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INTERIM REPORT ON ECOLOGICAL BENCHMARKING AND BIOMONITORING FOR DETECTION OF AIR-BORNE POLLUTANT EFFECTS ON VEGETATION AND SOILS, 1975 to 1978

by

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for

ALBERTA OIL SANDS ENVIRONMENTAL
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ABSTRACT

A set of 11 sites were established in the Alberta Oil Sands Environmental Research Program study area to provide baseline information on vegetation and soils with respect to air pollution impact. Sites were strategically located for use in long-term biomonitoring and were described with respect to their vascular and cryptogamic species list, stand density and age, soil characteristics and type, and cover and frequency of lower strata species. No apparent impact was detectable that could be attributed to air pollution. Additional sites of a temporary nature were established for use in the development of biomonitoring techniques. Several of these techniques were sensitive enough to detect air pollution impingement in the vicinity of Great Canadian Oil Sands Ltd. operations.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

In the past, many studies have examined the impact of air pollution on vegetation or vegetational components, especially lichens. Although there have been hundreds of such studies (James 1973), almost all have dealt with areas severely degraded. In the Alberta Oil Sands Environmental Research Program (AOSERP) study area there appears to be very little obvious damage to the forest ecosystem in the vicinity of the Great Canadian Oil Sands (GCOS) operations that can be attributed to air pollution. Since there is a considerable potential of 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 aims of this project are to:

1. Establish an air pollution biomonitoring network within the forested region in the vicinity of the AOSERP study area;
2. Determine the influence of air pollution on jack pine plant communities in the AOSERP study area;
3. Examine the influence to date of air pollution on representative soils in the AOSERP study area.

No previous work has been done on the influence of air pollutants in the AOSERP study area and only the work of Blauel and Hocking (1974), Legge *et al.* (1976), Skorepa and Vitt (1976) and Baker (1977) bear any similarity to the present study. All four studies, however, differ substantially from the present in both geographical position and scope. This report describes the biomonitoring network established in the AOSERP study area and summarizes the present or baseline conditions of the vegetation and soils within that network. Results of studies to determine current impact of air pollutants on vegetation and soils within the biomonitoring network and in other selected sites are also described.

Biomonitoring is a technique whereby plants and animals 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 absorption and storage of air-borne pollutants. If the vegetation of an area can provide a reliable and consistent measure of both impact and impingement of a pollutant source, the expense of establishment and maintenance of high-technology monitoring instrumentation can be eliminated.

Because of the interim nature of this report, the statements made herein are subject to revision upon completion of the project and release of the final report.

2. STUDY AREA

2.1 BIOMONITORING SITES

Jack pine stands in 11 locations were chosen for permanent plots (Figure 1). This plant community was selected because it is one of the dominant vegetation types in the AOSERP study area. These locations were selected based upon winter pollutant deposition (Barrie and Whelpdale 1978), topography and distance from both the GCOS processing plant and the Syncrude Canada Ltd. project currently under construction. 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.

2.2 GRADIENT SITES

Five jack pine sites were located between 2.8 and 8.3 km in a southerly direction from the GCOS plant (Figure 3). They were within a sulphur deposition gradient determined from a snow analysis survey (Barrie and Whelpdale 1978).

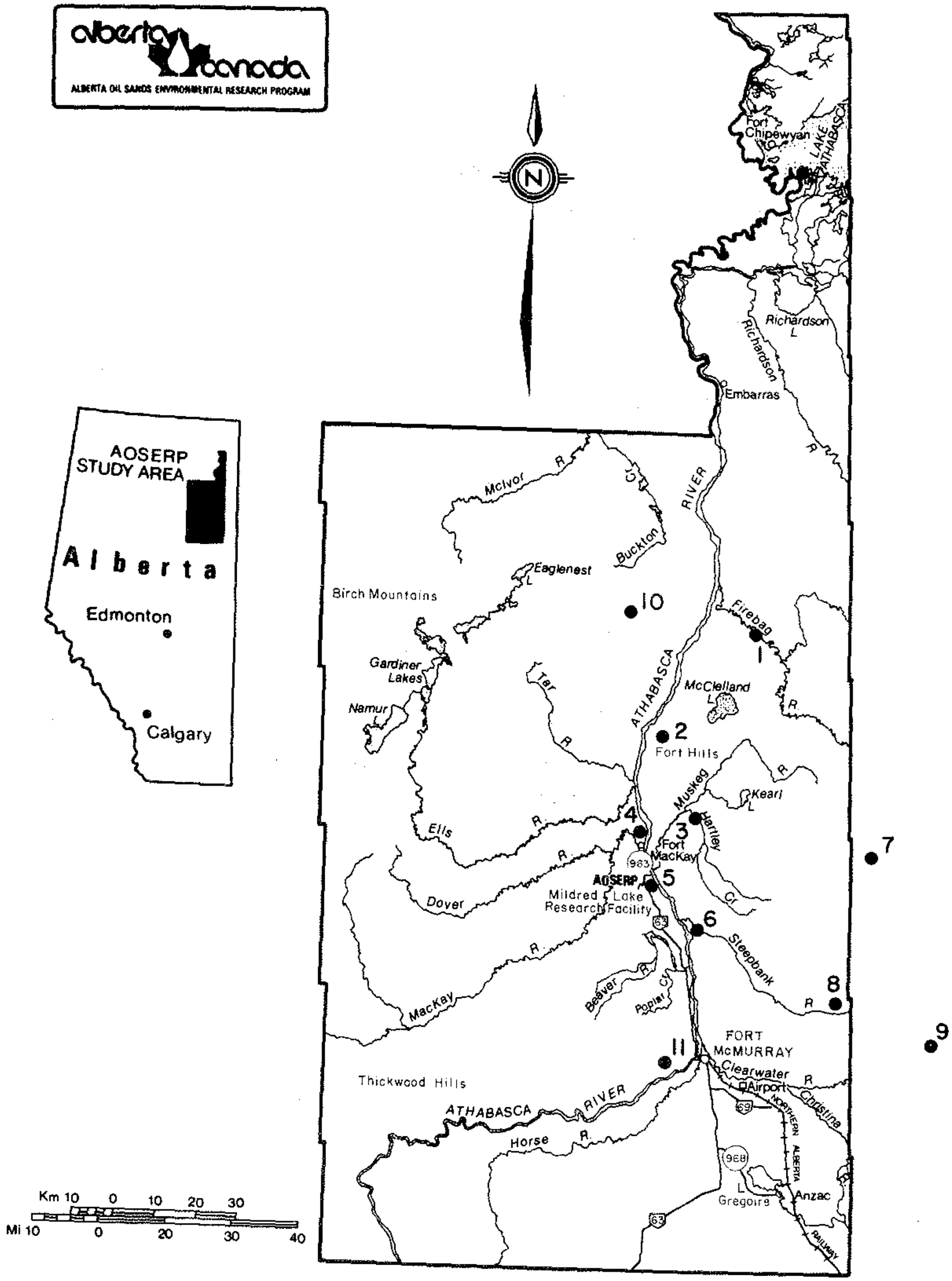

Figure 1. Location of permanent biomonitoring plots in the AOSERP study area. Sites are: (1) Firebag River, (2) Bitumount Tower, (3) Hartley Creek, (4) Fort MacKay, (5) AOSERP Mildred Lake Research Facility, (6) Fina Airstrip, (7) Muskeg Mountain Tower, (8) North Steepbank River, (9) Gordon Lake Tower, (10) Birch Mountain Tower, and (11) Thickwood Hills.

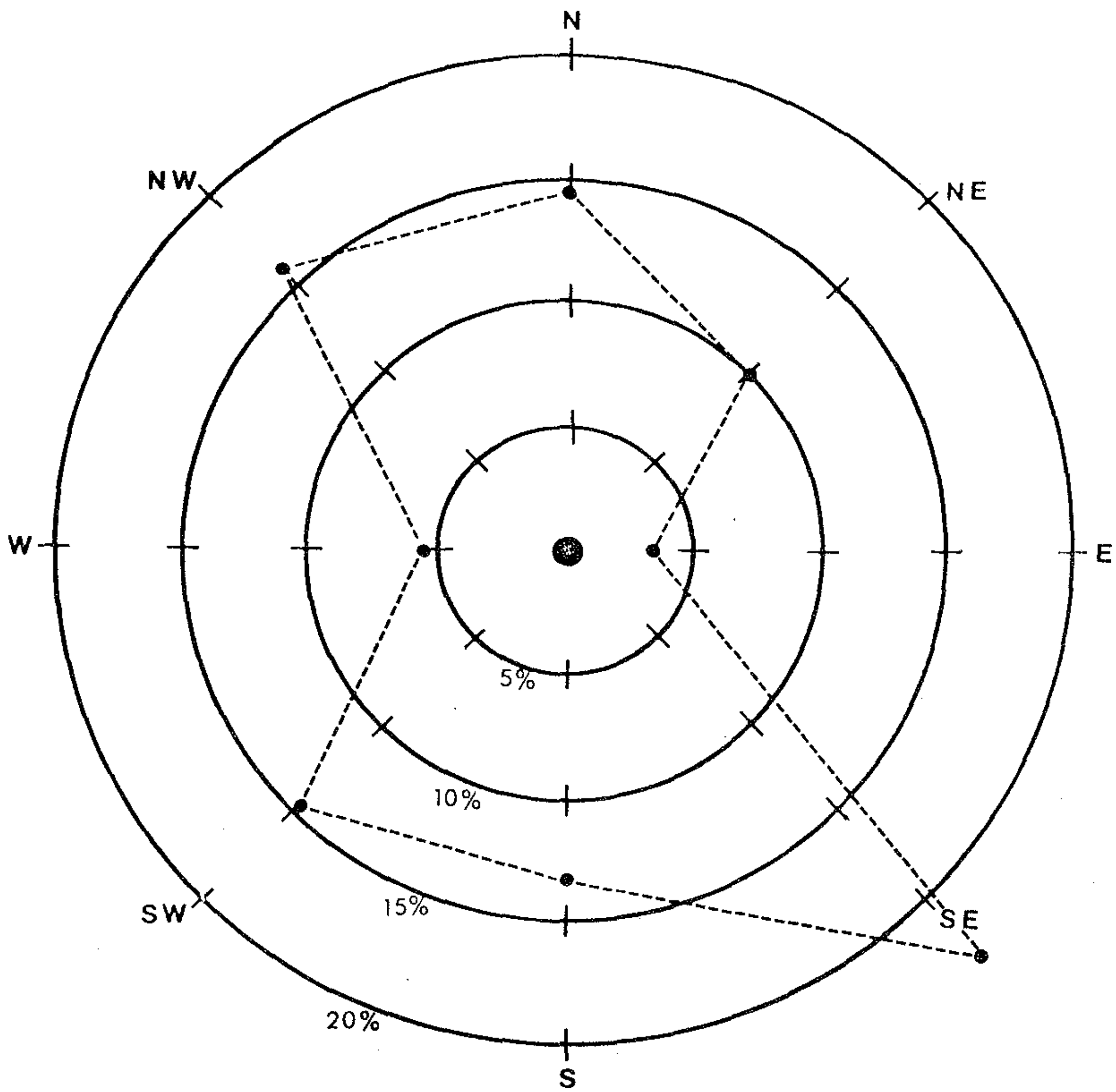

Figure 2. Wind rose of direction frequency for Mildred Lake (from Walmsley and Bagg 1977).

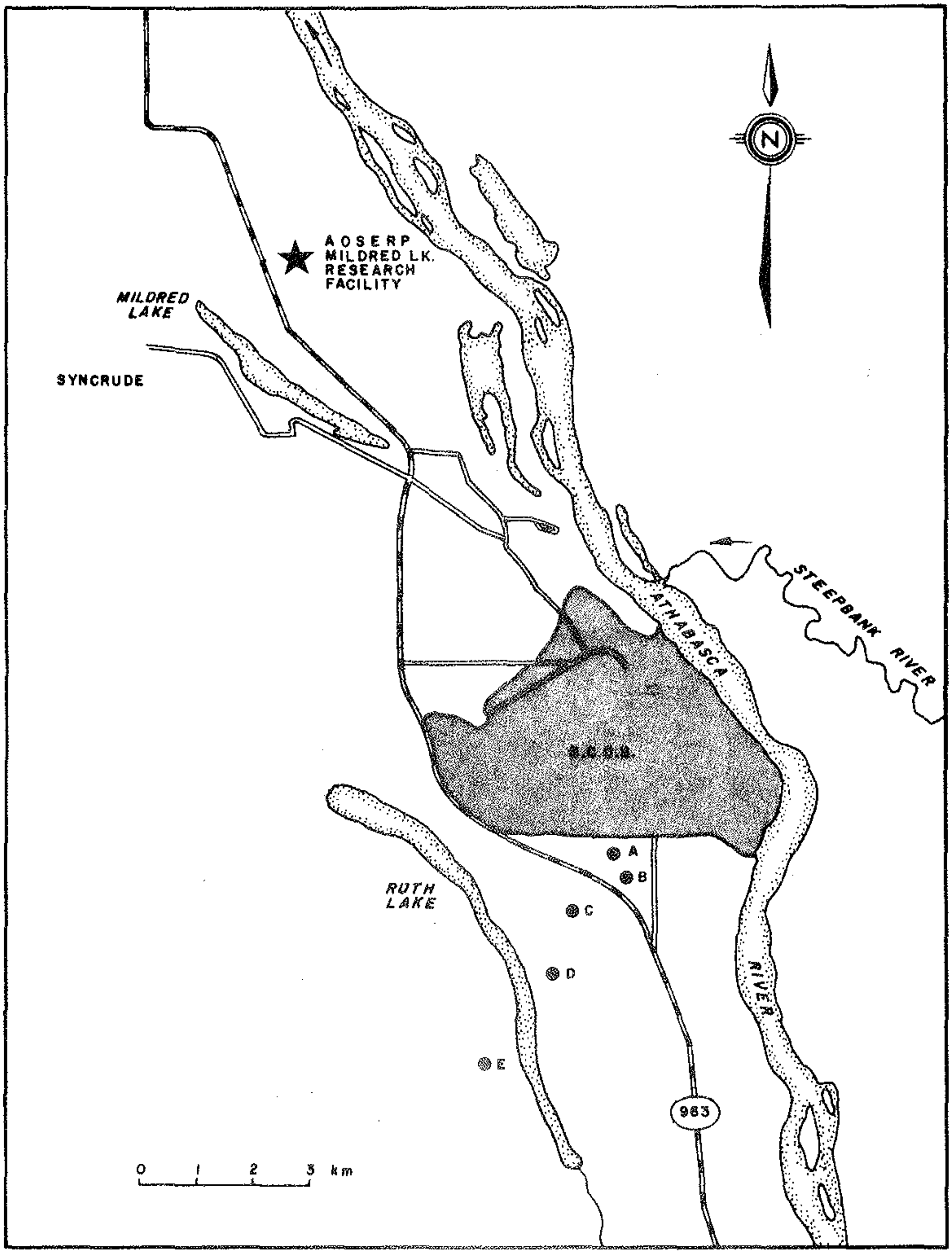

Figure 3. Location of gradient sites in the vicinity of Great Canadian Oil Sands (GCOS) operations.

3. MATERIALS AND METHODS

3.1 DESCRIPTION OF SITES

3.1.1 Vascular Plant Community

At all sites, a 20 x 20 m plot was established and vascular species lists, stand density and age, and cover and frequency of lower strata species were determined. Stand age was determined by boring 10 trees that appeared to be of average age. Cover and frequency were determined using a 1 x 1 m quadrat and sampling 5% of the total area. The size of quadrat was larger than the minimum sampling area required as defined by Cain and Castro (1959).

3.1.2 Branch Lichen Community

In the vicinity of each permanent plot, 10 spruce branches with a lichen stand of mainly fruticose and foliose types were selected. Quantification of the cover and frequency of the species groups present was accomplished using a 15 x 20 cm gray-card quadrat 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 gray-card quadrat below the branch. Lichens normally grow on the top and sides of branches and, hence, the entire stand was included in a photograph taken from directly above the branch.

Analysis of the photographs was done by projecting the transparency onto a 45 x 60 cm rear projection screen. The screen was divided into 100 units and presence of each lichen species or species group was recorded for each unit. A correction was made based on the average cover each species had in each unit.

3.1.3 Aerial Photography

Approximately 100 km of low level colour photography (1:2000) was flown at the end of July 1976 (Figure 4). At the same time

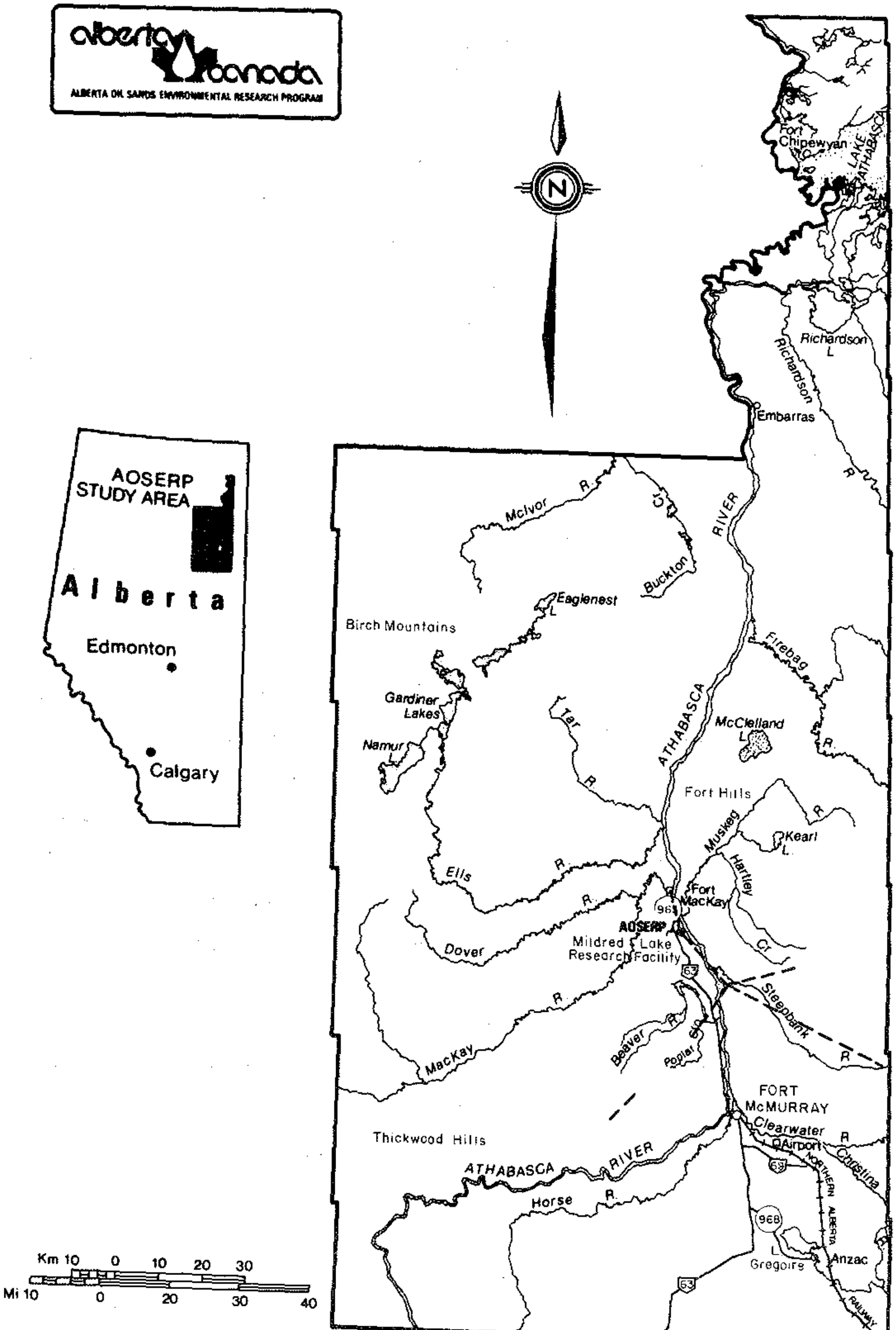

Figure 4. Flight lines of low level photography (1:2000) flown in 1976 in the AOSERP study area.

as the 100 x 1 km transect was flown, stereo pairs at 1:500 were taken every 2000 m. The aim of the aerial photography was to determine the stand condition of various communities in the area and to act as a baseline with which to compare future measurements of the same area.

3.1.4 Soil Description

A soil pit was dug 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 and texture by the hygrometer technique for sand, silt and clay fractions (Bouyoucos 1951).

3.1.5 Soil Chemical Analysis

Soil samples were collected from each horizon at each site. Both water and salt extractable fractions were analyzed for Ca, Fe, Al, Na, K, S, and P. The methods are described in detail by Baker (1977).

3.2 BIOMONITORING

3.2.1 Chemical Composition of Indicator 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 scheberi* (Brid.) Mitt.). These 6 species were selected because they demonstrated the greatest uptake of S close to the pollution source and represented both dry and moist microenvironments. Five replicates were collected for each species. Sulphur content was determined by oxygen flask combustion (Chan 1975) followed by a modified Johnson-Nishita method (Carson *et al.* 1972). Aluminum and iron content was determined on the combusted samples using atomic absorption spectrophotometry.

3.2.2 Lichen Community Description

Branch lichen plots described above, were also expected to yield a measure of atmospheric purity as a result of the proven sensitivity of lichens to air pollution (Rao and Le Blanc 1965; Puckett *et al.* 1974; Nash 1976). It is expected that it will be possible to correlate changes in species composition and cover of branch lichens with sulphur dioxide concentrations as determined by both the network of SO_2 monitors and of lead candles in the area.

3.2.3 Lichen Transplants

3.2.3.1 Initial test. A branch lichen transplant study was initiated in 1976. Branches of black spruce were collected at Fort MacKay and relocated in five microsites at each of 4 locations at varying distances from the GCOS processing plant (Figure 5). Two branches were placed in a clearing and under jack pine, white spruce, black spruce and aspen at a height of 1.5 m. Composition and cover of each species or species group was determined for each branch as described above. Ten percent of the transplants were damaged or destroyed in the first year and the rest of them were photographed again in the summer of 1977.

3.2.3.2 Gradient site transplants. Two types of lichen transplants were established at each of the gradient sites to the south of GCOS. Black spruce branches with a full lichen community were installed under spruce and these transplants were quantified in the same manner as described above. Ten branches were installed at each site. Pine branches bearing mainly *Evernia mesomorpha* Nyl. were placed under jack pine trees. Six replicates were used at each site and material was collected from these transplants, brought into the laboratory and analyzed for total sulphur and available

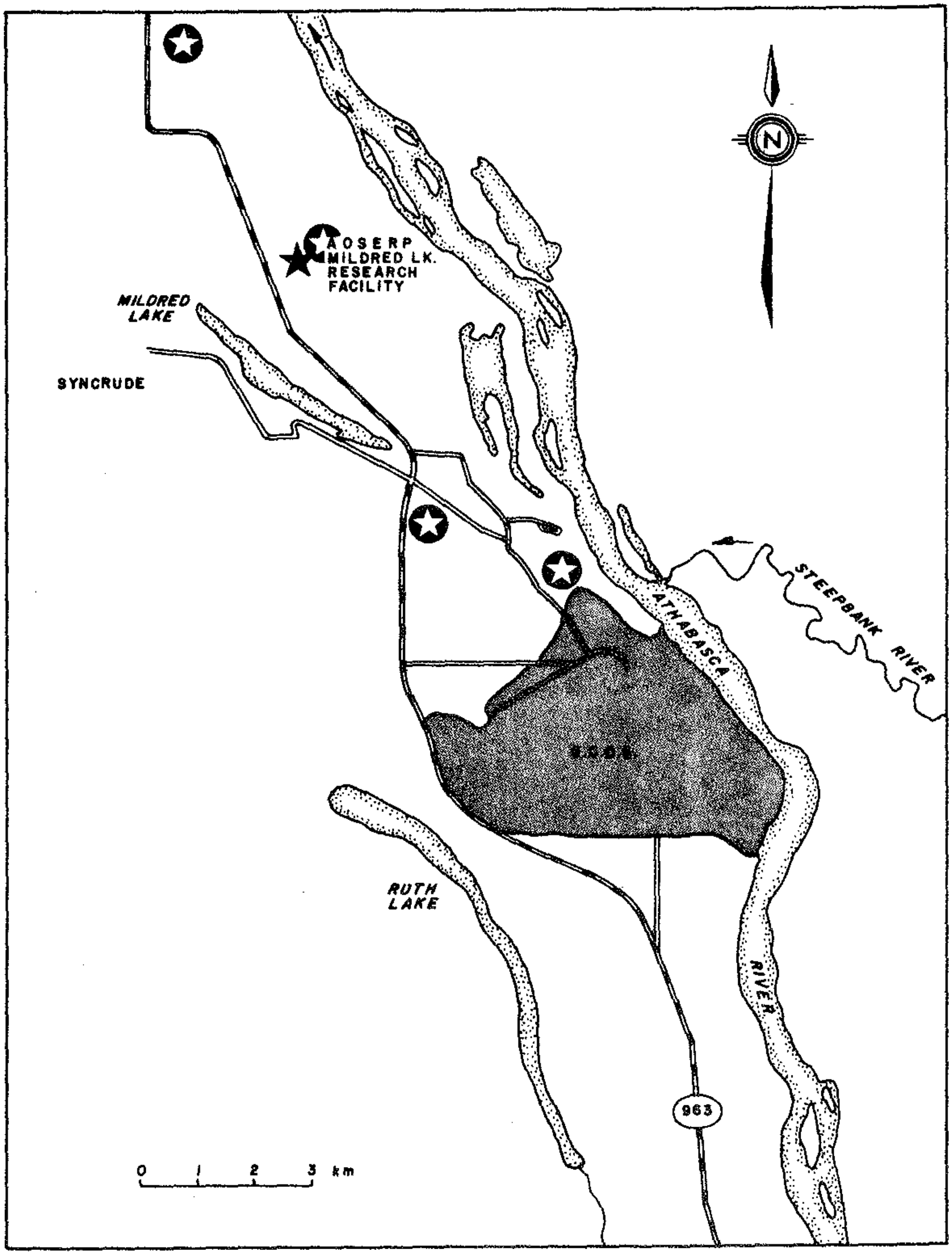

Figure 5. Location of sites in the AOSERP study area where initial lichen transplants were installed.

and total K^+ and Mg^{++} and chlorophyll/phaeophytin ratios. Available K^+ and Mg^{++} was extracted by gently shaking the lichens (*Evernia*) for 3 h in distilled water. Total K^+ and Mg^{++} was extracted by oxygen flask combustion method. Analysis for K^+ and Mg^{++} were done by atomic absorption spectrophotometry. Chlorophyll and phaeophytin contents were determined spectrophotometrically on an 80% acetone extract (White *et al.* 1969).

3.2.4 Lichen Survey

Samples of *Evernia mesomorpha* and *Hypogymnia physodes* (L.) W. Wats. were collected from 41 sites in the vicinity of GCOS operations (Figure 6). These two species were selected as they are the two most common corticolous lichens in the area and represent two distinct growth forms. At all sites, samples were collected from the most luxurient stands and a scale from 1 (degraded) to 5 (healthy) was used to indicate sample condition. The same samples were analyzed for S, V, Ti, Al and K both to define emission deposition and to determine whether a link could be made between chemical composition and physical condition of the thallus.

3.2.5 Vascular Plant Biochemistry and Physiology

On several occasions during the summer of 1977, samples of both jack pine and white spruce branches were collected in the field and transported to the laboratory for biochemical and physiological investigation. The tissue was examined for phosphatase and malate dehydrogenase activities, chlorophyll/phaeophytin ratio, total sulphur content, net photosynthesis and respiration. Details of the methods used in this investigation appear in Malhotra (in prep.).

3.2.6 Physical Pollutant Trapping

In order to compare biological response with air pollutant concentration, physical collection of these pollutants was necessary. Four precipitation collectors and 6 sulphation plates

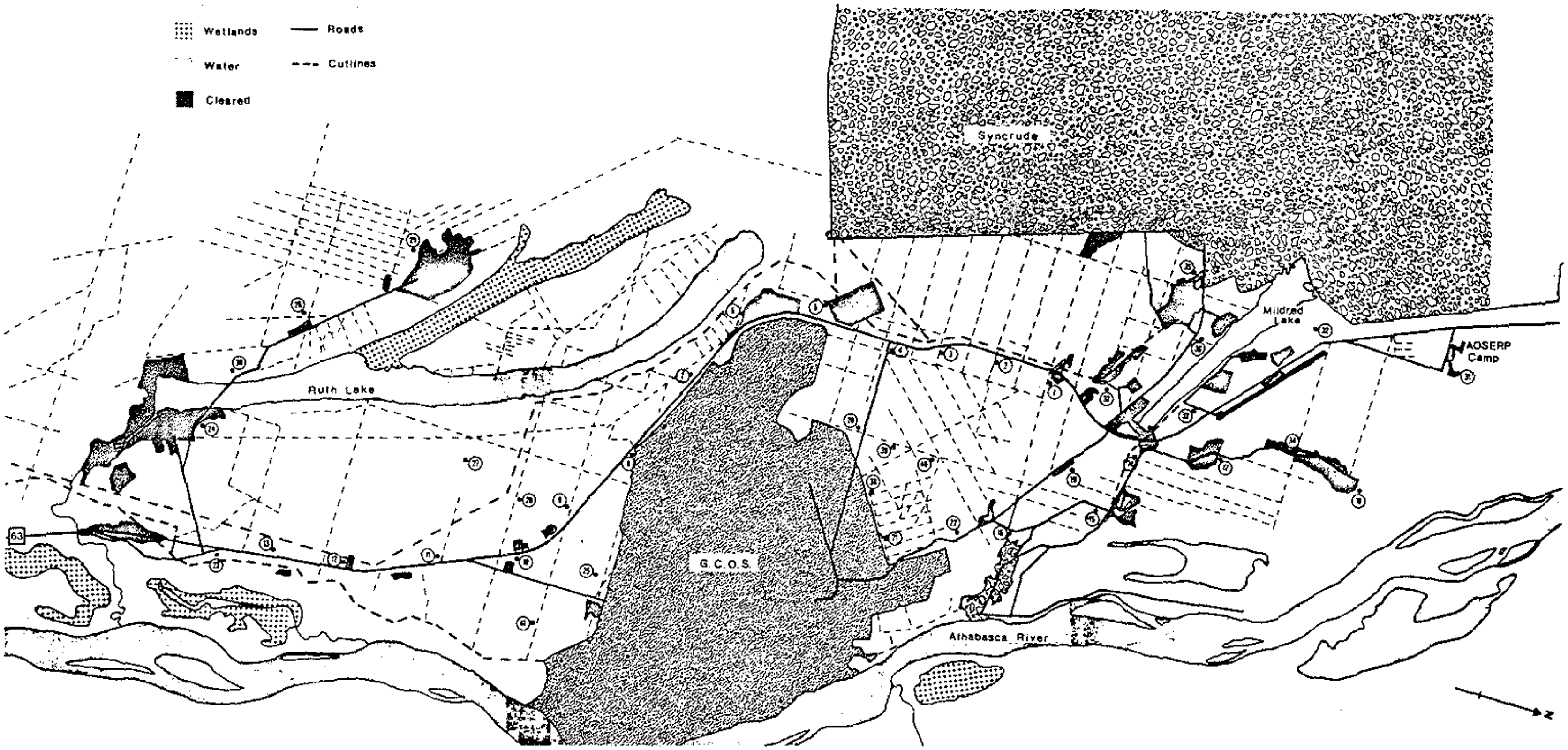

Figure 6. Detailed map of the area around Great Canadian Oil Sands (GCOS) and Syncrude Canada Ltd. showing collection location of the lichen survey.

(Huey Plates, 10 cm diam.) were installed at each site. Precipitation collectors were placed in natural clearings. Sulphation plates, on the other hand, were placed in duplicate at 1.5 m height in three different microenvironments (under pine, under spruce and in the open).

3.2.7 Plant and Soil Nutrient Analysis

At gradient sites A and D (Figure 3) soil pits were dug at the base of several jack pine trees. Four samples were collected from LFH, upper and lower Ae, upper and lower Bm and C horizons. Samples were stored in field moist conditions at 0°C before extraction according to Baker (1977). Extracts were analyzed for S, P, Ca, Mg, K, Al, Fe and Mn. Foliar material from the trees around the soil pit was collected and analyzed for the same elements as the soils.

4. RESULTS AND DISCUSSION

4.1 DESCRIPTION OF SITES

Description of the biomonitoring sites is critical to long-term monitoring of the AOSERP study area for the detection of air pollution impact on vegetation and soils. This report provides baseline data with which to compare similar descriptions proposed for 1979-80 and the more distant future. Description at 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, are also described in detail. Low-level aerial photography provides a baseline overview for tree crown impact by air pollutants in the vicinity of GCOS.

4.1.1 Vascular Plant Community

The jack pine stands, selected as monitor sites, were variable both in species composition and cover of the lower stratum of the plant community (Table 1). The stand order was determined by constructing as association table based on the average of plant cover and frequency. No distinct pattern was evident in the community descriptions and since these sites varied greatly in distance from the oil sands operations, the community structure and composition provided no evidence that there was any environmental change owing to the operation of the GCOS processing plant.

The stands appear to break into four groups based mainly on herb composition. Firebag River, Mildred AOSERP, Hartley Creek, and Fina Airstrip (# 1, 5, 3 and 6 respectively) all had several species in common that rarely occurred at other sites (e.g. *Campanula rotundifolia*, *Solidaga decumbens*, *Anemone multifida* and *Potentilla tridentata*). These sites appeared to be drier and more exposed than other stands and had the lowest stand densities (150-300 stems ha^{-1}; < 10 cm DBH). Bitumont Tower (#2) appeared to be transitional in species composition and cover, as

Table 1. Frequency-cover index of lower strata plant species at biomonitoring sites in the AOSERP study area.

	Species	Site Number										
		1	5	3	6	2	4	8	9	11	7	10
Trees	Larix laricina						2.5					
	Picea glauca					2.5		13.4				
	Picea mariana									42.1	2.5	12.2
	Pinus banksiana	2.5		22.7	5.1			5.1		7.6		
	Populus tremuloides	23.6		25.9	23.4	5.1	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		30.2		11.8				3.2	2.5	4.3	
	Betula occidentalis								10.2			
	Amelanchier alnifolia	22.9	5.1	43.6	23.5	10.1	5.2					
	Prunus pensylvanica	23.2	20.4	2.5								
	Prunus virginiana					10.2			5.1			
	Rosa acicularia		5.3	15.2	7.6						5.5	
	Rosa woodsii					43.2	20.3					
	Ledum groenlandicum					38.5	19.0			10.3	30.8	46.6
	Vaccinium myrtilloides	51.7	52.2	18.4	55.7	46.1	36.7	52.5	53.9	51.5	60.1	47.3
	Lonicera dioica				2.5							
	Viburnum edule								2.6			
Ground Shrubs	Arctostaphylois uva-ursi	31.6	61.2	54.3	64.5	44.5	11.5			8.2		
	Vaccinium vitis-idaea var. minus	31.7	51.5	42.6	41.3	58.4	57.6	63.1	55.8	22.8	28.3	55.2
	Linnaea borealis var. americana	2.6	20.2		7.6	5.2	35.6	20.5	46.6	5.1	5.4	
Herbs & Grasses	Elymus innovatus			5.1	32.9	17.7	40.6	32.7	47.9			
	Unidentified grass	47.9	50.5	50.4	50.4	20.1		7.6	15.1	22.6		
	Carex sp.	27.7			26.6	7.6						
	Lilium philadelphicum var. andinum											
	Maianthemum canadense var interius	22.7	50.7	50.3	40.4	47.9	10.1	25.2	50.6			
	Goodyera repens						2.5		7.6			
	Comandra pallida		47.8	22.4	27.7	22.6						
	Geocaulon lividum						5.1					
	Anemone multifida	7.6	5.0	12.6	2.5	2.5						
	Fragaria virginiana	7.6			7.6					2.5		
	Potentilla tridentata	2.5	22.7	12.6	37.9			2.5				
	Lathyrus ochroleucus							2.5				
	Viola nephrophila				10.1					2.5		
	Epilobium angustifolium						2.5	2.5	30.7		2.5	
	Aralia nudicaulis		2.5			15.2			25.4			
	Cornus canadensis						7.6	51.2	55.7	49.4	47.9	
	Pyrola secunda						2.5		10.1			
	Trientalis borealis				2.5				35.3			
	Apocynum androsaemifolumi	5.2	2.6			2.5						
	Melampyrum lineare	-										
	Galium boreale	7.6		2.5								
	Companula rotundifolia	7.6	10.1	17.6	7.6	5.1						
	Achillea millefolium			5.1	5.1							
	Artemisia biennis	10.1			10.1							
	Aster ciliolatus	20.2		40.4	2.5	5.1						
	Solidago decumbens	20.1	2.5	27.7	12.6	2.5						
Pteridophytes	Equisetum arvense						2.6			42.7		
	Lycopodium complanatum		42.0	12.8		20.9				7.6		
	Lycopodium obscurum								2.6			
Total	Vasculars	21.7	49.0	33.9	64.7	46.0	32.7	47.6	41.3	20.1	34.9	28.5
	Lichens	46.5	31.3	68.0	26.2	26.8	23.1	46.0	17.4	15.1	31.1	33.9
	Mosses	9.3	4.5	1.9	3.8	14.5	18.5	5.4	24.1	24.7	1.0	23.8
	Litter	38.0	25.1	28.3	65.5	55.5	48.1	48.5	49.8	60.2	66.2	41.0

well as in moisture status. The stand density (Table 2) was unusually high (2600 stems ha^{-1}) but, because the trees were clumped, the site was divided almost equally into moist and dry sections. The dry section appeared to be very similar to the first group described above. The moist section of Bitumount Tower was similar to Fort MacKay (#4), North Steepbank (#8), and Gordon Lake (#9) stands. These sites were more moist than the first group at least partially as a result of a higher stand density (575-1175 stems ha^{-1}; Table 2). These sites had several mesic plant species present (e.g. *Epilobium angustifolium* and *Aralia nudicaulis*). Sites such as Muskeg Mountain, Birch Mountain and Thickwood Hills represent the most hydric group of jack pine stands. They tend to grade into black spruce stands and, in fact, are 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) so that there would be less drying by wind. There was, however, some overlap in stand density with the Fort MacKay-North Steepbank-Gordon Lake group. This overlap is 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 DBH because of the recent fire history. Although these stems were not included in stand density estimates, they have an effect on wind speed and drying of the site.

4.1.2 Branch Lichen Community

Lichen community analysis also did not indicate any trend that could be attributed to air pollution injury (Table 3). It appears that most of the sites examined were outside of the air pollution impingement zone (0.03 mg S l^{-1}; Barrie and Whelpdale 1978) and even within this zone, damage could not be correlated with distance from GCOS alone. At present, the roles of topography and direction from GCOS are being considered but data are not yet available.

Table 2. Jack pine stand density of biomonitoring sites in the AOSERP study area.

Site No.	Site	Density (stems >10 cm DBH/ha)
1	Firebag River	300
2	Bitumount Tower	2600[a]
3	Hartley Creek	150
4	Fort MacKay	575
5	Mildred AOSERP	175
6	Fina Airstrip	175
7	Muskeg Mountain	6500
8	North Steepbank	825
9	Gordon Lake	1175
10	Birch Mountain	875
11	Thickwood Hills	1625

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

Table 3. Cover (%C) and frequency (%F) of lichen species groups at various sites in the AOSERP study area. Values are based on 9-12 quadrats per site.

Site No.	Site	Distance and Direction from GCOS (km)		Lichen Communities: Usnea-Evernia-Ramalina[a]		Parmelia-Hypogymnia		Alectoria		Cetraria	
				%C	%F	%C	%F	%C	%F	%C	%F
1	Firebag River	74.0	NNE	11.9	80	3.9	100	0.7	90	4.1	70
9	Gordon Lake	72.8	SE	9.2	97	5.5	100	0.8	100	1.5	85
8	North Steepbank	30.6	SE	14.4	100	1.3	95	1.0	100	3.1	55
3	Hartley Creek	25.7	N	0.8	87	8.8	60	0	10	0.5	50
4	Fort MacKay	23.7	NNW	13.6	93	4.9	100	0.6	90	0.7	60
5	Mildred AOSERP	10.5	NW	19.5	85	10.5	100	2.6	100	0.5	100
6	Fina Airstrip	4.0	ESE	1.6	67	7.4	100	0.3	89	3.2	84

[a] Note: Frequency is an average of the frequencies of the species in each group.

It is expected that the lichen community analysis will provide a useful tool with which to detect future air pollution injury to the forest ecosystem. Birch Mountain and Thickwood Hills have not been included in Table 3 because analyses have not been completed. A superficial examination of the photographs, however, indicated that the lichen communities were comparable with those from other sites at greater distances from the pollution source. Birch Mountain site was similar to North Steepbank whereas Thickwood Hills resembled Gordon Lake in both cover and frequency of lichens.

4.1.3 Aerial Photography

Aerial photography was "ground-truthed" both at each of the permanent sites and at selected locations where various plant communities were present. 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 in 5 years or if crown damage is detected before that time. There was no apparent injury to the crowns of any plant community in the vicinity of GCOS.

4.1.4 Soil Description

The soils underlying jack pine stands were quite similar with respect to soil type, texture and horizons present. All soils were Dystric Brunisols with one exception at Bitumount Tower where the thickness of the A horizon placed the soil in the Sombric Brunisol Great Group (Canadain Soil Survey Committee 1974). In all cases, the soils were acidic (pH >6.0 in water) and were coarse-textured (sandy loams to sands). The soil description served as background for both vegetation and soil chemical studies. Consistency of soil type, texture and pH indicated that similar pedogenic processes were active at all sites.

4.1.5 Soil Chemical Analysis

Soil analyses showed little correlation with either the soil type (Canadian Soil Survey Committee 1974) or with distance from the pollution source (Table 4). In all samples, sulphur content (water- and salt-extractable) was low and there was no indication that there had been any deposition by the processing plant (GCOS). Natural variability was the reason why it was impossible to detect soil modifications. It is expected that proposed studies over time will determine the impact of air pollution on soils since these studies are independent of natural variability. The addition of several sites closer to the plant will also aid in assessing the influence of air-borne pollutants.

There were higher concentrations of all ions in the LFH layer than in the mineral soil. Presumably this was a result of nutrient cycling maintaining high near-surface concentrations of elements essential for plant growth. Interpretation of the results on a horizon basis has yet to be attempted since total ion concentrations are not available.

4.2 BIOMONITORING

Many biomonitoring techniques were developed and tested in an air pollution impingement zone close to GCOS. These techniques ranged from purely monitoring dispersion and depositon of pollutants by analyzing the chemical composition of plants, to detailed studies on the influence of air pollutants on biochemistry and physiology of vascular plants. Lichen studies provided an important intermediate as they appear to be more sensitive to long-term, low-level air pollution fumigations as found in the AOSERP study area.

4.2.1 Chemical Composition of Indicator Species

4.2.1.1 Biomonitoring sites. Sulphur content of three tree species (Table 5) appeared to show a trend with distances from the GCOS processing plant. This relationship, however, was not significant (Product-moment correlation coefficient; Sokal and Rohlf 1969; $P < 0.05$) and, hence, present analyses did not provide conclusive

Table 4. Available concentrations of selected cations and anions from soils in the AOSERP study area. All values are in ppm.

Site No.	Site	Distance from GCOS (km)	Soil Type	pH in Water	Available Concentration (ppm) Ca	Mg	Fe	Al	Na	K	S	P
1	Firebag River	74.0	Orthic Dystric Brunisol	6.0	2856	147	1.3	2.5	4.7	133	2.7	9.1
9	Gordon Lake	72.8	Degraded Dystric Brunisol	4.9	1146	46	1.5	20.1	20.7	109	4.3	10.6
2	Bitumount Tower	39.8	Orthic Sombric Brunisol	5.1	673	34	3.1	21.6	9.7	93	4.9	4.5
7	Muskeg Mountain	39.4	Orthic Dystric Brunisol	5.0	722	42	4.0	91.0	9.5	86	5.6	3.7
8	North Steepbank	30.6	Gleyed Degraded Dystric Brunisol	5.3	1884	130	4.8	40.0	33.8	205	13.3	12.2
3	Hartley Creek	25.7	Degraded Dystric Brunisol	5.8	2362	138	1.8	8.0	4.1	126	8.8	2.0
4	Fort MacKay	23.7	Degraded Dystric Brunisol	5.4	1828	188	6.9	19.8	3.7	376	16.1	24.2
5	Mildred AOSERP	10.5	Degraded Dystric Brunisol	6.0	679	94	1.1	10.2	2.4	75	9.4	2.6
6	Fina Airstrip	4.0	Degraded Dystric Brunisol	5.7	2345	92	1.3	13.5	8.9	140	1.6	5.5

Table 5. Total sulphur content of leaf tissue from three species in the AOSERP study area. All values are mean ± 95% confidence limits.

Site No.	Site	Distance and Direction from GCOS (km)		Sulphur content (ppm) *Pinus banksiana*	*Picea glauca*	*Populus tremuloides*
1	Firebag River	74.0	NNE	979 ± 87	589 ± 27	1875 ± 128
9	Gordon Lake	72.8	SE	1175 ± 122	548 ± 28	1990 ± 131
2	Bitumount Tower	39.8	N	806 ± 47	768 ± 46	2238 ± 95
7	Muskeg Mountain	39.4	ENE	737 ± 31	N/S	2252 ± 176
8	North Steepbank	30.6	SE	369 ± 55	676 ± 34	1933 ± 326
3	Hartley Creek	25.7	N	656 ± 51	571 ± 33	1505 ± 90
4	Fort MacKay	23.7	NNW	799 ± 57	663 ± 93	1650 ± 47
5	Mildred AOSERP	10.5	NW	862 ± 45	854 ± 38	2102 ± 110
6	Fina Airstrip	4.0	ESE	809 ± 77	895 ± 124	2212 ± 251
13	GCOS	2.2	NNW	1200 ± 91	1001 ± 252	2352 ± 187

evidence of impingement of air pollution in the oil sands area. Regardless of whether or not a trend was observed, the S content of tissue from these sites will be used as baseline data with which to compare similar analyses in the future. In this manner, the rate of air pollution uptake by selected plants can be determined.

4.2.1.2 Gradient sites. Chemical analysis of selected plant species at the gradient sites showed a substantial increase in S content as one approached the pollution source (Table 6). Labrador tea and feathermoss had the highest S levels at all sites but the difference in S between sites A and E were similar for all species. Since there were substantial differences in S concentration between species at each site, no direct comparison could be made. Regressions were constructed for the S concentration of each species versus distance from the pollution source and the Y intercept in each case was considered as maximum S content (100%). Regression coefficients were determined for relative S contents versus distance and this gave a measure of the rate of decline of S concentration. Similar values were calculated for Huey plates and for branch lichen S content (Table 7).

Understory plant species in dry locations had a much greater increase in S with decreasing distance from the processing plant than did those species from moist locations. It is suggested that this may be related to the difference in stand density and the lushness of the lower strata vegetation. The dry sites were far more open than the moist ones and, hence, the pollutant could readily enter the stand and fumigate the ground vegetation. White spruce from moist sites, on the other hand, had a greater rate of increase in S content than jack pine. In this case, both samples were collected well up the tree where SO_2 could easily impinge on the tissue. It is felt that such differences may be related to resistance to entry of the gas. Experiments are currently in progress that will permit interpretation of these results.

Table 6. Sulphur content (ppm; mean ±95% confidence limits) of selected plant species at gradient sites in the AOSERP study area.

Site	Distance from GCOS (km)	Dry Phase			Moist Phase		
		Jack pine	Bear-berry	Ground lichens	White spruce	Labrador tea	Feather-moss
A	2.8	1002 ± 48	796 ± 71	629 ± 38	918 ± 81	1409 ± 92	1289 ± 49
B	3.4	940 ± 60	601 ± 34	439 ± 51	718 ± 41	1288 ± 64	1434 ± 54
C	4.2	964 ± 28	677 ± 28	545 ± 27	735 ± 37	1146 ± 86	1419 ± 89
D	5.3	828 ± 30	559 ± 23	284 ± 25	691 ±101	1180 ± 78	1195 ±230
E	8.3	723 ± 40	423 ± 76	313 ± 74	496 ± 31	1054 ± 98	928 ± 89

Table 7. Regression coefficients of relative sulphur content versus distance from pollution source for selected plant species and Huey Plates.

Material	Microsite		Regression Coefficient
	Type	Location	
Jack Pine	Dry	Canopy	-4.5
Bearberry	Dry	Ground	-6.5
Ground Lichens	Dry	Ground	-7.4
White Spruce	Moist	Canopy	-6.3
Labrador Tea	Moist	Ground	-3.7
Feathermoss	Moist	Ground	-5.1
Huey Plates	Both	1.5 m	-8.2
Branch Lichens	Dry	1.5 m	-9.6

In general, the rate of S uptake appears to be related mainly to the exposure of the target. Branch lichens have the highest rate of S uptake presumably because of (1) their very high surface area to volume (mass) ratio and (2) the location of the lichens on the outside of the canopy where they are readily exposed to gaseous pollutants. Huey plates were intermediate in S level between ground physical traps (lichens and mosses) and branch lichens because their position gave them better exposure than the ground traps but their surface area was much less than the branch lichens.

4.2.2 Lichen Community Description

As shown above (4.1.2) there was no apparent effect of GCOS emissions on lichen communities at the biomonitoring sites. The descriptions are important, however, as baseline information with which to compare future descriptions of these sites.

4.2.3 Lichen Transplants

4.2.3.1 Initial test. Table 8 indicates that although changes occur in cover of lichen species over a one year period, the pattern of change is somewhat complex. All fruticose lichens declined in cover with time whereas foliose lichens actually increased over the same period. The magnitude and direction of change is shown in Table 9. *Alectoria* had a greater decline in cover with time close to GCOS than at Fort MacKay but this pattern was not observed for other fruticose lichens (*Usnea-Evernia*). *Alectoria glabra* is the most sensitive lichen species in coniferous forests in Alberta (Skorepa and Vitt 1976) and was expected to be the first species to decline. *Parmelia-Hypogymnia* lichen group increased in cover more at GCOS than at Fort MacKay. Whether this is an artifact or a result of these more resistant species replacing more sensitive ones, is not known at this time. In all cases, the magnitude of change was not great enough to place very much confidence in the results but it is felt that some of these initial

Table 8. Cover of major branch lichen species groups on lichen community transplants.

Site	Distance (km)	Year	Percent Cover *Usnea-Evernia*	*Alectoria*	*Parmelia-Hypogymnia*	*Cetraria*
Fort MacKay	24	1976	75	8	41	8
		1977	69	7	42	13
Mildred	11	1976	84	11	40	1
		1977	73	7	38	2
Syncrude	5	1976	74	13	39	1
		1977	70	8	39	1
GCOS	2	1976	64	14	20	2
		1977	55	3	31	3

Table 9. Decline of cover of species groups on lichen transplants from 1976 to 1977.

Site	*Usnea-Evernia*	*Alectoria*	*Parmelia-Hypogymnia*	*Cetraria*
Fort MacKay	6	1	-1	-5
Mildred	11	4	2	-1
Syncrude	4	5	0	0
GCOS	9	9	-11	-1

changes may be air pollution induced. Further investigation in 1978 and 1979 will help to clarify this aspect.

4.2.3.2 Gradient site transplants. Lichen community transplants showed no apparent change during the first 4 months of exposure. Similarly, there was no measurable change in the physiology of *Evernia* transplants under pine. It appears that the time required for changes to occur is somewhat longer than just the summer season. Further work is planned in this area during 1978.

4.2.4 Lichen Survey

The lichen survey designed to demonstrate that lichens could be used to delineate pollutant impingement areas and assess the impact of pollutants, was only partially completed during the summer of 1977. Preliminary examination of the results indicated that there was a correlation between the S content of the air as measured by GCOS using lead candles and S concentration in branch lichen thalli. There was also a noticeable similarity between the pattern of S concentration in the tissue (Figure 7) and a qualitative estimate of lichen degradation (Figure 8). In general, all three measurements showed the same pattern with highest levels of S close to GCOS and the following the topography along the Athabasca River valley. Metal analysis of most of the samples has been completed but results have not been fully interpreted. Currently, results are being statistically analyzed and the number of sites is being increased to help delimit the pattern in specific areas.

4.2.5 Vascular Plant Biochemistry and Physiology

Results from biochemical and physiological analyses of jack pine and white spruce material from the vicinity of GCOS are presented by Malhotra (in prep.). Although S content in foliage at Site A was higher than in control areas, there were, in general, no measurable biochemical or physiological responses that could be attributed to air pollution, characteristic of oil sands operations.

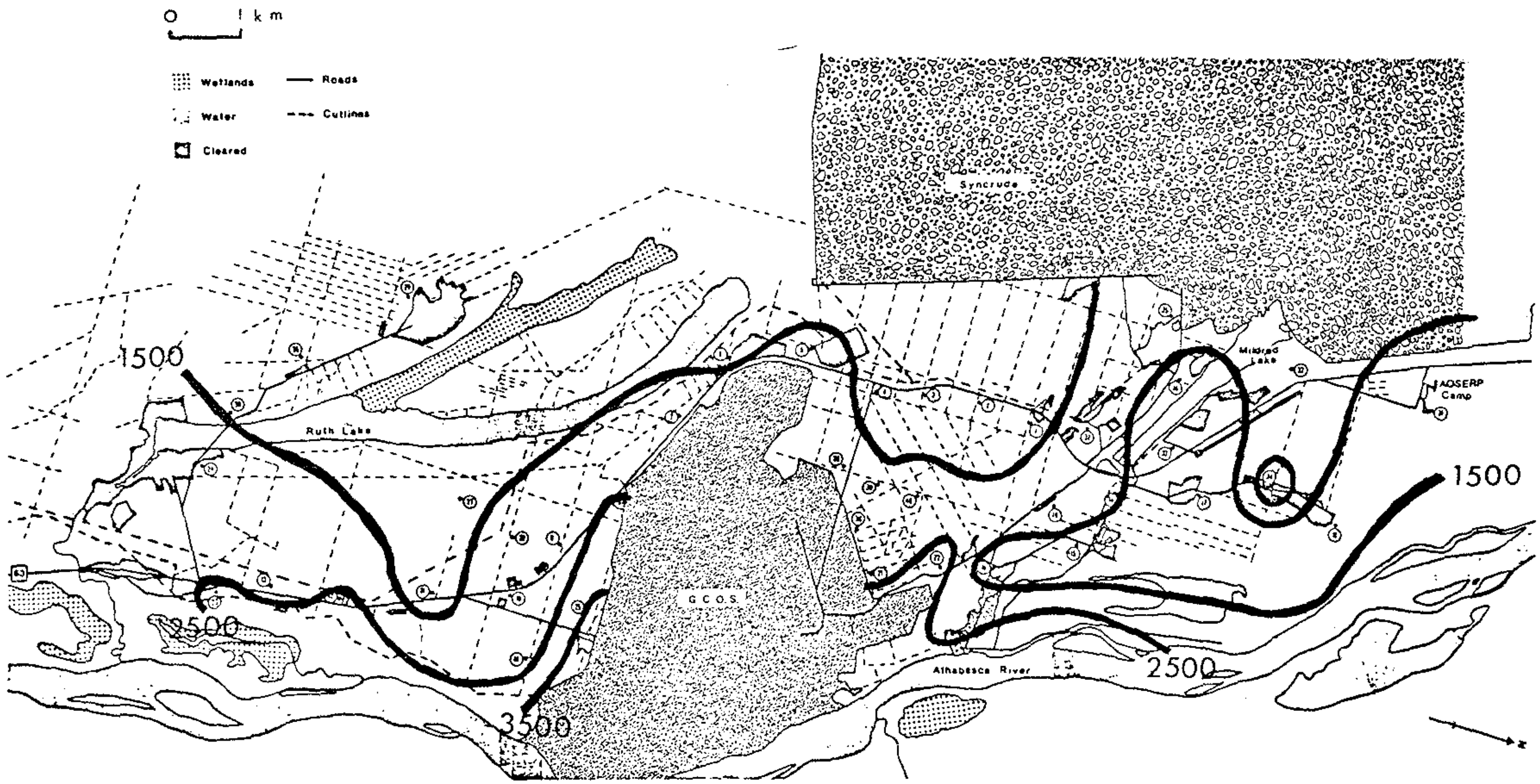

Figure 7. Sulphur content in *Evernia mesomorpha* in the vicinity of Great Canadian Oil Sands (GCOS). Isopleths follow 1500, 2500 and 3500 ppm in tissue.

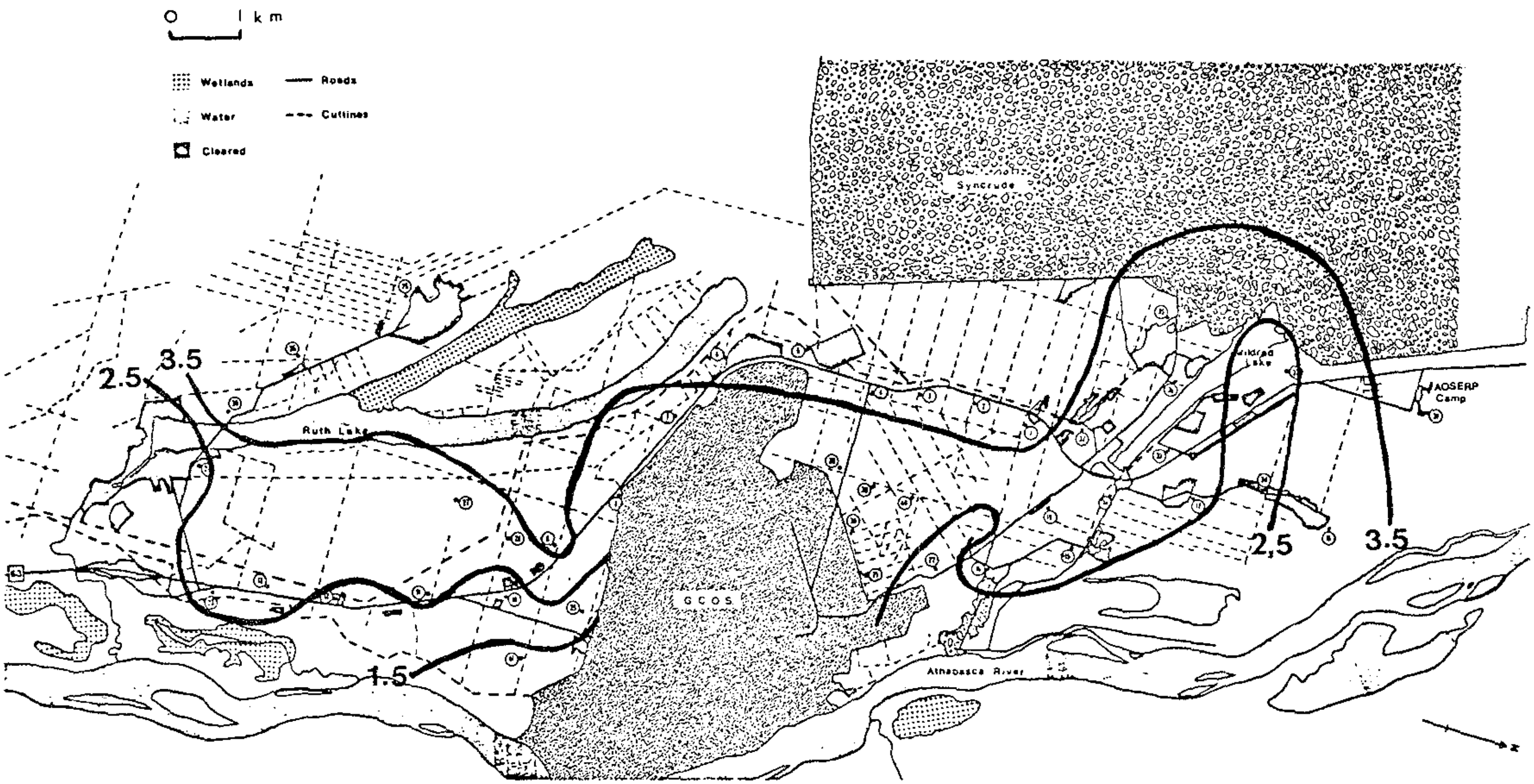

Figure 8. Relative condition of *Evernia mesomorpha* in the vicinity of Great Canadian Oil Sands (GCOS). Condition ranges from 1 (most degraded) to 5 (healthy).

4.2.6 Physical Pollutant Trapping

Precipitation samples were contaminated with insect and plant material even though attempts were made to ensure that only precipitation entered the gauge. In addition, black bear interest prevented a reasonable estimate of pollutant deposition by precipitation.

Huey plates were analyzed and the data were used to compare with the S uptake of plants at the gradient sites.

4.2.7 Plant and Soil Nutrient Analysis

Sulphur content was 600 ppm higher in jack pine foliage and 200 ppm higher in litter at Site A than at Site D (Table 10). Although these sites were significantly different ($p < 0.05$) in pollutant content (S), there did not appear to be much effect on the other macronutrients. Since both P and Mg were higher in the soil at Site A than Site D and other elements (except Ca) showed no difference, there was no obvious evidence of increased leaching with increased sulphur levels. Neither P nor Mg are emitted from GCOS in sufficient quantities to account for the increase. In addition, the increase in Al content in foliage that was shown by Baker (1977) to be correlated to forest soil contamination by SO_2 was not observed. Presumably, this is a result of too low levels or short duration of pollutants in the area. In general, the differences in nutrients (except S) between Sites A and D are attributable to natural site differences. Further sampling of these two sites will permit a more sensitive analysis since natural site differences can be eliminated.

Table 10. Nutrient content (mean ± 95% confidence limits) of one-year-old jack pine needles and soil samples at two sites in the vicinity of GCOS. All values are in ppm.

Material	Site	S	P	Ca	Mg	K	Al	Fe	Mn
Jack Pine Foliage	A	1674 ± 151	1128 ± 70	2938 ± 462	1349 ± 277	4215 ± 589	511 ± 66	318 ± 53	865 ± 120
	D	1074 ± 106	853 ± 124	3657 ± 700	869 ± 135	4125 ± 455	578 ± 79	371 ± 34	725 ± 168
Litter Exchangeable	A	239 ± 10	112 ± 12	4335 ± 83	496 ± 19	643 ± 40	689 ± 47	1364 ± 48	1296 ± 37
	D	48 ± 16	58 ± 13	2603 ± 168	206 ± 7	493 ± 18	579 ± 23	1002 ± 124	416 ± 16
	A	387 ± 31	239 ± 9	6703 ± 353	711 ± 20	850 ± 69	1536 ± 122	3766 ± 210	1472 ± 64
	D	169 ± 48	137 ± 39	3376 ± 173	295 ± 12	540 ± 22	1135 ± 71	2475 ± 262	456 ± 13
Mineral Soil	A	13 ± 2	85 ± 34	103 ± 10	16 ± 2	18 ± 2	240 ± 66	1190 ± 431	26 ± 9
	D	0.6 ± 0.4	7 ± 3	98 ± 17	15 ± 3	18 ± 3	167 ± 51	336 ± 97	14 ± 8
	A	26 ± 3	140 ± 44	156 ± 15	181 ± 33	73 ± 12	1324 ± 279	5141 ±1005	38 ± 8
	D	4 ± 1	67 ± 26	147 ± 23	210 ± 51	75 ± 16	1671 ± 460	4977 ±1356	26 ± 8

5. CONCLUSIONS

5.1 SITES

The biomonitoring sites established in 1976 and 1977 fell into three groups based upon water status as predicted from stand density. No pattern that could be attributed to air pollution was detected. There was also no apparent damage to either lichen communities at the biomonitoring sites or to the crowns of various plant communities in the vicinity of GCOS (Aerial Photography). These site descriptions although showing no pattern at this time, are critical in the long-term assessment of industrial emissions on the environment. They provide very important baseline information with which to compare similar measurements in the future.

5.2 BIOMONITORING

Vascular species appeared to show an increase in S content at biomonitoring sites close to GCOS. Although this trend was not significant ($p < 0.05$), a near-GCOS sulphur gradient demonstrated that this technique was sensitive enough to detect air pollution uptake by plants before they showed any visible, biochemical or physiological damage.

Lichens showed great promise as tools in biomonitoring. Lichen transplants showed initial trends in degredation but further work is necessary to determine their full usefulness. The lichen survey demonstrated the most obvious trends in both pollutant uptake and plant degredation and should prove to be a most useful tool for these purposes.

No difference in plant or soil nutrient content could be detected (except in sulphur). Site variability was large and further work is required before a full assessment of this technique is possible.

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7. AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
7.	AF 3.1.1	A Synopsis of the Physical and Biological Limnology and Fisheries Programs within the Alberta Oil Sands Area
8.	AF 1.2.1	The Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography)
9.	ME 3.3	Preliminary Investigations into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10.	HE 2.1	Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11.	AF 2.2.1	Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12.	ME 1.7	Very High Resolution Meteorological Satellite Study of Oil Sands Weather: "a Feasibility Study"
13.	ME 2.3.1	Plume Dispersion Measurements from an Oil Sands Extraction Plant, March 1976
14.	HE 2.4	Athabasca Oil Sands Historical Research Project. Volume I: Design
15.	ME 3.4	A Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area
16.	ME 1.6	The Feasibility of a Weather Radar near Fort McMurray, Alberta
17.	AF 2.1.1	A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18.	HY 1.1	Interim Compilation of Stream Gauging Data to December 1976 for the Alberta Oil Sands Environmental Research Program
19.	ME 4.1	Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area
20.	HY 3.1.1	Characterization of Organic Constituents in Waters and Wastewaters of the Athabasca Oil Sands Mining Area

21. AOSERP Second Annual Report, 1976-77
22. HE 2.3 Maximization of Technical Training and Involvement of Area Manpower
23. AF 1.1.2 Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24. ME 4.2.1 Review of Dispersion Models and Possible Applications in the Alberta Oil Sands Area
25. ME 3.5.1 Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area
26. AF 4.5.1 Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
27. ME 1.5.1 Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976
28. VE 2.1 Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29. ME 2.2 An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30. ME 2.1 Ambient Air Quality in the AOSERP Study Area, 1977
31. VE 2.3 Ecological Habitat Mapping of the AOSERP Study Area: Phase I
32. AOSERP Third Annual Report, 1977-78
33. TF 1.2 Relationships Between Habitats, Forages, and Carrying Capacity of Moose Range in northern Alberta. Part I: Moose Preferences for Habitat Strata and Forages.
34. HY 2.4 Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area
35. AF 4.9.1 The Effects of Sedimentation on the Aquatic Biota
36. AF 4.8.1 Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
37. HE 2.2.2 Community Studies: Fort McMurray, Anzac, Fort MacKay
38. VE 7.1.1 Techniques for the Control of Small Mammals: A Review
39. ME 1.0 The Climatology of the Alberta Oil Sands Environmental Research Program Study Area
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41. AF 3.5.1 Acute and Chronic Toxicity of Vanadium to Fish
42. TF 1.1.4 Analysis of Fish Production Records for Registered Traplines in the AOSERP Study Area, 1970-75
43. TF 6.1 A Socioeconomic Evaluation of the Recreational Fish and Wildlife Resources in Alberta, with Particular Reference to the AOSERP Study Area. Volume I: Summary and Conclusions
44. VE 3.1 Interim Report on Symptomology and Threshold Levels of Air Pollutant Injury to Vegetation, 1975 to 1978
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