Limnology and Fish Populations of Red Indian Lake, a Multi-Use Reservoir

by C.J. MORRY and L.J. COLE

FISHERIES AND MARINE SERVICE
SERVICE DES PÊCHES ET DES SCIENCES DE LA MER

TECHNICAL REPORT No. 691
RAPPORT TECHNIQUE N° 691

1977

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Fisheries and Marine Service
Research and Development Directorate

Ministère de l'Environnement
Service des Pêches et des Sciences de la mer
Direction du Recherche et Développement

TECHNICAL REPORT No. 691

RAPPORT TECHNIQUE N^{o}. 691

(Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. The series name was changed with report number 457).

(Les numéros 1-456 dans cette série furent utilisés comme Rapports Techniques de l'office des recherches sur les pêcheries du Canada. Le nom de la série fut changé avec le rapport numéro 457).

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by C.J. MORRY and L.J. COLE

This is the forty-seventh Technical Report from the Research and Development Directorate Newfoundland Biological Station St. John's, Newfoundland

Ceci est le quarante-septième Rapport Technique de la Direction du Recherche et Développement Station biologique de Terre-Neuve Saint-Jean, Terre-Neuve

1977

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ACKNOWLEDGMENTS

A number of people contributed greatly to the completion of this study. Among them and worthy of special note are: Dennis Riche, who analysed a great part of the data and produced numerous figures and tables; Andrew Jamieson, who performed all laboratory water quality analyses; William Bruce and Robert Wiseman, who contributed many ideas and suggested approaches in completing the work. George Furey and Stephen Parsons assisted in the field. Employees of the Environmental Protection Service collected and analysed core samples; Vern Pepper assisted in completing analyses of variance on the zooplankton data. Vince Taylor proved to be a valuable source of unpublished information concerning departmental involvement with the Exploits River. Dr. J.R. Pickavance of M.U.N. identified oligochaet samples. Mrs. Sylvia Kearsey is given a special note of thanks for her persistence and patience in typing the many drafts of this report.

Finally, particular thanks are due to Cal Whalen for suggesting the project and assisting in its commencement.

ABSTRACT

Morry, C.J. and L.J. Cole. 1977. Limnology and Fish Populations of Red Indian Lake, a Multi-Use Reservoir. Fish. Mar. Serv. Res. Dev. Tech. Rep. 691: 109 p.

A limnological survey, centering on fish populations, was conducted on Red Indian Lake in the summer of 1974. Physical parameters, as previously recorded, were verified and chemical parameters, including heavy metal concentrations, were observed in over 100 areas. Biological aspects of the project included benthos and plankton sampling and a rigorous gillnetting program aimed at giving a good representative sampling of fish populations throughout the lake. A 96-hour *in situ* bioassay using local brook trout and ouananiche as subjects was conducted in Buchans Brook to observe critical lethality due to tailings pond run-off. No direct bio-physical hazards could be attributed, as a result of this bio-assay nor the survey in general, to either of the two primary industrial users of Red Indian Lake. Low productivity may in part be due to unstable shoreline conditions resulting from severe fluctuations of water levels.

RÉSUMÉ

Morry, C.J. and L.J. Cole. 1977. Limnology and Fish Populations of Red Indian Lake, a Multi-Use Reservoir. Fish. Mar. Serv. Res. Dev. Tech. Rep. 691 : 109 p.

Une étude limnologique, centrée sur les populations de poissons, a été realisee dans le lac Red Indian durant l'été 1974. Des paramètres physiques releves anterieurement ont ete verifies, et des parametres chimiques, y compris les concentrations de métaux lourds, ont été observés dans plus de 100 secteurs. Les aspects biologiques du project comprenaient l'échantillonnage du benthos et du plancton et la pêche systématique du poisson au filet maillant pour obtenir un échantillonnage bien représentatif des populations lacustres. Un test biologique sur place d'une durée de 96 heures à l'aide d'ouananiches et d'ombles de fontaine locaux a été réalisé dans le ruisseau Buchans afin d'observer la létalité critique des eaux de ruissellement provenant d'un bassin de stériles. Aucun effet biophysique direct n'a pu être attribué, à la lumière de ce test ou de l'étude en général, à l'une ou l'autre des deux industries primaires qui utilisent l'eau du lac Red Indian. La faible productivité peut en partie être attribuable aux conditions instables du rivage dues à de grosse fluctuations du niveau des eaux.

INTRODUCTION

HISTORICAL BACKGROUND

Red Indian Lake, (Fig. 1) the second largest lake in Newfoundland, has been subject to man's use for thousands of years, ever since the Beothuk Indians found its shores ideal for their primary wintering grounds and thus gave the lake its name. It is only since the turn of the century that use has, from time to time, changed to abuse. At that time, Lewis Miller, a Scots lumberman opened up the heart of the island to forest harvesting operations when he commenced milling lumber and transporting it between his two self-named towns, Millertown and Lewisporte. At this recent time, however, little abuse of the Exploits waterway in general was involved, since water transport of logs (Fig. 2 and 3) only occurred on the lake itself and the finished product was shipped by rail from the shores of the lake to the seaport. Subsequently, in 1903 when H.J. Crowe and W.D. Reid purchased the Miller rights to form Newfoundland Timber Estates and later again, in 1905 when the Anglo-Newfoundland Development Company Limited was incorporated, the level of utilization of the waterway was increased. At that time log driving to the new mill at Grand Falls was commenced. Soon afterwards, in 1909, a dam was constructed at the outlet of Red Indian Lake into the Exploits River. This dam acted to regulate flows year-round to float logs down river and to generate electricity at Grand Falls. However, it also served to create annual water level fluctuations in excess of 30 ft. If one single anthropogenic factor was to be isolated as most disruptive to fish production over the years in Red Indian Lake, this would be it. This form of usage has continued over the years and is still conducted under the management of these timber rights by Price (Nfld.) Pulp and Paper Limited.

Concurrent with prosecution of this industry at Red Indian Lake, mining developments began to take shape. In 1905, copper and zinc deposits were discovered in the area of Buchans. However, the cost of shipping raw ore at that time was a deterrent and separation techniques by grinding and flotation had not yet been perfected. For these reasons it was not until 1928 that mining operations at Buchans were commenced by a subsidiary of the Anglo-Newfoundland Development Company called the Buchans Mining Company. Later these operations, and the mineral rights associated with them, were taken over by the American Smelting and Refining Company (ASARCO) in conjunction with Price (Nfld.) Limited.

It is these two industries, but primarily the latter, whose use of Red Indian Lake waters has given rise to concern during the last 15 years for the pollution they cause and their conflict with other beneficial uses including fisheries development.

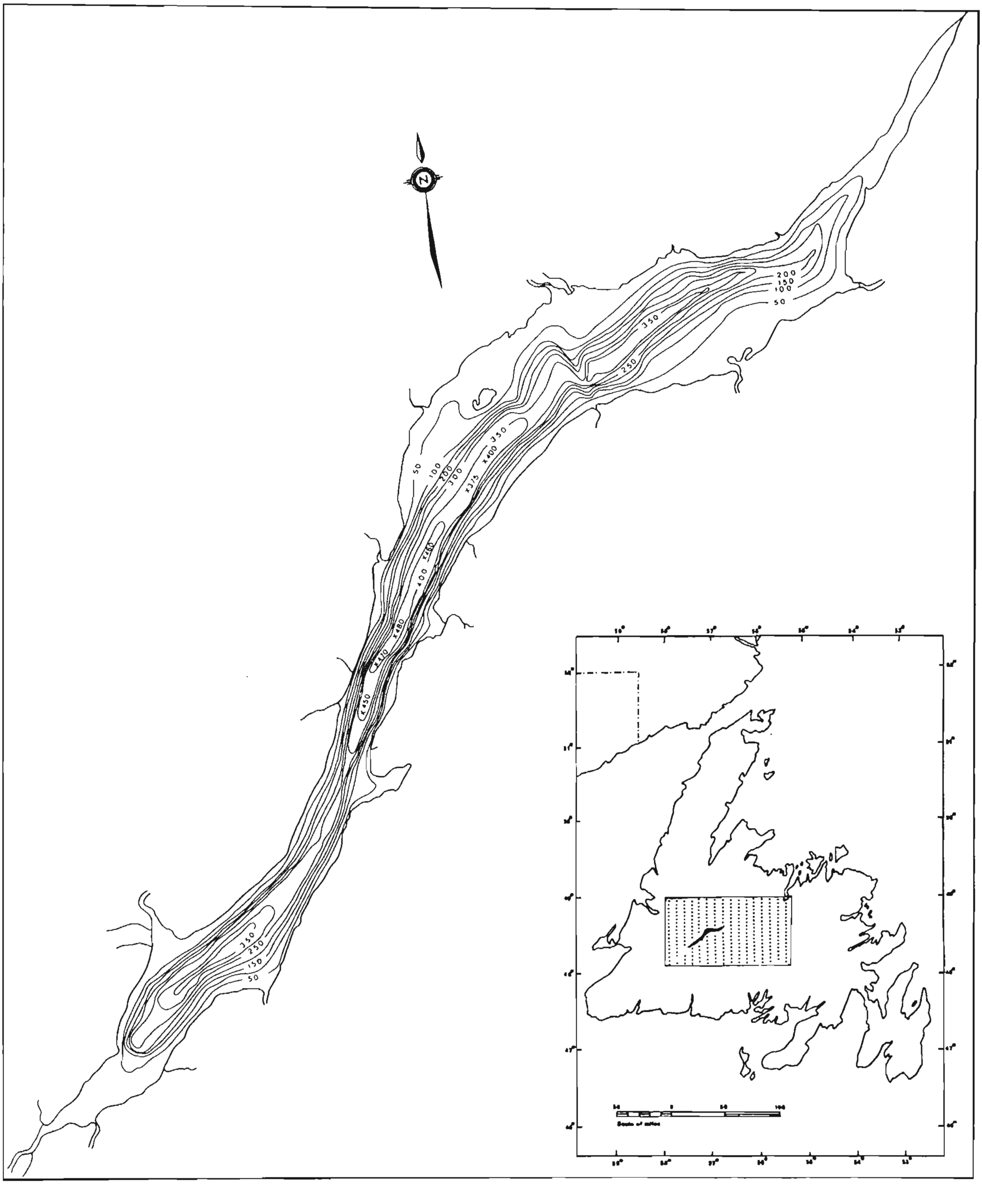

Fig. 1. Red Indian Lake bathymetry (depths in feet).

Fig. 2. Beachcombing for logs on Red Indian Lake.

Fig. 3. Log-strewn shoreline.

DEPARTMENTAL INVOLVEMENT

The Exploits River system (Fig. 4) is by far the largest watershed in insular Newfoundland, being over 236 km in axial length and 11,270 square kilometers in area. The potential of anadromous fish stocks present in this system has always been severely limited by natural obstructions to migration located at Bishop's and Grand Falls. Over the years, man-made obstructions have augmented this problem. A good example is the Exploits dam (Fig. 5) at the outlet of Red Indian Lake, which was constructed in 1909 as a reservoir control structure for the Grand Falls hydroelectric facility. This plant has an installed capacity of 43,500 h.p. with an average generating output of 207 million kwh for use in the Price (Nfld.) Pulp and Paper mill and for the town of Grand Falls. The Exploits dam also serves to retain water for log driving operations during the drier summer months. Beneficial economic effects aside, this dam effectively isolates greater than 50% of the Exploits River, from Red Indian Lake upstream. The Exploits River has an estimated potential to produce 80,000 Atlantic salmon; it follows, therefore, that unless some form of fishway is installed at the dam, this potential is reduced to only about 40,000 fish, assuming equal proportions of spawning and rearing area throughout the system.

It has long been the intention of the Fisheries and Marine Service of Environment Canada and its predecessors the Federal Department of Fisheries and Forestry and the Federal Department of Fisheries to realize this vast potential of salmon rearing capacity. Since 1961 over $1.5 million has been spent to see this dream materialize. These expenditures have resulted in the successful completion of the first two phases of the Exploits River Development project by opening to salmon migration the areas between Bishop's Falls and Grand Falls and between Grand Falls and Red Indian Lake.

At this point in time, it now becomes necessary to carefully analyze the success of the development program to date and to properly survey the real potential of its completion by rendering accessible the area above the Exploits dam. The Department has been concerned ever since 1961 that pollution of Red Indian Lake might negate the plans to encourage salmon migration through the lake and thus to spawning and nursery areas upstream. The loss of the headwaters of the Victoria River (Fig. 6) by diversion to the Bay d'Espoir Hydroelectric Development in 1969 gave extra vigor to the Department's concern. This interest has been evidenced in the large number of water quality studies which have been conducted in Red Indian Lake and the Exploits River. A summary of the results of these studies will be given later.

In order to bring together our knowledge of all aspects of the aquatic environment in Red Indian Lake, particularly as it is affected by industrial pollution, field research was conducted in the summer of 1974 and this report compares the results of that study with those conducted previously.

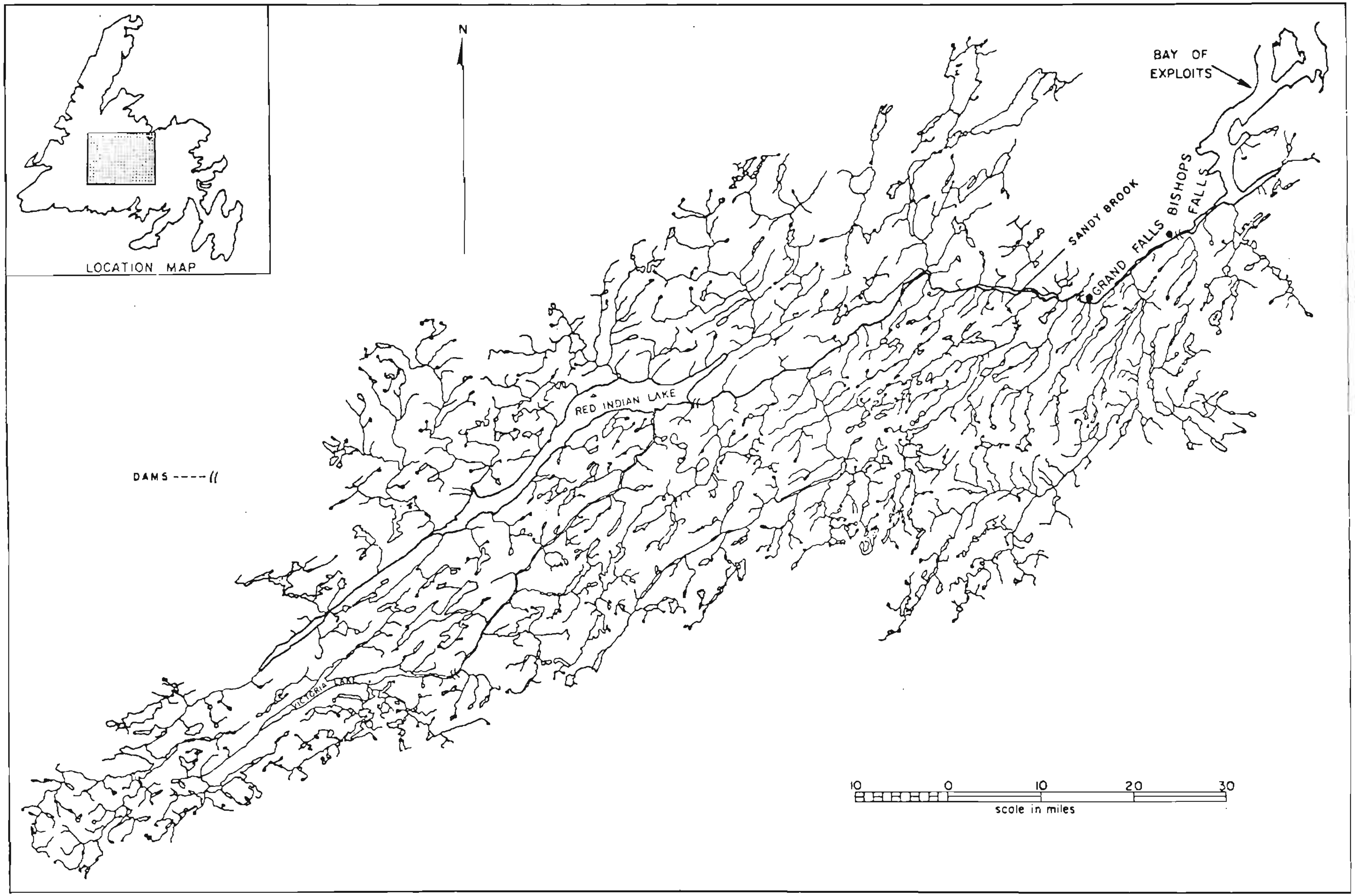

Fig. 4. Exploits River drainage area.

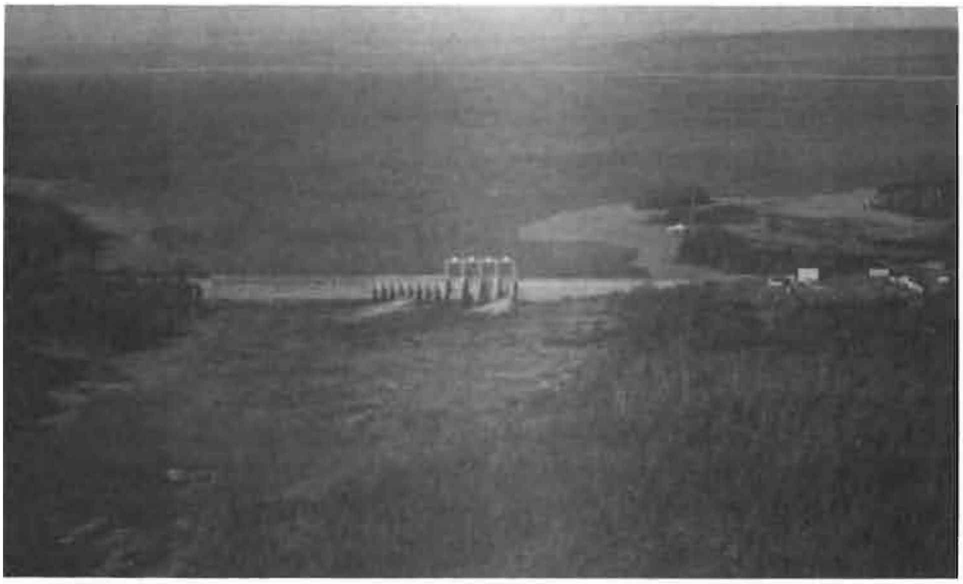

Fig. 5. Exploits Dam.

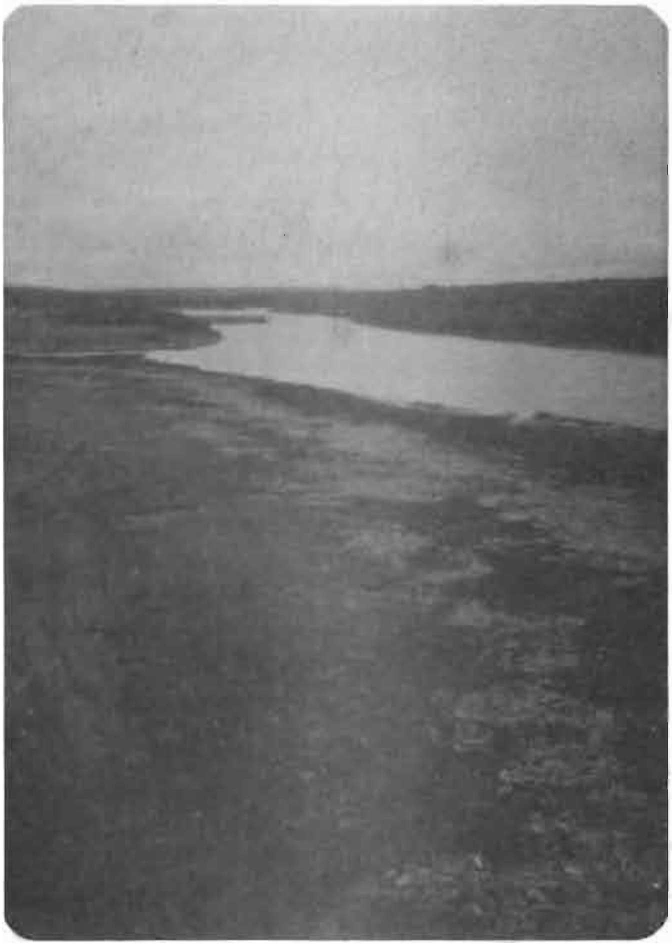

Fig. 6. Dewatered steady in Victoria River. (Note "drowned" pulp logs.)

DESCRIPTION OF STUDY AREA

Red Indian Lake constitutes the principal basin of the largest watershed in insular Newfoundland. The morphometric data for the lake are given in Table 1. Basically, the lake is a long (64.4 km), narrow (5.8 km), and deep (146.3 m) basin lying in a northeast-southwest attitude at an elevation of 152 m (see Fig. 1). Water levels can fluctuate as much as 8.8 m in a normal year and even more during a drought year. Though the shoreline is extremely regular, shoreline development is still relatively high (3.5) due to the narrowness of the lake.

Table 1. Morphometry of Red Indian Lake.

Area, including islands	18,121 (ha) 44,198 (acres)	Area, excluding islands	18,044 (ha) 44,011 (acres)
Maximum length	64.4 (km) 40.0 (mi)	Maximum effective length	36.1 (km) 22.4 (mi)
Maximum width	5.8 (km) 3.6 (mi)	Maximum effective width	5.8 (km) 3.6 (mi)
Maximum depth	146.3 (m) 480 (ft)	Mean depth	24.7 (m) 81.0 (ft)
Mean width	2.7 (km) 1.7 (mi)	Volume	4.2×10^9 (cu m) 1.5×10^{11} (cu ft)
Mean depth-maximum depth ratio	0.17	Volume development	0.51
Perimeter, including islands	163.6 (km) 101.6 (mi)	Perimeter, excluding islands	153.3 (km) 95.2 (mi)
Shore development, including islands	3.5	Shore development, excluding islands	3.2
Direction of major axis	NE-SW		

An excellent description of the geology and geography of Red Indian Lake is given by Seabrook (1962). Briefly, the lake owes its present morphology to a combination of an old geological zone of weakness and the process of glaciation. The substrate is principally Ordovician in origin, being mostly volcanic in structure with a small area of sedimentary outcropping in the northern end. There is also an area of Pennsylvanian or Mississippian sedimentary outcrop in the southern end. Buchans Brook itself is firmly embedded in Ordovician volcanics. Most other brooks on the West shore and those on the East run through granitic formations. It is this hard rock geology which gives the lake, like most in Newfoundland, its characteristic water quality with low total dissolved solids and conductivity.

The shoreline is well wooded back to about a mile from the lake at which point the land flattens out and barrens and bogs begin to predominate. This gives the drainage water a slight acidity which is, however, somewhat buffered during the retention period in Red Indian Lake. Forests are characterized by spruce and fir with some zones of hardwood, primarily birch. Along the shores of the Lloyds River there are still seen some massive old white pine. Once again, a more complete description of regional geography is available in Seabrook (1962).

Red Indian Lake covers an area of 18,121 ha including several islands, the only notable one of which is Buchans Island, about 70 ha in area. There are over 30 incurrent streams though the majority of these are intermittent or of little consequence in terms of their contribution to the drainage. The six major streams are Mary March Brook, Buchans Brook, Shanadithit Brook, Star Brook, Lloyds River and Victoria River. The latter can no longer be considered a major source of input since the majority of its 870 square kilometers of drainage area have been diverted to feed the hydroelectric turbines at Bay d'Espoir. This has reduced the total drainage area of Red Indian Lake to less than 4,800 km^2 from its former 5,700 km^2. The outlet from Red Indian Lake is via the Exploits River at the Exploits Dam, about 5 miles southwest of Millertown.

There are two towns located in the vicinity of the lake. Millertown (Fig. 7) with a population of 316, is located on the northeast shore of the lake near Mary March Brook. The town of Buchans has an incorporated population of 1907 (Statistics Canada, 1971 census) and is situated on Buchans Brook about 3 miles from the lake. Both these towns contribute sewage to Red Indian Lake but considering the small populations involved the polluting effect is deemed to be negligible. The population of the small community of Buchans Junction, located at the mouth of Mary March Brook, is considered a part of Millertown for census purposes and is therefore included above.

Fig. 7. Millertown.

METHODS AND MATERIALS

MORPHOMETRY

A bathymetric map prepared by Seabrook for his 1961 report but never completed at that time was augmented by sounding line measurements in deficient areas (Fig. 1). From this and from Department of Energy Mines and Resources 1:50,000 and 1:250,000 topographic series maps, the morphometric parameters for Red Indian Lake and its drainage area were calculated following the methods described by Welch (1948). These data will be listed and discussed further under the heading of "Results and Discussion".

PHYSICAL AND CHEMICAL STUDIES

Several series of physical and chemical surveys were conducted during the summer of 1974.

On June 19 water samples were collected in each of the 16 major in-current streams to be analysed by chemical and electrometric methods later in the laboratory. These samples were analysed for pH, total hardness, specific conductance, turbidity, total alkalinity and chloride as part of a general water quality survey of the Island of Newfoundland.

Throughout the summer a sampling program at a total of 109 systematically distributed locations included analysis of bottom type by 9 inches x 9 inches Ekman and Ponar dredges, determination of temperature profiles by use of a Y.S.I. telethermometer and collection of water samples in the epilimnion and hypolimnion for *in situ* (Fig. 8) and laboratory analysis. Samples were analysed *in situ* for oxygen concentration, pH, carbon dioxide and hardness and in the laboratory for pH, total hardness, specific conductance, turbidity, total alkalinity, calcium, chloride and bicarbonate. The overlap in parameters tested for served to verify the accuracy of the techniques employed. In the field, chemical parameters were measured by standard Hach Kit techniques.

On August 21 and 22, a total of 51 systematically selected sites were surface-sampled for dissolved heavy metals analysis. Only copper and zinc determinations were conducted because previous surveys had shown lead to be present in insignificant amounts.

Fig. 8. Water and plankton sampling.

Bottom cores were obtained by Environmental Protection Service personnel assisted by the Fisheries and Marine Service field team. A variety of corers (Fig. 9) and techniques were employed. A total of 41 cores were taken with the majority being from the outwash fan of Buchans Brook. These cores were all analysed at 10 mm intervals for copper, lead and zinc.

Fig. 9. Bottom core sampling.

A bioassay experiment was conducted on August 26-30 in Buchans Brook with a control site located about 15 miles south on Red Indian Lake. During the course of the test, 14 samples were collected at each site for analysis of heavy metals (copper and zinc) and five samples at each site for the standard run of parameters described above.

BIOLOGICAL STUDIES

The same 109 sampling sites were used for the background biological study program. At each of these, a zooplankton sample was taken (Fig. 8) using a standard oceanographic-style plankton net, 34 inches in length, with a mouth area of 114.5 square inches (diameter 12 inches) and composed of number 20 bolting silk (173 meshes per inch). A glass bottle was attached to the codend to trap the plankton and samples were preserved with 10% formalin. All plankton tows were vertical and taken from bottom to surface. These samples were returned to the laboratory and later analysed for species composition by use of compound and dissecting microscopes. In cases where more than 200 zooplankters were present, subsampling by means of a Hensen-Stempel pipet was first conducted to obtain a statistically valid subsample which would require less time-consuming analysis.

Benthic samples were taken at all the 109 sites by Ekman (Fig. 10) or Ponar dredge. However, at most sites no invertebrates were observed to be present. When macroscopic invertebrates were discovered by seiving the sample, these were retained for later identification.

Fig. 10. Benthic sampling using Ekman dredge.

The main thrust of the project was in the area of fish populations. In order to collect data on species and population dynamics, an experimental fleet of gill nets was set at 19 different locations over a 24-hour period. This fleet consisted of 1 fathom deep, 150 foot lengths of 1½ inch, 2 inch, 3 inch, 4 inch and 5 inch mesh sinking nets. This same format was used in all cases but one; in that instance the fleet had to be used without the 4 inch mesh net which was in need of repairs.

Small numbers of ouananiche and brook trout were also collected by electrofishing for use in live-cage bioassays.

In this simple experiment, six brook trout and four ouananiche of varying sizes were placed in a holding cage (Fig. 11) in Buchans Brook approximately 2 miles downstream from the tailings outfall. A control group matched for species, size, and sex as closely as possible, was placed in another holding cage in Red Indian Lake about 15 miles south of Buchans Brook. These fish were observed for behavioral changes and mortality over a period of 96 hours.

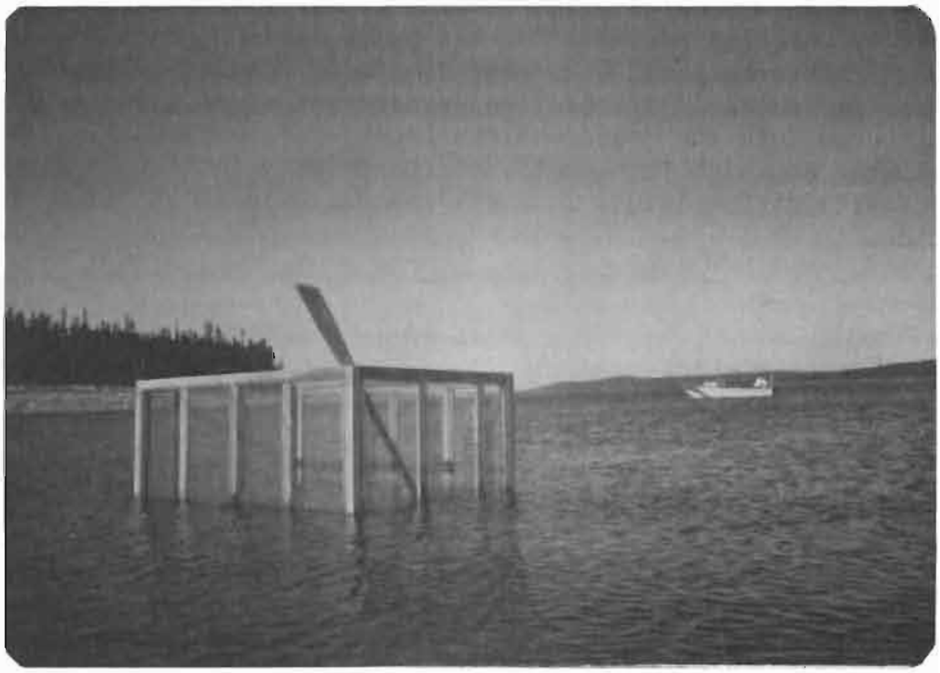

Fig. 11. Bioassay holding cage.

All gillnetted fish plus any fish sacrificed in bioassay work were systematically sampled in the following manner. Each fish was weighed to the nearest gram and measured to the nearest centimeter (fork length).

Sexual condition was recorded and a brief *in situ* analysis of stomach contents conducted. Scales were collected and retained for later age determination (using Bausch and Lomb microprojectors).

RESULTS AND DISCUSSION

PHYSICAL AND CHEMICAL ENVIRONMENT

Morphometry

Fig. 1 is a bathymetric map of Red Indian Lake. This map was produced from prior incomplete data and new soundings done in 1974. The maximum depth (146.3 m) seen here and also on the table of morphometric data (Table 1) was determined in this study, however, it is suspected that depths in excess of 150 m do occur.

The mean depth of about 25 m is moderated by the large areas of flood plain at both the northeast and southwest extremities of the lake. These flooded areas were created at the mouths of Mary March Brook and Lloyds River respectively when the Exploits Dam was built in 1909, raising the water level of the lake by about 8 m. The simple or regular shape of Red Indian Lake, reflected in a shoreline development of only 3.5 and the generally rapid drop into the deeper waters (volume development 0.51) coupled with the low T.D.S. and high mean depth are the primary factors leading to the low productivity of the lake. This will be discussed more fully under the next heading.

Physiochemical characteristics

Geochemistry

The series of cores were collected for heavy metals analysis of sediments in 1974. A broad spectrum series identified by letter A-J on Fig. 12 was collected to get some idea of background levels of zinc, copper and lead in the lake and also to determine how far and to what extent transport of heavy metals had occurred through seiche action and turbulent transport. The results (see Appendix 1) were quite interesting and in some cases rather astounding. For instance, although the majority of samples indicated concentrations of heavy metals which are not beyond recognized background levels from other large relatively non-industrialized lakes (eg. Lake Superior, see Table 2), some samples, especially H and I did exhibit unusually high concentrations. This is in fact very unexpected since these sites are at the extreme south end of the lake 20 miles or more from the only known source of heavy metals input, Buchans Brook. Because it is highly unlikely that concentrations in the range of 3000 ppm zinc and 1500 ppm copper occur naturally from sediment loading out of other brooks, it must be assumed that

Fig. 12. Sampling sites for sediment cores - I.

Table 2. Comparative heavy metal concentrations (ppm) in sediments.

	1969			(Hutchinson, 1974)		1974			
	Lloyds Lake	Star Lake	Victoria Lake	Lake Superior		Red Indian Lake			
						Numbered Series		Lettered Series	
				High	Low	High	Low	High	Low
Copper	34	22	47	277.5	0.5	5,460	<10*	850	10
Zinc	146	138	120	212.5	2.5	39,680	10	4,050	40
Lead	55	100	68	60.5	T	5,200	<10*	1,290	10

* 10 ppm is the lowest detectable concentration by technique employed.

turbulent transport from Buchans Brook is the mechanism of dispersal.

However, though these levels appear radical at first, in fact they do not necessarily indicate any potential for toxicity. To be injurious to living organisms the ions must first be dissolved and dispersed. Judging by water quality analyses for these parts of the lake, harmful concentrations are seldom leached from the sediment. This matter will be discussed further along with the topic of water quality and also benthic organisms.

The second series of cores was taken in a concentrated area close to the mouth of Buchans Brook (Fig. 13). This area is readily recognized visually by the reddish-brown "fan" of tailings fines washed out of the brook (Fig. 14 and 15). Sediments in the area are characteristically sandy or granular and either noticeably red or grey in colour, the grey matter being generally higher in metals concentrations. The results of these analyses, also found in Appendix 1, are as expected. Critically high levels of metals were found in all surface sediments. Depth of tailings - associated sediment decreased with increased distance from the brook. Some more distant samples (eg. 20-24) show negligible concentrations below 35 mm. This is to be expected since the majority of the metal bearing matter settles soon after entering the lake. This trend is magnified in the analysis of the first series of cores taken throughout the lake, in which background levels of metals were found below 25 mm in almost all cases.

There is no doubt that concentrations in the order of almost 40,000 ppm zinc constitute a constant source of return of metal ions to the water column. It is impossible to predict how long such a reserve would continue to contribute ions if milling operations were to cease. It is also rather disturbing to observe that no apparent reduction of concentrations in surface sediments has resulted over time with the introduction of more sophisticated pollution control measures at Buchans.

Water quality

Water level fluctuations

One of the most critical factors limiting the fish production of Red Indian Lake is the extreme fluctuation of water levels. Appendix VI records the daily water levels in feet above sea level at Exploits Dam. The low for the year was 480.90 and the high 504.00, a difference of 23.1 feet (7.6 m). (See Fig. 16 and 17). A range of 30 feet (9 m) is not abnormal and in a drought year this certainly would be exceeded.

Because of the particular morphometry of Red Indian Lake, such changes are radical for two reasons. Firstly, the majority of the lake is deep and unproductive with only a narrow band of productive littoral zone. If this is rendered unstable, the habitat of the greater part of the lake's benthic community and young fish fry is destroyed. Furthermore, any potential shoreline spawning of salmonids is precluded. Secondly, the large areas of shallows created by impoundment, which might otherwise have been considered

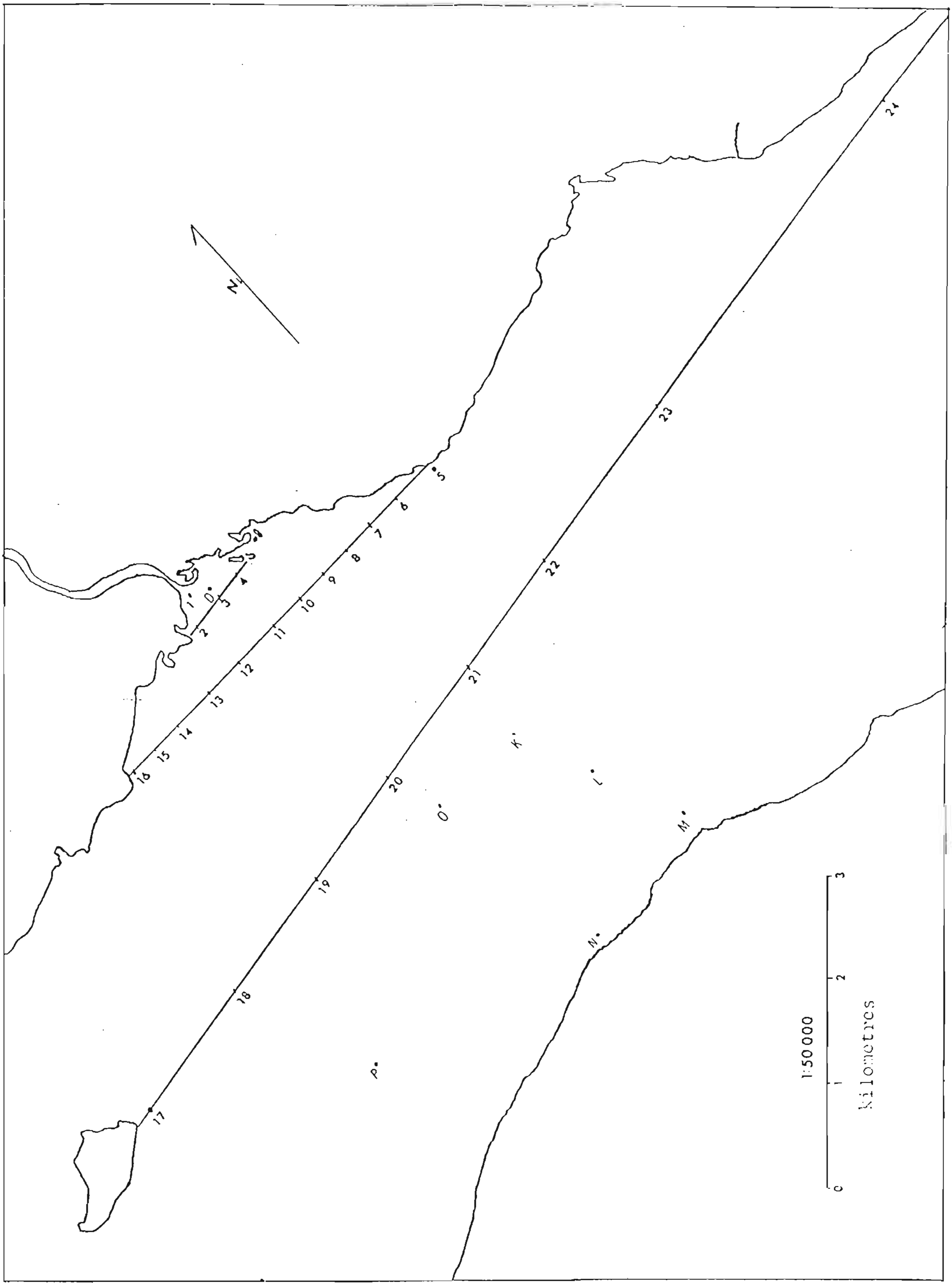

Fig. 13. Sampling sites for sediment cores - II.

Fig. 14. Mouth of Buchans Brook.

Fig. 15. Tailings "fan" in Red Indian Lake.

Fig. 16. High-water conditions, June 1974.

Fig. 17. Low-water conditions, August 1974.

a benefit of such impoundment, also become unstable habitat and their potential for fish production is lost. Though it would be a difficult variable to quantify, it only requires logic to see that water level fluctuations of this magnitude assist in deteriorating the already low trophic state indicated by the Morphoedaphic Index (to be discussed below).

The principal cause of such fluctuations is, of course, the retention and release of water at Price (Nfld.) Ltd.'s Exploits Dam. This serves a dual purpose: to float pulp logs to Grand Falls for milling, and to ensure an adequate water supply for hydro generation to run the mill at Grand Falls. An additional complication, however, exists in the diversion of the headwaters of Victoria River to the Bay d'Espoir hydro development. Low-spill or no-spill conditions are the general rule in Victoria River now (Fig. 18). Apart from the virtual destruction of 35 miles of productive river habitat this has also reduced flows to the Exploits River. In 1969, the first year of diversion, flows at Grand Falls fell below 5,000 c.f.s. for significant periods for the first time. To ensure sufficient flow to generate electricity there and, more importantly, to dilute effluent from the pulp mill below toxic levels, it now becomes necessary to draw off more and more of Red Indian Lake's reserves during dry periods. As a result, fluctuations in lake level are more severe than previously.

Fig. 18. Low-spill conditions on Victoria River.

Temperature profiles

Temperature readings were taken at all depths by bathythermograph at each sampling point during the main survey. These results are found in Appendix II.

The observed temperature profiles hold no surprises. As with any deep oligotrophic lake, isothermic conditions are the rule following ice-out, in this case being mid-June. This condition persists, while overall temperatures generally increase, due to wind generated mixing, until early July (Fig. 19), when a clinal change with increased temperatures near the surface begins to be observed. By July 17, a fairly clear epilimmion and hypolimmion has been established with a very deep thermocline at about 70 ft (20 m). For the rest of July and early August (Fig. 20) this trend continues with the thermocline gradually rising to about 50 ft (15 m) and minimum temperatures stabilizing at about 5 C. From this point onward the trend commences to reverse itself with the final autumnal overturn predicted to be in late September.

One would not expect to see any evidence of industrial thermal pollution in Red Indian Lake because of the relatively long retention time of the present tailings settling ponds. By our estimates, this settling system should allow 40 days settling at its inception and no less than 13 when the life expectancy of present ore reserves is completed.

In fact, surface temperatures never exceeded 17 C during the summer and this in itself, coupled with the relatively narrow photic zone of 30 ft (determined as 2X Secchi disc visibility) serves to limit primary and subsequent productivity.

Water chemistry

As was mentioned previously, three separate water chemistry sampling programs were conducted at Red Indian Lake in 1974, not including those done in conjunction with the bioassay experiment in Buchans Brook. Collection sites for the principal water quality study are illustrated in Fig. 21 and the results of these analyses are found in Appendices IV and V. The transect lines along which these samples were taken are numbered consecutively from 1 to 39, starting at the Millertown end of the lake, to help cross-reference these results with those for heavy metals. The heavy metals sampling sites are illustrated in Fig. 22 as are those of the stream surveys and also the gillnetting locations. Heavy metals results are tabulated in Appendix III while those of the stream survey are in Table 3.

There is an old "bromide" which states: "the solution to pollution is dilution". This of course is a shortsighted philosophy which has had disastrous results on the environment. Nevertheless, there is a grain of reason in these words to the extent that a very large "dynamic" body of water is capable of neutralizing substantial quantities of organic and, to some extent, inorganic pollutants. Red Indian Lake is a good case in point.

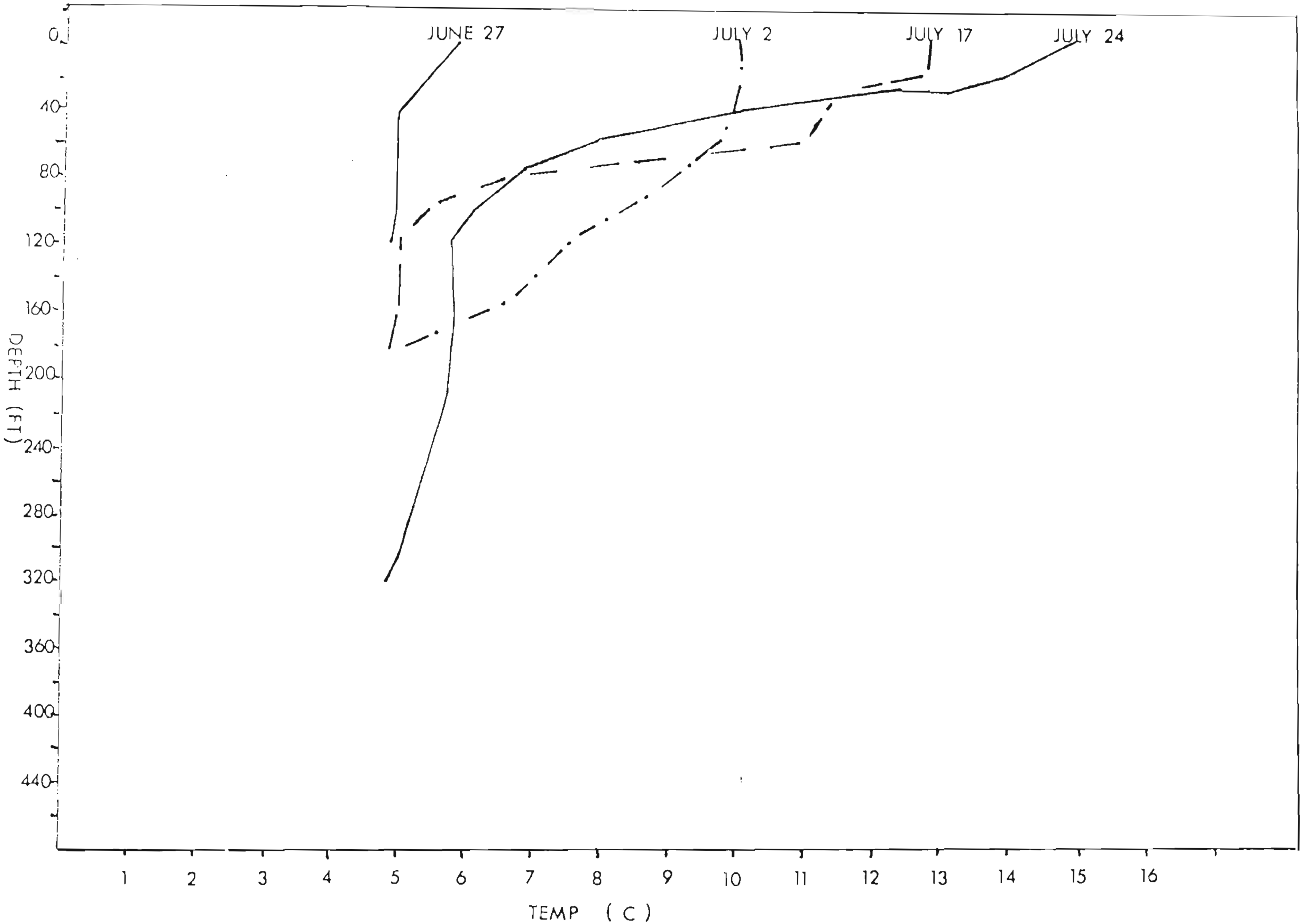

Fig. 19. Thermal stratification in Red Indian Lake, June-July 1974.

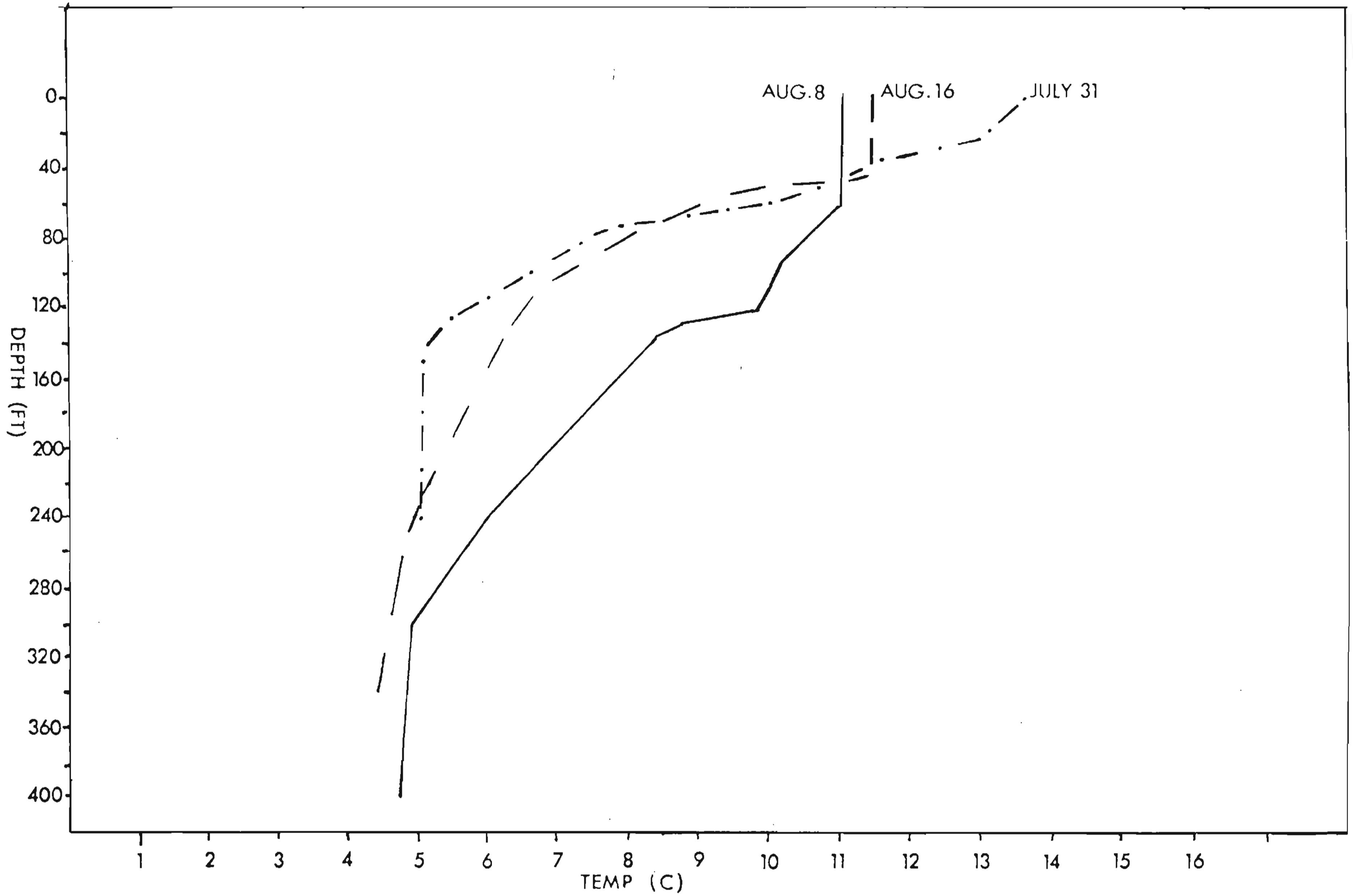

Fig. 20. Thermal stratification in Red Indian Lake, July-August 1974.

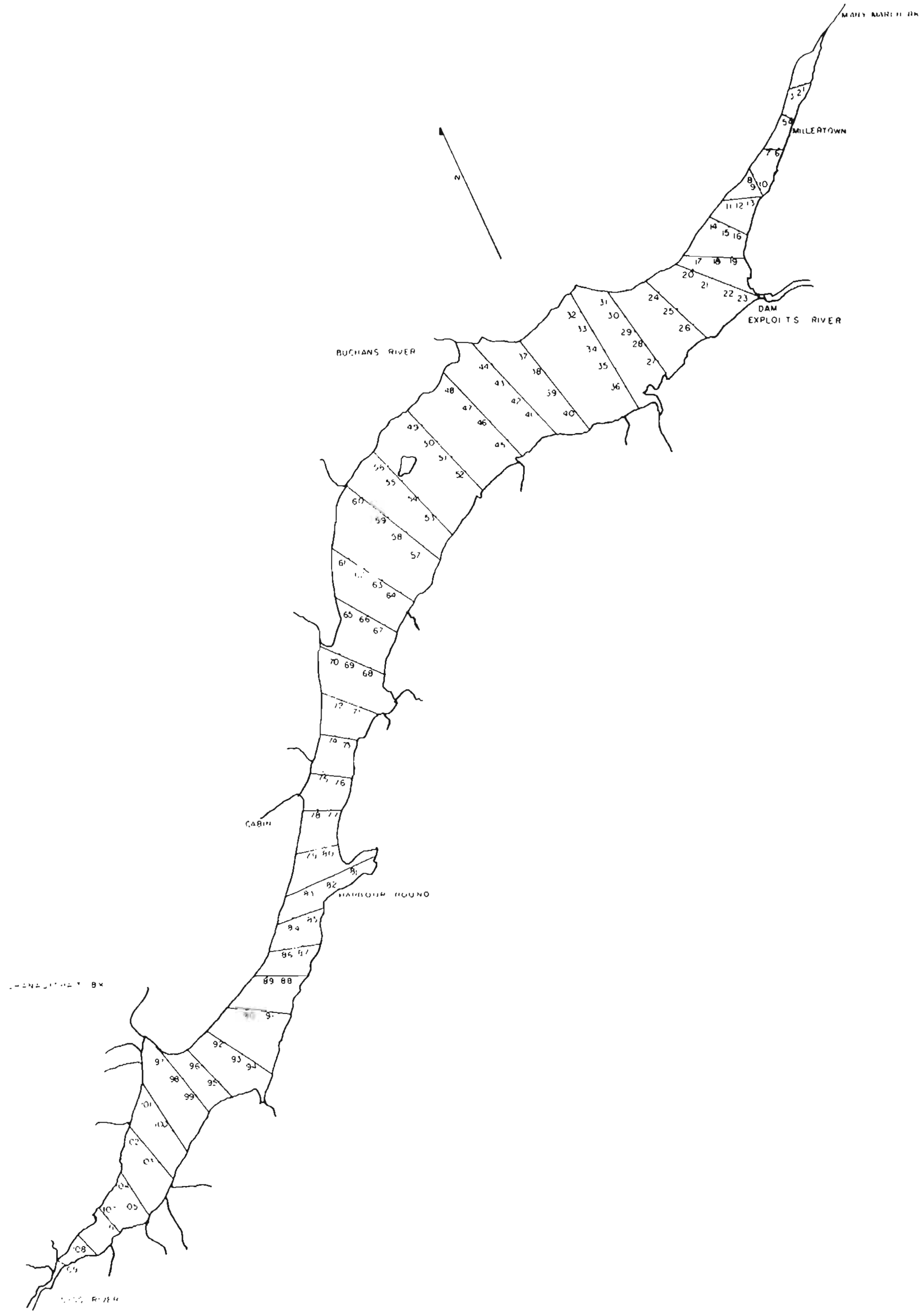

Fig. 21. General water quality sampling sites.

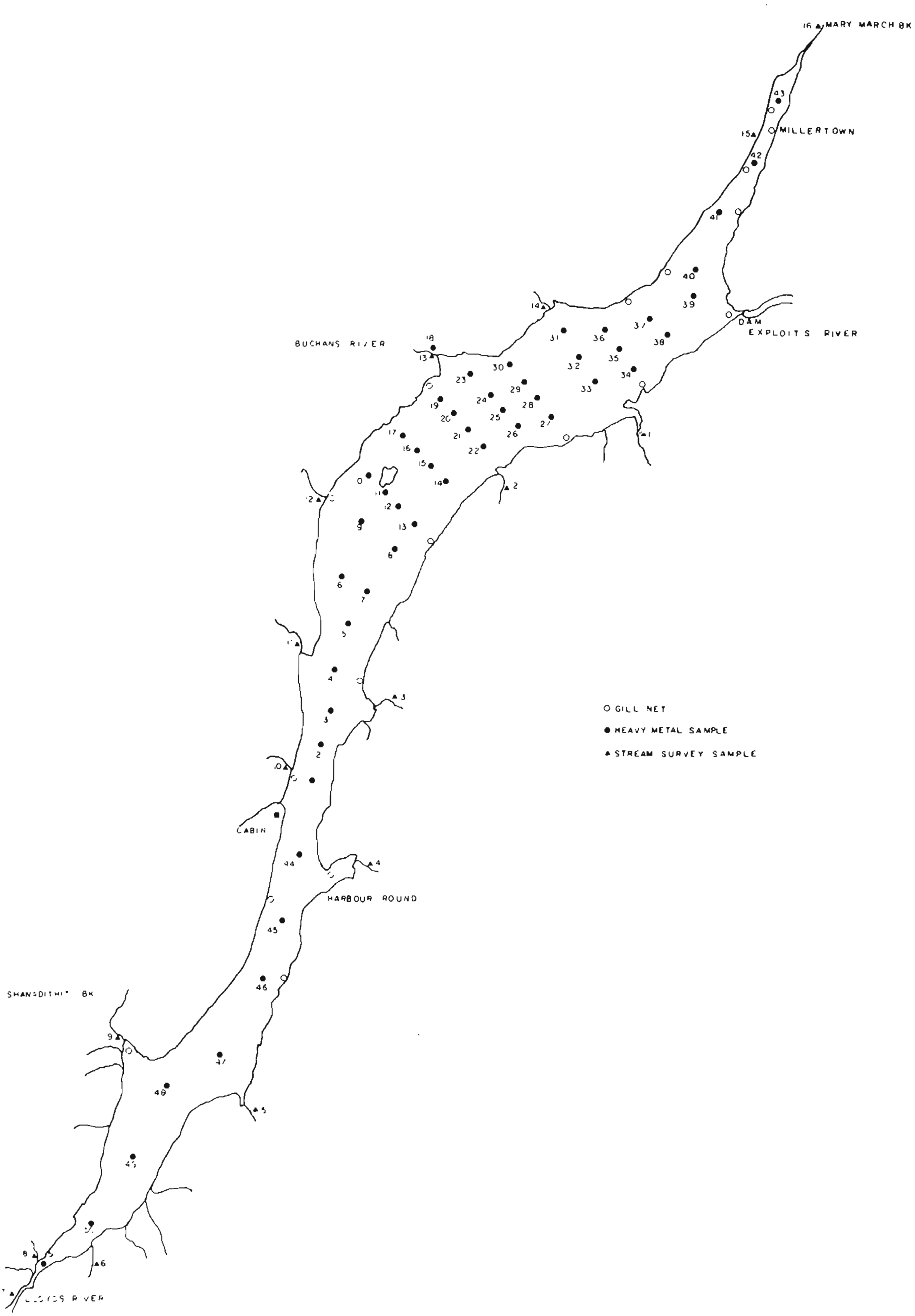

Fig. 22. Gillnet, heavy metal and stream survey sampling sites.

Table 3. Incurrent streams - water quality analysis.

Location	pH	Total Hardness	Spec. Cond.(1)	Turbidity JTU	Total Alk.	Cl
SS1	6.3	7.0	18.0	0.7	8.0	1.5
SS2	6.6	7.0	18.0	0.6	12.0	2.0
SS3	6.8	18.0	32.0	0.7	15.0	2.5
SS4	6.5	11.0	24.0	0.6	8.0	2.0
SS5	6.5	5.0	21.0	1.3	8.0	2.5
SS6	6.6	9.0	31.0	0.5	11.0	2.5
SS7	6.2	6.0	18.0	0.5	4.0	3.0
SS8	5.8	3.0	10.0	0.6	2.0	1.5
SS9	6.0	5.0	11.5	0.5	2.0	1.5
SS10	6.4	9.0	22.0	0.5	8.0	2.5
SS11	6.6	11.0	27.0	0.5	10.0	2.0
SS12	6.0	6.0	14.0	0.5	4.0	1.5
SS13	6.5	8.0	30.0	81.0	4.0	-
SS14	6.1	6.0	15.0	0.4	5.0	1.5
SS15	6.2	7.0	19.0	0.7	6.0	2.0
SS16	6.1	6.0	13.0	1.0	4.0	1.5

JTU = Jackson turbidity units
(1) = micromhos

The pulp and paper industry and, prior to it, the lumbering industry have utilized this lake for water transport of wood for three quarters of a century. And yet, essentially the water quality has remained unaffected. Bottom dredges and cores have revealed only minimal accumulation of wood fibre and bark indicating that the decomposer community is capable of handling the biological loading required of it. In a shallower lake with quantitatively less total oxygen available, O_2 depletion would almost certainly be found as an indicator of a eutrophying trend; such is not found here. Total hardness and specific conductance, as indicators of trophic "richness" would be expected to show elevated levels in a smaller body less capable of coping with such use; once again, not so here. Readings of specific conductance averaging about 20 micro mhos and total hardness 8-10 ppm are considered normal in the oligotrophic waters of Newfoundland (Jamieson, 1974a).

In so far as the metal mining industry is concerned, the effects have been somewhat more noteworthy. Since its inception in 1927, the ASARCO operations at Buchans have been responsible for pollution of Buchans Brook and Red Indian Lake with zinc-copper mining wastes, though the situation has improved somewhat in recent years. These wastes include dissolved ions and compounds of the metals themselves (including lead), the silt and fine granular fractions washed out of the tailings systems, as well as certain chemicals associated with the milling process. From the fisheries point of view, the significant pollutants are zinc, copper and silt.

Prior to 1961 there was absolutely no treatment of the 200,000 plus tons of tailings coming out of the Buchans mill annually before it was pumped into Buchans Brook. Consequently, without any exaggeration, several million tons of tailings, including vast quantities of metallic residue unrecoverable by existing technology at the time, had entered Red Indian Lake by that year. Departmental employees examining the situation in that year described Buchans Brook as an open sewer showing no evidence of biological activity whatsoever. This abiotic state extended far into the lake itself. Fish populations in the affected part of the lake were notably less abundant than elsewhere. A first attempt at creating settling ponds for the tailings actually within the riverbed of the brook failed when the ponds were silted beyond use in short order (Fig. 23). In 1966, an improved system with greater retention capacity was created to the southwest of the mill involving "Sand Slimes Pond" (Lake No. 2) and the surrounding bog land. The pond thus created was dyked to 919 ft in elevation with a weired sluiceway at 917 ft to decant the overflow. With a predicted output of 260,000 short dry tons of tailing annually, the capacity was only expected to serve for 6 years. Furthermore retention time was still insufficient to allow adequate settling and significant reduction in copper and zinc levels below the outfall.

Fig. 23. Original settling ponds at Buchans.

Later, in 1969, the use of lime as a precipitant was introduced in an attempt to improve settling and finally, in 1970 the company put forward what it hoped would be a definitive solution to the problem. This was a two-part proposal for an improved tailings disposal system. Phase I was to enlarge the present tailings pond by raising the dyke a further 10 ft. This would expand holding capacity and retention time over the short term. Meanwhile Phase II would be initiated. This would involve bringing a larger nearby waterbody, Jackson's Pond, into the tailings system providing what the company felt would be adequate settling during the lifetime of their operations. The capacity of the new system is 41 million cu ft; sufficient for 10 years production. This would mean the estimated retention time in 1980 would be only 1 day, if the system continued to operate until then, however, it was calculated that the ore would run out long before that time. When milling of presently known ore bodies would be completed, the company estimated an 18-day settling period (13 days by our calculations). Aside from the physically disruptive effect this system has had on the local terrain (Fig. 24), the results have been quite successful.

Fig. 24. Tailings system Phase II.

Visually, the impact is still pronounced (Fig. 25-27). However, chemically and biologically, improvement is evident. For example, Buchans Brook dissolved copper levels have gone from 40 ppb in 1966 and 12 ppb in 1970 to an average of 3 ppb in 1974. Zinc levels have declined similarly from between 450 to 550 in the years between 1966 and 1970 to an average of 200 ppb in 1974 (see Table 6). However, individual readings of 540 ppb of zinc (see Appendix III) are still occasionally obtained.

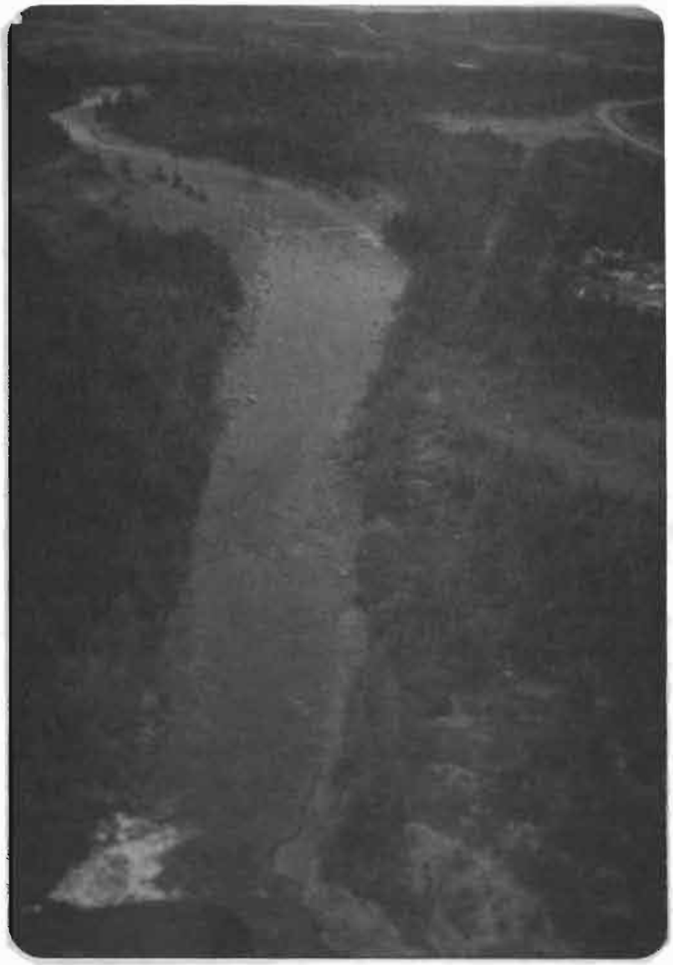

Fig. 25. Brook above tailings outfall.

Fig. 26. Buchans Brook below outfall.

Fig. 27. Buchans Brook and Red Indian Lake, 1974.

Table 4. Water quality analysis at control site.

Sampling Station	Time hrs.	Date	Temp. (C)	pH	Total Hardness	Spec. Cond.(1)	Turb. JTU	Total Alk.	Ca	Cl
Control 1	1530	26/8/74	15.0	7.3	34.0	68.0	1.4	32.6	7.4	4.5
Control 2	1330	27/8/74	12.9	7.1	35.0	70.0	1.5	34.0	7.4	5.5
Control 3	1330	28/8/74	13.4	7.2	34.0	66.0	0.7	30.0	7.2	4.5
Control 4	2130	29/8/74	12.1	7.2	35.0	70.0	1.2	34.0	7.4	4.0
Control 5	1330	30/8/74	12.2	7.1	35.0	70.0	0.6	34.0	7.4	4.5

Table 5. Water quality analysis at experimental site.

Sampling Station	Time hrs.	Date	Temp. (C)	pH	Total Hardness	Spec. Cond.(1)	Turb. JTU	Total Alk.	Ca	Cl
Ex-St (1)	1530	26/8/74	16.0	6.3	14.0	35.0	1.3	4.0	3.2	3.0
Ex-St (2)	1330	27/8/74	14.8	6.4	14.0	35.0	2.0	5.0	3.0	3.0
Ex-St (3)	1330	28/8/74	15.0	6.6	16.0	35.0	1.2	7.0	4.0	3.0
Ex-St (4)	2130	29/8/74	14.0	6.4	16.0	44.0	2.0	6.0	4.6	3.5
Ex-St (5)	1400	30/8/74	15.0	6.3	12.0	39.0	0.6	5.0	4.4	3.5

JTU - Jackson Turbidity Units
(1) - Micromhos

Table 6. Experimental - heavy metal concentrations.

Sample number	Time (hrs)	Date	Temp. (C) when taken	Copper ppb	Zinc ppb
1	1530	26/8/74	16.0	3.0	180.0
2	1730	26/8/74	17.0	3.0	328.0
3	0130	27/8/74	13.9	3.0	136.0
4	0930	27/8/74	12.2	5.0	250.0
5	1730	27/8/74	15.6	4.0	50.0
6	2130	27/8/74	14.2	3.0	129.0
7	0530	28/8/74	13.0	3.0	140.0
8	1330	28/8/74	15.0	3.0	180.0
9	2130	28/8/74	14.8	3.0	180.0
10	0530	29/8/74	12.0	4.0	285.0
11	1330	29/8/74	16.0	5.0	328.0
12	2130	29/8/74	14.0	3.0	145.0
13	0530	30/8/74	9.0	3.0	165.0
14	1400	30/8/74	15.0	5.0	300.0

Analysing these results from strictly a fisheries point of view, it must be stated that, though improvements are noteworthy, they are not sufficient to protect fish stocks in the local area. For Buchans Brook to be suitable as rearing area for salmonid fishes it would be necessary to have turbidity readings in the range of 10 JTU and dissolved zinc and copper readings not exceeding 14 μg/ℓ and 170 μg/ℓ respectively. In the latter cases these figures represent 0.4 of an Incipient Lethal Limit (ILL). One ILL is defined as "that level of toxicity at which an organism can no longer survive for an indefinite period of time" (Sprague, 1974) and 0.4 ILL is the level at which migrating salmonids have been found to be prevented from entering a stream. Initial examination of water quality results for the brook, given in Tables 4 and 6, indicate that levels of turbidity and copper are acceptable and zinc is approaching an acceptable level. However, it must be stated that during the 4-day period on which these tests were made, the brook was in a remarkably clean state, suggesting that possibly effluent from the mill was temporarily under curtailment for some reason. Other samples (see Table 3, SS13 and Appendix III, HM 18) have given readings far in excess of desirable levels on other occasions. All factors considered though, it would be unfair not to commend ASARCO's pollution abatement efforts.

General turbidity and dissolved zinc and copper levels (Fig. 28 and 29) within Red Indian Lake generally are well below Incipient Lethal Levels except in the near vicinity of Buchans Brook itself. This is a

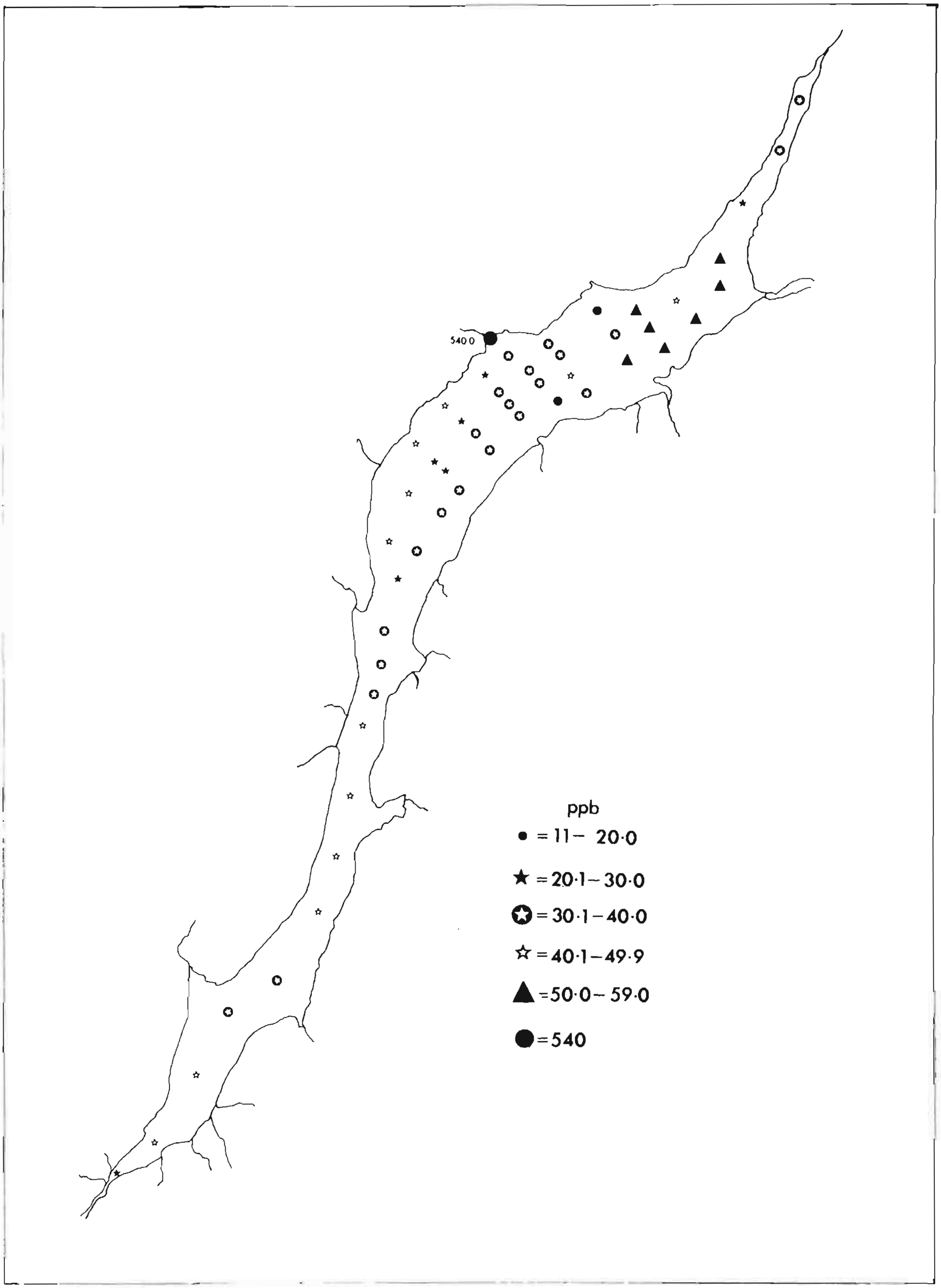

Fig. 28. Panorama of dissolved zinc concentrations in Red Indian Lake.

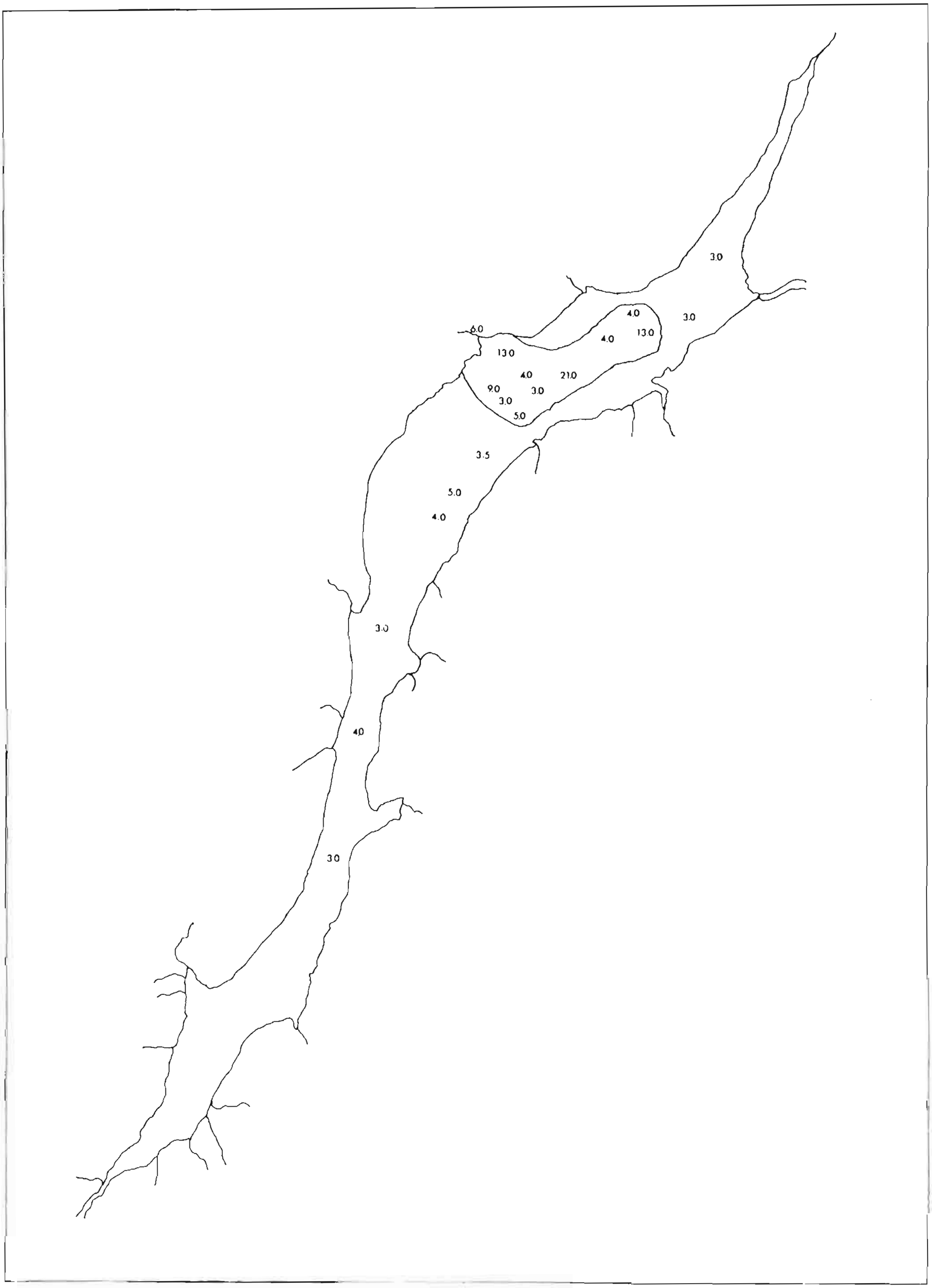

Fig. 29. Panorama of dissolved copper concentrations in Red Indian Lake (ppb).

healthy sign for the future. It leaves no doubt that the final phase of development of the Exploits River watershed for salmon production can go ahead; that is, that if salmon are enabled to bypass the Exploits dam, there is no question but that they will be able to safely pass through Red Indian Lake to the vast areas of spawning and rearing potential in incurrent streams above.

BIOLOGICAL ENVIRONMENT

Plankton

One hundred and nine plankton tows were made during the course of these surveys and the results subjected to specific identification and semi-quantitative enumeration. Due to the continuing controversy surrounding the efficiency of various methods of collecting plankton, no estimates of biomass were attempted. However simple dominance and abundance can be extrapolated from the results shown in Tables 9 and 10.

In general it can be stated that Red Indian Lake supports a depauperate population of zooplankton. Though specific analysis of phytoplankton was not carried out, the same holds true for this community assemblage. Only 12 species of entomostraca were identified (see Table 8). Of these only four, two cladocera, one cyclopoid and one calonoid, were present in significant numbers. All the species found were characteristic species of freshwaters of Newfoundland and indeed any of the unproductive waters of eastern Canada and the northeastern United States.

Perhaps the most striking feature of the zooplankton community of Red Indian Lake is the small size of all the species, with the exception of the rare predator, *Leptodora kindtii*. Selective pressure has undoubtedly been a contributing factor here. Smaller fish in this lake, deprived of a suitable benthic community upon which to feed, have facultatively switched over, to a large extent, to the planktivorous habit. It has therefore become evolutionarily more advantageous for the planktonic species present to be smaller and presumably less subject to predation. This in turn has had a stunting effect on the relative size of fishes in the lake which now have a poor source of food in both the benthos and plankton.

Analysis of variance was carried out on two groups of plankton samples, one collected from the so-called "affected area" in which copper and zinc levels were subjectively viewed to be disadvantageous and the other collected throughout the "unaffected" portion of the lake. It was thought that this statistical treatment might reveal species selectivity or community reorganization, inside and outside of the sphere of influence of Buchans Brook effluent, that was not immediately obvious to the naked eye. Because of shortcomings in the capability of the program, some samples had to be ignored in both subsample groups and these were selected as impartially as possible so as to avoid predjudicing the results. The two questions put to the CANOVA (component analysis of variance) were: (1) is there a difference between lake areas (defined by heavy metals

Table 7. Control heavy metal concentrations.

Sample Number	Time (hrs)	Date	Temp. (C) when taken	Copper ppb	Zinc ppb
1	1530	26/8/74	15.0	2.5	5.0
2	1730	26/8/74	15.0	2.5	13.0
3	0130	27/8/74	11.3	2.5	28.0
4	0930	27/8/74	11.2	2.5	3.5
5	1730	27/8/74	13.2	2.5	5.0
6	2130	27/8/74	12.2	2.5	2.0
7	0530	28/8/74	12.0	2.5	12.5
8	1330	28/8/74	13.4	2.5	13.0
9	2130	28/8/74	12.9	2.5	45.0
10	0530	29/8/74	9.7	2.5	36.0
11	1330	29/8/74	13.9	2.5	83.0
12	2130	29/8/74	12.1	2.5	49.0
13	0530	30/8/74	8.5	2.5	13.0
14	1330	30/8/74	12.2	2.5	8.0

Table 8. Complete list of species of entomostraca with author and year of description.

Cladocera:

- *Bosmina longirostris*, (O.F. Muller) 1785
- *Chydorus sphaericus*, (O.F. Muller) 1785
- *Daphnia catawba*, Coker 1926
- *Holopedium gibberum*, Zaddach 1855
- *Latona setifera*, (O.F. Muller) 1785
- *Leptodora kindtii*, (Focke) 1844
- *Sida crystallina*, (O.F. Muller) 1785

Copepoda:

Calanoida:

- *Diaptomus minutus*, Lilljeborg 1889
- *Diaptomus sanguineus*, S.A. Forbes 1876
- *Epischura lacustris*, S.A. Forbes 1882

Cyclopoida:

- *Cyclops scutifer*, Sars 1863
- *Cyclops vernalis*, Fischer 1853

Table 9 . Percentage presence of zooplankton species in the 39 samples of the Affected area. T represents a trace presence (seen in sample but not sub-sample); J indicates species was only present in juvenile form.

Sample No.	Date Collected	Depth (m)	B. longirostris	C. sphaericus	D. catawba	H. gibberum	L. setifera	L. kindtii	S. crystallina	Total Cladocera	D. minutus	D. sanguineus	E. lacustris	Total Calanoids	C. scutifer	C. vernalis	Total Cyclopoids
17	3/7	38	34.1			2.4				35.6	34.1		.	38.8	16.5	T	24.7
18	3/7	61	33.6			1.3				34.9	24.3			24.3	38.8		40.8
19	8/7	46	46.2			1.1				47.3	33.0			33.0	18.6		19.8
20	4/7	9	50.4			0.8				51.2	29.1			33.1	11.8		15.7
21	4/7	64	34.0			8.4	0.5			42.9	28.3		J	36.1	11.5		20.9
22	4/7	52	43.9							43.9	22.0			22.0	11.0		34.1
23	4/7	12	37.1							37.1	8.6			8.6	8.6		54.3
24	17/7	53	22.0	0.2		2.2				24.3	12.3		J	52.6	2.9		23.1
25	17/7	64	14.0		0.4	0.8		0.4		15.6	13.6		J	59.7	4.9		24.7
26	17/7	11	25.5	1.1		1.1				27.7	6.4		T	36.2	24.5		36.2
27	18/7	9	54.3							54.3	3.7		J	27.2	3.7		19.8
28	18/7	11	33.7			T		T	T	33.7	5.5		J	47.2	9.2		19.6
29	18/7	27	24.8			1.0				25.8	3.8		T	53.3	7.6		21.0
30	18/7	73	12.1			1.0				12.1	5.6			49.5	3.0		35.4
31	18/7	43	20.3			1.5				21.8	5.3			49.6	6.0		28.6
32	19/7	20	21.7							21.7	7.2			71.1	1.2		7.2
33	19/7	73	29.1			T				29.1	7.1			54.9	3.8		15.9
34	19/7	99	12.8			T			T	12.8	7.3		T	55.3	8.2		32.0
35	19/7	29	20.6			T				20.6	3.9			57.4	3.2		21.9
36	19/7	8	25.0							25.0	7.1			36.6	7.1		38.4
37	25/7	9	36.1							36.1	2.2		J	32.9	6.3		28.8
38	25/7	50	45.5			0.3	0.3			46.0	1.3		1.0	9.9	4.9	0.5	44.2
39	25/7	116	27.1							27.1	T			55.3	2.4		17.6
40	25/7	24	15.7			T			T	15.7	3.9		J	39.4	3.9		40.9
41	26/7	99	21.6			1.2				22.8	1.2		T	66.7	3.7		10.5
42	26/7	82	28.8			1.7				30.5	3.4		1.7	55.9	1.7		13.6
43	26/7	12	25.0			T				25.0	3.8		T	50.0		4.8	25.0
44	26/7	3	77.6							77.6	T			32.7	T		10.2
45	29/7	95	20.9			0.5				21.3	2.8		T	70.1	2.8		18.0
46	29/7	95	41.4			T				41.4	0.6			47.0	2.8		11.6
47	29/7	40	45.2			T				45.2	4.3			47.3	T		7.5
48	29/7	9	9.8			3.9				13.7	6.9			74.9	1.0		6.9
49	30/7	14	33.3							33.3	3.9		T	43.1	2.0		23.5
50	30/7	46	34.5							34.5	5.2		T	32.8			32.8
51	30/7	95	18.1			T				18.1	5.3		T	14.5	T		7.4
52	30/7	107	37.0			1.4				38.4	4.1			53.4	1.4		8.2
53	30/7	70	48.9							48.9	1.5		T	36.3	0.7		14.8
54	30/7	122	42.1			T				42.1	7.0			21.1	T		36.6
55	30/7	34	18.2			1.2				19.4	1.2			63.6	T		17.0

Table 10. Percentage presence of zooplankton species in the 34 samples of the Unaffected area. T represents a trace presence (seen in sample but not sub-sample); J indicates species was only present in juvenile form.

Sample No.	Date Collected	Depth (m)	B. longirostris	C. sphaericus	D. catawba	H. gibberum	L. setifera	L. kindti	S. crystallina	Total Cladocera	D. minutus	D. sanguineus	E. lacustris	Total Calanoids	C. scutifer	C. vernalis	Total Cyclopoids
1	25/6	7	54.5			4.5				59.1				39.8	J		2.3
2	25/6	6	65.1			3.2				68.3				29.4			2.4
3	25/6	7	53.7			3.7				57.3				36.6			6.1
4	26/6	8	22.6			5.7				28.3				67.9	1.9		3.8
5	26/6	4	43.5			8.7				52.2				37.0	2.2		10.9
6	27/6	19	18.2			27.3				45.5				27.3	9.1	9.1	27.3
7	27/6	6	16.7			16.7				33.3				66.7			-
8	27/6	27	9.1			36.4				45.5				27.3			27.3
9	27/6	38	11.8			52.9				64.7				17.6			17.6
10	27/6	24				42.9				42.9				14.3			42.9
11	28/6	37	78.6			7.1				85.6			J	7.1			7.1
12	28/6	46	55.5			11.1				66.6	J		J	22.2			11.1
13	28/6	36	25.0			25.0				50.0		8.3		16.7			33.3
14	2/7	36	36.4			2.5				38.9	23.5			27.8	25.9	0.6	33.3
15	2/7	52	30.7			0.6				31.3	38.0			41.3	22.0		27.3
16	2/7	49	34.2			1.0				35.2	39.2			39.7	22.1		25.1
58	30/7	113	47.8							47.8	3.3		2.2	29.3	2.2		22.8
61	31/7	18	19.6			0.9				20.6	3.7		J	68.2			11.2
64	31/7	69	23.1			T				23.1	3.3		T	57.1	T		19.8
67	1/8	76	34.6			1.3				35.9	2.6			28.2			35.9
70	1/8	60	22.6			0.4				23.0	1.5		0.4	52.9	T		24.1
73	9/8	143	22.6			J	T			22.6	9.7		1.6	54.8	1.6		22.6
76	9/8	137	32.0			T				32.0	7.2		T	48.8	0.8		20.8
79	14/8	55	48.7			0.9				49.6	2.6			29.9	T		20.5
82	14/8	52	38.3			0.9				39.3	9.3		0.9	44.9			15.9
85	14/8	52	44.6							44.6	6.1		T	44.6			10.8
88	15/8	69	22.4			T				22.4	14.0		T	58.9	0.9		18.7
91	15/8	75	34.0			0.5				34.5	7.9			49.8	0.5		15.8
94	16/8	49	32.8			T				32.8	6.0		T	53.7	T		13.4
97	19/8	6	32.0							32.0	8.7		T	67.0			1.0
100	19/8	81	32.8							32.8	7.8			53.4	0.9		13.8
103	19/8	49	44.3			T				44.3	2.9			32.9	1.4		22.9
106	20/8	4	88.8							88.8	0.6		T	8.3			3.0
109	20/8	3	53.5							53.5	1.9		T	11.9	T		34.6

concentration) with respect to numbers of animals counted and species relative abundance? and (2) is there a difference among species with respect to relative abundance? The data were analysed on the basis of percentage abundance (arc sin $\sqrt{\text{proportion}}$ transformed) and also total counts. Differences as determined by both forms of analyses were statistically insignificant. Interpreting these results, one would be forced to conclude that seeming differences in total counts which are not statistically valid could be a result of enumerable other factors not related to pollution, including depth, stage within the life-cycle of the most abundant organisms, seasonality, etc. The more important factor to be analysed, species relative abundance has been shown to differ insignificantly between the two areas and therefore one must conclude the heavy metal pollution within the lake is not a major factor in productivity at this level of trophism.

Benthos

The benthic community was also analysed semi-quantitatively at each of the 109 collecting sites. The results were remarkably poor. Out of 109 grabs, only 25 were found to contain any macroinvertebrates by gross separation techniques. Within these 25 successful samplings only five recognizably distinct taxonomic groups were found (see Table 11) though two of these, class Hirudinea and Family Chironomidae might well have been identified further to a group of species by expert taxonomic analysis. None of the taxa were found to be represented in what might otherwise be considered to be great numbers. Only one sample, R11, yielded 20 specimens.

Table 11. Taxonomy of benthic organisms in Red Indian Lake.

Phylum Annelida
- Class Oligochaeta
  - Family Lumbriculidae
    - *Stylodrilus heringianus* Claperede, 1862
  - Family Tubificidae
    - *Rhyacodrilus sp.* Bretscher, 1901
- Class Hirudinea

Phylum Mollusca
- Class Pelecypoda
  - Family Sphaeriidae
    - *Pisidium sp.* Pfeiffer

Phylum Arthropoda
- Class Insecta
  - Order Diptera
    - Family Chironomidae

The lack of species diversity and abundance both serve to demonstrate the unproductive nature of the waters of Red Indian Lake. The low relative occurrence and abundance of organisms in stations numbering between RI20 and RI50 (see Table 12) certainly is in part due to the unsuitable nature of the tailings covered bottom. However, it should be noted that other parts of the lake are equally depauperate in benthic organisms and therefore the generally unproductive nature of the lake must once again be considered to be the overriding factor.

Table 12. Occurrence and abundance of benthic organisms by station.

Station	Date	Depth (m)	Organism: *Stylodrilus*	*Rhyacodrilus*	*Hirudinea*	*Pisidium*	Chironomidae	Totals
RI1	25/6/74	7.3	8	6		5	1	20
RI4	26/6/74	7.3	1				1	2
RI6	27/6/74	18.9	1		1			2
RI8	27/6/74	27.4		1				1
RI10	27/6/74	27.4		2			2	4
RI11	28/6/74	36.6		10				10
RI12	28/6/74	45.7		13			1 (pupa)	14
RI13	28/6/74	33.5					1	1
RI14	2/7/74	33.5		3				3
RI15	2/7/74	51.8		3				3
RI16	2/7/74	48.8		9				9
RI18	3/7/74	61.0					2	2
RI19	3/7/74	45.7					1	1
RI22	4/7/74	51.8		3			4	7
RI24	17/7/74	53.4					1	1
RI39	25/7/74	115.9		1			5	6
RI41	26/7/74	99.1					3	3
RI69	8/8/74	131.1					1 (pupa)	1
RI74	12/8/74	115.9		1				1
RI84	14/8/74	64.0					1	1
RI90	15/8/74	106.7					1	1
RI98	19/8/74	85.4		1				1
RI102	19/8/74	82.3		1				1
RI103	19/8/74	48.8		4				4
RI107	20/8/74	4.6		2			6	8
		Total	10	60	1	5	31	107
		%	9.3	56.0	0.9	4.7	29.0	

The organisms specifically found here are among the more common benthic types in Newfoundland waters. Neither of the oligochaets, not even the tubificid, are associated with polluted conditions. According to Brinkhurst and Jamieson (1971), *Stylodrilus heringianus* is a very common species, holarctic in distribution and *Rhyacodrilus sp.* is said to be an indicator species of improving or "less polluted" conditions where tubificids are concerned. Both are normally associated with sandy sediments and it is this preference which suits them specifically to Red Indian Lake. Certainly they are not present there as a response to heavy bark or wood fibre loading since such a situation does not exist, as the low numbers of macro-decomposers indicates.

Like the sparse plankton populations, inadequate representation within the benthic community has a direct bearing on the growth and abundance of fishes. This discussion will be followed up under the next heading.

Fish population dynamics

Overview

Diversity of fish species in insular Newfoundland generally is extremely low. Unlike the mainland part of Canada, such abundant and widespread families as the Centrarchidae, Catostomidae, Coregonidae, Percidae and Esocidae are absent. In this respect, Red Indian Lake's rather sparse assemblage of only four species is not all that remarkable. Three of these are salmonids; landlocked Arctic char *(Salvelinus alpinus)*, ouananiche *(Salmo salar ouananiche)* and eastern brook trout *(Salvelinus fontinalis)*. The other is the ubiquitous three-spined stickleback, *Gasterosteus aculeatus*. This is the same species assemblage found by Pippy (1966) in Victoria Lake, a similar large oligotrophic lake also making up part of the upper Exploits River watershed. Though not remarkable in diversity, the fish population of Red Indian Lake is unusual for the island in its low over-all abundance. Nineteen nights of net sets (see Table 13) using a total of 750 ft (230 m) of net in five mesh sizes from 1½ inch to 5 inches yielded only 316 fish with a total weight of 97.7 lb (44.3 kg).

That such yields are low is an undisputable fact. Whether they are unexpectedly low is another question. By use of Ryder's (1974) Morphoedaphic Index, it can be predicted that, with a mean T.D.S. of 29 ppm* and a mean depth of 81 ft Red Indian Lake should have an annual fish production of 1.19 lb/acre/yr or 1.33 kg/ha/yr. According to Ryder, this

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1 T.D.S. here is calculated from conductivity by the following formulae:

$$Y\ (TDS) = 7.02 + (0.72)\ (C_1)$$

where C_1 is the conductivity at 77 F (25 C)

C_1 can be computed: $C_1 = \dfrac{C_2 \text{ (conductivity at } T_2)}{\dfrac{4 + T_2 \text{ (temperature at sampling)}}{4 + T_1}}$

puts Red Indian in the same trophic class as Great Bear Lake, Lake Superior and Rainbow Lake, British Columbia or, alternately just a little more productive than such notoriously unproductive bodies as Lake Baikal, Lake Tahoe and Chub Crater. In fact, such productive levels would put Red Indian Lake in the lower 1% of waters around the world.

Table 13. Species composition of net catch, Red Indian Lake, 1974.

Species	Number	Percent	Weight (gm)	Percent
Ouananiche	231	73.1	36,542.5	86.3
Brook trout	71	22.5	5,143.0	12.2
Arctic char	14	4.4	643.0	1.5
	316		44,328.5	

Wiseman (pers. comm.) has found that the average fish production, calculated by this method, for insular Newfoundland ponds is around 3 lb/acre/yr. Put into this reference framework it must be conceded that low productivity is principally a result of morphedaphic factors in Red Indian Lake. However, without a doubt, erratic fluctuations in water levels, as previously described, have resulted in the loss of shallows and shoreline areas for spawning and, far more importantly, for the production of benthic organisms, which normally provide the basis of the aquatic food chain. It would be almost impossible to demonstrate empirically how much the expected yield per unit has been reduced in this way. Such an intrinsic alteration in the environment would produce cryptic changes at all levels of the fish production picture; lower hatch rate, decreased fry survival, minimization of growth potential and probably even a curtailment of fertility.

A very useful comparison in this respect is between the general catch/effort found in Victoria Lake (Table 15) and that of Red Indian Lake. Pippy's (1966) results were obtained using the same methods as those employed in this survey and Victoria Lake is for our purpose the same kind of lake as Red Indian, though diminished somewhat in all dimensions (mean length 29.8 km, mean width 1.4 km, maximum depth 117 m). Though mean depth was not determined for Victoria Lake, it is certain that it would be only a little shallower than Red Indian and with a decreased T.D.S. of 15 ppm to compensate for the decreased depth, the predicted productivity of the two lakes should be virtually identical at about 1 lb per acre per yr.

Table 14. Catch per unit of effort (see text) for 14 sites in Red Indian Lake.

	June 26		June 27		July 3		July 4		July 5		July 18		July 19		July 26	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Arctic char	-	-	-	-	-	-	1	50	-	-	1	49	-	-	-	-
Brook trout	3	180	-	-	1	69	-	-	2	309	7	494	1	45	3	223
Ouananiche	7	1760	5	282	3	722	8	1057	15	1660	24	2902	9	1669	19	1916
Total	10	1940	5	282	4	791	9	1107	17	1969	32	3445	10	1714	22	2139

Buchans Brook

	July 30		July 31		Aug. 1		Aug. 9		Aug. 13		Aug. 14		Total	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Arctic char	1	40	-	-	-	-	7	302	3	148	-	-	13	589
Brook trout	9	473	4	376	5	446	-	-	5	367	1	76	41	3058
Ouananiche	18	2063	19	1890	12	1438	8	1363	2	89	6	1002	155	19,813
Total	28	2576	23	2266	17	1884	15	1665	10	604	7	1078	209	23,460

Table 15. Comparative catch/effort statistics for Victoria Lake (Pippy, 1966) and Red Indian Lake, 1974.

Victoria Lake, 1966, (11 net sets)

	Number of Fish	No. per Unit of Effort	Weight of Fish (gm)	Weight per Unit of Effort
Landlocked salmon	121	11.00	11,347.7	1,667.9
Brook trout	105	9.55	8,593.7	781.2
Arctic char	37	3.36	2,626.3	238.8
Total	263	23.91	29,567.7	2,687.9

Red Indian Lake, 1974 (14 net sets)

	Number of Fish	No. per Unit of Effort	Weight of Fish (gm)	Weight per Unit of Effort
Landlocked salmon	155	11.1	19,813	1,415.2
Brook trout	41	2.9	3,058	218.4
Arctic char	13	0.9	589	42.1
Total	209	14.9	23,460	1,675.7

This being the case, it follows that other factors being equal, catch per unit of effort should be the same. In fact Table 15 shows conclusively that this is not the case. Victoria Lake, which in 1966 was not subject to major fluctuations in water levels gave an overall C/E of 23.9 fish (all species) or 2687.9 gm while Red Indian C/E was only 14.9 fish with an average of 1675.7 gm. Confounding variables such as subjective choice of netting sites should have averaged themselves out over the number of sets involved in each survey. It is most likely that the 40% difference in catch/effort is in large part a result of disruption created by serious fluctuations in water level on Red Indian Lake.

This study was unable to demonstrate any direct deleterious effects to fish stocks clearly attributable to the Buchans zinc-copper operations. In fact, Table 14 demonstrates rather conclusively that avoidance of the most heavily affected areas of the lake does not occur as a behavioural pattern of the three sport fish species. This Table compares catches of each species, by weight (gm) and numbers for 14 sites throughout the lake. Each site was netted for 24 hours with the experimental fleet of gill nets previously described. Buchans Brook was netted at its mouth on July 29-30. The yield of each species was average or better than average in every case. In fact, total yield in terms of numbers was twice the average for the entire lake. Though these populations are mobile and therefore not necessarily subject to continuous exposure to the brook's effluents, it is noteworthy that no behavioural or physical differences could be observed between these fish and others in the lake. All age classes and both sexes were normally or usually represented. In short, without chemical analysis of the fish tissues to disclose possible elevated levels of zinc or copper, one would be hard-pressed to demonstrate any effect whatsoever from these results.

Ouananiche (landlocked salmon) *Salmo salar* Linnaeus

Ouananiche is the only species which occurs in Red Indian Lake as commonly (Table 15) as in Victoria Lake. This seems to indicate a facultative ability of the species to cope with environmental disruption.

The demographic statistics for the species compared to those for the Victoria Lake populations as observed in 1966 seem to bear out this trend of general wellbeing. The average age of the Red Indian Lake population is slightly lower (5.4 compared to 5.6), a generally favourable sign. Furthermore, longevity is greater since IX+ fish were common in Red Indian Lake but fish older than VIII+ were not seen in Victoria Lake. This situation soon changed in Victoria Lake, as might be expected, when it was impounded in 1969. With increased nutrients and expanded areas of shallows, the population thrived to the extent that in 1972, when a similar survey was conducted, fish up to XII+ were seen and average weight and length at a given age had increased tremendously. Red Indian Lake represents the next stage along for Victoria Lake; that is, the gradual drop in productivity as the massive new sources of trophic richness are used up. Mean weight of ouananiche in Victoria Lake in 1966 was 177 gm. By 1972 this had more than quadrupled to 865 gm. Mean weight in Red Indian Lake is only 158 gm. Perhaps this is not an entirely fair analogy but it does resemble the theoretical scenario for reservoir creation: moderate productivity before impoundment, massively increased productivity soon after impoundment and finally, lower than initial levels of productivity as time passes.

Ouananiche are clearly the dominant fish species in Red Indian Lake, both in terms of abundance and biomass (see Table 13). When inter-specific competition has occurred, this species has obviously prospered at the expense of the other two salmonids. Reasons for this are not entirely clear. Longevity is certainly an asset. In Table 16 it can be seen that, up to

Table 16. General growth and population statistics for the three salmonid species collected by gillnet, Red Indian Lake, 1974.

	Species											
	Ouananiche				Brook trout				Arctic char			
Age	No. in sample	Mean Length (cm)	Mean Weight (gm)	%	No. in sample	Mean Length (cm)	Mean Weight (gm)	%	No. in sample	Mean Length (cm)	Mean Weight (gm)	%
I+	-	-	-	-	-	-	-	-	-	-	-	-
II+	1	16.0	49.0	0.4	8	16.5	45.9	11.3				
III+	17	16.7	49.1	7.4	53	18.6	68.0	74.6	5	16.9	40.4	35.7
IV+	44	19.1	72.7	19.0	7	22.2	122.1	9.9	6	16.9	44.7	42.9
V+	71	20.4	91.5	30.7	3	25.4	172.7	4.2	2	18.8	53.0	14.3
VI+	51	24.5	170.3	22.1	-	-	-	-	1	19.7	67.0	7.1
VII+	19	28.8	281.1	8.2	-	-	-	-	-	-	-	-
VIII+	21	32.0	362.4	9.1	-	-	-	-	-	-	-	-
IX+	7	38.0	628.6	3.0	-	-	-	-	-	-	-	-
	231	23.0	158.5		71	19.0	75.3		14	17.4	45.9	

age V+, the empirical maximum age for brook trout in Red Indian Lake, they surpass the ouananiche in size and weight for each age class. Obviously, it is these extra year classes, VI+ through IX+ which add the bulk of weight and numbers to the ouananiche populations by their mere fact of being and also by the increased reproductive potential they represent. Arctic char, as seen in Table 16, do not pose a threat to either of the other two species in this respect, though the reasons for this must be sought elsewhere. The empirical average scale lengths and theoretical or "back-calculated" fork lengths at annulus formation for ouananiche are compared to those of brook trout in Table 17. From this it can be seen that, though ouananiche get off to a very strong start, early in their life cycle, brook trout seem to by-pass them by age III+, the strongest age class of that species in terms of contribution to total biomass, as well as vitality and robustness. This lead in size is maintained through the remaining 2-year classes for which brook trout are known to exist in the lake. It could be theorized, therefore, that if they were the more longlived species, brook trout would probably be the dominant species here.

A graphic comparison of fish length-scale radius data for ouananiche (Fig. 30) exhibited a curvilinear relationship. Therefore, the Monastyrsky (log-log regression) back-calculation technique was employed. The regression equation determined for grouped male and female data was:

$$\text{Log } L_f = 0.5818 \text{ Log } L_s + 0.8711 \quad (r = 0.8798 \quad Sb = 0.03175)$$

Using this equation, the theoretical fish length at each year was determined (Table 17) and the resulting graph can be seen in Fig. 31. Compared to ouananiche in Victoria Lake (Pippy, 1966) and on the Avalon Peninsula (Wiseman, 1972), this population exhibits considerably slower growth rate in later years but a very pronounced and rapid growth rate in the first 2 years. As mentioned previously, brook trout 3 years of age and older are at their strongest and probably provide very serious competition to the ouananiche of the same age class, as undoubtedly do the older ouananiche. The limited food source discussed earlier provides a critical barrier to growth at this size since the piscivorous habit is not predominant until much later in development, except in precociously large specimens.

The age-length distribution is tabulated in Table 18 and the two components, age and length are graphically depicted on Fig. 32 and 33 respectively. It should be noted that low frequency of observations for II+ and younger fish and fish less than 15.55 cm in fork length is largely attributable to experimental artifact since the gill nets fished selectively for the larger and older fish.

Overall mean length was 23.0 with only a slight variance by sex (males 23.1, females 23.0). Sex ratio was 0.79 to 1 (Males/Females).

A length-weight regression equation was obtained from ungrouped observations. The equation, Log W = 3.1799 Log L -2.2366, was used in its arithmetic form ($W = 0.0058 L^{3.1799}$), to derive the curve in Fig. 34. Plotted points represent mean weight for each length class with ranges denoted by the vertical lines. Numbers below the vertical lines represent

Table 17. Actual scale length and calculated fork length at annulus formation of ouananiche and brook trout for Red Indian Lake.

	Ouananiche								
	Age								
	I	II	III	IV	V	VI	VII	VIII	IX
Length of scale	0.83	1.71	2.78	3.99	5.24	6.79	8.41	9.81	11.34
Length of fish (cm)	6.80	10.2	13.5	16.6	19.5	22.7	25.7	28.1	30.5
	Brook trout								
Length of scale	.69	1.3	1.9	2.5	2.9				
Length of fish (cm)	4.6	9.6	14.8	20.3	24.1				

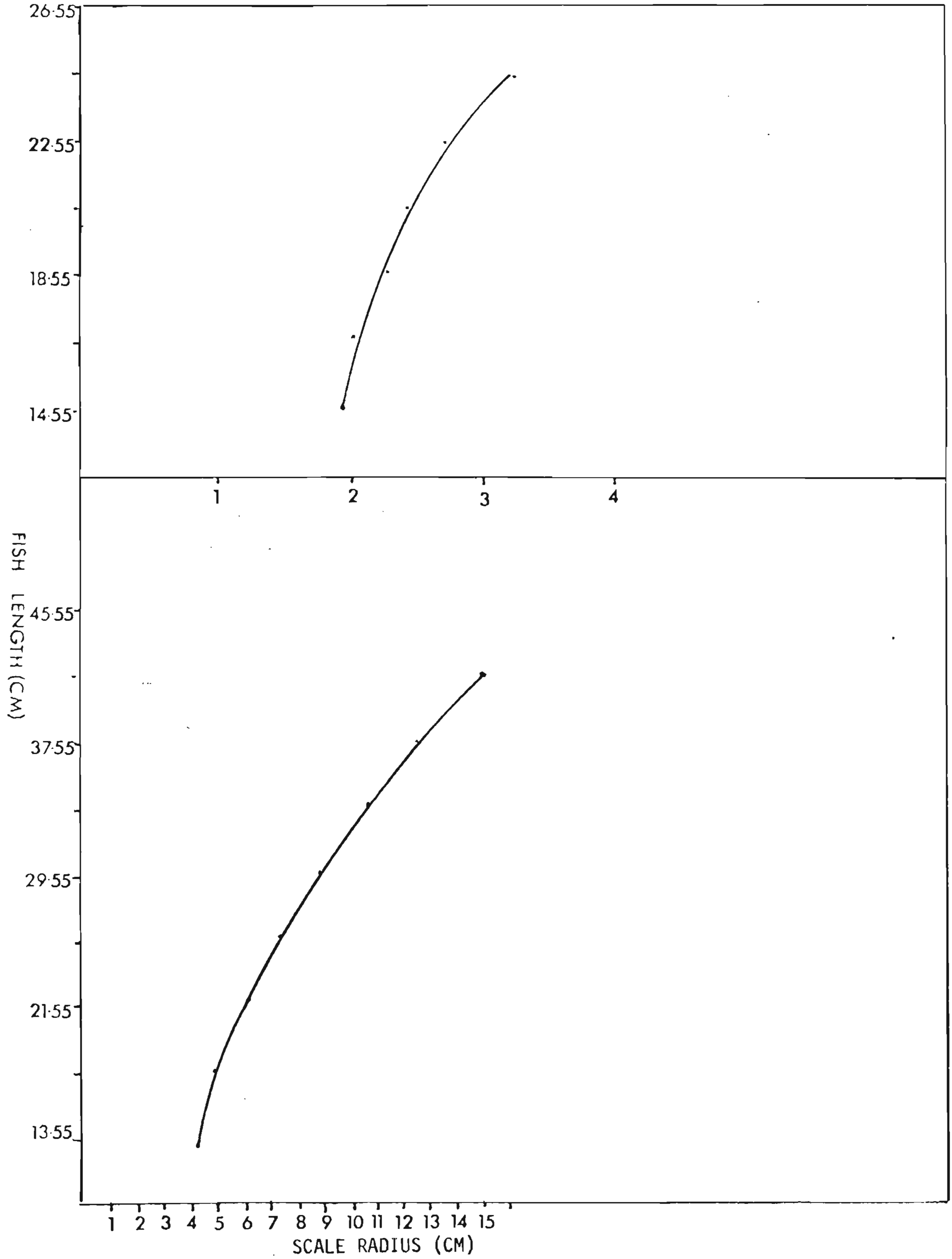

Fig. 30. Fish length-scale radius relationship for brook trout (top), ouananiche (bottom) taken at Red Indian Lake, 1974.

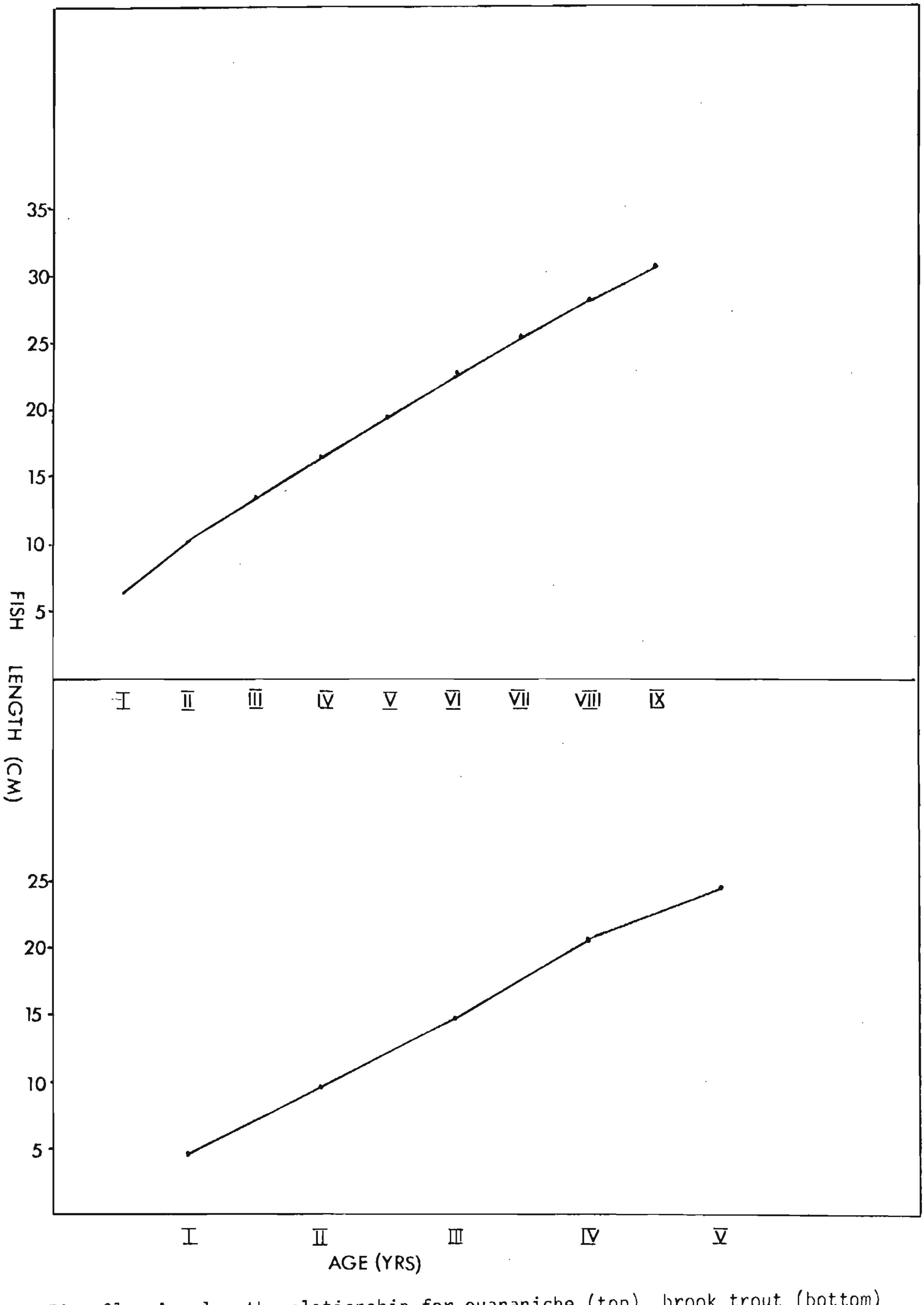

Fig. 31. Age-length relationship for ouananiche (top), brook trout (bottom) taken at Red Indian Lake, 1974.

Table 18. Age length distribution for ouananiche, Red Indian Lake, 1974. (Percentages in parentheses).

Fork length class	Age									TOTAL
	I+	II+	III+	IV+	V+	VI+	VII+	VIII+	IX+	
11.55-13.55			1(100.0)							1(0.4)
13.55-15.55			3(75.0)	1(25.0)						4(1.7)
15.55-17.55		1(5.3)	8(42.1)	7(36.8)	3(15.8)					19(8.2)
17.55-19.55			4(6.4)	17(27.0)	35(55.6)	7(11.1)				63(27.4)
19.55-21.55				16(34.7)	17(37.0)	11(23.9)	1(2.2)	1(2.2)		46(19.9)
21.55-23.55				3(15.8)	5(26.3)	8(42.1)	2(10.5)	1(5.3)		19(8.2)
23.55-25.55					6(42.9)	7(50.0)	1(7.1)			14(6.1)
25.55-27.55					4(40.0)	3(30.0)	1(10.0)	2(20.0)		10(4.3)
27.55-29.55					2(13.3)	6(40.0)	4(26.7)	3(20.0)		15(6.5)
29.55-31.55						5(41.7)	4(33.3)	2(16.7)	1(8.3)	12(5.2)
31.55-33.55						1(12.5)	2(25.0)	4(50.0)	1(12.5)	8(3.5)
33.55-35.55						3(37.5)		4(50.0)	1(12.5)	8(3.5)
35.55-37.55							3(42.9)	3(42.9)	1(14.2)	7(3.0)
37.55-39.55								1(33.3)	2(66.7)	3(1.3)
39.55-41.55									1(100.0)	1(0.4)
41.55-43.55										
43.55-45.55									1(100.0)	1(0.4)
Total										231

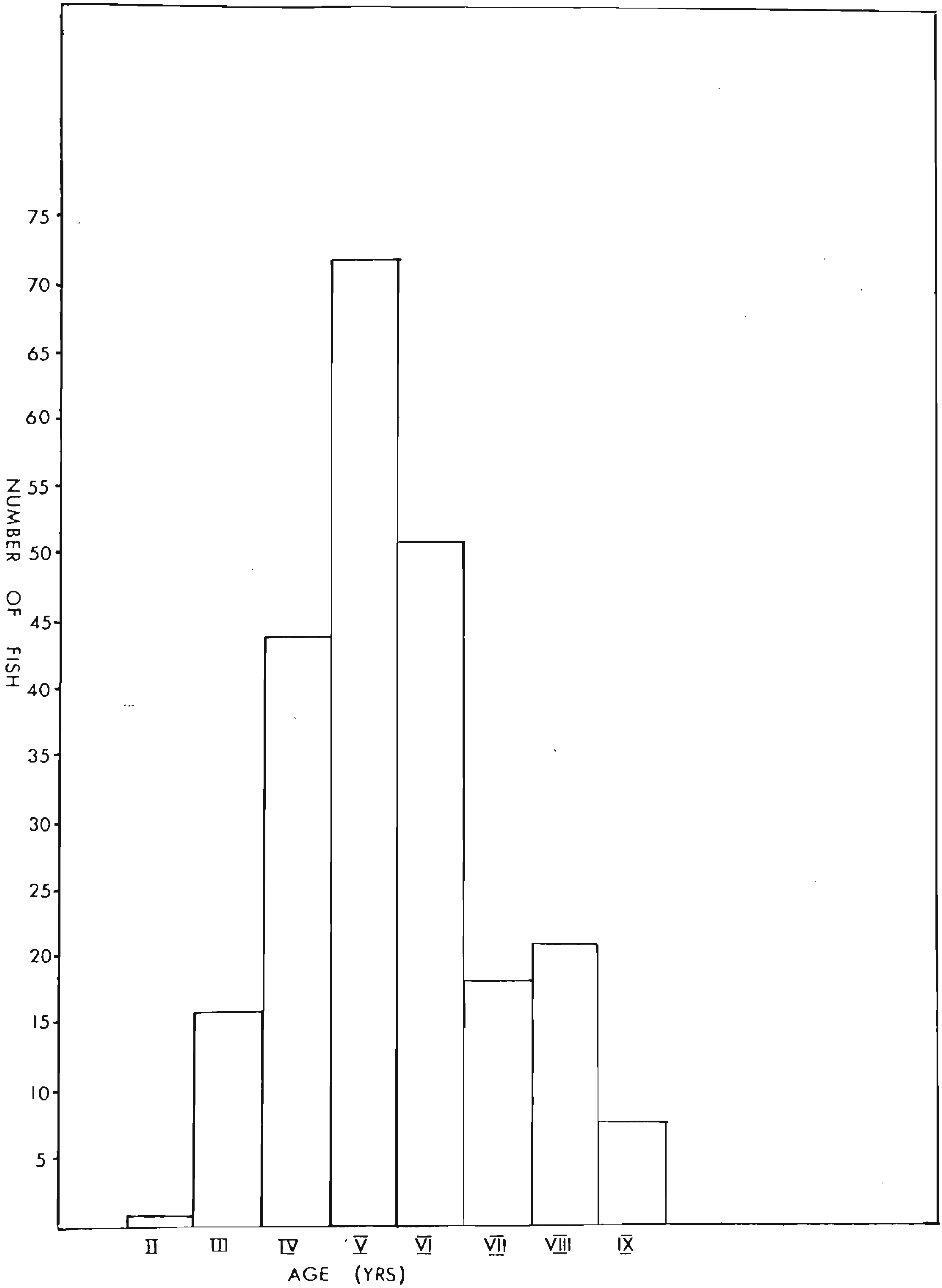

Fig. 32. Age composition of ouananiche taken at Red Indian Lake, 1974.

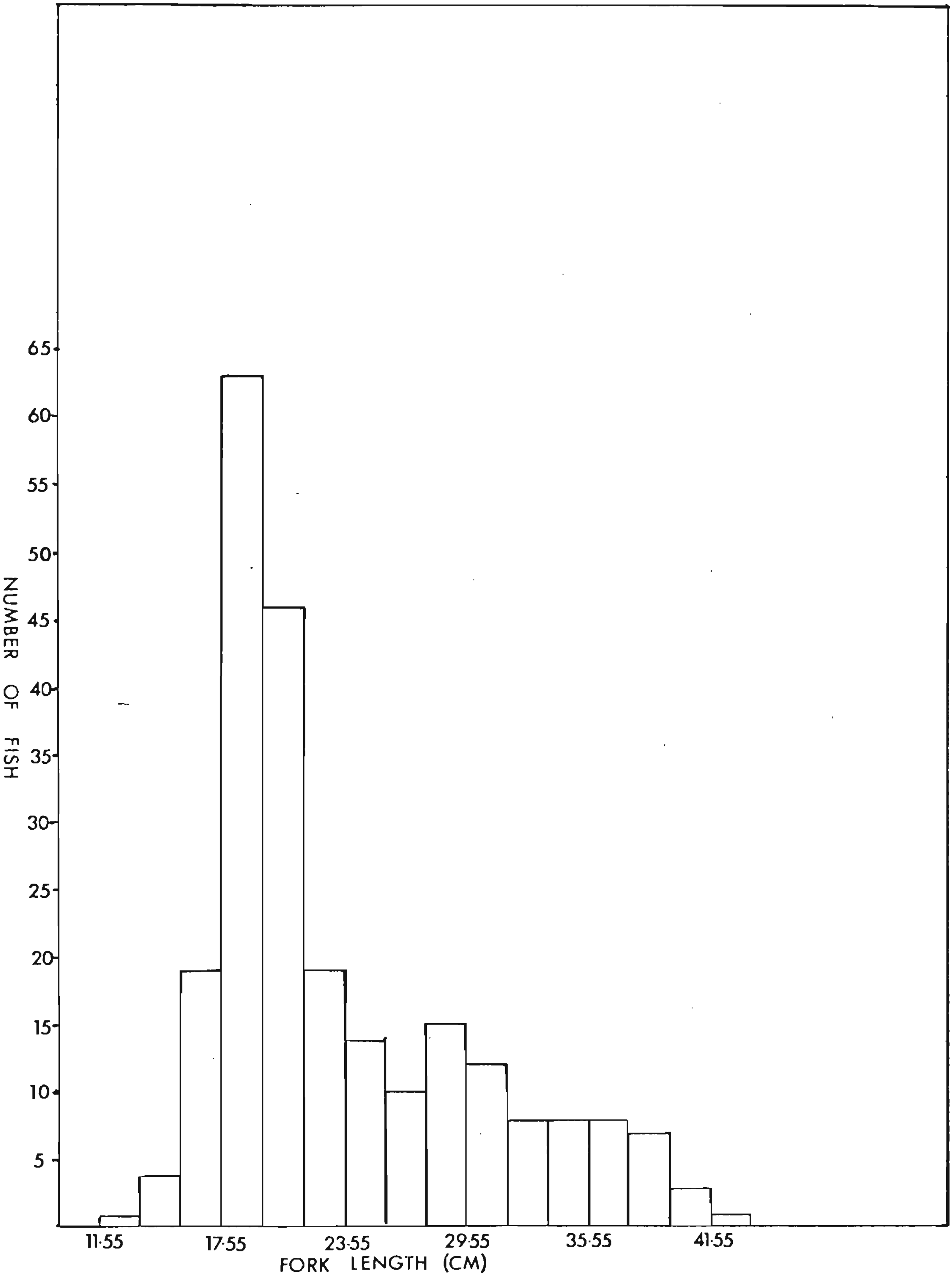

Fig. 33. Fork-length distribution of ouananiche taken at Red Indian Lake, 1974.

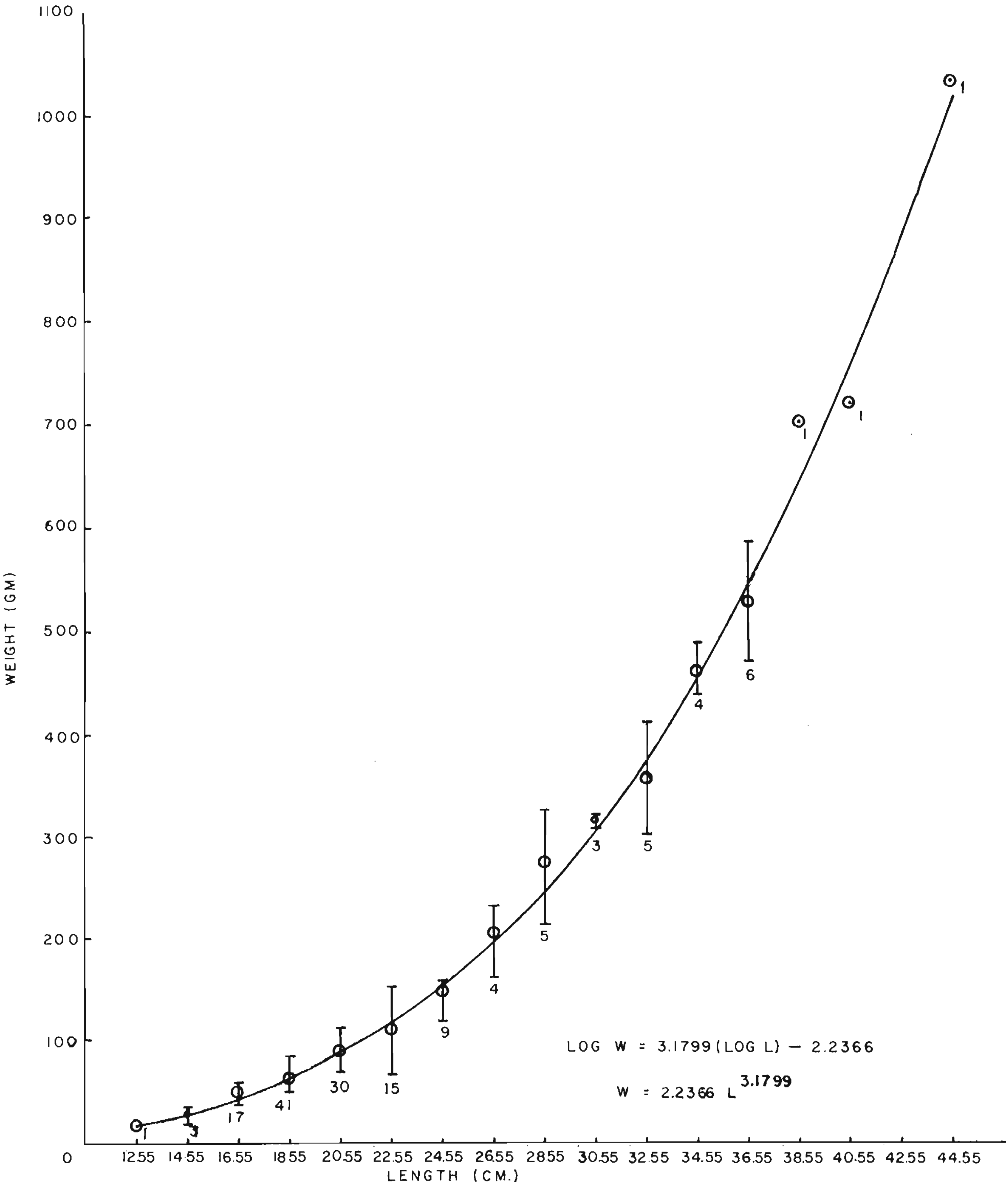

FIG. 34. LENGTH — WEIGHT RELATIONSHIP FOR OUNANICHE, RED INDIAN LAKE, 1974.

the number of fish in that length class. In general, range was greatest in the larger length classes. This might be taken to indicate an instability of overall condition in the larger and presumably older fish. However, one should be cautious in drawing inferences like this since a single meal comprising a small trout or ouananiche might be all that separates a specimen of "normal" weight for its length and one which appears to be in poor condition. In substantiation of this cautionary note, values of 3 or greater for the intercept in the length-weight regression equation are considered to indicate a population in which condition improves with length and therefore, with a value of 3.1799, this population should be considered healthy and adequately nourished on the whole.

Coefficients of condition were calculated by the Hile modification of the cube law where:

$$K = \frac{W \times 10^2}{L^3}$$

To test the hypothesis that condition improved with length in this population, condition coefficients were calculated for the means of length and weight at each length class. The results showed some disparity but the trend clearly existed with an increase in condition from 0.763 for the 12.55 cm class to 1.209 for the 44.55 cm class. Coefficients were also calculated for each age category but no significant trend could be seen since length at age was so variable. The overall condition factor for the entire population was 1.303. Though such a statistic tends to damp out all variability in the population it does serve to show that the ouananiche population in Red Indian Lake, although sparse in numbers, is in overall good physical condition. In other words the environment is not as stressful to ouananiche as might be expected and certainly not as limiting a factor as it proves to be for the other two species present. This concept will be fully elaborated in the discussion of those species.

Food habits of Red Indian Lake ouananiche are summarized in Table 19. Though precise taxonomic classification of stomach contents was not carried out, several significant observations can be made about the ouananiche diet. First of all, it should be noted that plankton was never found to be a constituent of their diet. There were fish netted which were sufficiently small (12.55 cm length class) to be utilizing this food source but evidently they have selected other foods. Scott and Crossman (1973) do not list plankton as a food item in the salmon diet in freshwater. Pippy (1966) and Wiseman (1972) found plankton to be either extensive or incidental respectively, as a food source in fish of middle length classes. Though plankton collections are not available for these studies, in both cases it was the "water-flea" or *Daphnia* which was cited as the type organism. These are among the larger planktonic organisms and are either rare or not present at all in Red Indian Lake. It is therefore most likely that the ouananiche have had to abandon this food source as being too unproductive and unavailable. Benthic organisms and incidental (terrestrial or aerial) insects comprise the large part of the ouananiche diet in the smaller length classes and this predominance is gradually taken over by fish in the larger specimens. Sticklebacks are eaten in prodigious quantities by ouananiche of all sizes but young salmonids are a component of the diet of older fish exclusively. Due to the state of decomposition it was not always possible to recognize the species of salmonids in stomachs. Some were definitely brook trout; others may have been ouananiche. It did not appear that any Arctic char were present, however this cannot be stated with certainty and, in any case, would probably only indicate the scarcity of this species.

Table 19. Food habits of Red Indian Lake ouananiche. (Percentages in parentheses).

Fork length class	Empty	Benthic and/or terrestorial invertebrates	Benthic and/or aerial invertebrates	Benthos	Detritus	Fish
12.55				1(100.0)		
14.55		1(33.3)		2(66.7)		
16.55	2	4(23.5)	8(47.1)	2(11.8)	2(11.8)	1(5.9)
18.55	6	20(50.0)	8(20.0)	8(20.0)	3(7.5)	1(2.5)
20.55	5	13(43.3)	10(33.3)	5(16.7)		2(6.7)
22.55	1	8(47.1)	2(11.8)	4(23.5)	1(5.9)	2(11.8)
24.55	1	5(45.5)	3(27.3)	1(9.1)		2(18.2)
26.55		3(50.0)	2(33.3)			1(16.7)
28.55	1		2(28.6)			5(71.4)
30.55	2	1(20.0)	2(40.0)	1(20.0)		1(20.0)
32.55	1		2(33.3)			4(66.7)
34.55	2		2(50.0)			2(50.0)
36.55	2		2(50.0)			2(50.0)
38.55						1(100.0)
40.55						1(100.0)
42.55	NO SAMPLE					
44.55						1(100.0)

Brook trout - *Salvelinus fontinalis* Mitchill

Brook trout are next in importance to ouananiche in Red Indian Lake in terms of abundance and contribution to biomass (Table 13). Seventy-one trout with a combined weight of 5143 gm were netted in this survey. This constituted 22.5% of the total sample by number but only 12.2% by weight, the mean weight of ouananiche being considerably higher.

As for ouananiche, the brook trout showed no avoidance reaction to the most concentrated dissolved levels of copper and zinc. Table 14 describes catch-effort for 14 selected sites in Red Indian Lake including the mouth of Buchans Brook. Not only did brook trout not avoid this area, they were actually caught in greater numbers there than anywhere else in the lake.

However, the brook trout population of Victoria Lake, a lake which in many ways is comparable to Red Indian Lake, is three times that of Red Indian Lake in terms of both numbers and weight caught per unit of effort (Table 15). Without attempting to draw too many broad conclusions from this one small fact, it does appear that brook trout are not as successfully established in Red Indian Lake as in Victoria Lake. One possible explanation could be that brook trout are not as capable of coping with instabilities within the environment, such as severe water fluctuations and chemical pollution, as are ouananiche and therefore are out-competed by that species.

The general population structure is much like other populations in Newfoundland with the fifth year class being the oldest observed and a mean age of 3.07. The largest fish observed was a V+ with fork length 29.9 cm and weighing 254 gm.

The Monastyrsky (log regression) method of back calculating ages is the accepted technique for brook trout. In order to verify the applicability of this method, paired observations of fork length and scale radius from empirical observations were plotted (Fig. 30). The resulting graph described a curvilinear relationship, the expected outcome, and therefore the Monastyrsky method was employed. The regression equation obtained was:

$$\text{Log } L_f = 1.1539 \text{ Log } L_s + 0.8492$$

The actual mean scale lengths and resulting calculated fork lengths at annulus formation are listed on Table 17 and graphically illustrated on Fig. 31. The growth rate thus described is not abnormal though it is generally slower than the average for 14 Newfoundland lakes compared by Wiseman (1972). No data are available for comparison with Victoria Lake stocks.

The age-length distribution of Red Indian Lake brook trout is summarized in Table 20 and the separate components, age distribution and fork length distribution are depicted in histogram form on Fig. 35 and 36 respectively. Once again, the reader is cautioned that gillnet selectivity is the principal cause of low relative abundance of observations below II+ years and 16.55 cm fork-length. As well, many of the younger brook trout and ouananiche would still be in their native streams judging by the large numbers obtained in electrofishing surveys.

Mean length was 19.0 cm for both sexes (19.5 males, 18.3 females) and mean weight was 75.3 gm. In Victoria Lake, though the mean length was slightly shorter (18.8 cm), mean weight was 81.8 gm. This seems to be an indication of somewhat better condition in the Victoria Lake population. However, sex ratio of Red Indian Lake brook trout was 1.15 to 1 (male: female) compared to 1.45 to 1 for Victoria Lake. Since males in both populations are generally heavier for their length than females, this is undoubtedly the major controlling factor in this observation.

Table 20. Age-length distribution for brook trout, Red Indian Lake, 1974. (Percentages in parentheses).

Fork length class	Age					TOTAL
	I+	II+	III+	IV+	V+	
14.55		1(50.0)	1(50.0)			2
16.55		6(27.3)	16(72.7)			22
18.55		1(3.4)	26(89.7)	1(3.4)	1(3.4)	29
20.55			7(77.8)	2(22.2)		9
22.55			4(100.0)			4
24.55				2(100.0)		2
26.55						0
28.55				1(33.3)	2(66.7)	3
Total		8	54	6	3	71

The logarithmic regression of weight on length was determined for the population of 71 brook trout and is described by the equation:

$$\text{Log } W = 2.9316 \text{ Log } L - 1.9169.$$

This regression line has been plotted on Fig. 37. Empirical observations are represented by discrete points surrounding the regression line since the population was not large enough to allow significant grouping of data. Nevertheless it is obvious from the array of observations that the regression line is a good fit since the discrete observations are so closely clustered around it.

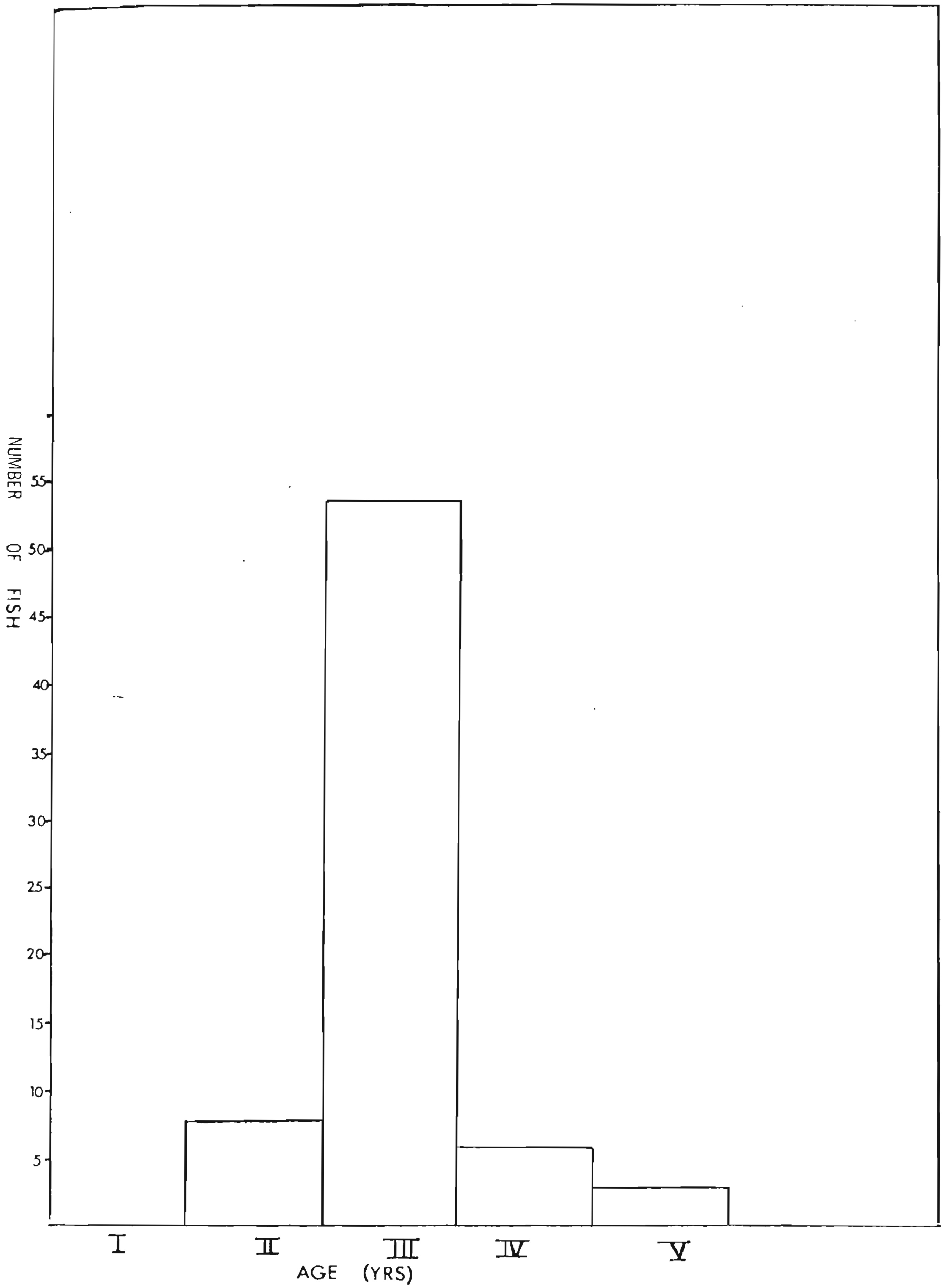

Fig. 35. Age composition of brook trout taken at Red Indian Lake, 1974.

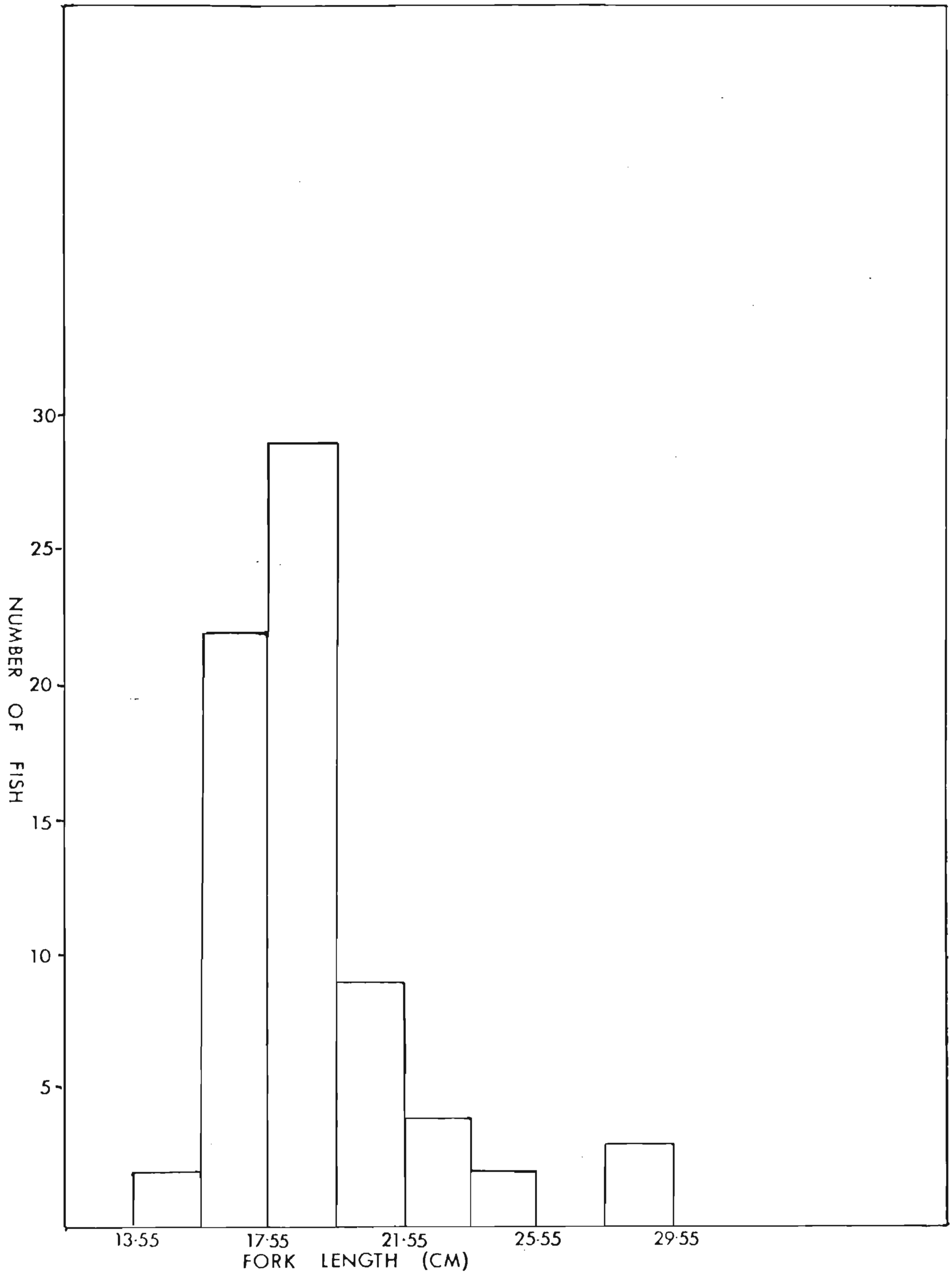

Fig. 36. Fork-length distribution of brook trout taken at Red Indian Lake, 1974.

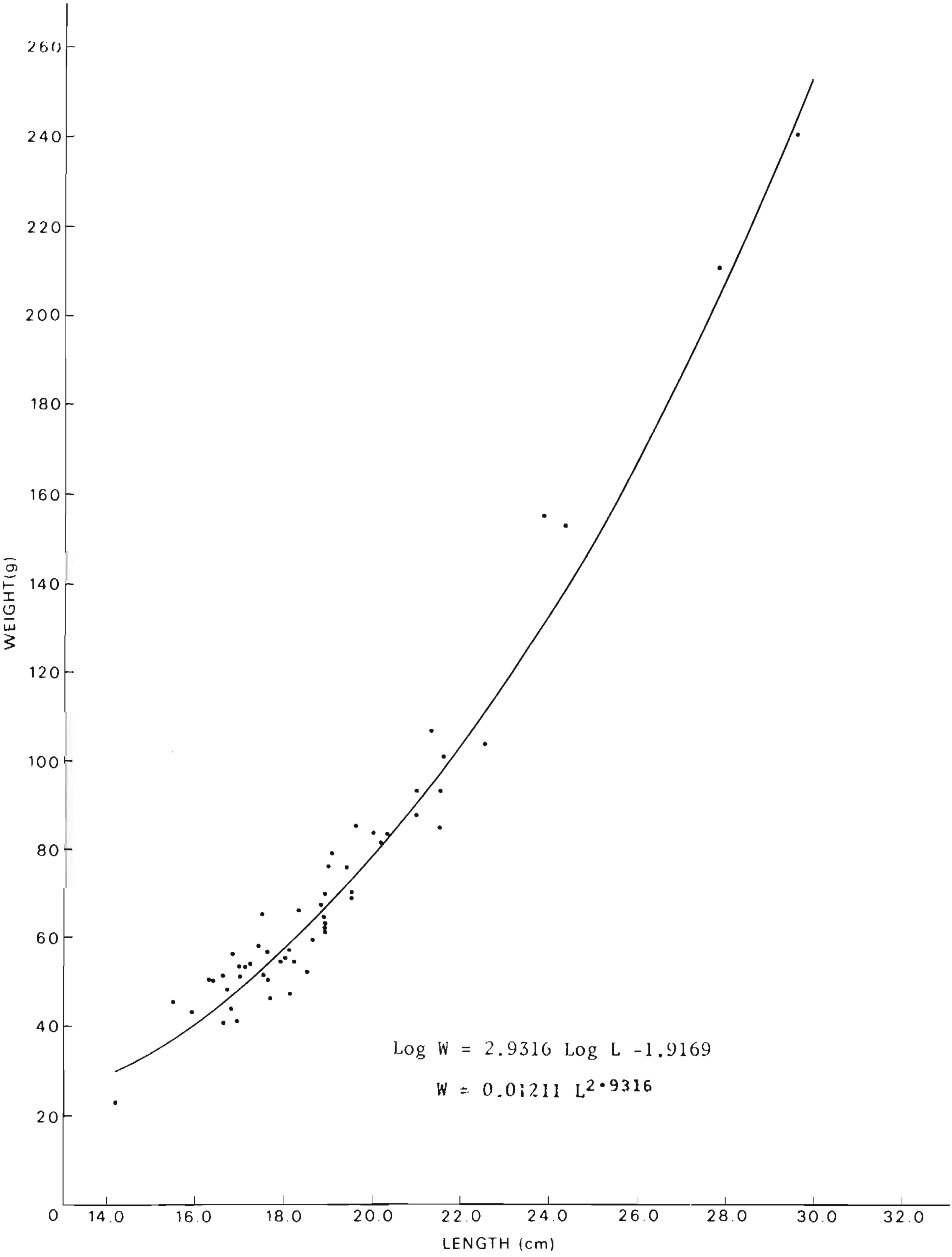

Fig. 37. Length-weight relationship for *Salvelinus fontinalis*, Red Indian Lake.

The regression coefficient (slope) in the equation is slightly less than 3 and in keeping with the theory of isometric growth, condition coefficients calculated for each length class were observed to show some slight lessening in condition with increase in size. Condition coefficients dropped from 1.038 and 1.043 for the 14.55 cm and 16.55 cm length classes to 0.987 and 0.951 for the 28.55 cm and 30.55 cm length classes, respectively. Condition coefficients calculated by age group failed to show any trend once again. The overall condition factor for the population was 1.098. Wiseman (pers. comm.) has calculated a mean condition factor for brook trout in ponds of insular Newfoundland to be 1.19. Comparatively speaking, therefore, Red Indian Lake trout are poorer in condition than average though this is perhaps statistically unverifiable without definite variances. The mean condition coefficient for brook trout in Pippy's study of Victoria Lake was 1.18, near the provincial average. Moreover, the fact that condition does drop with length rather than increase is generally considered to be indicative of some shortcoming in the environment. In this case, one could speculate that environmental disruption is a very real factor in producing this effect. And furthermore, since population numbers do appear to be down from what would otherwise be expected, the effect of this disruption is not only evidenced in a lessening of condition but also in a degraded reproductive potential.

Food sources are as limiting a resource to the brook trout as they were observed to be for the ouananiche. Once again, no fish, no matter how small, were found to be feeding on plankton. The small size and scarcity of planktonic forms is without a doubt responsible for this. The brook trout is a facultative omnivore, making use of all types of food material, both animal and plant. It is therefore indicative of the incredible scarcity of plankton that none was found in any of the stomachs observed.

What is equally astonishing is the fact that only three trout were found to be feeding on fish, in this case sticklebacks and trout. Fish are generally a favored food source of brook trout (Scott and Crossman, 1973) and they are not at all averse to engaging in cannibalism. It is quite possible that competition by ouananiche for this food source has rendered it virtually impossible for brook trout to make use of it.

The principal constitutent of the brook trout diet in Red Indian Lake is benthos with a substantial input of terrestrial and aerial insects as well.

Arctic char - *Salvelinus alpinus* Linnaeus

Arctic char are reported for the first time, in published form, in the results of this survey. A previous survey, conducted by the Department in 1972, discovered the presence of this species in Red Indian Lake but the results of that survey were not published. In fact, the species is so rare in this lake that it is little wonder its presence was not noted before. Only 14 specimens were collected out of a sample of

316 fish (Table 13). From this record it seems they represent less than 5% of the salmonid fish fauna of the lake. In fact, this is probably an underestimation of their presence since all netting in this survey was done near the shoreline. The char, however, were only caught when the nets happened to be placed in deeper water (greater than 8 m). Since "landlocked" char are known to prefer the deeper, colder waters of lakes, it is a fair assumption that netting away from the shoreline would have yielded a higher percentage of char.

Table 21. Food habits of Red Indian Lake brook trout. (Percentages in parentheses).

Fork length class	Empty	Benthic and/or terrestorial invertebrates	Benthic and/or aerial insects	Benthos and fish	Fish	Benthos	Detritus
14.55		1(50.0)			1((50.0)		
16.55	2	8(40.0)	9(45.0)			2(10.0)	1(5.0)
18.55	3	16(61.5)	4(15.4)	1(3.8)		5(19.2)	
20.55		5(50.0)	3(30.0)			1(10.0)	1(10.0)
22.55		3(100.0)					
24.55	1		1(100.0)				
26.55	NO SAMPLE						
28.55			1(50.0)	1(50.0)			
30.55		1(100.0)					

The scarcity of specimens made statistical analysis of the population impractical. The raw data obtained for the species are displayed in Table 22. From this it can be seen that the mean age is 3.9 with a range from III+ to VI+. This is the same range of ages found in Victoria Lake (Pippy, 1966), however, the mean age there was 5.08. The Victoria Lake study also found char to be in greater abundance with a catch/effort of 3.36 individuals or 238.8 gm compared to 0.9 individuals and 42.1 gm on average for Red Indian Lake. Both these phenomena may be in part due to experimental design in that the Victoria Lake survey did employ some deep water netting, thus sampling the areas where the char are in greater abundance and also where the older individuals of the species generally congregate.

Table 22. Raw data on Red Indian Lake Arctic char.

Fork length (cm)	Whole weight (gm)	Sex	Age	Stomach contents
14.7	26	M	3+	Plankton
17.2	42	M	3+	Empty
16.6	46	M	3+	Benthos
16.4	38	F	3+	Plankton
19.8	50	F	3+	Insects
17.2	43	M	4+	Moths*, Insects
17.6	46	M	4+	Empty
17.0	47	M	4+	Benthos & Plankton
15.7	38	F	4+	Benthos, Moths, other Insects
16.2	40	F	4+	Detritus
17.4	54	F	4+	Empty
18.3	49	M	5+	Plankton
19.2	57	M	5+	Plankton
19.7	67	M	6+	Benthos, Moths, other Insects

*These moths were adult spruce budworm, *Choristoneura fumiferana* which hatched in the millions during one two-day period. Fish of all three species gorged themselves on these moths during this period.

The average lengths at age of char are very similar in both these lakes. However, the mean weight at a given age or length is considerably less in Red Indian Lake (eg. VI+ 67 gm in Red Indian Lake, 83 gm in Victoria Lake). The mean length and weight for the population is 17.4 cm and 45.9 gm in Red Indian Lake, and 18.2 cm and 71.1 gm in Victoria Lake. In both cases, the results are lower than those found in Butts Pond (Seabrook, 1961) and are also lower than average for island populations in general. More importantly, the age structure is drastically stunted. Landlocked char in Butts Pond live to IX+ and elsewhere to XV+ or more (Scott and Crossman, 1973). All these phenomena indicate a degree of unsuitability within the environment, more so in Red Indian Lake than in Victoria Lake.

As a final note of substantiation on the matter of habitat unsuitability, the condition coefficients for the population are demonstrably poor. The overall coefficient is 0.871 (1.179 in Victoria Lake). As mentioned previously, this is generally taken to indicate some insufficiency in the environment. There is no progressive trend in the coefficients associated with age; they are all invariably poor. However, an overall decreasing trend associated with length can be detected (0.932 at length 16.55 cm to 0.759 at 20.55 cm). This too indicates an unsatisfactory *statis quo* between the species and its surroundings.

The male-female ratio in Red Indian Lake was 1.8 to 1; high compared to the 1.25 to 1 found in Victoria Lake but no inferences can be drawn from this.

The choice of food of the char population (Table 22) is interesting. Like the other two salmonid species, the benthic community along with incidental occurrences of non-aquatic insects are the large contributors to the diet of char. However, unlike brook trout and ouananiche, the char were found to depend rather heavily on the sparse plankton community for nourishment. It may be this single fact more than any other which has led to the poor body condition of the char. The inference drawn is that a combination of two factors has ruled in the selection of this diet item. Firstly, the char occupy a niche which is uncondusive to healthy growth; the deep and unproductive profundal zone. And then, when the char, particularly the younger element, venture into the shallows, they are poorly equipped to compete with the brook trout and ouananiche which are both larger at any given age and also considerably larger in general. In other areas (Scott and Crossman, 1973) landlocked char are known to be predominantly carnivorous and, to some extent cannibalistic at lengths in excess of 20 cm. No fish of this size were captured at Red Indian Lake and therefore the theory cannot be tested. None of the fish netted showed any tendency to the carnivorous habitat.

IN SITU BIOASSAY EXPERIMENT

In an effort to determine the deleterious effects, if any, of existing dissolved heavy metals concentrations and silt loading in Buchans Brook a simple bioassay experiment was designed and carried out.

Briefly, the method used was to expose 10 fish (six trout and four ouananiche) of varying sizes to the presumed deleterious environment by holding them in a wire mesh cage partially submerged in the Brook (see Fig. 11). The cage was placed just north of the Highway 370 bridge, about 2 miles downstream from the tailings outfall (Fig. 38). A control group of 10 fish, closely matched for species, size and sex, was placed in an identical holding cage in Red Indian Lake itself near the mouth of a small brook about 15 miles southwest of Buchans Brook.

The fish used were obtained by electrofishing in small brooks near the control site and were held for 48 hours prior to commencement of the experiment to ensure that no harmful effects had resulted from this mode of capture and subsequent handling.

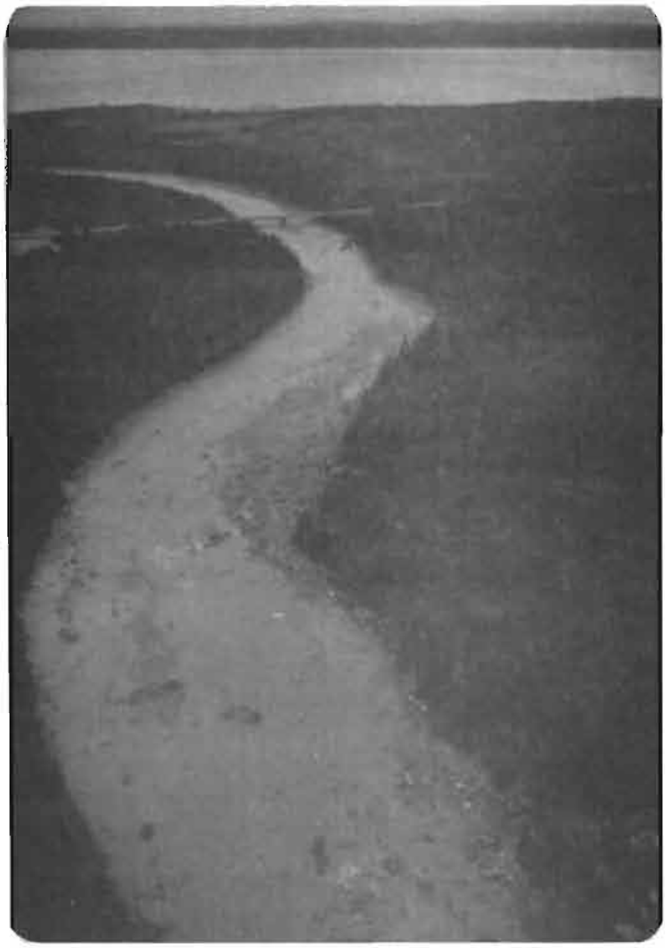

Fig. 38. Location of *In Situ* bioassay (X), Buchans Brook.

No Arctic char were used in the experiment. It was felt any results obtained using char would be invalid since char were not observed in the brooks and they would therefore be in an alien environment subject to stresses the other species were accustomed to.

The experiment lasted for 96 hours. Observations were made for the first 8 hours as follows: after ½ hour, 1½ hours, 3½ hours and 7½ hours. From that point on, observations were made at 4-hour intervals except during the third and fourth nights when an 8-hour period between observations elapsed. At intervals during the 96 hours, 14 water samples were collected for analysis of heavy metals concentrations at each site and five samples for standard water quality analysis.

Fluctuations in water level in both the brook and lake hampered the experiment constantly. At the start of the experiment the cages were in approximately 2½ ft of water. Each night the water level in the brook dropped continually until about 6:30 a.m. at which time it began to rise again. Total fluctuations varied but on average were about 13 inches. The presumed reason for this fluctuation was shutdown of certain mill operations during the night. Over the full duration of the experiment there was an overall drop in water level in the brook sufficient to necessitate moving the cage farther out into the stream. At the control site in the lake, water fluctuations were even more severe due to spilling at the Exploits dam. The cage there had to be moved twice to deeper water. A side effect of fluctuations in the brook was the tremendous increase in silt loading as water levels rose again in the mornings, resulting from the sudden increase in current velocity and increased runoff from tailings ponds.

The results of the water quality analyses are found in Tables 4, 5, 6 and 7. General water quality at the control site is rather interesting in that it shows elevated levels of pH, total hardness, specific conductance, calcium and chloride ion all of which are indicators of more productive waters than are generally found in Newfoundland. Evidently, the small brook near which the control cage was positioned is spring fed. Though this was not known before the experiment was completed, it is not felt to be a significant confounding variable.

General water quality at the experimental site is unremarkable (Table 5) though the pH is a little lower than might be considered the norm for such a brook.

Heavy metal concentrations at the experimental site fluctuated somewhat but in not one case did they attain critical lethal levels for salmonids. In fact, the Incipient Lethal Limits of copper and zinc to these species are 35 μg/ℓ and 425 μg/ℓ respectively and even these levels were not obtained. Of course, the heavy metal concentrations at the control site never went much beyond what might be considered normal background levels in a watershed containing metals-bearing rock (Table 7).

From these results then, it is little wonder that no chemically-related mortality occurred during the 96 hours. In fact, the only two fish to die were crushed by a rock used to weighdown the experimental holding cage when it was necessary to move it because of lowered water levels. No subjective behavioural differences could be observed between the experimental and control fishes and they all appeared in equally good condition at the end of the experiment.

At the time these results were obtained it was felt that possibly a 96-hour period was insufficient to demonstrate more chronic effects. For, if indeed these results were valid there should be fish occurring naturally in the brook. To test this assumption a second trip to the brook was made 1 month later and a brief electrofishing survey was conducted in the area of the experiment. Several sticklebacks and young brook trout were collected, in apparently excellent physical condition. It could only be concluded, then, that if fish were not spawning in the brook, they were at least utilizing it for a rearing area. Furthermore, the fish captured were almost certainly inhabiting that stretch of river for extended periods since the nearest "clean" water was at least 2 miles upstream above the tailings outfall, or 3 miles downstream in Red Indian Lake itself.

SUMMARY

1. A limnological survey was conducted at Red Indian Lake in the summer of 1974 to assess the impact of industrial activities on the fish resource.

2. Two principal disruptive activities, zinc-copper mining and milling, and pulp and paper harvesting, were isolated for particular examination.

3. Environment Canada requires specific information at this time regarding the suitability of Red Indian Lake for fish passage in order to decide on implementation of Phase III of its multi-million dollar Exploits River salmon development scheme.

4. Analyses of general water quality, dissolved copper and zinc ions, and sediment chemistry were among the physical observations completed.

5. An existing incomplete bathymetric map of the lake was further refined in order to obtain accurate morphometric data.

6. Biological observations included sampling of plankton, benthos, and fish populations.

7. General water quality throughout the lake was found to be typical of the unproductive oligotrophic waters of Newfoundland.

8. Applying Ryder's Morphoedaphic Index it was determined that, due to the low ionic content of the water and the extreme depth of the lake, Red Indian Lake has a predicted fish production of only 1.19 lb/acre/yr.

9. Heavy metals within the lake are present at concentrations well below lethal levels. Some readings in excess of 1(one) Incipient Lethal Limit of zinc were found within Buchans Brook itself.

10. Extreme levels of heavy metals accumulation in the sediment (e.g. 40,000 ppm zinc) were observed; excessive levels in the magnitude of 1500 ppm copper and 3000 ppm zinc were recorded as far away as 25 miles from Buchans Brook.

11. Water levels fluctuated more than 23 ft (7 m) in 1974; fluctuations in excess of 30 ft (9 m) are not uncommon.

12. Both the plankton and benthic communities were found to be depauperate; co-variance analysis showed no significant reaction of plankton communities to elevated levels of dissolved copper and zinc. It is speculated that low abundance of these organisms results from the oligotrophy of the lake and, for the benthos, from instability of the littoral zone due to water level fluctuations.

13. Four species of fish are endemic to Red Indian Lake: landlocked *Salmo salar* Linnaeus (ouananiche), landlocked *Salvelinus alpinus* Linnaeus (Arctic char), *Salvelinus fontinalis* Mitchill (brook trout), and *Gasterosteus aculeatus* Linnaeus (three-spined stickleback).

14. From comparison of growth parameters, length-weight regressions, condition coefficients and stomach analyses, it was found that, of the three salmonids, only the ouananiche were normally represented and in average or better physical condition. The primary cause of insufficiencies in these populations was a shortage of available food sources which in turn was closely associated with oligotrophy and fluctuating water levels.

15. A short-term *in situ* bioassay in Buchans Brook failed to show chronic mortality or behavioural changes in ouananiche or brook trout resulting from levels of zinc and copper present there.

16. No direct deleterious effects within the lake itself could be attributed to heavy metal concentrations. In any case, levels present were invariably below ILL and should therefore not present a barrier to migration.

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Appendix I

Heavy metals concentrations in bottom cores
from Red Indian Lake, 1974.

Appendix I.

Sample	Chemical parameter (ppm) \ Core length (mm) top - bottom	15	25	35	45	55	65	75	85	95	105	115	125
Core 1	Copper	280	200	40	40	10	10	10	10	10	10	10	<10
	Lead	480	300	120	10	<10	10	<10	<10	<10	<10	<10	<10
	Zinc	2630	2000	630	180	120	120	100	80	60	80	80	70
Core 2	Copper	980	320	150	70	60	30	50	10	10	10		
	Lead	670	270	110	70	70	40	50	30	20	30		
	Zinc	5230	1280	730	680	700	380	350	230	150	130		
Core 3	Copper	1010	960	820	1850	1380	610	1150	4750	5480	1840		
	Lead	2440	1700	1900	3600	2070	970	1210	5200	2180	1630		
	Zinc	10130	11130	8580	11500	5830	1900	3750	34080	39680	6580		
Core 4	Copper	860	750	790	800	1130	820						
	Lead	860	380	680	1010	1140	950						
	Zinc	7500	6180	6180	5880	7050	6300						
Core 5	Copper												
	Lead	No core received											
	Zinc												
Core 6	Copper												
	Lead	No core received											
	Zinc												
Core 7	Copper												
	Lead	No core received											
	Zinc												

Appendix I (Cont'd.)

Sample	Core length (mm) top - bottom / Chemical parameter (ppm)	15	25	35	45	55	65	75	85	95	105	115	125
Core 8	Copper	1000	930	1000	1160	690							
	Lead	720	720	800	910	260							
	Zinc	6380	6130	6300	6550	4050							
Core 11	Copper	1410	1030	1260	1500	1980	1980	1830	1580	2030	50		
	Lead	1100	2430	1460	1060	1200	1360	1800	1370	1130	20		
	Zinc	12500	9880	10000	10000	12500	13000	12500	12500	13000	180		
Core 12	Copper	4800	4650	4800	4750	4650	4450	4890	3730	4600			
	Lead	670	470	1240	1040	910	880	1050	1320	990			
	Zinc	26250	25000	28000	30000	26750	26750	28750	20500	29250			
Core 13	Copper	780	220	220	490	220	530	780	40				
	Lead	740	1300	1130	600	900	880	2080	780				
	Zinc	13000	3000	3130	8000	2250	5000	11750	4380				
Core 20	Copper	740	30	10	10	10	10	10	10				
	Lead	940	70	30	20	20	20	20	20				
	Zinc	3960	190	130	100	70	80	70	60				
Core 21	Copper	580	40	20	20	30	20	30	30	30	40		
	Lead	570	70	20	20	30	10	10	10	10	20		
	Zinc	8050	430	130	140	170	140	160	140	140	190		
Core 22	Copper	880	2000	20	40	40	40	40	30	40	40	50	50
	Lead	1330	1780	1740	20	20	20	20	10	20	20	10	10
	Zinc	16250	13750	180	130	100	110	110	90	110	100	100	100

Appendix I (Cont'd.)

Sample	Chemical parameter (ppm) \ Core length (mm) top - bottom	135	145	155	165	175	185	195	205	215	225	235	245	255
Core 22 (Cont'd.)	Copper	50	40	40	40	40	40							
	Lead	10	10	10	10	10	10							
	Zinc	90	80	90	80	90	80							
		15	25	35	45	55	65	75	85	95	105	115	125	
Core 23	Copper	700	960	2000	2300	20	40	30	40	40	40	30	40	
	Lead	90	340	1950	1130	30	30	20	20	20	20	20	20	
	Zinc	8380	7130	11750	7430	10	140	110	110	100	100	100	100	
		135	145	155	165	175	185	195	205	215	225	235	245	255
	Copper	40	30	50	30	40	40	40	40	30	50	40	40	50
	Lead	20	20	20	10	10	10	10	10	10	10	10	10	40
	Zinc	110	60	110	70	90	100	100	90	80	90	80	90	160
		15	25	35	45	55	65	75	85	95	105			
Core 24	Copper	660	1050	20	10	10	10	30	30	30	30			
	Lead	1400	590	10	20	10	20	30	20	30	20			
	Zinc	6480	6150	50	70	60	70	80	70	80	70			

Appendix I (Cont'd.)

Sample	Chemical parameter (ppm) \ Core length (mm) top - bottom	15	25	35	45	55	65	75	85	95	105	115	125	135
Core B	Copper	420	120	20	20	30	30	30	30	30	30	30	30	
	Lead	1080	350	10	10	10	10	10	10	10	10	10	10	
	Zinc	4050	1800	130	130	130	130	130	100	100	80	160	130	
Core C	Copper	850	30	40	40	40	40	40	40	40	40			
	Lead	1290	30	30	20	30	20	30	30	20	20			
	Zinc	3800	100	100	90	100	90	90	90	90	80			
Core E	Copper	20	20	30	30	30	20	30	20	50				
	Lead	10	10	10	10	10	10	10	10	10				
	Zinc	130	110	70	60	60	60	60	60	60				
Core F	Copper	430	170	40	30	30	30	40	10	10	10			
	Lead	700	540	80	20	20	20	10	10	10	10			
	Zinc	3180	1250	280	140	110	70	40	40	40	60			
Core G	Copper	50	50	40	40	40	40	50						
	Lead	20	20	20	20	20	20	20						
	Zinc	190	280	240	180	130	90	90						
Core H	Copper	220	190	50	50	70	50	40	60	60	40	40	50	50
	Lead	520	490	70	40	90	40	20	30	50	30	30	30	70
	Zinc	1250	930	230	230	280	300	370	230	230	160	230	180	240
Core I	Copper	120	380	220	50	40	40	50	30	30				
	Lead	560	1450	620	160	130	90	190	40	50				
	Zinc	1000	2750	1250	250	190	190	330	170	180				

Appendix II

Temperature recordings at 20 ft intervals for each station.

Appendix II.

Station Number / Depth Feet	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0	12.0	12.5	13.0	9.9	10.1	5.5	7.2	6.0	6.0	5.4	6.4	6.6	6.5	10.5	10.1	10.3	10.7	10.9	9.7	10.6	10.2
20	10.0	9.2	9.1	7.0		5.5	6.0	6.0	5.5	5.0	5.5	5.2	5.9	10.0	10.1	10.0	10.3	10.1	9.2	10.2	10.1
40						5.2		6.0	5.1	5.0	5.1	5.1	5.0	10.0	10.0	9.8	10.1	9.6	9.1	10.0	9.1
60						4.8		5.2	5.0	5.0	5.1	5.0	5.0	10.0	9.7	9.8	9.5	9.0	9.1		8.8
80								5.0	5.0	4.8	5.0	5.0	5.0	10.0	9.0	9.2	9.0	9.0	8.9		7.9
100									5.0		5.0	5.0	5.0	8.5	8.5	8.4	8.8	8.4	8.2		7.0
120									4.9		4.9	5.0		7.7	7.5	8.8	8.0	8.0	7.2		6.1
140												4.8			6.5	8.0		7.0	6.9		5.4
160															5.2	6.1		5.7	6.8		5.0
180																					
200																		5.3			
220																					4.2
240																					
260																					
280																					
300																					
320																					
340																					
360																					
380																					
400																					
420																					
440																					
460																					
480																					
Date	25/6		26/6	27/6						28/6			2/7			3/7			4/7		

Appendix II (Cont'd.)

Station Number / Depth Feet	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
0	9.1	8.7	12.8	12.7	12.0	14.2	13.0	13.0	12.3	11.8	11.8	11.6	11.5	11.3	11.8	12.2	12.2	12.7	12.7	12.5	12.1
20	9.1	8.0	12.8	11.5	11.5	11.0	10.1	11.0	11.5	11.7	11.5	11.6	11.4	11.3	11.8	11.0	11.6	12.3	12.5	11.5	11.9
40	8.2	7.4	11.3	11.0	10.0		9.5	10.8	10.7	10.5	11.5	11.5	11.4	11.3		10.0	10.5	10.2	10.2	10.1	10.0
60	7.9		11.0	10.5				9.3	6.5	9.8	11.2	11.2	11.4	11.3			9.6	9.0	9.0	8.1	8.1
80	7.3		7.0	8.0				7.0	5.5	6.5	11.1	10.9	11.0	10.8			8.8	8.1	7.3	6.4	7.2
100	6.2		5.5	7.0				5.5	5.4	6.0		10.0	9.5	8.0			8.0	7.7		6.0	6.4
120	5.9		5.1	6.1					5.1	5.6		2.5	7.3				6.9	7.0		6.0	6.2
140	5.7		5.1							5.3		6.3	6.5				6.5	6.2		5.8	5.8
160	5.2		5.0	5.7						5.0		6.0	6.0				6.0	6.0		5.7	5.5
180	5.0		4.9														5.5				
200																					
220				4.8																	
240									4.5	4.1		4.8								5.0	
260																					
280																					4.3
300																					
320																					
340													4.3							4.2	
360																					
380																					
400																		4.2			
420																					
440																					
460																					
480																					
Date	4/7		17/7			18/7						19/7				25/7				26/7	

Appendix II (Cont'd.)

Station number / Depth Feet	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
0	13.0	13.2	15.5	15.0	16.0	15.0	12.0	12.3	12.6	13.8	13.7	12.2	13.0	12.2	12.3	12.1	12.3	13.3	13.5	13.5	12.9
20	12.1			14.0		11.9	10.3	11.5	11.9	12.1	12.9	11.0	12.3	10.1	12.2	11.7	11.6	12.5	12.8	11.9	12.4
40	9.6		10.7	10.1		9.4	9.8	9.9	11.0	11.4	11.0	9.9	9.8		11.2	10.5	11.3	12.0	11.1	11.0	10.9
60				8.0	8.1		8.5	8.4	8.8	9.8	7.9	8.2	9.1		8.2	10.1	9.8	10.1	10.1	8.2	8.2
80				7.0				8.1	7.9	7.3	7.3	7.9	8.5		7.3	7.2	8.7			7.9	7.2
100			6.7	6.2	6.9			7.7	7.2	6.9	7.0	7.1	7.2		6.9	7.0	7.9			7.1	6.8
120				5.8				7.4	7.0	6.9	6.8	6.8	6.9		6.4		7.0				
140					5.2			7.1	6.8	6.2	6.2	6.3			5.8	6.0				6.1	6.0
160				5.9				6.8	6.3	6.1	6.1	6.0									
180																					
200																					
220																					
240											5.1										
260																				4.6	
280																					
300																					
320									4.5						4.5						
340				4.8																	
360										4.3											
380																4.5					4.2
400												4.3									
420																					
440																					
460																					
480																					
Date	26.7		29/7				30/7								31/7						

Appendix II (Cont'd.)

Station number / Depth Feet	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
0	13.6	13.0	11.0	13.8	13.5	9.2	12.8	10.0	10.5	12.8	13.2	13.1	13.0	12.0	12.0	11.1	12.2	13.2	12.4	12.0	11.8
20	13.0	12.0	11.0	12.0	12.5	9.0	12.4	10.0	10.4	12.8	13.0	12.5	12.3	12.0	11.9	10.5	12.0	12.0	11.8	11.3	11.3
40	11.2	11.2	11.0	10.0	10.6	8.7	11.0	9.9	10.1	11.2	11.9	12.2	11.2	11.5	11.6	9.0	10.0		10.5	9.9	10.0
60	10.1	10.0	11.0	8.2	9.5	8.1	10.1	9.9	10.0	10.2	10.9	10.7	10.1	10.3	11.2	8.4	8.9		9.1	8.5	8.3
80	7.4	8.0	10.5	8.0	8.0	7.8	8.5	9.8	10.0	9.7	9.8	9.5	9.9	9.8	10.3	7.1	8.2		8.0	7.3	7.0
100	6.7	7.0	10.1	7.2	7.1	7.3	7.2	9.6	10.0	9.1	9.2	9.2	9.5	9.4	9.9	6.3	7.0		7.5	6.5	6.2
120			9.8			7.0		9.0	9.1	8.8	8.9	9.0	9.0	9.0	9.1	6.0	6.1		7.0	6.0	5.9
140	5.2		8.3			6.6		8.7	8.0	8.5	8.0	8.8	8.7	8.5	9.0	5.7	5.9		5.9	5.8	5.6
160			7.9			6.1		8.1		8.1	7.9	8.5	8.2	8.0	8.8	5.5	5.7		5.0	5.5	5.5
180							5.8									5.1			5.0		
200																					
220																				5.1	
240	5.0			5.1				5.1			5.9	6.3			5.9						
260																					
280																					
300			4.9			5.0			5.5	5.2			5.2	6.5							
320																	5.0				
340												5.5									
360																					
380								5.0			5.0				5.0						
400																					
420			4.7			4.6								5.0							
440					4.8								5.1								
460										5.1											
480									4.8												
Date	31/7		8/8	1/8		8/8	1/8	8/8		9/8				13/8		14/8					

Appendix II (Cont'd.)

Station Number / Depth Feet	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
0	12.0	13.0	13.8	14.0	14.0	12.3	12.0	11.4	11.4	12.0	12.0	11.8	12.0	12.2	12.8	12.7	11.9	12.2	12.5	13.1	14.4
20	11.6	11.5	12.7	12.0	11.7	12.0	12.0	11.4	11.4	11.9	11.9	11.1	11.0	12.0	12.3	11.9	11.3	11.4	11.9	9.9	9.3
40	10.9	9.8	11.6	10.8	11.0	10.5	11.0	11.1	11.4	10.6	10.9	11.1		10.5	10.0	9.9	10.0	10.1	9.9		
60	10.0	8.3	9.2	8.3	9.1	9.2	9.0	9.9	9.0	8.8	9.0	10.0		9.0	8.9	9.3	9.1	9.0	9.0		
80	8.8	6.5		6.8		8.0	7.4	8.0	8.0	7.0	7.3	8.3		7.8	7.0	7.0	8.0	7.5	7.7		
100	7.1	7.0	7.0		7.2	6.8	6.0	7.0	7.0	6.0	6.8	7.8		6.4	6.0	6.0	6.6	6.7	6.5		
120	6.9	6.0					5.8	6.8	6.5	5.8	6.1	6.9		6.0	5.8	5.8	6.0	5.9	5.8		
140	6.2	5.3		5.7	5.8		5.4	6.0	6.2	5.4	6.0	6.4		5.5	5.4	5.5	5.7	5.6	5.4		
160	5.7	5.1	5.8				5.0	5.8	5.9	5.4	5.9	5.9		5.3	5.5	5.3	5.4	5.3	5.1		
180															5.2						
200																					
220					5.1												5.0				
240				5.0		5.0	5.0	5.0	4.9			5.0									
260			4.9								5.0										
280	4.8	5.0												4.7		4.8		4.9			
300					5.0												4.7				
320							4.8														
340				4.8		4.7			4.4												
360												4.8									
380																					
400																					
420																					
440																					
460																					
480																					
Date	14/8	15/8					15/8	16/8					19/8							20/8	

Appendix II (Cont'd.)

Station number	106	107	108	109
0	15.1	15.0	15.4	17.0
20	10.0	10.0		
40				
60				
80				
100				
120				
140				
160				
180				
200				
220				
240				
260				
280				
300				
320				
340				
360				
380				
400				
420				
440				
460				
480				
Date	20/8	20/8	20/8	20/8

Depth Feet

Appendix III

Heavy metal concentrations -
Red Indian Lake water samples.

Appendix III.

Station	Line No.	Date	Temp. C at depth 5 ft	Copper ppb	Zinc ppb
HM 1	23	21/8/74	14.2	4.0	41.0
HM 2	22	21/8/74	14.3	2.5	38.0
HM 3	21	21/8/74	14.9	2.5	35.0
HM 4	20	21/8/74	14.7	3.0	35.0
HM 5	19	21/8/74	15.3	2.5	30.0
HM 6	18	21/8/74	15.4	2.5	49.0
HM 7	18	21/8/74	15.0	2.5	35.0
HM 8	19	21/8/74	15.1	4.0	38.0
HM 9	19	21/8/74	15.8	2.5	49.0
HM 10	16	21/8/74	16.2	2.5	41.0
HM 11	16	21/8/74	16.0	2.5	25.0
HM 12	16	21/8/74	15.6	2.5	26.0
HM 13	16	21/8/74	15.6	5.0	38.0
HM 14	15	21/8/74	15.9	3.5	35.0
HM 15	15	21/8/74	16.0	2.5	35.0
HM 16	15	21/8/74	16.1	2.5	25.0
HM 17	15	21/8/74	16.9	2.5	44.0
HM 18	Mouth of Buchans Brook	21/8/74	19.5 (surface)	6.0	540.0
HM 19	14	21/8/74	16.8	2.5	28.0
HM 20	14	21/8/74	17.0	9.0	32.0
HM 21	14	21/8/74	16.9	3.0	33.0
HM 22	14	21/8/74	16.2	5.0	33.0
HM 23	13	21/8/74	16.9	13.0	38.0
HM 24	13	21/8/74	16.9	4.0	35.0
HM 25	13	21/8/74	16.9	3.0	33.0
HM 26	13	21/8/74	16.4	2.5	20.0
HM 27	12	21/8/74	16.2	2.5	38.0
HM 28	12	21/8/74	17.1	21.0	43.0
HM 29	12	21/8/74	17.0	2.5	35.0
HM 30	12	21/8/74	17.1	2.5	33.0
HM 31	11	21/8/74	17.0	2.5	20.0
HM 32	11	21/8/74	16.3	4.0	38.0
HM 33	11	21/8/74	16.9	2.5	55.0
HM 34	10	21/8/74	17.1	2.5	54.0
HM 35	10	21/8/74	18.0	13.0	50.0
HM 36	10	21/8/74	18.0	4.0	50.0
HM 37	9	21/8/74	17.6	2.5	46.0
HM 38	9	21/8/74	17.4	3.0	55.0
HM 39	8	21/8/74	17.4	2.5	55.0
HM 40	7	21/8/74	17.9	3.0	59.0
HM 41	5	21/8/74	19.0	2.5	23.0
HM 42	3	21/8/74	17.3	2.5	35.0
HM 43	1	21/8/74	19.0	2.5	32.0

Appendix III (Cont'd.)

Station	Line No.	Date	Temp. C at depth 5 ft	Copper ppb	Zinc ppb
HM 44	25	22/8/74	13.9	2.5	41.0
HM 45	27	22/8/74	14.1	3.0	50.0
HM 46	29	22/8/74	13.3	2.5	48.0
HM 47	31	22/8/74	14.1	2.5	35.0
HM 48	33	22/8/74	13.4	2.5	31.0
HM 49	35	22/8/74	12.0	2.5	48.0
HM 50	37	22/8/74	12.8	2.5	46.0
HM 51	39	22/8/74	16.0	2.5	26.0

Appendix IV

Field analysis of water quality,
Red Indian Lake, 1974.

Appendix IV.

Station	O_2 upper	O_2 lower	pH	CO_2	Hardness	Secchi ft
1	11		7.8	5	17.0	11
2	13		7.3	5	17.0	11
3	13		7.2	5	17.0	11
4	12		7.4	5	34.0	9
5	11		7.1	5	34.0	9
6	10	8	7.2	5	34.0	10
7	7		7.2	5	42.5	11
8	13		7.4	5	17.0	14
9	12		7.4	5	17.0	12
10	10	13	7.4	5	17.0	13
11	13		7.3	5	8.5	14
12	12		7.3	5	8.5	13
13	13		7.5	5	8.5	13
14	12	12	7.3	5	17.0	12
15	12	12	7.1	5	8.5	11
16	11	13	7.2	5	8.5	11
17	12		7.4	5	8.5	11
18	13	12	7.3	5	8.5	11
19	13		7.3	5	8.5	11
20	12		7.4	5	8.5	11
21	13	13	7.4	5	8.5	12
22	12		7.4	5	17.0	12
23	12		7.3	5	8.5	13
24	13	12	7.4	5	8.5	13
25	13		7.4	5	8.5	14
26	12		7.2	5		14
27	11		7.4	10	8.5	14
28	12		7.4	5	8.5	14
29	11		7.4	5		12
30	11	12	7.3	5	17.0	13
31	11	11	7.2	5	8.5	12
32	12		7.3	5	8.5	12
33	12	13	7.3	5	17.0	12
34	9	12	7.3	5	17.0	12.5
35	10		7.4	5	8.5	11
36	10		7.4	5	8.5	12
37	10		7.4	5	17.0	11.5
38	10		7.4	5	8.5	13
39	10	10	7.4	5	8.5	13
40	10		7.4	5	17.0	12.5
41	11	12	7.4	5	8.5	13
42	10	11	7.4	5	8.5	14
43	10		7.4	5	8.5	14
44	9		7.4	5	8.5	12
45	11	11	7.4	5	8.5	16.5

Appendix IV (Cont'd.)

Station	O_2 upper	O_2 lower	pH	CO_2	Hardness	Secchi ft
46	10	13	7.3	5	8.5	18
47	10		7.2	5	8.5	16
48	9		6.9	5	8.5	17
49	10		7.0	5	8.5	12
50	10		7.0	5	8.5	15
51	10	11	7.1	5	8.5	15.5
52	10	10	7.3	5	8.5	15
53	10	11	7.0	5	8.5	16
54	11	11	7.1	5	8.5	15
55	10		7.1	5	8.5	18
56	9	9	7.3	5	8.5	14
57	10	11	7.3	5	8.5	14
58	10	11	7.1	5	8.5	14
59	9		7.1	5	8.5	14
60	10		7.0	5	8.5	14
61	10		7.0	5	8.5	14
62	9	11	7.0	5	8.5	14
63	11	12	7.0	5	8.5	14
64	11		7.2	5	8.5	16
65	12	12	7.0	5	8.5	13
66	10	12	7.2	5	17.0	15
67	11	12	7.2	5	8.5	13
68	11	12	7.1	5	8.5	15
69	10	12	7.2	5	8.5	15
70	11	12	7.1	5	8.5	14
71	10	10	7.2	5	8.5	14
72	10	12	7.2	5	8.5	14
73	10		7.3	5	8.5	18
74	10	12	7.3	5	8.5	17
75	10	11	7.3	5	8.5	18
76	10	11	7.2	5	8.5	18
77	11	13	7.2	5	8.5	16
78	9		7.3	5	8.5	15
79	10		7.4	5	8.5	17
80	10	11	7.4	5	17.0	18
81	11		7.3	5	8.5	17
82	10		7.3	5	8.5	15
83	10	11	7.2	5	8.5	16
84	11	12	7.2	5	8.5	17
85	9		7.3	5	8.5	14
86	10	11	7.1	5	8.5	17
87	10		7.2	5	8.5	16
88	9		7.2	5	8.5	16
89	11	11	7.3	5	8.5	16

Appendix IV (Cont'd.)

Station	O_2 upper	O_2 lower	pH	CO_2	Hardness	Secchi ft
90	10	11	7.3	5	8.5	17
91	10		7.2	5	8.5	17
92	10	11	7.2	5	8.5	16
93	10		7.3	5	8.5	16
94	10		7.3	5	8.5	17.5
95	10		7.3	5	8.5	17
96	10	11	7.3	5	8.5	18
97	10		7.3	5	8.5	15.5
98	10	11	7.2	5	8.5	17
99	10		7.1	5	8.5	17.5
100	10	12	7.2	5	8.5	18
101	10		7.3	5	8.5	17
102	10	11	7.2	5	8.5	17
103	10		7.1	5	8.5	17
104	10		7.2	5	8.5	19
105	10		7.1	5	8.5	19
106	9		7.1	5	8.5	14
107	10		7.2	5	8.5	15
108	9		7.1	5	8.5	10
109	10		7.3	5	8.5	12

Appendix V

Laboratory analysis of water quality,
Red Indian Lake, 1974.

Appendix V.

Station	pH	Total Hardness	Spec. Cond.(1)	Turbidity JTU	Total Alk.	Ca	Cl	(2) HCO^-_3
RI 1	6.3	8.0	20.0	0.9	4.0	2.0	2.2	4.9
RI 2	6.8	8.0	19.0	0.9	4.0	2.2	2.0	4.9
RI 3	6.6	8.0	18.5	0.9	4.0	1.9	2.5	4.9
RI 4	6.6	8.0	19.0	1.0	4.0	2.0	2.5	4.9
RI 5	6.6	10.0	19.5	3.2	4.5	1.9	2.0	5.5
RI 6	6.5	6.0	19.5	0.9	4.0	1.9	2.5	4.9
RI 7	6.6	8.0	20.5	1.1	4.0	1.9	2.5	4.9
RI 8	6.4	8.0	20.5	0.9	4.0	2.0	2.5	4.9
RI 9	6.6	6.0	19.0	1.6	4.0	1.8	2.3	4.9
RI 10	6.6	9.0	20.0	1.5	3.5	1.8	2.3	4.3
RI 11	6.3	8.0	20.0	1.0	4.0	1.9	2.5	4.9
RI 12	6.5	8.0	20.5	1.0	4.5	1.9	2.3	5.5
RI 13	6.2	8.0	20.0	1.8	4.0	2.0	2.5	4.9
RI 14	6.2	8.0	20.0	0.8	4.0	1.9	2.3	4.9
RI 15	6.2	9.0	20.0	0.9	4.0	1.9	2.5	4.9
RI 16	6.2	8.0	20.0	0.9	4.0	1.9	2.3	4.9
RI 17	6.4	8.0	19.0	1.3	4.0	1.9	2.3	4.9
RI 18	6.1	8.0	20.0	1.2	4.0	1.9	2.5	4.9
RI 19	6.8	9.0	20.0	1.8	4.0	1.9	2.5	4.9
RI 20	6.3	8.0	21.0	1.2	3.5	1.9	2.5	4.3
RI 21	6.4	9.0	20.5	1.5	4.0	1.9	2.5	4.9
RI 22	6.4	8.0	20.0	1.0	4.0	1.9	2.5	4.9
RI 23	6.5	8.0	20.5	0.9	4.0	1.9	2.5	4.9
RI 24	6.2	8.0	20.0	0.9	4.0	1.9	2.5	4.9
RI 25	6.3	9.0	20.0	0.8	3.0	1.9	2.5	3.7
RI 26	6.3	8.0	21.0	0.7	4.0	1.9	3.0	4.9
RI 27	6.3	8.0	21.0	0.7	4.0	1.9	2.0	4.9
RI 28	6.3	9.0	20.0	0.7	4.0	1.8	2.5	4.9
RI 29	6.3	8.0	20.5	1.3	4.5	1.8	2.5	5.5
RI 30	6.3	9.0	20.5	2.0	4.0	1.9	2.5	4.9
RI 31	6.3	8.0	21.0	1.0	4.9	1.9	2.0	6.0
RI 32	6.3	8.0	20.0	0.8	4.0	1.9	2.5	4.9
RI 33	6.4	8.0	20.0	1.1	4.0	1.9	2.0	4.9
RI 34	6.3	8.0	20.0	1.3	3.5	1.9	2.0	4.3
RI 35	6.4	8.0	20.0	1.2	3.5	1.9	2.5	4.3
RI 36	6.5	8.0	20.5	1.5	4.0	1.9	2.5	4.9
RI 37	6.4	8.0	21.0	0.9	4.0	1.9	2.5	4.9
RI 38	6.4	8.0	20.0	1.0	4.0	1.9	2.5	4.9
RI 39	6.4	9.0	20.0	1.4	4.0	1.9	2.5	4.9
RI 40	6.3	8.0	20.5	1.0	4.0	1.9	2.3	4.9
RI 41	6.4	8.0	20.5	1.2	4.5	1.9	2.3	5.5
RI 42	6.5	10.0	19.5	0.9	4.0	1.9	2.5	4.9
RI 43	6.6	9.0	20.0	1.0	4.0	1.9	2.3	4.9
RI 44	6.4	9.0	20.0	1.5	4.0	1.9	2.5	4.9
RI 45	6.5	8.0	20.0	1.5	3.0	1.9	2.3	3.7

Appendix V (Cont'd.)

Station	pH	Total Hardness	Spec. Cond.(1)	Turbidity JTU	Total Alk.	Ca	Cl	HCO^-_3
RI 46	6.5	8.0	20.0	1.1	4.0	1.9	2.5	4.9
RI 47	6.5	8.0	20.0	1.5	4.0	1.9	2.5	4.9
RI 48	6.4	10.0	20.0	1.3	4.0	1.9	2.3	4.9
RI 49	6.4	8.0	20.0	1.5	4.0	1.9	2.5	4.9
RI 50	6.3	8.0	20.0	2.0	4.0	1.9	2.5	4.9
RI 51	6.5	9.0	20.0	1.8	4.0	1.9	2.5	4.9
RI 52	6.4	8.0	20.0	1.5	4.0	1.9	2.5	4.9
RI 53	6.4	8.0	20.0	1.4	3.5	1.9	2.3	4.3
RI 54	6.5	8.0	20.0	1.4	4.0	1.8	2.3	4.9
RI 55	6.5	8.0	19.5	1.2	4.0	1.9	2.3	4.9
RI 56	6.4	8.0	20.0	1.4	4.0	1.9	2.0	4.9
RI 57	6.4	8.0	20.0	1.6	4.0	1.9	2.5	4.9
RI 58	6.5	8.0	20.0	1.8	4.0	1.9	2.0	4.9
RI 59	6.5	8.0	20.0	2.0	4.0	1.9	2.0	4.9
RI 60	6.5	8.0	20.0	1.4	4.0	1.9	2.3	4.9
RI 61	6.4	8.0	20.0	2.4	4.0	1.9	2.3	4.9
RI 62	6.6	8.0	20.0	1.5	4.0	1.9	2.0	1.9
RI 63	6.6	8.0	20.0	2.2	4.5	1.9	2.5	5.5
RI 64	6.4	8.0	21.0	1.4	3.0	1.8	2.0	3.7
RI 65	6.4	8.0	20.0	1.5	4.0	1.9	2.5	4.9
RI 66	6.3	8.0	20.0	0.5	4.0	1.6	2.5	-
RI 67	6.4	8.0	20.0	2.3	4.0	1.9	2.0	4.9
RI 68	6.0	8.0	23.0	2.0	3.0	1.9	2.5	3.7
RI 69	6.4	8.0	20.0	0.6	4.0	1.6	2.5	-
RI 70	6.5	8.0	20.0	1.7	4.0	1.9	2.5	4.9
RI 71	6.3	8.0	20.0	0.6	4.0	1.6	2.5	-
RI 72	6.3	8.0	20.0	0.6	4.0	1.7	3.0	-
RI 73	6.6	8.0	20.0	0.5	4.0	1.6	2.0	-
RI 74	6.6	8.0	20.0	0.6	4.0	1.7	2.5	-
RI 75	6.2	8.0	20.0	0.5	3.0	1.7	3.0	3.7
RI 76	6.3	8.0	20.0	0.6	4.0	1.6	2.5	-
RI 77	6.4	8.0	20.0	0.6	4.0	1.7	3.0	-
RI 78	6.3	8.0	20.0	0.5	4.0	1.7	2.5	-
RI 79	6.2	7.5	20.0	0.6	4.0	1.7	2.5	-
RI 80	6.2	8.0	20.0	0.4	4.0	1.7	2.5	-
RI 81	6.4	8.0	20.0	0.5	4.0	1.6	2.0	-
RI 82	6.2	8.0	20.0	0.7	4.0	1.6	2.5	-
RI 83	6.3	7.0	20.0	0.6	4.0	1.7	2.5	-
RI 84	6.3	7.0	20.0	0.6	5.0	1.6	2.5	6.1
RI 85	6.3	8.0	20.0	0.4	4.0	1.6	2.5	4.9
RI 86	6.3	8.0	20.0	0.8	3.0	1.6	2.5	3.7
RI 87	6.5	7.0	20.0	0.4	4.0	1.7	2.5	4.9
RI 88	6.3	8.0	20.0	0.5	4.0	1.6	2.5	4.9
RI 89	6.1	8.0	20.0	0.4	4.0	1.7	2.5	4.9

Appendix V (Cont'd.)

Station	pH	Total Hardness	Spec. Cond.(1)	Turbidity JTU	Total Alk.	Ca	Cl	(2) HCO^-_3
RI 90	6.6	8.0	20.0	0.4	4.0	1.6	2.5	4.9
RI 91	6.5	8.0	20.0	0.4	4.0	1.6	2.5	4.9
RI 92	6.4	7.5	20.0	0.6	4.0	1.6	2.5	4.9
RI 93	6.4	8.0	20.0	0.5	4.0	1.6	2.0	4.9
RI 94	6.4	8.0	20.0	0.6	4.0	1.6	2.5	4.9
RI 95	6.5	8.0	20.0	0.6	4.0	1.6	3.0	4.9
RI 96	6.6	8.0	20.0	0.4	4.0	1.6	3.0	4.9
RI 97	6.4	8.0	20.0	0.4	4.0	1.6	2.5	4.9
RI 98	6.5	8.0	20.0	0.3	4.0	1.6	3.0	4.9
RI 99	6.4	8.0	20.0	0.6	4.0	1.7	2.5	4.9
RI 100	6.4	8.0	20.0	0.5	4.0	1.7	2.5	4.9
RI 101	6.5	8.0	20.0	0.5	4.0	1.7	3.0	4.9
RI 102	6.4	8.0	20.0	0.4	4.0	1.7	3.0	4.9
RI 103	6.4	8.0	20.0	0.5	4.0	1.7	2.5	4.9
RI 104	6.7	8.0	20.0	0.6	4.0	1.7	3.0	4.9
RI 105	6.3	8.0	20.0	0.7	4.0	1.7	2.5	4.9
RI 106	6.5	8.0	20.0	0.5	4.0	1.7	3.0	4.9
RI 107	6.3	8.0	20.0	0.4	4.0	1.7	2.5	4.9
RI 108	6.4	8.0	20.0	0.4	4.0	1.7	2.5	4.9
RI 109	6.4	8.0	20.0	0.5	4.0	1.7	2.5	4.9

(1) Micromhos
(2) Bicarbonate
JTU - Jackson Turbidity Units
Results in ppm unless otherwise specified

Appendix VI

Daily water levels (ft ASL)
of Red Indian Lake for year 1974.

Appendix VI.

Date	January	February	March	April	May	June	July	August	September	October	November	December
1	498.60	492.33	485.95	481.00	482.90	501.55	501.73	495.90	488.60	484.70	489.20	488.70
2	498.45	492.05	485.80	481.20	483.40	502.10	501.60	495.70	488.33	484.70	489.35	488.80
3	498.30	491.80	485.75	481.20	483.95	502.70	501.47	495.50	488.05	484.60	489.55	488.80
4	498.10	491.55	485.65	481.10	484.40	503.40	501.37	495.25	487.80	484.60	489.70	489.00
5	497.90	491.25	485.40	481.00	484.70	503.70	501.20	495.00	487.60	485.00	489.70	489.40
6	497.70	491.00	485.30	480.95	485.00	503.95	500.95	494.80	487.42	485.40	489.75	489.60
7	497.70	490.80	485.20	480.90	485.33	504.00	500.75	494.60	487.25	485.80	489.80	489.70
8	497.50	490.60	485.10	480.90	486.05	504.00	500.48	494.32	487.08	486.20	489.75	489.85
9	497.30	490.30	485.00	480.95	486.80	504.00	500.23	494.10	486.90	486.20	489.65	490.00
10	497.15	490.05	484.90	481.05	487.55	504.00	500.03	493.90	486.80	486.30	489.60	490.30
11	497.00	489.75	484.75	481.15	488.35	503.95	499.93	493.60	486.60	486.40	489.45	490.70
12	496.80	489.55	484.60	481.40	489.00	503.80	499.70	493.40	486.40	486.60	489.23	491.50
13	496.60	489.35	484.45	481.75	489.60	503.70	499.50	493.18	486.30	486.75	488.93	491.80
14	496.40	489.10	484.25	481.90	490.30	503.65	499.30	492.98	486.30	486.90	488.75	492.10
15	496.20	488.80	484.00	482.05	491.10	503.60	499.10	492.70	486.40	487.00	488.65	492.40
16	496.05	488.55	483.75	482.25	491.90	503.55	498.95	492.45	486.48	487.20	488.65	492.50
17	495.80	488.30	483.60	482.40	492.95	503.45	498.75	492.20	486.45	487.20	488.60	492.65
18	495.55	488.00	483.45	482.40	493.90	503.30	498.55	491.95	486.45	487.20	488.50	492.55
19	495.33	487.80	483.30	482.50	495.00	503.22	498.35	491.70	486.30	487.20	488.35	442.65
20	495.10	487.50	483.10	482.55	495.80	503.16	498.16	491.45	486.15	487.30	488.05	492.70
21	494.90	487.25	482.95	482.60	496.55	503.10	497.90	491.20	486.05	487.50	487.80	492.65
22	494.60	487.10	482.85	482.55	497.20	502.93	497.65	490.95	485.95	488.10	487.75	492.60
23	494.40	486.85	482.70	482.60	497.90	502.85	497.50	490.70	485.95	488.55	487.60	492.55
24	494.20	486.70	482.50	482.60	498.50	502.72	497.30	490.45	485.65	488.70	487.40	492.55
25	493.95	486.60	482.30	482.50	499.00	502.55	497.13	490.20	485.50	488.90	487.25	492.55
26	493.65	486.40	482.10	482.40	499.45	502.40	497.05	489.95	485.40	489.10	487.10	492.55
27	493.40	486.30	481.95	482.40	499.90	502.30	496.90	489.65	485.20	489.20	487.35	492.45
28	493.20	486.15	481.80	482.40	500.15	502.20	496.70	489.40	485.10	489.40	487.88	492.25
29	493.00		481.60	482.50	500.45	502.03	496.48	489.15	484.95	489.35	488.30	492.05
30	492.80		481.40	482.65	500.80	501.85	496.28	488.82	484.80	489.20	488.50	491.90
31	492.65		481.20		501.10		496.10	488.65		489.33		491.70

Appendix VII

Data on mill operations
at Buchans; 1967, 1968 and 1975.

Appendix VII.

		1967	1968	1975
1. Daily water requirements for mill operation		1.6 m gal	1.6 m gal	1.9 m gal
2. Daily water requirements for townsite		0.5 m gal	0.5 m gal	0.5 m gal
3. Tons of ore mined per year		355,000	378,000	232,000
4. Tons of concentrate produced annually		108,488	116,732	60,227
5. Tons of tailings discharged annually		246,511	261,267	171,773
6. Ore composition:	Copper	1.07%	1.11%	0.95%
	Lead	7.20%	7.14%	5.92%
	Zinc	13.0%	12.83%	10.54%
	Iron	3.6%	4.31%	4.12%
	Sulphur	10.9%	11.5%	10.6%
	$BaSO_4$	24.1%	25.4%	23.4%
	SiO_2	23.5%	23.3%	36.39%
	Al_2O_3	4.4%	4.5%	3.8%
	$CaCO_3$			4.28%
	CaO	1.8%	2.3%	
	Gold	0.31 oz/ton	0.29 oz/ton	-
	Silver	4.47 oz/ton	3.93 oz/ton	-
7. Reagents used (lb/ton of original ore):				
	Sulphur	1.524	1.524	1.50
	Sodium Cyanide	0.194	0.194	0.15
	Zinc Sulphate	1.65	1.65	1.86
	Xanthates (total)			0.36
	Butyl Xanthate	0.124	0.124	
	Isopropyl Xanthate	0.163	0.163	
	Thiocarbonilide	0.059	0.059	0.06
	Copper Sulphate	1.02	1.02	1.00
	Hydrated Lime	1.145	1.145	1.43
	Dowfroth 250(R)	0.015	0.015	0.019
	Cresylic Acid	0.059	0.059	0.056
	Sodium Bichromate	0.532	0.532	0.49
8. Number of milling days yearly		301	305	205*

*A strike during part of 1974 and 1975 reduced the total number of milling days and thus the total production.