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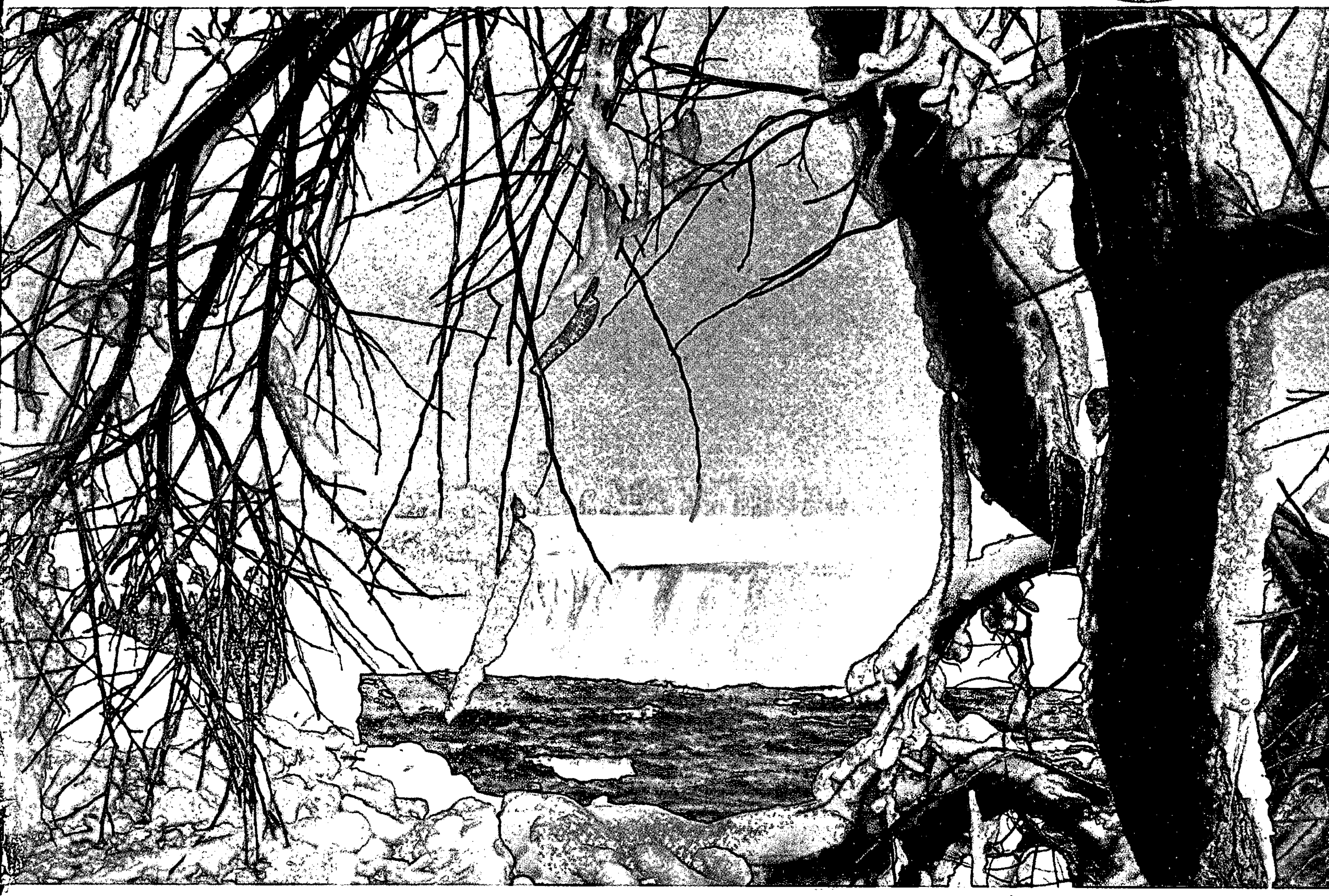
Observations on Bacteriological Conditions in the Upper Great Lakes 1968-1974

S. S. Rao



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(Résumé en français)

INLAND WATERS DIRECTORATE,
CCIW BRANCH,
BURLINGTON, ONTARIO, 1976.

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*The material contained in this report documents summaries of bacteriological observations made on the upper Great Lakes as part of the International Joint Commission Upper Lakes Study and represents contributions from the Microbiology Laboratories, Applications Research Division (ARD), CCIW, and the former Kingston Branch of the Public Health Engineering Division, Department of National Health and Welfare.

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Abstract

The summary report presents bacteriological data collected on Lake Superior in 1968, 1971 and 1973; on Lake Huron in 1968, 1969, 1970, 1971 and 1974; and on Georgian Bay in 1971 and 1974. As part of the International Joint Commission (IJC) Upper Lakes Study, it contains information which complies with the objectives outlined in the IJC Great Lakes Water Quality Agreement.

The report describes near-shore lake-wide bacterial levels showing their temporal and spatial variations. Information is also included which gives the existing bacterial base-line levels in the main bodies of Lake Superior, Lake Huron and Georgian Bay, and indicates near-shore areas with elevated bacterial levels (potential problem areas or areas of non-compliance).

Résumé

Le présent rapport traite des données bactériologiques recueillies lors de l'étude du lac Supérieur en 1968, 1971 et 1973; du lac Huron en 1968, 1969, 1970, 1971 et 1974; et de la baie Georgienne en 1971 et 1974. Relié à l'Étude du bassin supérieur des Grands lacs par la Commission mixte internationale (CMI), il contient des renseignements qui répondent aux objectifs fixés en vertu de l'Accord sur la qualité des eaux des Grands lacs de la CMI.

Le rapport décrit les variations spatio-temporelles des concentrations bactériennes le long des rives. Il comprend aussi des renseignements sur les concentrations bactériennes de base et actuelles dans le lac Supérieur, le lac Huron et la baie Georgienne et il indique les régions périphériques où les concentrations sont élevées (régions où peuvent surgir des problèmes ou régions où les concentrations dépassent les limites fixées).

Observations on Bacteriological Conditions in Lake Superior, 1968, 1971 and 1973

INTRODUCTION

This Chapter contains bacteriological data collected in August 1968, May and October, 1971, and May to November, 1973, as part of the work performed for the International Reference Group on Upper Lakes Pollution. These surveys were conducted by the Water Quality Assessment Unit, Microbiology Laboratories, CCIW, and the former Kingston Branch of the Public Health Engineering Division, Department of National Health and Welfare, to obtain bacteriological data,[1] to establish baseline bacteriological levels and to develop criteria for non-degradative water quality standards.

The data summarized mainly concern the health-oriented and trophic indicator organisms, thus conforming to the "Specific Water Quality Objectives, Annex 1" of the Canada-United States Great Lakes Water Quality Agreement.

One cruise was made in August 1968 aboard the research vessel MV THERON, sampling a total of 58 stations. Two cruises were made in May and October, 1971, sampling a total of 65 and 71 stations, respectively. Six cruises were made in 1973, from May to November, sampling a total of 117 stations on each cruise (Fig. 1). The MV MARTIN KARLSEN was used for the cruises in 1971 and 1973.

BACTERIOLOGICAL PARAMETERS

Total coliform and fecal coliform densities were determined on all cruises during 1968, 1971 and 1973. In addition, fecal streptococci densities were estimated on all cruises during the 1973 survey period. Heterotrophic bacterial populations were estimated using the 20°C standard plate count (1968, 1971) and 20°C spread plate techniques (1973).

[1] Very limited open-lake bacteriological data are available on the United States side. Consequently, the data presented here are taken solely from Canadian studies.

Water samples were collected from depths of 1 m, 10 m and 50 m. An additional sample, from 2 m from the bottom, was obtained at 19 stations on the 1973 cruise.

All of the samples were fully processed on board the vessel. Although occasional unfavourable weather conditions made it impossible to sample at every station, the amount of data collected and the apparent homogeneity of the water allow reasonable conclusions to be made (1).

BACTERIOLOGICAL PROCEDURES

The bacteria were isolated using enrichment and selective media in combination with different incubation periods and temperatures (2).[2]

Coliform Density Determination (MF) (1968, 1971, 1973)

The American Public Health Association (APHA) membrane filter (MF) procedure (3) was used as the basic method for the estimation of coliform concentrations. Water samples were tested using Bacto-m Endo Agar LES. Membrane filtrations were made from appropriate volumes of each water sample. Incubation was at 35 ± 0.5°C for 22 ± 2 hours in air of 100% relative humidity. The development of dark colonies with a golden metallic-appearing surface luster (sheen) was interpreted as direct evidence of the presence of coliform organisms. The numbers of sheened colonies appearing on the MF preparations were determined from the appropriate sample volumes.

[2] A comprehensive manual (2), *Methods for Microbiological Analysis of Water, Wastewater and Sediments*, prepared by Mr. B.J. Dutka, Head, Microbiology Laboratories, CCIW, is presently available at the IJC Office in Windsor. This manual describes the detailed composition of the media and microbiological procedures used by the Microbiology Laboratories, ARD, CCIW. Each technique described has been field-tested and proven reliable.

All colony counts were performed with the aid of a ten-power stereomicroscope. Counts were calculated and recorded in terms of coliforms per 100 ml of water sample (4).

Fecal Coliform Density Determination (MF) (1968, 1971, 1973)

In 1968, a technique perfected by Geldreich *et al.* (5), based on the use of Bacto-m FC Broth base to which a reagent containing rosolic acid was added, coupled with an incubation temperature of 44.5 ± 0.5°C for 24 ± 2 hours, was used for the estimation of fecal coliform density by membrane filtration.

Sample quantities that would yield 20 - 60 colonies per filtration were chosen for the membrane filter test. The membranes were placed on pads soaked with 2 ml of Bacto-m FC Broth in tight-fitting plastic petri dishes (Millipore). The petri dishes were placed in waterproof plastic bags (Whirl-pak), inverted and submerged in a 44.5 ± 0.5°C water bath for 24 ± 2 hours.

The development of blue colonies was interpreted as evidence of the presence of fecal coliforms. All colony counts were performed with the aid of a ten-power stereomicroscope. Counts were calculated and recorded in terms of fecal coliform per 100 ml (6).

Fecal Streptococci Density Determination (MF) (1973)

The APHA membrane filtration procedure (3) was used as the method for the estimation of fecal streptococci concentrations. Water samples were tested using m-Enterococcus Agar. Membrane filtrations were made from appropriate volumes of each sample. Incubation was at 35 ± 0.5°C for 48 ± 2 hours in a well-humidified incubator. The development of typical pink to maroon colonies was interpreted as direct evidence of the presence of fecal streptococci. The numbers of typical colonies appearing on MF preparations were determined with a ten-power stereomicroscope. Counts were expressed in terms of fecal streptococci per 100 ml of lake sample (6).

Aerobic Heterotrophic Bacterial Density Determination

Standard Plate Counts (1968, 1971)

The APHA standard plate count (SPC) procedure (3) was used to estimate total bacteria (viable) numbers. Bacto-Plate Count Agar was used. Plate counts were made using 1 ml of the appropriate dilutions of each water sample. One-millilitre sample aliquots were mixed with the liquified (45°C) agar, allowed to solidify and then incubated at 20°C. The viable total counts were read at 48 ± 2 hours. Counts were recorded in terms of standard plate counts per millilitre of water (7).

Spread Plate Counts (1973)

Total viable heterotrophic bacterial populations were determined on all 1973 samples by a spread plate procedure on a pre-dried solid media (8). The composition of the media is given in *Methods for Microbiological Analysis of Waters, Wastewaters and Sediments* (2). One millilitre of the appropriate dilution of water sample was used. Inoculated plates were incubated at 20°C for seven days. Counts were recorded in terms of heterotrophic bacteria per millilitre of water.

Membrane Filtration Procedure (1968, 1971)

Aerobic heterotrophic bacterial densities were determined on all samples by the membrane filtration technique using Foot and Taylor medium (8) with aerobic incubation at 20°C for 48 ± 2 hours. Membrane filtrations were made from appropriate dilutions and colony counts were read with the aid of a ten-power stereomicroscope. Counts were calculated and recorded in terms of 20°C plate count per millilitre of water (9, 10).

Variations in technique and media used in the estimation of aerobic heterotrophic bacterial population during these surveys prevent quantitative determination of the annual trends. The spread plate technique estimates relatively larger populations than the SPC 20°C procedure. Qualitative comparison, however, is given to display the MF procedure data.

Some other parameters were estimated using a relatively consistent technique and are therefore applicable to determining trends in the lake.

BACTERIOLOGICAL CHARACTERISTICS OF THE MAIN LAKE AND COASTAL ZONE

Coliforms (MF)

The term "coliform" is used to describe various genera of the family Enterobacteriaceae. They are presently used as indicator organisms to denote the potential presence of feces in the water. Coliform sources include feces of man, animals and some fish; domestic and industrial sewage; soil; and plants (1).

Spatial and temporal variations of coliforms in the near-shore areas (within three miles of land) and lake-wide are presented in Figure 2 and Table 1.

Table 1. Trends in Coliform (MF) Organisms %<X/100 ml* in Lake Superior, 1968, 1971, 1973

Month		1968	1971	1973
May				
Inshore value	<1	ND†	25	65
	<100		100	97
Lake-wide value	<1		43	78
	<100		100	94
June				
Inshore value	<1		ND	56
	<100			98
Lake-wide value	<1			67
	<100			98
July				
Inshore value	<1			38
	<100			91
Lake-wide value	<1			51
	<100			93
August				
Inshore value	<1	11		ND
	<100	100		
Lake-wide value	<1	21		
	<100	100		
September				
Inshore value	<1	ND		11
	<100			71
Lake-wide value	<1			27
	<100			77
October				
Inshore value	<1		10	20
	<100		91	71
Lake-wide value	<1		21	28
	<100		93	79
November				
Inshore value	<1		ND	9
	<100			83
Lake-wide value	<1			79
	<100			95

*Values are at 95 % confidence limits
†ND – No data

Table 2. Trends in Fecal Coliform (MF) Organisms %<X/100 ml* in Lake Superior, 1968, 1971, 1973

Month		1968	1971	1973
May				
Inshore value	<1	ND†	73	75
	<100		100	96
Lake-wide value	<1		81	86
	<100		100	98
June				
Inshore value	<1		ND	84
	<100			99
Lake-wide value	<1			77
	<100			93
July				
Inshore value	<1			81
	<100			95
Lake-wide value	<1			95
	<100			
August				
Inshore value	<1	67		ND
	<100	100		
Lake-wide value	<1	69		
	<100	100		
September				
Inshore value	<1	ND		88
	<100			99
Lake-wide value	<1			91
	<100			99
October				
Inshore value	<1		76	91
	<100		100	100
Lake-wide value	<1		70	91
	<100		100	100
November				
Inshore value	<1		ND	73
	<100			97
Lake-wide value	<1			83
	<100			98

*Values are at 95 % confidence limits
†ND – No data

The data from the August 1968 cruise indicate that over 99% of the water samples analyzed had coliform counts less than 100 per 100 ml (Fig. 3a). Data obtained during May and October cruises in 1971 also showed a similar count. Due to limited data, it is rather difficult to indicate any trend from observations during these two years. It is possible, however, to establish a seasonal cycle from the 1973 data because of the extensive surveys. [For details, please refer to an earlier report (1).] The most significant (seasonal) trend was found in the near-shore areas where total coliform densities increased considerably throughout the year (Fig. 3a). High counts were discovered in several inshore areas, e.g., Duluth (1968, 1971, 1973), Ashland (1973), Au Sable Point (1971, 1973), Thunder Bay (1971, 1973), Michipicoten Harbour (1968, 1971), Marathon (1968, 1973) and Nipigon areas. Yet on a lake-wide basis, the majority of stations sampled had counts of less than 10 per 100 ml (Fig. 3a).

Fecal Coliforms (MF)

Fecal coliforms include those genera which specifically originate in the intestinal tract of warm-blooded animals. They are indicative of fecal pollution (1).

Practically no data are available for the offshore stations during the August 1968 cruise (Table 2). From the available near-shore data, it is clear that the majority of stations monitored (over 90%) had counts less than 1 per 100 ml (Fig. 3b).

Similar observations were made during the May and October cruises in 1971 (Fig. 3b). Main lake waters were practically free from detectable fecal coliform contamination. These observations were substantiated during extensive cruises in 1973. Data from the cruises in 1973 permitted the establishment of some seasonal trends. The observed low fecal coliform densities remained relatively constant (over 80% of the analyzed water sampled showed fecal coliform populations of less than 1 per 100 ml) (1). Near-shore areas had relatively higher densities. These include Duluth, Thunder Bay, Whitefish Bay, Grand Island and the Keweenaw Peninsula (Fig. 4).

Fecal Streptococci (MF)

No fecal streptococci data are available for 1968 and 1971. A detailed account of the distribution in both lake-wide and near-shore areas is presented in an earlier report (1). Based on the available 1973 data (Table 3), it is evident that their densities remained relatively constant. On a lake-wide basis, over 80% of the analyzed samples showed densities of less than 1 per 100 ml. During the October-November period, however, a further decline was noticed (over 90% <1/100 ml) (Fig. 3c).

Aerobic Heterotrophic Bacteria

During the cruise in August 1968 and during cruises in May and October, 1971, heterotroph densities did not show any substantial difference. Densities in main lake waters rarely exceeded 100 per ml. In most inshore areas, however, densities were higher than in the main body of the lake. These included areas near Duluth, Marathon, the coastal area between Ashland and the Keweenaw Peninsula and Grand Island.

A comparison of data obtained during 1971 and 1973, however, showed an increase in heterotrophs in the lake (Table 4) (Figs. 3d & 5). These changes are not highly significant. The 1973 surveys, being more extensive, allow some trends to be seen. A comprehensive report on the data obtained during 1973 surveys is available (1). On a lake-wide basis, heterotrophs rarely exceeded 100 per millilitre of the water sample. During the August-September period, heterotroph densities reached a peak, and then their levels started to decline (Fig. 3d).

CAUSES AND EFFECTS OF OBSERVED BACTERIAL CONTAMINATION

In the *Second Annual Report on Great Lakes Water Quality,* published by the International Joint Commission in April 1973 (11), it is stated that

> "it is not sufficient to monitor the quality of this lake in the open waters in order to protect it. The water quality parameters of interest must be measured in those local areas of known waste loading."

This must be done because the impact of pollution from specific sources is readily masked by the lake's large diluting capacity. It becomes essential, then, to consider those regions of the coastal zone which may be locally subjected to the addition of pollutants. Owing to the possibilities for exchange with the great volume of main lake water, however, it is difficult to estimate the long-term effects of such organic loading. In most cases, only certain generalizations can be drawn. More detailed information, however, is available for Nipigon (12) and Marathon (13) areas. Postulations can and should be outlined for future reference even though they may have to be revised later.

Western Basin

The water of the main body and most of the coastal zones of Lake Superior is of high quality. Fecal pollutants are almost nonexistent and heterotrophic bacterial populations are at levels consistent with oligotrophic waters (14). Where heterotrophic bacterial populations do increase near some of the coastal areas, this is believed to be the result of higher temperatures and an abundance of nutrients. These problem areas need to be considered, particularly as sources of local pollution in the lake.

In the western end of the lake, near Duluth-Superior, it is clear that although shallow water, higher temperatures (10°C-12°C, as compared to 5°C-6°C in the main body), and good vertical mixing are important factors contributing to the increased heterotrophic bacterial populations, these do not account for bacterial population levels in excess of 8000 found during the last cruise.

The fecal coliform/fecal streptococcus ratio (FC:FS) in early summer was very low, indicating a land-drainage-wash type of contamination. The ratio, however, changed to values between 0.7 and 4 in midsummer, and at times, the ratio exceeded 4 during the fall, indicating sewage contamination. The western basin is the only area in the lake where fecal streptococci counts were constantly available to permit this type of observation. In fact, except for the odd random counts (usually 1 or 2 per 100 ml), fecal coliforms and fecal streptococci were practically absent from the sampled lake waters.

Other coastal areas in the western half of the lake, where organic loading may be taking place, need to be studied more carefully to determine if any problem exists. The coastal area between Ashland and the Keweenaw Peninsula has many small rivers flowing into the lake, which may account for the slight increase in the bacterial counts.

Table 3. Trends in Fecal Streptococci (MF) Organisms %<X/100 ml* in Lake Superior, 1968, 1971, 1973

Month		1968	1971	1973
May				
Inshore value	<1	ND†	ND	74
	<100			98
Lake-wide value	<1			87
	<100			99
June				
Inshore value	<1			76
	<100			100
Lake-wide value	<1			76
	<100			100
July				
Inshore value	<1			73
	<100			100
Lake-wide value	<1			76
	<100			100
August				
Inshore value	<1			
	<100			
Lake-wide value	<1			
	<100			
September				
Inshore value	<1			81
	<100			100
Lake-wide value	<1			86
	<100			100
October				
Inshore value	<1			90
	<100			100
Lake-wide value	<1			95
	<100			100
November				
Inshore value	<1			90
	<100			100
Lake-wide value	<1			94
	<100			100

*Values are at 95 % confidence limits
†ND – No data

Table 4. Trends in Aerobic Heterotroph Distribution %<X/ml* in Lake Superior, 1968, 1971, 1973

Month			1968	1971	1973
May					
Inshore value					
	<100	F&T †	ND §	56	ND
	<100	SPC ‡		100	
	<1000	F&T		81	
	<1000	SPC		100	
Lake-wide value					
	<100	F&T		44	
	<100	SPC		98	
	<1000	F&T		88	
	<1000	SPC		100	

*Values are at 95% confidence limits
†F&T – Foot and Taylor procedure at 20°C, 7 days
‡SPC – Standard plate count procedure at 20°C, 2 days
§ND – No data

Table 4. Continued

Month			1968	1971	1973
June					
Inshore value					
	<100	F&T	ND	ND	70
	<100	SPC			
	<1000	F&T			100
	<1000	SPC			
Lake-wide value					
	<100	F&T			83
	<100	SPC			
	<1000	F&T			100
	<1000	SPC			
July					
Inshore value					
	<100	F&T			25
	<100	SPC			
	<1000	F&T			100
	<1000	SPC			
Lake-wide value					
	<100	F&T			56
	<100	SPC			
	<1000	F&T			100
	<1000	SPC			
August					
Inshore value					
	<100	F&T			
	<100	SPC	100		ND
	<1000	F&T			
	<1000	SPC	100		
Lake-wide value					
	<100	F&T			
	<100	SPC	100		
	<1000	F&T			
	<1000	SPC			
September					
Inshore value					
	<100	F&T	ND		37
	<100	SPC			
	<1000	F&T			99
	<1000	SPC			
Lake-wide value					
	<100	F&T			47
	<100	SPC			
	<1000	F&T			99
	<1000	SPC			
October					
Inshore value					
	<100	F&T		96	43
	<100	SPC		100	
	<1000	F&T		100	97
	<1000	SPC		100	
Lake-wide value					
	<100	F&T		96	66
	<100	SPC		97	
	<1000	F&T		100	99
	<1000	SPC		100	
November					
Inshore value					
	<100	F&T		ND	56
	<100	SPC			
	<1000	F&T			92
	<1000	SPC			
Lake-wide value					
	<100	F&T			67
	<100	SPC			
	<1000	F&T			97
	<1000	SPC			

Northeastern Basin

In the northeastern basin of the lake, conditions similar to those observed in the western basin exist. In August 1973, during a one-week study of the influence of waste from a pulp and paper mill at Marathon, Ontario, on the inshore waters of Lake Superior, it was found that sufficient nutrients were present in the five square kilometre study area to support an existing bacterial population of approximately 2000 times that found in the main body of the lake. This effluent has an influence on the water quality of the lake that extends more than 5 km into the lake, where it is eventually diluted to the extent that it is no longer detectable. Similar observations were obtained in the Nipigon area (12).

CONCLUSIONS

The present water quality of Lake Superior, based on our bacteriological findings, appears to be good; the main body of the lake is free from detectable fecal contamination of either human or animal sources. To date, waste discharges from the coastal areas seem to have had no significant effect on the main lake's present water quality. Efforts, however, will have to be concentrated on evaluating seasonal fluctuations in near-shore water quality (e.g., near Thunder Bay, Marathon, Nipigon, Duluth, Ashland and the Keweenaw Peninsula) to establish clearly the zone of influence of organic input in the lake and to assess its seasonal assimilative capacity.

Observations on Bacteriological Conditions in Lake Huron, 1968-1971 and 1974 (Including North Channel) and in Georgian Bay, 1971 and 1974

INTRODUCTION

In this Chapter, bacteriological data are summarized in two parts: a) Lake Huron (including the North Channel) for 1968, 1969, 1970, 1971 and 1974, and b) Georgian Bay for the years 1971 and 1974.[3]

Water quality cruise data collected during 1968, 1969, 1970, 1971 and 1974 from Lake Huron are presented in Tables 5 to 8, and the data from Georgian Bay for the years 1971 and 1974 are listed in Tables 9 to 12. The seven cruises made during 1974 provide information on seasonal trends. Data collected during the previous years are also presented to document the levels observed and to show the differences over the years. Some of the available bacteriological data during these years are given and observed trends in the lake are shown. Wherever possible, attempts have been made to indicate potential problem areas and provide information on cross-boundary pollution, if any. Values are presented for both lake-wide and inshore stations. Inshore stations here refer to those that are within three miles from the shoreline. Sampling and processing of the samples were carried out aboard the MV MARTIN KARLSEN, MV PORT DAUPHINE and the CCIW research vessel CSS LIMNOS.

BACTERIOLOGICAL PARAMETERS

Populations of health-oriented bacteria [total coliforms (MF), fecal coliforms (MF), fecal streptococci (MF, 1974 only)] and aerobic heterotrophs were the parameters considered to ascertain the water quality, the former reflecting the possible influx of pathogenic micro-organisms and the latter, the trophic status. During these monitor cruises the water samples were collected from 1 m, 10 m, 50 m and 2 m from the bottom. During the 1974 surveys, however, samples from the top bend of the thermocline, mid-thermocline and the bottom bend of the thermocline were obtained during stratified conditions. All samples were processed immediately or after storage of no longer than 10-12 hours at 4°C.

[3] Very limited open-lake bacteriological data are available on the United States side. Consequently, the data presented here are taken solely from Canadian studies.

Table 5. Trends in Coliform (MF) Distribution % <X/100 ml* in Lake Huron, 1968, 1969, 1970, 1971, 1974

Month		1968	1969	1970	1971	1974
April						
Inshore value	<1	ND†	ND	ND	ND	82
	<100					99
Lake-wide value	<1					86
	<100					99
May						
Inshore value	<1			41	28	85
	<100			94	97	99
Lake-wide value	<1			49	38	89
	<100			97	100	99
June						
Inshore value	<1			ND	ND	65
	<100					99
Lake-wide value	<1					69
	<100					99
July						
Inshore value	<1				40	37
	<100				100	99
Lake-wide value	<1				43	38
	<100				100	99
August						
Inshore value	<1	21			ND	33
	<100	97				97
Lake-wide value	<1	29				38
	<100	99				99
September						
Inshore value	<1	ND	13			ND
	<100		88			
Lake-wide value	<1		27			
	<100		92			
October						
Inshore value	<1		ND	0	93	42
	<100			84	93	99
Lake-wide value	<1			4	30	56
	<100			87	95	99
November						
Inshore value	<1			ND	ND	ND
	<100					
Lake-wide value	<1					
	<100					
December						
Inshore value	<1					32
	<100					96
Lake-wide value	<1					50
	<100					84

*Values are at 95% confidence limits
†ND – No data

Table 6. Trends in Fecal Coliform (MF) Distribution %<X/100 ml* in Lake Huron, 1968, 1969, 1970, 1971, 1974

Month		1968	1969	1970	1971	1974
April						
Inshore value	<1	ND†	ND	ND	ND	97
	<100					100
Lake-wide value	<1					97
	<100					100
May						
Inshore value	<1			70		96
	<100			100		100
Lake-wide value	<1			75		98
	<100			100		100
June						
Inshore value	<1			ND		82
	<100					100
Lake-wide value	<1					88
	<100					97
July						
Inshore value	<1				68	88
	<100				100	100
Lake-wide value	<1				67	90
	<100				98	100
August						
Inshore value	<1	73			ND	80
	<100	100				97
Lake-wide value	<1	71				82
	<100	100				98
September						
Inshore value	<1	ND	72			ND
	<100		97			
Lake-wide value	<1		85			
	<100		99			
October						
Inshore value	<1		ND		70	94
	<100				96	100
Lake-wide value	<1				70	96
	<100				98	100
November						
Inshore value	<1				ND	ND
	<100					
Lake-wide value	<1					
	<100					
December						
Inshore value	<1					91
	<100					100
Lake-wide value	<1					84
	<100					100

*Values are at 95% confidence limits
†ND – No data

Table 7. Trends in Fecal Streptococci (MF) Distribution %<X/100 ml* in Lake Huron, 1968, 1969, 1970, 1971, 1974

Month		1968	1969	1970	1971	1974
April						
Inshore value	<1	ND†	ND	ND	ND	91
	<100					100
Lake-wide value	<1					94
	<100					100
May						
Inshore value	<1					93
	<100					100
Lake-wide value	<1					94
	<100					100
June						
Inshore value	<1					86
	<100					99
Lake-wide value	<1					87
	<100					99
July						
Inshore value	<1					56
	<100					100
Lake-wide value	<1					61
	<100					100
August						
Inshore value	<1					97
	<100					100
Lake-wide value	<1					93
	<100					100
September						
Inshore value	<1					ND
	<100					
Lake-wide value	<1					
	<100					
October						
Inshore value	<1					81
	<100					100
Lake-wide value	<1					87
	<100					100
November						
Inshore value	<1					ND
	<100					
Lake-wide value	<1					
	<100					
December						
Inshore value	<1					96
	<100					100
Lake-wide value	<1					100
	<100					100

*Values are at 95% confidence limits
†ND – No data

BACTERIOLOGICAL PROCEDURES

The procedures followed have been described in Chapter 1.

BACTERIOLOGICAL CHARACTERISTICS OF THE MAIN LAKE AND COASTAL ZONE

Spatial and temporal variations of coliforms in the near-shore areas (within three miles of land) and lake-wide are presented in Figure 6 and Table 5.

BACTERIOLOGICAL CHARACTERISTICS OF LAKE HURON (INCLUDING NORTH CHANNEL)

Annual and/or seasonal variation in densities of total coliforms (MF), fecal coliforms (MF), fecal streptococci (MF) and aerobic heterotrophs are presented in Tables 5 to 8 and Figures 6 to 9 (values presented are at 95% confidence levels at 95% confidence coefficient). Figures 6 to 9 show the distribution patterns of these bacterial populations in the lake. It is evident from the data that densities of health-oriented bacteria at all stations monitored in Lake Huron during all years come within the limits of the present IJC Water Quality Standards. (Current Water Quality Standards are for coliforms, 1000 per 100 ml, and for fecal coliforms, 200 per 100 ml. No water quality standards are currently available for fecal streptococci and aerobic heterotrophs.)

Average coliform densities (Fig. 6) were less than 10 per 100 ml in the majority of open lake or offshore waters. Elevated counts were found in certain near-shore areas. Over 90% of the analyzed water samples showed counts less than 100 per 100 ml in near-shore areas. Near-shore locations having elevated levels of coliform densities include Saginaw Bay, Thunder Bay and areas in proximity

Table 8. Trends in Aerobic Heterotroph Distribution % <X/ml* in Lake Huron, 1968, 1969, 1970, 1971, 1974

Month		SPC†				F&T‡ (MF)		F&T
		1968	1969	1970	1971	1970	1971	1974
April								
Inshore value	<100	ND§	ND	ND	ND	ND	ND	39
	<1000							90
Lake-wide value	<100							66
	<1000							95
May								
Inshore value	<100			94	0		85	56
	<1000			100	85		69	90
Lake-wide value	<100			93	3		46	69
	<1000			100	97		82	90
June								
Inshore value	<100			ND	ND		ND	17
	<1000							100
Lake-wide value	<100							31
	<1000							97
July								
Inshore value	<100				97		82	43
	<1000				100		91	100
Lake-wide value	<100				97		37	55
	<1000				100		94	99
August								
Inshore value	<100	91			ND		ND	28
	<1000	100						100
Lake-wide value	<100	94						31
	<1000	100						99
September								
Inshore value	<100	ND	97					ND
	<1000		100					
Lake-wide value	<100		99					
	<1000		100					
October								
Inshore value	<100		ND		93	37	93	35
	<1000				100	90	100	99
Lake-wide value	<100				97	62	97	46
	<1000				100	91	100	99
November								
Inshore value	<100				ND	ND	ND	ND
	<1000							
Lake-wide value	<100							
	<1000							
December								
Inshore value	<100							32
	<1000							95
Lake-wide value	<100							50
	<1000							96

*Values are at 95% confidence limits
†SPC – Standard plate count procedure at 20°C, 2 days
‡F&T – Foot and Taylor procedure at 20°C, 7 days
§ND – No data

Table 9. Trends in Total Coliform (MF) Distribution %<X/100 ml* in Georgian Bay, 1971, 1974

Month		1971	1974
April			
Inshore value	<1	ND†	78
	<100		100
Lake-wide value	<1		80
	<100		100
May			
Inshore value	<1	50	69
	<100	100	89
Lake-wide value	<1	58	82
	<100	100	95
June			
Inshore value	<1	ND	61
	<100		93
Lake-wide value	<1		68
	<100		98
July			
Inshore value	<1		48
	<100		98
Lake-wide value	<1		39
	<100		99
August			
Inshore value	<1	43	ND
	<100	100	
Lake-wide value	<1	40	
	<100	100	
September			
Inshore value	<1	ND	6
	<100		97
Lake-wide value	<1		7
	<100		98
October			
Inshore value	<1	14	27
	<100	71	100
Lake-wide value	<1	6	22
	<100	72	98
November			
Inshore value	<1	ND	ND
	<100		
Lake-wide value	<1		
	<100		
December			
Inshore value	<1		22
	<100		93
Lake-wide value	<1		22
	<100		77

*Values are at 95% confidence limits
†ND – No data

Table 10. Trends in Fecal Coliform (MF) Distribution %<X/100 ml* in Georgian Bay, 1971, 1974

Month		1971	1974
April			
Inshore value	<1	ND†	95
	<100		100
Lake-wide value	<1		95
	<100		100
May			
Inshore value	<1	67	88
	<100	100	100
Lake-wide value	<1	75	93
	<100	100	100
June			
Inshore value	<1	ND	76
	<100		96
Lake-wide value	<1		81
	<100		98
July			
Inshore value	<1		89
	<100		98
Lake-wide value	<1		95
	<100		99
August			
Inshore value	<1	50	ND
	<100	100	
Lake-wide value	<1		
	<100		
September			
Inshore value	<1	ND	82
	<100		100
Lake-wide value	<1		87
	<100		99
October			
Inshore value	<1	57	86
	<100	100	100
Lake-wide value	<1	69	94
	<100	100	100
November			
Inshore value	<1	ND	ND
	<100		
Lake-wide value	<1		
	<100		
December			
Inshore value	<1		86
	<100		100
Lake-wide value	<1		93
	<100		100

*Values are at 95% confidence limits
†ND – No data

to the towns of Kincardine, Goderich and Harrisville.

Seasonal Changes in the Lake

Extensive data from 1974 periods establish seasonal fluctuations in the water body. In the near-shore area, total coliform counts rose to peak values during the July-August period, dropped slightly (10%) in October, then rose to peak levels again during the November-December period (Fig. 9a). Similar trends were observed on a lake-wide basis.

Fecal Coliforms (MF)

Limitations of the available data pertaining to fecal coliform densities include the lack of data for the offshore waters for 1968, the North Channel for 1968, 1970, and the north central portion of the lake for the years 1970 and

1971. The following observations, however, have been derived from the available data. Counts from the offshore stations were generally less than 1 per 100 ml. Approximately 70% of the inshore stations were free from detectable fecal contamination. By 1974 this value had risen to 80% (Fig. 9b).

The data indicated that certain near-shore areas exhibited elevated bacterial densities, suggesting that these areas are significant source areas. These include Saginaw Bay, Thunder Bay, Rogers City, Kincardine and Goderich.

On a seasonal basis, the 1974 data show that near-shore fluctuations were similar to that seen on a lake-wide basis, showing peaks in June and August (Fig. 9b).

Table 11. Trends in Fecal Streptococci (MF) Distribution %<X/100 ml* in Georgian Bay, 1971, 1974

Month		1971	1974
April			
Inshore value	<1	ND†	96
	<100		100
Lake-wide value	<1		96
	<100		100
May			
Inshore value	<1		97
	<100		100
Lake-wide value	<1		92
	<100		100
June			
Inshore value	<1		83
	<100		100
Lake-wide value	<1		85
	<100		100
July			
Inshore value	<1		83
	<100		100
Lake-wide value	<1		78
	<100		100
August			
Inshore value	<1		ND
	<100		
Lake-wide value	<1		
	<100		
September			
Inshore value	<1		90
	<100		100
Lake-wide value	<1		93
	<100		100
October			
Inshore value	<1		91
	<100		100
Lake-wide value	<1		94
	<100		100
November			
Inshore value	<1		ND
	<100		
Lake-wide value	<1		
	<100		
December			
Inshore value	<1		86
	<100		100
Lake-wide value	<1		96
	<100		100

*Values are at 95 % confidence limits
†ND – No data

Table 12. Trends in Aerobic Heterotroph Distribution %<X/ml* in Georgian Bay, 1971, 1974

Month		F&T† (MF) 1971	SPC‡ 1971	F&T 1974
April				
Inshore value	<100	ND§	ND	50
	<1000			77
Lake-wide value	<100		100	62
	<1000		100	92
May				
Inshore value	<100	67	94	ND
	<1000	100	100	
Lake-wide value	<100	64	ND	97
	<1000	100		100
June				
Inshore value	<100	ND		32
	<1000			81
Lake-wide value	<100			44
	<1000			93
July				
Inshore value	<100			49
	<1000			98
Lake-wide value	<100			32
	<1000			99
August				
Inshore value	<100	28		86
	<1000	86		100
Lake-wide value	<100	24		94
	<1000	95		100
September				
Inshore value	<100	ND		10
	<1000			100
Lake-wide value	<100			8
	<1000			100
October				
Inshore value	<100	100	100	54
	<1000	100	100	91
Lake-wide value	<100	100	100	50
	<1000	100	100	97
November				
Inshore value	<100	ND	ND	30
	<1000			100
Lake-wide value	<100			30
	<1000			100
December				
Inshore value	<100			72
	<1000			100
Lake-wide value	<100			ND
	<1000			

*Values are at 95% confidence limits
†F&T – Foot and Taylor procedure at 20°C, 7 days
‡SPC – Standard place count procedure at 20°C, 2 days
§ND – No data

Fecal Streptococci (MF)

Fecal streptococci densities were determined only during 1974 surveys. The majority of water samples analyzed showed densities of less than 1 per 100 ml. Fecal streptococci densities fluctuated throughout the year, with maximum density in July (Fig. 9c).

Aerobic Heterotrophs

Lack of uniform technique for determining heterotroph densities prevented the establishment of annual trends. Heterotroph data are presented in Figure 9d. The 1974 data were collected using a uniform and improved technique. This enabled the establishment of seasonal variations in the lake. A detailed account of their distribution and variations noticed is presented in Table 8 and Figures 8 and 9d. Several near-shore areas in Lake Huron exhibited high counts. These include Saginaw Bay, Thunder Bay, Rogers City and the western side of the Bruce Peninsula. On a seasonal basis, counts were found to fluctuate throughout the sampling season, with maximum densities occurring in June (Fig. 9d).

BACTERIOLOGICAL CHARACTERISTICS OF GEORGIAN BAY

Bacteriological data for cruises during 1971 and 1974 are summarized in Figures 10 and 11 and Tables 9 to 12. (Values indicated in the tables are at 95% confidence limits at 95% confidence coefficient.)

Coliforms and Fecal Coliforms (MF)

It is apparent from the collected data that the densities of coliforms and fecal coliforms are well below the current bacteriological standards presently set by the International Joint Commission (Fig. 11a, b). During 1971 and 1974 the average coliform density was less than 50 per 100 ml, and fecal coliforms and fecal streptococci (for 1974 only) were less than 1 per 100 ml (Figs. 10a, b & 11a, b, c).

In both years, maximum counts of coliforms were obtained during the fall period (September 1971 and October 1974), but declined during the December period (1974). This trend has been exhibited in both near-shore and offshore waters.

The majority of offshore stations monitored had no detectable fecal contamination in either 1971 or 1974. In the near-shore areas, maximum total coliform densities occurred in the August-September period, then dropped slightly and stabilized during the October-December period (Fig. 11a).

Data also indicate a greater number of stations showing fecal contamination in 1971 (50%-67% vs 76%-95% counts <1/100 ml).

Fecal Streptococci (MF)

Fecal streptococci data are available only for 1974. Densities were fairly stable during the sample period, with nearly 90% or more of the water samples having counts less than 1 per 100 ml. Samples indicating the presence of these organisms were obtained in the Owen Sound–Midland–Collingwood areas and in the vicinity of Parry Sound. Counts fluctuated randomly, with the maximum populations occurring in the June-July period.

Aerobic Heterotrophs

Comparison of 1971 and 1974 data is not attempted here due to variations in the techniques employed during these years. On a seasonal basis, maximum lake-wide densities were obtained during the August-September period in both lake-wide and near-shore areas, and dropped in October to densities similar to April values. Aerobic heterotrophs in the main Bay waters remained less than 100 per 100 ml (Fig. 11d).

CAUSES AND EFFECTS OF BACTERIAL CONDITIONS

Lake Huron (Including North Channel)

The waters of the main lake are practically free from fecal contamination as determined by the lack of fecal indicator organisms. Near-shore fecal contamination was rarely greater than that of the main lake waters. Specific near-shore areas exhibiting relatively higher bacterial densities (contamination) include Saginaw Bay (fed by the Saginaw River flowing through Bay City), Thunder Bay, Rogers City, Calcite and those regions of the North Channel receiving inputs from the St. Marys and Spanish rivers, and the town of Blind River. These elevated bacterial densities are found to be specifically associated with industrial and domestic sewage discharge areas (15). Details of near-shore bacteriological water quality are documented in the IJC *Final Report on Great Lakes Water Quality* (16).

Georgian Bay

Data indicate that in the main body of Georgian Bay, fecal coliforms and fecal streptococci densities are similar to those found in Lake Huron. Near-shore areas had higher bacterial densities than the main body. Total coliforms rose above 30 per 100 ml near the southeastern coastal areas receiving outflow from the Severn River.

Aerobic heterotrophs in the majority of stations monitored were also comparable with Lake Huron levels. Counts in excess of 300 per ml were found only in the southeastern part of Georgian Bay, specifically at Owen Sound, Meaford, Collingwood and Wasaga Beach. Similar elevated bacterial counts in these near-shore areas in Lake Huron and Georgian Bay were observed during the 1973-74 surveys conducted by the Ontario Ministry of the Environment (17). These elevated bacterial levels are attributed to point source pollution from municipal and industrial wastewaters (15).

CONCLUSIONS

Data indicate that the present water quality of both Lake Huron and Georgian Bay is good and easily meets all bacteriological standards. The main body of Lake Huron and the main body of Georgian Bay are practically free from detectable fecal contamination. Waste material discharges from the coastal areas, if any, seem to have no apparent effect on the main water bodies. Several coastal areas had relatively higher densities of heterotrophic bacterial populations: Saginaw Bay and areas near Port Hope in Lake Huron, and some eastern areas in Georgian Bay, e.g., Collingwood, Wasaga Beach, Midland, Penetanguishene and Owen Sound. These areas should be studied in greater detail to define the extent of local discharge effects on the main body. From the collected bacteriological data there is no evidence of any cross-boundary movements of the bacterial populations.

Microbiological Recommendations for the Upper Great Lakes

OFFSHORE WATERS

Offshore waters have water quality better than that prescribed by the International Joint Commission water quality standards (objectives). The following new standards are therefore proposed to maintain or enhance current water quality:

1) The data and conclusions from the most recent, properly conducted IJC surveys should form the standard for the main lake water body.
2) A well-conducted survey should provide geometric mean densities based on statistically acceptable data from at least five surveys during the sampling season (April-December). There should be a minimum of 21 days between surveys.
3) When a subsequent survey is conducted that shows significantly poorer water quality (P less than 0.05), then the offshore waters should be considered degraded. Action should be taken to restore the water quality to its former state (as in the previous survey).
4) When subsequent surveys are conducted and data indicate that water quality has improved significantly (P less than 0.05), the data and conclusions of that survey should automatically form the current standards.
5) Allowance for seasonal and natural fluctuations should be considered in interpreting and reporting each survey.

NEAR-SHORE WATERS

Since the majority of near-shore waters have better water quality than current International Joint Commission standards (objectives), the following new standards are recommended:

a) Clean water areas should have standards set in the same manner as the offshore waters [see recommendation (1)].
b) A properly conducted survey should provide geometric mean densities based on statistically acceptable data from a sampling frequency of not less than once per day for five days at any sampling site over not more than a thirty-day period. Parameters used should include fecal coliforms, *Pseudomonas aeruginosa* and aerobic heterotrophic bacteria. Total coliforms have been shown to be an inadequate index of water quality and their use as an indicator should be re-evaluated.
c) Survey data from degraded near-shore waters of better quality than current IJC standards should be used to set temporary standards; but every effort should be made to restrict and reduce the affected area and ultimately to restore the water to the quality of surrounding cleaner areas.
d) Waters used for recreational activities involving body contact should be substantially free from bacteria, fungi or viruses that may produce enteric disorders or eye, ear, nose, throat, skin infections or other human diseases and infections (e.g., *Pseudomonas aeruginosa).*

FUTURE STUDIES

Future studies should be sufficiently intensive to establish the areas of impact and influence of point sources of pollution. More efficient, effective, economical survey designs, such as the zonal grid sampling approach, should be considered as a potential replacement for lake-wide and near-shore monitoring schemes.

Bacteriological Water Quality Criteria for the Upper Great Lakes

POLLUTION INDICATOR SYSTEMS

Bacteriological studies carried out in the 1973-75 period on Lake Superior, Lake Huron, the North Channel and Georgian Bay have shown that the main bodies of these lakes are free from fecal contamination. The majority of the stations have an average of less than one coliform, fecal coliform and fecal streptococcus per 100 ml. Some inshore areas (3 km), however, were found to have higher densities of the groups mentioned above. Yet the average values (<50/100 ml) were well below water quality standards set forth in "Specific Water Quality Objectives, Annex 1 (a) Microbiology," of the Canada-United States Great Lakes Water Quality Agreement. Some localized areas, although presently complying with bacteriological-recreational standards, may develop into potential problem areas because of the continuing waste input. Since the present indicator system is based on coliforms [coliform tests are inaccurate (18) and coliforms are known to reproduce in enriched waters], a "false" indicator of potential problem areas often exists. At present, the main lake water quality appears to be excellent and there is no evidence of fecal pollution. This apparently implies no cross-boundary movements of bacterial populations. Yet it should be borne in mind that this circumstance could be due to the very high dilution caused by the large volumes of water and the insensitivity or inaccuracy of the coliform test. Therefore, to set specific bacteriological standards for public health and to establish an indicator system for upper lakes, some modification of the presently stipulated bacterial types and numbers in the specific water quality objectives is necessary.

Any change from the present bacteriological condition (both numbers and types) implies either deterioration or an improvement of the lake, depending upon the direction in relation to the present base-line levels.

International Joint Commission Standards indicate that waters with coliform counts of 1000 per 100 ml or less are acceptable for bathing (19). This deteriorated condition rarely, if ever, is found in any of the open waters of the upper Great Lakes. Also, recent work (18) clearly indicates that coliforms isolated from these lakes and other water bodies are not true representatives of bacterial population of fecal origin, and therefore, applying or including these populations as basic bacteriological indicators in IJC water quality objectives has little justification. This contention was supported by our work on the upper Great Lakes, which clearly showed that "true or confirmed coliforms" (Enterobacteriaceae) consist only of a certain fraction of the total isolates obtained on LES-Endo's media (Rao and Jurkovic, unpublished). Therefore any attempt to apply coliform data to fit water quality standards, if at all necessary, should be attempted with extreme caution. There are several parameters which are believed to be more valid indicators of public health concern and fecal pollution. These include fecal coliforms, fecal streptococci, *Pseudomonas aeruginosa* and pathogenic fungi. Virus incidence studies may also prove important in heavily used inshore areas near discharges. These parameters are presently being extensively studied in the Great Lakes system and a wealth of background data is now available to allow the development of water quality criteria in terms of base line.

NON-DEGRADATION

Microbiological biotypes and densities can also be used to measure or monitor nutrient loadings and the extent of their effect on the water bodies. Owing to the sensitivity of heterotrophic bacterial populations to "minute" fluctuations in nutrients, they are often the sentinels of changing conditions and may be one of the better indicators of cross-boundary movements of nutrient inputs. Also, heterotrophic bacterial density determinations near point source discharges up to 10 km in a lake would aid in establishing "mixing zones" or "zones of influence," as well as in assessing the near-shore bacteriological water quality and its impact on main lake waters. These aspects provide a good basis for an intelligent water management program to evaluate non-degradation criteria. The two point source microbiological studies completed during 1973-74 and 1974-75 on the effects of pulp mill wastes on bacterial communities in Lake Superior using the zonal grid approach supported this concept (12). Therefore it is essential to include heterotrophic bacterial densities in water quality surveillance programs, not only for the development of water quality criteria but also as a tool to delineate the zone of influence.

ACKNOWLEDGMENTS

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Figures 1 to 11

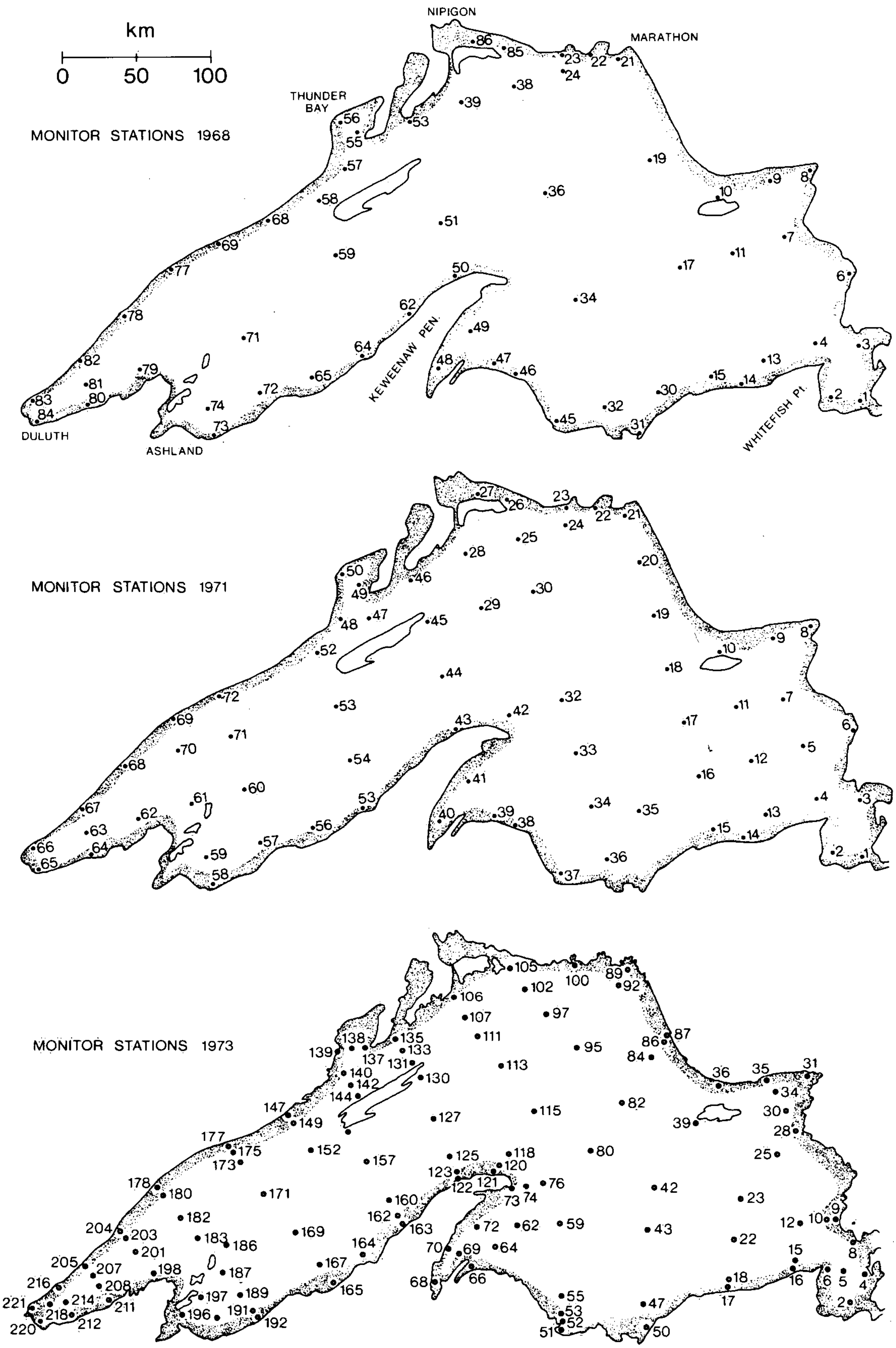

Figure 1. Lake Superior inshore and offshore stations.

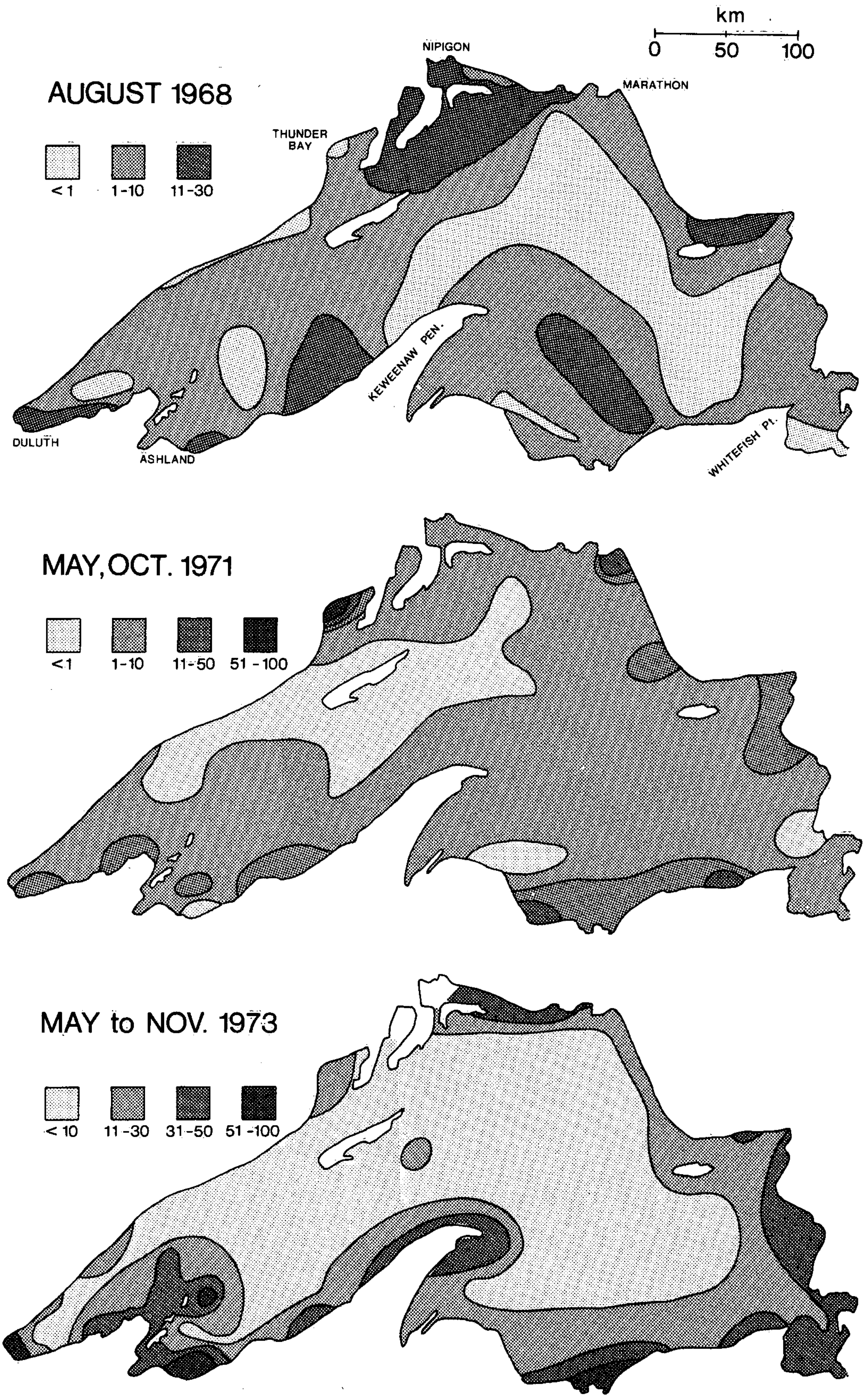

Figure 2. Distribution of total coliforms (MF) in Lake Superior #/100 ml (average values of all depths).

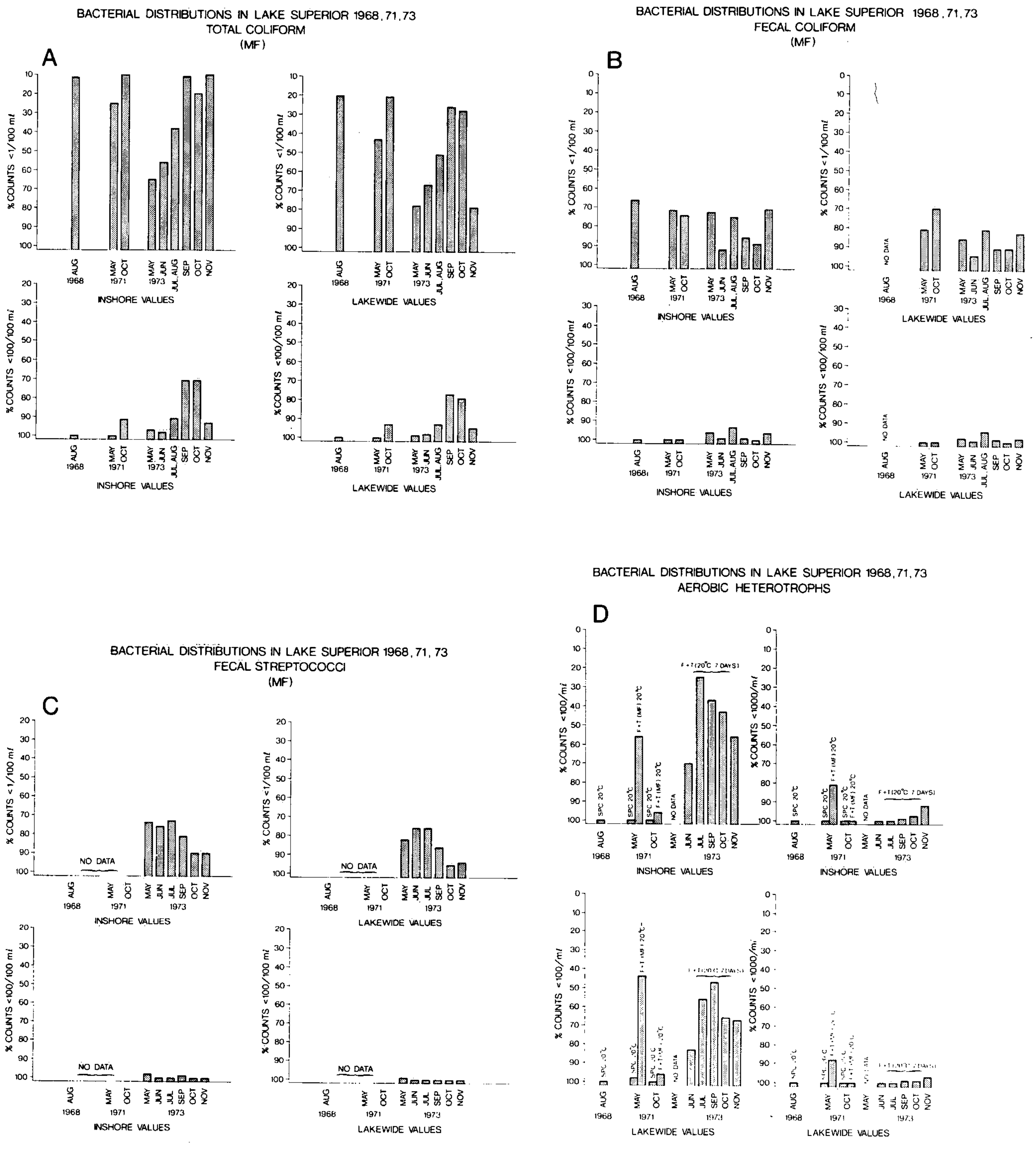

Figure 3. Trends in bacterial distribution in Lake Superior.

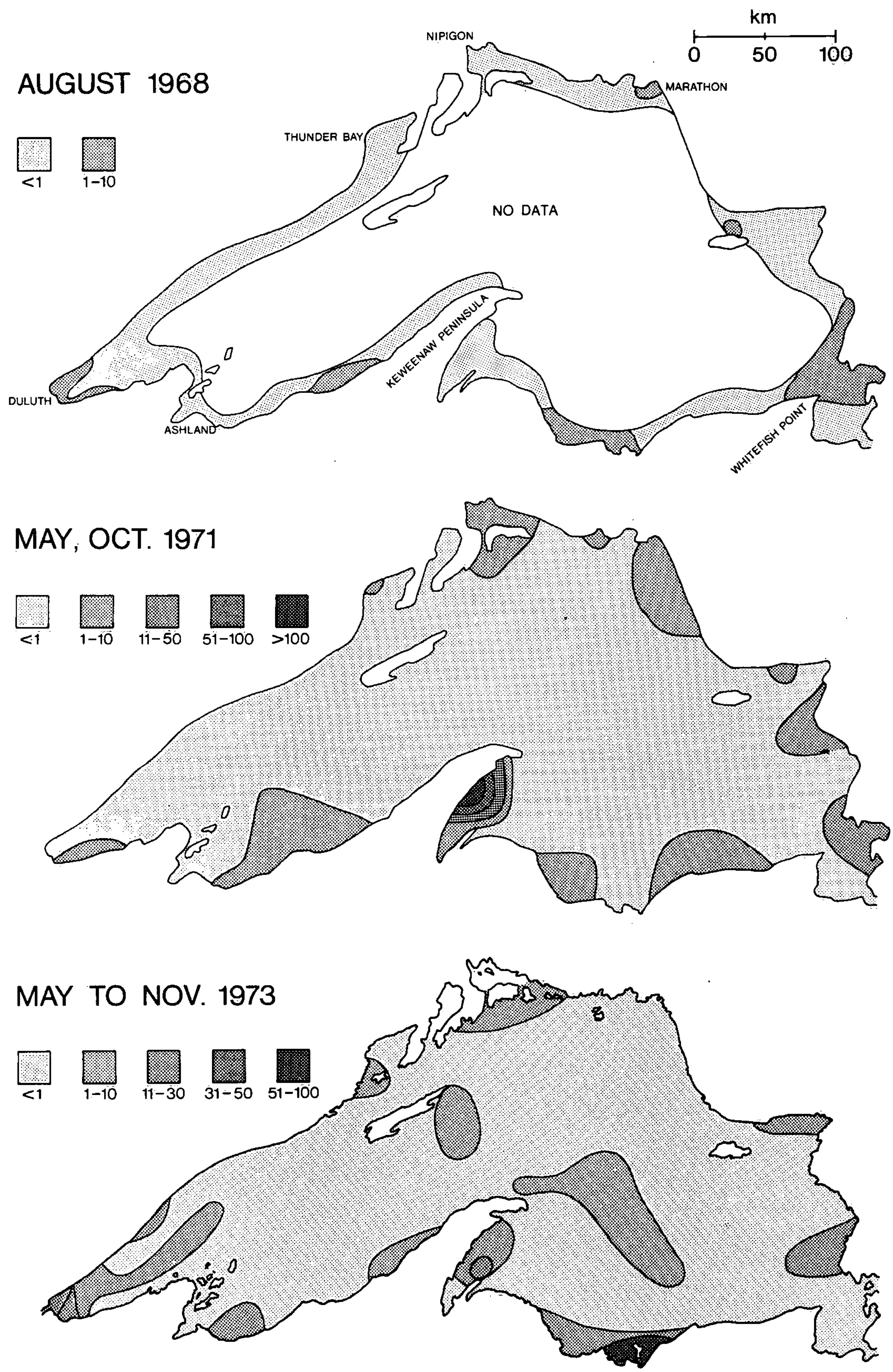

Figure 4. Distribution of fecal coliforms (MF) in Lake Superior #/100 ml (average values of all depths).

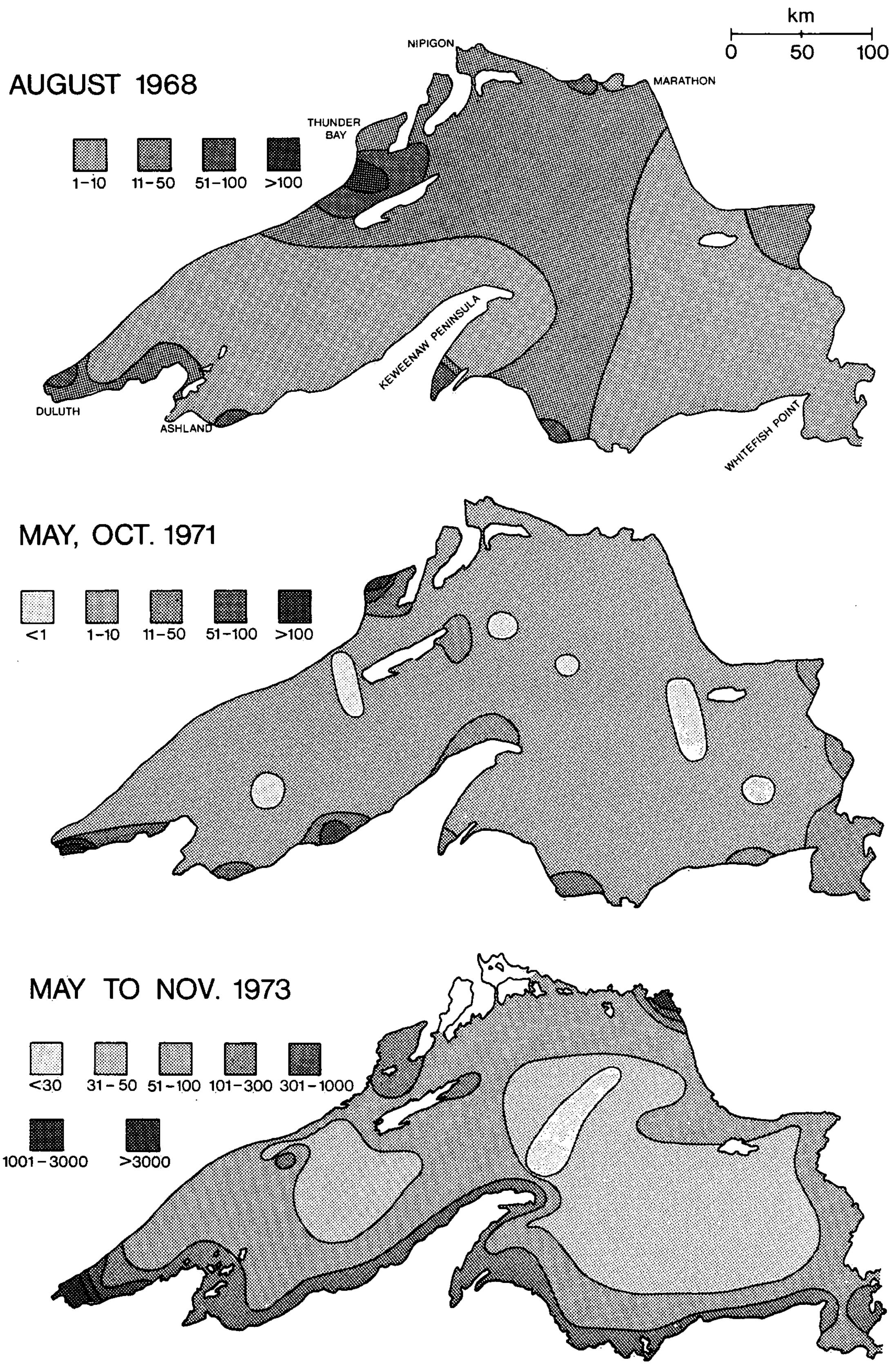

Figure 5. Distribution of aerobic heterotrophs in Lake Superior #/ml (average values of all depths).

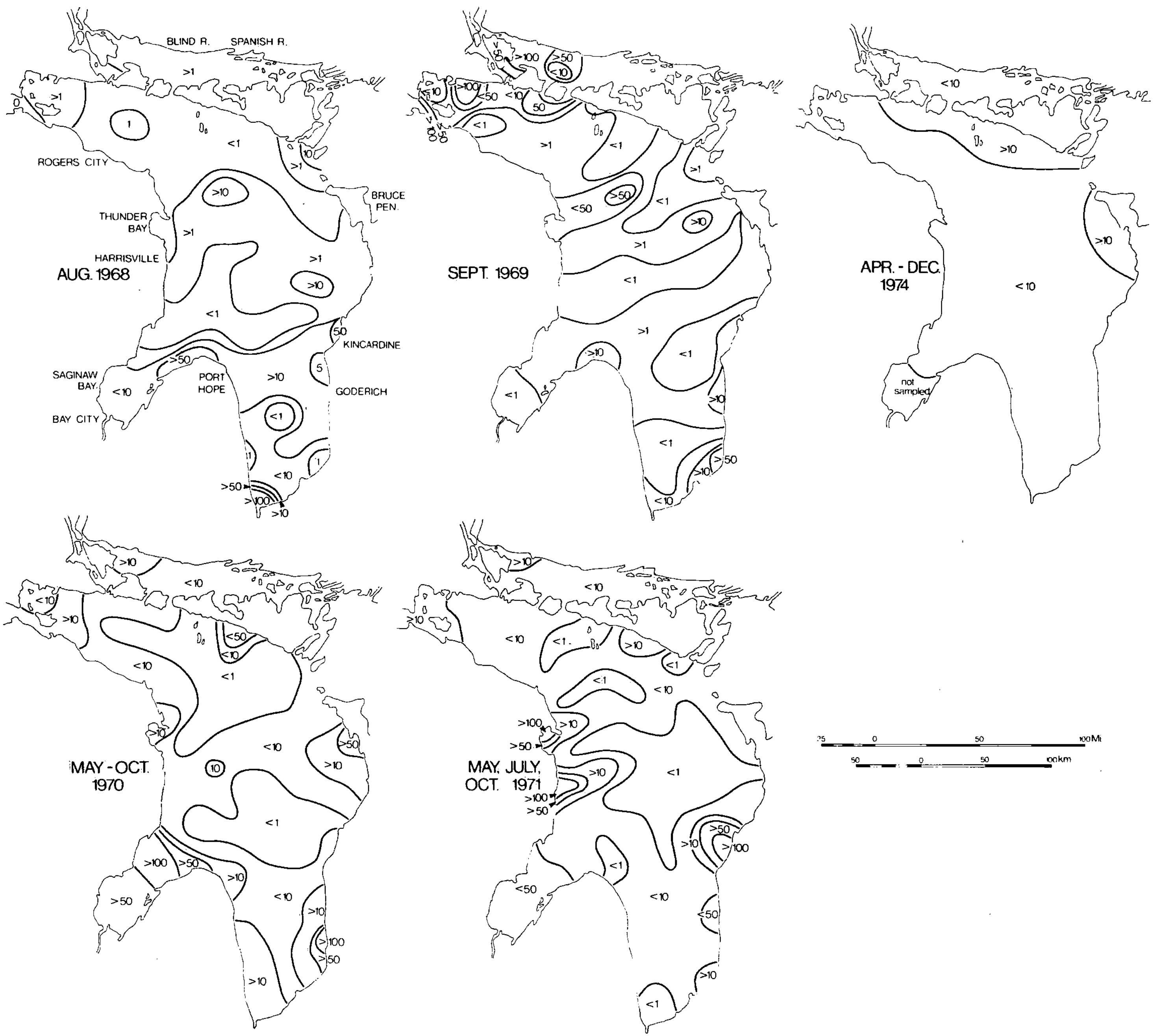

Figure 6. Distribution of total coliforms (MF) in Lake Huron #/100 ml (average values of all depths).

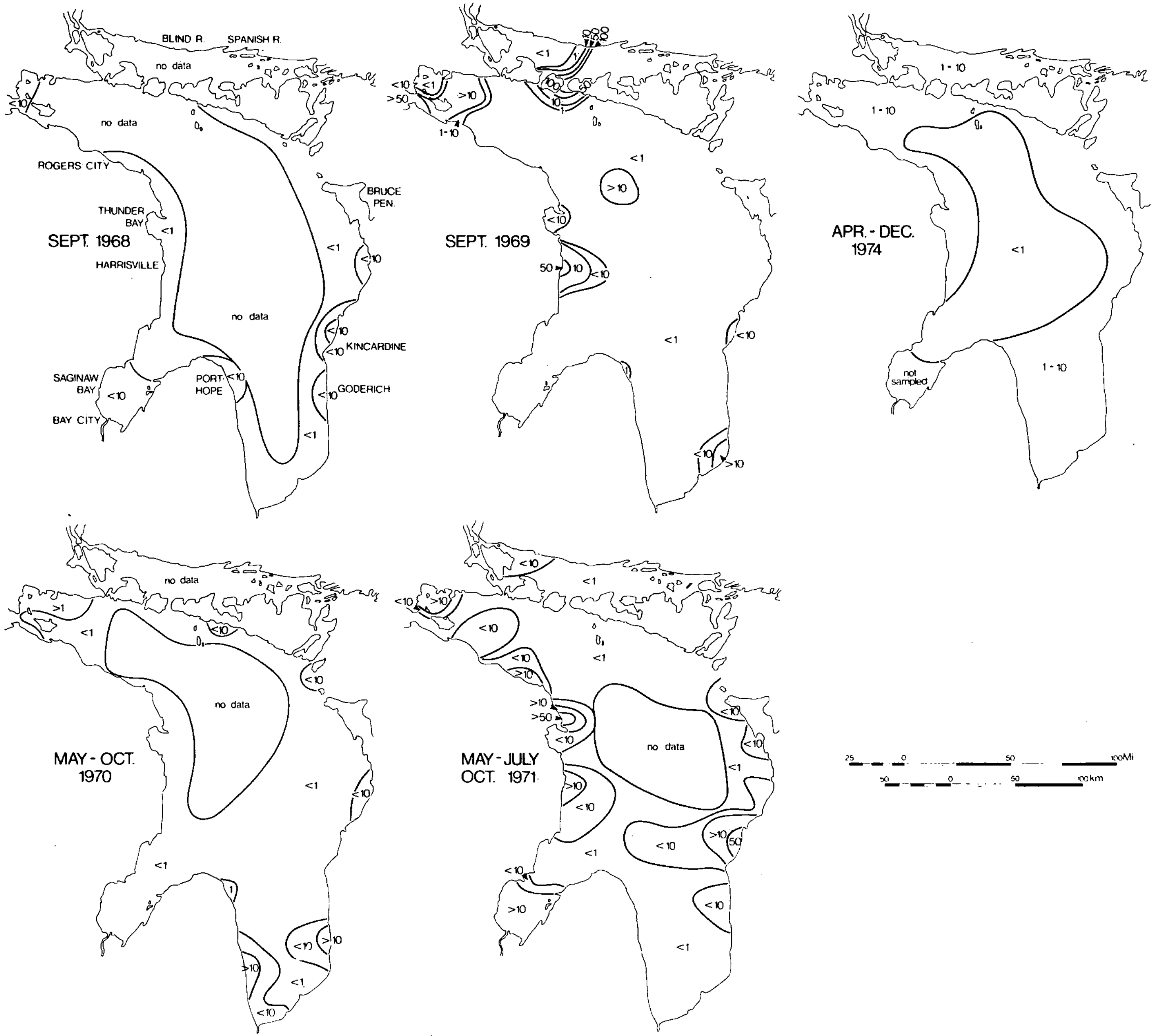

Figure 7. Distribution of fecal coliforms (MF) in Lake Huron #/100 ml (average values of all depths).

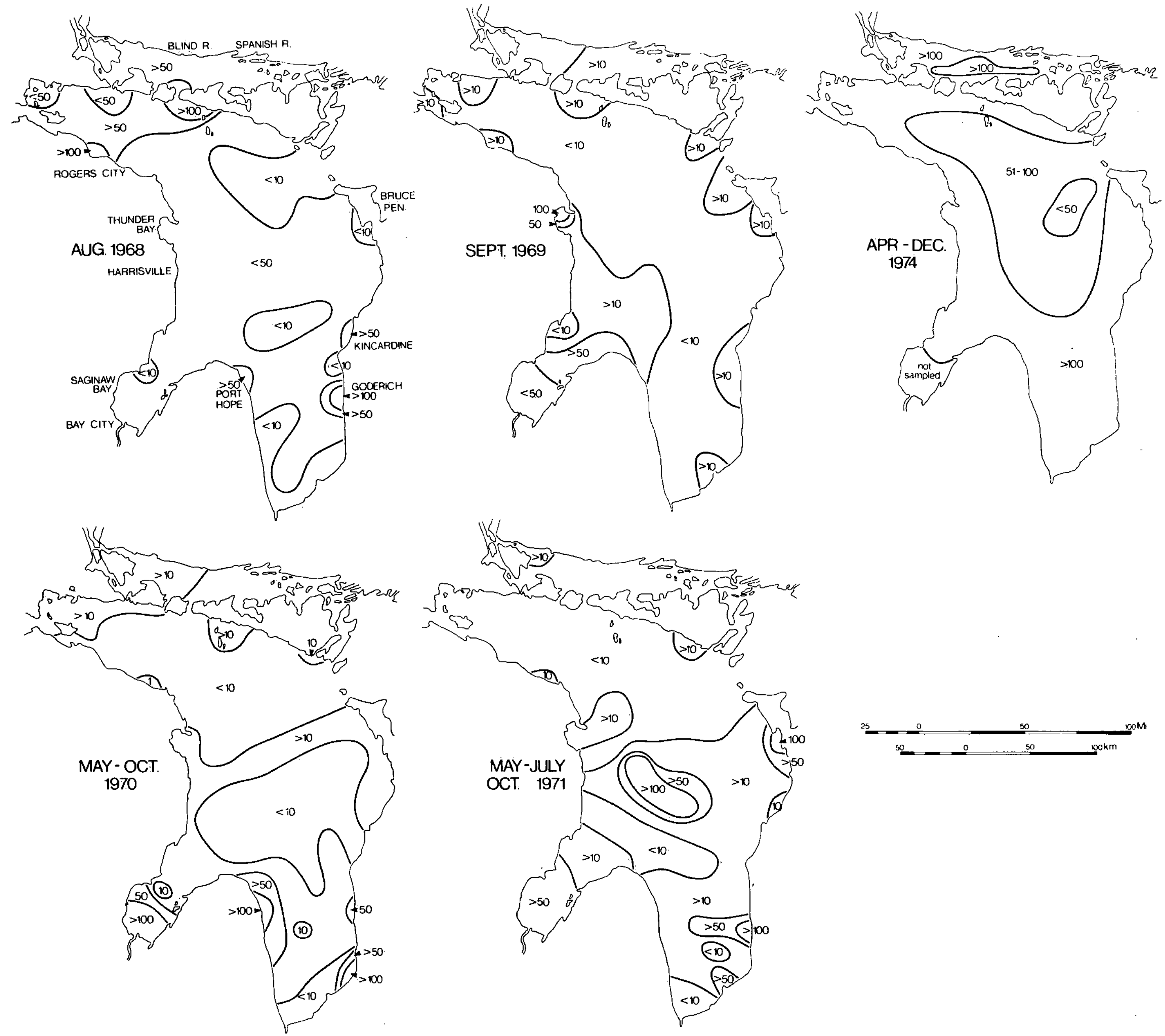

Figure 8. Distribution of aerobic heterotrophs in Lake Huron #/ml (average values of all depths).

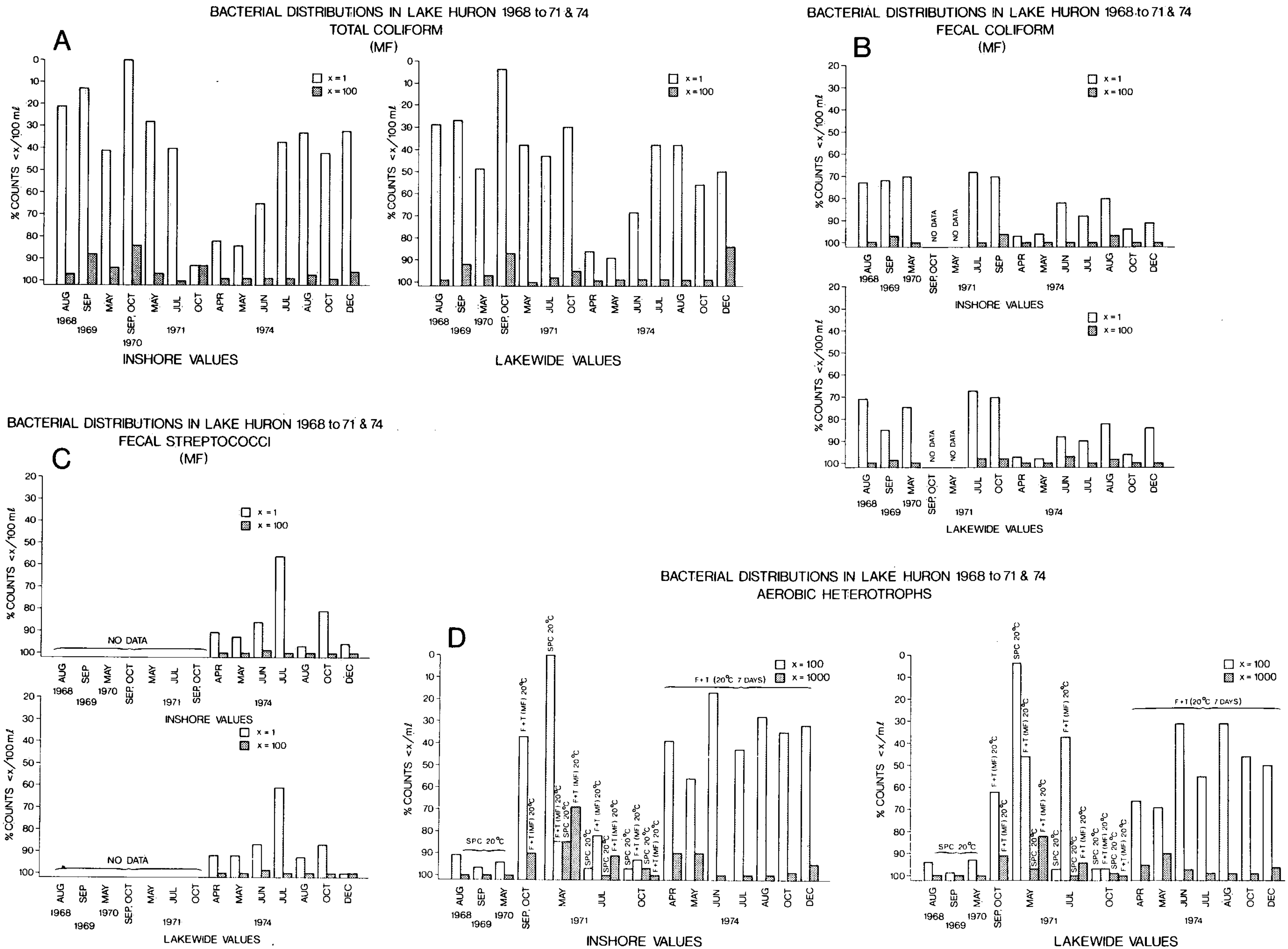

Figure 9. Trends in bacterial distributions in Lake Huron.

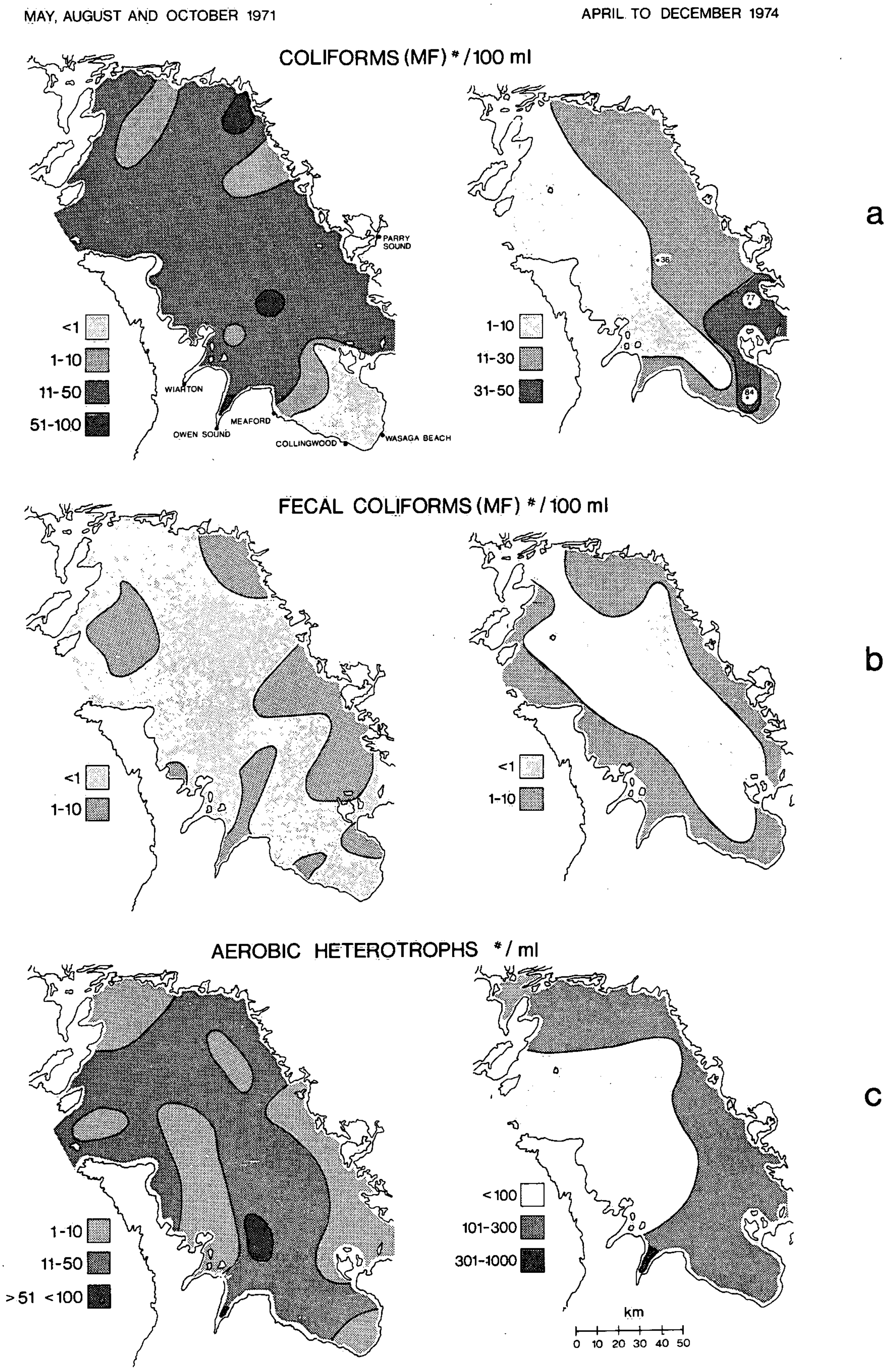

Figure 10. Distribution of bacteria in Georgian Bay, 1971 and 1974 (average values of all depths).

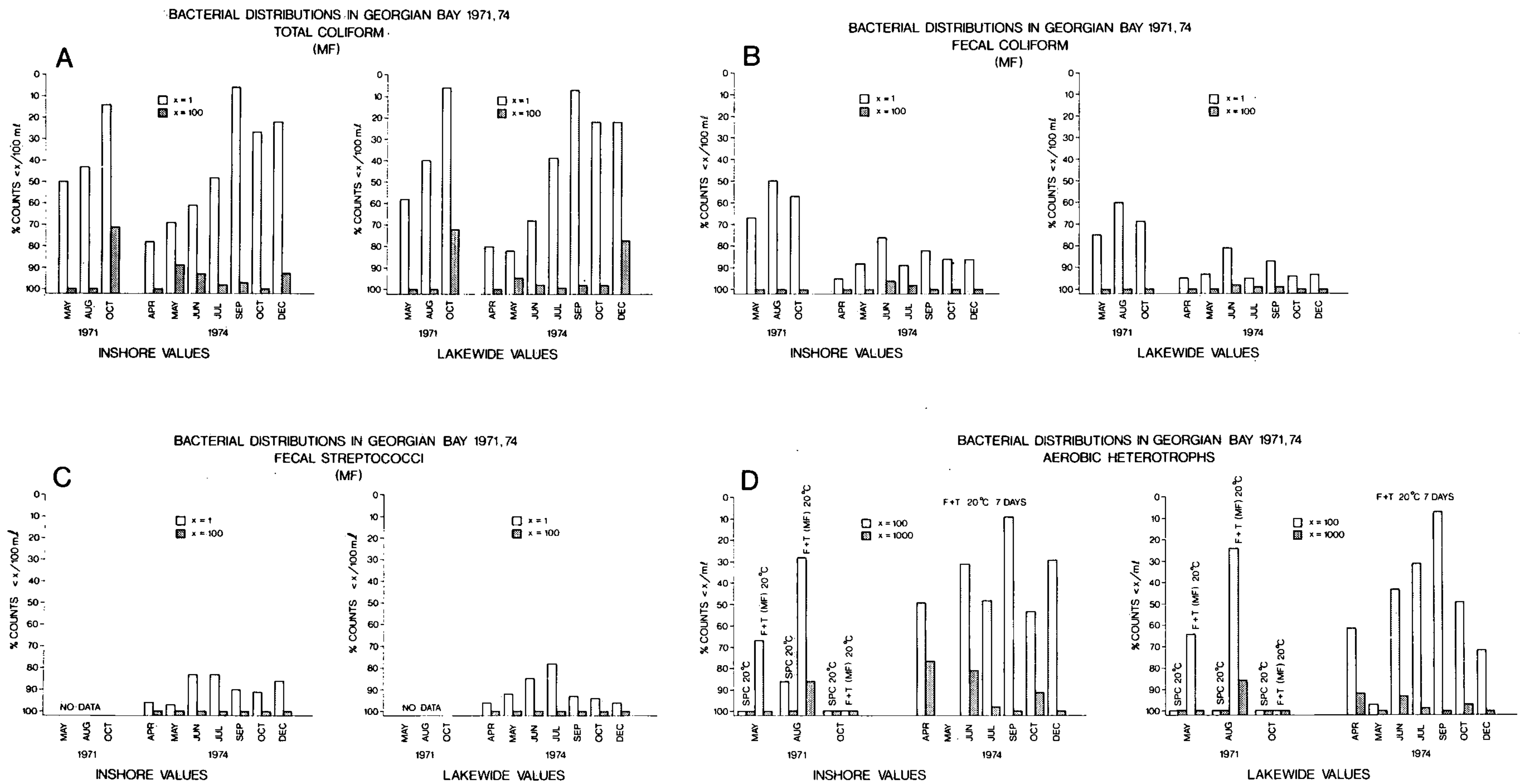

Figure 11. Trends in bacterial distributions in Georgian Bay.