

AN INVESTIGATION INTO SELECTED ECOLOGICAL ASPECTS
OF THE AQUATIC AND TERRESTRIAL ENVIRONMENT
OF AN ABANDONED URANIUM MILL TAILINGS POND
BANCROFT, ONTARIO

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M. Kalin, Editor
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GENERAL INTRODUCTION

In many areas of Canada, uranium mill tailings are produced or have been produced in the past. Abandoned areas which received the tailings material contain hazardous materials such as heavy metals, radioactive isotopes and sometimes acid-generating materials. The long term fate of these materials is largely unknown. Sites are open to the natural processes of invasion by biota and exposed to weathering and leaching processes.

It was the aim of this Experience '79 project to identify and delineate invading biota by studying abandoned uranium mill tailings sites in the Bancroft area, with the ultimate aim of compiling information on the potential hazards associated with these sites.

At Bicroft mine, located about 2 km west of Cardiff, off highway 121, uranium was milled from 1956 to 1963. The two main areas used for tailings disposal (in some files referred to as tailings No.1 and No. 2) were the sites chosen for the 1979 Experience project. The two sites referred to as Auger Lake and Bicroft Proper are distinctive in their physiognomy. Auger Lake is very shallow with beaches and sediment composed mainly of tailings which were disposed of in the lake. Bicroft Proper is a small pond, of which 80% is exposed tailings, with several small islands apparent remnants of the original or natural situation. These islands are quite densely vegetated.

Four independent projects were carried out each aiming to describe the present condition of these two sites, with respect to vegetation, aquatic biology, invasion of the soil by microfungi and nematodes and details of surface water flow.

The following report is set out in four sections each describing the independent projects.

SECTION I

SURFACE WATER MOVEMENTS IN THE BICROFT TAILINGS AREA

M. Kalin assistant G. Jones

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SURFACE WATER MOVEMENTS IN THE BICROFT TAILINGS AREA

M. Kalin assistant G. Jones

INTRODUCTION

SITE DESCRIPTION

The study area is about 2 km by 1.25 km and contains two major water bodies called Auger Lake and Bicroft Proper Pond. Both of these have some drainage which meets in a small swamp referred to as the tailings swamp. From this swamp, a stream 2 m wide and 0.5 m deep flows into Deer Creek which originates in Clear Lake. For details see Map 1-1.

OBJECTIVE

The aim of this section of the study was to facilitate an assessment of possible routes of dissolved or suspended contaminants and their potential sinks. To this end the major objective was to describe the movements of surface waters around the tailings area.

AUGER LAKE

INFLOWS - Auger Lake has 4 inflows and 6 outflows. Two of these inflows (East shore #1 and 2) were observed to be intermittent, in contrast to those on the south-western area (#3 and 4) which are permanent. Table 1-1 summarizes these inflows.

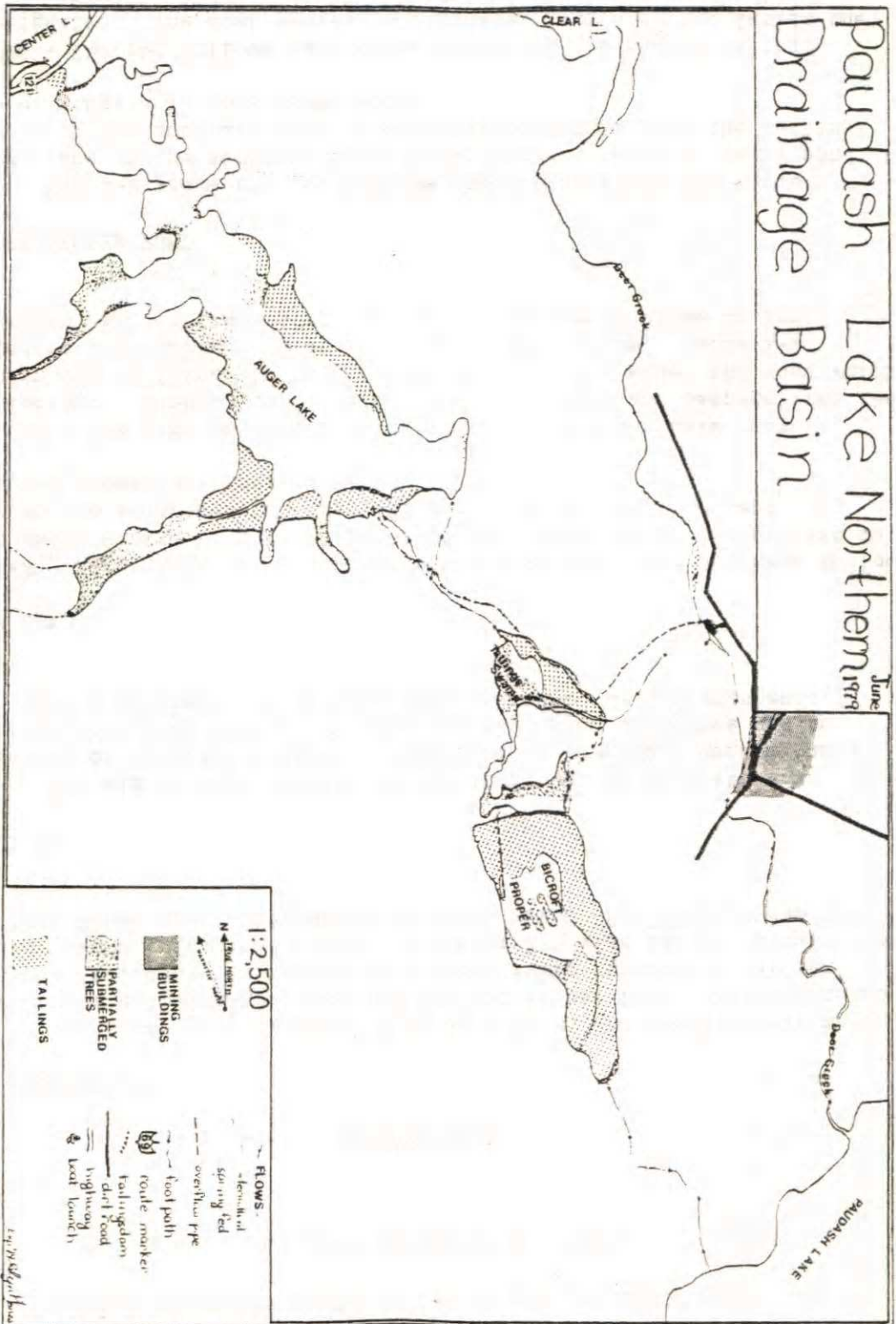
OUTFLOWS - The size of creeks and seepages from Auger Lake vary considerably. Sunfish pond, which receives creeks and seepage from the northern dam is joined to Centre Lake by a culvert under the road which carried no measurable flow at the time of this study. Table 1-1 summarises the outflows #5 to 10, their location is given in Map 1-2.

BICROFT PROPER POND

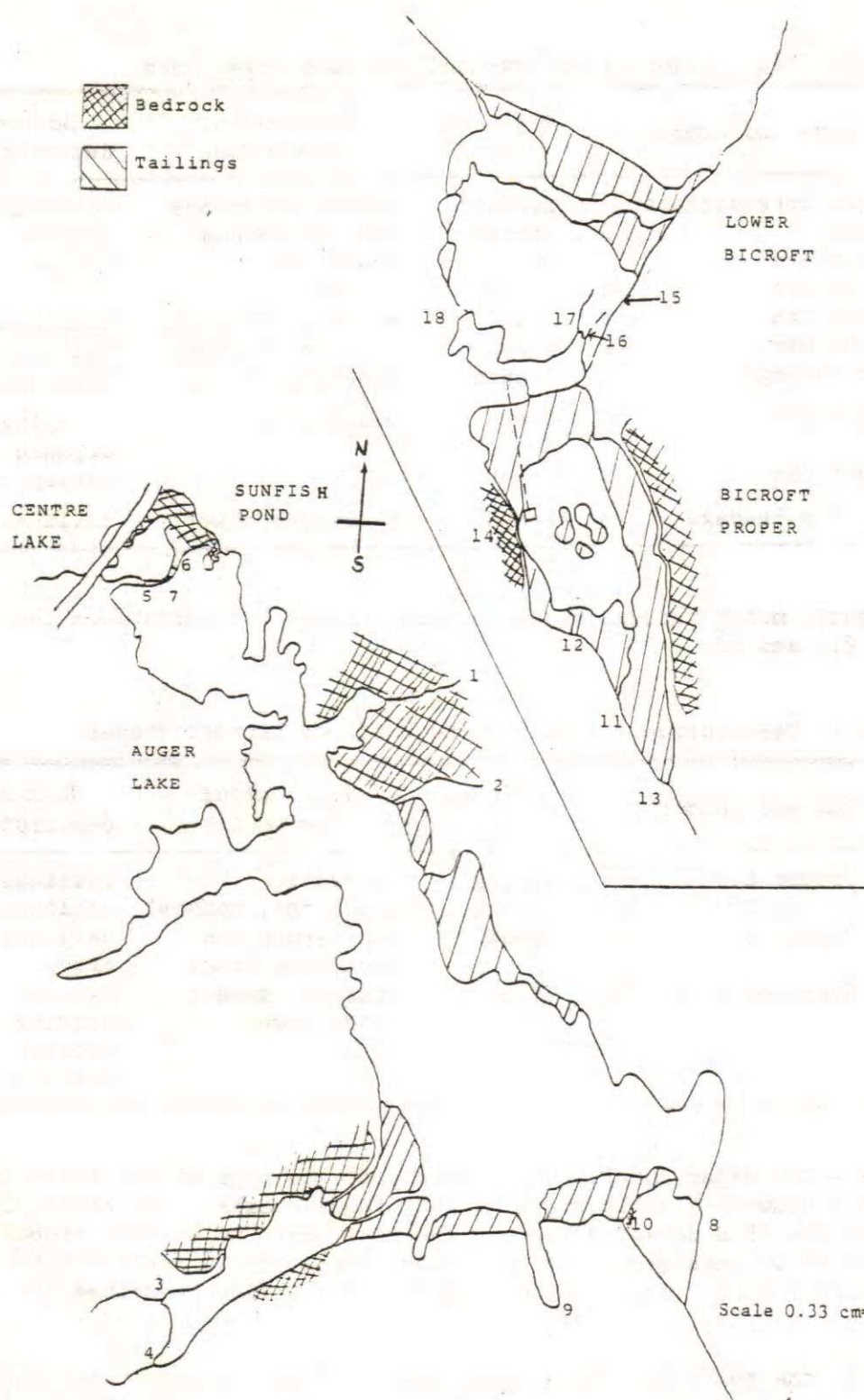
Map 1-2 shows the two inflows and two outflows for Bicroft Proper. One of the outflows feeds Lower Bicroft Pond, a small pond at the base of the northern dam. A creek which drains into the tailings swamp originates in this lower pond.

INFLOWS - The two inflows were dried up during the summer of this investigation. The most westerly originates from a spring inside the forest. Its flow seeps through the soil of the banks, which is

Paudash Lake Northern Drainage Basin



Map 1-1. General Overview of Study Area



Map 1-2. Inflow and outflow locations

Table 1-1. Description of Inflows and Outflows Auger Lake

Site name and number		Drainage type	Surrounding vegetation	Bottom description
N.E. Auger Intermittent	1	Spring	(Mixed deciduous	(decaying
S.E. Auger	2	Spring	and coniferous	organic
N.W. Auger Arm	3	Spring	trees and	matter)
S.W. Auger Arm	4	Spring	shrubs)	i.e.
N.W. Auger Dam	5	Creek	mosses, seedlings	tailings
N.E. Auger Dam	6	Creek	coniferous trees	tailings
N. Auger Seepage	7	Seepage	deciduous trees	tailings
S.E. Auger Dam	8	Creek	mixed cover	decaying organic
S.W. Auger Dam	9	Creek		matter, clay
S. Auger Dam Seepage	10	Seepage	deciduous trees	tailings

consequently moist throughout the season. Table 1-2 summarizes the inflows #11 and 12.

Table 1-2. Description of Inflows and Outflows Bicroft Proper

Site name and number		Drainage type	Surrounding vegetation	Bottom description
Bicroft Proper E.	11	Spring	(grasses,	tailings
Bicroft Proper W.	12	Spring	seedlings, mosses)	tailings
Bicroft Proper S.	13	Creek	coniferous and	tailings,
			deciduous trees	clay
Bicroft Overflow Pipe	14	Creek	grasses, mosses	(pipe-
			floor cover	decaying organic matter)

OUTFLOWS - One major outflow originates from the base of the south dam. It flows southward finally draining into Paudash Lake. The other outflow consists of a decant system on the west shore of Bicroft Proper Pond. It flows underground by pipe suspected to drain finally into lower Bicroft Pond. The outflows #13 and 14 are also described in Table 1-2.

At the north dam where Lower Bicroft Pond collects water due to a beaver dam, there are several further outflows which all eventually meet in the waters of the tailings swamp. In the northeast corner

there are 2 small intermittent creeks (#15 and 17) which serve as a drainage system for the spring runoff and any excessive seasonal precipitation. The other two permanent flows that drain the pond, flow from the far northwest of the pond and the south east (#18 and 16). These are summarized in Table 1-3.

Table 1-3. Description of Inflows and Outflows Lower Bicroft Pond

Site name and number	Drainage type	Surrounding vegetation	Bottom description
Lower Bicroft Pond N.E. 15	Creek	(mixed forest,	(organic
Lower Bicroft Pond S.E. 16	Creek	seedlings	decaying
Lower Bicroft Pond N.E. 17	Creek	dense floor	
Lower Bicroft Pond N.W. 18	Creek	cover)	matter)

MAP CONSTRUCTION

A map was drawn showing Paudash Lake's northern drainage basin (Map 1-1). This was accomplished with the use of existing maps and the aerial photographs of the area. A grid was drawn on paper (9 cm²). A similar grid of $\frac{1}{4}$ cm² was laid on the photograph. This enabled accurate transference of the images and enlargement of the map to scale of 1:2,250. Other details were added from visual inspection and the use of topographic maps.

METHODS USED TO ESTIMATE SURFACE WATER FLOW

Three different methods were used termed flotation, bucket and estimation.

FLOTATION

The float method requires that flow rates be determined for predetermined distances, in this instance, 5 m. Three measurements were made at each site. At some sites along the timed zone, transects were taken across the creek width and depth, profiles were made. From these profiles and the flow rates, determination of the flow through an area was determined and a volume per unit time measurement was calculated.

BUCKET

When dealing with flows as small as some in this area, the float method is not feasible. When this occurred, the bucket method was adopted.

At the flow site the measurement was taken close to the water bodies to ensure that the measurement only included water entering or leaving the water body under study. In order to measure the flow accurately, a point at which the flow collects to a width of about 5-35 cm was found. Here a bucket was placed in the flow and a measured volume was collected in a given period of time. This was repeated three times and an average flow rate was determined.

ESTIMATION

Where flows were unsuitably small for either of the above methods, the flow was estimated subjectively.

RESULTS AND DISCUSSION

Table 1-4 summarizes the flow rates for three sampling times over the 12 week period of this investigation. Drainage is clearly occurring from both Auger and Bicroft Proper, but there was a great decrease in inflows in mid-June as shown in Fig. 1-1.

Precipitation for the three month period in 1979 was compared with previous typical values obtained from the Atmospheric Environment Service, for the Bancroft weather station appears to be abnormally low (Fig. 1-2). This suggests that the decrease in inflows into the tailings ponds and the complete drying out of certain "intermittent" inflows may have been unusual, the results of an excessively dry season. Surface waters in these abandoned tailings sites are of interest, especially since there is seepage through the tailings dams. In a later Section (Limnology) some evidence for increased concentrations of metals in seepages is presented.

The present investigation has documented an excess of outflow over inflow during the summer of 1979. Further quantitative investigation of dissolved materials in water is now required in order to determine the fate of metals and radionuclides through the surface water route.

Table 1-4. Summary of flow rates

Site number	Inflows in l/min			Outflows in l/min			Flow type
	June 18/19	July 1/2	July 16/17	June 18/19	July 1/2	July 16/17	
Auger Lake							
1	0	0	0				intermittent
2	40	0	0				intermittent
3	16	10	2				spring
4	12	6	1				spring
5				17	15	6	creek
6				20	18	16	creek
7				1	1	1	seepage
8				8	6	5	creek
9				60	60	52	creek
10				1	1	1	seepage
Bicroft Proper							
11	4	1	0				spring
12	6	3	1				spring
13				5	5	3	creek
14				6	6	5	overflow pipe
15				3	1	$\frac{1}{2}$	creek
16				0	0	0	intermittent
17				0	0	0	intermittent
18				9	6	5	creek
Sub-totals							
Auger Lake Site 1-10	68	16	3	107	101	81	
Total	= 87			= 289			
Bicroft Proper							
Site 11-18	10	4	1	23	18	13	
Total	= 15			= 54			

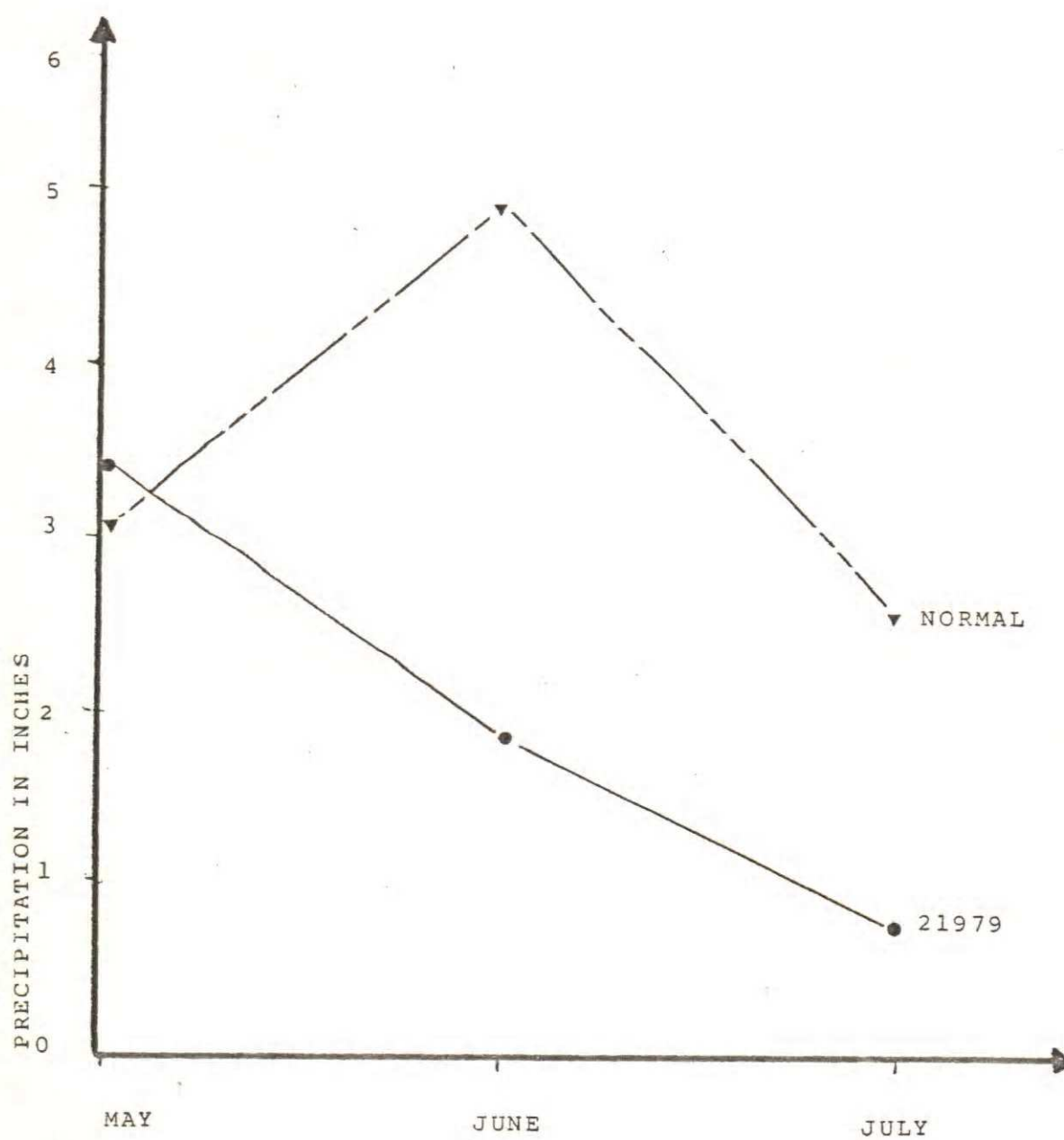


Fig. 1-2. Monthly mean precipitation in the Bancroft area



Plate 2.1: Bicroft Proper



Plate 2.2: Lower Bicroft Pond



Plate 2.3 : Auger Lake



Plate 2.4: Centre Lake

SECTION II

A LIMNOLOGICAL SURVEY OF WATERS AND
ABANDONED URANIUM MILL TAILINGS

Steve Taylor

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A LIMNOLOGICAL SURVEY OF WATERS AND ABANDONED URANIUM MILL TAILINGS

Steve Taylor

INTRODUCTION

This brief limnological survey seeks to provide information on the following two questions. Firstly, to what extent do uranium mill tailings affect water bodies, and, secondly, what entities are affected? To begin to assess these questions, a number of physical, chemical and biological parameters were investigated from water bodies which had received tailings.

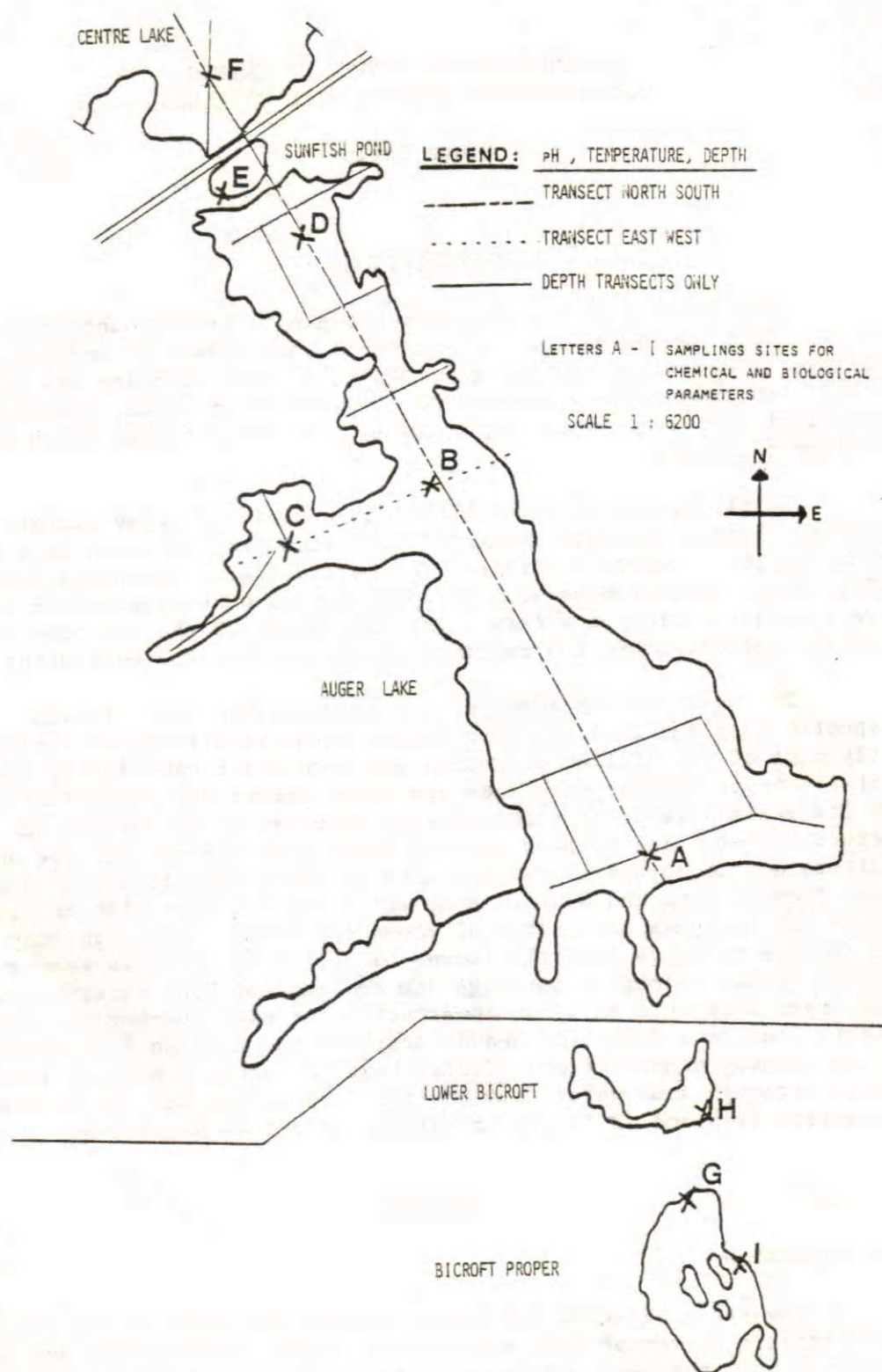
Acidification of water bodies is a topic of prime concern in Ontario. Recent evidence indicates that acid precipitation is a major hazard to the Province's waters. The Ontario Water Resources Commission (1971) found that uranium mill tailings can also be responsible for severe acidification of waters. The minerology of the ore body in Bancroft suggests that the tailings should not be acid generating.

The water bodies surveyed are shown in Map 2-1. It was suspected that the tailings were dumped into Bicroft Proper during the early part of the milling operation and into Auger Lake during the latter. Auger Lake is more than ten times larger than Bicroft Proper and its maximum depth is eight meters, compared to two meters at Bicroft Proper. The deepest part of Auger Lake did not receive any tailings so the bottom is covered with decaying organic matter densely. Lower Bicroft Pond and Sunfish Pond are about the same size as Bicroft Proper and have maximum depths of about one meter. Although they did not receive tailings directly, Lower Bicroft Pond receives seepage from Bicroft Proper through a tailings dam and Sunfish Pond receives seepage from Auger Lake through a dam constructed of mine overburden. Lower Bicroft Pond is a result of beaver activity and Sunfish Pond was formed during highway construction. Centre Lake served as a control in this survey although some water from Sunfish Pond enters it. It is over ten meters deep and is larger in surface area than Auger Lake.

METHODS

SITE SELECTION

The sites selected for investigation are shown in Map 2-1. A preliminary survey of lake morphometry, depth, temperature and pH indicated that the best allotment of sampling locations was at sites A-F along the two transects in Auger Lake and at points G, H and I in



Map 2-1. Location of transects and sampling sites

Bicroft Proper Pond. A water sample from Deer Creek (Map 1-1) was also collected for metal analysis.

PARAMETER SAMPLED

Physical parameters

WEATHER - A daily weather record was coded by S. Taylor according to symbols and terminology used by the Atmospheric Environment Service of Canada. The entities and their methods of measurement include temperature (indoor-outdoor thermometer manufactured by Taylor of Canada, accuracy 0.5°C), precipitation amount (rain gauge constructed by author, accuracy 0.5 mm) and wind speed, wind direction and cloud cover (all measured by subjective interpretation of author).

LAKE AREA AND DEPTH - Depth contour maps of the water bodies under investigation were constructed using depth measurements and enlargements of aerial photographs. Depth was measured with the use of a weighted line. Several depth transects were run across Auger Lake (Map 2-1) and spot measurements were made on Bicroft Proper, which did not lend itself to depth transects because of its uniformity and shallowness. The enlargements were made according to the method of squares outlined in Debenham (1937) based on aerial photograph #69-4441-54-31 from 1969. Although later photographs were available, it was felt that this one better represented the area. Subsequent changes in landscape have been taken into account following visual examination.

SHORELINE CHARACTERISTICS - A description of all shorelines was compiled by visual examination.

LAKE SUBSTRATE - Substrate was examined at all nine stations shown in Map 2-1 by using a Peterson Dredge. The samples taken were coded subjectively according to colour, texture, firmness and apparent organic content.

INFLOWS AND OUTFLOWS - These were determined and are presented in Section I.

WATER TRANSPARENCY - A standard black and white secchi disc 20 cm in diameter and constructed of laminate countertop was used. Transparency was measured at site E (Centre Lake) and C (Auger Lake) as all other sites were too shallow.

WATER TEMPERATURE - This was measured for each of the sites shown in Map 2-1 by using a submersible thermometer. Depth measurements were taken by hauling up water using the sampler referred to in the water collection section and taking a thermometer reading.

CHEMICAL PARAMETERS

WATER COLLECTION - All water samples from the surface were taken by submerging a jar to about 0.25 m and letting it fill up. Depth samples were taken by using a box-type sampler designed by P. Stokes. The volume thus brought to the surface was about 2.5 l.

METALS - 250 ml samples were filtered through 0.45 μ g sartorius membrane filter (type 11106) and placed in an acid-washed bottle (4% HCl, 7 rinses in distilled water) and acidified to pH 2 with concentrated nitric acid. Filtration was facilitated by the use of a millipore apparatus and a hand pump. The metals were then analysed by atomic absorption. Aluminum, manganese, copper, calcium, zinc and nickel were treated in this way. Deer Creek was also sampled here as another control.

OTHER CHEMICALS AND MEASUREMENTS - A series of measurements was made using a Hach kit (DR-EL/1), after Hach manual (1978). A list of entities measured, precision and materials used is given in Table 2-1.

BIOLOGICAL PARAMETERS

PHYTOPLANKTON - Water samples were collected from sites A-G at the surface and at 3.0-3.5 and 7.0-7.5 m where possible, using the water collection methods described in the chemical parameter section.

About 400 ml samples were preserved in Lugols solution, which was prepared after Ward and Whipple (1959). The algae were observed under a compound microscope at a magnification of 400 times. They were counted on a haemocytometer so that 8 sets of squares were counted per sample. They were then measured for length and classified into divisions according to Ward and Whipple (1959). Ting Kit Yong confirmed identification of some algae, and further identified those which were not recognized by the author.

ZOOPLANKTON - Zooplankton samples were collected by dragging a Wisconsin tow net for about 15 m with the top of the tow net just above the water surface. Samples were preserved in 4% formalin and counted under a dissecting microscope at a magnification of 30 times. They were then classified into orders according to Ward and Whipple (1959).

SAMPLING SCHEDULE

The study involved an eight week field period. In the first two weeks, methods were tested and some physical data were collected, along with a set of pH and temperature data. The next six weeks were divided into three two-week sampling periods for chemical and

Table 2-1. HACH specifications

Parameter	Precision	Range of technique	Equipment used
pH	0.05 pH units	pH 0 - pH 14	pH 4 and pH 10 buffers to standardize pH meter probe model number
Conductivity	0-100>1 100-1000, 10 1000-10, 100, 100	0 - 10,000 mohos/cm	conductivity probe model #17250
Dissolved oxygen	1 mg/l	0 - ∞	Dissolved oxygen reagent 1-Bach #9052 Dissolved oxygen reagent 2-Bach #9099 Dissolved oxygen reagent 3-Bach #9085 PAO Titrant Bach #9110
Nitrate	varies	0-30 mg/L	Nitraver V Bach #9038
Ammonia	varies	0-3 mg/L	Nessler's reagent Bach #9116
Sulfide	varies	0 - ∞	Alka Seltzer tablets H2S test paper #8356
Sulfate	varies	0-150 mg/L	Sulfaver IV #8346
Phosphate	varies	0-3 mg/L	Phosver III #9149, 9024
Turbidity	varies	0-1500 FTU	
Alkalinity	1 mg/l	0 - ∞	Bromo Cresol Green-Methyl Red Indicator Bach #9085 Phenolphthalien - Bach #9113 Sulfuric acid (0.02N) Bach #9048

biological data. The sampling schedule is given in Table 2-3. Weather conditions and other circumstances did not alter this schedule significantly.

RESULTS

LAKE AREA AND DEPTH

The map enlargements and the results of the depth transects are shown in Map 2-2. Bicraft Proper, Lower Bicraft Pond and Sunfish Pond are all small shallow ponds. Bicraft Proper is about 2.1 m deep, and the others have a maximum depth of about 1 m. Auger Lake is shallow, less than 2.0 m deep over most of the south end, but is consistently 3 to 4 m deep over the north end. The transition is marked by a sharp drop near Site B in the central portion. The deepest part of Auger Lake is the west arm which reaches 8.1 m in depth. Centre Lake deepens steadily from the shore to a depth greater than 10 m. Centre Lake has a larger surface than Auger Lake, which in turn has a surface area which is more than ten times that of the three smaller ponds.

SITE CHARACTERISTICS

The overall geography and vegetation cover of the area is shown in Map 1-1. Bicraft Proper is surrounded completely by tailings. Lower Bicraft Pond has tailings on the south end, but the remainder is surrounded by forest and beaver dams; standing dead trees in this pond suggest the beaver activity. Auger Lake is mostly surrounded by tailings at the south end and by rock and trees over the north half and the west arm. Map 2-2 shows the beaver dam at the south end adjacent to the tailings dam. There are also several groups of dead trees standing in Auger Lake, as Map 1-1 shows, but these are probably related to the construction of the manmade dams at both ends. Sunfish Pond is surrounded by rock and gravel and a highway at the north end.

PHYSICAL AND CHEMICAL PARAMETERS

SUBSTRATE

Tailings were detectable in the water as a fine orange substrate. The south end of Auger Lake consisted of a tailings substrate with an abrupt transition into a bottom cover of brown organic matter around the middle part (Site B). No tailings were visible to the eye at the north end. At 7 m depth in the west arm of Auger Lake, the substrate was very soft and black and there was a strong rotting odour to it. This contrasts with 7 m depth in Centre Lake, where the bottom consisted of a firm mixture of sand, gravel and organic matter. Bicraft Proper and Lower Bicraft Pond sediments were composed mostly of tailings, although there was a large amount of organic material in Lower Bicraft Pond.

Table 2-2. Sampling schedule

Parameter	May 23	June 4	June 11	June 18	June 25	July 2	July 9	July 16
Weather		c o n t i n u o u s s a m p l i n g						
Lake area and depth	X	X						
Shoreline characteristics	X	X						
Lake substrate	X	X						
Inflows and outflows		s e e h y d r o l o g y s e c t i o n						
Water transparency			X		X		X	
Water temperature			X		X		X	
Heavy Metals			X					
Other chemical parameters			X		X		X	
Phytoplankton				X	X			X
Zooplankton				X	X			X

TEMPERATURE

A ranked plot of temperature at each site (Fig. 2-1a) revealed that the coolest sites were the 7 m deep sites and the warmest ones were the surface sites where the water was less than 2 m deep. Upon closer inspection, one can notice that in overall temperature values from highest to lowest, we find Centre Lake, the north half of Auger Lake, the south half of Auger Lake, Sunfish Pond and the Bicroft ponds. Except at the Bicroft ponds, temperatures rose steadily over time.

Depth temperature profiles of Auger Lake are shown in Fig. 2-1b. No sharp thermocline seemed to be present. Instead, there seemed to be a gradual decrease in temperature with depth. After 6 m, there was an abrupt rise in temperature on June 6. This pattern seemed to disappear over time as the lower part of the lake warmed up.

pH

pH was plotted in the same manner as temperature. Figure 2-2b shows a slight trend towards lower pH over time. The only site showing a rising trend was site A at the south end of Auger Lake. We find that overall, Centre Lake has the highest pH, followed by Sunfish Pond, Auger Lake and the Bicroft Ponds. There is no pronounced trend in pH along any of the transects in Auger Lake.

As shown in Fig. 2-2a, there was a persistent trend in the pH depth profile for Auger Lake. pH slowly decreased with depth to 6 m (except in July where it remained steady) and then rose markedly below 6 m. This trend did become slightly less pronounced with time.

A comparison of Fig. 2-2a with 2-2b shows that the temperature and pH profiles mirror each other somewhat.

CONDUCTIVITY - Table 2-3 shows the conductivity results.

Table 2-3. Averaged conductivity results in micromohos for the survey sites

Depth	Site A South Auger	B Middle Auger	C West Auger	D North Auger	E Sunfish Pond	F Centre Lake	G Bicroft Pond	H Lower Bicroft
0-0.5M	235	230	240	230	265	72	1125	1400
3.0-3.5M	-	235	230	225	-	60	-	-
7.0-7.5M	-	-	1,500	-	-	56	-	-

Fig. 2-1a Ranked temperature of study sites

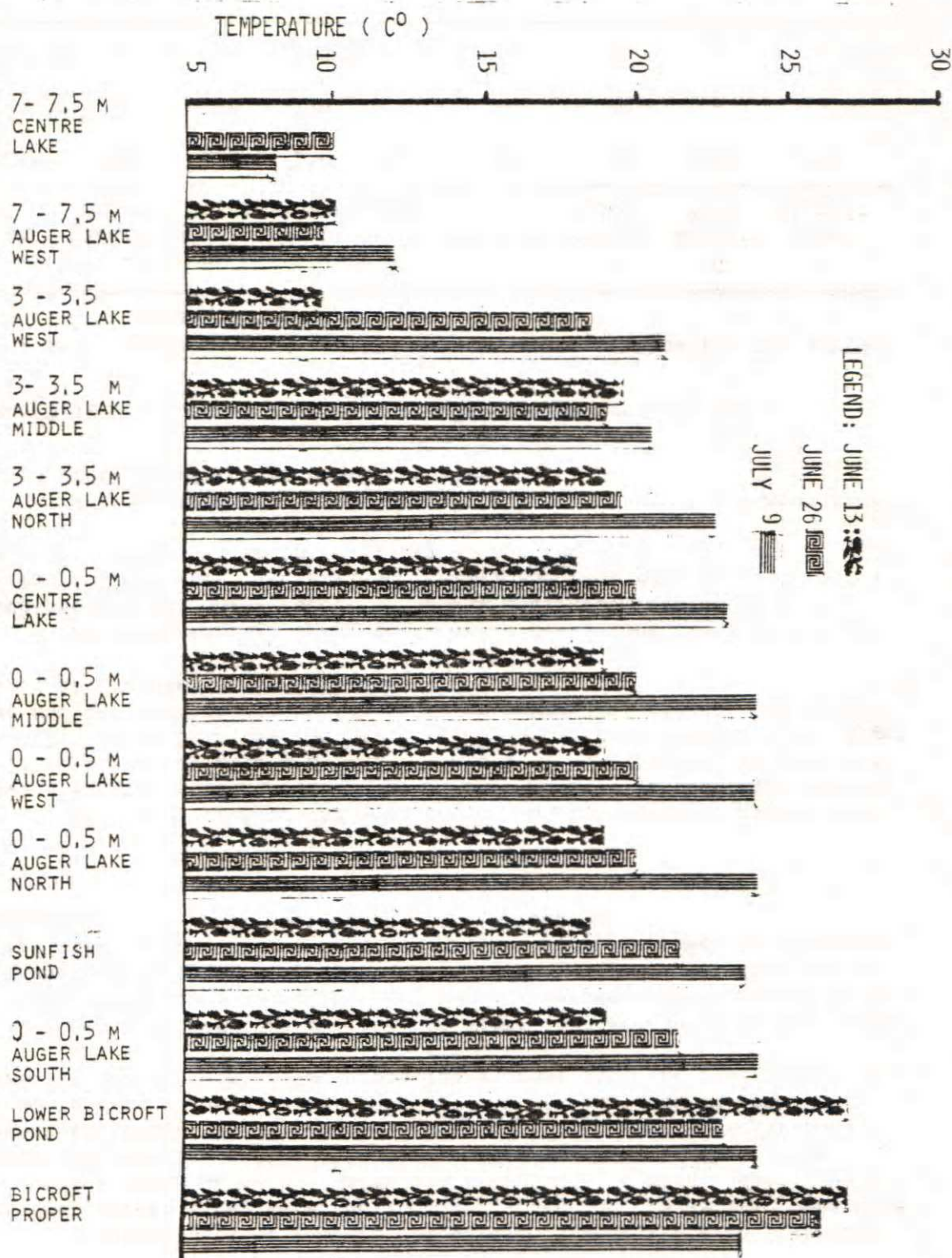
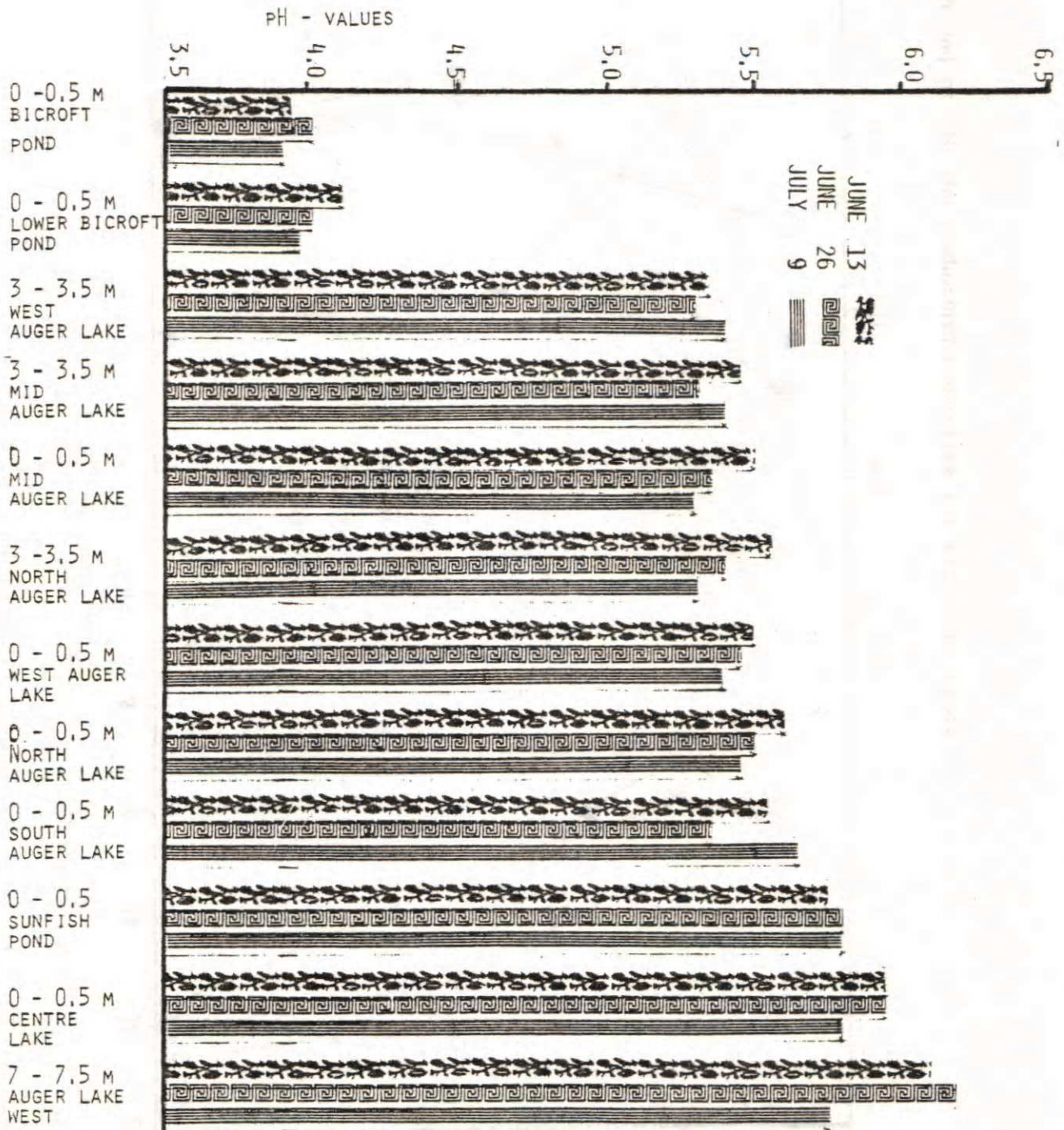


Fig. 2-1b Ranked pH values



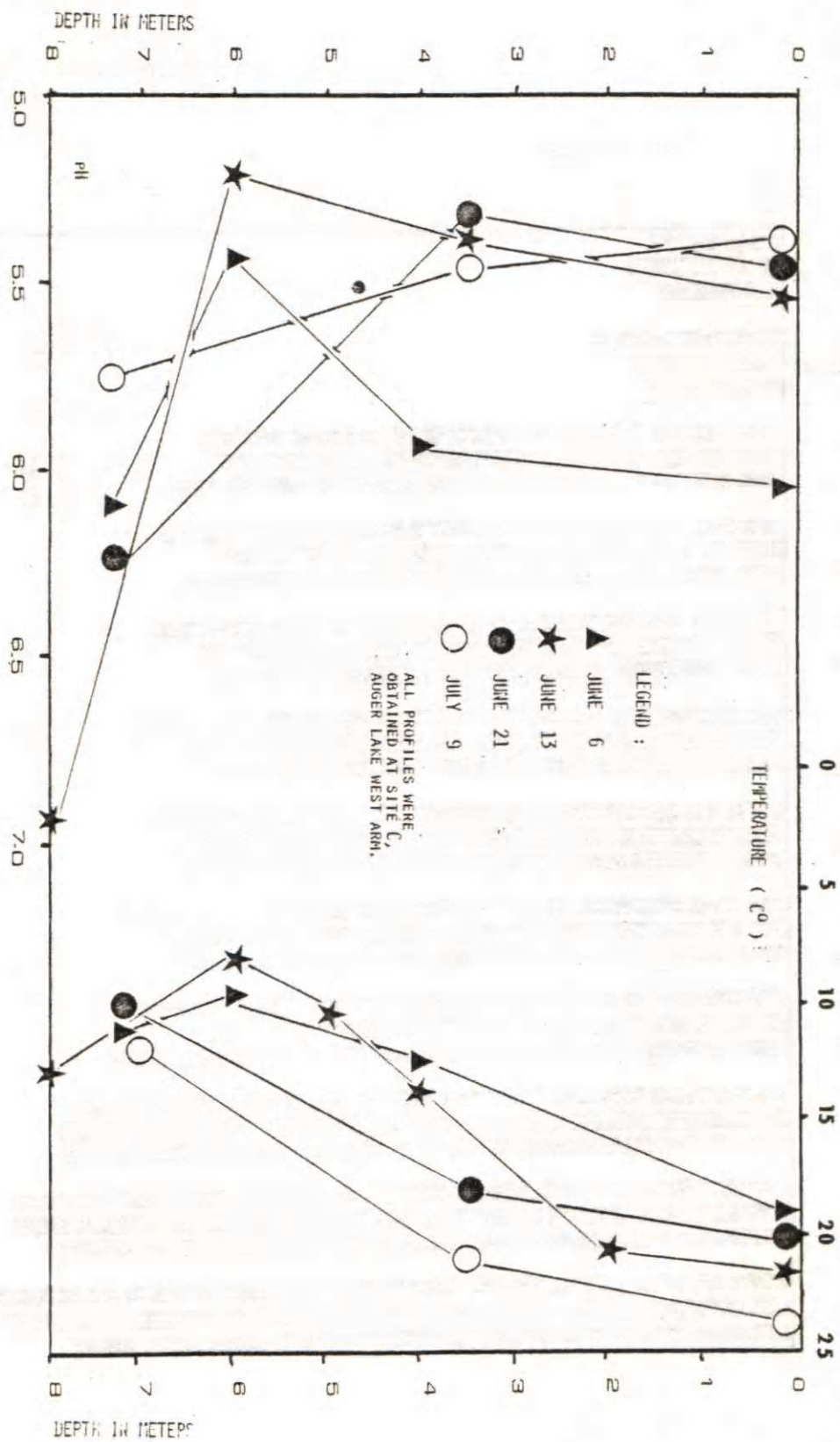


Fig. 2-2a and b. pH and temperature profiles for different times

The key points to note in Table 2-3 are as follows:

1. By increasing conductivity, the following order is established: Centre Lake, Auger Lake, Sunfish Pond, Bicroft Pond and Lower Bicroft Pond.
2. Conductivity is much higher at 7 m in Auger Lake than at the surface. This does not occur in Centre Lake.
3. Conductivities are higher in the seepage ponds than in the waters where tailings were dumped.

ALKALINITY

These results were averaged over time and ranked by site in order of increasing alkalinity. These results are shown in Table 2-4. No trends over time were rated.

Table 2-4. Alkalinity

Site (m)	Average Alkalinity mg/l	Range	# of Measurements
A 0-0.5	2.3	5	3
B 0-0.5	7.0	3	3
B 3-3.5	7.0	4	3
C 0-0.5	7.7	3	3
D 3-3.5	8.0	4	2
D 0-0.5	8.3	3	3
C 3-3.5	9.0	5	3
F 0-0.5	11.0	6	3
F 7-7.5	14.5	6	2
H 0-0.5	20.0	6	3
E 0-0.5	22.3	5	3
G 0-0.5	165.0	30	2
C 7-7.5	678.3	1300	3

There is a slight trend towards increased alkalinity in Auger Lake from the south to north end (A-D). There is a pronounced trend towards higher alkalinity with depth in Auger Lake (Site C). This does not occur in Centre Lake (F-sites). The alkalinity is also very high in Bicroft Proper (G) relative to all of the other surface sites including Lower Bicroft Pond (H). As one would expect, the range between the readings increased as the average increased.

TURBIDITY

Turbidity results were somewhat higher over the last two sets of readings than over the first, but since relative trends remained the same, they were averaged over time and treated the same as the alkalinity data. The results are shown in Table 2-5.

Table 2-5. Turbidity

Site (m)	Average Turbidity FTU	Range	# of Measurements
B 0-0.5	4	4	2
C 3-3.5	5	1	2
G 0-0.5	6	3	3
C 0-0.5	7	3	3
D 0-0.5	7	3	3
A 0-0.5	8	3	3
F 0-0.5	12	9	2
E 0-0.5	13	24	3
H 0-0.5	24	33	3
B 3-3.5	50	130	3
C 7-7.5	116	208	3
E 7-7.5	233	434	2

Centre Lake, Sunfish Pond and Lower Bicroft Pond appeared to have turbidity values about twice those of Auger Lake and Bicroft Proper (three times greater for Lower Bicroft Pond). The most pronounced trend was with depth, however. Highest turbidities were between 7 and 7.7 m in both Auger and Centre Lakes.

WATER TRANSPARENCY

Where depth permitted, secchi depths were consistently around 4 m in Centre and Auger Lakes.

DISSOLVED OXYGEN

Dissolved oxygen values for all sites were consistently between 6 and 9 mg/l except for the 7-7.5 m deep site in Auger Lake, where the readings were 1 mg/l on June 13 and 26 and 5 mg/l on July 11.

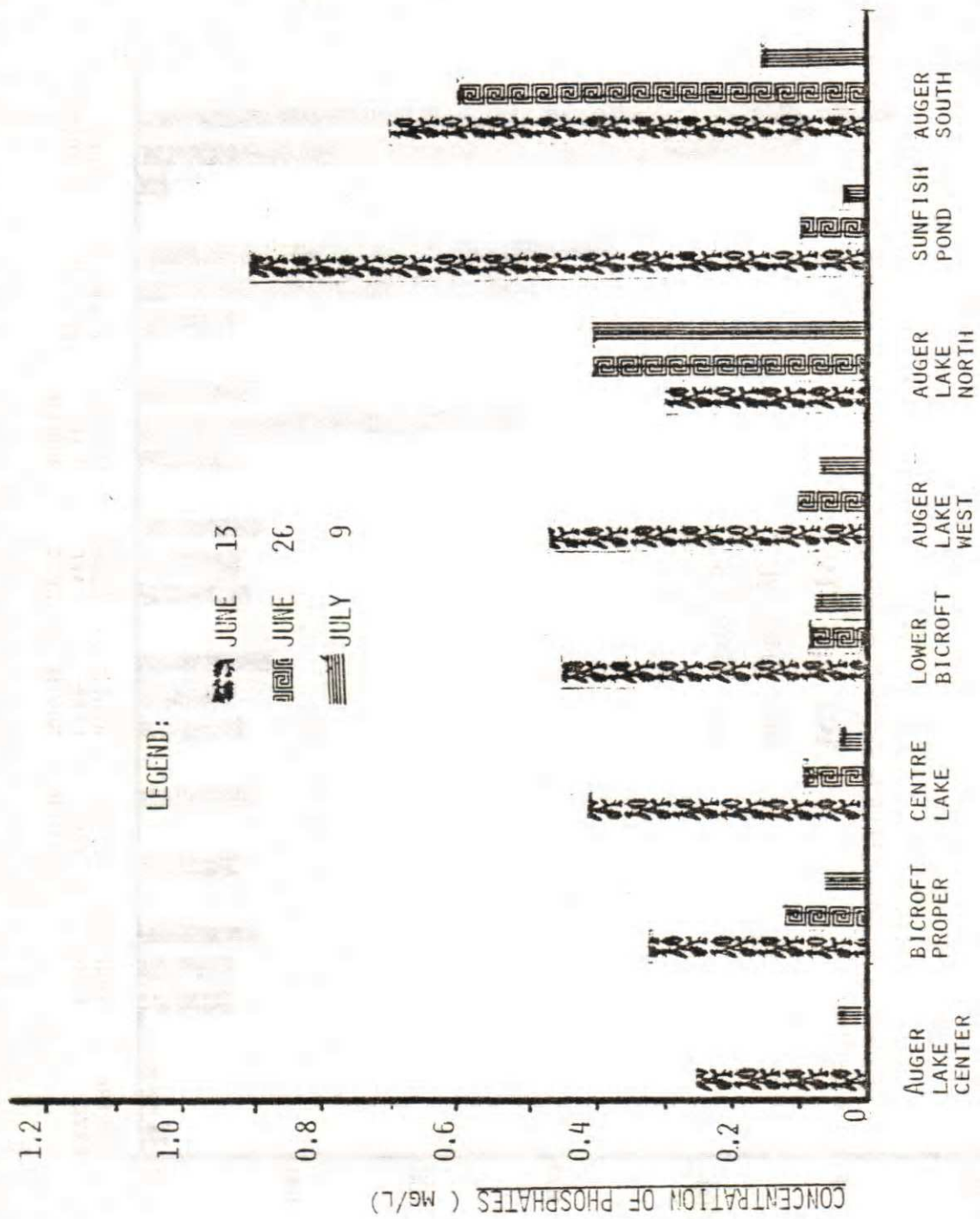


Fig. 2-3a. Ranked levels of phosphate

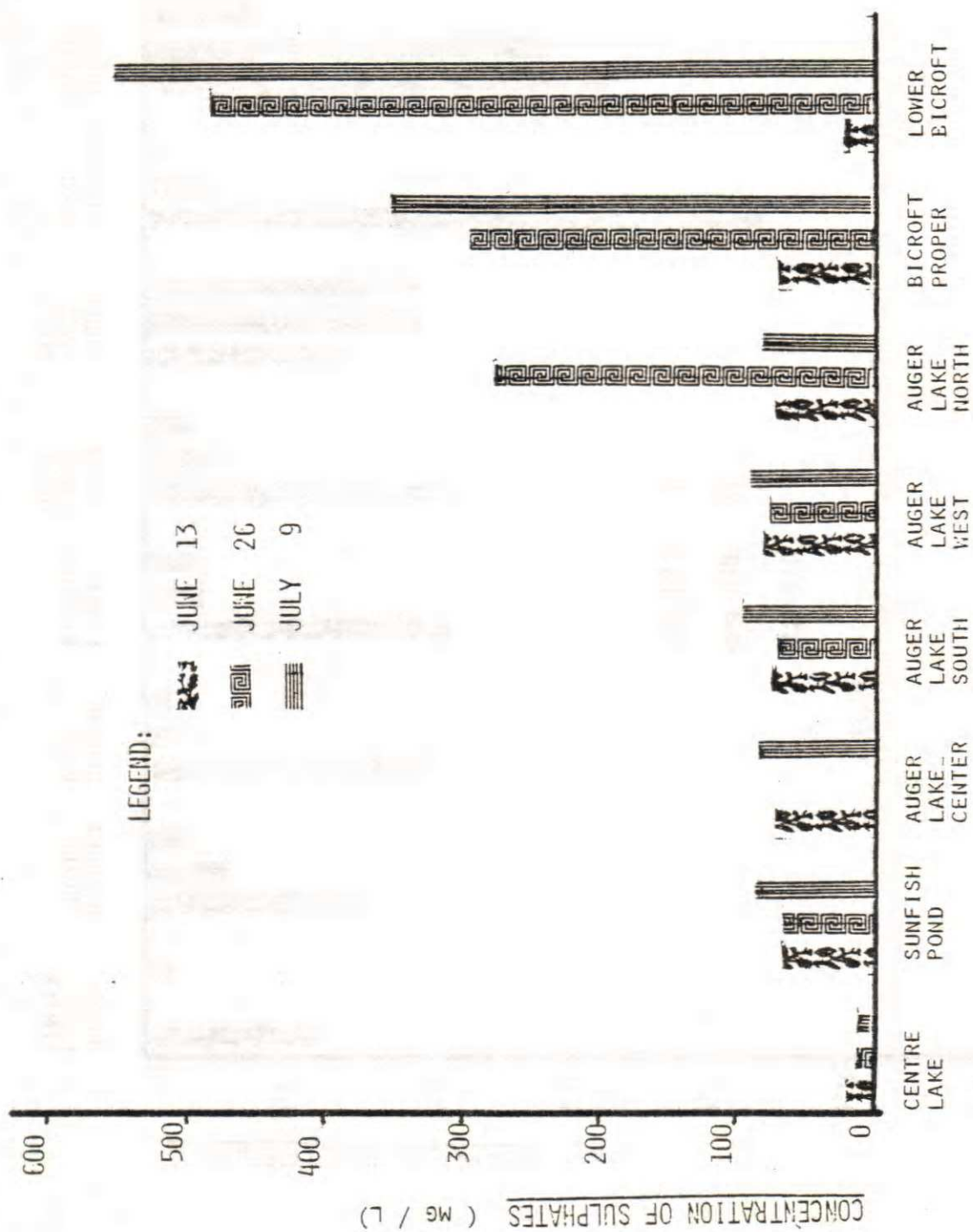


Fig. 2-3b Ranked levels of sulphate

AMMONIA

Consecutive ammonia readings of 6.8 (June 13), 300 (June 26) and 0.3 (July 17) mg/l were taken from 7 m depth in Auger Lake. All of the other sites had average ammonia levels of less than 2.5 mg/l.

SULFIDES

Levels of H_2S were determined, but were negligible at all sites.

SULFATES

Sulfates were ranked by site from low sulfate levels to high and the results are shown in Fig. 2-3b. Trends can be summarized as follows:

1. There were no trends in sulfate concentration over time except for an increase in Bicroft Proper and Lower Bicroft Ponds.
2. When the lakes are arranged in order of average sulfate concentration from low to high, we find that Centre Lake < Sunfish Pond < Auger Lake < Bicroft Proper < Lower Bicroft Pond. This trend is pronounced.

It is also worth mentioning that from 0.7 m depth, the concentration of sulfate dropped from 33-14 in Centre Lake, and rose from 88-350 in Auger Lake on July 17. All readings were high at the bottom of Auger Lake (360, 500 and 350 mg/l).

PHOSPHATES

The data for phosphates were treated the same as the data for sulfates. The results are shown in Fig. 2-3a. The only apparent trend here is that phosphorus concentration decreased over time.

NITRATES

The nitraver compound precipitated some of the suspended solids. The results could not be used.

METALS - TABLE 2-6

The first point to note here is that all of the metals show their lowest concentrations in Centre Lake and Deer Creek and their highest concentrations in Bicroft Proper and Lower Bicroft Pond. The

Table 2-6. Metals - Concentrations of heavy metals found in the survey

Letter map	Name of site	Depth (m)	Element concentrations in ppm					
			Zn ±0.001	Ca ±1.0	Cu ±0.003	Ni	Mn	Al ±0.05
A	South Auger	0-0.5	0.017	26	<0.004	<0.004	0.123	0.30
B	Middle Auger	0-0.5	0.011	27	<0.004	0.014 ± 0.003	-	0.31
B	Middle Auger	3-3.5	0.026	27	<0.004	0.007 ± 0.002	0.141	0.31
C	West Auger	0-0.5	0.016	26	<0.004	0.030 ± 0.004	0.141	0.33
C-W		7-7.5	0.020	63	<0.004	0.014 ± 0.004	1.71	1.10
D	North Auger	0-0.5	0.012	27	<0.004	0.016 ± 0.003	-	0.44
E	Sunfish Pond	0-0.5	0.012	29	<0.004	0.016 ± 0.003	0.179	<0.05
F	Centre Lake	0-0.5	0.004	4	<0.004	0.007 ± 0.002	0.029	<0.05
G	Bicroft Proper	0-0.5	0.461 (±0.002)	110	<0.034	0.057 ± 0.004	1.44	3.60
H	Lower Bicroft	0-0.5	0.240	165	<0.028	0.089 ± 0.006	1.71	6.15
	Deer Creek		<0.001	4	<0.004	0.012 ± 3	-	<0.05
1. ¹	Recommended		0.03	-	0.005	0.025	-	0.10
2. ²	Natural water		0.01	15	0.01	0.01	0.01	0.24
3. ³	Drinking water		5.0	-	1.00	-	0.05	-
4. ⁴	Experimentally Toxic		-	-	0.04	0.25	-	-

¹ Water quality objectives for fresh water according to the Ministry of the Environment (1978)² Typical values for natural waters (Bowen 1966)³ Water quality recommendations for drinking water according to MOE (1978)⁴ Level of hindrance to growth of laboratory *Scenedesmus* in nutrient solution (Hutchinson and Stokes 1975)

concentrations are intermediate in Auger Lake and Sunfish Pond. The concentrations of zinc were above that normally found in fresh water everywhere except Centre Lake and Deer Creek and above the recommended level in Bicroft Proper and Lower Bicroft Pond. The amount of calcium was very much above that usually found in fresh water in Bicroft Proper and Lower Bicroft Pond and was below that level only in Deer Creek and Centre Lake. Copper was within the acceptable range everywhere but in Bicroft Proper and Lower Bicroft Pond, where it was found to be close to the growth-limiting level found by Hutchinson and Stokes (1975). They also found that the effect of copper was also synergistic in the presence of other metals such as nickel. Levels of nickel were well below the toxic level everywhere, but were above the recommended level in Bicroft Proper and Lower Bicroft Pond. Levels of manganese were above those usually found in fresh water everywhere. Finally, the levels of aluminum were above the level recommended by the Ministry of the Environment everywhere except in Sunfish Pond, Centre Lake and Deer Creek. It should also be noted that within Auger Lake, there were relatively elevated levels of aluminum, manganese and calcium at a depth of 7 m in the west arm.

ZOOPLANKTON

Copepods and several types of Cladocerans (*Daphniidae*, *Leptodora*, *Bosminidae*, *Sisidae*) were found in this study everywhere except Bicroft Proper, where no zooplankton were found, and Lower Bicroft, where a few Copepods and *Leptodora* were found. No trends in zooplankton over time were evident. Copepods and Cladocerans were considered separately, and the total number of each observed was determined. The numbers observed at each site as a percentage of the total were calculated. The results are shown in Fig. 2-4a and 2-4b. Data from Sunfish Pond and Lower Bicroft Pond were not included because sampling was biased at these sites due to obstructions (logs) in the water. There is a clear trend towards fewer numbers of Cladocerans and Copepods from Centre Lake to Auger Lake to Bicroft Proper. It is also evident that sites with tailings substrates have fewer zooplankton than sites with no tailings substrates.

PHYTOPLANKTON

Due to sampling problems and counting problems, it was not possible to discern trends over time. When numbers of algae cells were added up over the three sampling periods, however, some interesting results occurred. Numbers of algae in each size class are shown in Table 2-7.

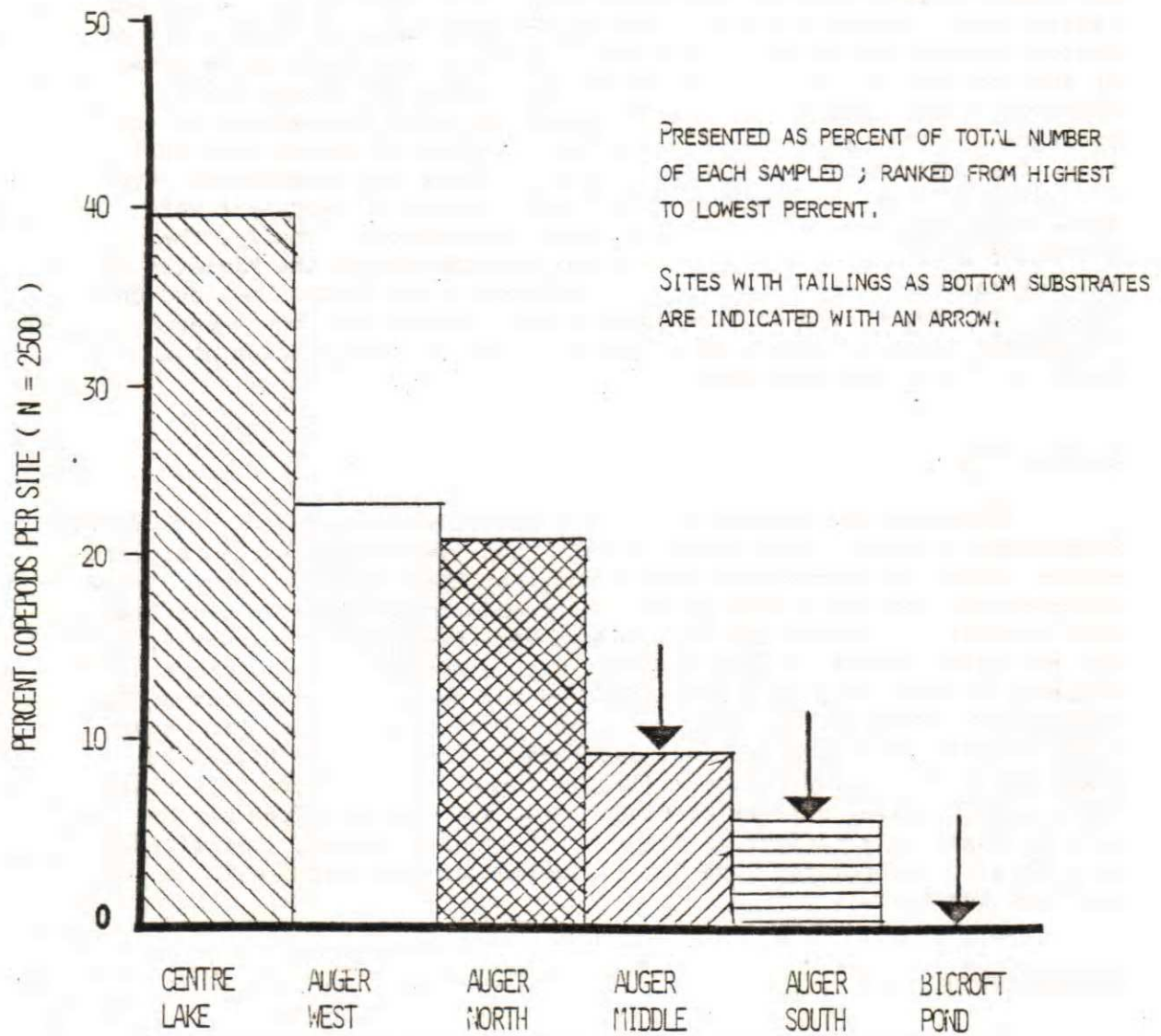


Fig. 2-4a. Number of copepods per site

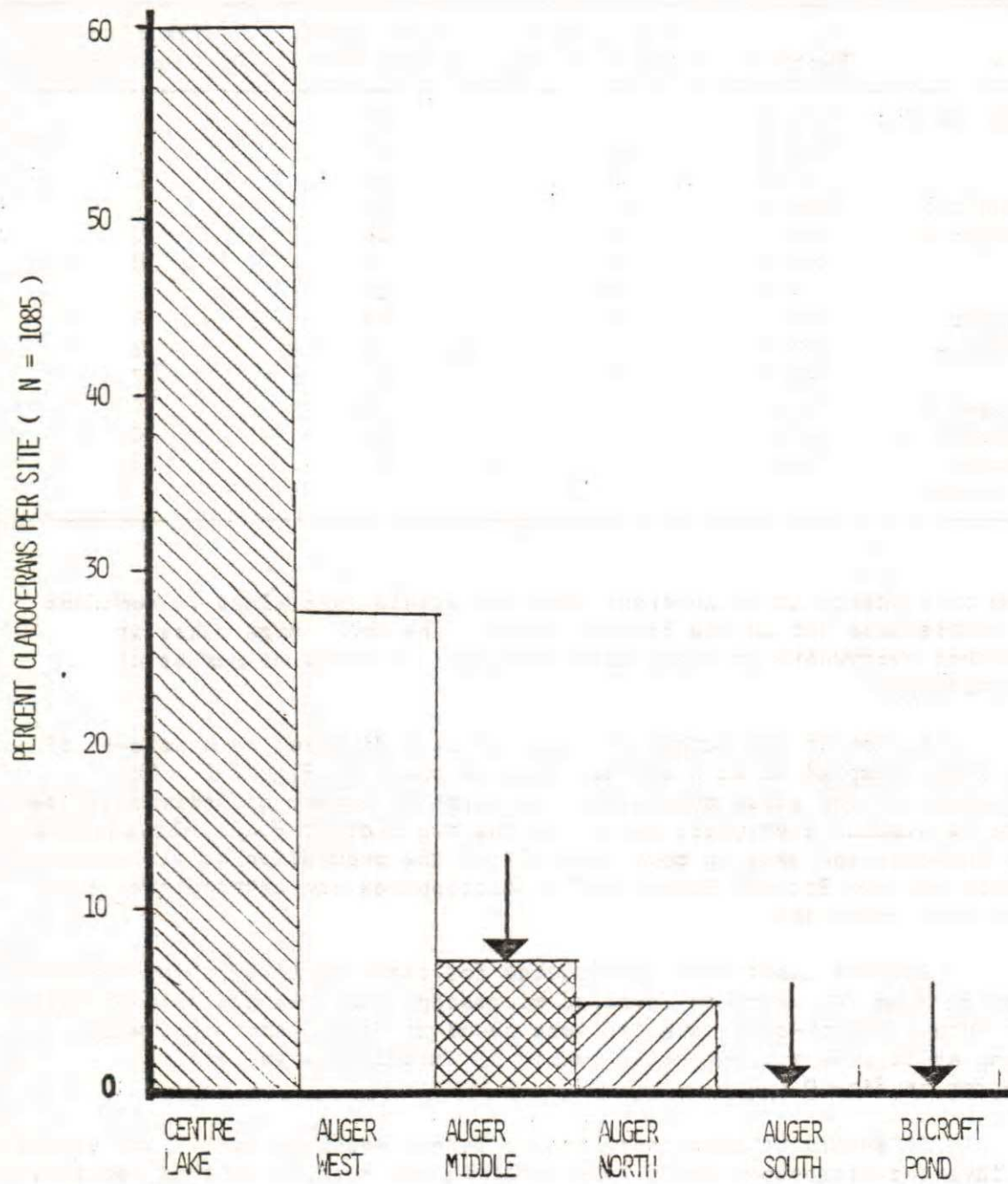


Fig. 2-4b. Number of cladocerans per site

TOTAL NUMBER OF ALGAE

Table 2-7. Total number of algae

Site	Depth m	Size class	Size class	Size class
		0.005-0.019 mm	0.02-0.09 mm	0.09 mm + greater
F-Centre L.	0-0.5	0	22	3
	3-3.5	14	13	6
	7-7.5	12	45	0
E-Sunfish	0-0.5	53	13	1
D-Auger N.	0-0.5	311	20	8
	3-3.5	28	4	0
	7-7.5	20	18	2
B-Auger Middle	0-0.5	74	18	8
	3-3.5	3	8	2
	0-0.5	107	13	7
A-Auger S.	0-0.5	14	8	2
G-Bicroft P.	0-0.5	9	61	0
N-Lower Bicroft	0-0.5	10	99	7

From this chart, it is apparent that the middle size class is dominant in Centre Lake and in the Bicroft Ponds. The small size class is dominant everywhere in Auger Lake (dominant in terms of number of individuals).

A plot of the number of algae in each division as a percent of all algae sampled at each surface site is shown in Fig. 2-5. The structure of the algae populations in terms of number of individuals per site is similar everywhere except in the two Bicroft Ponds. Chrysophytes are dominant and make up more than 50% of the population at all sites except the two Bicroft Ponds, where chlorophytes and cryptophytes are much more important.

Species lists were constructed for sites North(D), South (A) and Bicroft Pond (G) using an inverted microscope and with the help of Ying Kit Yung. Twenty-seven species were found at Site D and eight were found at Site G, but the total number of individuals was visibly greater at Site D.

It should be noted here that a better settling method and use of an inverted microscope would have enhanced the results of this section. It seemed that the use of a haemocytometer selected against filamentous algae (Table 2-8).

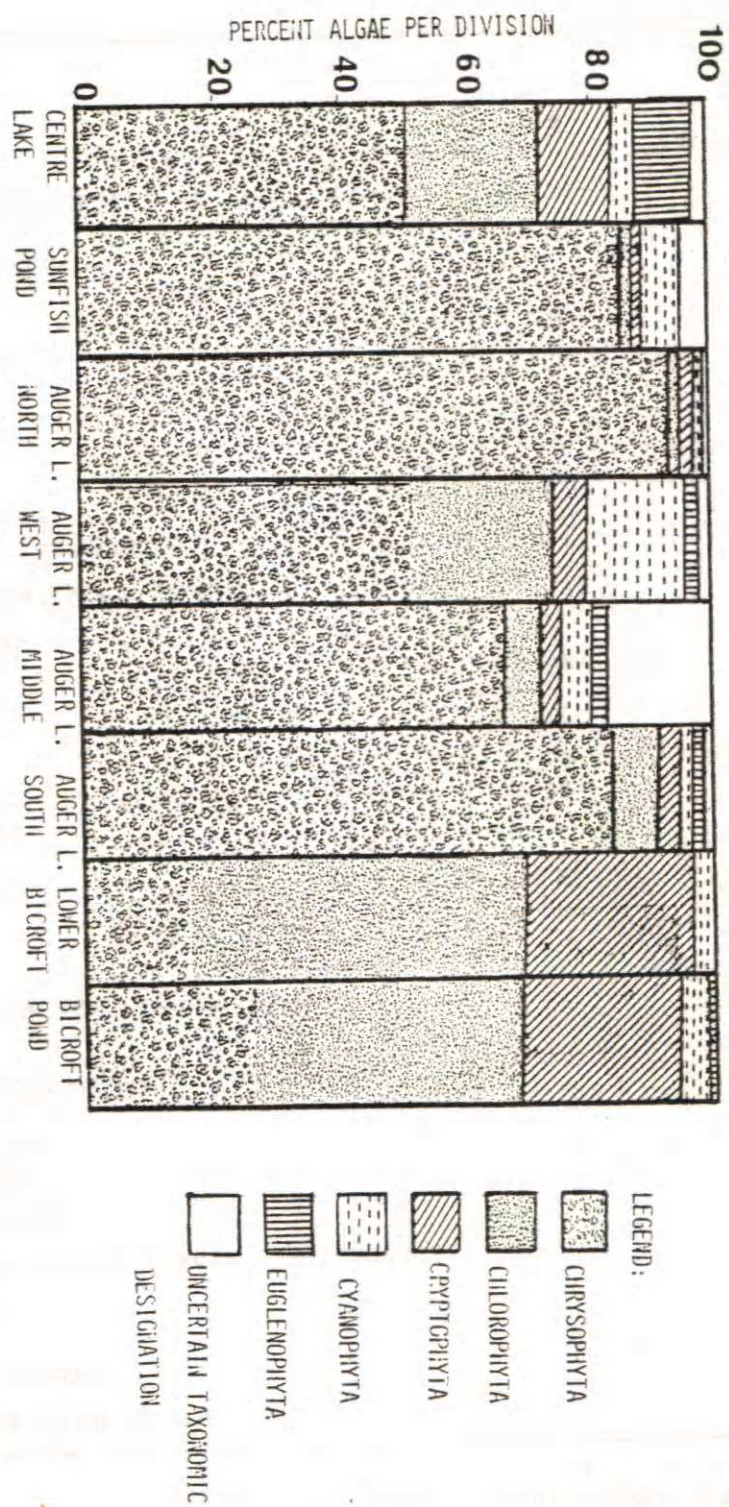


Fig. 2-5. Relative percentage of algal divisions at the surface of each site

Table 2-8. Species list for three sites

Sites:	North Auger	South Auger	Bicroft Proper
	D	A	G
Cyanochloronta (blue-green algae)			
<i>Merisnopedia elegans</i>	x		
<i>Oscillatoria</i>		x	
<i>Phormidium</i> sp.	x		
Cryptophyta (Dinoflagellates cryptomonads)			
<i>Cryptomonas erosa</i>	x		
<i>Cryptomonas</i> sp.	x		
<i>Gloenodinium</i> sp.	x		x
<i>Peridinium</i> sp.			x
<i>Peridinium inconspicuum</i>	x		
<i>Rhodomonas</i>	x		
Chrysophyta (Golden algae diatoms)			
<i>Achanthes</i> sp.		x	
<i>Cymbella</i> sp.		x	
<i>Dinobryon</i> sp.	x		
<i>Eunotia</i> sp.			x
<i>Fragillaria</i> sp.	x		
<i>Frustulina</i> sp.	x	x	x
<i>Navicula</i> sp.	x	x	
<i>Nitschia</i> sp.	x	x	
<i>Ochromonas</i> sp.	x		x
<i>Tabellaria</i> sp.	x	x	x
<i>Uroglenopsis</i> sp.	x		
Chlorophycophyta (Green algae)			
<i>Ankistrodesmus falcatus</i> - <i>spirilliformis</i>	x		
<i>Closterium</i>	x		x
<i>Cosmarium</i>		x	
<i>Desmatractum</i> sp.	x		
<i>Diceras</i> sp.	x		
<i>Gonatozygon</i> sp.	x	x	
<i>Mougeotia</i> sp.	x	x	
<i>Netrium</i> sp.			x
<i>Scenedesmus acutus</i>	x		
<i>Scenedesmus bijuja</i>	x		
<i>Scenedesmus quadricauda</i>	x		
<i>Selenastrum</i> sp.	x		
<i>Spirogyra</i> sp.		x	
<i>Strauastrum</i> sp.	x		
<i>Tetrahedron</i> sp.	x		

DISCUSSION

For parameters showing trends over time, weather must be considered as a possible factor. As Fig. 2-1a shows, there was a gradual warming trend in the water over most of the study sites over the course of the survey. This is probably due to the fact that the average air temperature increased over time. The average maximum air temperature increased over time. The average maximum air temperature rose from about 20°C at the start of the survey to about 30°C at the end. The downward trend in temperature at Bicroft Proper and Lower Bicroft Ponds can be attributed to the fact that these ponds are small and shallow. They are more subject to daily fluctuations, and although the overall weather trend was to warmer temperatures, the maximum temperatures on the day before sampling were 24°C (June 14), 21°C (June 25) and 18°C (July 8). That this phenomenon does not occur at the shallow south end of Auger Lake is evidence that daily variations here are diluted by mixing from the remainder of the lake. With the given information, the fact that sulfates (Fig. 2-3b) and turbidity (Table 2-5) increased in the last two sampling periods could not be explained. A heavy rainstorm did drop over 20 mm of rain on July 1 and 2 and may have had something to do with these readings.

The presence of algae and the expected decrease in PO_4 from the 0.4 mg/l range to the 0.05 mg/l range (Fig. 2-3a) reflects a normal lake situation. Phosphates tend to accumulate in the winter and then become incorporated into algae biomass in the summer. This was apparently unaffected by weather and the mill tailings as bottom sediments.

Referring to the results for pH (Fig. 2-1b), sulfates (Fig. 2-3b), conductivity (Table 2-3) and metals (Table 2-6), one can discern a common trend over distance among these variables. Across the sequence, Centre Lake, Auger Lake, Sunfish Pond, Bicroft Proper, Lower Bicroft Pond, pH falls, and sulfates, conductivity and metals all increase. These parameters usually act in tandem. Oxidation to sulfates releases hydrogen ions, so that large amounts of sulfates are generally accompanied by depreciated levels of pH. Low levels of pH generally cause increased solubility of salts and metal ions so that conductivity and metal concentrations rise. In trying to explain the behaviour of these parameters across the sequence mentioned above, two other trends across this sequence are worth pointing out. First, there is a sharp decrease in water volume from Centre Lake to Auger Lake to Bicroft Proper and Lower Bicroft Ponds. Second, the ratio of tailings to bottom substrate increases across this sequence. Sunfish Pond is excluded from this part of the discussion, as it is the only water body which can be expected to show some effects due to interference from the highway. It is possible that filling in of the water bodies by tailings and subsequent evaporation cause the sulfates and metals to become concentrated in the water. This process would be expected to occur most prominently in Bicroft Proper and Lower Bicroft Pond and not

at all in Centre Lake. Some explanation of this nature is also supported by the fact that the aquatic and terrestrial pH values do not agree (Fig. 2-1b; Table 3-4). In particular, pH is lower in the water at Biccroft Proper relative to Auger Lake and higher on land. Nonetheless, the sulfates had to get into the water in order to be concentrated, and it thus appears that the tailings do contribute some acidity.

Expected horizontal trends in chemical parameters along the north-south transect in Auger Lake did not occur. It was expected that pH would drop and sulfates, conductivity and metal concentrations would rise from north to south in Auger Lake. As previously mentioned, the fact that temperature also was not higher at the south end suggested that water movement was dispersing the heat throughout the lakes, in which case it would also be dispersing most of the chemical parameters.

There were pronounced changes in chemistry with depth in Auger Lake. As Fig. 2-2b shows, there was a consistent drop in temperature from the surface down to about 6 m. This drop was most pronounced between 3 and 6 m, and it also occurred in Centre Lake (Fig. 2-1a). This is part of the normal pattern of summer stratification in lakes that occurs because cooler water tends to be more dense (down to 4°C). Below 6 m in Auger Lake, the temperature began to rise again (Fig. 2-2b). At the bottom of Auger Lake, there were also marked increases in the pH (Fig. 2-2a), conductivity (Table 2-3) and alkalinity (Table 2-4), while concentrations of ammonia, sulfate (Fig. 2-3b), manganese, aluminum and copper (Table 2-6), and dissolved oxygen decreased. None of these trends was observed in Centre Lake. The decrease in oxygen and increase in ammonia at the bottom of a lake is often indication of biological decomposition. There was no evidence to suggest that primary production was high enough to account for the observed results, though, so this idea was discounted. These observations do suggest that perhaps Auger Lake is at least partially chemically meromictic. This occurrence needs further confirmation, but it is extremely interesting in the framework of this preliminary investigation. Little information could be extracted regarding the persistence of these depth trends due to the short time span of the study. Previous work done on meromictic lakes indicates that variations in iron content can give rise to this phenomenon (Kjensmo 1967). Because of the fact that high iron contents were noted in the soil (Section III), and because sulfates (which are often associated with iron) were high in the water, this is a realistic possibility. It is also worth noting that the sheltered location of the West Arm of Auger Lake and the slow rate of flowthrough are both conducive to meromixis (Kjensmo 1967).

Turbidity values increased with depth both in Auger Lake and Centre Lake (Table 2-5). This is typical in lakes and is likely a result of higher water density with depth due to cooling. Turbidity levels at the bottom of Auger Lake were probably affected by the sediments, as there seemed to be no clear-cut sediment-water interface.

Of ecological significance is the fact that when one looks at the site rankings for pH and temperature (Fig. 2-1) as well as the results for conductivity (Table 2-3), sulfates (Fig. 2.3b) and metals (Table 2-6), one can see that for these variables, ponds receiving seepage (Sunfish and Lower Bicroft) most closely resembled their respective tailings ponds. This suggests that some of the chemical characteristics of the tailings ponds are escaping through the dams. It should again be mentioned that Sunfish Pond chemistry could also be partly the result of the highway.

Some of the chemical results could not be interpreted. There was no apparent reason why turbidity values in Lower Bicroft Pond and Auger Lake (Table 2-5) should have been as high as they were relative to the other water bodies. Also inexplicable was the fact that alkalinity (Table 2-4) was an order of magnitude higher in Bicroft Proper and Lower Bicroft Pond while the pH was lower. One might expect high alkalinity due to the elevated levels of calcium in these ponds (Table 2-6), since calcium carbonate is the main component in the buffering system in most lakes. If this is true, then there must be a tremendously high concentration of hydrogen ions in Bicroft Proper and Lower Bicroft Ponds to overcome this buffering system.

The Ontario Ministry of the Environment (1978) has set pH 6.5 to pH 8.5 and dissolved oxygen greater than 5 mg/l as the desirable ranges for these parameters in its water quality objectives. All of the surface waters meet the objective for oxygen, but they are all below that for pH (Fig. 2-1b), although Centre Lake is close. As Table 2-7 indicates, Deer Creek and Centre Lake meet the specified requirements for drinking water. The other sites are all above the recommended level for manganese. Although none of the copper and zinc values were found to be above those found experimentally to be toxic by Hutchinson and Stokes (1975), one should note that the forementioned also found synergistic effects between zinc and copper. In reality, the toxic levels are probably below those found by Hutchinson and Stokes. In particular, levels of nickel, zinc, copper, manganese and aluminum were found to be above the concentrations recommended by the Ministry of the Environment (1978) as being acceptable. Summing this up, one can see that there is a very real potential for the waters of Bicroft and Lower Bicroft Pond to adversely affect the biota. This potential would appear to be only slight in Auger Lake.

Most biological results do appear to be somewhat related to the chemical results. As Fig. 2-4 shows, the zooplankton data follow the same previously mentioned trend followed by some of the chemical data. The sequence from greatest numbers of both Cladocerans and Copepods to lowest is Centre Lake to Sunfish Pond and Auger Lake to Bicroft Proper and Lower Bicroft Pond. Of special interest is the observation that, unlike the chemistry data, numbers of zooplankton appear to be related directly to the presence of tailings substrate within Auger Lake.

Referring to Fig. 2-4, there are generally fewer zooplankton at the north end than at the south end. It is possible that the shallow water at the south end of Auger Lake disrupts the normal deep water wave pattern so that the water is too turbulent for zooplankton. These results could have implications with respect to the food chain. Zooplankton are part of the link between phytoplankton and fish in most aquatic food webs. The lack of zooplanktons at the south end of Auger Lake (and particularly in Bicroft Pond) could make these areas unsuitable for fish.

The algae data also yield some meaningful results. That the size classes were most similar between Bicroft Proper and Auger Lake (Table 2-7) was probably just a coincidence. As Fig. 2-5 indicates, in terms of population structure, Auger Lake, Centre Lake and Sunfish Pond are all grouped together, but Bicroft Proper and Lower Bicroft Pond form another group. Chrysophytes are dominant in the first group. This is typical of circumneutral lakes on the Canadian Shield. Cryptophyta can assimilate nitrogen at night (Bold and Wynne 1978). That should give them a competitive advantage in a nutrient limiting environment. Unfortunately, the nutrient status (and availability) of Bicroft Proper and Lower Bicroft Ponds was not determined. The algae species lists (Table 2-8) for Site D (North Auger) and Site G (Bicroft Pond) also bear out the difference in the community structure. Of significance is the fact that there were 27 species at Auger Lake and only 8 at Bicroft Proper, while the number of individuals appeared to be lower in Auger Lake. The reduction of species number is a classical sign of a stressed environment.

Finally, it is easy to see that much more work needs to be done on this subject. To get a complete limnological picture, one needs to measure the parameters over a much longer time period (at least three years). It is possible that a particular water condition which affects biota occurs only under certain conditions at a specific time of the year. Perhaps, for example, leaves falling into the water in the autumn change the chemistry. It would also be interesting to determine if there are year to year trends occurring. As well, a better picture of the food chain including fish, macrophytes, aquatic insects and a more detailed algae study may yield interesting information.

SUMMARY

In response to the questions posed in the introduction, it appears that the tailings exert a substantial influence on the water. Some of these influences are expressed more in depth in the water and other influences can be noted horizontally. Some of the entities affected include pH, conductivity, depth, temperature, substrate, concentrations of sulfate, metals, dissolved oxygen and ammonia, numbers of zooplankton and algae population structure.

REFERENCES

- Bold, H.C. and M.J. Wynne 1978. Introduction to the algae-structure and reproduction. Prentice Hall.
- Bowen, H.J.M. 1966. Trace elements in biochemistry. Academic Press.
- Debenham, F. 1937. Exercises in cartography. Blackie, Toronto.
- HACH 1978. Manual.
- Hutchinson, T.C. and P.M. Stokes 1975. Heavy metal toxicity and algae bioassays. Water quality parameters. ASTM STP 573, pp. 320-343.
- Kjensmo, J. 1967. The development of "iron-meromictic" soft water lakes. Arch. Hydrobiol. suppl. 32(2):137-312.
- Ontario Ministry of the Environment 1978. Water management - goals, policies, objectives and implementation. Ministry of the Environment, Toronto.
- Ontario Water Resources Commission 1971. Water pollution from uranium mining industry in the Elliot Lake and Bancroft areas. Ontario Water Resources Commission, Toronto.
- Ward, H.B. and G.C. Whipple 1959. Fresh water biology, 2nd ed. Ed. W.T. Edmondson. Wiley, New York.

SECTION III

A PRELIMINARY STUDY OF THE INVASION OF
URANIUM MILL TAILINGS BY VEGETATION

Caroline Caza

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A PRELIMINARY STUDY OF THE INVASION OF URANIUM TAILINGS BY VEGETATION

Caroline Caza

INTRODUCTION

A study of vegetation invading uranium mill tailings was conducted within an area of approximately 2.6 km², 17.7 km southwest of Bancroft, Ontario. Located within this area were two lakes. The tailings were dumped at various places into these lakes between the years 1956-1963. At present there are several exposed tailings sections on the lake, which are subject to seasonal changes in water levels. The object of the study was to investigate the invasion of these sites by vegetation and to describe certain chemical and physical parameters characterizing these sites.

METHODS

A visual description of a tailings site on the larger of the two lakes, Auger Lake, suggested the presence of zones or belts of vegetation. To establish the presence of these zones the principle features of the area were classified into fourteen categories (TABLE 3.1). Three lines were then run equidistance apart, along the area, parallel to the lakeshore. At 5 m intervals, quadrats of 1 m² were laid and percent cover or, when appropriate, presence or absence, was recorded for the parameters in each quadrat. A comparison of the changes in cover or presence over 75 m revealed some zonation on the tailings.

Subsequently, six more sites were recognized on Auger Lake and three on the smaller lake, Bicroft Proper (MAP 3.1). Eight of the nine sites were surveyed and zoned in a manner similar to that described above. In all, fourteen zones were identified (TABLE 3.2). Eight sites were mapped out by zones.

I. VEGETATION DESCRIPTION

The belt-transect method as described by Mueller-Dombois and Ellenberg (1974) was chosen to sample vegetation. A comparison between the zones of different sites determined where transects were laid. Within a zone, all transects were of equal length, but transect length differed between zones of different area.

TABLE 3.1

Parameters Used in the Establishment of Zones of Vegetation

1. Bare Tailings - wet
2. Bare Tailings - dry
3. Grasses
4. Mosses
5. Dead Wood - natural
6. Dead Wood - treated for construction of slurry pipes
7. Fungi
8. Rumex
9. Sumac
10. Equisetum
11. Low Vegetation (<0.5m)
12. Medium Vegetation (>0.5m - <3.0m)
13. High Vegetation (>3.0m)
14. Leaf Litter

Map 3-1a and b. Location of tailings shores on Auger Lake and Biccroft Proper

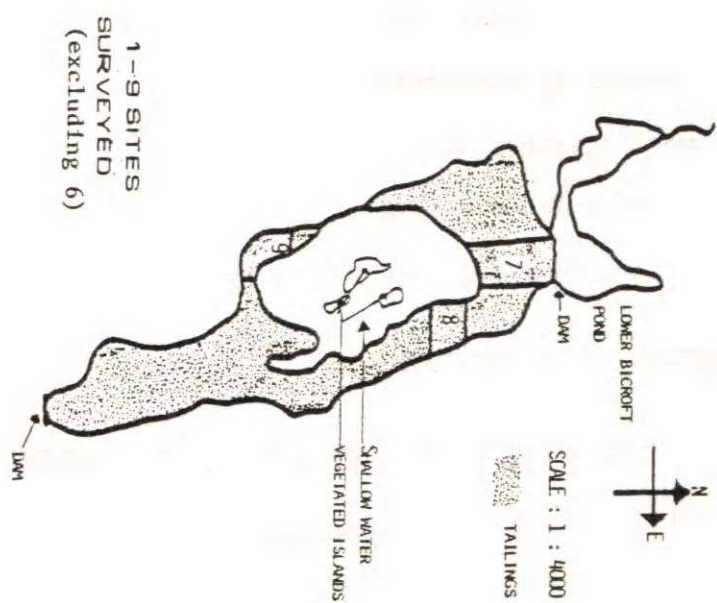
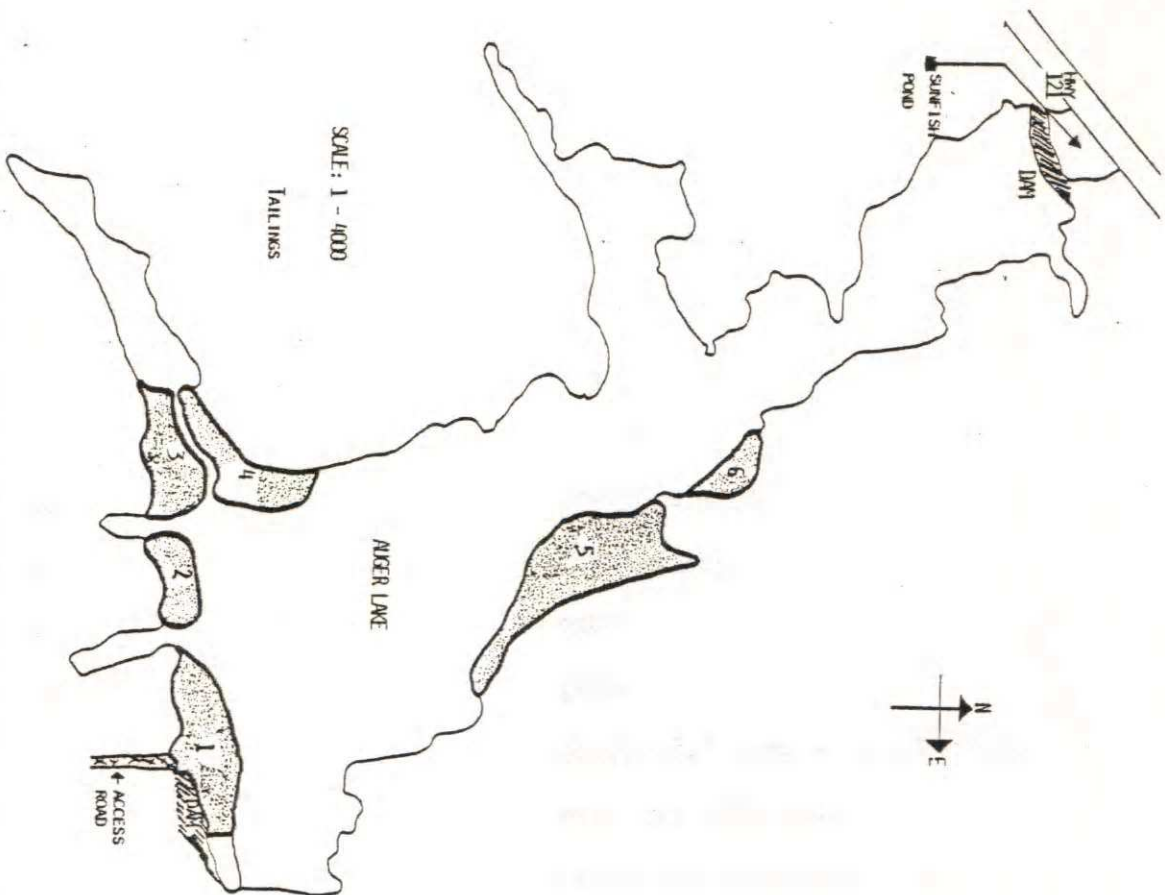


TABLE 3.2

Zones Identified on Eight Tailings Sites

<u>Zone</u>	<u>Characterizing Features</u>
A	Bare Tailings (dry)
B	Moss and Seedlings
C	Willow (aquatic, semi-aquatic)
D	Grass and Seedlings
E	Seedlings
F	Shoreline Vegetation
G	Grass and Equisetum
H	Bare Tailings (wet)
I	Seedlings, Dead Wood and Fungi
J	Typha
K	Grass
L	Grasses and Ferns
M	Black Tailings
N	Equisetum

Quantitative data were collected for approximately 5% of the area of a zone. This was done by laying quadrats, 1 m^2 , at specific intervals along each transect. The interval was determined by the area of the zone. Within each quadrat, relative cover, frequency, and height of plants were measured, although not all parameters were recorded for each species. For grasses and sedges only relative cover and frequency were determined. All three parameters were recorded for trees and shrubs. Only frequency was noted for fungi. Total relative cover and presence or absence of individual species were determined for mosses and lichens. In addition, other features considered necessary for the interpretation of data, such as the percentage covered with bare tailings, dead wood and organic debris, were also noted.

Representatives of all species found growing in the quadrats were collected for reference, identification and documentation. Larger specimens were collected in a plant press for preservation in an herbarium (Lawrence, 1951). Smaller specimens, such as mosses, fungi and lichens were preserved in moss bags, as described by Watson (1955).

Heights of trees growing on the tailings were measured. At both Auger Lake and Bicroft Proper, two transects were run (for location of transects, see MAP 3.2), one parallel and one perpendicular to the shoreline. At 2 m intervals along these transects, $2 \text{ m} \times 1 \text{ m}$ quadrats were laid. The heights of all trees of the predominant species in these quadrats were recorded.

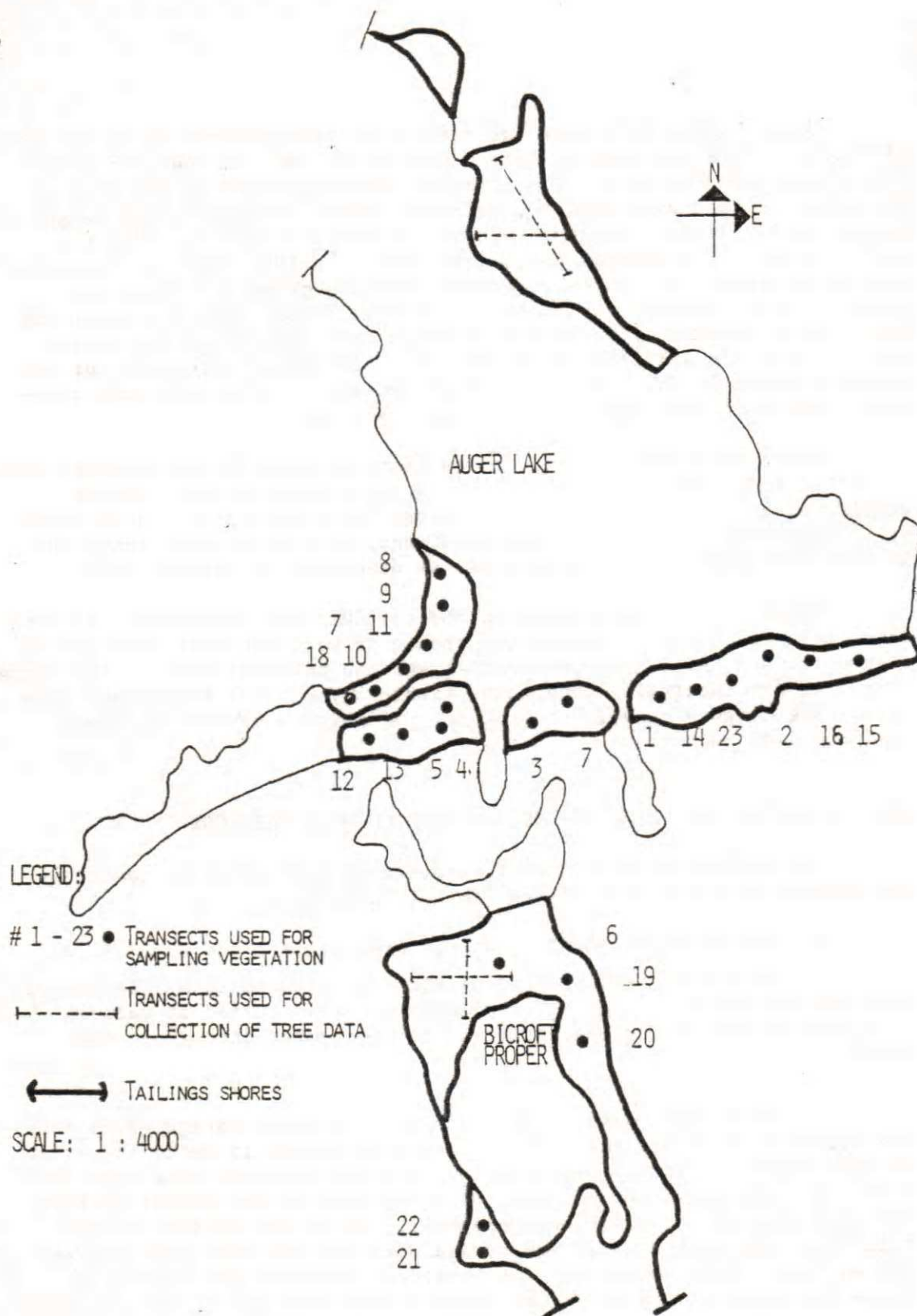
II. INVESTIGATION OF MICROFUNGI IN URANIUM MILL TAILINGS

Two techniques were used to provide an indication of the types and numbers of microfungi present in the tailings material.

1. BURIED SLIDE METHOD (adapted from Johnson and Curl, 1972)

Microscope slides were soaked for 36 hours in a 70% alcohol solution for sterilization. The slides were then buried at various locations chosen as representative of certain zones throughout the sites.

Thin, dyed-green bamboo stakes, 1 m long, were used to mark the location of each slide. The slides were buried 15 cm to the left of each stake. A trowel was inserted into the tailings to a depth of 8 cm. A slide was inserted into the space made by the trowel so that the long edge of the slide was perpendicular to the surface of the tailings. The entire slide was buried with the top edge just beneath the surface. Data concerning the physical, chemical and biological characteristics of the locations where slides were buried was collected.



Map 3-2. Location of vegetation transects and transects used to measure tree heights

The slides were removed after 40 days. Subsequently, they were rinsed with distilled water, air dried and examined for hyphal growth with a compound microscope of 400X power.

2. SOIL-PLATING METHOD (adapted from Johnson and Curl, 1972)

Soil samples were collected from the locations where slides were buried by inserting sterilized 40 ml glass vials into the tailings, 15 cm in front of the green stakes previously described and withdrawing them filled with tailings material.

Sterilized plastic petri dishes, 100 mm x 15 mm were plated with four types of media. Four agar media were prepared using V-8 Juice, Soil Extracts (prepared with both garden soil and tailings material) and Peptone-Dextrose-Rose Bengal (recipes adapted from Johnson and Curl, 1972). A weighed amount of soil from each sample was spread out over a plate of each media and incubated at 27° C for six days.

After incubation, the plates were removed and examined for fungal growth. Slides were prepared from fungal colonies and identification to genus were made with a compound microscope.

III. DETERMINATION OF CHEMICAL AND PHYSICAL PARAMETERS AND pH CONDUCTIVITY

pH readings were taken with a HACH pH meter, Model DR-EL/1. Conductivity was measured in micromhos/cm with a Hach conductivity probe, Model RG-58A/U and a Hach conductivity meter Model 17250.

The pH probe was standardized before each use with standard buffers of pH 4 and pH 10.

Different proportions of tailings and water were combined and tested to determine the best ratio to use for pH measurements (TABLE 3.3). Based on the results, a decision was made to use 2 parts tap water to 1 part tailings material. The resulting slurry was left to stand for 5 minutes before measurements were made.

The pH probe and the conductivity probe were left in the slurry for another 5 minutes before measurements were taken. For each tailings sample, two separate slurries were prepared and tested as replicates.

TAILINGS PROFILE AND PARTICLE FRACTIONATION

To study the tailings profile, a small hole, approximately 50 cm deep, was dug with a spade. Water levels in several locations would not permit a deeper profile.

TABLE 3.3

Determination of Proportions for pH Readings

<u>Tailings : H₂O ratio</u>	<u>Tailings + Tailings +</u> <u>H₂O (distilled) H₂O (tap)</u>	
1:1	4.2	5.6
1:2	4.3	5.8
1:3	4.5	5.8
1:5	4.5	5.9

pH - pure tap water: 7.6, 7.6 (repeated readings)

pH - pure distilled water: 4.8, 4.7 (repeated readings)

Each layer of the tailings was described with respect to colour of the material, texture, presence of roots, and other characteristics. Particle fractions were determined for each pit by air drying a tailings sample for three days. After air drying, approximately 0.5 kg was sifted through a series of sieves of, in descending order of mesh size, 250 μm , 150 μm and 120 μm . The resulting particle size classes were weighed out to give particle size fractions.

Loss on Ignition and Moisture Content

Moisture Content and Loss on Ignition were determined for each sample.

A tailings sample was weighed and then dried in a circulating air drying oven at 75° C to dry point. The difference between the initial weight and the weight at dry point was a measure of the moisture content of the sample.

The sample was next placed in an ignition furnace at 450° C for approximately 20 hours. The sample was reweighed to give a value for weight loss on ignition. This value is an approximation to the organic content of the sample.

RESULTS

VEGETATION DESCRIPTION

The location of the transects along which vegetation was described is indicated in MAP 3.2. For each site (MAP 3.2), the zones, as identified in TABLE 3.2, were sampled by transects covering 5% of their area. The distribution of all species identified within these transects is indicated in FIGURE 3.1a by the presence or absence of a species per transect.

It can be seen in FIGURE 3.1a that the total number of species found in the zones sampled was low, approximately fifty. In some cases, specimens in poor condition enabled identification only to genus. The species have been grouped in FIGURE 3.1a into the following life forms: trees, shrubs, herbs (mostly perennial), grasses and sedges and rushes, fungi and lichens, and mosses. Due to difficulties in recognizing moss species in the field, this group is probably incomplete.

From the available data, however, as FIGURE 3.1a indicates, trees were represented by the largest number of species. In comparison there were few perennial herbs and the majority of these were identified in only one of the 23 transects.

A comparison between the life form groups, as presented in

Fig. 3-1a Presence or absence of species per transect

TRANSECT NUMBER	SPECIES NAME																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	POPULUS BALSAMISERA L.																				
	P. TREMULOIDES MICHX																				
	P. GRANDIDENTATA MICHX																				
	BETULA PAPIRIFERA MARSH																				
	ACER RUBRUM L.																				
	A. SACCHARUM MARSH																				
	QUERCUS RUBRA																				
	TSUGA CANADENSIS (L.) CARR																				
	PICEA GLAUCA (MOENCH) VOSS																				
	PRINUS STROBILIS L.																				
	PRINUS BALSAMICA (L.) MILL																				
	SALIX HUMILIS MARSH																				
	S. PYRIFOLIA ANDERSS																				
	S. INTERIOR ROWLEY																				
	S. FRAGILIS L.																				
	AMELANCHIER SPINATA (LAM.) K. KOCH																				
	LYCOPUS SP. L.																				
	GALIUM SP. L.																				
	LINNAEA BOREALIS L.																				
	CHAENORRHINUM MINUS (L.) LANGE																				
	RUMEX CRISPUS L.																				
	HIERACIUM AURGNLIACIUM L.																				
	TYPHA LATIFOLIA																				
	EQUISETUM ARVENSE																				
	DREPDITUM BOWLINGII																				
	AGROPYRON SP. GAERTA																				
	POA COMPRESSA L.																				
	FESTUCA OVINA L.																				
	CAREX BEBBII OLNEY																				
	C. AQUATILIS																				
	SARBUS SP. L.																				
	JUNCUS TENUIS																				
	PEZIZA SP.																				
	INOCYBE SP.																				
	THELEPHORA SP.																				
	FOMES SP.																				
	CLAVARIA SP.																				
	CLADONIA CRISTATELLA																				
	CLADONIA PYXIDATA																				
	CLADONIA SP. 3																				
	POHLIA MUTANS																				
	DECRANELLA VARIA																				
	DICRANUM SCOPARIUM																				
	CALLICLADIUM HALDENIANUM																				
	ONCOPHORUS WAHLENBERGII																				
	DREPAPHOCLODUS UNCINATUS																				
	BRACHYTHECAUM REFLEXUM																				
	MOSS COVER																				
	TATLINGS (WET)																				
	TATLINGS (DRY)																				
	DEAD WOOD (NATURAL)																				
	DEAD WOOD (MANMADE)																				
	LEAF LITTER																				
	WHITE PRECIPITATE																				
	BLACK ORGANIC																				
	RED COVERING																				

FIGURE 3.1a, reveals a common feature. Within each life form group, there is, characteristically, one species which occurs in almost every transect. In contrast, the majority of the species in each group occur in only a few transects.

Referring to FIGURE 3.1a, for example, Populus tremuloides and Betula papyrifera occurred in >80% of the transects laid. Within these transects, the two species also occurred regularly and frequently.

Similarly, the shrubby species Salix humilis was recorded in over 90% of the transects. No other shrub was identified in >10% of the transects.

The seven herbaceous species occurred too infrequently to permit any analysis of their distribution.

Carex bebbii, a sedge species, was found in >90% of the 23 transects, as can be seen from FIGURE 3.1a. The next most frequent species of the grass, sedge and rush group was the rush, Juncus tenuis. It, however, occurred in only 17% of the transects.

Inocybe spp. were the most frequent macrofungi species. They occurred in approximately 75% of the transects. The next most common fungi, a Thelophora species, occurred less than 40% of the time.

The Moss group also had one dominant species in the areas sampled. FIGURE 3.1a shows Pohlia nutans as the most frequent moss species, occurring in 74% of the transects.

To calculate values for relative cover transects were grouped according to the zonation (TABLE 3.2) of the location in which they were laid. Of 23 transects, 6 were located in Moss and Seedlings zones, 6 in Seedlings, Dead Wood and Fungi zones and 11 were laid in a series of zones collectively called Miscellaneous, but comprising Grass and Equisetum, Grass and Fern, Grass and Seedlings, Grass, and Equisetum zones. The three histograms in FIGURE 3.1b illustrate the differences between the three groupings in terms of dominance by certain species.

Within the Moss group (FIGURE 3.1b), there were consistently high values for moss cover, primarily by the species, Pohlia nutans. Interestingly, high values of dead organic matter are associated with this group of transects.

The Sedge group, in comparison (FIGURE 3.1b), had relatively low values for moss cover. Within this group, the sedge Carex bebbii was the predominant species, both in numbers and in cover. The transects in the Sedge group contained large areas of bare tailings, both wet and dry. No dry bare tailings occurred in the Moss group. The values for wet and dry bare tailings in the Tree and Dead Wood group and for

*Relative cover of individual moss species, lichens and fungi not estimated.
Relative cover of herbaceous species negligible

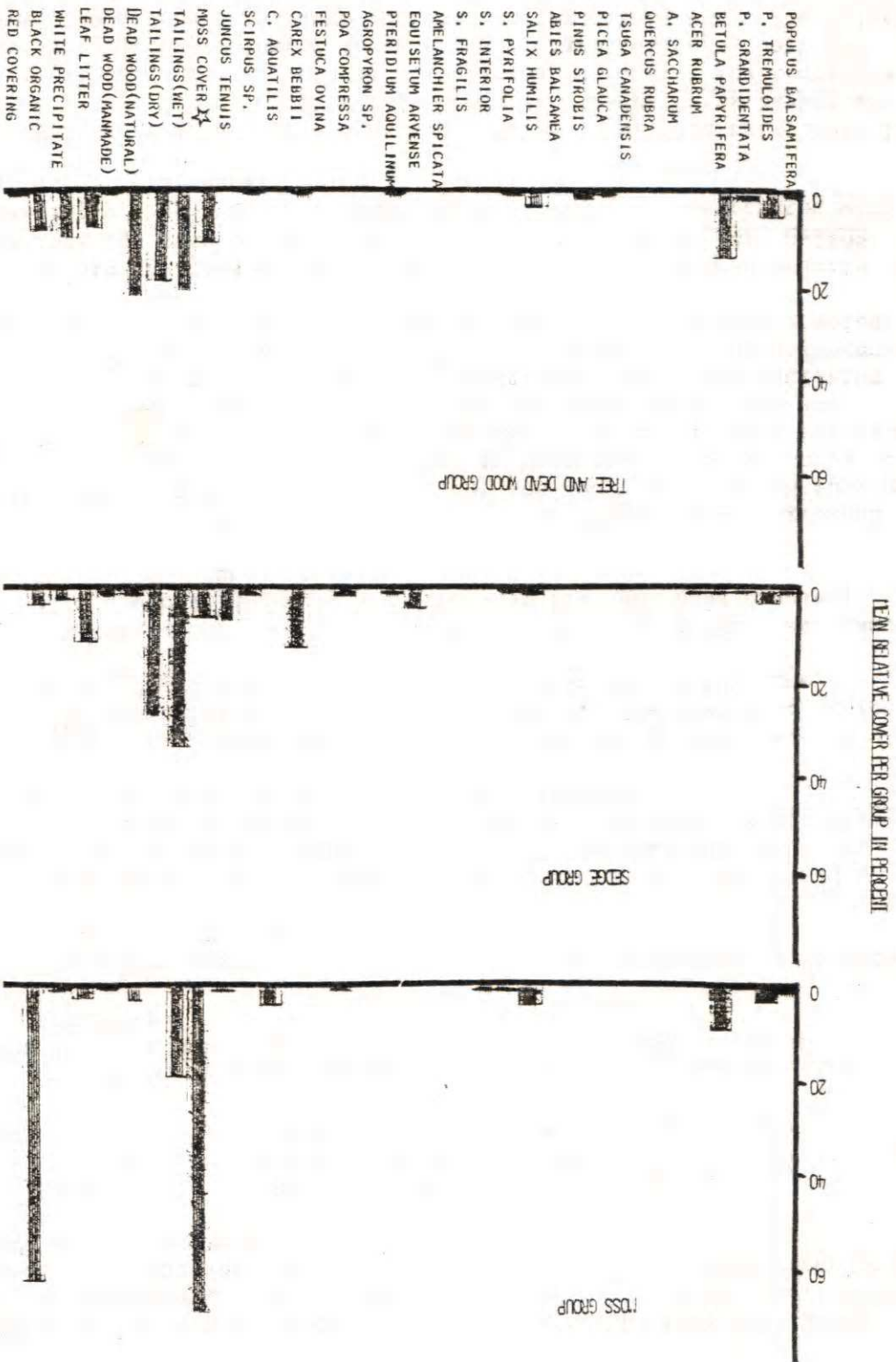


Fig. 3-1b Relative cover per group per species

wet tailings in the Moss group were $<2/3$ the values in the Sedge group.

The transects comprising the Tree and Dead Wood group (FIGURE 3.1b) shared values for dead wood cover 10-20x those for transects in other groups. Within this group there were also relatively higher values for cover by the tree species, Betula papyrifera.

Differences between the three groups identified above can also be seen in the total number of species per transect, (TABLE 3.4). The Moss group, and the Tree and Dead Wood group had a mean of 15 and 16 (respectively) species per transect, with ranges of 11-21 and 13-19. In contrast, the Sedge group had a mean of only 8 species per transect with a range of 5-13.

PHYSICAL AND CHEMICAL DATA RELATING TO VEGETATION SAMPLING

TABLE 3.4 presents data on pH, conductivity, moisture content, loss on ignition and species numbers to characterize each transect.

pH and conductivity values might be expected to differ between dry, bare sites on the tailings and wet, organic ones. However, as can be seen in TABLE 3.4, there are no differences between transects at different locations. For example, Transect 4, though relatively much higher in moisture, organic matter and species number has a pH only 0.3 - 0.4 units higher than the dry, bare Transect 12. The pH values do indicate, however, that despite the small site-to-site difference, all sampled areas were significantly acidic and in the majority of cases, acidity increased with depth. Conductivity values revealed greater ionic movement at a depth of 0.5 m as compared with surface values.

The graphs in FIGURE 3.2a+b indicate positive correlations between moisture content and organic content (with $r = .64$) and between species number and organic content (with $r = .60$). Moisture content, organic content and species number, in addition to pH and conductivity can affect both species composition and plant growth in a particular environment. Whereas the latter two parameters had similar values throughout the sites sampled, the first three showed much greater site-to-site differences.

FIGURE 3.3 presents data from the tailings profiles. Data was recorded on root depth, substrate type and depth from pits whose locations are indicated in MAP 3.3.

In most pits, at depths ranging from 0-45 cm, a reddish substrate, forming a crust-like layer, harder than the overlaying tailings, was identified. Maximum root depth rarely exceeded the first appearance of this red substrate. Maximum root depth ranged from 2-40 cm; however, in $>75\%$ of the profiles recorded, maximum root depth was

TABLE 3.4 TAILINGS CHARACTERISTICS OF TRANSECTS 1-23

TRANSECT	pH		CONDUCTIVITY ($\mu\text{MHOS}/\text{cm}^3$)		MOISTURE CONTENT (%)	LOSS ON IGNITION (%)	SPECIES NUMBERS
	Surface	0.5m	Surface	0.5m			
1	5.4	4.7	400	400	15.9	0.70	13
2	5.7	5.1	540	500	19.9	1.55	14
3	5.0	4.3	440	1800	3.8	1.01	21
4	4.7	4.6	430	550	23.6	1.84	16
5	4.7	4.6	430	550	23.6	1.84	11
6	5.6	5.6	480	2500	0.8	1.51	14
7	4.9	4.7	940	1500	17.5	0.57	5
8	5.0	4.4	630	1600	11.2	0.58	7
9	5.2	4.1	480	1700	14.5	0.73	11
10	5.0	5.4	640	1600	13.7	1.43	16
11	5.2	4.7	480	520	0.1	0.48	13
12	4.3	4.3	510	1700	0.1	0.67	6
13	4.3	4.3	510	1700	0.1	0.67	8
14	5.5	5.0	420	2000	0.2	0.26	13
15	5.6	5.6	590	480	0.2	3.35	8
16	5.4	5.0	580	2300	0.5	0.47	8
17	5.2	4.8	430	1600	0.2	1.72	17
18	5.3	4.6	410	1800	0.04	0.37	13
19	5.0	5.2	1400	2200	9.7	1.92	16
20	5.0	5.3	1800	2400	23.3	2.44	18
21	5.5	5.8	990	2500	48.5	4.46	10
22	5.5	5.8	990	2500	48.5	4.46	5
23	5.3	5.1	410	1900	0.2	0.30	10

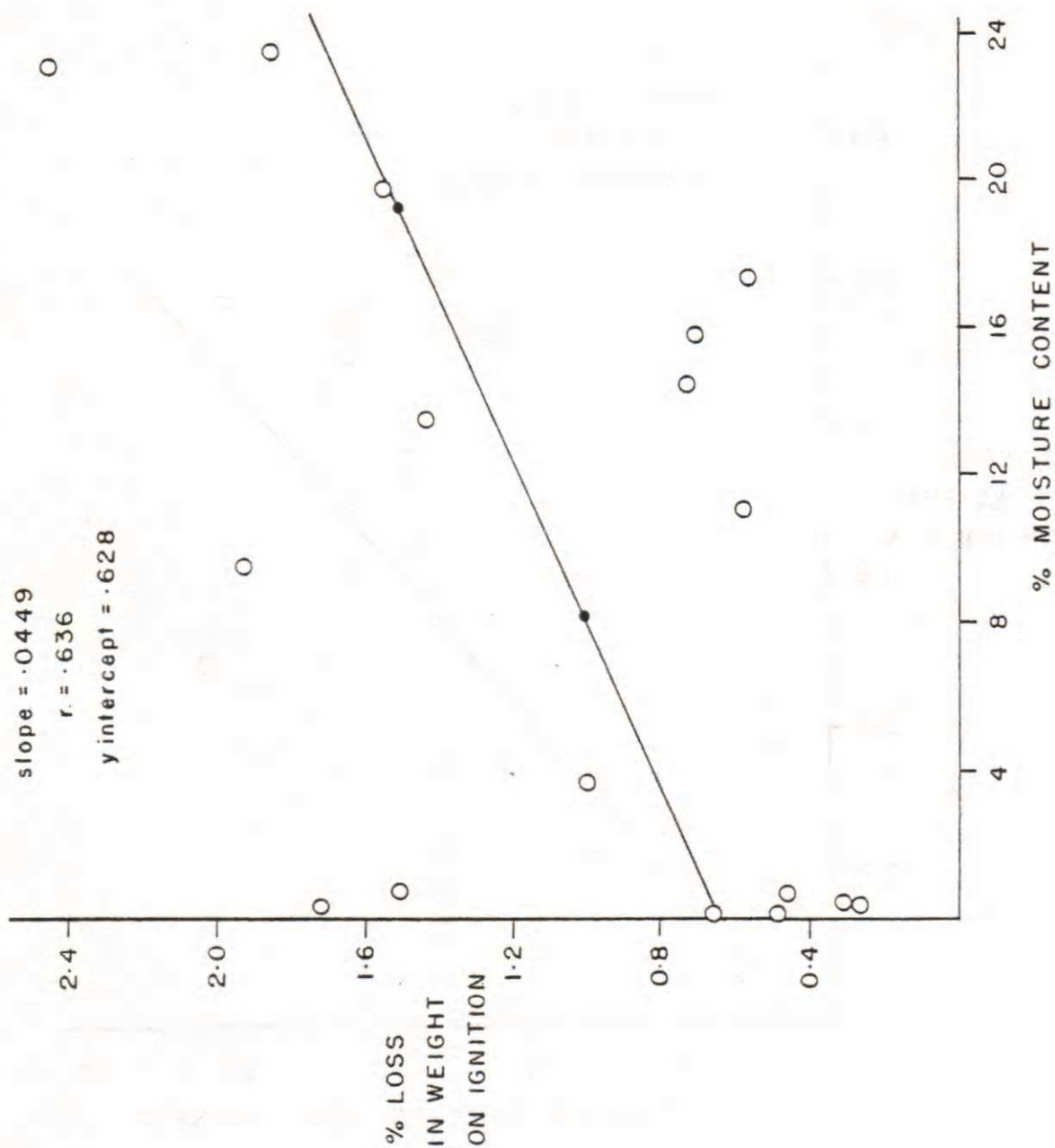


Fig. 3-2a Loss on ignition versus moisture content

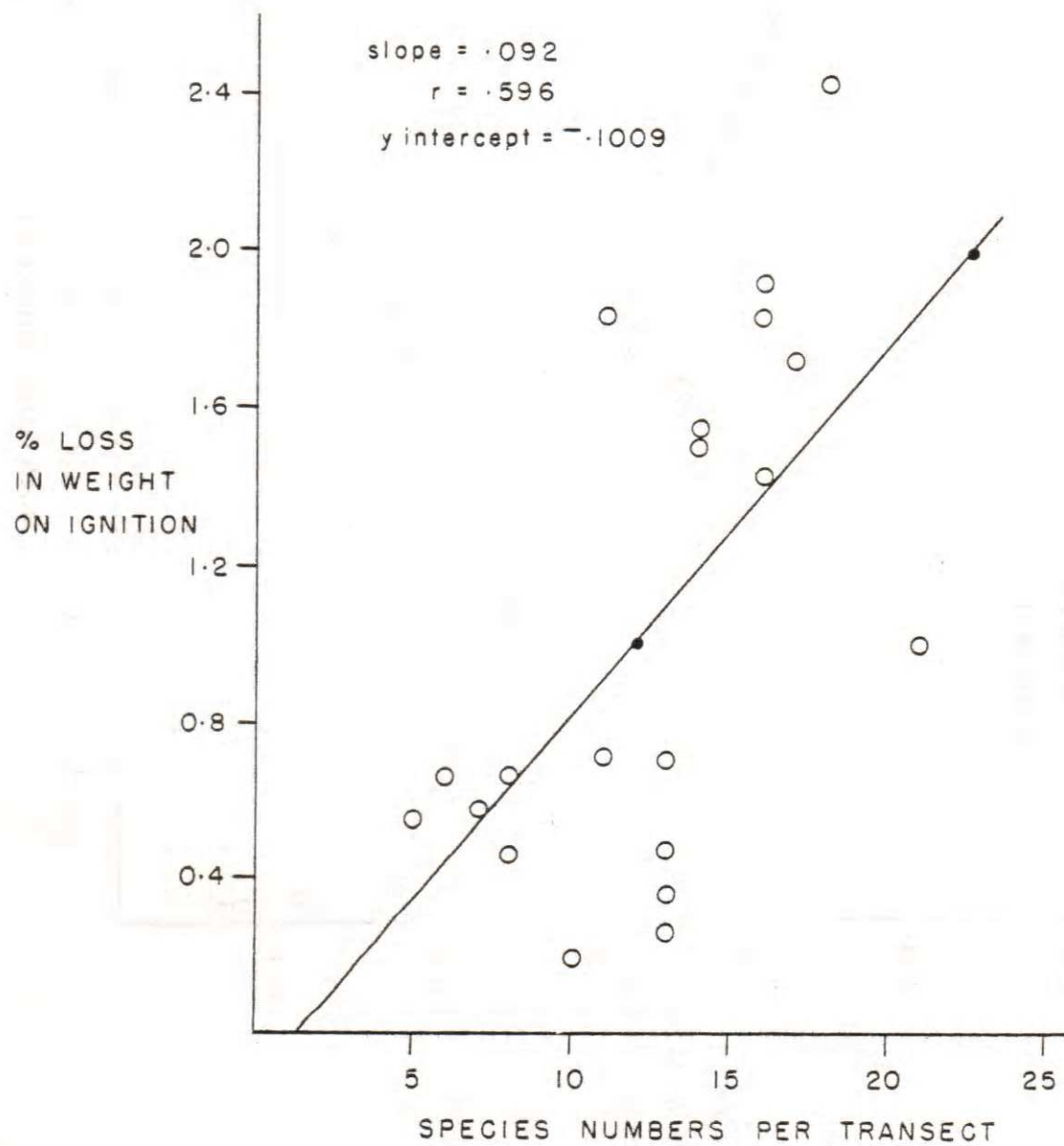


Fig. 3-2b Loss on ignition versus species diversity

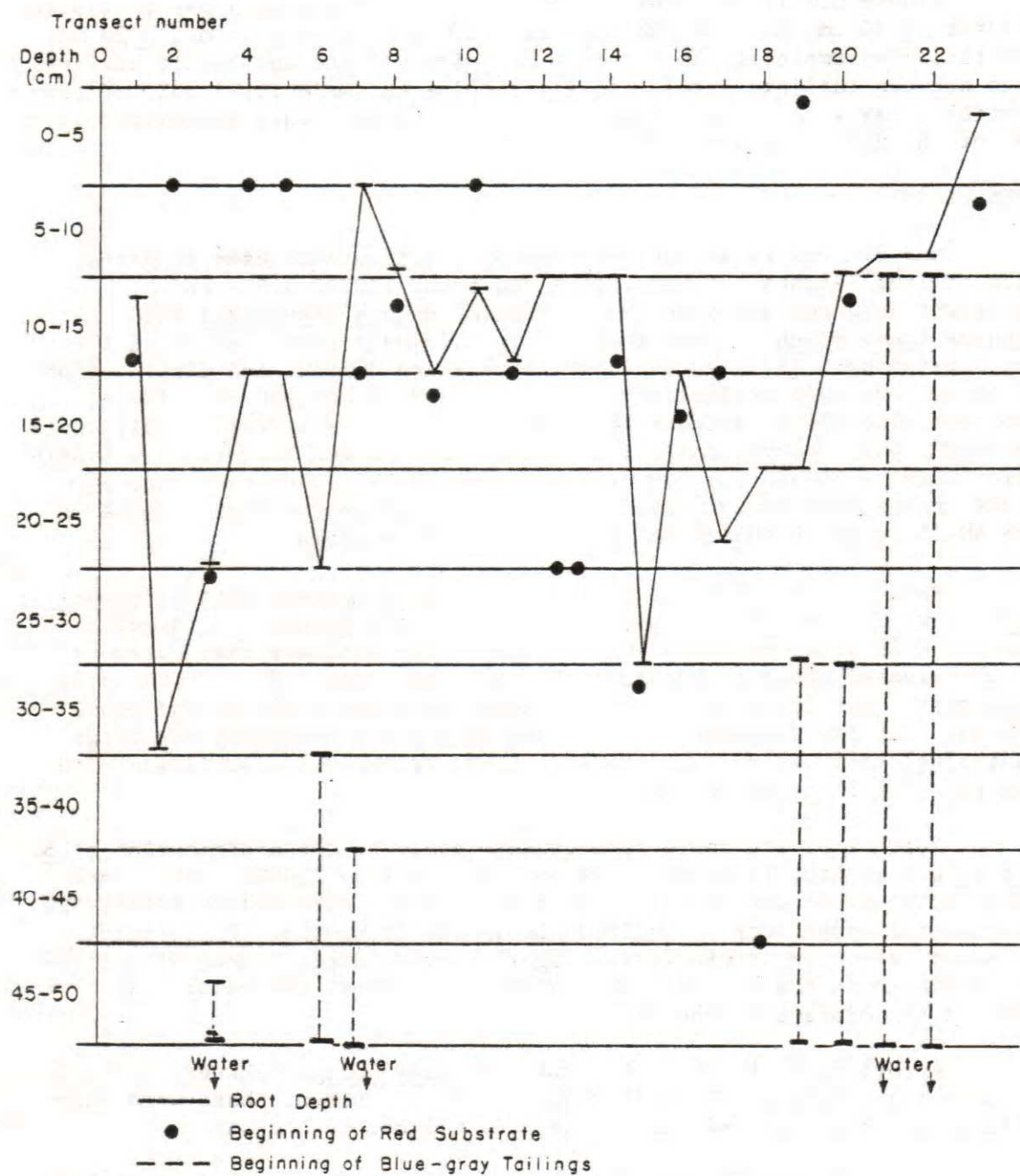


Fig. 3-3. Tailings profiles

≤15 cm. At several sites, a blue-gray, claylike substrate was identified above 0.5 m and in 13.0% of the pits, water was encountered near 0.5 m (FIGURE 3.3).

FIGURE 3.4 illustrates the distribution of the four particle size classes ($\geq 250 \mu\text{m}$, $>150 \mu\text{m}$ and $<250 \mu\text{m}$, $>120 \mu\text{m}$ and $<150 \mu\text{m}$ and $\leq 120 \mu\text{m}$) for tailings samples collected from the pits. There was little difference between tailings sites. In all samples the majority (>50%) of the particles lay within the 150 μm - 250 μm size range. Only approximately 20% of the particles were $>250 \mu\text{m}$.

TREE HEIGHTS

MAP 3.2 indicates the location of the transects used to gather data on tree heights. FIGURE 3.5 a and b and FIGURE 3.6 a and b represent data collected on the heights of Betula papyrifera and Populus tremuloides. These were the two dominant tree species on the tailings sites. The figures show the relative numbers and distribution of three tree-size categories: <40 cm, 40-79 cm and ≥ 80 cm. The smallest size class included seedlings in their first year. Individuals in this class, though small, frequently had numerous leaves. The middle size class contained the most robust individuals. Whereas in the ≥ 80 cm class, trees were often wilted and leaves slightly chlorotic, those in the 40-79 cm group showed no apparent stress symptoms.

Referring to FIGURE 3.5 a & b the results suggest that B. papyrifera grows differently at Auger Lake and Bicroft Proper. Auger Lake (FIGURE 3.5a) has more individuals in the smallest size category in the area adjacent to the surrounding forest (MAP 3.2). FIGURE 3.5a suggests a distinct relationship between individuals ≥ 80 cm and those <40 cm. The distribution is such that at any one location, one large individual (≥ 80 cm) will be found in close geographic association with several ($\bar{X} = 5$) trees <40 cm.

Neither of the above observations apply to the distribution of B. papyrifera at Bicroft Proper. As can be seen from FIGURE 3.5b, there were distances of approximately 20 m between the surrounding forest and the initial appearance of individuals on the transects. In contrast to Auger Lake, too, there were a significantly larger number of individuals <40 cm in the area of the transect closest to the water, as opposed to adjacent to the woods.

According to FIGURE 3.6 a and b, P. tremuloides behaved similarly at both Auger Lake and Bicroft Proper. At both sites, there were significantly more trees <40 cm in the area closest to the water.

Unlike B. papyrifera, the distribution of P. tremuloides at both sites suggested no relationship between either different size classes or with the surrounding forests. The distribution of the latter was much more discontinuous than that of B. papyrifera.

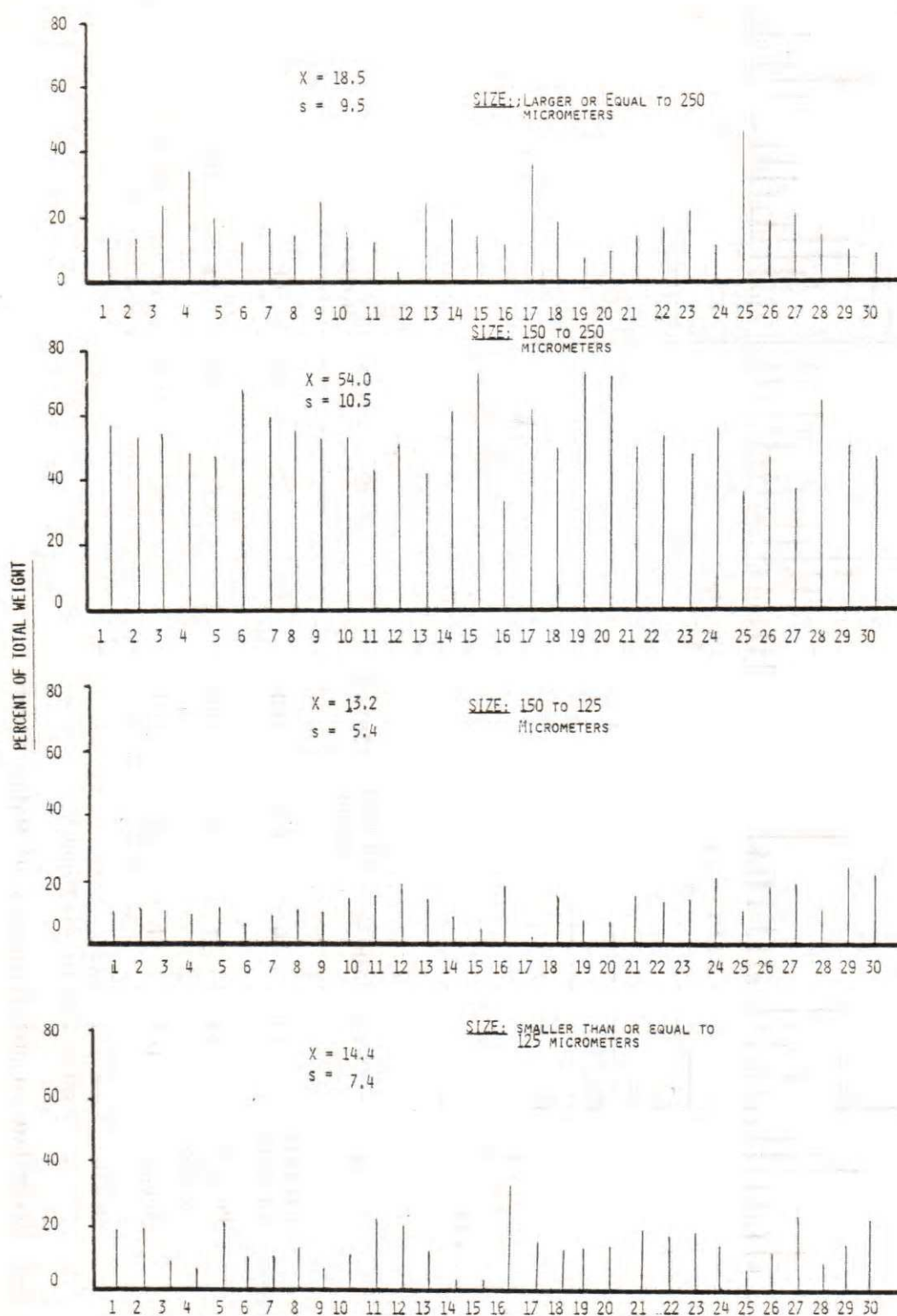
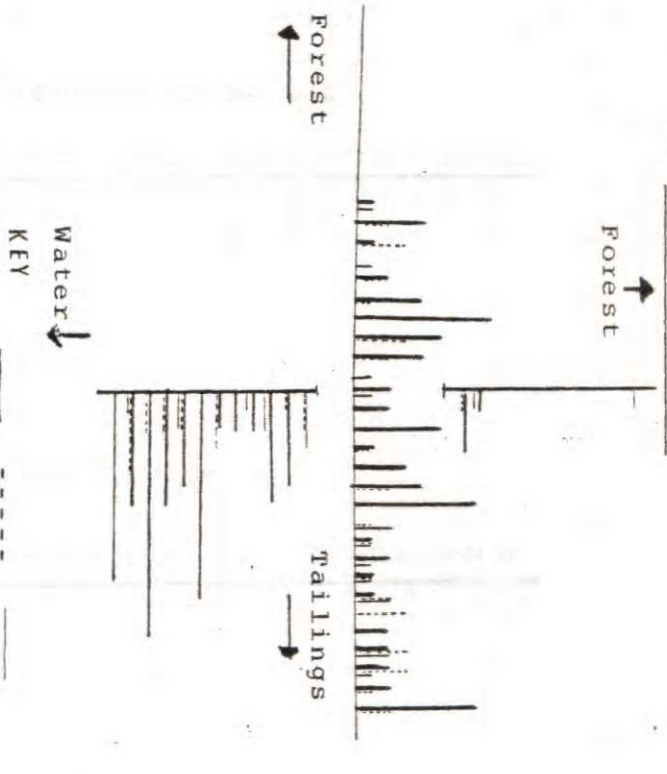
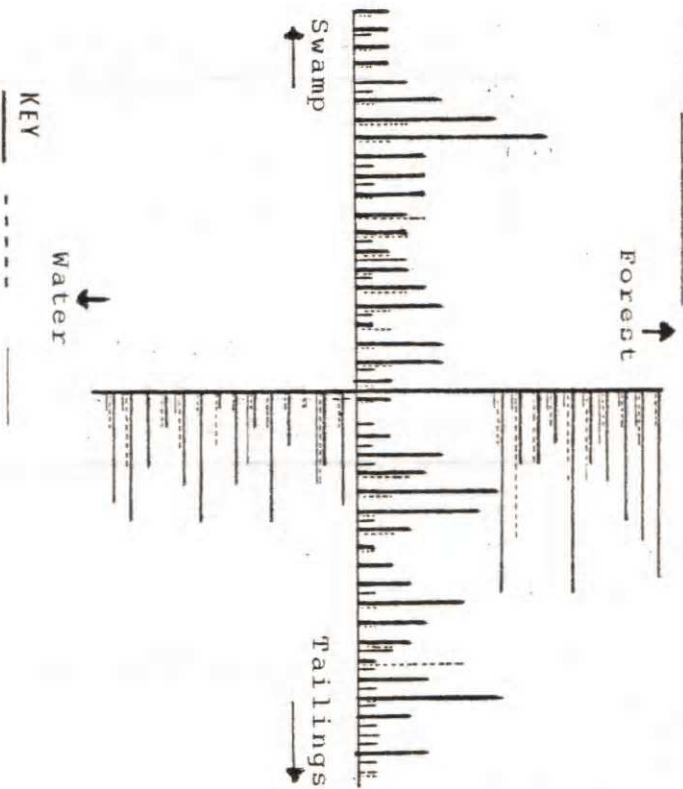


Fig. 3.4 Tailings particle size fractionation per pit

b) BICROFT PROPER



a) AUGER LAKE

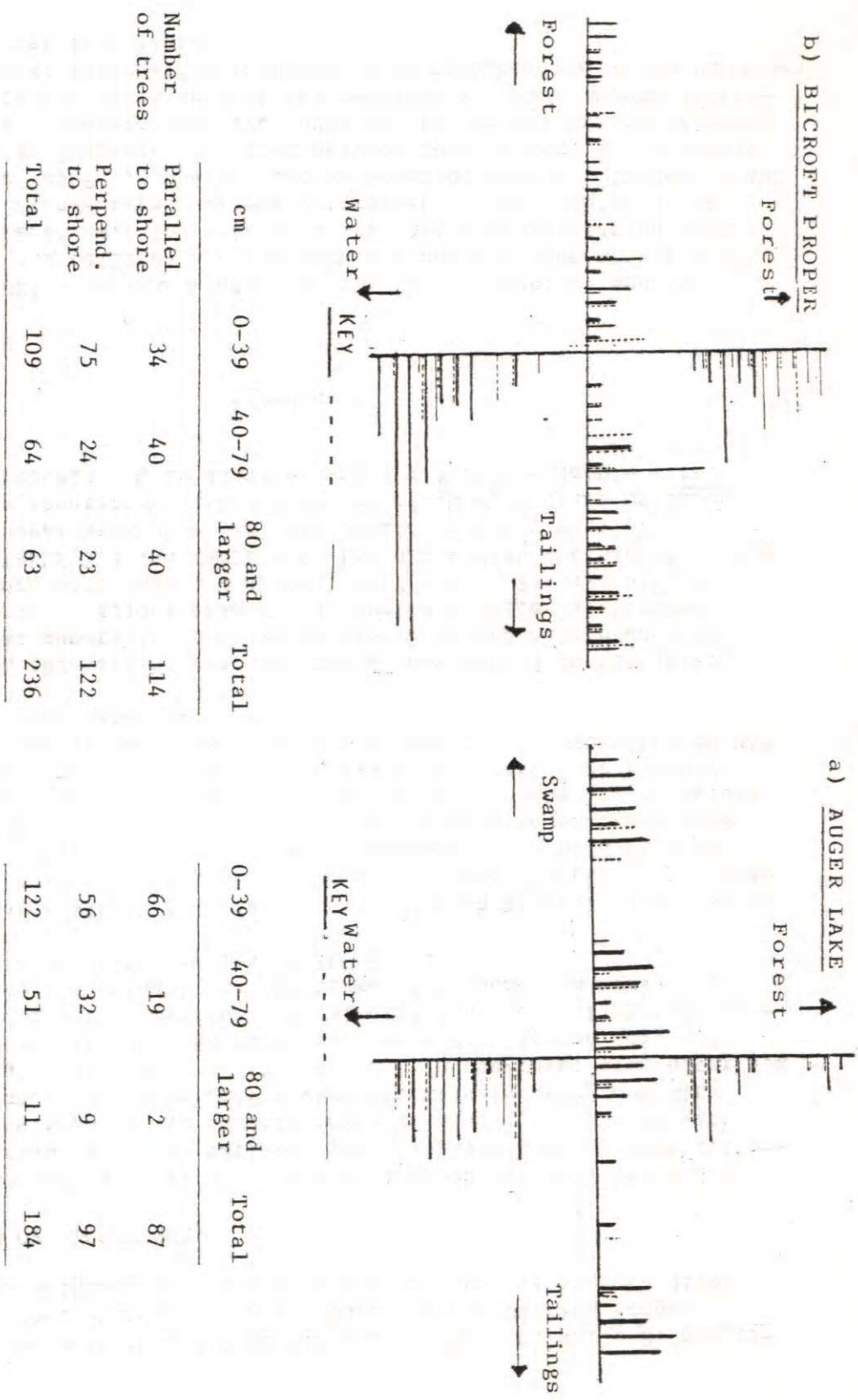


Number of trees	Parallel to shore	Perpend. to shore	Total
73	34	13	120
75	17	8	100
148	51	21	220

cm	0-39	40-79	80 and larger	Total
Parallel to shore	152	53	21	226
Perpend. to shore	127	66	23	216
Total	297	119	44	442

Scale: 3 mm = 1 tree
3 mm = 2 m in distance

Fig. 3-5 Distribution and frequency of White Birch



Scale: 3 mm = 1 tree
3 mm = 2 m in distance

Fig. 3-6 Distribution and frequency of Trembling Aspen

As can be seen from FIGURE 3.5 and FIGURE 3.6, while B. papyrifera was much more abundant at Auger Lake than at Bicroft Proper, P. tremuloides maintained approximately equal numbers at both sites.

INVESTIGATION OF MICROFUNGI

Location of tailings samples, indicated on MAP 3.3, TABLE 3.5 presents the results of the tailings samples plated out on four different media. The results are clearly media-related. All plates with Peptone-Dextrose-Rose bengal media were extensively overgrown with fungi after only three days of incubation. In contrast, even after six days, the plates with Soil Extract agar (both with garden soil and tailings) showed little evidence of colonization. On all plates where fungi grew, the predominant one (in terms of presence and relative cover) was a TRICHODERMA species (TABLE 3.5).

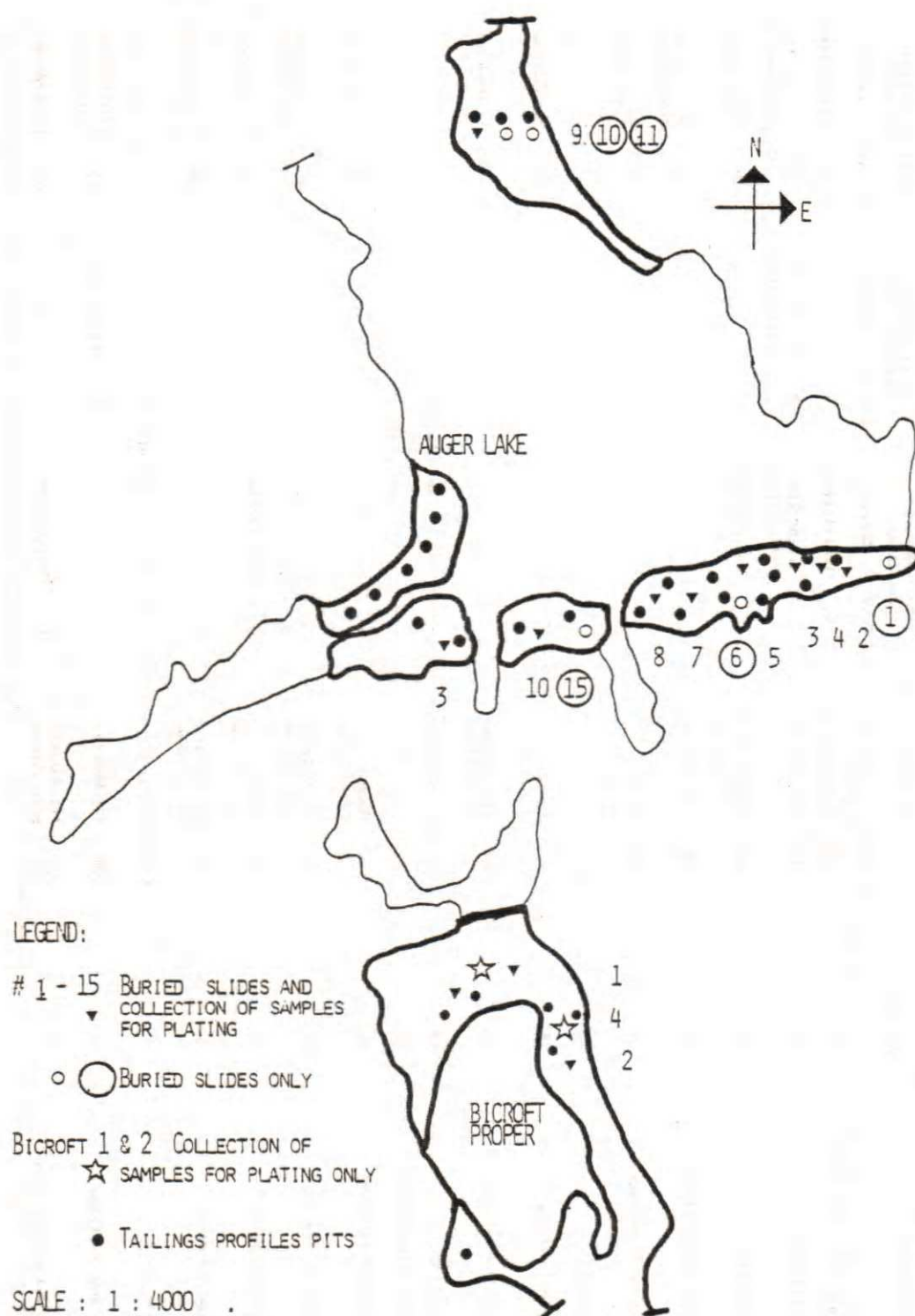
The plates with V-8 Juice Agar showed much greater variation in percent cover by fungi than any of the media types (TABLE 3.5). Those plates with the highest values (see for example 2, 3, BICROFT 2 on MAP 3.3 and TABLE 3.6 and TABLE 3.3) were plated with tailings from dry, bare locations. Conversely, those plates with the lowest values were primarily those plated with tailings from sites of relatively high organic content and vegetation cover (see 5, 11, BICROFT 3 on MAP 3.3, TABLE 3.5 and TABLE 3.6).

As with the plating results, the slides buried in the drier, barer sites had generally more hyphal growth (based on presence or absence per unit of slide) than slides buried in sites with higher organic content, both dead and alive (TABLE 3.6). For example, as indicated in TABLE 3.5 and TABLE 3.6, the slide with the highest value for relative cover by hyphae (#6) was buried in bare, very dry tailings, the only vegetation within a radius of 20 m, a clump of Ulnus ragosa approximately 2 m in diameter and 2 m from the sample site.

DISCUSSION

A. VEGETATION

As FIGURE 3.1 a and b indicate, the total number of species identified on the tailings and the relative cover of the majority of these species were low. The spatial distribution of vegetation within an individual transect was extremely irregular. This variation is illustrated in TABLE 3.7 where relative cover of moss in Transect 1 and bare tailings in Transect 17 varied between zero in some m² to almost 100% in others. Average relative cover values for the entire transect do not indicate the patchiness of the vegetation. This uneven distribution may reveal interesting information on revegetation of the tailings and needs further investigation.



Map 3-3 Location of buried slides, collection of tailings samples for plating and tailings profile pits

Table 3-5. Fungal presence in uranium mill tailings

Location and site description	Buried slide technique Relative presence of hyphae on slides (%)	Plating technique							
		V-8 juice		Media types		Peptone-dextrose rose bengal			
		% Cover	Genera	% Cover	Genera	% Cover	Genera		
1. Tailings and forest soil	64	30	Unidentified	<1	Penicillium	-	-	95	Trichoderma
2. Bare tailings	21	75	Trichoderma	<1	Trichoderma Penicillium	2	Trichoderma Penicillium	90	Trichoderma Chrysosporium
3. Bare tailings	50	80	Unidentified Trichoderma	<1	Penicillium	-	-	100	Trichoderma
4. Tailings and seedlings	28	15	Trichoderma	-	-	-	-	50	Alternaria Trichoderma
5. Moss-covered tailings	11	10	Mucor Penicillium	-	-	-	-	90	Trichoderma
6. Bare tailings	89	(-----) not plated -----)							
7. Grass and seedlings	18	10	Mucor Trichoderma	-	-	-	-	100	Trichoderma
8. Moss-covered tailings	48	30	Trichoderma Penicillium	-	-	-	-	90	Trichoderma
9. Bare tailings	40	(-----) not plated -----)							
10. Tailings and seedlings	43	(-----) not plated -----)							
11. Moss-covered tailings	0	5	Mucor Penicillium	-	-	-	-	90	Trichoderma
12. Tailings and dead wood	43	95	Trichoderma Penicillium	-	-	-	-	85	Trichoderma Penicillium
13. Tailings and moss	7	40	Mucor Penicillium	<1	Penicillium	-	-	50	Trichoderma
14. Tailings and moss	25	95	Trichoderma Penicillium	-	-	-	-	90	Trichoderma
15. Equi and grass	4	(-----) not plated -----)							
Microft 2. Tailings and seedlings	-	80	Trichoderma	-	-	<1	Penicillium	85	Trichoderma Penicillium
Microft 3. Tailings and pitcher plant	-	20	Trichoderma Penicillium	<1	Penicillium	-	-	80	Trichoderma

TABLE 3.6 TAILINGS CHARACTERISTICS FOR THE BURIED SLIDES
AND FUNGI PLATES

LOCATION	pH		CONDUCTIVITY		MOISTURE CONTENT	ORGANIC CONTENT
	Surface	0.5m	Surface	0.5m		
1	--	--	--	--	--	--
2	5.6	5.6	590	480	0.2	3.35
3	5.2	5.1	500	2100	0.1	0.36
4	5.3	4.8	640	2200	3.9	0.52
5	5.2	5.0	550	520	13.9	1.12
6 •	5.8	5.3	500	460	0.2	0.07
7	5.5	5.0	420	2000	0.2	0.26
8	5.8	4.9	460	480	15.2	1.08
9 •	4.2	4.9	2000	1800	18.6	1.71
10 •	5.1	4.6	460	1800	0.3	0.73
11	5.1	4.4	500	1300	0.1	--
12	5.0	4.3	440	1800	3.8	1.01
13	4.7	4.6	430	550	23.6	1.84
14	5.6	5.6	480	2500	0.8	1.51
15 •	4.9	4.7	940	1500	17.5	0.57
BICROFT* 2	5.7	5.0	510	570	0.1	0.22
BICROFT* 3	5.8	5.3	780	1500	33.1	3.99

• SLIDE ONLY

* PLATE ONLY

TABLE 3.7 TRANSECT DATA TO ILLUSTRATE CLUMPED
NATURE OF VEGETATION

<u>RELATIVE COVER BY MOSS</u>			<u>RELATIVE COVER BY BARE TAILINGS</u>		
<u>TRANSECT 1</u>			<u>TRANSECT 17</u>		
QUADRATS (1m ²)			QUADRATS (1m ²)		
1	30		1	85	
2	20		2	5	
3	50		3	85	
4	80		4	40	
5	60		5	60	
6	10		6	-	
7	25		7	-	
8	60		8	80	
9	50		9	5	
10	95		10	80	
11	75		11	82	
12	100		12	90	
13	85		13	90	
14	90		14	55	
15	90				
16	90				
17	70				
18	30				
19	25				
20	1				
21	1				
22	-				
23	-				
24	85				

FIGURE 3.1b illustrates differences in species composition between areas on the tailings. The three types of areas that emerge in FIGURE 3.1b are referred to as the Moss, Sedge and the Tree and Dead Wood groups. Only approximately 1% of the total area ($\approx 35,000 \text{ m}^2$) of the tailings was sampled. It is possible then that other areas with different species associations existed but were not identified because they were never sampled.

It is interesting to note that the most widespread species occurring on the tailings were also the dominant species in terms of frequency and relative cover. However, dominance by a particular species was always confined to a specific location as suggested by FIGURE 3.1b.

The majority of the moss species identified on the tailings were species of dead, decaying wood (Crum, 1973). For example, in Transect 17, 5 of the 7 species identified were found on dead wood (FIGURE 3.1a). However, the transects with the greatest values for moss cover (such as Transect 1-6) contained very little dead wood. The predominant moss species within these transects was Pohlia nutans. This species is not characteristic of decaying wood. It has been recorded on mine waste sites (Antonovics, Bradshaw and Turner, 1971) and on uranium mill tailings (Stokes and Kalin, 1978). It is especially associated with soils high in copper. Elevated copper levels have been identified in plant samples from Bicroft Proper (Kalin, unpublished). Whereas most of the other identified mosses were woody species, unrelated to the actual tailings, Pohlia nutans was definitely closely associated with the tailings substrate.

Although widely distributed Pohlia nutans covered extensive areas only in certain locations (i.e. Transect 1-6). These locations shared relatively high moisture contents (TABLE 3.4), low amounts of dead wood and very high relative cover by a black organic crust, unidentified at this time (FIGURE 3.1b).

An average of 16 species per transect were identified within the Moss group, compared to 15 for the Tree and Dead Wood group and 8 for the Sedge group. As many of the species identified in the Tree and Dead Wood group were found on dead wood, the average number of species actually associated with the tailings was lower than 15. The four moss species, two lichens and one fungus all found exclusively in the Tree and Dead Wood group (FIGURE 3.1a) occurred only on dead wood. The transects in the Moss group, then, supported the largest number of species growing directly on the tailings.

The anchoring of the fine tailings material by mats of Pohlia nutans, which serves to increase moisture retention and available nutrients might permit germination by species unable to survive on bare tailings. Despite the larger number of species in the Moss group, relative cover values for all species (excepting Pohlia nutans) were

lower here than in the other groups. This cannot be explained by either the type of vegetation present or the chemical and physical data collected during this project.

Total moss cover was lowest in the Sedge group (FIGURE 3.1b). The dominant species in this group was Carex bebbii. This is a common, wide-ranging sedge, adapted to open waste sites and frequently appearing after a fire (Voss, 1972). On the tailings, it occurred in areas with large amounts of bare tailings and adjacent to areas of pure tailings (i.e., no vegetation). Individuals never exceeded 20 cm in height though the average height range is approximately 20-75 cm (Britton and Brown, 1968). Nutritional stress and continual exposure to wind-borne tailings were the most likely causes of the stunted growth.

The ability of the sedge to survive on bare tailings, both very wet and very dry (TABLE 3.4, compare Transect 21 and Transect 13), suggests it might be of value in reclamation projects. Murray and Moffett (1977) seeded uranium mill tailings at Elliot Lake with 8 grasses, 6 legumes and 10 annuals. Of all species, only 6 grasses and 3 legumes lived for over four growing seasons. Of these three grasses, reed canary-grass, creeping red fescue and Kentucky bluegrass were selected as useful for reclamation purposes. The ability to survive on bare tailings plus good sod-forming capacity were cited as characteristics, shared by these species, that enable successful establishment on the tailings sites. Carex bebbii also shared these characteristics. This species, however, was not identified on the Madawaska Mines uranium mill tailings (Stokes and Kalin, 1978) indicating that certain conditions must be present if it is to establish itself. For example, the surface pH's of all sites at Madawaska were in the range 6.0-9.0. The highest surface pH at the Bicroft Mines was 5.6 (TABLE 3.4). Such a large difference in the pH of the two sites could account for the difference in species compositions. The differences in particle sizes of the Madawaska Mine tailings and the Bicroft Mine tailings were also great. The results of particle fractionations of the upper level of the Madawaska Mines showed a variation in particle sizes within the size categories ≤ 0.425 mm, 0.425 to 1.0 mm, 1.0 to 4.0 mm and ≥ 4.0 mm (Stokes and Kalin, 1978). The majority of particles fell in the first and second of these categories. In contrast, the majority of particles at Auger Lake and Bicroft Proper fell in the 0.150 mm to 0.250 mm category. Less than 20% of the particles were > 0.250 mm. (FIGURE 3.4). The substrate was much finer at the Bicroft Mine sites. This would also influence vegetation and might account for the widespread distribution of Carex bebbii on the Bicroft sites and its absence from the Madawaska sites.

Equisetum arvense was another species dominant in several transects within the Sedge group. This species was also dominant in several locations on the Madawaska tailings (Stokes and Kalin, 1978).

Interestingly, the species was found only on tailings which had recently been covered by water. On the Bicroft sites, E. arvense occurred on both wet and dry sites which had doubtfully ever been under water. When a dominant, it grew along with Carex bebbii or with Juncus tenuis (FIGURE 3.1a, Transect 15, 17 and 22). E. arvense individuals found on Auger Lake sites were severely stunted and misshapen while those growing at Bicroft Proper were only slightly stunted. This difference can most likely be attributed to greater exposure to wind and wind-borne tailings at Auger Lake. A significantly lower number of species (eight per transect) were identified in the Sedge group as compared with the Moss (16 per transect) and Tree and Dead Wood (15 per transect) groups. This may be a consequence of the greater exposure to sun and wind, the large areas of bare tailings (that result in large fluctuations in moisture content) and the low organic content (TABLE 3.4) of the tailings experienced by the vegetation in transects of the Sedge group.

A striking feature of vegetation on the tailings was the frequent and widespread occurrence of trees. Seven deciduous and four coniferous species were identified throughout the transects. The dominant tree species recorded in the area of the Bicroft Mine (Forest Stands Map of Faraday Township, 1960) include Acer saccharum, Populus species, Betula papyrifera, Tilia americana, Quercus rubra and Tsuga canadensis. Representatives of all of these species except for Tilia americana were identified on the tailings. All species found on the tailings occurred in the surrounding forest, which was a mixed deciduous and coniferous woodland (Hosie, 1975).

All four coniferous species on the tailings occurred infrequently. Generally, these species are better adapted to more shaded, moist soils. Pinus strobis was the most successful species. As it has a much wider habitat range than either Abies balsamea, Picea glauca or Tsuga canadensis, it may be better equipped for uranium mill tailings (Hosie, 1975).

At Elliot Lake, five coniferous species were planted on both vegetated and bare tailings (Murray, 1978). The five species were Tsuga occidentalis, Picea glauca, Pinus sylvestris, P. banksiana and P. strobis. There was no survival of individuals planted on bare fine tailings. Murray found that the tailings characteristics and vegetation cover influenced tree survival. Plant tops frequently died with new growth arising from the plant base or lower branches in subsequent years. This was extremely characteristic of the larger trees at Auger Lake and Bicroft Proper. Murray concluded that the Pinus species were the most suitable for growing on uranium tailings. This agrees with the observation that P. strobis did best of conifers at Bicroft. Most likely, T. occidentalis and P. glauca could not tolerate the acidic conditions (pH 1.9-2.3) of the Elliot Lake tailings. Picea glauca and Pinus strobis, the only two of the five species that were identified at the Bicroft Mine sites occurred on bare fine tailings. However, the

individuals were neither large nor numerous suggesting that coniferous species are not well-adapted to uranium tailings.

Two of the seven deciduous species found on the tailings were Acer rubrum and A. saccharum. Although both were widely distributed and numerous (especially A. rubrum) no individual of either species ever exceeded a maximum height of approximately 10 cm or produced more than two leaves. Both species were common in the surrounding forest providing a large seed source for the tailings. However, both A. rubrum and A. saccharum thrive in the moist upland habitats, as was found in these woods (Hosie, 1975). They are not adapted to the open, variable environmental conditions of the tailings. Seeds falling on the tailings may have contained enough nutrients and moisture to support the production of the first two leaves. Once these reserves had been exhausted, however, the individual would be unable to survive on its own. The validity of this hypothesis could be tested by marking the locations of seedlings and determining their survival from season to season.

The three Populus species and Betula papyrifera were apparently the most successful species on the tailings (FIGURE 3.1a).

Species of Populus are extremely wide-ranging in Canada and are found in most types of habitats (Hosie, 1975). Their ability to hybridize freely accounts for their adaptability (White & Hosie, 1977). Populus tremuloides was particularly well-established on the tailings. It thrives in dry, open areas and frequently forms pure stands on recently burned soils (White & Hosie, 1977).

Betula papyrifera was the most widely distributed species on the tailings (FIGURE 3.1a). It dominated the tree species in terms of relative cover (FIGURE 3.1b). B. papyrifera is characteristic of sterile soils and, like P. tremuloides and Carex bebbii, often establishes after a fire (Hosie, 1975). This species was also identified as a dominant on the Madawaska uranium mill tailings (Stokes and Kalin, 1978). There, however, the species grew only on mixed substrates of tailings and natural soil. In contrast, B. papyrifera was found on both wet and dry bare tailings at Auger Lake and Bicroft Proper. Its presence as a dominant at two sites as different as Madawaska Mines tailings (where pH was much higher, moisture content lower, particle sizes larger and organic content higher) and Bicroft Mines tailings indicates the adaptability of this species.

P. tremuloides and B. papyrifera grew especially abundantly on dead wood as is indicated by the relative cover values for the Tree and Dead Wood group in FIGURE 3.1b. Many of the plant species identified on the transects in this group were found on decaying wood. Some of this wood was driftwood deposited on the tailings shores. The majority was the remnants of trees that had been growing on the sites prior to the dumping of the tailings and had subsequently died and

fallen or been cut down. Possibly, this dead wood provides a firm substrate permitting plants such as lichens, which are characteristically closely associated with their substrate, to grow. Some of the largest tree individuals were also growing on dead wood. The wood may also be providing a source of nutrients for species unable to survive on the nutrient-poor tailings. For example, fungi of decaying wood release nutrients and act as a source of nutrients themselves (Johnson and Curl, 1972).

It has been suggested that the formation of mycorrhizal relationships is necessary to the survival of Populus and Salix individuals on metallic mine tailings (Harris and Jurgensen, 1977). Failure to form an association with fungi was cited as the probable reason for failure of these species to establish on copper tailings. Two confirmed mycorrhizal fungi were identified on the tailings sites studied in this project. The two fungi, Inocybe and Thelophora were probably mycorrhizal with Populus species, Betula papyrifera and Salix humilis which was also common on the tailings (FIGURE 3.1a). Work to confirm these mycorrhizal relationships is in progress.

Salix humilis, like other frequently-occurring species, grows best in open sites which are dry and sandy or rocky (Petrides, 1958). In comparison, the three other Salix species which were identified (FIGURE 3.1a) prefer much wetter habitats. They occurred only once or twice throughout the transects (FIGURE 3.1a).

Antonovics (1971) states that perennial herbs are the most frequent invaders of metallic mine sites. Figure 3.1 a and b indicate that there were few herbaceous perennials and annuals identified in the transects. That they are poorly represented on the tailings can be seen by comparison with the number and distribution of such species identified on the Madawaska Mine tailings (Stokes and Kalin, 1978). The proximity of these tailings to Highway 28 may have accounted for the greater number of well-established species. These species were extremely characteristic of roadsides and waste sites. The tailings sites at Auger Lake and Bicroft Proper were bordered either by open water or woodland forest. The natural vegetation surrounding all tailings sites, then, was characteristic of woodland habitats and not waste sites. For example, three of the herbaceous perennials identified on the tailings occurred adjacent to the natural forest (MAP 3.2, Transect 3). The three species: Linnaea borealis, Lycopus sp. and a Galium sp. are all characteristically woodland species (Peterson and McKenney, 1968). As each of these species was represented by only one small individual, it is likely that none have established on the tailings.

Rumex crispus, Hieracium aurantiacum and Chaenorrhinum minus (an annual) are species more characteristic of the open, waste-site nature of the tailings. Though each of these species was also represented by only a few individuals in the transects, their more widespread distribution and higher frequencies suggest they may be establishing on the tailings.

B. VEGETATION AS IT RELATES TO THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE TAILINGS SITES

Analysis and discussion of the transect data have so far revealed the probable existence of certain species associations, striking patterns in spatial distribution and distinctive growth characteristics of the vegetation on the tailings. It is of interest, then, to speculate on the possible relationship between certain chemical and physical characteristics of the tailings and the nature of the overlying vegetation.

As MAP 3.2 illustrates, the transects that comprised either the Moss, Sedge or the Tree and Dead Wood group were scattered throughout the tailings sites and were not located in a confined geographical area. Heterogeneity of the tailings within a small area has resulted in distinct changes in the nature of the overlying vegetation.

There is no obvious relationship between these changes and changes in the pH and conductivity of the tailings (TABLE 3.4). The average surface pH was 5.2 with a range of 4.3-5.8 or 1.5 pH units. This is approximately the same as the expected pH of the soils of the natural forest bordering the tailings (Gillespie and Wicklund, 1962). The pH of the tailings, then, should not prevent any of the forest species from invading the tailings. pH and conductivity values revealed increased conductivity at 0.5m as compared with the surface layer. This suggests greater availability of the ions with increasing depth as expected.

Changes in moisture content between different tailings areas did influence vegetation. There was less vegetation cover and fewer species identified on very dry sites (TABLE 3.4, Transect 15). On the other hand, on very wet sites, there was very high vegetation cover but again low species diversity (TABLE 3.4, Transect 21). Changes in moisture content always indicated changes in vegetation type and cover. Such changes sometimes occurred within short distances. For example, as illustrated in MAP 3.2, Transect 3 and Transect 7 were approximately 10 m apart. The moisture content of a tailings sample from Transect 3 was 17.5% and the number of species identified was 21. (TABLE 3.4). In comparison, the moisture content for a tailings sample from Transect 7 was 3.8% and only 5 species were identified in this transect. Nor could moisture values be related to the surrounding areas because Transect 3 was on tailings adjacent to natural woodland while Transect 7 was on tailings next to a swamp.

Moisture content was positively correlated with organic matter (with $r = 0.636$). (FIGURE 3.2a). Although the organic content (measured as loss on ignition) of the samples collected for analysis was relatively low (TABLE 3.4), the values were also correlated with species diversity ($r = 0.596$) (FIGURE 3.2b). Drought and lack of nutrients may be major problems on mill tailings sites (Stokes and Kalin,

1978). When these conditions are alleviated, species would be able to colonize where they had been previously unable to. The establishment of more species would result in increased nutrient availability (for example, as from dead wood and dead organic matter) and increased moisture-holding capacity of the tailings.

TABLE 3.4 and TABLE 3.8 indicate that the tailings particles fall predominantly into the 0.05 - 0.002 mm or "silt" category (as defined by Donahue, Shickluna and Robertson, 1971). The tailings, then, represent a very fine substrate which is a problem to invading vegetation. In elevated areas, constant exposure to wind and wind-blown tailings was apparently the reason for the stunted vegetation in these areas. In addition, the dryness of the tailings in many locations made them easily disturbed by walking. Human tracks plus those of deer, moose and smaller mammals were regularly observed. Uprooted and crushed vegetation was frequently associated with these tracks.

All vegetation investigated on the tailings was shallow-rooted (FIGURE 3.3). Murray (1978) observed that the Pinus species planted on the Elliot Lake uranium mill tailings, formed major branch roots but also showed distinctive bending of the roots from vertical to horizontal penetration. He also noted that all of the five coniferous species planted on the tailings had shallow roots (Murray, 1978).

On the Bicroft Mine tailings sites the shallow rooting behaviour of all species may have been a consequence, at least in some locations, of the close proximity of the water table to the surface of the tailings (FIGURE 3.3), or of the fineness of the tailings particles. FIGURE 3.3, however, suggests that the most probable reason was the appearance of a red layer of substrate at varying distances from the surface. This substrate, which may be very high in iron, frequently formed a hard, crust-like layer, characteristically called "iron-pan". If high levels of iron are present, they may be toxic to the roots of the tailings species or, it is possible the roots may have been physically incapable of penetrating the "iron-pan" layer.

C. TREE HEIGHTS

Initial observations on the distribution of the trees growing on the tailings and possible relationships between height and frequency stimulated further investigation into their behaviour. The results as presented in FIGURE 3.5 a and b and FIGURE 3.6 a and b revealed some interesting patterns in both distribution and frequency.

There appears to be a relationship for example, between the two size classes: <40 cm and ≥80 cm, of Betula papyrifera growing on Site 5 at Auger Lake (MAP 3.1). The close association between one individual ≥80 cm and several individuals <40 cm suggests that the larger individuals arose from seeds, the source of which was the surrounding forest. The smaller individuals have arisen as suckers from

TABLE 3.8 DEFINITIONS OF PARTICLE SIZES*

<u>TYPE OF SOIL</u>	<u>DIAMETER (mm) OF PARTICLES</u>
<u>VERY COARSE SAND</u>	<u>2.0 - 1.0</u>
<u>COARSE SAND</u>	<u>1.0 - 0.5</u>
<u>MEDIUM SAND</u>	<u>0.5 - 0.25</u>
<u>FINE SAND</u>	<u>0.25 - 0.10</u>
<u>VERY FINE SAND</u>	<u>0.10 - 0.05</u>
<u>SILT</u>	<u>0.05 - 0.002</u>
<u>CLAY</u>	<u><0.002</u>

* after Donahue, Shickluna, and Robertson, 1971

the root system of the larger tree. Propagation by root suckers is the most common form of reproduction for Populus species and for Betula papyrifera (Hosie, 1975). Initial establishment by seed with subsequent propagation through suckers is probably the case for Populus tremuloides, the co-dominant tree species on the tailings, but FIGURE 3.6 a and b indicate no distinct relationship between different size classes.

There were more than twice as many individuals of Betula papyrifera on Site 5 at Auger Lake as compared to an area of equal size on Site 7 at Bicroft Proper. Numbers of P. tremuloides were approximately the same at both sites. B. papyrifera may be more common in the woods around Site 5 or it may be responding to differences between the two sites. Site 7 at Bicroft Proper (the tree height transect actually was laid on the tailings adjacent to Site 7, MAP 3.2) was much drier than Site 5 at Auger Lake. In addition it sloped gently upwards to meet the forest behind it. The most striking difference between the two sites was the total absence of dead wood on Site 7 whereas dead wood was very abundant on Site 5. B. papyrifera, older trees especially, was often associated with the dead wood at Site 5. If this wood gives the species an advantage, in terms of nutrients and substrate, over individuals growing in bare tailings, this would account for the larger number of individuals on Site 5. P. tremuloides was not frequently associated with dead wood and this would account for similar species numbers at both Site 5 and Site 7 (FIGURE 3.6 a and b).

There are several features of FIGURE 3.5 and FIGURE 3.6 that, though interesting and noteworthy, cannot be explained with the information that is available at this time. B. papyrifera has a larger fraction of individuals <40 cm adjacent to the natural forest at Auger Lake (FIGURE 3.5a). However, at Bicroft Proper there are distances of approximately 20 m between the forest and the first appearance of B. papyrifera. This suggests that either some characteristic of the tailings is preventing the species from establishing within these 20 m or that perhaps some feature of B. papyrifera seed dispersal (for example, the minimum and maximum distance seeds will travel) is influencing the distribution. On the Madawaska Mine sites (Stokes and Kalin, 1978), B. papyrifera was a dominant in 6 out of 9 areas. However, it was completely absent from the other 3 locations suggesting it is some tailings characteristic preventing establishment. What that characteristic might be remains, at present, unknown.

Another striking feature of the distribution of P. tremuloides in particular and B. papyrifera to a lesser degree on Site 7, is the increase in the number of individuals <40 cm as the transects approach the water (FIGURE 3.6 a and b, FIGURE 3.5 b). The reason for this change in the distribution of the size classes is also a mystery, but it certainly deserves further investigation.

Both P. tremuloides and B. papyrifera are normally fast-growing species (White & Hosie, 1977). The average heights for mature individuals is 13-20 m for P. tremuloides and 26 m for B. papyrifera (Hosie, 1975). The largest individual measured on the tailings was only 3 m high. As the tailings are 15-20 years old, this suggests that either these species are just recent invaders or else their growth has been severely limited on tailings. More work on the aging of individuals and the study of the spatial distribution and frequency distribution of the two species Betula papyrifera and Populus tremuloides is called for.

D. FUNGI IN URANIUM MILL TAILINGS

The results from the slides buried in the tailings (TABLE 3.5) indicated the presence of fungi throughout the sampled sites. The greatest value for relative cover by hyphae belonged to the slide buried in the driest location, with very little organic matter (TABLE 3.6). No obvious relationship between any of the parameters measured and hyphal presence exists (TABLE 3.6). Differences between the amount of hyphal growth in each location may be related to the type of fungi attached to the slide. Several different growth forms were observed on the slides suggesting the presence of more than one species. As the majority of hyphae were present as fragments only, however, no attempt was made to categorize different growth forms for each slide.

The use of the plating method enabled isolation and identification of the major types of fungi in the tailings. The dominant Trichoderma species, which appeared on almost all plates, is a very fast-growing species, extremely common in all types of soils. All the other identified fungi were also common, fast-growing types, their adaptability enabling them to establish successfully in the tailings.

Much higher growth on the Peptone-Dextrose-Rose-bengal agar (TABLE 3.5) suggests the strong inhibitory effect of bacteria on fungal growth. This media was the only one to which an antibiotic (Streptomycin) was added. All other plates had obvious bacterial growth (TABLE 3.5) usually evident as shiny white rings around tailings particles. As bacteria require water for growth and multiplication (reference), the low moisture content of certain tailings samples (TABLE 3.6, Location 2, 3, 14 and BICROFT 2) may have enabled faster fungal growth at these locations (TABLE 3.5).

CONCLUSION

The chemical and physical parameters measured in this study could not explain the tremendous heterogeneity, in terms of vegetation, that existed on the tailings. A comparison of the results of this project with those of a similar study on the Madawaska Mines uranium mill tailings (Stokes and Kalin, 1979) would reveal even greater differences between the vegetation at the two mines. Despite these differences, however, several shared features are apparent.

Given time, vegetation will naturally invade mill tailings, unaided by man. Certain species, however, are apparently much more likely to establish successfully than others. In particular, species adapted to open waste sites and environmental conditions that are found after fires seem to dominate the tailings sites. On both Madawaska and Bicroft sites, there was always one or two dominant species, the dominance changing in different areas. Several of these species were common to both sites such as Populus species, Betula papyrifera and Equisetum arvense.

Additions of nutrients might aid the natural revegetation process; however, anchoring of the tailings material (compare, for example, the anchoring of dead wood and moss) so that the substrate is firmer and undergoes less fluctuation in moisture content may be more valuable. The presence of macro and micro fungi in the tailings may be contributing to the nutrient supply, especially in areas of almost bare tailings. Their presence may even be a prerequisite for the establishment of species unable to obtain sufficient nutrients otherwise. This might involve two processes. One might be the establishment of mycorrhizal associations, whereby the fungi obtain from the tailings nutrients plants are less efficient at absorbing. The nutrients are transported to the plant by the fungus which in turn receives compounds it is incapable of synthesizing. This symbiotic relationship would be of great value to a species trying to establish on a nutrient-poor substrate. Fungi may also, by their death, increase the organic content of the tailings. There is evidence they exist in the bare tailings where presumably they would constitute the largest source of organic matter. Their breakdown after death would release nutrients that could be used by an establishing species. There is no doubt that the fungi in tailings demand further attention due to the potential importance they may play in revegetation of the tailings.

The nature of the natural vegetation surrounding tailings sites influences the revegetation of the tailings. For example, the proximity of the Madawaska Mines tailings sites to Highway 28 may have accounted for the much greater number of well-established perennial and annual herbaceous species at that site. These species were extremely characteristic of roadsides and waste sites. Conversely, the tailings at Auger Lake and Bicroft Proper were bordered either by water or woodland forest. As pointed out in the discussion, there were few herbaceous species, none established, at the Bicroft sites.

An investigation of the major tree species on the tailings, more detailed than the one time permitted in this study, may yield valuable information on the dynamics of invasion and the relationship between vegetation on the tailings and in the surrounding natural forests.

This study was designed to be a preliminary investigation of the invading vegetation on uranium mill tailings. The results have suggested where lie interesting avenues for further investigation.

REFERENCES

- Alexopoulos, C.J. 1962. Introductory mycology. Wiley, New York.
- Andrews, W. 1973. Soil ecology. Prentice-Hall, Scarborough, Ontario.
- Antonovics, J. 1971. Heavy metal tolerance in plants. *Adv. Ecol. Research*, 7:1-85.
- Britton and Brown 1968. New Britton and Brown illustrated flora. Hafner, New York, Vol. 1-3.
- Crum, H. 1973. Mosses of the Great Lakes. Univ. Michigan, Ann Arbor.
- Donahue, R., J. Shickluna and L. Robertson 1971. Soils: an introduction to soils and plant growth. Prentice-Hall, Englewood Cliffs, N.J.
- Forest Resources Inventory 1960. Dept. Lands and Forests, Ontario.
- Gillespie, J.E. and R.E. Wicklund 1962. Soil survey of Hastings County. Rep.#27, Ontario Soil Survey, Canada, Dept. Agriculture, Ottawa.
- Gleason and Cronquist 1963. Manual of vascular plants. Nostrand, N.Y.
- Harris, M.M. and M.F. Jurgensen 1977. Development of salix and populus mycorrhizae in metallic mine tailings. *Plant and Soil*, 47:509-517.
- Hale, M.E. 1969. How to know lichens. Brown Publ., Dubuque, Iowa.
- Hosie, R.C. 1975. Native trees of Canada. Can. Forestry Serv., DOE.
- Johnson, L.F. and E.A. Curl 1972. Methods for research on the ecology of soil-borne plant pathogens. Burgess Publ., Minnesota.
- Lawrence, G.H. 1951. The taxonomy of vascular plants. Macmillan, N.Y.
- Mueller-Dombois, D. and H. Ellenberg 1974. Aims and methods of vegetation ecology. Wiley, Toronto.
- Murray, D. and D. Moffett 1977. Vegetating the uranium mine tailings at Elliot Lake, Ontario. *J. Soil and Water Conservation*, 32(4).
- Murray, D.R. 1978. Influence of uranium mill tailings on tree growth at Elliot Lake. *CIM Bull.*, December pp. 79-81.
- Peterson, R. and M. McKenney 1968. A field guide to wildflowers. Houghton Mifflin, Boston.
- Petrides, G. 1958. A field guide to trees and shrubs. Houghton Mifflin, Boston.
- Voss, E.G. 1972. Michigan Flora, Part I. Cranbrook Inst. of Science, Bloomfield Hills, Mich.
- Watson, E.V. 1955. British mosses and liverworts. Cambridge Univ. Press, Cambridge, England.

SECTION IV

SOIL NEMATODES IN URANIUM MILL TAILINGS

Scott Abernethy

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SOIL NEMATODES IN URANIUM MILL TAILINGS

Scott Abernethy

INTRODUCTION

Nematodes are considered one of the most successful groups of animals because they have filled many ecological niches. They exhibit a variety of feeding habits and a tolerance to wide ranges in environmental conditions (Wallwork 1970).

Free-living soil nematodes inhabit the water-films around soil particles. They are most concentrated in the rhizosphere because their food, roots, root exudates, organic matter and micro-organisms are most abundant in this area.

Nematodes are interesting because they exist in ecological association with other micro-organisms such as bacteria and fungi essential to soil-forming processes. For the present investigation such processes were deemed important because they help ameliorate some of the undesirable properties of tailings.

The existence of nematodes in tailings (despite its fine texture, low water-holding capacity and lack of other micro-organisms) was shown by Stokes and Kalin (1978). A study of invertebrates (Berlese funnel method) performed during earlier work resulted in the extraction of very few other soil invertebrates in sites where nematodes were extracted.

It was the purpose of this study to find out how nematodes are distributed over the various tailings sites and suggest some factors influencing their distribution.

METHODS

SELECTION OF SAMPLING SITES

Sampling sites were arranged parallel and perpendicular to the shore of the tailings ponds. Depth samples were taken at two locations along a transect perpendicular to the tailings pond.

SITE DESCRIPTION

The vegetation and litter of the sample sites (1 m^2) were described and subjective ratings of the sites' physical and chemical

characteristics were made. pH measurements were taken in the laboratory. Moisture content and then loss on ignition were measured from a replicate sample from the same site. Particle size fractionation data was obtained in locations where soil profiles were dug (Map 3-3).

SAMPLING METHOD

All collection was done on dry days between 1500 and 1700 hours. Tailings were sampled by pushing the point of a trowel into the substrate to a depth of 10 cm and removing a core sample. This was placed in a plastic bag which was twisted shut and sealed with tape. Vertical sampling was done in the same manner, except the trowel was pushed to a depth of 3 cm for the first sample. The next sample was taken from 3 to 6 cm deep. Then 6 to 9 cm and 9 to 12 cm yielded four depth samples per site.

As the sites were not easily accessible, transportation from the field to the extraction funnel was standardized as well as possible. The average time between sampling and setting-up the funnel was 1.5 to 2 hours.

EXTRACTION METHOD

The extraction method chosen for this study was designed by Baermann and is called the "Baermann funnel wet extraction method." However, the fine texture of the tailings necessitated some modification of the method. The best results were obtained with 50 g of tailings wrapped in a double layer of cheesecloth, 20 x 10 cm. This bag was suspended by a thread tied around the top of the cheesecloth in the funnel. 150 mls of tap water was added to each funnel and a 60 W light bulb was placed above.

After an average extraction period of 17 ± 1 hours, the tailings sample was weighted and discarded. The extracted nematodes were secured by clamping the bottom 5 cm of tubing. The extract varied in volume from 3 to 5 mls.

COUNTING NEMATODES

The nematodes were counted by the "Aliquot Method" (Black 1965). The nematodes in the whole extract were counted by placing each aliquot (1 drop = 0.3 mls) in a depression slide, divided into four equal sections. Counts were made at "1.6 x 4" power under a stereoscopic microscope. No attempt was made to identify types of nematodes for a number of reasons. Identification would require

histological preparation, and this was outside the scope of this summer project.

RESULTS

The three tailings areas where samples were taken and the sample sites are shown in Maps 4-1 to 4-3.

Table 4-1 is a tabulation of the site description parameters. Subjective and objective determinations of tailings moisture content appear to correspond, but subjective judgement of organic matter ratings did not correspond with the loss on ignition results. For instance, both samples 8 and 15 were rated as 3; however, percentage loss on ignition was 1.1 and 29.2 respectively.

The site description shows that a variety of sites were sampled. Intermediate levels between the extremes were well represented for moisture content and vegetation cover. The low values were not reliable and could be used only comparatively. The lowest values were computed from weight losses of 0.001 g. This approaches the balance precision. Litter cover results did not represent low and intermediate levels very well. Over half the sites had 80% or more cover. An examination of the number of nematodes at the individual sites along the transects shows some relation of moisture content, vegetation cover, type of vegetation and litter cover on abundance. As Table 4-1 shows, sites 5 and 6, 9 and 10, and 23 and 24 are similar in all site description parameters except moisture. In each case the site with the higher moisture content yielded more nematodes. Comparison of nematode abundance at sites 23 and 24 is especially interesting, for the drier site 24 had slightly more vegetation cover, litter cover and organic matter. Sites 8, 11 and 13 were the sites with the greatest number of nematodes and the most vegetation cover.

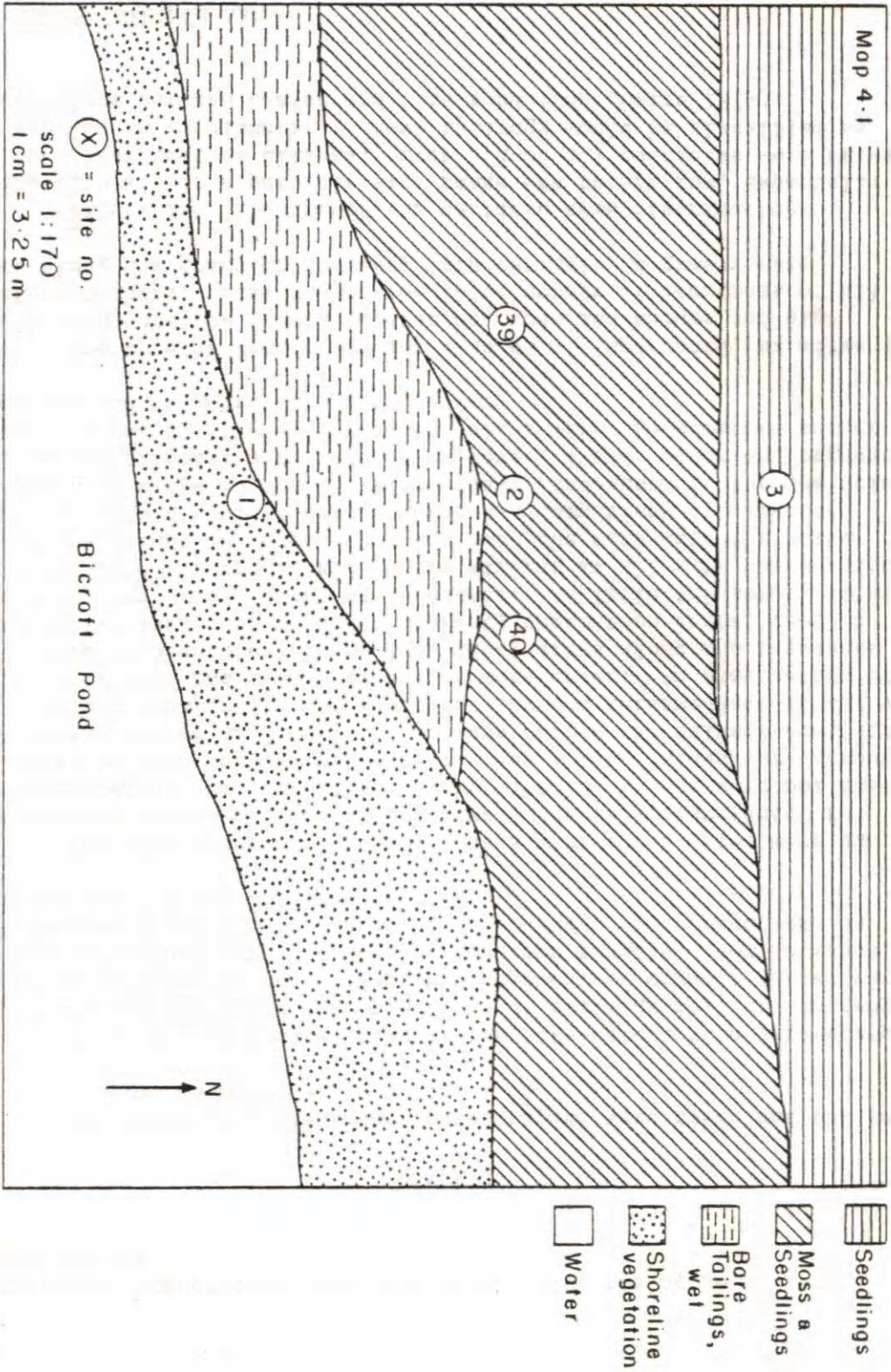
The type of vegetation may also be of importance, as sites 8 and 13 both have low growth vegetation, moss and shrubs and high nematode numbers. Site 21 had the least number of nematodes of all the sites along the transect and was, interestingly, a grassy site.

Figure 3-4 illustrates the particle size distributions. Variability within a particle size range was rather low, especially in the two finer texture classes. Over 50% of all particles were between 250 and 150 μm in diameter. These tailings would be classified as intermediate between coarse and fine sand (Daubenmire 1974).

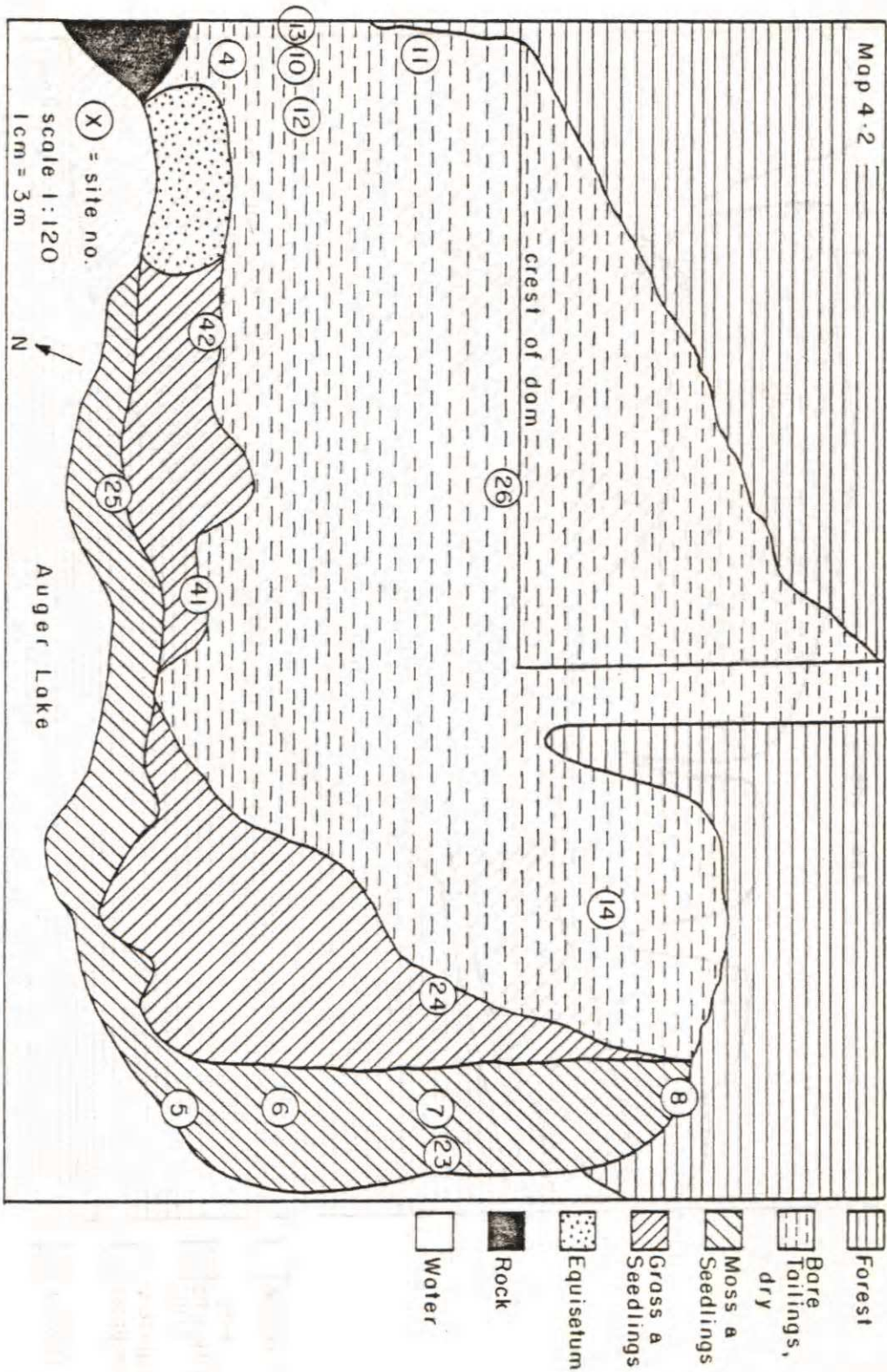
THE THREE TAILINGS AREAS

Frequency distributions of samples with grouped total number of

Map 4-1 Biccroft Proper north shore



Map 4-2 Auger Lake east shore



Map 4-3 Auger Lake south shore

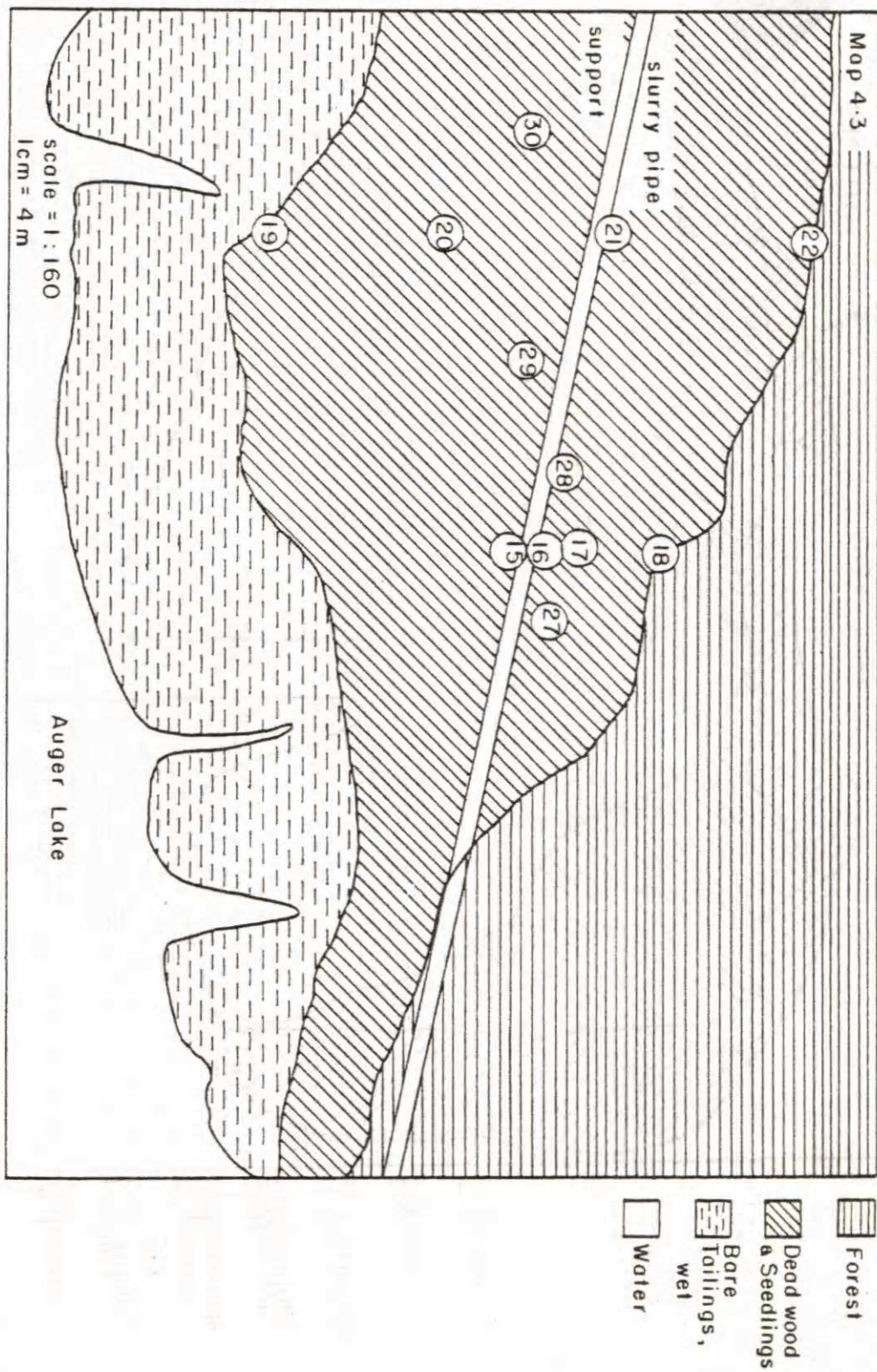


Table 4-1 Site description

Site No.	SOUTH SHORE OF ANGER LAKE														NORTH SHORE OF BICHOPT						
	5	6	7	8	9	10	11	12	13	14	23	24	25	26	41	42	1	2	3	39	40
Physical																					
Moisture rating	3	2	2	1	3	1	1	1	2	1	3	1	3	1	2	2	3	1	1	1	2
Shade rating	2	2	3	3	3	3	3	1	3	2	1	1	2	2	2	2	3	2	1	2	2
Organic increment litter cover	0	0	60	80	50	70	100	40	100	0	15	50	90	80	30	50	100	100	0	90	95
Litter thickness cm	-	-	1.5	0.5	0.8	1.2	1.0	0.8	1.5	-	0.1	0.2	0.1	0.2	0.3	0.3	1.2	0.7	-	0.6	0.5
Degree of decomposition rating	2	2	2	3	2	2	2	2	2	0	1	1	3	1	2	2	3	2	1	2	2
Vegetation																					
Trees																					
Percent cover	90	90	90	80	100	100	100	0	0	70	0	0	0	0	0	0	75	90	60	95	80
Height m	1.8	0.8	1.2	3.0	4.0	4.0	4.0	-	-	4.0	-	-	-	-	-	-	2.5	3.0	1.5	3.1	4.2
Shrubs																					
Percent cover	0	5	0	0	5	0	0	5	90	0	20	5	70	0	55	70	90	0	0	5	15
Height m	-	0.5	-	-	0.4	-	-	0.5	0.4	-	0.2	0.3	0.4	-	0.4	0.5	0.5	-	-	0.3	0.2
Grass																					
Percent cover	5	5	5	0	5	5	0	30	5	0	10	50	10	80	0	0	10	10	0	0	0
Height m	0.3	0.2	0.2	-	0.2	0.2	-	0.2	0.2	-	0.2	0.2	0.1	0.3	-	-	0.1	0.2	-	-	-
Moss																					
Percent Cover	70	75	60	80	45	0	0	0	5	0	5	0	50	0	0	0	10	0	0	0	0
Percent moisture loss	20.9	10.8	8.0	0.2	10.7	0.1	0.2	0.3	10.6	0.1	21.0	1.4	22.2	2.4	8.8	1.4	30.6	0.1	0.1	2.5	5.0
Percent loss on ignition	0.6	1.4	1.0	1.1	1.4	0.9	1.5	1.1	4.6	0.1	0.6	0.6	1.2	0.8	1.2	0.6	8.4	0.7	0.5	0.8	0.7

Parameter ranges: Percent moisture loss 0-60; Percent loss on ignition 0.1-29.2; Total percent vegetation cover 0-175; Percent litter cover 0-100
 Code for subjective ratings: Moisture: 1 = dry; 2 = moist; 3 = wet; 4 = saturated; Shade: 1 = no shade; 2 = slight shade; 3 = complete shade
 Degree of decomposition: 1 = no organic increment in substrate; 2 = slight organic matter incorporation; 3 = much organic matter in substrate

Table 4-1. Site description (continued)

Site No.	EAST SHORE OF AUGER LAKE										Depth samples (cm)											
	15	16	17	18	19	20	21	22	27	28	29	30	31	32	33	34	35	36	37	38		
Physical	#25																				#26	
Notalute rating	4	4	4	4	3	3	1	1	3	3	2	3	3	3	3	3	1	1	2	2		
Shade rating	1	3	1	2	2	3	2	2	2	3	1	1	2	3	3	3	2	3	3	3		
Organic increment																						
Litter cover	100	100	100	100	100	100	90	80	100	100	100	10	90	-	-	-	80	-	-	-		
Litter thickness cm	0.3	0.8	0.1	0.3	0.5	0.3	0.1	0.2	0.1	0.2	0.3	0.1	0.1	-	-	-	0.2	-	-	-		
Degree of decomposition rating	3	3	3	3	3	3	1	2	3	2	2	3	3	-	-	-	1	-	-	-		
Vegetation																						
Trees																						
Percent cover	0	70	0	50	30	50	0	70	30	40	80	15	0	-	-	-	0	-	-	-		
Height m	-	20	-	4.0	2.1	2.0	-	3.1	1.5	1.9	2.7	1.1	-	-	-	-	-	-	-	-		
Shrubs																						
Percent cover	0	0	0	50	0	0	0	5	0	5	5	10	70	-	-	-	0	-	-	-		
Height m	-	-	-	1.3	-	-	-	0.1	-	0.3	0.2	0.3	0.4	-	-	-	-	-	-	-		
Grass																						
Percent cover	0	0	0	0	0	0	20	15	0	5	5	0	10	-	-	-	80	-	-	-		
Height m	-	-	-	-	-	-	0.5	0.2	-	0.1	0.1	-	0.1	-	-	-	0.3	-	-	-		
Moss																						
Percent cover	0	10	0	15	20	5	0	40	10	0	70	5	50	-	-	-	0	-	-	-		
Percent moisture loss	60.5	35.2	35.3	26.3	19.0	13.9	0.1	0.9	27.6	21.9	15.9	25.0	23.5	19.1	17.8	22.6	2.3	5.0	7.6	9.0		
Percent loss on ignition	29.2	2.6	3.3	2.6	2.2	2.3	0.5	0.9	3.9	0.8	1.3	4.3	2.3	0.6	0.7	0.6	1.3	0.7	0.7	0.7		

Parameter ranges: Percent moisture loss 0-60; Percent loss on ignition 0.1-29.2; Total percent vegetation cover 0-175; Percent litter cover 0-100
 Code for subjective ratings: Moisture: 1 = dry; 2 = moist; 3 = wet; 4 = saturated. Shade: 1 = no shade; 2 = slight shade; 3 = complete shade
 Degree of decomposition: 1 = no organic increment in substrate; 2 = slight organic matter incorporation; 3 = much organic matter in substrate

nematodes extracted from the various sites are given in Fig. 4-1. The south shore of Auger Lake had the highest number of nematodes and Bicroft's north shore had the lowest. The distribution suggests a difference in area; however, more samples are needed to substantiate this. Overall, most extracts had less than 100 nematodes. All sites at the forest edge yielded high numbers, 354, 243 and 197 respectively. As expected, sites in the interior between forest edge and water had quite low numbers and were mostly areas in sites with little vegetative cover. The numbers of nematodes were as low as 0, 4, 9 and 14.

EVALUATION OF THE EXTRACTION PROCEDURE

The reliability of the population data depends to a great extent on standardization of the method. Since the extraction method utilizes the activity of nematodes, parameters which may affect nematode activity, such as site temperature, water temperature after extraction, pH of the sample and the water volume of the sample, were recorded. Means and standard deviations were calculated for the number of nematodes related to each parameter. Variability in numbers was high: many standard deviations within a group were as great or greater than the mean itself. It was concluded that none of the extraction parameters are related to low or high numbers of nematodes.

THE NUMBER OF NEMATODES AND TYPE OF SITE

No significant correlation was found between moisture content, loss on ignition, vegetation height, total vegetation cover or litter cover and the number of nematodes.

Sites were grouped according to location within each area. They were classified as shoreline, forest or interior sites according to criteria listed in Table 4-2. The table shows the mean number of nematodes and site parameters averaged within these locations.

In general, nematodes were more abundant at forest sites compared to shoreline sites. The interior of this site had the lowest number as well as the lowest moisture content, loss on ignition and vegetation cover. As expected, the shoreline had the highest moisture values, while the forest had the greatest loss on ignition values and litter cover.

VERTICAL DISTRIBUTION (FIG. 4-2)

Two sites were sampled vertically on the south shore of Auger Lake. The largest number of nematodes were extracted from the 3 to 6 cm depth, with a slight reduction above and a more drastic reduction

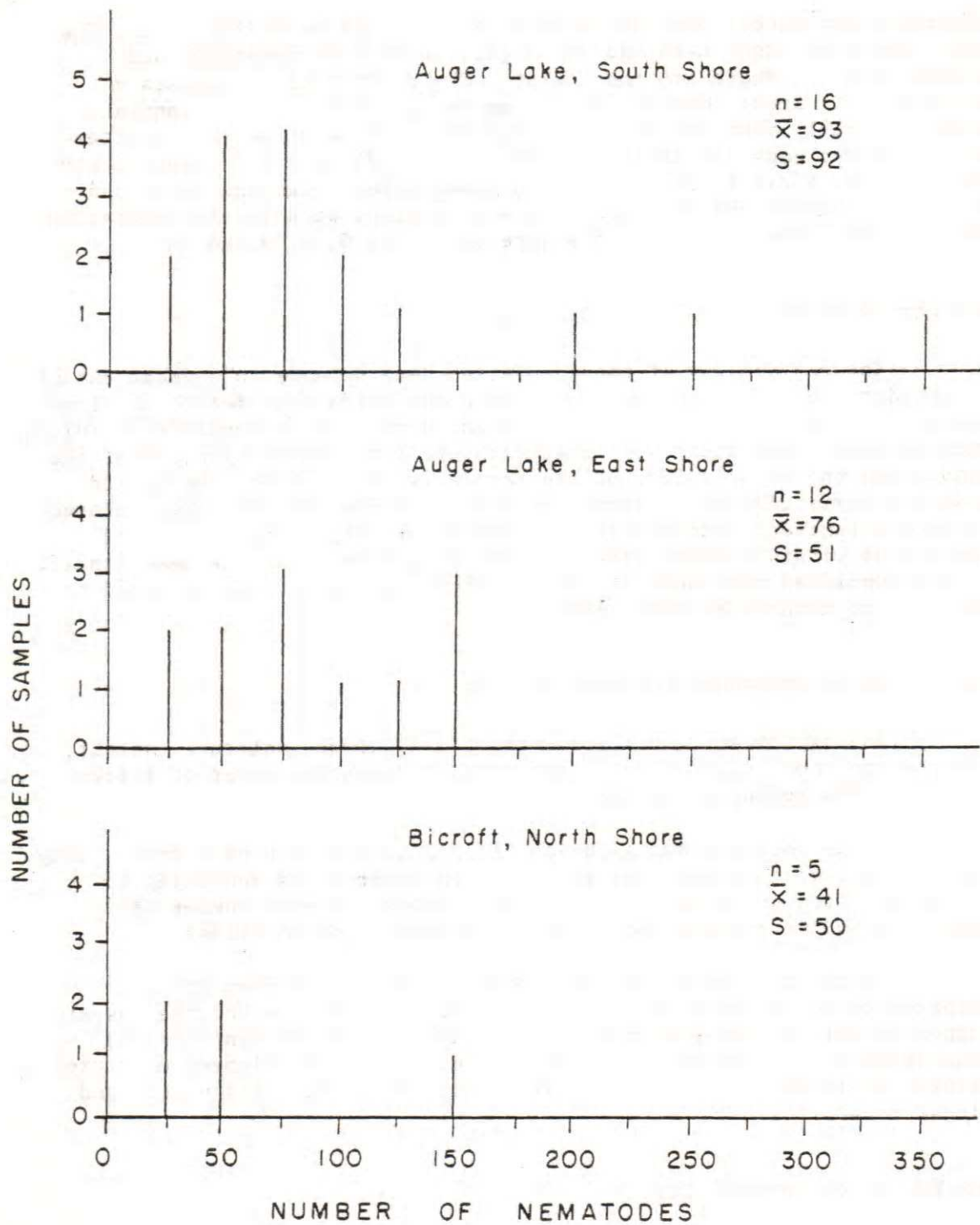


Fig. 4-1 Frequency distribution of nematodes

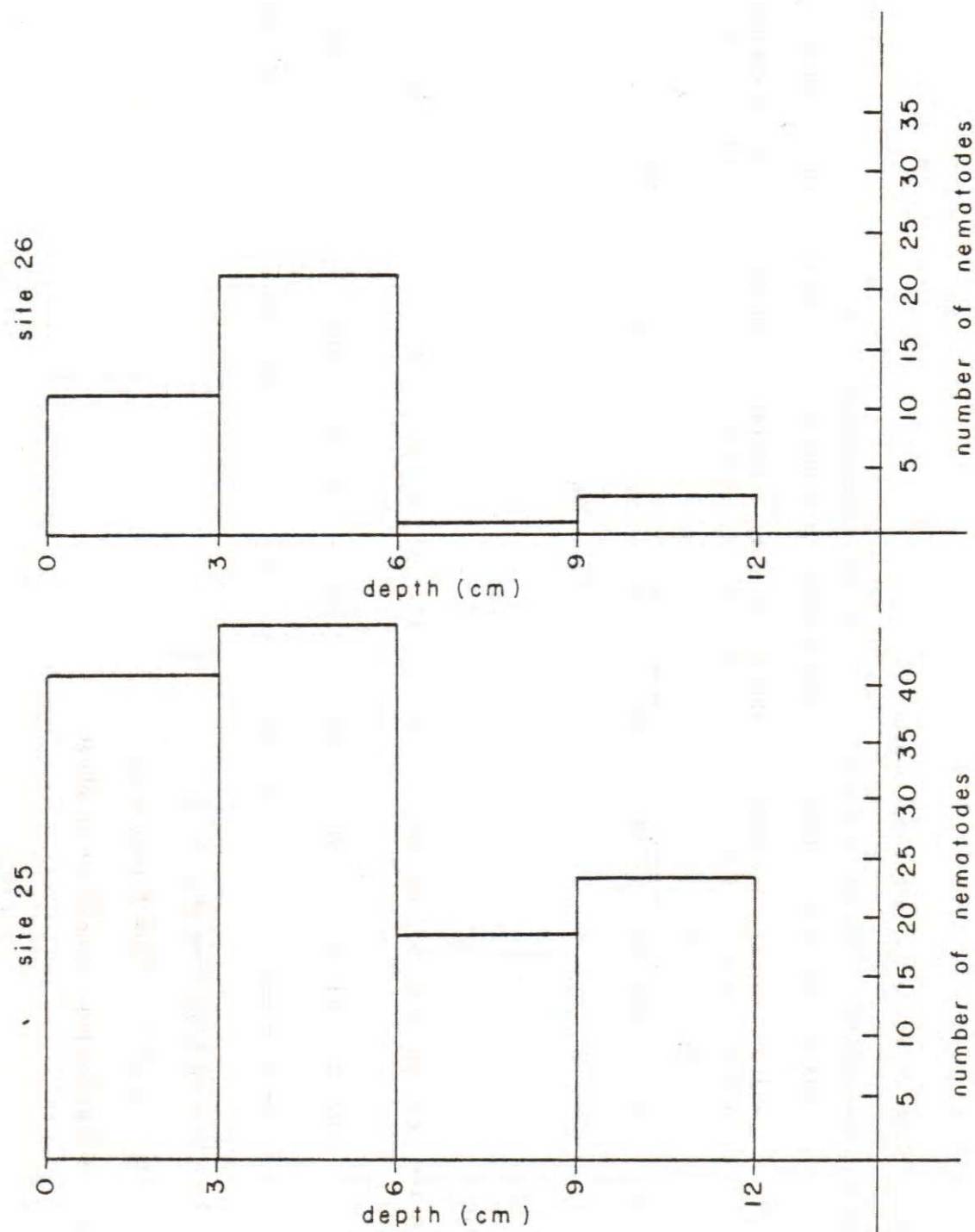


Fig. 4-2 Vertical distribution of nematodes

Fig. 4-3a

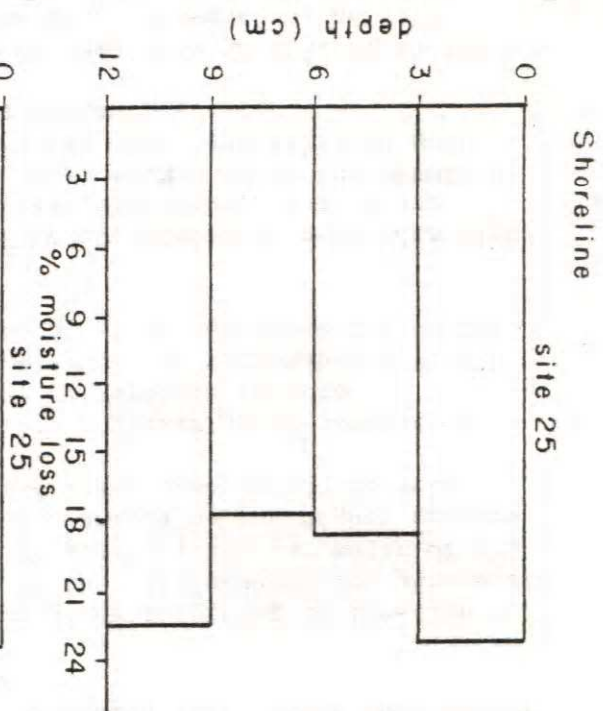


Fig. 4-3b

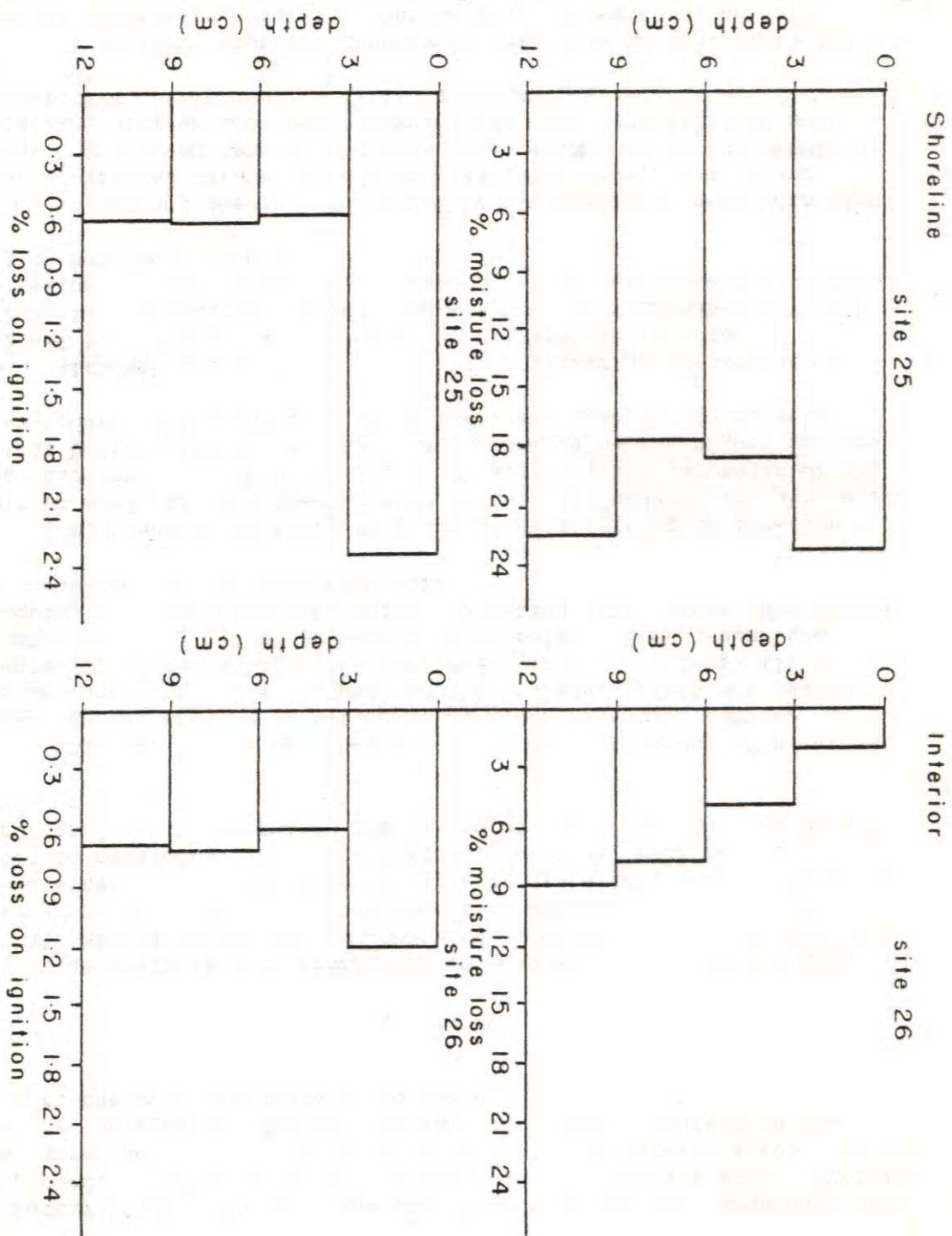


Fig. 4-3a - 4-3b Moisture content and loss on ignition versus depth

immediately below. Overall, the shoreline site had more nematodes and, as expected, a higher moisture content than the interior site. Profiles of moisture and L.O.I. (Fig. 4-3a, 4-3b) differed between sites. On the shoreline the moisture did not decrease with depth, whereas in the interior, the moisture content increased.

DISCUSSION

The particle size fractionation suggests the three tailings areas all have a rather uniform textured substrate. Particle size was probably not an important factor affecting nematode distribution between sites. This may, however, affect vegetation, which indirectly relates to nematodes. The fine texture, moreover, will not be unimportant, as it determines the nature of their microhabitat (Croll 1970).

This may be one explanation of the reduced number of nematodes in tailings compared to uncultivated soil populations. Samples with 100 nematodes were quite frequent in the tailings. This was estimated to represent approximately 1400 nematodes per m^2 . Wallwork (1970) estimates millions per m^2 in uncultivated soils. Even though the extraction will underestimate total population size, there were clearly fewer nematodes in tailings than soil.

It proved interesting to group sites according to location within an area, as it suggested some of the site description parameters being relevant to nematode ecology. In general, the perimeter of the tailings bodies, the forest edge and the shoreline had higher numbers of nematodes and the interior sites had lower numbers (Table 4-2).

Although the maps delineate broad categories of vegetation (Maps 4-1 to 4-3), the wide ranges and variability in site characteristics relates the heterogeneity of the microhabitat within a shoreline, forest or interior location. This was reflected in the range of nematode numbers.

It was not possible to correlate the number of nematodes with a single observed parameter such as vegetation cover or moisture content. Any given sample population size seemed to be the result of interaction between many environmental factors, especially in such a restrictive environment as tailings bodies.

It is known that the density of nematodes is related to the amount of vegetation cover and root material present in the soil (Wallwork 1970). Cover, both vegetative and litter, would shade the substrate and buffer against fluctuations in temperature and moisture content. Both these factors affect nematodes, especially if extreme (Croll 1970). Cover, especially litter, would absorb

and retain water such that a site may be drier than expected. The forest edge sites, for example, were relatively dry with high litter cover.

The type of vegetation also appeared important because vegetation not only supplies a food source for nematodes, but also alters the microhabitat of the site. The sites with high moss cover had relatively high numbers of nematodes. The growth habit of moss would make it a good buffer against environmental fluctuations for the tailings below. A site with thick, low-lying shrubs as the dominant vegetation yielded the third largest number of nematodes in the entire survey.

Vegetation clearly contributes to the organic increment of a site. Organic matter is important because it improves the physical structure of the substrate (Daubenmire 1974). It also allows the development of saprophytic populations, which along with roots and root exudates are potential food sources for nematodes. Despite the low levels of organics, nematodes seem to have adapted to the uranium mill tailings substrate along with some vegetation. The relatively high number of nematodes at shoreline sites with reduced vegetation suggests that moisture is a very important factor for nematodes, in tailings material. Moisture is important to nematodes due to their small size (high surface area to volume ratio), which makes them easily desiccated (Milne 1971; Kevan 1963). This is reflected especially in the sites from the interior at the south shore of Auger Lake (Fig. 4.3). This was the driest part of the area and had the fewest nematodes. The importance of moisture is emphasized as vegetation cover, loss on ignition and litter cover values did not appear restrictive at the interior sites. They were higher than shoreline sites.

The vertical distribution of nematodes seemed to vary with site; however, the 3 to 6 cm layer had the highest number of nematodes of all layers at both sites. The slight reduction in abundance in the layer above may reflect the lethal nature of solar radiation or the inability to tolerate the wider fluctuations in environmental factors which occur closer to the surface (Daubenmire 1974). A general reduction in abundance below 6 cm was probably due to a reduction in potential food sources (Wallwork 1970). Overall, the dryness of the interior site may account for the reduced number of nematodes.

SUMMARY

Emphasis in this brief survey was placed on extraction technique and the apparent site heterogeneity. It was demonstrated that site differences, and not sampling and extraction procedure, were responsible for differences in the number of nematodes extracted. Expected trends in distribution of nematodes in these waste sites were discovered.

REFERENCES

- Black, C.A. 1965. Methods in Soil Analysis.
- Croll, N.A. 1970. The Behaviour of Nematodes. Edward Arnold Ltd.
- Daubenmire, R.F. 1974. Plants and Environment. John Wiley.
- Kevan, D.K. 1963. Soil Animals. H.F. and G. Witherby Ltd.
- Milne, L. and Milne, M. 1971. The Arena of Life. Doubleday Natural History Press.
- Stokes, P.M. and M. Kalin 1978. An Abandoned Uranium Mine Tailings Pond. IES, Univ. Toronto, EZ-5.
- Wallwork, J.A. 1970. Ecology of Soil Animals. McGraw Hill.