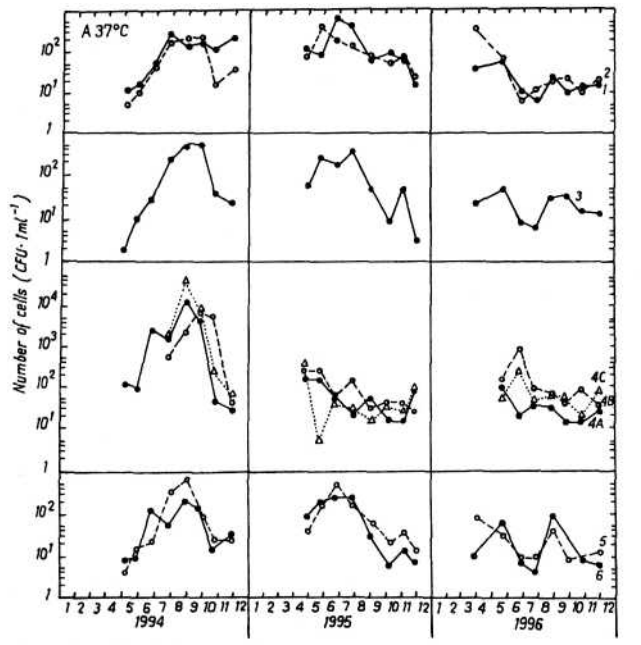

Fig. 3. Seasonal changes of the number TVC 37°C in pelagic waters of Lake Wigry on sites 1-6.

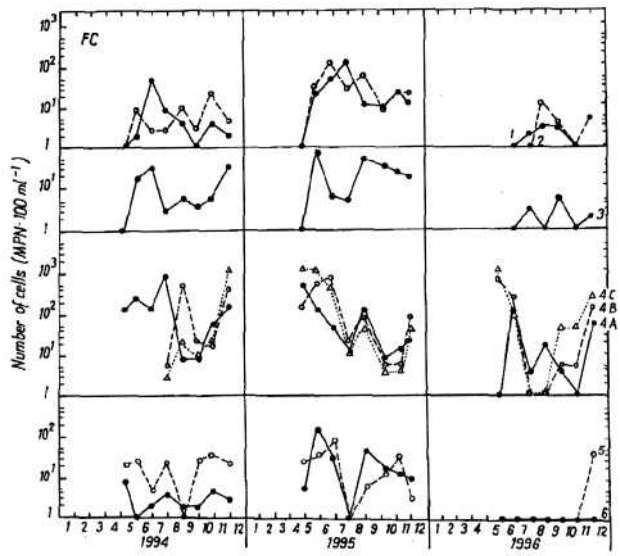

Fig. 5. Seasonal changes of the number FC in pelagic waters of Lake Wigry on sites 1-6.

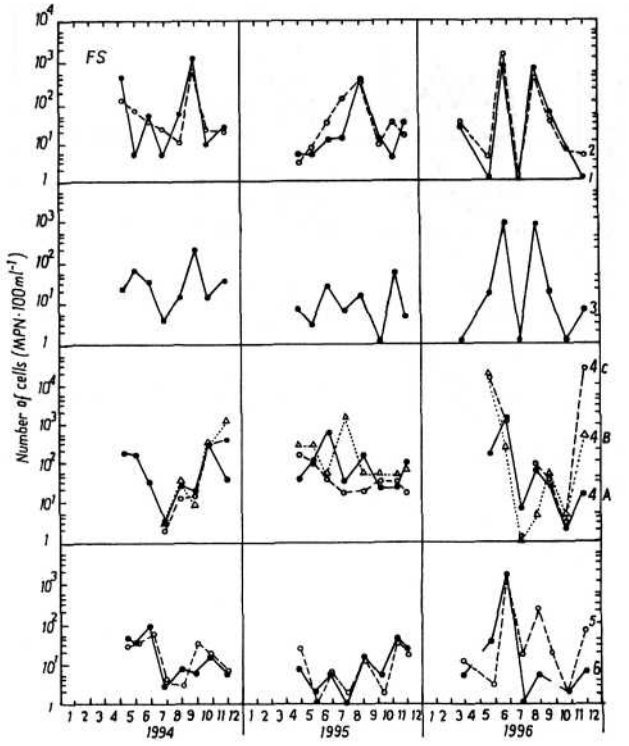

Fig. 6. Seasonal changes of the number FS in pelagic waters of Lake Wigry on sites 1-6.

FC and FS numbers were characterized by higher values in different summer and autumn months (Figs. 2-6). TVC 20°C at station 6 in the region of Potwysep Wysoki Wegiel reached maximally 5160 CFU/1 ml, and TVC 37°C - 525 CFU/1 ml. The maximal number of TC and FC was 1400 MPN/100 ml, of FC - 110 MPN/100 ml. The latter 3 groups of indicatory bacteria were often not present at all. Average numbers of indicatory bacteria for the entire study period were close to those found at station 5 in the region of P6twysep Rosochaty Rog and Rosochaty Rog village. Average numbers of TVC 20°C and TVC 37°C decreased in consecutive years, average numbers of TC and FC increased in 1995 and decreased in 1996, while FS decreased in 1995 and increased in 1996 (Tables 3 and 4). All groups of indicatory bacteria reached maximal numbers in summer months, rarely in autumn (Figs. 2-6).

Middle part of Lake Wigry. Two stations were distinguished in the middle part: Zatoka Jastrzebia and Zatoka Bielariska. As regards Zatoka Jastrzebia (station 7), only TVC 20°C and TVC 37°C suggested slightly higher pollution. Maximal numbers of these bacteria reached, respectively, 5330 and 1535 CFU/1 ml, while mean values for the whole water column were 425 and 52 CFU/1 ml, repectively. TC, FC and FS numbers did not exceed 460, 1100 and 1400 MPN/100 ml, respectively, the mean values for the whole water column and study period being 55, 30 and 75 MPN/100 ml. Average TVC 20°C numbers were higher

Table 5. The analysis of water quality of Lake Wigry using criteria given by Albinger [1]. Percent distribution of samples relevant to the given class

Water quality criteria		Water quality level[3]	Site*														
Microorganisms	Number of bacteria		1	2	3	4A	4B	4C	5	6	7	8	9	10	11	12	13
TVC[1] 20°C	0 – 500	1	78	82	83	53	77	86	89	89	86	89	86	95	88	87	77
(CFU/1 ml)	500 – 1000	2	15	9	14	17	8	14	8	5	8	6	5	5	6	8	9
	1000 – 10000	3	7	9	3	23	8	0	3	6	6	5	9	0	6	5	14
	10000 – 50000	4	0	0	0	7	7	0	0	0	0	0	0	0	0	0	0
	50000 – 100000	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	100000 – 750000	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	> 750000	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			(72)	(89)	(133)	(40)	(13)	(7)	(125)	(140)	(87)	(101)	(98)	(74)	(92)	(118)	(86)
FC[2]	1 – 10	1	76	79	78	43	23	29	75	81	78	91	94	83	96	92	92
(MPN/100 ml)	10 – 100	2	19	18	21	41	38	43	22	17	15	9	6	17	4	8	7
	100 – 1000	3	5	3	1	14	31	14	3	6	5	0	0	0	0	0	1
	1000 – 5000	4	0	0	0	2	8	14	0	6	2	0	0	0	0	0	0
	5000 – 10000	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10000 – 100000	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	> 100000	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			(63)	(87)	(133)	(44)	(13)	(7)	(126)	(143)	(89)	(101)	(97)	(75)	(92)	(122)	(83)

Explanations:

* - See Figure 1

[1] - Total viable count at 20°C (saprophytic bacteria)

[2] - Number of faecal coliforms

[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

- In brackets number of samples investigated

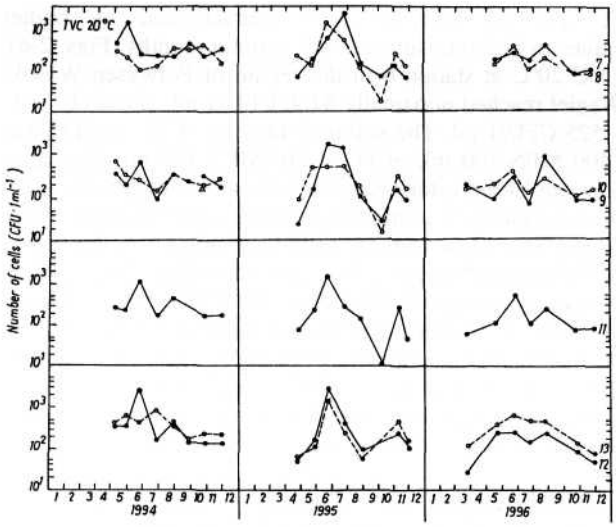

Fig. 7. Seasonal changes of the number TVC 20°C in pelagic waters of Lake Wigry on sites 7-13.

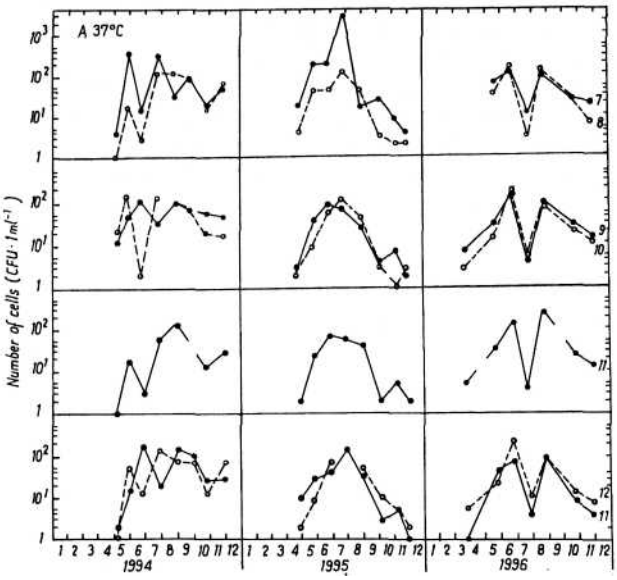

Fig. 8. Seasonal changes of the number TVC 37°C in pelagic waters of Lake Wigry on sites 7-13.

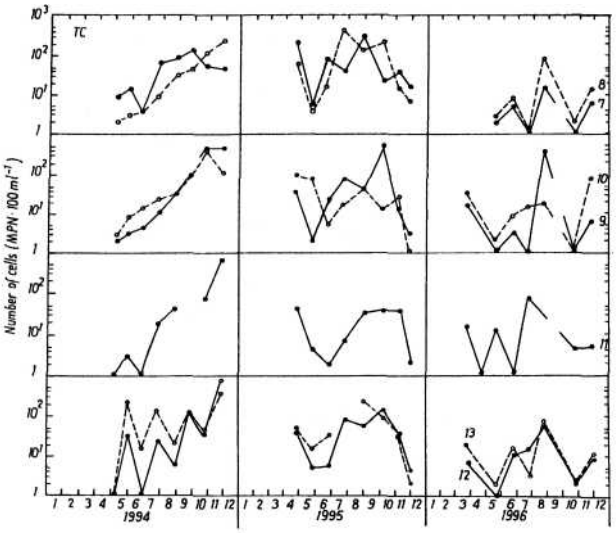

Fig. 9. Seasonal changes of the number TC in pelagic waters of Lake Wigry on sites 7-13.

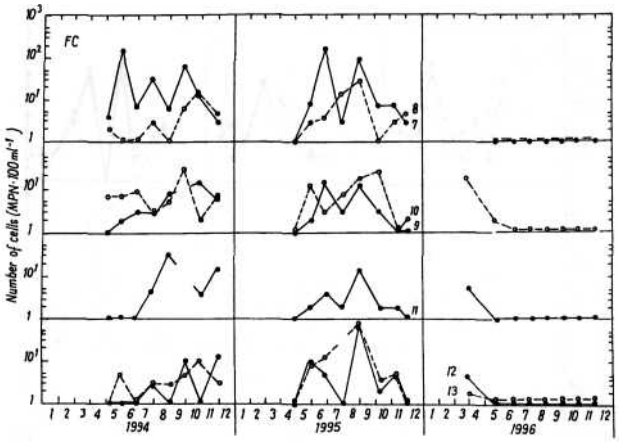

Fig. 10. Seasonal changes of the number FC in pelagic waters of Lake Wigry on sites 7-13.

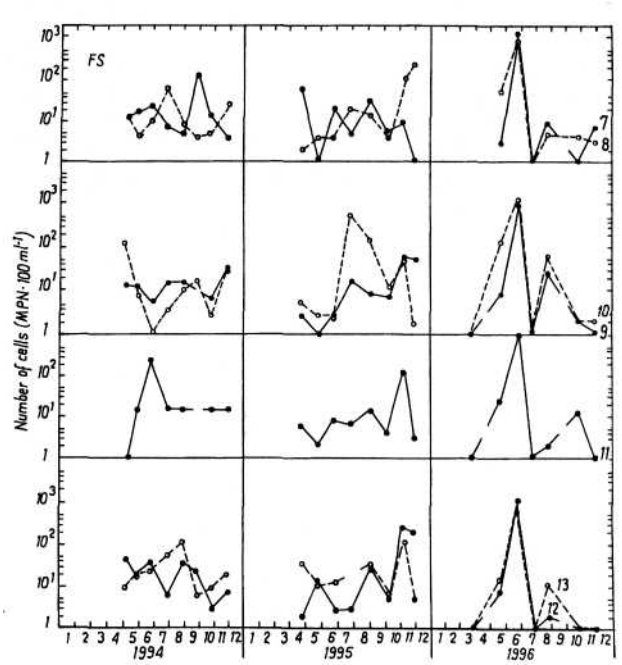

Fig. 11. Seasonal changes of the number FS in pelagic waters of Lake Wigry on sites 7-13.

in 1994 and 1995, of TVC 37°C - in 1995, of TC and FC in 1995, and of FS in 1996 (Tables 3 and 4). More of these bacteria were usually present in different summer months, rarely in spring or autumn (Figs. 7-11). As regards Zatoka Bielanska (station 8), numbers of TVC 20°C and TVC 37°C did not exceed 2560 and 325 CFU/1 ml respectively, with the mean values for the study period amounting to 280 and 45 CFU/1 ml. Numbers of TC, FC and FS reached maximally 1100, 93 and 1400 MPN/100 ml, the average values for the whole study period and water column being 75, 4 and 75 MPN/100 ml. Average numbers of TVC 20°C, TC and FC were higher in 1995, of TVC 37°C and FS in 1996 (Tables 3 and 4). Seasonal changes of the numbers of these bacteria were the same as in Zatoka Jastrzebia (station 7) (Figs. 7-11).

Southwestern part of Lake Wigry. Analyses were made using water samples collected from the deepest part of Plos Bryzglowski (station 9), in the region of Ostrów Island opposite Bryzgiel village (station 10) and in Zatoka

Slupianska Bay (station 11). At all stations numbers of TVC 20°C and TVC 37°C did not exceed (respectively) 3450 and 800 CFU/1 ml, the mean values for the whole water column and study period being 215 and 45 CFU/1 ml. Average number of TVC 20°C were higher in 1994 and 1995, while of TVC 37°C in 1996. Numbers of TC reached higher values (up to 2400 MPN/100 ml) in Zatoka Slupianska (station 11). FC were similarly scarce at all three stations, while FS attained the highest numbers at station 9 (up to 1400 MPN/100 ml). Average numbers of TC were usually higher in 1994, of FS in 1996, while average numbers of FC were more or less similar during the 3 years (Tables 3 and 4). TVC 20°C, TVC 37°C and TC were usually more numerous in summer, FC and FS - at the end of summer and/or in autumn (Figs. 7-11).

Bays Zatoka Wigierki and Zatoka Uklei. Samples were collected from the deepest parts of Zatoka Wigierki (station 12) and Zatoka Uklei (station 13). At station 13 numbers of TVC 20"C and TVC 37°C did not exceed 1200 and 850 CFU/1 ml respectively, while in Zatoka Uklei the respective numbers were 3200 and 715 CFU/1 ml. Mean values of TVC 20°C for the whole study period and water column were 360 CFU/1 ml in Zatoka Wigierki and 340 CFU/1 ml in Zatoka Uklei, being very close to the values noted in the bay Zatoka Zadworze (station 1) and Wapiennica (station 2). Mean numbers of TVC 37°C for the whole water column and the whole study period was 40 CFU/1 ml in Zatoka Wigierki and 45 CFU/1 ml in Zatoka Uklei, and was similar to the values observed in the deepest place of Plos Bryzglowski (station 9), the region of Ostrow Island and the village Bryzgiel (station 10), and in Zatoka Slupianska Bay (station 11). Mean numbers of TVC 20°C in Zatoka Wigierki and Zatoka Uklei were higher in 1994; of TVC 37°C in Zatoka Wigierki in 1994, and Zatoka Uklei in 1996. Numbers of TC, FC and FS did not exceed 2400, 43 and 1400 MPN/100 ml, respectively. The mean values were more or less similar in the two bays. The mean number of TC was higher in 1994, of FC in 1995, and of FS in 1996 (Tables 3 and 4). Seasonal variations in the numbers of TVC 20°C, TC, FC and FS were similar as in the Zatoka Slupianska Bay (station 11) (Figs. 7-11).

Numbers of Indicatory Bacteria and the Degree of Pollution of Pelagic Waters in Lake Wigry

Comparison of results pertaining to TVC 20°C and FC numbers in the lake pelagial to the bacteriological water criteria presented by Albinger [1] and given in Table 5 makes it possible to assess lake loading with organic matter decomposed by heterotrophic bacteria, and with human and animal faeces, as follows:

1. Water in the northern part of Lake Wigry is characterized by the lowest loading with organic matter easily decomposed by heterotrophic bacteria, and with human and animal faeces in the region of Wysoki Wegiel peninsula

Table 6. The analysis of bacteriological water quality of Lake Wigry using criteria given by Cabejszek et al. [4]

Bacteriological water quality criteria		Water quality level[4]	Site*														
Microorganisms	Number of bacteria (CFU/ 1ml)		1	2	3	4A	4B	4C	5	6	7	8	9	10	1	12	13
TVC[1] 20°C	< 300	A	61	56	70	30	47	26	74	78	68	75	78	72	78	77	69
	300 – 5000	B	39	37	30	60	35	58	26	20	30	25	22	28	22	21	31
	5000 – 10000	C	0	0	0	1	5	10	0	2	2	0	0	0	0	2	0
	> 10000	D	0	0	0	9	13	6	0	0	0	0	0	0	0	0	0
			(72)	(89)	(133)	(67)	(40)	(19)	(125)	(140)	(67)	(102)	(99)	(75)	(93)	(116)	(82)
TVC[2] 37°C	< 200	A	88	83	89	84	57	68	92	88	88	96	98	93	94	96	90
	200 – 1000	B	10	17	11	6	28	16	8	12	10	4	2	7	6	4	10
	1000 – 5000	C	2	0	0	4	8	10	0	0	2	0	0	0	0	0	0
	> 5000	D	0	0	0	6	7	6	0	0	0	0	0	0	0	0	0
			(73)	(9)	(133)	(65)	(40)	(19)	(126)	(139)	(87)	(102)	(99)	(76)	(92)	(116)	(82)
Coli titre[3]	> 1	A	96	95	98	77	67	68	96	98	87	100	100	100	98	99	99
	1 – 0.1	B	4	5	2	20	23	16	4	1	10	0	0	0	2	0	1
	0.1 – 0.01	C	0	0	0	3	7	16	0	1	3	0	0	0	0	0	0
	< 0.01	D	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
			(74)	(89)	(133)	(69)	(40)	(19)	(126)	(141)	(88)	(102)	(99)	(76)	(93)	(117)	(82)

Explanations:

* - See Figure 1

[1] - Total viable count at 20°C

[2] - Total viable count at 37"C

[3] - Faecal coliforms titre

[4] - A - unpolluted, B - insignificantly polluted, C - distinctly polluted, D - heavily polluted. Percent distribution of samples relevant to the given class

- In brackets number of samples investigated

(station 6), and the highest in the region of Zatoka Hanczanska (stations 4A, 4B, 4C).

2. Water in the middle part of Lake Wigry is characterized by the lowest loading with organic matter decomposed by heterotrophic bacteria, and with human and animal faeces in the region of Zatoka Bielańska (station 8), and a little higher in the region of Zatoka Jastrzebia (station 7).

3.Water in the southwestern part of Lake Wigry is characterized by a more or less similarly low loading with organic matter and human and animal faeces in the regions Plos Bryzglowski (station 9), Ostrow Island and Bryzgiel village (station 10) and Zatoka Słupinska (station 11). Only single samples collected at these stations showed moderate loading with organic matter easily decomposed by heterotrophic bacteria and with bird faeces (water fowl).

4. Water in Zatoka Wigierki and Zatoka Uklei was usually characterized by very low, rarely low, and/or moderate loading with organic matter easily decomposed by heterotrophic bacteria, and with human and/or animal faeces.

On the other hand, comparison of the results on the numbers of TVC 20°C, TVC 37°C, and FC (the author dispense of the data on coli titre) in the pelagic waters of Lake Wigry with the standards of water purity given by Cabejszek et al. [4] and presented in Table 6, makes it possible to classify the northern part (Ploso Northern) as clean or only slightly polluted (with the exception of Zatoka Hanczanska), whereas Zatoka Hanczanska should be classified sometimes as moderately, and sometimes as noticeably or even strongly polluted. Region Ploso Szyja close to Rosochaty R6g peninsula (station 5) and Wysoki Wegiel (station 6), as well as the regions Ploso Middle with Zatoka Jastrzebia (station 7), Zatoka Bielanska (station 8), Ploso Western close to Plos Bryzglowski (station 9), Ostrow Island and Bryzgiel village (station 10), Zatoka Słupiańska (station 11), Zatoka Wigierki (station 12) and Zatoka Uklei (station 13) could be classified as slightly polluted. Only single samples collected from these stations showed noticeable pollution.

Taking into account the data on FC and the standards of lake water classification given in the Regulation by the Council of Ministers of 14 December 1987 [16] it can be said that 95-100% of the samples collected from Ploso Northern (stations 1, 2 and 3), Ploso Szyja (stations 5, 6), Zatoka Bielanska (station 11), Zatoka Wigierki and Zatoka Uklei (stations 12 and 13) can be classified as class I of purity. As regards Zatoka HaAczanska (station 4A, 4B and 4C) only 67-77% of the samples could be classified as class I, while 16-23% had FC levels characteristic of class II, and 3-16% - even of class III. In the region of Zatoka Jastrzebia (station 7) 87% of water samples could be classified as class I, 10% showed FC levels characteristic of class II, and 3% of class III.

Numbers of Bacteria Indicatory of Sanitary State and Quality Standards for Waters Used for Recreational Purposes

According to the data of the US Department of the Interior [17], numbers of TC and FC in surface waters used for bathing should not be higher than 1000 and 200 MPN/100 ml, respectively. In waters used for boating, canoeing and sailing, when there is no direct contact with the human body, maximal numbers of these bacteria may reach

Table 7. Analysis of bacteriological water quality of Lake Wigry using criteria given by U.S. Department of the Interior (Federal Water Pollution Control Administration 1968) [17] as the percent distribution of samples relevant to the given criteria.

Site*	Number of samples investigated	Bacteriological water quality standards					
		Total coliforms (MPN/100 ml)			Faecal coliforms (MPN/100 ml)		
		Recreational		Public water supply	Recreational		Public water supply
		I	II		I	II	
		1000	5000	10000	200	1000	2000
1	73	93	100	100	98	100	100
2	89	93	100	100	93	100	100
3	132	95	100	100	98	99	99
4A	69	67	97	97	57	97	100
4B	40	77	97	97	65	87	97
4C	20	85	100	100	70	85	100
5	126	97	100	100	100	100	100
6	141	98	100	100	99	99	100
7	88	99	100	100	95	99	100
8	102	97	100	100	99	99	100
9	99	95	100	100	100	100	100
10	75	97	100	100	99	100	100
11	94	99	100	100	100	100	100
12	117	98	100	100	100	100	100
13	78	99	100	100	99	100	100
1-13	1343	95.7	99.8	99.8	96.0	98.9	99.8

Explanations:
* – See Figure 1 I – Primary contact II – Secondary contact

5000 and 1000 MPN/100 ml. As results from the data presented in Table 7, 93-95% of samples collected in Ploso Northern, 57-70% of samples collected in Zatoka Hanczariska, and 95-100% of samples from Ploso Szyja and the middle and southwestern parts of Lake Wigry conformed to these standards. As regard other recreational purposes, proper standards were fulfilled by all or almost all samples with the exception of those collected in Zatoka Hanczaiiska. In the latter region, only 85-97% of samples conformed to the mentioned stardards. Water samples collected in all other regions of Lake Wigry also conformed to the standards of public water supply.

According to the standards of the European Commission on Water Quality for Recreational Purposes (bathing) [5], it is recommended that water used for bathing not contain more than 500 MPN/100 ml TC and 100 MPN/100 ml FC and FS (guide values) in 85% of samples. It is, however, permitted to have TC and FC numbers of no more than 10,000 and 2000 MPN/100 ml in at least 95% of samples (mandatory value), at total lack of pathogenic *Salmonella* in 1 1 of water and of enteric pathogenic viruses in 10 1 of water. Water examination for the presence of *Salmonella* and enteropathogenic viruses is, however, required only when it is suspected that these micro-organisms may occur. Guide values for TC and FC in pelagic waters of lake Wigry were fulfilled in 93-99% and 94-100% of samples respectively, and for FS in 85-97% of samples from the north (without Zatoka Hanczanska), middle and southwestern part of the lake. As regards Zatoka Hańczańska, the recommended guide values for TC, FC and FS were fulfilled respectively by 80-93%, 70-87% and 72-97% of water samples.

Table 8. The analysis of water quality of Wigry Lake using critera given by EEC [5]. Percent distribution of samples fulfilling guide value for bathing waters.

Site*	Number of samples investigated	TC[1]	FC[2]	FS[3]
		MPN/100 ml		
		500	100	100
1	73	93.1	95.9	84.9
2	89	93.2	97.2	91.5
3	131	86.2	98.4	95.1
4A	69	92.7	86.9	96.8
4B	36	80.5	75.0	72.2
4C	20	80.0	70.0	72.2
5	126	96.8	97.6	95.1
6	146	94.5	95.2	94.2
7	88	98.8	93.2	93.2
8	102	97.0	100.0	90.2
9	101	95.0	100.0	94.0
10	75	97.3	100.0	85.3
11	94	98.9	100.0	91.4
12	117	93.2	100.0	92.3
13	82	93.9	93.9	87.8
1-13	1349	93.0	96.1	88.6

Explanations: * – See Figure 1, [1] – total coliforms, [2] – faecal coliforms, [3] – faecal streptococci

Discussion

Differentiated character of northern, middle and southwestern parts of Lake Wigry with respect to the morphomery, development of the surrounding land, inflows and outflows, is reflected in the degree of bacteriological pollution. Higher numbers of bacteria indicatory of water pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) in the north part are due to the vicinity of farm buildings (Stary Folwark, Wigry, Magdalenowo villages), numerous recreation centres, camping places, individual bathing sites etc. Maximal numbers of the mentioned bacteria in Zatoka Hanczanska are caused by the inflow of pollutants with the Czarna Hańcza River [14]. As a result, this part of Lake Wigry is more eutrophic [18] as well as of lower sanitary and bacteriological quality than the middle and south-west parts. Numbers of bacteria indicatory of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) found in this area are comparable to the data of 1966-1997 obtained from a number of Masurian lakes more or less polluted with domestic sewage and wastes from food processing plants [7, 8, 9, 10, 11, 12]. Prolongation of Zatoka Hanczanska towards the peninsula and Rosochaty Rog village, i.e. Plos Wigierski (station 5), and a valley part called Ploso Szyja (station 6), were characterized by much lower numbers of bacteria indicatory of water pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS). This is due to pollutant dilution and sedimentation, and a lack of point-sources of pollution in this region. Surface run-off in the region of Rosochaty Rog and Mikolajewo are of no greater significance as the eastern lake shores are densely overgrown with grass and a broad littoral zone prevents sanitary pollution. Consequently, a majority (if not all) of water samples collected from this part of Lake Wigry were classified as clean or negligibly polluted [1, 4, 16], permitting recreational use [5, 17]. A slight increase of the numbers of bacteria indicatory of pollution (TVC 20°C, TVC 37°C) in water collected at Zatoka Jastrzebia (station 7) might have been connected with intensive recreational use of this lake part in summer. A camping site and water recreation centre are located nearby, both crowded with tourists.

The results of sanitary and bacteriological analyses of water collected from the southwestern part of Lake Wigry revealed that water in this lake part was clean or at most very slightly polluted. With the exception of single samples, all of them conformed to various quality standards set for clean waters and waters used for recreation. The majority of the samples fulfilled the criteria of clean water. This lake part is surrounded by coniferous and mixed forest and there are no villages, while a few farms carry out extensive farming. Higher numbers of FS found from time to time in water collected from this part were due to water fowl faeces [6].

Seasonal changes in the numbers of bacteria indicatory of pollution (TVC 20°C, TVC 37°C) and sanitary state (TC, FC, FS) in the pelagic waters of Lake Wigry were related to thermal and oxygen conditions, migrations of birds, bird hatching, activity of wild animals (beavers), atmospheric conditions and recreational uses of the lake. Plant and animal organisms modified these changes. It is generally known that UV solar light is lethal for the microflora in surface waters. The effect of plant organisms might have been also connected with algal excretions which can be used by bacteria; and in more polluted areas - with the bacteriostatic effect of blue-green algae. The effect of ani-

mal organisms consisted of bacteria consumption by protozoans and - indirectly - by zooplankton. Excrements of these organisms are frequently colonized by psychrophilic bacteria, and this might have also affected the discussed seasonal changes.

Conclusions

1. Pelagic waters in the northern part of Lake Wigry showed more differentiated degrees of bacteriological pol lution than waters in the middle and southwestern part of this lake. The lowest degree of bacteriological pollution was noted in the tunnel-valley part of the lake (Ploso Szyja), the highest in Zatoka Hanczanska.

2. Pelagic water of the middle and southwestern parts of Lake Wigry (Zatoka Jastrzebia and Bielanska, Plos Bryzglowski, region of Ostrow Island, Zatoka Słupianska) was classified as clean in 85-100% of samples; this could be used safely for bathing and recreational pruposes. In Zato ka Wigierki percentage of clean water samples was even higher, while it was slightly lower in Zatoka Uklei.

3. Higher pollution of Lake Wigry with bacteria indica tory of water pollution (TVC 20°C, TVC 37°C) and sanita ry state (TC, FC, FS) was usually observed in spring-sum mer period (June, August), rarely in autumn (October, No vember). This might have been related to the activity of water fowl and wild animals in the lake catchment area, and to some extent also with recreational use of the lake.

4. To maintain bacteriological purity of lake water it is necessary to subordinate agriculture, forest management practices, fisheries, and tourism in the surrounding areas to the requirements of lake protection.

5. It is necessary to carry out continuous bacterial moni toring, especially of point pollution sources, with special attention paid to the pollution brought in by the Czarna Hancza River, which discharges sewage from the treatment plant in Suwalki, but also leaks from sceptic tanks and manure storage places in Sobolewo village.

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