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SANITARY AND BACTERIAL ANALYSIS OF WATER AND BOTTOM SEDIMENTS OF A HEAVILY POLLUTED, HYPERTROPHIC LAKE *

ABSTRACT: Sanitary and bacteriological studies of a hypertrophic Lake Bęskie, in the Masurian Lakeland carried out in the period 1982–1984, indicate that the degree of pollution of its water and bottom sediments with indicatory microorganisms varied between the sampling sites, study years, and over a yearly cycle. It is emphasized that the bacterial pollution level in the water and bottom sediments is higher near the sites of discharge of sewage from sewered settlements than in other parts of the lake. It was also higher in 1982 when the livestock in the catchment area and the amount of slurry wastes, with which crop-fields, meadows and pastures were treated, were twice as high as in 1983 or 1984.

KEY WORDS: Polluted lake, water and bottom sediments, indicator microorganisms.

1. INTRODUCTION

The development of cattle and pig fattening farms constitutes a serious threat to the cleanliness of lakes. Particulary dangerous are the slurry wastes if applied in excess to crop-fields, meadows and pastures. Under the conditions of the Masurian Lakeland agricultural utilization of slurry wastes with a contamination load equal to that produced by 4–5 mlln. inhabitants (Scientific and Economic Committee attached to the Olsztyn Voivode's Office – "Utilization and protection of surface waters and groundwaters of the Olsztyn voivodship" – in form of a manuscript) is difficult already now, because of the low permeability of the soils there. Poured out in excess, slurry wastes get, not infrequently with surface- and drainage-waters, into the nearest streams and lakes bringing in immense amounts of pollutants in the form of organic mass and

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nutrients, as well as many biological pollutants, including pathogenic bacteria, viruses and eggs of parasites (Evans and Owens 1972, Carrington 1978, Crane et al. 1980, Pike 1980, Patni et al. 1984). This considerably reduces the possibility, or makes it absolutely impossible to use such waters for recreational purposes. The aim of the present study was a sanitary and bacteriological assessment of the water and bottom sediments of a highly eutrophic lake in a situation where the surrounding crop-fields, meadows and pastures are intensively treated with inorganic (N + P + K) and organic (manure + slurry wastes) fertilizers (Niewolak and Solarski 1987). The investigations were carried out in 3 yearly cycles, from January 1982 to October 1984. Besides sanitary and bacteriological investigations of the surface and drainage water of the basin of the lake (Niewolak 1987, Niewolak and Solarski 1987) this paper presents part of a study dealing with the impact of basin development on a lake.

2. STUDY AREA

The lake under study was Lake Bęskie (Fig. 1) located in the basin of the rivers Sajna, Guber, Łyna and Pregoła at the edge of the settlement of Bęsia, in the northern part of the Olsztyn voivodship, 53°56.6′ northern latitude and 21°00.1′ eastern longitude, 154 m a.s.l. The lake is 56.2 ha in surface area, 1051 m in maximum length, 910 m in maximum width, 3925 m in shoreline length, 8.4 m (3.5 m average) maximum depth, with a water volume of 1987.5×1000 m^3. Characteristically, its water circulation is slow. In summer there occurs a thermical stratification in the deepest part of the lake, with a 2–4–metre epilimnion and a thermocline reaching down to the lake floor. It is a highly eutrophic lake (water pH 7.4–8.9; oxididability 16.0–33.6 mg·dm^{-3} O_2; BOD_5 1.6–40.5 mg·dm^{-3} O_2; N-total 1.26–10.26 mg·dm^{-3}; P-total 0.113–0.474 mg·dm^{-3}; P-sestonic 0.000–0.191 mg·dm^{-3}), with its metalimnion becoming deoxidized after the termination of the spring circulation, with a marked autumn circulation in October and strong deoxidation of deeper waters in winter (K. Lossow – unpublished data). The edges of the lake are crop-fields, meadows and pastures, partly woodland and settlements. The lake is polluted by sewage from sewered settlements, with a total of 500 inhabitants, water from woodlands (88.9 ha) and arable land, meadows and pastures used alternately (144.3 ha), intensively treated with mineral salts (N + P + K 300 kg · ha^{-1}), and with organic fertilizers (manure 15–30 t·ha^{-1} in an area of 453 ha, and slurry wastes 40–190 m^3·ha^{-1} in an area of 436 ha). Besides, over some fields faeces and slurry wastes from settlements were distributed in an uncontrolled way, especially in winter and early spring when access to fields was difficult.

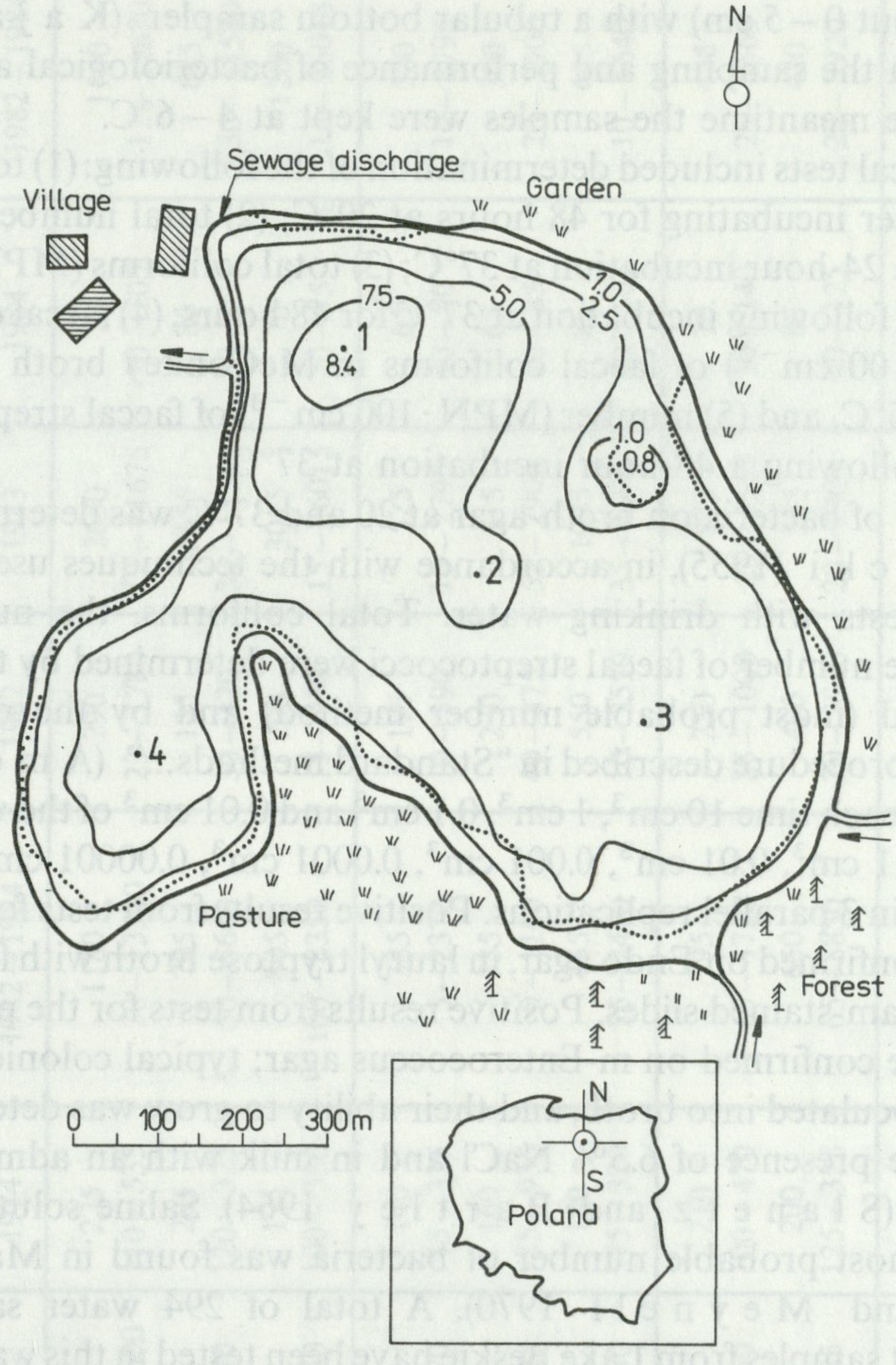

Fig. 1. Location and morphology of Lake Beskie
1, 2, 3, 4 — sampling sites

3. METHODS

Investigations were carried out at four sites in Lake Bęskie, located in the most typical areas (Fig. 1): (a) site 1 at a depth of 8.4 m in the northern part of the lake in the area where sewage from settlements is discharged; (b) site 2 at a depth of 5.5 m in the middle of the lake; (c) site 3 at a depth of 3.0 m in the south-eastern part of the lake, and (d) site 4 at a depth of 3.0 m in the south-western part of the lake (a bay).

Water samples were taken with a Ruttner water sampler from the surface- (0.3 m) and near-bottom (0.2 m above the bottom) layers, and additionally at site 1 at a depth of 4.0 m, and at site 2 at a depth of 3.0 m. Bottom-sediment samples were collected from the top layer (about 0 – 5 cm) with a tubular bottom sampler (K a j a k et al. 1965). The time between the sampling and performance of bacteriological analyses did not exceed 6 h. In the meantime the samples were kept at 4 – 6°C.

Microbiological tests included determination of the following: (1) total viable count on broth-agar after incubating for 48 hours at 20°C; (2) total number of bacteria on broth-agar after a 24-hour incubation at 37°C; (3) total coliforms (MPN $\cdot$ 100 cm^{-3}) in McConkey broth following incubation at 37°C for 48 hours; (4) faecal coli titre and the number (MPN $\cdot$ 100 cm^{-3}) of faecal coliforms in McConkey broth after a 24-hour incubation at 44.5°C, and (5) number (MPN $\cdot$ 100 cm^{-3}) of faecal streptococci in azide dextrose broth following a 48-hour incubation at 37°C.

Total number of bacteria on broth-agar at 20 and 37°C was determined according to P r z e s m y c k i (1955), in accordance with the techniques used in Poland for bacteriological tests with drinking water. Total coliforms, the number of faecal coliforms, and the number of faecal streptococci were determined by the fermentation test tube method (most probable number method) and by the dilution method according to the procedure described in "Standard methods..." (A m e r i c a n P.H. A. 1975), seeding each time 10 cm^3, 1 cm^3, 0.1 cm^3 and 0.01 cm^3 of the water tested, and 10 cm^3, 1 cm^3, 0.1 cm^3, 0.01 cm^3, 0.001 cm^3, 0.0001 cm^3, 0.00001 cm^3 of the bottom sediments tested in 3 parallel replications. Positive results from tests for the presence of coliforms were confirmed on Endo agar, in lauryl tryptose broth with fermentation test tubes, and on Gram-stained slides. Positive results from tests for the presence of faecal streptococci were confirmed on m-Enterococcus agar; typical colonies grown on this medium were inoculated into broth, and their ability to grow was determined at 44°C; at pH 9.6; in the presence of 6.5% NaCl and in milk with an admixture of 0.01% methylene blue (S l a n e t z and B a r t l e y 1964). Saline solution was used as a diluent. The most probable number of bacteria was found in MacCrady's tables (M e y n e l l and M e y n e l l 1970). A total of 294 water samples and 122 bottom-sediment samples from Lake Bęskie have been tested in this way. Simultaneous with the bacteriological investigations of the lake were meteorological observations carried out for the nearby Łężany Meteorological Station (Department of Meteorology, Academy of Agriculture and Technology in Olsztyn), and physico-chemical (K. Lossow – unpublished) and biological, including algological studies (M. Rybak – unpublished).

Data from microbiological studies were analysed statistically and the following were determined: (1) value of the coefficients of correlation between the number of indicatory microorganisms in the water and bottom sediments of Lake Bęskie and total precipitation for the period of 7 and 2 days preceding the sampling, and air temperature (N i e w o l a k and S o l a r s k i 1987) and algal biomass (M. Rybak – personal communication), (2) value of the u coefficient (the smallest significant difference) from tables of the critical Student's t value for $\alpha_1 = 0.05$ and $\alpha_1 = 0.01$ and the number of degrees of freedom $r = n_x + n_y - 2 = 58$, between the means of the number of indicatory microorganisms at particular sites (sites 1, 2, 3 and 4) in water and bottom sediments.

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

Site *	Depth	Number of samples		Total viable count at 20°C number · 1 cm^{-3}				Total viable count at 37°C number · 1 cm^{-3}			
				1982	1983	1984	1982–1984	1982	1983	1984	1982–1984
1	surface	30	mean	1055	1925	225	1180	290	2650	70	1100
			range	30–7780	95–13500	110–535	30–13500	23–1780	12–11675	20–105	12–11670
	4 m	30	mean	505	1230	205	705	155	1655	80	685
			range	50–1700	90–5640	120–325	50–5640	30–420	30–11540	30–215	30–11540
	near bottom	30	mean	630	1405	175	805	200	3015	70	1200
			range	160–2265	150–8350	100–330	100–8350	15–930	15–26015	20–75	15–26015
2	surface	29	mean	1345	570	140	385	195	525	65	300
			range	5–1160	85–2370	15–325	5–2370	10–390	10–2795	30–90	10–2795
	3 m	27	mean	430	430	160	335	230	515	65	300
			range	0–1160	75–1125	85–935	0–1160	40–875	55–2900	20–85	20–2900
	near bottom	29	mean	440	660	180	455	550	1075	85	645
			range	25–1750	55–2450	75–320	25–2450	10–3550	35–4640	40–165	10–4640
3	surface	30	mean	1125	800	210	795	230	895	70	435
			range	65–4720	95–4750	100–470	65–4750	25–1000	25–4565	30–140	25–4565
	near bottom	30	mean	1085	460	200	650	490	565	85	420
			range	105–8850	65–1685	125–325	65–8850	20–3920	20–2300	40–125	20–3920
4	surface	30	mean	535	655	175	495	260	670	70	365
			range	20–2750	60–3750	100–260	20– 3750	25–1200	20–2860	35–110	20–2860
	near bottom	29	mean	505	515	195	435	550	425	85	395
			range	55–1750	75–2200	135–290	55–2200	35–4870	35–2680	45–170	35–4870

* See Figure 1.

4. RESULTS

4.1. TOTAL VIABLE COUNT AND ENTERIC BACTERIA CONCENTRATION IN LAKE WATER

N u m b e r o f i n d i c a t o r y m i c r o o r g a n i s m s. Numbers of indicatory microorganisms of the pollution state (total number of bacteria determined on broth agar at 20 and 37°C – hereafter referred to as TVC at 20 and 37°C) and of the sanitary state (total number of coliforms, number of faecal coliforms and number of faecal streptococci – hereafter referred to as TC, FC and FS, respectively) were subject to wide variation within and between sites, between depths, during and between study years and over yearly cycles (Tables 1, 2, Figs. 2 – 6). TVC at 20°C varied between 5 cells in 1 cm^3 (in surface water at site 2) and 13500 cells per 1 cm^3 (in surface water at site 1). TVC at 37°C ranged from 10 cells in 1 cm^3 (in surface water at site 2) to 26015 cells in 1 cm^3 (in near-bottom water at site 1), (Table 1). TC varied between 7 – 9 cells per 100

Table 2. Mean (for study period) and range for the numbers of total coliforms,

Site *	Depth	Number of samples		Total coliforms (MPN · 100 cm^{-3}) 1982	1983	1984	1982 – 1984	1982
1	surface	30	mean	688	375	350	510	303
			range	43 – 4500	75 – 1400	43 – 1100	43 – 4500	9 – 2500
	4 m	30	mean	260	193	366	260	230
			range	39 – 1100	43 – 460	23 – 1100	23 – 1100	21 – 1100
	near bottom	30	mean	4860	232	194	2080	262
			range	30 – 45000	23 – 1400	23 – 460	23 – 45000	21 – 1100
2	surface	29	mean	595	473	138	440	110
			range	20 – 4500	43 – 1500	23 – 450	20 – 4500	4 – 450
	3 m	27	mean	295	360	60	255	65
			range	21 – 1100	15 – 1100	23 – 93	15 – 1100	0 – 240
	near bottom	29	mean	1133	187	176	545	750
			range	21 – 11000	15 – 460	9 – 460	15 – 11000	4 – 4500
3	surface	30	mean	270	182	248	235	92
			range	15 – 1100	43 – 460	15 – 1100	15 – 1100	4 – 460
	near bottom	30	mean	442	216	67	305	128
			range	21 – 1400	15 – 460	9 – 1100	9 – 1400	7 – 460
4	surface	30	mean	110	118	142	125	88
			range	15 – 240	7 – 240	9 – 460	7 – 460	15 – 240
	near bottom	29	mean	135	297	194	220	60
			range	60 – 240	9 – 1400	9 – 1100	9 – 1400	9 – 240

* See Figure 1.

cm³ (in near-bottom water at site 3 and in surface- and near-bottom water at site 4) and 45000 cells in 100 cm³ (in near-bottom water at site 1). Number of FC did not exceed 4500 cells per 100 cm³ (in near-bottom water at site 2); often the above-specified amounts of water did not contain any of these bacteria. FS numbers varied between 3 – 15 cells in 100 cm³ (in water samples from different depths at sites 2, 3 and 4) and 140000 cells per 100 cm³ (in surface-water samples at site 1). The numeric FC : FS ratio ranged from 0.001 in near bottom water at sites 2 and 3 to 642.8 (in near-bottom water at site 2) (Table 2). In 68.2 – 75.8% of the water samples tested it appeared to be below 0.7; in 17.2 – 22.8% of the water samples tested it ranged from 0.7 to 4.0; in 5.3 – 12.3% of the water samples tested it was higher than 4.0 (Table 3).

H o r i z o n t a l d i s t r i b u t i o n o f i n d i c a t o r y m i c r o o r g a n i s m s. In 1982 and 1983 a lower presence of indicatory bacteria as a rule was recorded at sites 2, 3 and 4, a higher one at site 1. In 1984 the particular sites as a rule did not significantly differ in the presence of these bacteria (Tables 1, 2).

V e r t i c a l s t r a t i f i c a t i o n o f i n d i c a t o r y m i c r o o r g a n i s m s. All the indicator bacterial groups studied were present at sites 1 and 2, being usually less abundant in deeper water layers (3 or 4 m) and more numerous in the

fecal coliforms and fecal streptococci in the water of Lake Bęskie

Fecal coliforms (MPN · 100 cm⁻³)			Fecal streptococci (MPN 100 cm⁻³)				FC : FS ratio
1983	1984	1982 – 1984	1982	1983	1984	1982 – 1984	
90	11	155	12855	275	275	5300	–
0 – 460	0 – 28	0 – 2500	23 – 140000	23 – 1100	43 – 1100	23 – 140000	0.009 – 20.0
152	5	150	857	860	399	750	–
4 – 460	0 – 9	0 – 1100	43 – 45000	23 – 4500	9 – 460	9 – 45000	0.006 – 9.13
118	42	155	5078	452	724	2290	–
4 – 460	0 – 240	0 – 1110	43 – 45000	23 – 1400	15 – 1400	15 – 45000	0.003 – 4.94
150	2	40	400	102	439	295	–
4 – 460	0 – 9	0 – 460	15 – 1400	23 – 250	23 – 1100	15 – 1400	0.003 – 10.4
89	8	60	340	158	248	265	–
4 – 240	0 – 15	0 – 240	9 – 1500	3 – 1100	7 – 460	3 – 1500	0.006 – 26.6
78	6	315	1016	176	452	575	–
4 – 460	0 – 23	0 – 4500	7 – 4500	21 – 950	23 – 1100	7 – 4500	0.001 – 642.8
60	35	70	933	155	286	500	–
4 – 240	0 – 240	0 – 460	9 – 4500	15 – 950	3 – 1100	3 – 4500	0.003 – 51.1
180	5	120	1500	168	460	775	–
4 – 1100	0 – 23	0 – 1100	23 – 4500	15 – 950	93 – 1100	15 – 4500	0.001 – 6.52
60	40	65	1157	62	246	540	–
0 – 460	0 – 240	0 – 460	16 – 4500	3 – 240	7 – 1100	3 – 4500	0.008 – 15.0
55	8	50	880	44	328	460	–
0 – 240	0 – 23	0 – 240	43 – 2500	9 – 93	9 – 1100	9 – 2500	0.008 – 26.6

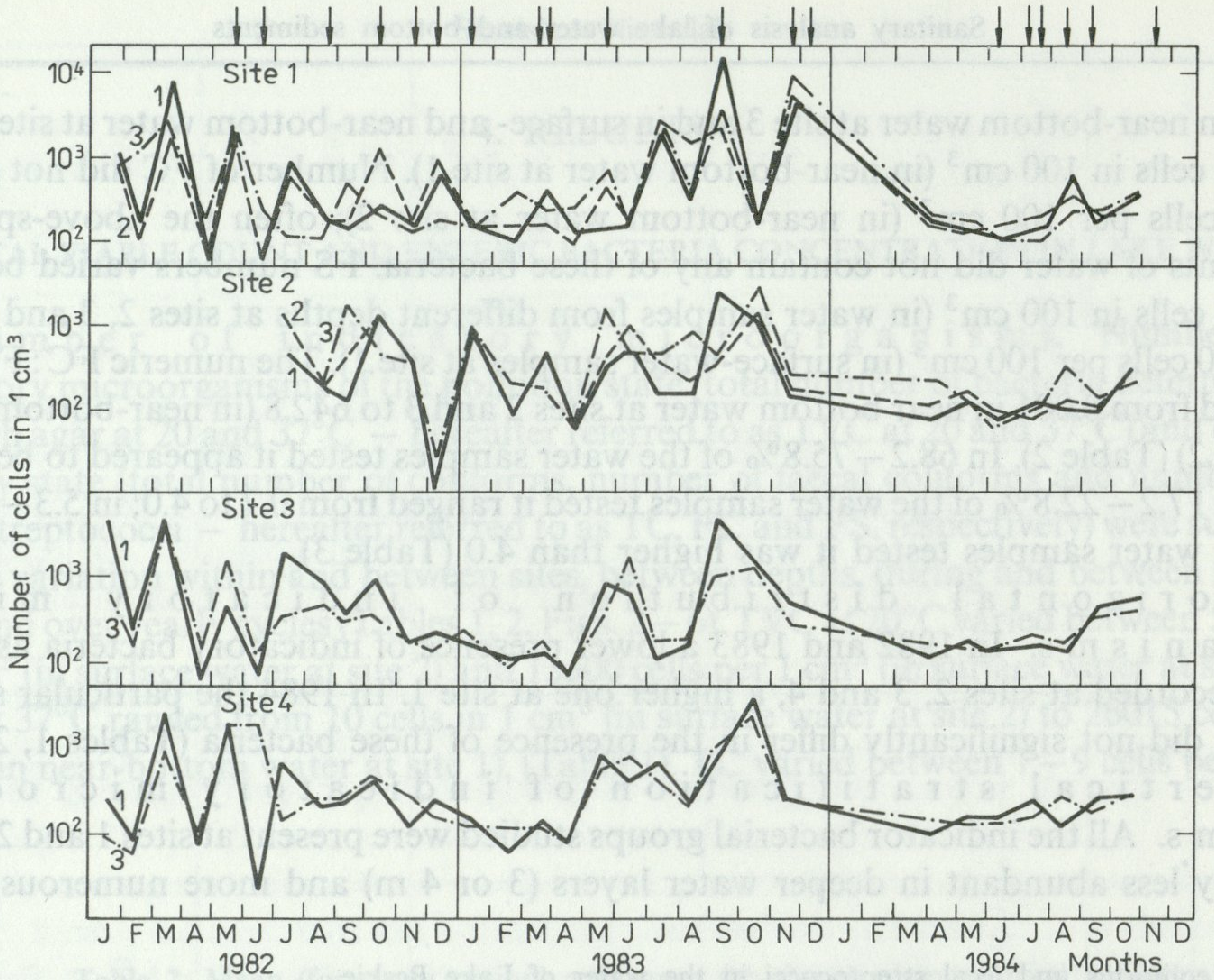

Fig. 2. Seasonal changes in number of total viable count at 20°C in the water of Lake Bęskie Each point is an average of 3 parallel repetitions (semi-log. scale). 1 — surface (0.3 m) water, 2 — water from 4 m (at site 1) or 3 m (at site 2), 3 — near-bottom water. Vertical arrows indicate rainfall

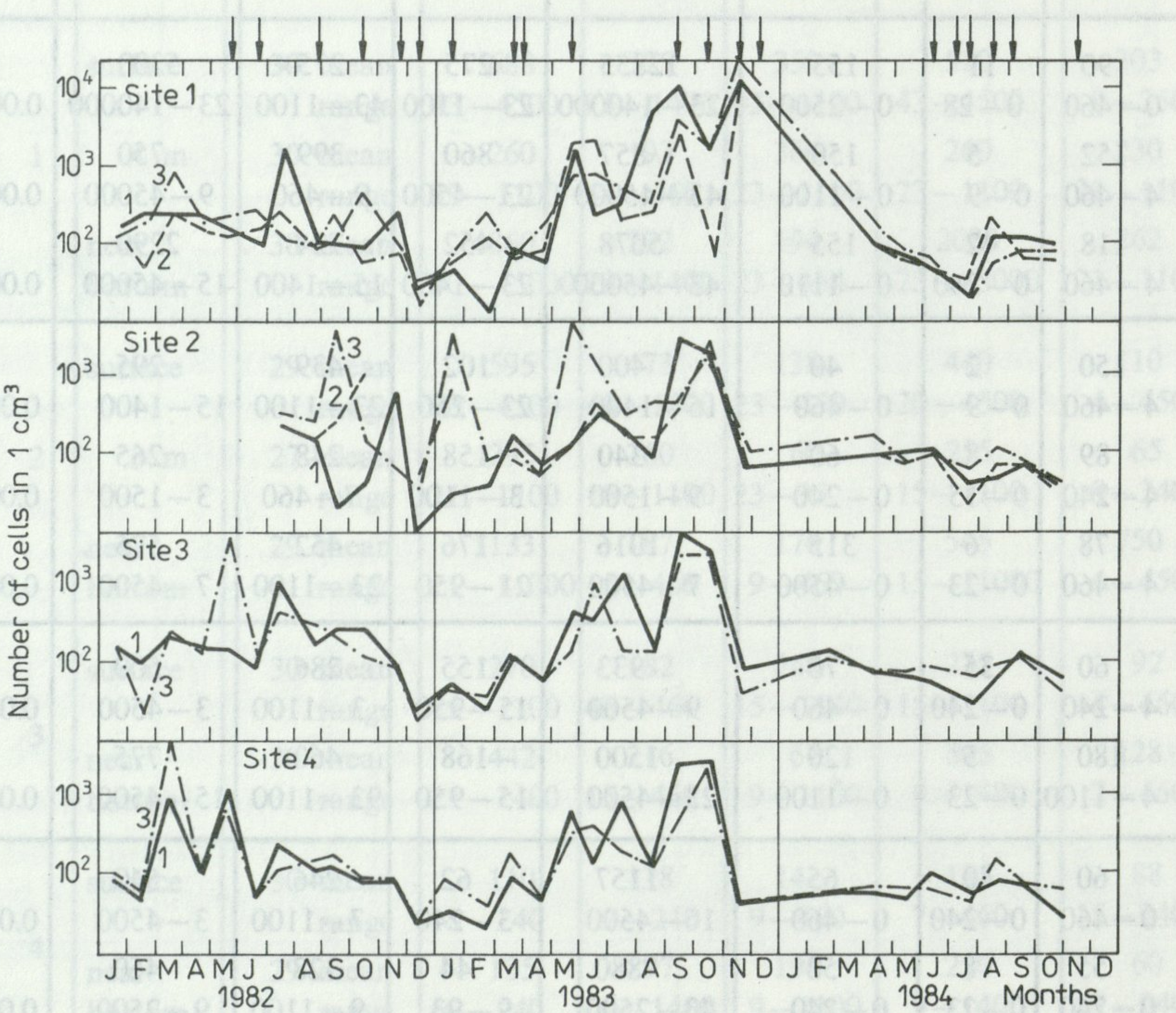

Fig. 3. Seasonal changes in number of total viable count at 37°C in the water of Lake Bęskie Each point is an average of 3 parallel repetitions (semi-log. scale). Denotations as in Figure 2

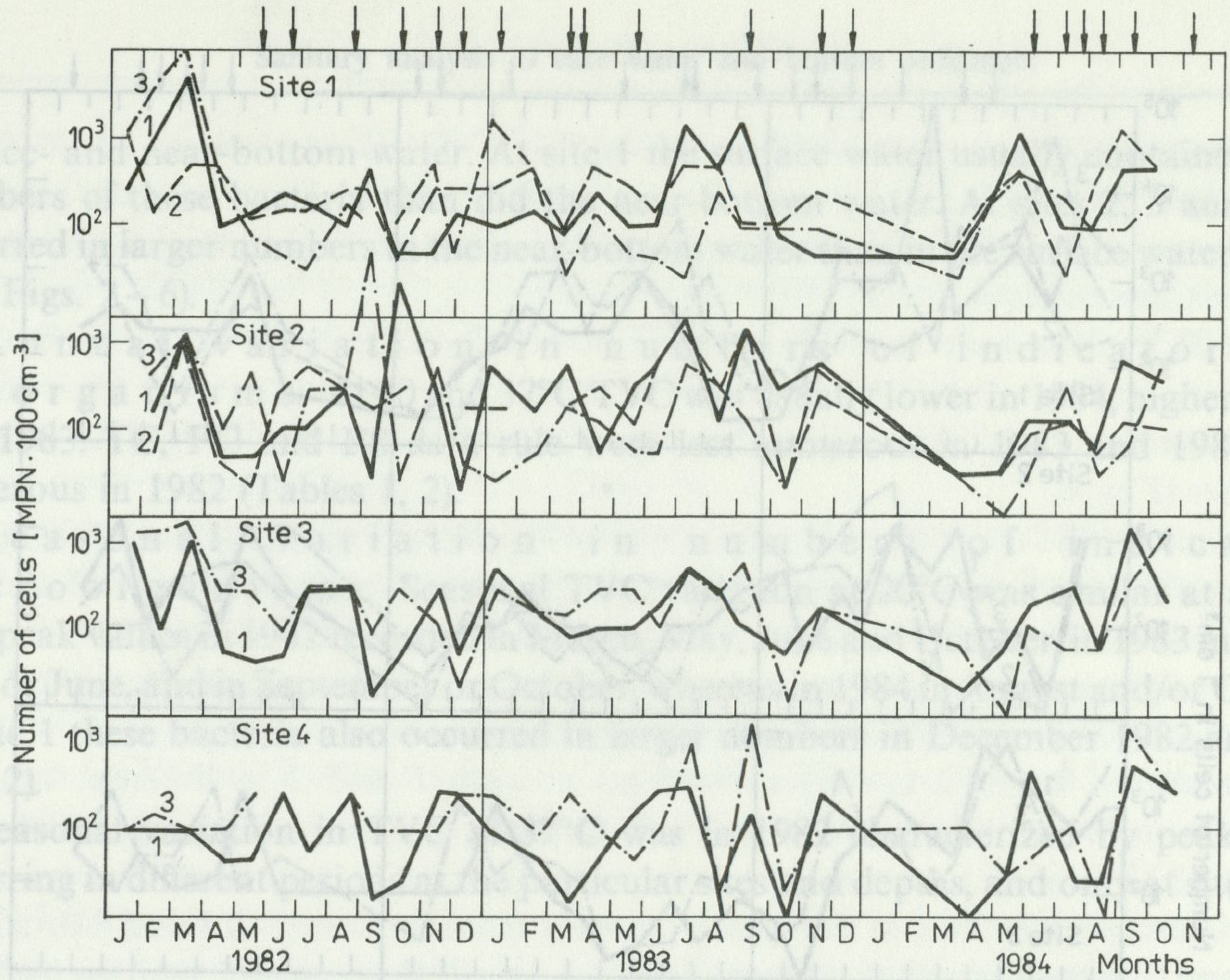

Fig. 4. Seasonal changes in number of total coliforms in the water of Lake Bęskie
Each point is an average of 3 parallel repetitions (semi-log. scale). Denotations as in Figure 2

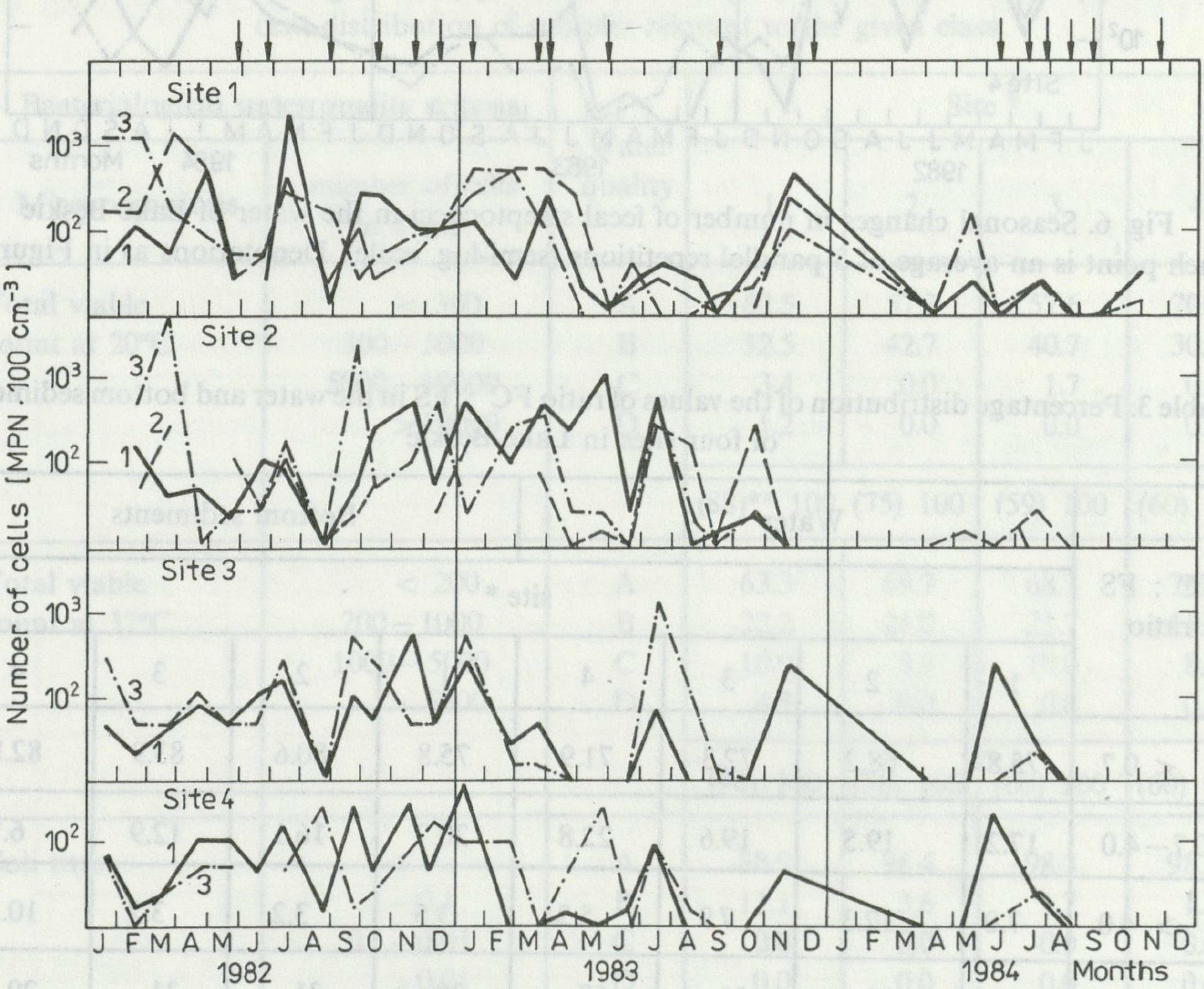

Fig. 5. Seasonal changes in number of fecal coliforms in the water of Lake Bęskie
Each point is an average of 3 parallel repetitions (semi-log. scale). Denotations as in Figure 2

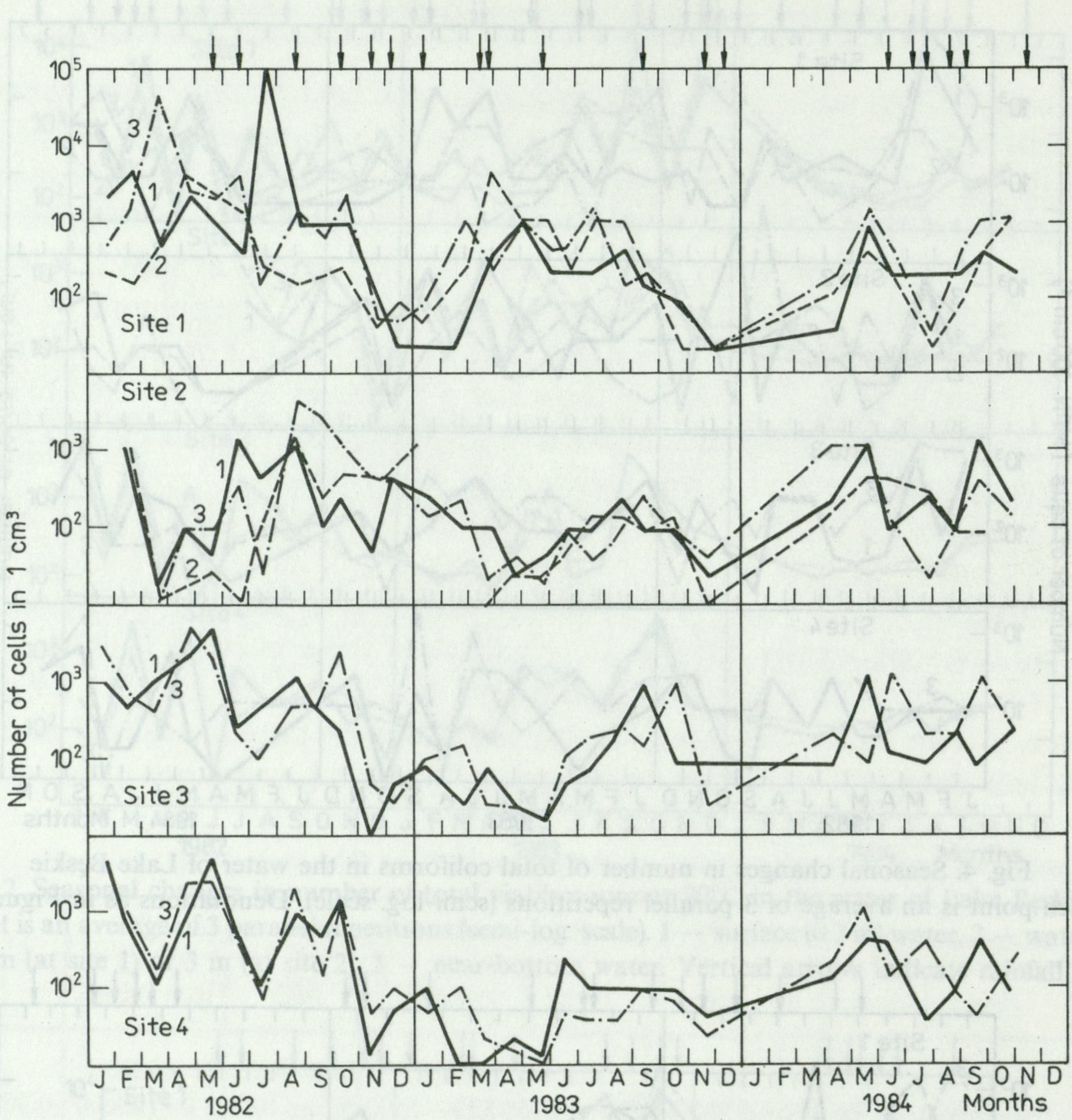

Fig. 6. Seasonal changes in number of fecal streptococci in the water of Lake Bęskie
Each point is an average of 3 parallel repetitions (semi-log. scale). Denotations as in Figure 2

Table 3. Percentage distribution of the values of ratio FC : FS in the water and bottom sediments of four sites in Lake Bęskie

FC : FS ratio	Water				Bottom sediments			
	site *							
	1	2	3	4	1	2	3	4
< 0.7	75.8	68.2	72.3	71.9	75.8	80.6	83.9	82.8
0.7 – 4.0	17.2	19.5	19.6	22.8	20.7	16.1	12.9	6.7
> 4.0	7.0	12.3	7.9	5.3	3.5	3.2	3.2	10.5
	87[a] (100)[b]	82 (100)	51 (100)	57 (100)	28 (100)	31 (100)	31 (100)	29 (100)

* See Figure 1. [ab] Number and per cent (in brackets) of samples investigated.

surface- and near-bottom water. At site 1 the surface water usually contained larger numbers of these bacteria than did the near-bottom water. At sites 2, 3 and 4 they occurred in larger numbers in the near-bottom water than in the surface water (Tables 1, 2, Figs. 2 – 6).

Annual variation in numbers of indicatory microorganisms. At 20 and 37°C TVC was usually lower in 1984, higher in 1982 and 1983. TC, FC and FS as a rule were less numerous in 1983 and 1984, more numerous in 1982 (Tables 1, 2).

Seasonal variation in numbers of indicatory microorganisms. Seasonal TVC variation at 20°C was similar at all sites, with peak values in 1982 recorded in March, May, June and October, in 1983 in March, May or June, and in September or October, whereas in 1984 in August and/or October. At site 1 these bacteria also occurred in larger numbers in December 1982 and 1983 (Fig. 2).

Seasonal variation in TVC at 37°C was in 1982 characterized by peak values occurring in different periods at the particular sites and depths, and only at site 4 were

Table 4. The analysis of bacteriological water quality of Lake Bęskie, using criteria given by Cabejszek et al. (1960)
A – unpolluted, B – insignificantly polluted, C – distinctly polluted, D – heavily polluted, per cent distribution of samples relevant to the given class

Bacteriological water quality criteria		Water quality	Site *			
Microorganisms	number of cells in 1 cm^3		1	2	3	4
Total viable count at 20°C	< 300	A	62.5	57.3	57.6	70.0
	300 – 5000	B	32.5	42.7	40.7	30.0
	5000 – 10000	C	3.4	0.0	1.7	0.0
	> 10000	D	1.2	0.0	0.0	0.0
			(88)** 100	(75) 100	(59) 100	(60) 100
Total viable count at 37°C	< 200	A	63.3	69.7	68.3	76.6
	200 – 1000	B	22.2	21.0	21.7	15.0
	1000 – 5000	C	10.0	9.3	10.0	8.4
	> 5000	D	4.5	0.0	0.0	0.0
			(90) 100	(76) 100	(60) 100	(60) 100
Coli titre	< 1	A	88.9	96.4	98.3	98.3
	1 – 0.1	B	11.1	3.6	1.7	1.7
	0.1 – 0.01	C	0.0	0.0	0.0	0.0
	> 0.01	D	0.0	0.0	0.0	0.0
			(90) 100	(84) 100	(60) 100	(59) 100

* See Figure 1. ** Number of samples investigated.

they similar to TVC values at 20°C. In 1983 higher TVC values occurred at the end of May, in July (at sites 3 and 4), as well as in September and October, very rarely in December (site 1). In 1984 TVC values gradually decreased from winter to summer, to reach their lowest level in July (Fig. 3).

Peak TC values were in 1982 recorded in March (except site 4), rarely in other periods (at site 2 in water from depth 3 in September, in surface water in October), in 1983 in January, July and September, in 1984 in June and/or July, less often in September (Fig. 4).

FC were in 1982 more abundant in March or April (depending on the depth), at site 2 also from September to November (depending on the depth), and at sites 3 and 4 in November; in 1983 they were more numerous in January, March, July and November, less often in other months, and in 1984 in May (at site 1) or June (at sites 3 and 4). At site 2 bacteria of this group were hardly ever found in the water.

FS occurred in 1982 in larger numbers at sites 1 and 2 in different months, depending on the depths, at sites 3 and 4 in January, April and/or May, as well as in August and November, very rarely in other months. In 1983 these bacteria were found in larger numbers: at site 1 in the spring-summer months, at sites 2, 3 and 4 usually in winter and summer months, whereas in 1984 at all sites usually in May or June (depending on the depth) and in September.

Number of indicatory microorganisms and the pollution of the lake under study. A comparison of the

Table 5. Analysis of bacteriological water quality of Lake Bęskie using criteria given by U.S. Department of Interior (Federal Water Pollution Control Administration 1968), as the per cent distribution of samples relevant to the given criteria
I — primary contact, II — secondary contact

Site *	Number of samples investigated	Bacteriological water quality standards					
		total coliforms MPN · 100 cm^{-3}			fecal coliforms MPN · 100 cm^{-3}		
		recreational		public water supply	recreational		public water supply
		I 1000	II 5000	10000	I 200	II 1000	2000
1	90	86.7	96.7	100.0	76.7	95.6	100.0
2	84	90.5	98.8	100.0	83.3	97.6	100.0
3	60	86.6	100.0	100.0	85.0	98.3	100.0
4	59	96.6	100.0	100.0	88.1	100.0	100.0

* See Figure 1.

results from TVC tests at 20 and 37°C and the coli titre (data on the coli titre can be obtained from the author of the paper) for the water of Lake Bęskie with data from Cabejszek et al. (1960), set out in Table 4, indicates that its bacterial pollution is relatively low. Clearly or heavily polluted were no more than 10% of the water samples, tested, from this lake. Data from TC and FC investigations in Lake Bęskie compared with those of Federal Water... (1968) indicate that in 15.0 – 32.3% of water samples the level of those microorganisms was, especially in 1982, above the allowable level for open-water watering resorts (Table 5).

Particularly high coliform and faecal streptococci counts in the water of Lake Bęskie in 1982 (the average was then twice as high as the average for the whole study period) were most likely connected with the numbers of livestock, amount of slurry wastes produced and distributed over arable land, meadows and pastures in the catchment area of the lake, which were nearly twice as high as in 1983 and 1984 (Niewolak and Solarski 1987). The FC : FS ratio, below 0.7 in most of the water samples tested, confirms such a nature of the pollution. According to Geldreich and Kenner (1969) and Feachem (1974), a FC : FS ratio below 0.7 indicates pollution with animal faeces, 0.7 – 4.0 pollution with mixed faeces – human and animal, and above 4.0 – pollution with human faeces.

4.2. TOTAL VIABLE COUNT AND ENTERIC BACTERIA CONCENTRATION IN BOTTOM SEDIMENTS

Numbers of indicatory microorganisms. TVC at 20°C varied between 5280 cells per 1 g bottom-sediment dry weight at site 2 and 43451000 cells per 1 g bottom-sediment dry weight at site 1; narrower oscillations occurred at sites 2 and 3, wider ones at sites 1 and 4. TVC at 37°C ranged from 1500 cells in 1 g bottom-sediment dry weight at site 2 to 31835000 cells in 1 g bottom-sediment dry weight at site 1; narrower variation was recorded for sites 2, 3 and 4, wider for site 1. TC ranged from 400 cells in 100 cm^3 wet mass at sites 2 and 3 to 2400000 cells per 100 cm^3 wet mass at site 4; narrower oscillations occurred at sites 1, 2 and 3, higher at site 4. The number of FC varied between 40 cells in 100 cm^3 wet weight at sites 1 and 3 and 140000 cells in 100 cm^3 wet mass at site 4, with narrower oscillations occurring at site 1, wider at sites 2, 3 and 4. The number of FS varied between 400 cells per 100 cm^3 wet mass at site 3 and 11000000 cells per 100 cm^3 wet mass at site 3, with narrower oscillation at sites 1, 2 and 3, wider at site 4. The FC : FS ratio ranged from 0.0006 – 0.0009 at sites 2, 3 and 4 to 27.5 at site 3. In 75.8 – 83.9% of the bottom-sediment samples tested it was below 0.7; in 6.7 – 20.7% of the bottom sediment samples tested it varied between 0.7 and 4.0; in 3.2 – 10.5% of the bottom-sediment samples it was above 4.0 (Tables 3, 6, 7).

Horizontal distribution of indicatory microorganisms. All the indicatory bacterial groups studied were usually less abundant at sites 2 and 3 and more abundant at sites 1 and 4. At 20 and 37°C TVC was at sites 1, 2 and 3 higher in 1983 and 1984, and at site 4 – in 1982; at site 1 higher TC values were recorded in 1983 and 1984, at sites 2, 3 and 4 in 1982; FC appeared to be more abundant at all sites in 1982, while FS in 1982 and 1984 (Tables 6, 7).

Table 6. Mean (for study period) and range for the numbers of total viable counts at 20 and 37°C in the bottom sediments (0 – 5 cm layer) of Lake Bęskie

Site *	Number of samples		Total viable count at 20°C ($1 \cdot 10^3 \cdot$ g dry wt $^{-1}$)				Total viable count at 37°C ($1 \cdot 10^3 \cdot$ g dry wt $^{-1}$)			
			1982	1983	1984	1982 – 1984	1982	1983	1984	1982 – 1984
1	30	mean	176	6736	1188	2700	228	8823	693	2430
		range	40 – 495	215 – 43451	200 – 3700	40.0 – 43451	8.8 – 955	382 – 31835	8.1 – 1620	8.1 – 31835
2	30	mean	37	633	464	369	111	987	276	465
		range	5 – 91	12 – 3980	52 – 1602	5.0 – 3980	1.5 – 443	31 – 8961	44.0 – 754	1.5 – 8961
3	31	mean	132	306	271	233	175	379	366	297
		range	23 – 613	6 – 2334	69 – 638	6.0 – 2334	15.0 – 282	8 – 3118	34.0 – 1136	8.0 – 3118
4	31	mean	4446	552	500	1789	1563	581	1304	1160
		range	24 – 34055	15 – 2197	66 – 1360	15.0 – 34055	38.0 – 4752	13 – 3568	77.0 – 7063	12.7 – 7064

* See Figure 1.

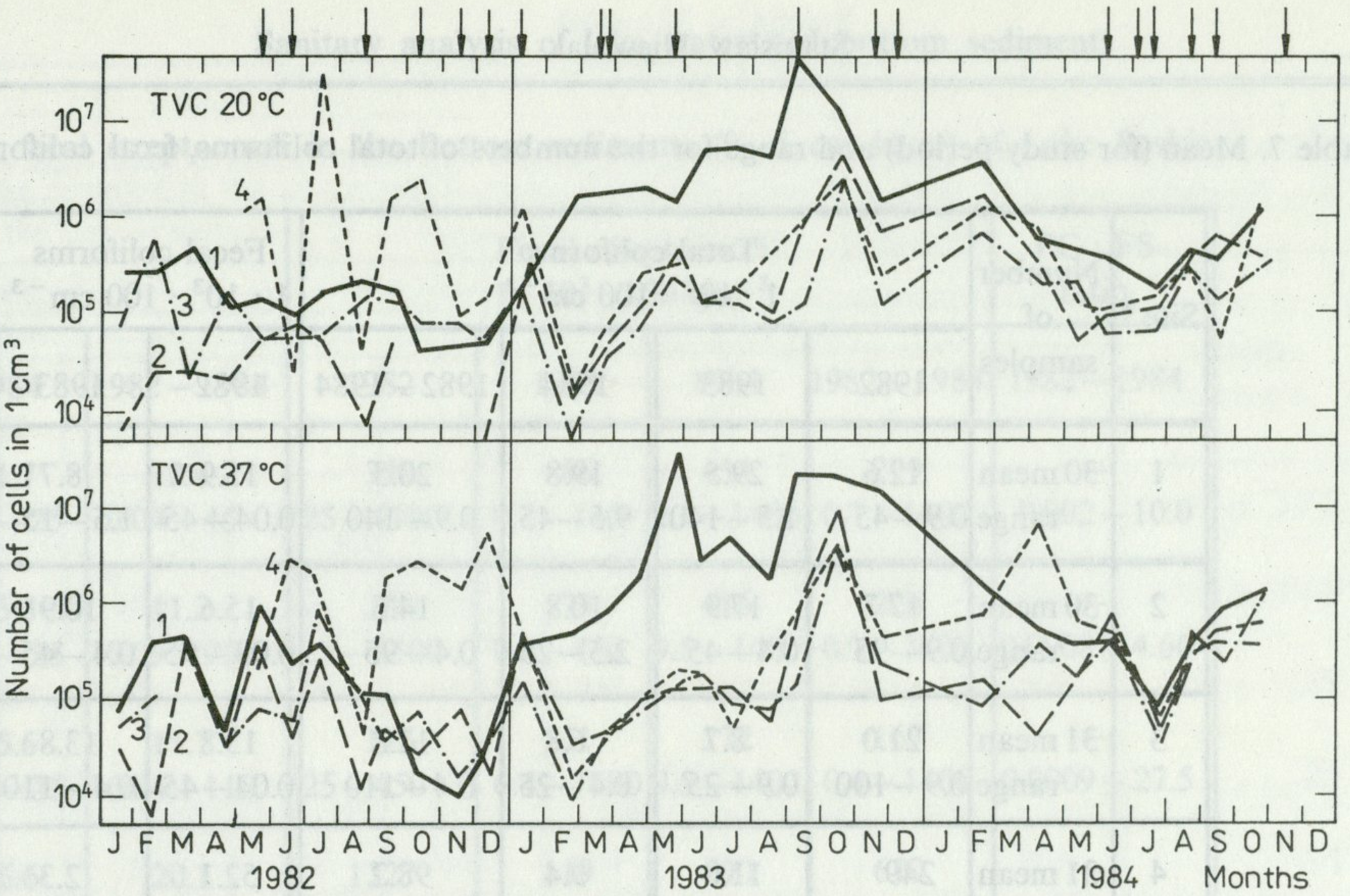

Fig. 7. Seasonal changes in number of total viable count at 20°C (TVC 20°C) and 37°C (TVC 37°C) in the bottom sediments of Lake Bęskie

Each point is an average of 3 parallel repetitions (semi-log. scale). 1 — at site 1, 2 — at site 2, 3 — at site 3, 4 — at site 4 (see Fig. 1). Vertical arrows indicate rainfall

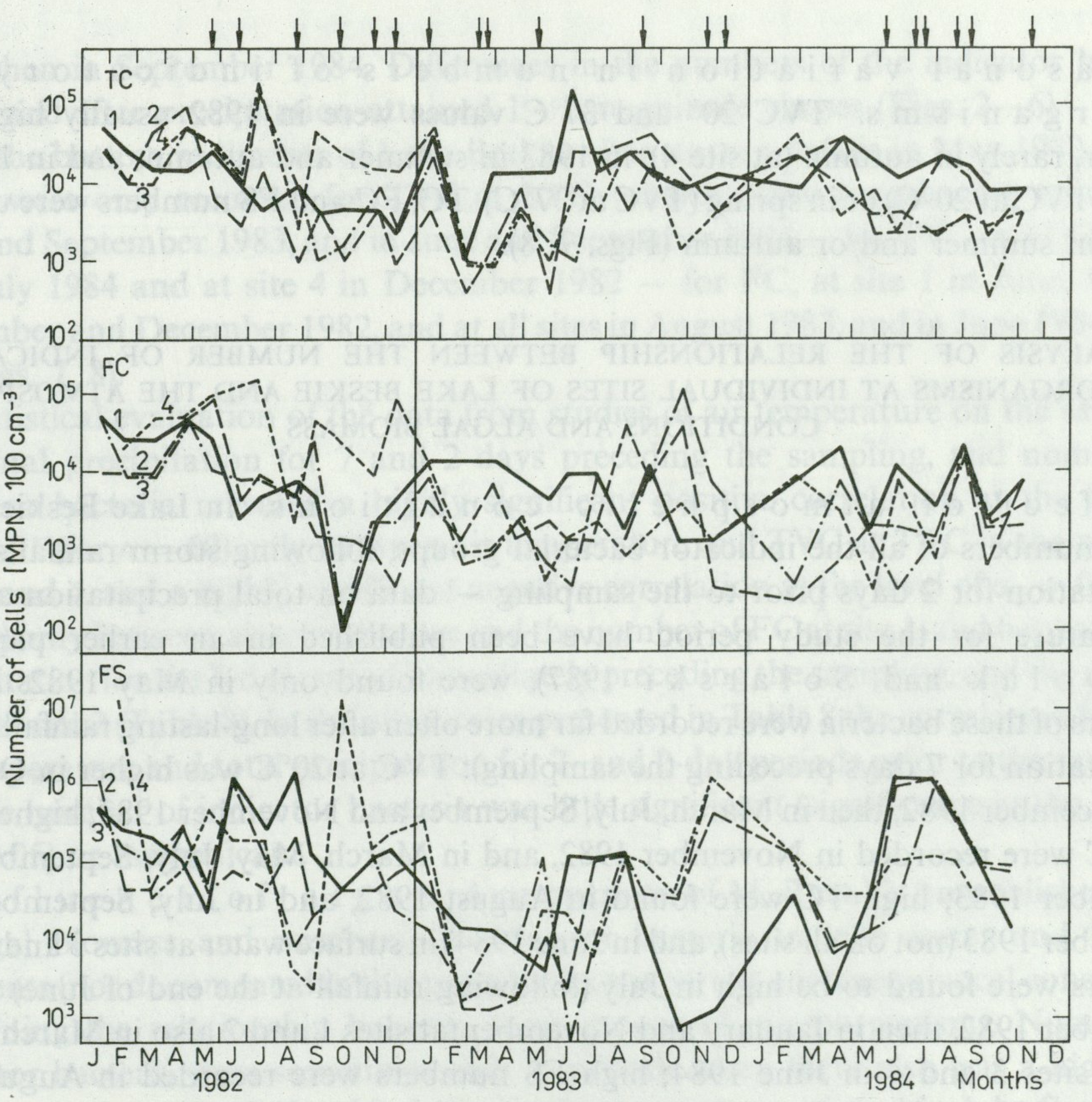

Fig. 8. Seasonal changes in number of total coliforms (TC), fecal coliforms (FC) and fecal streptococci (FS) in the bottom sediments of Lake Bęskie

Each point is an average of 3 parallel repetitions (semi-log. scale). Denotations as in Figure 7

Table 7. Mean (for study period) and range for the numbers of total coliforms, fecal coliforms

Site *	Number of samples		Total coliforms $1 \cdot 10^3 \cdot 100\ cm^{-3}$				Fecal coliforms $1 \cdot 10^3 \cdot 100\ cm^{-3}$	
			1982	1983	1984	1982–1984	1982	1983
1	30	mean	12.6	29.5	19.8	20.5	15.9	8.7
		range	0.9–45	1.5–140	9.5–45	0.9–140	0.04–45	1.5–15
2	30	mean	17.7	17.9	10.8	14.6	15.6	10.9
		range	0.9–95	0.4–45	2.5–25	0.4–95	0.09–95	0.4–45
3	31	mean	21.0	8.7	6.8	12.8	13.8	13.8
		range	0.9–100	0.9–25	0.4–25	0.4–110	0.04–45	0.4–110
4	31	mean	249	11.0	9.4	98.2	52.1	2.3
		range	2.5–2400	0.9–45	2.5–45	0.9–2400	9–140	0.4–9

* See Figure 1.

S e a s o n a l v a r i a t i o n i n n u m b e r s o f i n d i c a t o r y m i c r o o r g a n i s m s. TVC 20° and 37°C values were in 1982 usually higher in summer, rarely in autumn (at site 4), in 1983 in summer and autumn, and in 1984 in winter (TVC at 20°C) or in spring (TVC at 37°C). TC, FC and FS numbers were usually higher in summer and/or autumn (Figs. 7, 8).

4.3. ANALYSIS OF THE RELATIONSHIP BETWEEN THE NUMBER OF INDICATORY MICROORGANISMS AT INDIVIDUAL SITES OF LAKE BĘSKIE AND THE ATMOSPHERIC CONDITIONS AND ALGAL BIOMASS

E f f e c t o f a t m o s p h e r i c c o n d i t i o n s. In Lake Bęskie water higher numbers of all the indicator bacterial groups, following storm rainfalls (total precipitation for 2 days prior to the sampling – data on total precipitation and air temperature for the study period have been published in an earlier paper – N i e w o l a k and S o l a r s k i 1987), were found only in May 1982. Larger numbers of these bacteria were recorded far more often after long-lasting rainfalls (total precipitation for 7 days preceding the sampling): TVC at 20°C was higher in October and December 1982, then in March, July, September and November 1983; higher TVC at 37°C were recorded in November 1982, and in March, May, July, September and November 1983; high TC were found in August 1982, and in July, September and November 1983 (not on all sites), and in June 1984 (in surface water at sites 3 and 4); FC numbers were found to be high in July (following rainfall at the end of June) and in November 1982, then in January and November (at sites 1 and 2 also in March) 1983, and at sites 3 and 4 in June 1984; high FS numbers were recorded in August and October 1982 (at sites 2, 3 and 4), in March (site 1) and in September (at sites 2 and 3) and fecal streptococci in the bottom sediments (0 – 5 cm layer) of Lake Bęskie

		Fecal streptococci $1 \cdot 10^3 \cdot 100\ cm^{-3}$				FC : FS ratio
1984	1982 – 1984	1982	1983	1984	1982 – 1984	1982 – 1984
11.7	12.4	340	46	434	299	–
2 – 25	0.04 – 45	25 – 1100	0.7 – 140	2.5 – 1400	0.7 – 1400	0.002 – 10.0
5.3	11.2	234	79	416	226	–
0.3 – 25	0.09 – 95	7 – 1100	0.9 – 450	9.5 – 1400	0.9 – 1400	0.0008 – 4.66
5.6	11.7	126	131	272	167	–
0.4 – 25	0.04 – 110	25 – 450	0.4 – 1100	9.5 – 1400	0.4 – 1400	0.0009 – 27.5
6.6	20.1	1227	119	490	610	–
4 – 25	0.4 – 140	2.5 – 11000	1.5 – 1100	45 – 1400	1.5 – 11000	0.0006 – 10.0

1983, then in September 1984. Differences in the numbers of the indicator bacteria before and after precipitation attained 1 – 2 magnitude classes (Figs. 2 – 6).

In the bottom sediments of Lake Bęskie, after storm rainfalls in May 1982, higher values were only recorded for TVC at 20°C; whereas after long-lasting rainfalls in May and September 1983, and in June and September 1984 – for TVC at 37°C; at site 1 in July 1984 and at site 4 in December 1982 – for FC; at site 1 in June, August, November and December 1982, and at all sites in August 1983, and in June 1984 – for FS (Figs. 7, 8).

Statistical evaluation of the data from studies of air temperature on the sampling day, total precipitation for 7 and 2 days preceding the sampling, and numbers of indicator bacteria revealed a highly significant positive correlation at the level of $\alpha_1 = 0.01$ (for $n = 60$) only between air temperature and TVC at 37°C in the water at sites 3 and 4, and a highly significant negative correlation at the level of $\alpha_1 = 0.01$ (for $n = 60$) only between air temperature and the number of FC at site 1, and between total precipitation for the 7-day period immediately preceding the sampling, and the number of FC at site 2 (Table 8). In the other cases presented in Table 8 the correlation between air temperature and total precipitation for 7- and 2-day periods prior to the sampling, and the number of indicator bacteria was little significant (significance at the level of $\alpha_1 = 0.05$) or insignificant.

I n f l u e n c e o f a l g a e. A comparison of M. Rybak's (unpublished) data on algal biomass and numbers of indicator bacteria in lake water and bottom sediments (not documented in this paper) does not permit any unequivocal conclusions concerning the relationship between these groups of microorganisms. Numbers of indicator bacteria were sometimes high in periods when there also was a high algal biomass. An inverse relationship between these groups was found in July, September

Table 8. Correlation coefficients between bacteriological indices and some meteorological data and A and B — rainfall recorded during 7 and 2 days (respectively) before sampling, C — air temperature

Elements compared	Micro-organisms	Site * 1 A	1 B	1 C	1 D	2 A	2 B	2 C	2 D
Water	TVC at 20°C	NS **	NS	NS	NS	NS	NS	NS	NS
	TVC at 37°C	NS	NS	NS	NS	NS	NS	NS	NS
	TC	NS	NS	NS	NS	NS	NS	NS	NS
	FC	−0.2834^a	NS	−0.4298^b	NS	−0.3454^b	NS	−0.2883^a	NS
	FS	NS	NS	NS	NS	NS	NS	NS	NS
Bottom sediments	TVC at 20°C	NS	+0.4051^a	NS	NS	NS	NS	NS	NS
	TVC at 37°C	NS	NS	NS	NS	NS	NS	NS	NS
	TC	NS	NS	NS	NS	−0.3629^a	NS	NS	NS
	FC	NS	NS	NS	NS	NS	NS	NS	NS
	FS	NS	NS	NS	NS	NS	+0.3659^a	NS	NS

* See Figure 1. ** Not significant. ^{a}Significant at level 0.05. ^{b}Significant at level 0.01.

and October 1982 (peak numbers of indicator bacteria with minimum, of the range of 4.0 – 9.0 mg · dm^{-3}, algal biomass), and in May 1984 (minimum numbers of indicator bacteria with a maximum, of the range of 44.0 mg · dm^{-3}, algal biomass). A statistical evaluation of the data from studies of algal biomass, numbers of indicator bacteria has not revealed any highly significant relationships between them (Table 8).

Values of the *u* coefficient (smallest significant difference in numbers of indicator bacteria between particular sites of the lake under study). Results from statistical calculations indicate highly significant differences at the level of $t_1 = 0.01$ (for $n_x + n_y - 2 = 58$) between the numbers of FS in the water at sites 1 and 2, 1 and 4, and TVC 20°C and TVC 37°C in the bottom sediments at sites 1 and 3, 1 and 4, 2 and 3, 2 and 4, and highly significant differences at the level of $t_1 = 0.05$ (for $n_x + n_y - 2 = 58$) between TC in the water at sites 2 and 4, as well as in the bottom sediments at sites 1 and 4 (Table 9). In the other cases presented in Table 9 the differences between the mean numbers of indicator bacteria in the water and bottom sediments at particular sites in Lake Bęskie were insignificant. In those cases *u* values were lower than $t_{0.01}$ and $t_{0.05}$, and ranged from 0.021 to 1.957, which has not been documented in Table 9.

algae biomass in the water and bottom sediments of Lake Bęskie on the day of sampling, D – algae biomass in the water of the lake

3				4			
A	B	C	D	A	B	C	D
NS	NS	NS	NS	NS	NS	+0.3043[a]	NS
NS	NS	+0.3862[b]	NS	NS	NS	+0.3458[b]	NS
NS	NS	NS	NS	NS	NS	NS	NS
NS	+0.2778[a]	NS	NS	NS	+0.2766[a]	NS	NS
NS	NS	NS	NS	NS	NS	NS	NS
NS	NS	NS	NS	NS	NS	NS	NS
NS	NS	NS	NS	NS	NS	NS	NS
NS	NS	NS	NS	NS	NS	NS	NS
NS	NS	NS	NS	NS	NS	NS	NS
NS	NS	NS	NS	+0.4122[a]	NS	NS	NS

5. DISCUSSION

5.1. TOTAL VIABLE COUNT AND ENTERIC BACTERIA CONCENTRATION IN LAKE WATER

Levels of TVC 20°C and 37°C, TC, FC and FS in the water of Lake Bęskie are in principle typical of the clean or slightly polluted eutrophic lakes of the East-Pomeranian (N i e w o l a k 1966, 1971, 1973) and Masurian Lake Districts (N i e w o l a k 1974, 1975). Their clearly more abundant presence in the water at site 1 is related to the input of pollution from point sources (sewage from settlements with sewerage systems) in that part of the lake. The latter factor accounts for the significant differences in FS numbers in the water at sites 1 and 2 and 1 and 4. Such phenomena have been known from the author's other studies, quoted above, and from investigations carried out in Lake Niegocin (N i e w o l a k 1983).

More numerous occurrence of indicator bacteria in the surface-layer water (from a depth of 0.3 m) at site 1 is connected with the discharge of household sewage which is usually warmer than the lake water, and therefore its mixing with the water bulk is slower. Their, usually more abundant, presence in the near-bottom water layer at sites

Table 9. The smallest significant difference (value of the coefficient *u*) in numbers of indicator bacteria in the water and bottom sediments at particular sites in Lake Bęskie

Site *		Water samples					Bottom sediments samples				
		TVC at 20°C	TVC at 37°C	TC	FC	FS	TVC at 20°C	TVC at 37°C	TC	FC	FS
1 x	2	NS	NS	NS	NS	2.625[b]	NS	NS	NS	NS	NS
	3	NS	NS	NS	NS	NS	4.248[b]	3.500[b]	NS	NS	NS
	4	NS	NS	NS	NS	3.076[b]	4.431[b]	3.335[b]	2.655[a]	NS	NS
2 x	3	NS	NS	NS	NS	NS	2.717[b]	3.199[b]	NS	NS	NS
	4	NS	NS	2.344[a]	NS	NS	2.684[b]	3.017[b]	NS	NS	NS
3 x 4		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* See Figure 1. [a] Significant at level 0.05. [b] Significant at level 0.01.

2, 3 and 4 may be connected with the bacteriocidal effect of the solar ultraviolet rays, and a secondary contamination with these microorganism from the top layer of the bottom sediments where they are many times more abundant than in the water. Sedimentation of suspensions containing adsorbed cells of indicator bacteria may also play some role.

Over a yearly cycle a more abundant presence of indicator bacteria in Lake Bęskie, recorded sometimes after storm rainfalls or long-lasting rainfalls, is attributed to their being washed out from arable soils, meadows and pastures treated with manure and slurry wastes (N i e w o l a k and S o l a r s k i 1987) deposited by farm animals and wild animals living in the catchment area. The lack of a statistically significant relationship (except for a few cases, as a rule negative) to the total precipitation for 7- and 2-day periods preceding the collecting of water samples in the lake may be related to the modifying effect of the photo- and zooplankton, protozoa, bacteriophages, variation in the quality and quantity of pollution inputs from point and diffuse sources, timing of fertilization of crop-fields, meadows and pastures, activity of the waterfowl.

The impact of phytoplankton on the numbers of indicator bacteria in Lake Bęskie (statistically insignificant) was ambiguous. An inverse relationship between these units of the aquatic biocoenosis, recorded in April 1982, March 1983 and in May 1984, may have resulted from the bacteriocidal effect of algal extracellular products or, more likely, from an impoverishment or enrichment of the lake water bulk with easily assimilable organic substances of the growing and dying phytoplankton. As has been known from the literature, extracellular products of phytoplankton can be metabolized by *Echerichia coli* (M c F e t e r s et al. 1978).

The presence of indicator bacteria, sometimes abundant, in Lake Bęskie in winter and early spring (especially in 1982) may be connected with a low air temperature favouring the survival of enteric bacteria deposited on arable soils, in meadows and pastures with manure, slurry wastes and faeces and washed off into the lake at flood time (G r a n a i and S j o g r e n 1981, F a u s t 1982, L e s s a r d and S i e b u r t h 1983). For the same reason, it is believed (F a u s t et al. 1975, C r a n e et al. 1980, F a u s t 1982) that the distribution of manure and slurry wastes in winter causes a heavier contamination of surface waters with enteric bacteria than when this is done in other seasons. The higher survival rate of enteric bacteria at low temperatures in winter is believed to account for the statistically significant negative correlation between air temperature and the number of FC at sites 1 and 2.

5.2. TOTAL VIABLE COUNT AND ENTERIC BACTERIA CONCENTRATION IN LAKE BOTTOM SEDIMENTS

TVC values at 20 and 37°C in the bottom sediments of Lake Bęskie were similar to those recorded for sapropel sediments of the eutrophic lakes Jeziorak Mały and Jeziorak in the East-Pomeranian Lake District, in the zone of discharge of municipal sewage and industrial (dairy, slaughterhouse) wastes of the town of Iława (N i e w o- l a k 1968). Comparatively small differences in numbers of the two bacterial groups (in most of the bottom-sediment samples tested the ratio TVC 20°C : TVC 37°C, so-called temperature ratio test, was below 10) indicate that the bottom sediments of the lake are polluted with human and animal sewage. The fact that TC, FC and FS numbers are many times higher in the bottom sediments of Lake Bęskie than in the water of that lake is a phenomenon known from the literature (Rittenberg et al. 1958, Hendricks 1971a, 1971b, Van Donsel and Geldreich 1971, Mennon and Bedford 1972, Babinchak et al. 1977a, Matson et al. 1978, Niewolak 1985) and is accounted for by their longer survival (Niewolak 1980). It is believed (Hendricks 1971a, 1971b) that bottom sediments exert a favourable influence on the survival of the above enteric bacteria by neutralizing the antagonistic environmental factors, or owing to the presence of a different microflora in the bottom sediments the enteric bacteria can more successfully compete in them for carbon and energy-sources (Gerba and McLeod 1976). A more abundant, as a rule, presence of the indicator bacteria studied in the bottom sediments at site 1 (as in the main water bulk) is related to the input of sewage from settlements in that part of the lake, and at site 4 it is connected with the pouring out of slurry wastes over adjacent meadows and pastures (Niewolak and Solarski 1987), and possibly their occasional runoff into the lake, together with the bacteria contained in them.

Seasonal variation in numbers of indicatory bacteria in the bottom sediments of Lake Bęskie may be caused by variation in the quality and quantity of the sewage from settlements (site 1) or wastes distributed over arable land, meadows and pastures (sites 2, 3 and 4) and carried into the lake with the runoff during winter and spring thaws, as well as during storm- and long-lasting rainfalls in spring and summer (Gerba and Schaiberger 1973, Niewolak 1978a, 1978b, Niewolak and Solarski 1987). There can also be a modifying effect of waterfowl activity, particularly gulls, wild ducks and geese, excreting incommensurably (relative to their body size) high numbers of faecal bacteria of the coliform group, of the range of $10^7 - 10^9$ cells · individual^{-1} · 24 h^{-1} (Geldreich and Kenner 1969, Hussong et al. 1979, Standridge et al. 1979) and pathogenous bacteria of the genera *Salmonella* and *Shigella* (Feddoul and Fellows 1966, Mitchell and Ridgwell 1971). The hundred-fold growth reported in the literature, in number of the coliform faecal bacteria in the bottom sediments of water bodies after their colonization by waterfowl is the result of the sedimentation of the excrements of these animals. It cannot be ruled out that certain bacteria multiply in the bottom sediments, particularly during the first days following their introduction (Hendricks 1971a, 1971b, Van Donsel and Geldreich 1971). This growth can balance their continuous death, so their numbers can be maintained at a stable, high level for a longer time, which accounts for the wide seasonal variation in their numbers at particular sites. Due to the higher survival of enteric bacteria in the bottom sediments, and perhaps their multiplication, the differences in their abundance, by contrast to the situation in the water, in the period 1982 – 1984 are relatively small, although there was a nearly 2-fold reduction in livestock and amount of slurry wastes distributed in the drainage area of the lake under study (Niewolak and

Solarski 1987). This type of lake pollution is dominant, as indicated by the FC : FS ratio which is below O.7 in at least 3/4 of the water- and bottom-sediment samples tested (Geldreich et al. 1968).

5.3. NUMBER OF INDICATOR BACTERIA AND THE POTENTIAL OCCURRENCE OF PATHOGENIC BACTERIA (*SALMONELLA*) IN LAKE WATER AND BOTTOM SEDIMENTS

The numbers of faecal pollution indicator bacteria found during the present study must be considered from the viewpoint of potential occurrences of bacteria pathogenic for human beings and animals. The only genus of pathogenic bacteria so far detected by this indirect method is *Salmonella*. According to Geldreich (1972, 1974), the frequency of detecting *Salmonella* increases with the growth in number of the FC bacteria. In the water *Salmonella* is detected in 27.6% of samples containing over 200 FC cells $\cdot$ 100 cm^{-3}, and in nearly 100% of samples containing above 2000 FC cells $\cdot$ 100 cm^{-3}. Comparing these data with the FC values found in the water of the lake investigated, it may be presumed that a higher probability of an occurrence of *Salmonella* was associated with site 1, where sewage from settlements with sewerage systems is discharged. Above 200 FC cells $\cdot$ 100 cm^{-3} were in 23.3% of the samples from that site, by contrast to 16.7%, 15.0% and 11.9% at sites 2, 3 and 4, respectively.

There may have been a similarly high frequency of *Salmonella* in the bottom sediments of Lake Bęskie. According to Van Donsel and Geldreich (1971), the frequency of isolation of *Salmonella* from bottom sediments rises when the ensity of FC in the overlying water attains at least 200 cells $\cdot$ 100 cm^3, the maximum allowable level for coastal watering-places (Federal Water... 1968). They isolated *Salmonella* from 19% of bottom-sediment samples at FC densities of 1 – 200 cells $\cdot$ 100 cm^{-3} in the overlying water, in 50% of bottom-sediment samples at FC levels of 201 – 2000 cells $\cdot$ 100 cm^{-3} in the overlying water, and in 80% of bottom-sediment samples at FC densities above 2000 cells $\cdot$ 100 cm^{-3} in the overlying water. From the comparison of the FC contents found in Lake Bęskie with the above data one may presume that at least 26.6% of the bottom-sediment samples at sites 1 and 3, 27.4% at site 2 and 10.0% at site 4 contained *Salmonella*. Adopting, after Van Dosel and Geldreich (1971), a ratio of FC : *Salmonella* in the bottom sediments of freshwater bodies of the range 14000 : 1, one would expect *Salmonella* to occur in at least 36.6% of the bottom-sediment samples tested at site 1, in 31.0% of bottom-sediment samples tested at site 2, and in 16.1% of bottom-sediment samples tested at sites 3 and 4 – in most cases in 1982. Babinchak et al. (1977a) claim that bottom sediments containing over 1000 FC cells $\cdot$ 100 cm^3 bottom sediments are already potentially dangerous from the sanitary point of view. In this study such FC numbers were found in 96.6% of the bottom-sediment samples tested at site 1, in 79.4% of bottom sediment samples at site 2, and in 77.5% of bottom-sediment samples at sites 3 and 4. The above permits the presumption that the bottom sediments of Lake Bęskie contain sufficiently high numbers of pathogenic bacteria of the genus *Salmonella* to be a serious threat to human beings and animals using its water. For although in the adsorbed form on the lake floor the bacteria are not so dangerous (Gerba and Schaiberger 1975), one must remember that they can penetrate into the water bulk. The water-sediments interface is not static — the mineral and organic particles of the bottom sediments can get into the bulk of the lake water as the result of convection currents, stirring of the bottom sediments by benthonic animals, by wading and diving human beings and waterfowl, dredging, by storms, particularly at shallow sites (Serruya 1974, Grimes 1975, Babinchak et al. 1977b, Grundmanis and Murray 1977, Matson et al. 1978). Enteric bacteria adsorbed on the solid particles of the bottom sediments can be released into the water bulk also due to changes in the salinity (Weiss 1951) or in organic matter concentration (Carlson et al. 1968, Gerba and Schaiberger 1975).

6. SUMMARY

Presented in the paper is an assessment of the nature and level of bacterial pollution of the water and bottom sediments of a hypertrophic lake (Lake Bęskie in the Masurian Lakeland) in the neighbourhood of crop-fields, meadows and pastures intensively treated with mineral (N + P + K) and organic (manure + slurry wastes + faeces) fertilizers. The evaluation was done on the basis of the values of TVC at 20 and 37°C, TC, FC and FS in the top-water layer (0.3 m below the water surface), from a depth of 3 or 4 m (at sites 1 and 2) and from the near-bottom (0.2 m above the bottom) water layer, and in the bottom-sediment layer from the depth of 0—5 cm, collected at monthly intervals in the period 1982—1984 at 4 most characteristic sites (Fig. 1): (1) in the northern part of the lake, in the area where sewage is discharged from settlements with sewerage systems, at a depth of 8.4 m; (2) in the middle of the lake, at a depth of 5.5 m; (3) in the north-eastern and (4) in the south-western part of the lake — in both cases at depths of 3.0 m.

About 90% of the TVC 20°C and 37°C (5—13500 and 10—26015 cells per 1 cm^3, respectively), coliform titre (0.01 — > 10), TC, FC and FS (7—45000; 0—4500 and 3—140000 cells per 1 cm^3, respectively) values recorded for the water of Lake Bęskie indicate a clean, or slightly polluted state, and only about 10% — a marked or heavy pollution. A higher, comparatively, contamination of the water with the indicator bacteria studied is found at site 1 in the area where sewage from settlements is discharged, particularly in the top water layer. At sites 2, 3 and 4 as a rule larger numbers of these bacteria are found in the near-bottom water layer. In the study period heavier contamination of the lake water by them was usually recorded in 1982, a lower one in 1983 and 1984. The fact is attributed to a larger livestock size, almost twice, higher amounts of manure and slurry wastes distributed over the arable land, meadows and pastures in 1982 than in the following years. This type of pollution is confirmed by the FC : FS ratio, below 0.7 in 68.2—75.8% in the water samples tested (Tables 1—5). Over a yearly cycle a heavier pollution of Lake Bęskie with indicator bacteria was recorded in different months in spring, summer and autumn, rarely in winter, often after storm or long-lasting rainfalls, less often after algal blooms and death (Figs. 2—6).

The values of TVC 20°C and 37°C (5280—43451000 and 1550-31835000 cells per 1 g dry weight, respectively), TC, FC and FS (400—2400000; 40—140000 and 400—11000000 cells per 100 cm^3, respectively) and the FC : FS ratio (0.0006—27.5) recorded for the bottom sediments of Lake Bęskie were subject to wider variation than those found for the water, both between the sites and years, and over the yearly cycles. The bacteria were usually less numerous at sites 2 and 3, more abundant at sites 1 and 4. Their high abundance at the particular sites occurred in different years, whereas over a yearly cycle they were usually more abundant in summer and autumn, rarely in winter and/or spring. As in the water of the lake studied, the dominance of FS over FC in most of the bottom-sediment samples tested (in 75.8—83.9% of the samples the FC : FS ratio was below 0.7) confirms a higher proportion of animal excrements among the pollutants in Lake Bęskie (Tables 3, 7, 8, Figs. 7, 8).

7. POLISH SUMMARY

Praca obejmuje ocenę charakteru i stopnia zanieczyszczenia bakteriologicznego wody i osadów dennych hypertroficznego jeziora (Jez. Bęskie na Pojezierzu Mazurskim) w warunkach intensywnego nawożenia mineralnego (N + P + K) i organicznego (obornik + gnojowica + fekalia) pobliskich pól uprawnych, łąk i pastwisk. Ocenę tę przeprowadzono na podstawie liczebności bakterii oznaczanych na agarze zwykłym w temperaturze 20 i 37°C, ogólnej liczby bakterii z grupy pałeczki okrężnicy, liczby i miana coli kałowych bakterii z grupy pałeczki okrężnicy oraz liczby paciorkowców kałowych w wodzie powierzchniowej (0,3 m od powierzchni lustra wody), z głębokości 3 lub 4 m (na stanowiskach 1 i 2) i przydennej (0,2 m od dna) oraz w warstwie osadów dennych z głębokości 0 – 5 cm, pobieranych w odstępach miesięcznych w latach 1982 – 1984. Próby pobierano na 4 stanowiskach najbardziej charakterystycznych (rys. 1): (1) w północnej części jeziora, w rejonie dopływu ścieków ze skanalizowanych osiedli na głębokości 8,4 m: (2) w centralnej części jeziora, na głębokości 5,5 m; (3) w południowo-wschodniej i (4) w południowo-zachodniej części jeziora – w obu przypadkach na głębokości 3,0 m.

W wodzie badanego jeziora ogólna liczba bakterii oznaczana na agarze zwykłym w temperaturze 20 i 37°C (odpowiednio 5 – 13 500 i 10 – 26 015 komórek w 1 cm^3), miano coli typu kałowego (0,01 – > 10), ogólna liczba bakterii z grupy pałeczki okrężnicy, liczba kałowych bakterii z grupy pałeczki okrężnicy i liczba paciorkowców kałowych (odpowiednio 7 – 45 000; 0 – 4500 i 3 – 140 000 komórek w 100 cm^3) w około 90% prób wskazują na czysty charakter lub nieznaczne zanieczyszczenie, a tylko w 10% prób na wyraźne lub silne zanieczyszczenie. Stosunkowo częściej większe zanieczyszczenie wody badanymi bakteriami wskaźnikowymi występuje na stanowisku 1, w rejonie dopływu ścieków komunalnych, zwłaszcza w warstwie powierzchniowej. Na stanowiskach 2, 3 i 4 z reguły większe zanieczyszczenie wody tymi bakteriami występuje w warstwie przydennej. W okresie badawczym z reguły większe zanieczyszczenie nimi wody występuje w 1982 r., mniejsze w latach 1983 i 1984. Tłumaczy się to prawie 2-krotnie większą obsadą inwentarza żywego oraz ilością wywożonych na pola uprawne, łąki i pastwiska obornika i gnojowicy w 1982 r. aniżeli w latach następnych. Ten charakter zanieczyszczenia potwierdza stosunek liczbowy kałowych bakterii z grupy pałeczki okrężnicy do paciorkowców kałowych, niższy od 0,7 w 68,2 – 75,8% badanych prób wody (tab. 1 – 5). W cyklu rocznym większe zanieczyszczenie wody badanego jeziora bakteriami wskaźnikowymi występowało w różnych miesiącach wiosną, latem i jesienią, rzadziej zimą, często po opadach deszczu o charakterze burzowym i ciągłym, rzadziej po zakwicie i obumarciu glonów (rys. 2 – 6).

W osadach dennych badanego jeziora ogólna liczba bakterii oznaczana na agarze zwykłym w temperaturze 20 i 37°C (odpowiednio 5 280 – 43 451 000 i 1550 – 31 835 000 komórek w 1 g suchej masy), ogólna liczba bakterii z grupy pałeczki okrężnicy, liczba kałowych bakterii z grupy pałeczki okrężnicy i liczba paciorkowców kałowych (odpowiednio 400 – 2 400 000; 40 – 140 000; i 400 – 11 000 000 komórek w 100 cm^3) oraz stosunek liczbowy kałowych bakterii z grupy pałeczki okrężnicy do paciorkowców kałowych (0,0006 – 27,5) podlegały jeszcze większym wahaniom aniżeli w wodzie zarówno w obrębie poszczególnych stanowisk, jak również w poszczególnych latach i w cyklu rocznym. Z reguły mniej ich występowało na stanowiskach 2 i 3, więcej na stanowiskach 1 i 4. Na poszczególnych stanowiskach więcej ich występowało w różnych latach, w cyklu rocznym zaś z reguły liczniej latem i jesienią, rzadziej zimą i (lub) wiosną. Podobnie jak w wodzie tego zbiornika przewaga paciorkowców kałowych nad kałowymi bakteriami z grupy pałeczki okrężnicy w większości badanych prób osadów dennych (w 75,8 – 83,9% prób stosunek liczbowy kałowych bakterii z grupy pałeczki okrężnicy do paciorkowców kałowych był niższy od 0,7) potwierdza przeważający udział odchodów zwierzęcych w zanieczyszczeniu badanego jeziora (tab. 3, 7, 8, rys. 7, 8).

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