ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

RESEARCH REPORTS

These research reports describe the results of investigations funded under the Alberta Oil Sands Environmental Research Program, which was established by agreement between the Governments of Alberta and Canada in February 1975 (amended September 1977). This 10-year program is designed to direct and co-ordinate research projects concerned with the environmental effects of development of the Athabasca Oil Sands in Alberta.

A list of research reports published to date is included at the end of this report.

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Baseline Condition of Jack Pine Biomonitoring Plots in the Athabasca Oil Sands Area 1976-1977

Project LS 3.4.2

AOSERP Report 98

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The Hon. J.W. (Jack) Cookson
Minister of the Environment
222 Legislative Building
Edmonton, Alberta

and

The Hon. John Roberts
Minister of the Environment
Environment Canada
Ottawa, Ontario

Sirs:

Enclosed is the report "Baseline Condition of Jack Pine Biomonitoring Plots in the Athabasca Oil Sands Area; 1976 and 1977".

This report was prepared for the Alberta Oil Sands Environmental Research Program, through its Terrestrial Fauna Technical Research Committee (now the Land System), under the Canada-Alberta Agreement of February 1975 (amended September 1977).

Respectfully,

W. Solodzuk, P.Eng.
Chairman, Steering Committee, AOSERP
Deputy Minister, Alberta Environment

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BASELINE CONDITION OF JACK PINE BIOMONITORING PLOTS IN THE ATHABASCA OIL SANDS AREA 1976-1977

DESCRIPTIVE SUMMARY

Biomonitoring is a technique whereby biological species are used both as indicators of air pollution impingement and as a measure of air-pollution impact. The expense of establishment and maintenance of high technology monitoring instrumentation can be eliminated by use of vegetation.

The aim of this report is to define the current condition of a set of jack pine (*Pinus banksiana* Lamb) stands established during 1976 and 1977 on 13 different sites in the vicinity of existing and proposed oil extraction plants. Jack pine stands were selected as they predominate in exposed upland sites in the Athabasca Oil Sands Area and hence, have a high likelihood of impingement by air-borne pollutants. In addition, jack pine has been shown to be very sensitive to air pollution both under field and laboratory conditions.

The baseline study revealed there was no effect of pollutants at present levels on jack pine or lichens associated with them. Feathermoss was the only lower plant showing taking up and retaining aerial emissions.

The tree species *Picea glauca* (white spruce) also appeared to give a good indication of pollutant impingement. Monitoring of pollutant impact on plant communities can be accomplished only by successive sampling, analysis, and interpretation.

The report has been reviewed and accepted by the Alberta Oil Sands Environmental Research Program.

W.R. MacDonald
Director (1980-81)
Alberta Oil Sands Environmental
Research Program

BASELINE CONDITION OF JACK PINE BIOMONTIROING PLOTS IN THE ATHABASCA OIL SANDS AREA 1976-1977

by

P.A. ADDISON

Northern Forest Research Centre

Canadian Forestry Service

for

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

Project LS 3.4.2

August 1980

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ABSTRACT

In 1976-77, a set of 13 jack pine biomonitoring sites was established in the Athabasca Oil Sands area in order to biomonitor both impingement and impact of emissions characteristic of oil sands extraction operations. No measureable air pollutant effect was observed on either vascular or lichen communities at any site even though significantly high tissue pollutant concentrations were documented from sites within 10 km of GCOS. The importance of future time-course sampling of permanent sites is emphasized because our inability to measure a biological effect at these sites may have been purely because of the great natural variability in the region.

ACKNOWLEDGEMENTS

This research project LS 3.4.2 was funded by the Alberta Oil Sands Environmental Research Program, established to fund, direct, and co-ordinate environmental research in the Athabasca Oil Sands area of northeastern Alberta.

1. INTRODUCTION

Biomonitoring is a technique whereby biological species are used both as indicators of air pollution impingement and as a measure of air pollution impact. Obviously, the state of health of any organism is the best measure of air pollution impact on that organism. In addition, several plant groups, particularly mosses and lichens, have been shown to be very efficient in taking up and storing airborne pollutants. If the vegetation of an area can provide a reliable and consistent measure of both impingement and impact of a pollutant source, the expense of establishment and maintenance of high-technology monitoring instrumentation can be eliminated in many cases.

In the past, many studies have examined the impact of air pollution on vegetation or vegetational components. Although there have been hundreds of such studies, almost all have dealt with severely degraded areas. In the Athabasca Oil Sands area, there appears to be very little obvious damage to the forest ecosystem in the vicinity of the Great Canadian Oil Sands (GCOS)[1] operations that can be attributed to air pollution. GCOS has been operating at their present location (ca. 30 km north of Fort McMurray) since 1967 and for most of that time has emitted about 300 t of SO_2 per day. In addition, 40 $t \cdot day^{-1}$ of particulates containing mainly Si, Al, Fe and V have been emitted to the atmosphere. Since there is considerable potential for air pollutants (especially SO_2) to injure forest ecosystems (Pyatt 1973; Habjorg 1975), it is important that a record of current forest condition be established in order to assess pollutant impact on vegetation and soils in the future. The potential for forest injury is particularly great in this area in view of current and proposed expansion of oil sands extraction and processing by Syncrude Canada Ltd., Shell Canada Ltd. and several other oil companies and consortia [Chaapel 1974; Alberta Oil Sands Environmental Research Program (AOSERP) 1975].

[1] GCOS amalgamated with Sun Oil Company in August 1979, after the writing of this report was completed, to become Suncor, Inc.

The aim of this report is to define the current condition of a set of pack pine (*Pinus banksiana* Lamb.) stands established during 1976 and 1977 in the vicinity of existing and proposed oil extraction plants. This set of sites will permit delineation of pollutant impingement and long-term biomonitoring for the detection of air pollution injury to the forest. Jack pine stands were selected as they predominate in exposed upland sites in the Athabasca Oil Sands area and, hence, have a high likelihood of impingement by airborne pollutants. In addition, jack pine has been shown to be very sensitive to air pollution both under field and laboratory conditions (Berry 1971; Blauel and Hocking 1974; Legge et al. 1977).

2. STUDY AREA

Jack pine stands at 13 locations were chosen for permanent plots (Figure 1). These locations (Table 1) were selected based on winter pollutant deposition (Barrie and Whelpdale 1978), topography, and distance from both the GCOS processing plant and the Syncrude project recently gone into production. In Alberta, there is a general west to east airflow (Boughner and Thomas 1962) but this general flow is modified by local topographic features such as the Athabasca River valley (Mickle et al. 1978). A substantially modified airflow pattern results (Figure 2; Walmsley and Bagg 1977) and the deployment of sites followed this pattern.

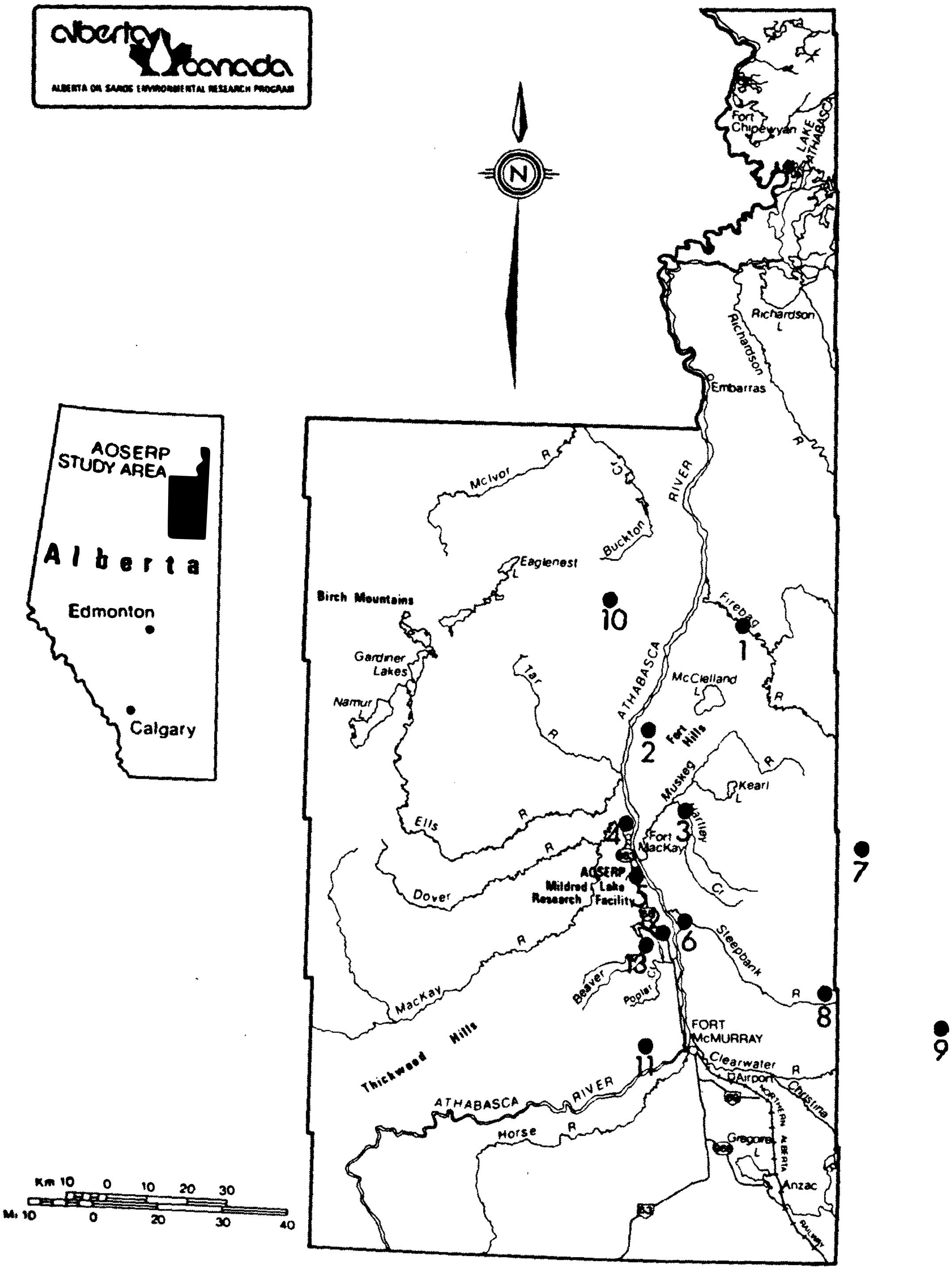

Figure 1. Location of permanent biomonitoring plots in the Athabasca Oil Sands area. For site names, see Table 1.

Table 1. Legal description of jack pine biomonitoring sites in the Athabasca Oil Sands area.

Site Number	Site Name	LDS.	Sec	Twp	Range
1	Firebag River	14	02	100	8
2	Bitumount Tower	15	27	96	10
3	Hartley Creek	13	09	95	9
4	Fort MacKay	12	36	94	11
5	Mildred Lake Camp	1	19	93	10
6	Fina Airstrip	15	20	92	9
7	Muskeg Mountain	4	15	94	6
8	North Steepbank River	8	32	90	7
9	Gordon Lake	10	11	88	4
10	Birch Mountain	10-11	24	100	12
11	Thickwood Hills	4	34	89	11
12	Gradient Site A	7	14	92	10
13	Gradient Site D	11	2	92	10

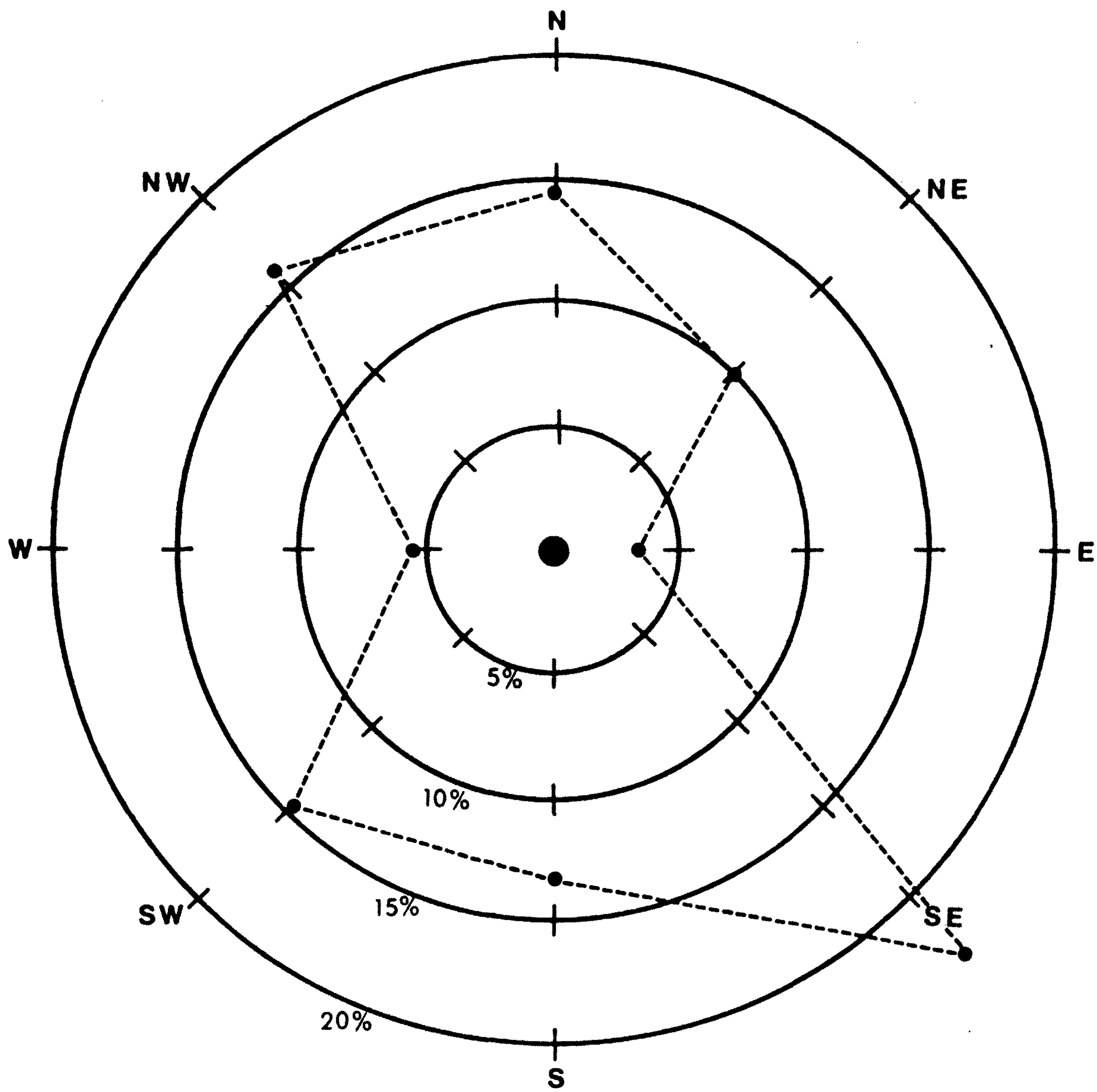

Figure 2. Wind rose of direction frequency for Mildred Lake (from Walmsley and Bagg 1977).

3. METHODS AND MATERIALS

Description of the biomonitoring sites is critical to long-term monitoring of the Athabasca Oil Sands area for the detection of air pollution impact on vegetation and soils. Description of each site consisted mainly of quantification of the vascular plant community with respect to both vegetational and soil components. Lichens, because of their high sensitivity to air pollutants, also were described in detail. Low-level aerial photography provided a baseline overview for tree crown impact by air pollutants in the vicinity of GCOS.

3.1 VEGETATION DESCRIPTION

3.1.1 Vascular Plant Community

At all sites, a 20 x 20 m plot was established and a vascular plant species list, stand density and age, and cover and frequency of lower stratum species were determined. Stand age was obtained by boring 10 trees of average size at stump height (30 cm) and adding three years to the number of annual rings. All cores were taken on the south side of the tree.

Cover and frequency of lower stratum plant species were quantified using 20 1 x 1 m quadrats that were randomly selected from a 20 x 20 m matrix of the plot. The sample area represented 5% of the total and quadrat size was greater than the minimum sampling area required as defined by Cain and Castro (1959). All quadrats were marked permanently so that future measurements of the site would be identical.

3.1.2 Cryptogamic Plant Community

In the vicinity of each permanent plot, 10 spruce branches with a lichen stand of mainly fruiticose and foliose types were selected. Species were combined to form four groups based on morphology and ease of recognition (Table 2). Quantification of the cover and frequency of the species groups was accomplished using a 15 x 20 cm grey-card quadrat

Table 2. Corticolous branch lichens on jack pine and black and white spruce in the Athabasca Oil Sands area.

Species	Species Group Name	Group Characteristics
Usnea spp. *Evernia mesomorpha* *Ramalina* spp.	Evernia	Yellow fruticose (branched)
Cetraria halei *C. pinastri*	Cetraria	Brown and yellow foliose (leaf-like)
Parmelia sulcata *Hypogymnia physodes*	Hypogymnia	Gray foliose
Alectoria spp.	Alectoria	Black fruticose (hair-like)

and photographs. Each branch to be sampled was marked and labelled and the lichens moistened slightly so that they were pliable. Spruce branches are oriented mainly on a plane and, hence, there was no difficulty in placing the grey-card quadrat below the branch. Lichens normally grow on the top and sides of branches so the entire stand was included in a photograph taken from directly above the branch. In all cases, the most luxurient lichen community present at each site was sampled. The use of a grey-card (19% reflectance, Kodak Inc.) permitted a qualitative estimate of lichen condition to be made based on colour since a standard colour was present in each photograph.

Analysis of the photographs was accomplished by projecting the transparency onto a 45 x 60 cm rear projection screen. The screen was divided into 100 units and the presence of each lichen species or species group was recorded for each unit. Since none of lichens covered the entire unit, it was necessary to calculate the average cover each species had when it did occur in a unit. This was accomplished by estimating the cover of each species in each unit of 12 quadrats that encompassed the range of lichen densities found in the field and multiplying the frequency of occurrence in the 100 units by the average cover per unit.

3.2 SOIL DESCRIPTION

A soil pit (1 x 0.5 m) was dug to a depth of 1 m at each site, photographed, and described according to the categories outlined in the System of Soil Classification for Canada (Canadian Soil Survey Committee 1974). Carbon content was determined by combustion, texture by the hygrometer technique for sand, silt, and clay fractions (Bouyoucos 1951), and colour followed the Munsell Colour Charts. Drainage and slope also were recorded for each site.

3.3 CHEMICAL CONTENT

3.3.1 Soils

Duplicate soil samples were collected from each horizon of the profile at each site. The soils were oven dried ($105^{o}C$ for 24 h) and digested using an aluminum block digester (Technicon Inc.) and teflon beakers. Samples (0.5 g) were predigested in 10 mL of 16N HNO_3 and 2 mL of 10N $HClO_4$ for 1.5 h at $70^{\circ}C$. Silica was then driven off with 20 mL of 29N HF at $150^{\circ}C$. The sample was taken to near dryness, dissolved into 1 mL of 12N HCl and brought to 50 mL with glass distilled water. Digests were analyzed for Al and Fe with an atomic absorption spectrophotometer (Instrumentation Laboratories #251) and for S using a modified Johnson-Nishita method (Carson et al. 1972).

3.3.2 Selected Plant Species

Six species or species groups were sampled at all sites and analyzed for S, Al, and Fe. The species included jack pine (*Pinus banksiana* Lamb.), white spruce [*Picea glauca* (Moench) Voss], common Labrador tea (*Ledum groenlandicum* Oeder), common bearberry [*Arctostaphylos uva-ursi* (L.) Spreng.], ground lichens [mainly *Cladina mitis* (Sandst.) Hale and W. Club.] and feathermoss [mainly *Pleurozium schreberi* (Brid.) Mitt.]. These six species were selected because they demonstrated the greatest uptake of S close to the pollution source of the 15 species analyzed in 1976 (Addison unpublished). These species also represented both dry and moist microenvironments. Five replicates were collected for each species. Pine and spruce samples consisted of 1 year old material collected 7 to 10 m above ground, whereas other samples were of indeterminant age. Duplicate plant samples were passed through a 20 mesh screen and mineralized using an oxygen flask combustion technique (Chan 1975). Elemental analysis was carried out as described above.

3.4 AERIAL SURVEY

Approximately 100 km of low level colour photography (1:2000) were flown (July 1976) in the vicinity of GCOS in order to assess forest crown condition close to the pollution point source (Figure 3). At the same time as the 100 x 1 km transect was flown (Figure 3), stereo pairs at 1:500 were taken every 2000 m with a Vinten Camera and 279 mm lens. The main transect was photographed with the same camera type and 76 mm lens. Both cameras were mounted on a Bell 500 helicopter that flew at a height of 175 m.

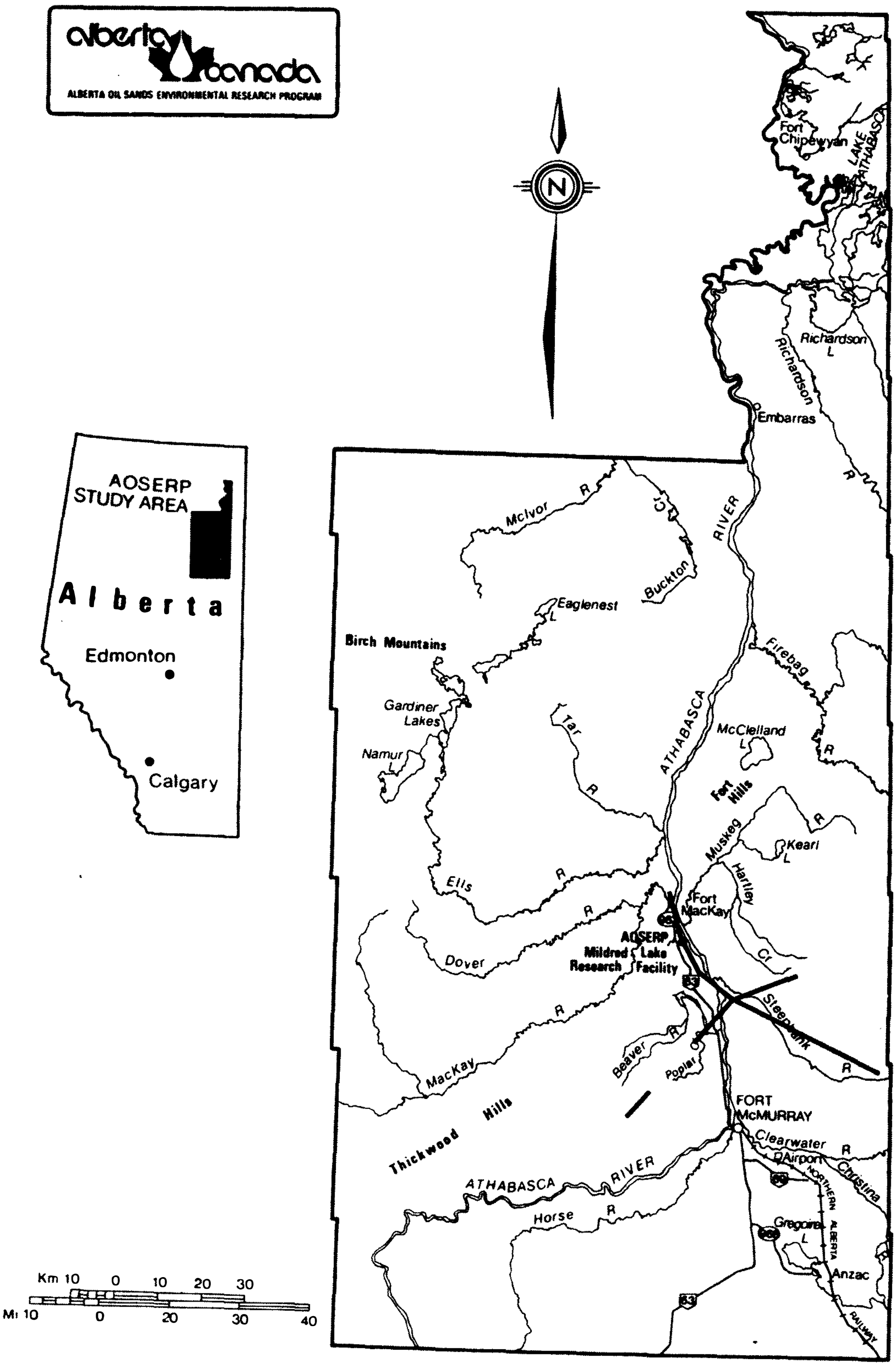

Figure 3. Flight lines of low level photography (1:2000) flown in 1976 in the Athabasca Oil Sands area.

4. RESULTS AND DISCUSSION

4.1 VEGETATION DESCRIPTION

4.1.1 Vascular Plant Community

The jack pine stands, selected as biomonitor sites, were variable both in species composition and cover of lower stratum in the plant community (Table 3). The stand order seen in Table 3 was determined by constructing the association table based upon a frequency-cover index (% cover + % frequency ÷ 2). No distinct pattern was evident in the stand descriptions that could be related to the distance that sites were from the oil sands operations. Community structure and composition, therefore, provided no evidence that there was any effect of the GCOS processing plant on jack pine stands in the Athabasca Oil Sands area.

The stands appear to break into four groups based on the frequency-cover indices of the species present. Harley Creek, Fina Airstrip, Firebag River, Mildred Camp, and Gradient Site A (#3, 6, 1, 5 and 12, respectively) all had several species in common that rarely occurred in other stands (e.g., *Campanula rotundifolia* L., *Amelanchier alnifolia* Nutt. and *Potentialla tridentata* Ait.). These sites also had the lowest stand densities of trees greater than 10 cm DBH (150 to 300 stems$\cdot$ha^{-1}; Table 4). Because of the low stand density, the surfaces of the sites were more exposed to drying winds. The lower stratum vegetation reflects this exposure and these sites represent the driest type of jack pine stand found in the area. Gradient Site D (#13) as a whole appeared to be transitional in species composition, cover, and stand density as well as in moisture status, whereas Bitumount Tower (#2) was not. The stand density of Bitumount Tower (Table 4) was unusually high (2600 stems$\cdot$ha^{-1}) but, because the trees were clumped, the site was divided almost equally into moist and dry sections. Stand density in the moist section was about 4000 stems$\cdot$ha^{-1}. The dry section appeared to be very similar in species composition and cover to the group described above. The moist section of Bitumount Tower, on the other hand, was similar to the Fort MacKay (#4), North Steepbank (#8), and Gordon

Table 3. Association table of frequency-cover indices of lower stratum plant species at biomonitoring sites in the Athabasca Oil Sands area.

Species	Stands												
	3	6	1	5	12	2	13	4	8	9	11	7	10
Trees													
*Larix laricina**								2.5					
Picea glauca						2.5							
Picea mariana									13.4		62.1	2.5	12.2
Pinus banksiana	22.7	5.1	2.5		2.5				5.1		7.6		
Populus tremuloides	25.9	23.4	23.6		5.0	5.1	25.2	5.0	12.6	12.6	7.6		5.4
Betula papyrifera						2.5					2.5		2.6
Shrubs													
Salix sp.											17.9	2.9	5.1
Alnus crispa		11.8		30.2	10.1		14.3			5.2	2.5	6.3	
Betula occidentalis										10.2			
Amelanchier alnifolia	43.6	23.5	22.9	5.1	5.1	10.1			5.2				
Prunus pensylvanica	2.5		23.2	20.6									
Prunus virginiana					5.0	10.2				5.1			
Rosa acicularis	15.2	7.6		5.3	7.6							9.5	
Rosa woodsii						43.2		20.3					
Ledum groenlandicum						38.5	13.6	19.0			10.3	30.8	46.6
Vaccinium myrtilloides	18.4	55.7	51.7	52.2	55.9	46.1	54.9	36.7	52.5	53.9	51.5	60.1	47.3
Lonicera dioica		2.5											
Viburnum edule										2.6			
Ground Shrubs													
Arctostaphylos uva-ursi	54.5	64.5	31.6	61.2	54.0	44.5	13.6	11.5			8.2		
Vaccinium vitis-idaea var. *minus*	42.6	41.3	31.7	51.5	33.1	38.4	56.8	57.6	63.1	55.8	22.8	28.3	55.2
Linnaea borealis var. *americana*		7.6	2.6	20.2	25.3	5.2	25.4	35.6	20.5	46.6	5.1	5.4	
Herbs and Grasses													
Elymus innovatus	5.1	32.9				17.7		60.6	32.7	47.9			
Unidentified grass	50.4	50.4	47.9	50.5	50.3	20.1	50.3		7.6	15.1	22.6		
Carex sp.		22.6	27.7			7.6							
Lilium philadelphicum var. *andinum*							15.1						
Maianthemum canadense var. *interius*	50.3	40.4	22.7	50.7	50.5	47.9	50.5	10.1	25.2	50.6			
Goodyera repens								2.5		7.6			
Comandra pallida	22.4	27.7		47.8	50.3	22.6							
Geocaulon lividum								5.1					
Anemone multifida	12.6	2.5	7.6	5.0		2.5							
Fragaria virginiana		7.6	7.6								2.5		
Potentilla tridentata	12.6	37.9	2.5	22.7	22.7		12.6		2.5				
Lathyrus ochroleucus									2.5				
Viola nephrophylla		10.1			2.5						2.5		
Epilobium angustifolium							12.6	2.5	2.5	30.7		2.5	
Aralia nudicaulis				2.5		15.2				25.4			
Cornus canadensis					15.1		50.9	7.6	51.2	55.7	49.4	47.9	
Pyrola secunda								2.5		10.1		2.5	
Trientalis borealis		2.5								35.3			
Apocynum androsaemifolium			5.2	2.6		2.5							
Melampyrum lineare		17.6		2.6	10.1		22.6		2.5	15.1	25.2	2.5	
Galium boreale	2.5		7.6										
Campanula rotundifolia	17.6	7.6	7.6	10.1	2.5	5.1	5.0						
Achillea millefolium	5.1	5.1											
Artemisia biennis		10.1	10.1										
Aster ciliolatus	40.4	2.5	20.2			5.1							
Solidago decumbens	27.7	12.6	20.1	2.5		2.5							
Pteridophytes													
Equisetum arvense								2.6			42.7		
Lycopodium complanatum	12.8			42.0		20.9	2.5				7.6		
Lycopodium obscurum										2.6			
TOTAL COVER													
Vascular Plants	33.9	64.7	21.7	49.0	29.4	46.0	41.1	32.7	47.6	41.3	20.1	34.9	28.5
Lichens	68.0	26.2	46.5	31.3	30.3	26.8	36.6	23.1	46.0	17.4	15.1	31.1	33.9
Mosses	1.9	3.6	9.3	4.5	0	14.5	0	18.5	5.4	24.1	24.7	1.0	23.6

* Nomenclature of vascular plant species follows Moss (1959).

Table 4. Jack pine stand density of biomonitoring sites in the Athabasca Oil Sands area.

Site 4		Density (stems >10 cm DBH$\cdot$ha^{-1})[a]
3	Hartley Creek	150
1	Firebag River	300
5	Mildred Lake Camp	175
6	Fina Airstrip	175
12	Gradient Site A	175
2	Bitumount Tower	2600[b]
13	Gradient Site A	175
4	Fort MacKay	575
8	North Steepbank River	825
9	Gordon Lake	1175
7	Muskeg Mountain	6500
10	Birch Mountain	875
11	Thickwood Hills	1625

[a] DBH - Diameter at Breast Height.

[b] Stand is clumped: Open area ≃ 200; Closed area ≃ 4000.

Lake (#9) stands. These sites were more moist than the first group, at least partially as a result of a higher stand density (575 to 1175 stems·ha^{-1}; Table 4). These sites had several mesic plant species present (e.g., *Epilobium angustifolium* L., *Elymus innovatus* Beal and *Aralia nudicaulis* L.). Sites such as Muskeg Mountain, Birch Mountain, and Thickwood Hills represented the most hydric group of jack pine stands. They graded into black spruce stands and, in fact, were the only plots where black spruce was found. In addition, Muskeg Mountain, Birch Mountain, and Thickwood Hills had high stand densities (6500, 875 and 1625 stems·ha^{-1}, respectively) that would lower near-surface wind speeds, reduce evapotranspiration, and maintain high soil moisture at these sites. There was, however, some overlap in stand density with the Fort MacKay-North Steepbank-Gordon Lake group. This overlap was a result of the low stand density at Birch Mountain. At this site, there were many black spruce stems that were slightly less than 10 cm in diameter at breast height. These stems were not included in stand density estimates and yet appeared to have a substantial impact on wind speed.

The Bray-Curtis ordination (Dripps and Gauch 1971) graphically expresses how stands of vegetation compare with one another. This method of expression clumps individual stands into groups that have similar characteristics based on frequency-cover indices of the species present. Figure 4 graphically summarizes Table 3 and shows the same trend as the association table with one notable exception. Hartley Creek (#3) was substantially different than the other dry sites (#1, 5, 6, and 12) and appeared to represent the driest phase of jack pine stand found in the area. This site had the lowest stand density, the greatest ground lichen cover (mainly *Cladina mitis*), and was missing several key species [e.g., *Linnaea borealis* var. *americana* (Forbes) Rehd. and *Melampyrum lineare* Desr.] that were common in more mesic sites (Table 3). The X-axis of the ordination appeared to relate to site moisture status. Stand densities (Table 4) tend to support this hypothesis as they also increase along this axis.

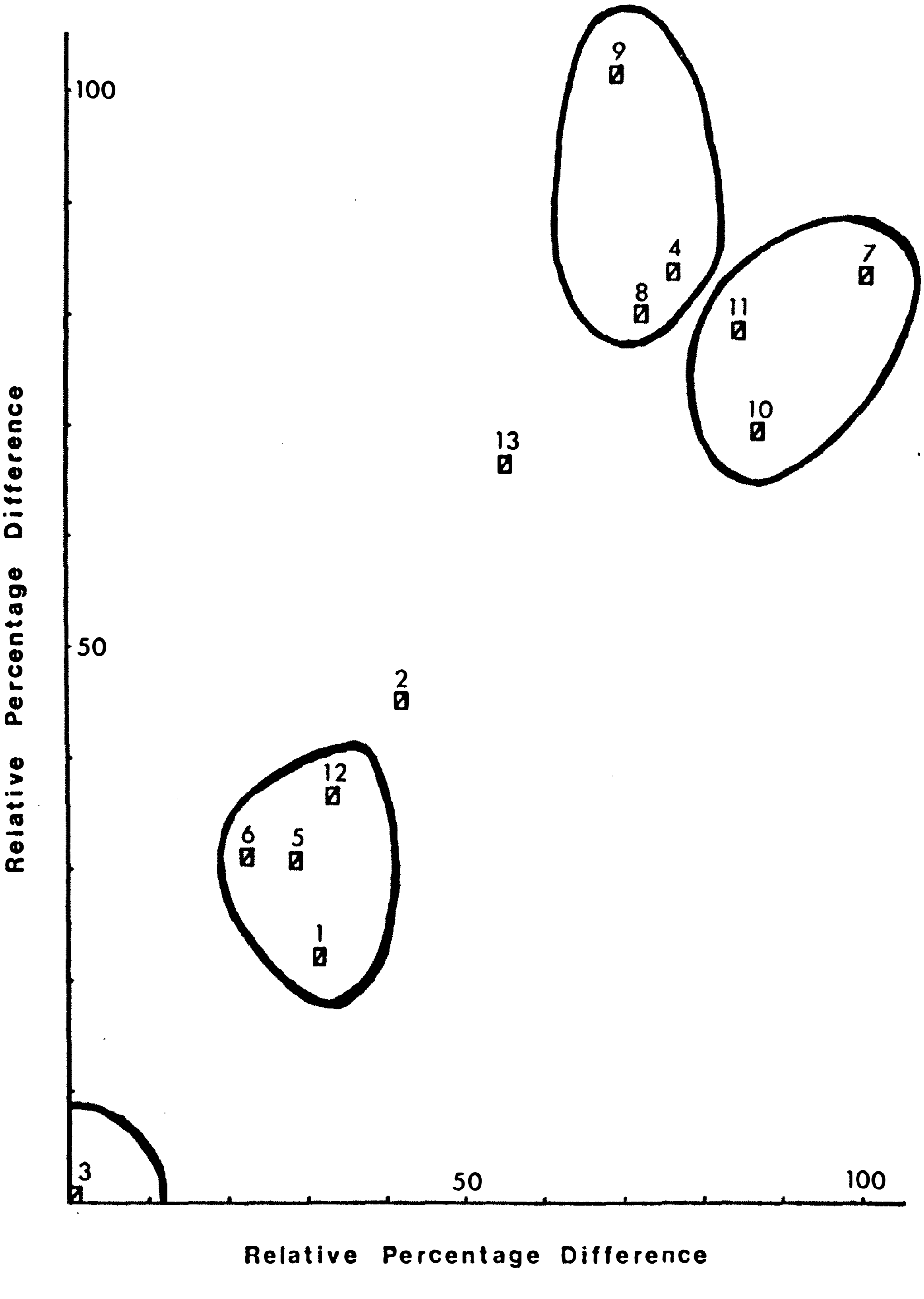

Figure 4. Bray-Curtis ordination of jack pine biomonitoring stands based on frequency-cover indices of lower stratum vascular species.

The major purpose of the ordination was to synthesise the large amount of community information. This method can also be used to detect subtle changes in stand composition and cover over time which would be reflected as a shift in the relative position of the stands. A future examination (to be done in 1980) of these stands, using the same quadrats, will provide sufficient information to determine the effect of airborne pollutants characteristic of oil sands operations on the cover or frequency of plant species in these stands. Essentially, changes in each site will be monitored over time. This would eliminate the need of making comparisons between sites that often have considerable natural variability.

4.1.2 Cryptogamic Plant Community

The association table (Table 5) uses frequency-cover indices of the species present to rank the stands in order of their similarity. In this case, the frequency of each species group was the mean of the frequencies of each species and cover was the percentage that each species contributed to the area that the branch plus lichen occupied. Using this basis for cover, quadrat size varied from branch to branch and reported lichen covers were independent of branch size. The variability in the amount of lichen present as a result of different branch sizes and configuration, therefore, was removed from comparisons between sites.

The lichen association table did not show a pattern that could be attributed to air pollution (Table 5). The stands, however, were divided into four groups as shown in the Bray-Curtis ordination (Figure 5). These groups are arbitrary and were based on the similarity between sites as determined by the frequency-cover indices of the species present. It was not possible to relate the axes of this ordination to environmental factors as was done with vascular communities. The major reason for this is the paucity of information as to what factors control the distribution and constitution of corticolous lichen communities in the boreal forest.

Table 5. Association table of lichen stands at biomonitoring sites in the Athabasca Oil Sands area. Values are frequency-cover indices (frequency + cover ÷ 2) of 10 quadrats at each site.

Species	Stands								
	4	5	9	10	1	6	11	8	3
Evernia mesomorpha, *Usnea* spp. and *Ramalina* spp.	75.3	71.5	75.6	61.1	66.5	44.8	51.9	36.2	56.3
Alectoria glauca	45.3	50.6	50.4	50.4	45.3	44.7	30.1	51.2	5.0
Hypogymnia physodes and *Parmelia sulcata*	54.2	55.5	55.0	53.8	53.8	57.2	55.9	48.1	37.8
Cetraria halei and *Cetraria pinastri*	30.4	50.4	43.9	43.1	36.7	43.4	41.8	28.2	25.5
Distance from GCOS (km)	24	11	73	61	74	4	30	31	26

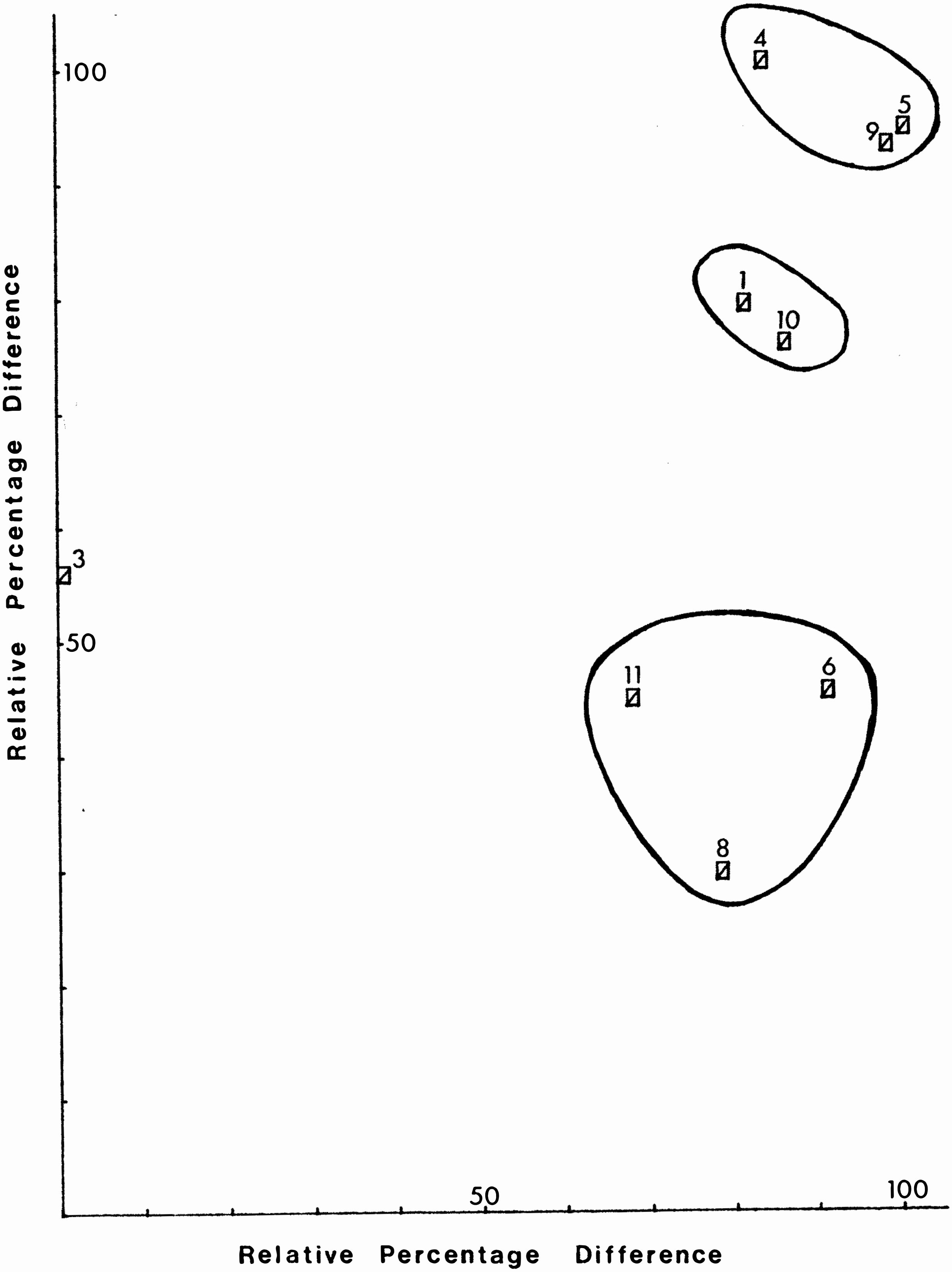

Figure 5. Bray-Curtis ordination of corticolous lichens at biomonitoring sites in the Athabasca Oil Sands area.

Lichen communities have not been used extensively to describe air pollution impact on forests (Hawksworth 1973). In most cases, the distribution of selected sensitive species has been used to indicate pllutant impingement (Gilbert 1969; Rose 1973). This has been possible in areas where there has been sufficient impact of the pollutants to eliminate certain species of lichen from the immediate vicinity of the source. In the Athabasca Oil Sands area, air pollution has been neither long nor intense enough to eliminate even the most sensitive lichen species from forests in the area. Historic approaches, therefore, were inappropriate and hence the more detailed examination of lichen communities was adopted. Changes with time in presence, frequency or cover of any lichen species resulting from air pollution injury will be reflected as a shift in the relative position of the stand. This shift can be quantified and compared with air pollution concentrations at the site.

4.2 SOIL DESCRIPTION

The soils underlying the jack pine biomonitoring plots were very similar in type, texture, and horizons present. Modification of the parent material occurred to about 32 cm below the surface of the mineral soil and resulted in Ah, Ahe, Ae and Bm horizons (Table 6). Ah and Ahe horizons appeared to result from frequent fire incidents that produced a substantial quantity of carbon that was incorporated readily into the mineral soil. The more common method of organic matter incorporation into mineral horizons by soil microfaunal activity appears to be minor at these sites. In all cases, the soils were acidic (pH <5.5 in $CaCl_2$) and were coarse textured (sands to sandy-loams).

All soils were dystric brunisols with one exception at Bitumount tower, where thickness of the Ah horizon was sufficient to place the soil in the sombric brunisol great group (Table 7; Canadian Soil Survey Committee 1974). Most of the soils were classified as degraded because of their well-devloped Ae horizon. A gleyed C horizon at North Steepbank river was responsible for this prefix being

Table 6. Example of soil type and characteristics at biomonitoring plots in the Athabasca Oil Sands area.

Degraded Dystric Brunisol

The site was depressional to level and had no evidence of either water or wind erosion. The soil was well drained and supported a vegetative community dominated by *Pinus banksiana* and *Populus tremuloides* Michx. in the shrub stratum and *Arctostaphylos uva ursi* and ground lichens (*Cladina mitis*) in the lower stratum.

Horizon	Depth (cm)	Description
LFH	+3-0[a]	Very dark gray (10 YR 3/1 m & d), semi-decomposed organic matter; many fine vertical roots; abrupt smooth boundary; 3 cm thick; pH 5.4 (in water).
Ahe	0-4	Gray (10 YR 5/1 m), gray brown (10 YR 5/2 d); loamy sand; single grain; loose; many medium to fine vertical roots; abrupt, wavy boundary; 2 to 6 cm thick; pH 5.7 (in water).
Ae	4-6	Light gray (10 YR 7/2 m), very pale brown (10 YR 7/4 d); loamy sand; single grain; loose; very few fine horizontal roots; abrupt, wavy boundary; 1 to 3 cm thick; pH 5.4 (in water).
Bm	6-25	Reddish yellow (7.5 YR 6/8 m), (7.5 YR 6/6 d); loamy sand; single grain; loose; few medium horizontal roots; gradual smooth boundary, 15 to 22 cm thick; pH 5.7 (in water).
C	25+	Brownish yellow (10 YR 6/6 m), yellow (10 YR 7/6 d); loamy sand; single grain; loose; very few medium to very fine horizontal roots; pH 6.0 (in water).

[a] 0 indicates the surface of the mineral soil.

Table 7. Type and depth of soils at jack pine biomonitoring sites in the Athabasca Oil Sands area.

Site	Name	Soil Type	Depth to C Horizon
1	Firebag River	Orthic Dystric Brunisol	45
2	Bitumount Tower	Orthic Dystric Brunisol	40
3	Hartley Creek	Degraded Dystric Brunisol	38
4	Fort MacKay	Degraded Dystric Brunisol	15
5	Mildred Lake Camp	Degraded Dystric Brunisol	32
6	Fina Airstrip	Degraded Dystric Brunisol	25
7	Muskeg Mountain	Orthic Dystric Brunisol	25
8	North Steepbank River	Gleyed Degraded Dystric Brunisol	26
9	Gordon Lake	Degraded Dystric Brunisol	45
10	Birch Mountain	Degraded Dystric Brunisol	31
11	Thickwood Hills	Degraded Dystric Brunisol	20
12	Gradient Site A	Degraded Dystric Brunisol	42
13	Gradient Site D	Degraded Dystric Brunisol	32

added to the soil name. The consistancy of soil types, textures, pH, and horizons present indicated that similar pedogenic processes were occurring at all sites.

4.3 CHEMICAL CONTENT

Chemical analysis of plant material from the biomonitoring sites showed a substantial increase in Sulphur (S), Aluminum (A) and Iron (Fe) as one approached the GCOS pollution source (Table 8). This increase was great enough that, for all elements, at least four of the six species studied had significantly ($p < 0.05$) higher pollutant contents <10 km from the source than either 10 to 25 or >25 km from the stack. Three to seven sites were included in each zone. The pattern was not related to total soil content of these elements as initially expected, since there was no significant difference ($p < 0.05$) in S, Al or Fe content among the means at increasing distance from GCOS for any horizon (Table 9). In general, the influence of emissions appears to be limited to about 10 km from the pollution source if all plant species and the major pollutants are considered as a whole (Tables 8 and 9).

In addition to the use of soil analyses as a baseline with which to compare plant analyses, the soil, particularly the LFH horizon, can be used as an indicator of pollutant deposition. In some ways, the LFH horizon represents a better measure of long-term deposition since it accumulates pollutants for a longer period of time than plant foliage. In the Athabasca Oil Sands area, pollutant deposition did not appear to be enough to show any real difference between sites especially in view of large natural site variability (Table 9). Aluminum and iron content of the soil (Tables 9B and C) however, did demonstrate the effect of the natural pedogenic processes of eluviation from the A horizon and illuviation into the B. The C horizon Al and Fe contents were intermediate to those of the A and B horizons. The levels of these two elements in the C horizon probably represent the levels that existed before leaching or deposition occurred.

Table 8. Pollutant content (ppm) of plant material from biomonitoring plots in the Athabasca Oil Sands area (Mean ±95% confidence limits).

Distance from GCOS (km)	*Pinus banksiana*	*Picea glauca*	*Arctostaphylos uva-ursi*	*Ledum groenlandicum*	Ground lichens	Feather-moss
A. SULPHUR						
<10[a]	880 ± 38[b]	883 ± 61	780 ± 66	1101 ± 87	457 ± 40	1229 ± 77
10-25	772 ± 36	697 ± 45	473 ± 29	1015 ± 68	445 ± 48	1076 ± 71
>25	781 ± 45	675 ± 23	538 ± 41	1116 ± 42	304 ± 15	839 ± 37
B. ALUMINUM						
<10	654 ± 67	240 ± 69	250 ± 52	316 ± 50	436 ± 150	1678 ± 404
10-25	513 ± 57	68 ± 14	125 ± 22	116 ± 18	123 ± 31	1091 ± 172
>25	588 ± 41	48 ± 11	179 ± 35	156 ± 19	161 ± 18	587 ± 46
C. IRON						
<10	177 ± 47	187 ± 62	160 ± 27	267 ± 49	176 ± 55	1160 ± 356
10-25	113 ± 16	72 ± 8	109 ± 24	117 ± 20	76 ± 21	872 ± 169
>25	130 ± 18	61 ± 16	141 ± 27	140 ± 20	154 ± 19	532 ± 53

a Three sites occurred <10 km from GCOS, 3 sites from 10 to 25 km, and 7 sites >25 km.
b Vertical lines indicate means that are not significantly different ($p < 0.05$) in a Student-Newman-Keuls test.

Table 9. Total pollutant content (ppm) of soils from the biomonitoring sites in the Athabasca Oil Sands area (Mean ±95% confidence limits).

Distance from GCOS (km)	LFH	Ah + Ahe	Ae	Bm	BC	C
A. SULPHUR						
<10[a]	394 ± 127	[b] 194 ± 100	40 ± 17	38 ± 17	49 ± 31	61 ± 16
10-25	466 ± 32	114 ± 68	-	63 ± 20	48 ± 20	39 ± 23
>25	374 ± 48	72 ± 22	25 ± 20	6 ± 19	39 ± 26	26 ± 12
B. ALUMINUM						
<10	6743 ± 1812	8585 ± 1503	10503 ± 4173	15347 ± 4173	16544 ± 635	13108 ± 1183
10-25	7848 ± 914	12247 ± 2997	-	15547 ± 3215	12219 ± 617	13047 ± 5289
>25	11105 ± 3181	12850 ± 6247	16377 ± 6630	20933 ± 7123	15349 ± 4624	16927 ± 4793
C. IRON						
<10	2665 ± 1085	2848 ± 920	2939 ± 154	10043 ± 4365	6876 ± 1786	6458 ± 1253
10-25	3459 ± 1182	3532 ± 1281	-	6385 ± 1256	6782 ± 597	5575 ± 1818
>25	4425 ± 1449	2862 ± 1196	3938 ± 1460	9962 ± 4185	7130 ± 3708	7676 ± 2849

a Three sites occurred <10 km from GCOS, 3 sites from 10 to 25 km, and 7 sites >25 km.
b Vertical lines indicate means that are not significantly different ($p < 0.05$) in a Student-Newman-Keuls test.

Feathermoss appeared to be the best species group to demonstrate a gradient of pollutant deposition in the oil sands area (Table 8). Uptake and retention of pollutants by mosses appears to be purely a physical (ion exchange) process (Clough 1974). Mosses are excellent pollutant traps and have been used extensively to monitor or map both gaseous and particulate pollutants (Taoda 1973; Leblanc and Rao 1974; Grodzinska 1978).

Tree species, particularly *Picea glauca,* also appeared to give a good indication of pollutant impingement (Table 8), whereas the lower stratum species did not. The use of plant species as indicators of pollution impingement has been used extensively in the past (vam Raay 1968; Pyatt 1973). In this case, plant pollutant content appeared to be related to both the physical position of the tissue and to the ability of the plant to avoid pollutant entry. The actual tissue concentration of the element, however, did not indicate how good a pollutant trap a species is, as evidenced by high *Ledum groenlandicum* S content which was not related to distance from the source (Table 8).

Pine and spruce samples were taken 7 to 10 m above the ground and this, in conjunction with low stand densities at most sites (<1000 stems•ha^{-1}; Table 4), ensured that the target was in the open and fully exposed to the pollutant. Lower stratum vascular species were more protected as a result of both canopy and ground boundary layers. These species, therefore, were not exposed either as frequently or to as high concentrations as the trees. Addison and Baker (1978) also showed that ground dwelling species had low pollutant uptake rates than more exposed species.

The capability of plants to exclude pollutants from their structure also appeared to be important in understanding plant pollutant content (Table 8). Vascular species have been shown to exclude pollutants through stomatal action (Farrar et al. 1977; Caput et al. 1978) and, in fact, plant populations resistant to SO_2 injury have been shown to have higher stomatal resistance (Braun 1977). Stomatal control of pollutant entry appears to separate plants into vascular and non-vascular species since the latter had no control over pollution uptake.

It was not surprising, therefore, that cryptogamic plants revealed a more distinct pattern of pollutant absorption (particularly S; Table 8A). As mentioned above, feathermosses were the best pollutant deposition indicators. Dry lichens are practically inert to pollutants (Marsh 1975) and, since boreal ground lichens are dry for much of the year (Rouse and Kershaw 1971; Lindsay in prep.), it was not surprising that lichens did not show as distinct a pollutant deposition pattern as feathermoss.

Using feathermoss as a bioindicator, distinct gradients in S content were observed in northerly (Mildred Lake Camp-Fort MacKay-Birch Mountain), southwesterly (Gradient Site A-Gradient Site D-Thickwood Hills), and southeasterly (Fina Airstrip-North Steepbank River-Gordon Lake) directions (Appendix 7, Table 10). These gradients appeared to be unrelated to soil S content (Appendix 7, Table 13) and reflected pollutant deposition over a seven- to nine-year period. All values of S content were in the normal range expected in plant material (Chapman and Pratt 1961). These gradients indicate how sensitive and useful this method is for long-term biomonitoring of pollutant deposition.

4.4 AERIAL SURVEY

Aerial photography was "ground truthed" both at the permanent sites that were on the flight lines and at selected locations where plant communities other than *Pinus banksiana-Alnus crispa* occurred. Ground truthing involved both on-site observations and the use of large-scale stereo pairs (1:500) that were taken at the same time as the main transect. The photography has been catalogued according to flight line and location and is on file at Northern Forest Research Centre. Photography will be flown again if casual observations indicate that crown damage in the vicinity of the two operating oil extraction plants has occurred. In 1976, there was no apparent injury to the crowns of any stand in the vicinity of GCOS.

5. CONCLUSIONS

A set of jack pine biomonitoring sites established in the Athabasca Oil Sands area follows a pattern that is related to air-shed characteristics, topography and geographical position. These sites are sufficiently scattered to permit long-term biomonitoring of both present and proposed air pollution sources.

There was no measureable impact of air pollutants on either vascular or cryptogramic plant communities. Vascular plant communities appeared to be patterned along a moisture gradient that was at least partially caused by differences in stand density among the sites.

Since little is known about the factors that control branch dwelling corticolous lichen communities in the boreal forest, no explanation for lichen community pattern is proposed.

Feathermoss appeared to be most effective species group in taking up and retaining aerial emissions. Other species, particularly trees, showed a similar but less distinct pattern of pollutant deposition with distance from the source. In general, significant uptake of emissions occurred less than 10 km from the pollution source even though specific gradients in plant pollutant content extended up to 25 km.

Since natural variability, particularly in soil and plant pollutant content, may have masked significant effects of air pollution in the region, the need for resampling and comparison of each site with itself over time is of critical importance. Monitoring of pollutant impact on plant communities can be accomplished only by successive sampling, analysis, and interpretation.

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7. APPENDIX

Since this is a baseline document, it was deemed necessary to provide chemical analyses of both soil and vegetation at the permanent biomonitoring sites to enable future site-specific comparisons to be made. In addition, because of the multidisciplinary nature of the Alberta Oil Sands Environmental Research Program, data are provided as support for ongoing and future studies in a variety of fields. Specific use of this appendix is made in the Results and Discussion section of the text (Table 10 to 15).

Table 10. Sulphur content (ppm) of tissue of selected species from the Athabasca Oil Sands area (mean ±95% confidence limits.)

Sites	Distance & Direction from GCOS km		Sulphur Content of Foliage					
			Pinus banksiana	*Picea glauca*	*Arctostaphylos uva-ursi*	*Ledum groenlandicum*	Ground lichens	Feather-moss
12 Gradient Site A	2.8	SSW	1002 ± 48	918 ± 81	796 ± 71	1409 ± 92	629 ± 38	1289 ± 49
6 Fina Airstrip	4.0	ESE	809 ± 77	895 ± 124	984 ± 131	714 ± 73	458 ± 24	1205 ± 62
13 Gradient Site D	5.3	SSW	828 ± 30	691 ± 101	559 ± 23	1180 ± 78	284 ± 25	1195 ± 230
5 Mildred Lake Camp	10.5	NW	862 ± 45	854 ± 38	533 ± 69	814 ± 34	392 ± 40	1252 ± 100
4 Fort MacKay	23.7	NNW	799 ± 57	667 ± 93	461 ± 41	924 ± 79	499 ± 84	930 ± 72
3 Hartley Creek	25.0	N	656 ± 51	571 ± 33	425 ± 29	1306 ± 93	N/A	1043 ± 154
11 Thickwood Hills	30.0	SW	677 ± 43	N/A	613 ± 70	1271 ± 127	297 ± 16	823 ± 115
8 North Steepbank River	30.6	ESE	369 ± 55	676 ± 34	676 ± 115	1150 ± 101	323 ± 37	825 ± 47
7 Muskeg Mountain	39.4	ENE	737 ± 31	N/A	N/A	1239 ± 124	299 ± 79	983 ± 204
2 Bitumount Tower	39.8	N	806 ± 47	768 ± 46	692 ± 49	1107 ± 86	350 ± 33	866 ± 121
9 Gordon Lake	72.8	SE	1175 ± 122	548 ± 28	356 ± 66	1168 ± 104	341 ± 35	791 ± 52
1 Firebag River	74.0	NNE	979 ± 87	589 ± 27	365 ± 55	746 ± 108	255 ± 18	831 ± 102
10 Birch Mountain	80.0	NNW	730 ± 36	N/A	N/A	1118 ± 39	265 ± 23	759 ± 39

Table 11. Aluminum content (ppm) of tissue of selected species from the Athabasca Oil Sands area (mean ±95% confidence limits).

Sites	Distance & Direction from GCOS km		Aluminum Content of Foliage: *Pinus banksiana*	*Picea glauca*	*Arctostaphylos uva-ursi*	*Ledum groenlandicum*	Ground lichens	Feather-moss
12 Gradient Site A	2.8	SSW	643 ± 60	303 ± 195	397 ± 70	399 ± 54	738 ± 369	2150 ± 1089
6 Fina Airstrip	4.0	ESE	604 ± 139	165 ± 71	174 ± 79	181 ± 39	183 ± 71	810 ± 162
13 Gradient Site D	5.3	SSW	655 ± 100	253 ± 92	196 ± 35	350 ± 76	386 ± 181	2073 ± 262
5 Mildred Lake Camp	10.5	NW	438 ± 123	48 ± 34	164 ± 49	159 ± 36	117 ± 36	1651 ± 134
4 Fort MacKay	23.7	NNW	466 ± 73	83 ± 10	101 ± 36	77 ± 24	163 ± 40	1003 ± 129
3 Hartley Creek	25.0	N	627 ± 84	74 ± 30	106 ± 25	114 ± 19	N/A	619 ± 75
11 Thickwood Hills	30.0	SW	639 ± 91	N/A	365 ± 71	254 ± 47	254 ± 34	793 ± 82
8 North Steepbank River	30.6	ESE	423 ± 96	0	160 ± 59	114 ± 35	93 ± 30	681 ± 97
7 Muskeg Mountain	39.4	ENE	519 ± 45	N/A	N/A	129 ± 30	204 ± 42	646 ± 86
2 Bitumount Tower	39.8	N	619 ± 78	63 ± 25	152 ± 41	162 ± 41	185 ± 28	578 ± 89
9 Gordon Lake	72.8	SE	514 ± 86	68 ± 45	111 ± 26	156 ± 54	131 ± 21	492 ± 53
1 Firebag River	74.0	NNE	558 ± 100	37 ± 17	93 ± 27	131 ± 80	67 ± 41	301 ± 89
10 Birch Mountain	80.0	NNW	830 ± 126	N/A	N/A	141 ± 38	195 ± 43	635 ± 107

Table 12. Iron content (ppm) of tissue of selected species from the Athabasca Oil Sands area (mean ±95% confidence limits).

Sites	Distance & Direction from GCOS km		Iron Content of Foliage					
			Pinus banksiana	*Picea glauca*	*Arctostaphylos uva-ursi*	*Ledum groenlandicum*	Ground lichens	Feather-moss
12 Gradient Site A	2.8	SSW	191 ± 18	126 ± 34	215 ± 34	248 ± 20	293 ± 127	753 ± 373
6 Fina Airstrip	4.0	ESE	154 ± 63	134 ± 61	77 ± 33	141 ± 26	67 ± 39	386 ± 86
13 Gradient Site D	5.3	SSW	120 ± 25	300 ± 169	190 ± 27	412 ± 78	168 ± 61	2341 ± 338
5 Mildred Lake Camp	10.5	NW	150 ± 35	85 ± 9	176 ± 42	167 ± 39	63 ± 28	1442 ± 105
4 Fort MacKay	23.7	NNW	110 ± 17	53 ± 4	85 ± 34	81 ± 20	91 ± 33	717 ± 68
3 Hartley Creek	25.0	N	94 ± 11	78 ± 21	69 ± 12	112 ± 16	N/A	443 ± 83
11 Thickwood Hills	30.0	SW	201 ± 41	N/A	293 ± 60	155 ± 62	213 ± 30	569 ± 59
8 North Steepbank River	30.6	ESE	102 ± 19	33 ± 86	131 ± 51	133 ± 16	79 ± 20	504 ± 61
7 Muskeg Mountain	39.4	ENE	107 ± 10	N/A	N/A	101 ± 28	104 ± 21	481 ± 43
2 Bitumount Tower	39.8	N	101 ± 10	30 ± 11	93 ± 13	149 ± 30	108 ± 20	382 ± 102
9 Gordon Lake	72.8	SE	133 ± 59	58 ± 20	73 ± 13	120 ± 18	220 ± 52	940 ± 103
1 Firebag River	74.0	NNE	56 ± 7	29 ± 8	92 ± 14	145 ± 66	111 ± 13	320 ± 46
10 Birch Mountain	80.0	NNW	220 ± 50	N/A	N/A	190 ± 112	246 ± 77	512 ± 64

Table 13. Total sulphur content (ppm) of soils in the Athabasca Oil Sands area (mean 95% confidence limits).

Sites	Distance & Direction from GCOS km		Sulphur Content of Soil LFH	Ah + Ahe	Ae	Bm	BC	C
12 Gradient Site A	2.8	SSW	634 ± 119	390 ± 54	25 ± 16	35 ± 35	-	87 ± 9
6 Fina Airstrip	4.0	ESE	370 ± 73	30 ± 24	-	35 ± 40	49 ± 31	62 ± 4
13 Gradient Site D	5.3	SSW	178 ± 14	162 ± 3	54 ± 28	44 ± 59	-	33 ± 30
5 Mildred Lake Camp	10.5	NW	481 ± 4	77 ± 28	-	66 ± 14	48 ± 20	4 ± 6
4 Fort MacKay	23.7	NNW	413 ± 66	11 ± 6	-	27 ± 19	-	51 ± 14
3 Hartley Creek	25.0	N	504 ± 60	254 ± 8	-	97 ± 14	-	63 ± 75
11 Thickwood Hills	30.0	SW	425 ± 51	142 ± 11	86 ± 20	112 ± 24	-	70 ± 69
8 North Steepbank River	30.6	ESE	592 ± 146	-	1 ± 2	-	-	10 ± 11
7 Muskeg Mountain	39.4	ENE	273 ± 39	0	-	0	-	13 ± 12
2 Bitumount Tower	39.8	N	233 ± 40	-	-	20 ± 28	-	48 ± 20
9 Gordon Lake	72.8	SE	274 ± 82	26 ± 1	5 ± 4	0	-	3 ± 5
1 Firebag River	74.0	NNE	447 ± 20	119 ± 22	-	53 ± 9	47 ± 71	3 ± 9
10 Birch Mountain	80.0	NNW	371 ± 82	-	9 ± 11	92 ± 17	31 ± 16	33 ± 48

Table 14. Total aluminum content (ppm) of soils in the Athabasca Oil Sands area. Values are averages of two replicates.

Sites	Distance & Direction from GCOS km		Aluminum Content of Soil LFH	Ah + Ahe	Ae	Bm	BC	C
12 Gradient Site A	2.8	SSW	7300	9431	8268	16364	-	11863
6 Fina Airstrip	4.0	ESE	8214	9582	-	11254	16544	13190
13 Gradient Site D	5.3	SSW	4714	6742	12805	18424	-	14271
5 Mildred Lake Camp	10.5	NW	6953	9584	-	17783	12219	6907
4 Fort MacKay	23.7	NNW	8814	15684	-	18133	-	17876
3 Hartley Creek	25.0	N	7777	11472	-	16728	-	14359
11 Thickwood Hills	30.0	SW	22106	23430	23982	35081	-	33671
8 North Steepbank River	30.6	ESE	10631	-	18910	-	-	21881
7 Muskeg Mountain	39.4	ENE	10107	14070	-	30054	-	16396
2 Bitumount Tower	39.8	N	8159	-	-	9695	-	12490
9 Gordon Lake	72.8	SE	5166	4483	4166	10068	-	7323
1 Firebag River	74.0	NNE	7126	9418	-	11362	12881	12434
10 Birch Mountain	80.0	NNW	14442	-	18451	29337	17817	14298

Table 15. Total iron content (ppm) of soils in the Athabasca Oil Sands area. Values are averages of two replicates.

Sites	Distance & Direction from GCOS km		Iron Content of Soil LFH	Ah + Ahe	Ae	Bm	BC	C
12 Gradient Site A	2.8	SSW	3718	3920	2935	12240	-	7999
6 Fina Airstrip	4.0	ESE	2537	2622	-	4703	6875	5689
13 Gradient Site D	5.3	SSW	1605	2003	2943	13186	-	5686
5 Mildred Lake Camp	10.5	NW	3262	5060	-	6129	6782	4503
4 Fort MacKay	23.7	NNW	4803	2589	-	7824	-	7805
3 Hartley Creek	25.0	N	2313	2947	-	5203	-	4419
11 Thickwood Hills	30.0	SW	7807	4641	3184	14600	-	15023
8 North Steepbank River	30.6	ESE	4375	-	5830	-	-	14843
7 Muskeg Mountain	39.4	ENE	3421	2226	-	13735	-	5783
2 Bitumount Tower	39.8	N	2640	-	-	3247	-	3487
9 Gordon Lake	72.8	SE	1994	1345	1666	4045	-	2973
1 Firebag River	74.0	NNE	2449	3236	-	4548	5113	4678
10 Birch Mountain	80.0	NNW	8286	-	5072	19595	9148	6942

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2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
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22.		Alberta Oil Sands Environmental Research Program Interim Report to 1978 covering the period April 1975 to November 1978
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