APPROACHES TO THE DESIGN OF A BIOMONITORING PROGRAM USING ARTHROPODS AS BIOINDICATORS FOR THE AOSERP STUDY AREA

by

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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 "Approaches to the design of a biomonitoring program using arthropods as bioindicators for the AOSERP study area".

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,

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Chairman, Steering Committee, AOSERP
Deputy Minister, Alberta Environment

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APPROACHES TO THE DESIGN OF A BIOMONITORING PROGRAM USING ARTHROPODS AS BIOINDICATORS FOR THE AOSERP STUDY AREA

DESCRIPTIVE SUMMARY

A large number of the ultimate impacts of development projects on the terrestrial ecosystems of the AOSERP study area may occur as very subtle changes in the fauna and flora over long time periods. One way these subtle changes may be detected is through a long-term biomonitoring program. Since such a program should run for a relatively long time period, it must be well designed to avoid measuring parameters inappropriate or inapplicable to the area. It is imperative that a preliminary design study be completed prior to the initiation of any biomonitoring studies.

Arthropods offer considerable potential as bioindicators of the impacts of atmospheric pollutants. Studies have shown that carabids, beetles, ants, and spiders have been eradicated within a certain range of several atmospheric pollution sources.

The purpose of this report was to assess the feasibility of using certain arthropod groups as bioindicators of atmospheric pollutants in the AOSERP study area and was based on an evaluation of the success of other studies together with an assessment of the availability of the particular arthropod group used in the AOSERP study area. This project will assist in providing a permanent biomonitoring program for the terrestrial environment to detect subtle changes.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Present oil sand extracting plants are licensed to emit up to 635 t of SO_2 per day, along with large quantities of other gasses and fly ash. Additional oil sand extraction plants are in the planning stages. The cumulative effect of additional plants will tax the ability of the local environment to remove pollutants. A literature review on the effects of pollution showed that, while vegetation is the most conspicuous victim of pollution damage, arthropods clearly respond to the effects of industrial emissions, and may be used as an early warning system for harmful effects. Insects possess certain characteristics desirable for biomonitoring organisms. They are abundant, cosmopolitan, sensitive to pollution, and show definite responses to pollutants. Several insect species and groups of insects are examined in relation to their potential as biological indicators in the Alberta Oil Sands Environmental Research Program (AOSERP) study area. Pitfall traps (for ground beetles), emergence traps (for production measurements), and a survey of scale insects are recommended. In addition, bark beetles, honey bees, and insect species diversity indices are discussed in relation to AOSERP biomonitoring.

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1. INTRODUCTION

Pollution is a vague term given to any substance (thing) added to a system to which the substance does not belong above a baseline (natural) level. Pollution is normally thought of as an artifact of man's activities, but this is not necessarily so. Natural phenomena can introduce pollutants to an area, i.e., forest fires (smoke), volcanic eruptions (dust and toxic gasses), and decomposition of organic materials (organic acids, H_2S). In general, it is not the naturally occurring pollutants that are of interest, but those pollutants released by man into the environment, which may have a detrimental effect on his own health, his livestock and crops, and the natural environment.

In the Alberta Oil Sands Environmental Research Program (AOSERP) study area (Figure 1), atmospheric pollutants [fly ash, sulphates, CO, N_xO_x, dust (Shelfentook 1978)] are being emitted by the Great Canadian Oil Sands (GCOS)[1] plant, the Syncrude plant, and the town of Fort McMurray. Future oil sands plants and towns are planned, with the Alsands plant being the next to be constructed. One plant alone may not greatly alter the area through its atmospheric pollutants, but the cumulative effects of several plants may have a severe environmental impact. It is imperative that a biological monitoring system be set up to detect environmental damage before the area is permanently and seriously altered.

The main purpose of this paper is to review the literature on atmospheric pollutants expected to result from oil sands development projects, to review literature on the use of terrestrial arthropods as bioindicators, and to propose a biomonitoring program utilizing suitable organisms in the AOSERP study area.

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

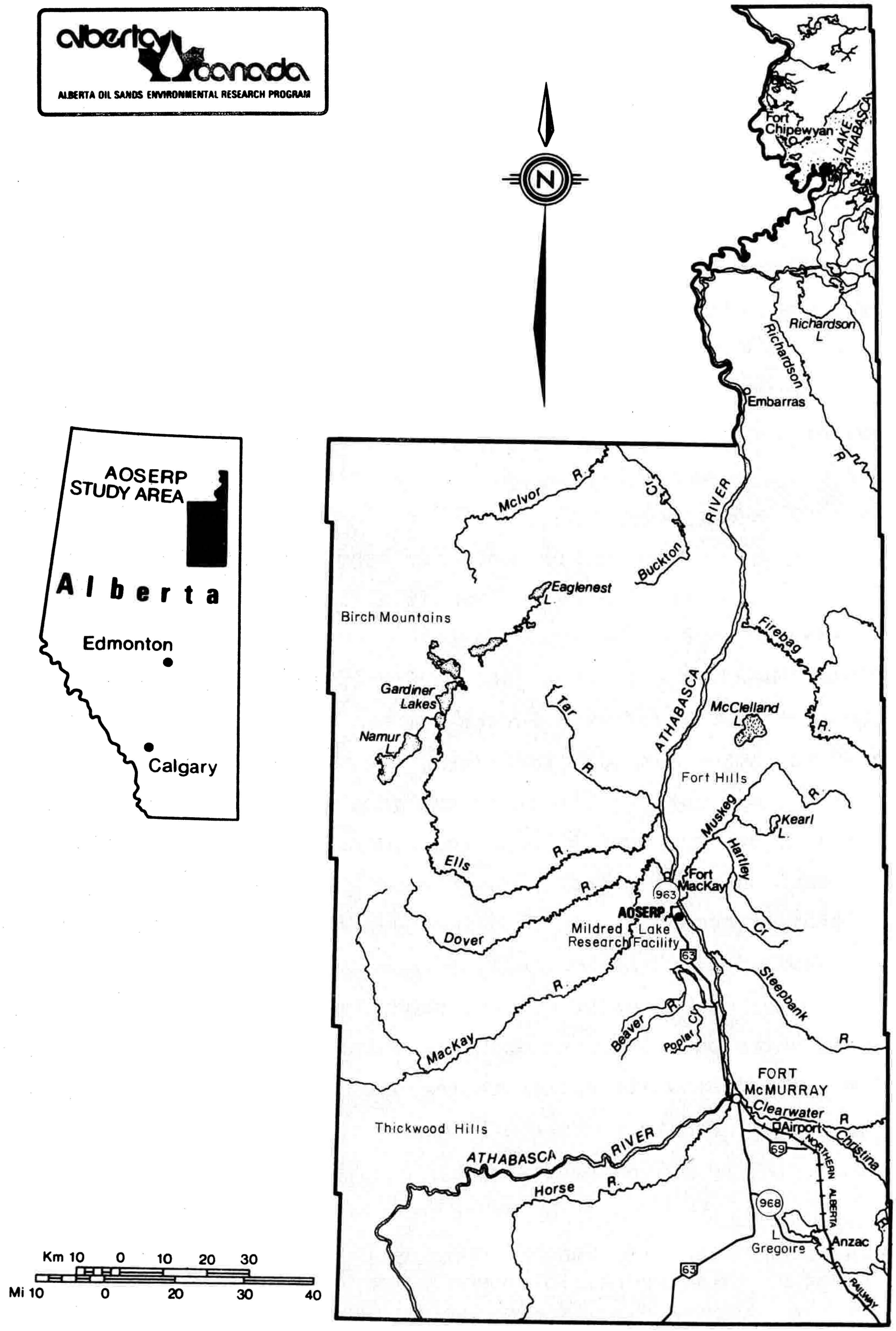

Figure 1. Location of the AOSERP study area.

2. REVIEW OF AOSERP LITERATURE ON ATMOSPHERIC POLLUTANTS

Atmospheric emissions on the Athabasca oil sands processing plants have recently received the attentions of many researchers. Two of these plants, GCOS and Syncrude Canada Ltd., are currently in operation. More oil sands extraction plants should begin operations before the end of the century, including the Texaco, Amoco, Mobile Oil, and Alsands plants, and others are projected. There are indications that 11 oil sands recovery plants will be constructed in Alberta.

Each oil sands plant will release large volumes of gaseous products into the atmosphere. Air contaminants from oil recovery procedures which the Department of the Environment considers to be of prime concern are sulphur-bearing compounds, oxides of nitrogen, and particulates, including heavy metals (Alberta Environment 1972). Partial removal of these effluents is feasible but expensive because of the large volumes involved. For example, the GCOS flue gasses at full load contain about 300 t per day of SO_2 and about 72 t per day of fly ash (Suntech 1976). In addition, the GCOS incinerator stack is licensed to vent 48 t of SO_2 per day (Alberta Environment 1973a). The fly ash contains 46.8% water and burnable materials, 25.6% SiO_2, 13.4% Al_2O_3, and lesser amounts of other metal oxides (Suntech 1976). Two analyses of the elemental composition of this ash and measurements of the particulate content of air near and distant from the GCOS plant are shown in Table 1. Most of these elements occur as stable metallic oxides.

Syncrude, despite its being a larger operation, is designed to produce fewer air contaminants. The limit of permitted SO_2 emissions from its main stack is 287 to per day (Alberta Environment 1973b). Particulate emissions are projected to be less than those of GCOS (Shelfentook 1978), due largely to Syncrude being supplied with electrical energy from the Alberta power grid, while GCOS operates its own generating plant, which produces particulates.

The fate of emissions from these operations have been investigated by AOSERP. Characteristics of plume dispersion have been measured for the GCOS plant (Davison et al. 1977). These show distinctive streaming

Table 1. Elemental composition of GCOS fly ash versus measured particulates in air.

Substance	Fly Ash Composition[a]		Ambient Air ($ng\cdot m^{-3}$)		
	Suntech (1976)	Shelfentook (1978)[b]	Fanaki (1978)		Strosher (1978)
			All sites (4)	Birch Mtn.	Birch Mtn.
Loss on ignition	46.8				
Carbon		14.1			
Aluminum	7.07	11.6	BDL[c]	BDL	56
Antimony					< 0.12
Arsenic		7 ppm			
Beryllium		BDL	BDL	BDL	
Bromine					2.9
Cadmium		BDL	(1)[d]	(1)	
Calcium	0.39	1.95			33
Chlorine					100
Chromium		0.018	3	BDL	
Cobalt		0.019	(3)	(2)	
Copper		0.038	182	181	< 1.3
Hafnium		BDL			
Iodine					0.51
Iron	3.4	4.61	3011	138	
Lead		0.026	35	14	
Lithium	0.009				
Magnesium	0.40	0.800			27
Manganese	0.077	0.089	39	13	0.86
Mercury		7.3 ppb	(0.2)	0.2	
Molybdenum	0.18	0.235	(1)	BDL	
Nickel	0.644	0.998	13	5	
Phosphorus	0.065	0.099			
Potassium	0.65				31
Scandium					< 0.15
Silicon	11.5	16.0			
Sodium	0.50				91
Strontium		0.035			
Sulphur	2.0	1.56			
Titanium	1.88	1.71			< 6.5
Uranium		BDL			
Vanadium	1.85	2.55	(2)	BDL	3.2
Zinc		0.040	32	35	< 5.8
Zirconium		BDL			

[a] Weight % as element
[b] Means of three measurements
[c] Below detectable limit
[d] Brackets indicate means calculated from results including BDL values, which are set equal to 0.

patterns dependent on weather conditions. The fallout pattern is predominantly north-south in the vicinity of GCOS (Murray and Kurtz 1976). Chemical transformation processes relevant to oil sands air pollutants are described in detail by Bottenheim and Strausz (1977). These authors review the fate of SO_2 gas in particular, and the rate at which it converts to SO_4 in the atmosphere.

Maximum SO_2 concentrations initially found attributable to GCOS (2.3 km north and south) were about 20 $\mu g \cdot m^{-3}$, while the SO_2 concentration at ground level from Syncrude operations was expected to be about 1 $\mu g \cdot m^{-3}$(Walmsley and Bagg 1977). The models used for these assessments do not predict plume behavior under all atmospheric conditions particularly during inversions and at wind speeds below $m \cdot s^{-1}$ (Fanaki 1978). During two inversions, the SO_2 concentrations rose briefly from 1 $\mu g\ S \cdot m^{-3}$ to between 30 and 50 $\mu g\ S \cdot m^{-3}$ at one monitoring station. Climatic conditions in 1977 caused SO_2 readings in excess of environmental objectives for 64 half-hour periods, 46 one-hour periods, and 6 twenty-four-hour periods (Strosher 1978). These figures represent reductions from 1974-75 levels.

The deposition of sulphur on snowpack regions has been examined (Fanaki 1978). A calculated 3.8 t of anthropogenic sulphur found in the top layer of snow within a 25 km radius represented 1.14% of the 2690 t released by the GCOS plant and available for deposition. Snow below this depth contained more anthropogenic sulphur, but represented 0.062% of the quantity emitted. This sulphur may be concentrated by snowpack leaching. An acid spring-runoff caused a salmon kill in a Norwegian River (Leivestad and Muniz 1976). Acid in the AOSERP study area snow was neutralized by anthropogenic substances of undetermined composition.

The projected and already measured atmospheric emissions from four sources (two oil extraction plants) are discussed in Shelfentook (1978). Figure 2 shows a comparison of the quantities and origins of the most abundant atmospheric pollutants. Sulphur dioxide emissions from GCOS and Syncrude will stabilize at about 2.10 t annually in 1980 to 1985 (this does not include emission modifications which may be

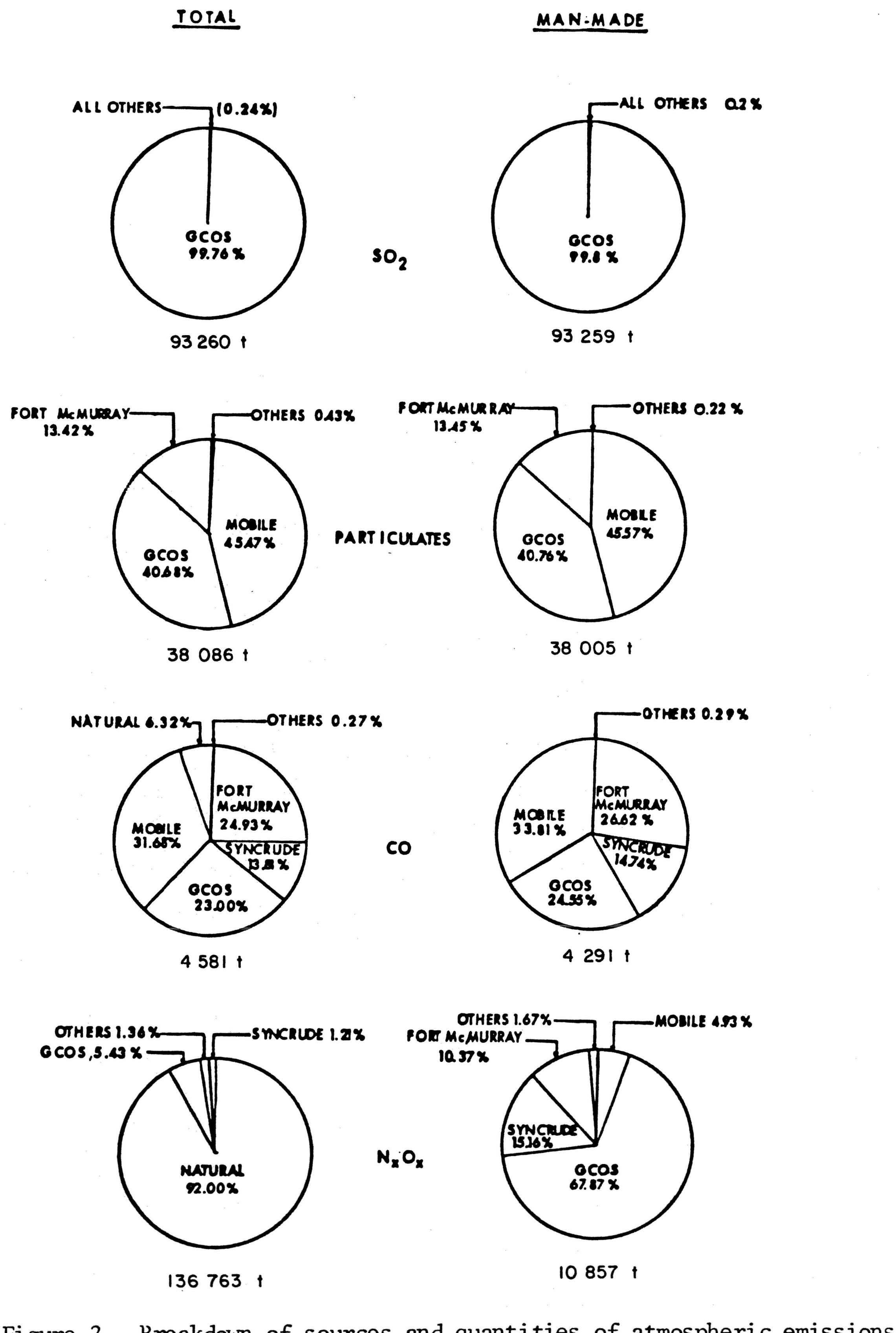

Figure 2. Breakdown of sources and quantities of atmospheric emissions in the AOSERP study area in 1976 (from Shelfentook 1978).

introduced to the Syncrude stack). Carbon monoxide emissions will be approximately $14 \cdot 10^3$ t annually in this time period. Nitrogen oxides will be emitted at a rate of about $5 \cdot 10^4$ t annually. Particulate emissions will decrease from about $2.2 \cdot 10^4$ t annually, while water vapour will stabilize at about $5 \cdot 10^3$ t annually in the 1980-85 period. These emissions can be compared to natural emissions to gain a perspective from which their significance can be evaluated. For example, in 1976 the nitrogen oxides emitted by all oil sands plants accounted for 8% of the atmospheric nitrogen oxides; i.e., 92% of the measured nitrogen oxides were from natural sources. Projecting to the 1980-85 period, it appears that about 35% of atmospheric nitrogen oxides will be generated by oil sands plants. Natural sources accounted for 97% of total atmospheric organics and 99% of atmospheric water in 1976. Virtually all sulphur dioxide and particulate emissions in 1976 were from oil sands plant operations. Carbon monoxide emissions were 93% anthropogenic, of which 25% were generated in the town of Fort McMurray.

The main atmospheric pollutant of biological concern is sulphur dioxide. Carbon monoxide and some nitrogen oxides may prove to be causes of concern. Other emission constituents presently do not appear to pose particular hazards.

3. EFFECTS OF POLLUTION

Insects may be affected directly or indirectly by pollution. The most obvious and often most detrimental effects are from direct causes. Indirect changes may have similar harmful effects. Destruction or alteration of a food source may have profound impact farther down the food chain, especially when the damage occurs to the primary food sources, plants. Harm may occur in more subtle ways, such as through loss of camouflage protection on sooty plants.

Few published papers were found which were directly applicable to insect biomonitoring studies in the AOSERP study area. Therefore this section includes reviews of studies which illustrate principles about pollution and its effects on arthropods. Many principles of responses to pollution have been realized through the study of plants, especially lichens. These principles may be applied to the study of arthropod responses. Arthropods are sensitive to a wide range of mangenerated substances, including sulphur compounds, fluorides heavy metals, hydrocarbons, and biocides.

3.1 EFFECTS ON VEGETATION AND INSECT RESPONSES

Arthropods need not be directly affected by toxic emissions. Indirect effects can greatly influence survival. Gilbert (1971) observed arthropods on boles of trees and tree trunks. Pollution damage to lichens caused a loss of food for herbivores, and ultimately a reduction in food supply for some carnivores. Birds tend to collect conspicuous light coloured insects from soiled tree trunks, ultimately resulting in an increase of dark coloured insects.

With pollutants, the threshold level required to damage plants is affected by the dose (duration of exposure x concentration of pollutant) plus a multitude of interacting biological and meteorological conditions (Heagle 1973). Effects of pollutants at ground level are dependent on meteorological conditions, distance from the source, topography of the land, concentration, and quantity of pollutants emitted from the source. Plant species (even within species) vary considerably in sensitivity to pollutants. Heagle reports that plants are most sensitive to pollutants during daylight hours, under humid conditions with moderate temperature and adequate soil moisture. Sensitive plants may be damaged in 8 h by exposure to concentrations of 0.10 to 0.50 parts per million (ppm) of SO_2. Most plants are damaged by SO_2 concentrations of 0.20 to 2.50 ppm for 8 h.

In the AOSERP study area, Murray and Kurtz (1976) report SO_2 critical concentrations in excess of 0.5 $ppm \cdot hr^{-1}$ and an area of 39 km^2, with a concentration over 0.17 ppm for the Syncrude oil sands plant. Inversion break-ups have led to SO_2 concentrations reaching 1.1 ppm. Episodes of 1.0 ppm or greater occurred on 17 out of 251 mornings and usually lasted less than 30 min.

Ozone, an important oxidant of photochemical air pollution, may cause damage to sensitive plants in 8 h by exposing them to concentrations of 0.04 to 0.10 ppm. Most plants require an 8 h dose of 0.08 to 0.20 ppm O_3 before damage is apparent. For a discussion of factors affecting plant sensitivity to oxidant pollution, see Heck (1968).

Ozone production is dependent on emissions of N_xO_x (Bottenheim and Strauss 1977). In the AOSERP study area, 92% of N_xO_x is produced by natural sources. The balance is man made. Inversions may trap industrial N_xO_x emissions in a localized area, which may then significantly raise N_xO_x concentration above natural, baseline levels. Photochemical reactions produce elevated levels of ozone, especially during the warm growing season (Shelfentook 1978).

In Alberta, Loman et al. (1972) examined the effects of sulphur dioxide on forest vegetation. They reported that emissions of 1.0 ppm or less will injure all species of trees found in Alberta forests. Sulphur dioxide pollution standards (0.17 ppm), under the Clean Air Act, Department of Environment, are below this threshold level for Alberta trees. Populations of plants more sensitive to SO_2 emissions will be severely damaged or destroyed at this level. Gilbert (1970) proposed a damage measurement scale using lichens as biomonitors of air pollution. In the AOSERP study area, Douglas and Skorepa (1976) proposed a predictive study to monitor air quality with lichens. This was followed by a report providing baseline data on lichens (Peterson and Douglas 1977).

Smith (1974) discussed three categories of pollution damage to temperate forest ecosystems. The first he called Class I, or low pollution load. In this case, most emissions found in the air are the direct result of natural ecosystem processes; i.e., natural carbon monoxide, H_2S, NH_3, NO_x and H_nC_n usually exceed those produced from man made sources. In general, ecosystems act as a sink for emissions. Addition of emissions may produce a fertilization effect, transferring pollutants from the atmosphere to soil nutrient sinks.

In areas of increased pollution load, a Class II relationship may develop. Instead of stimulating growth, the effect of an intermediate pollution load is to reduce vitality or increase morbidity of the plants. Emissions may reduce normal nutrient uptake from atmospheric sources, living and dead organic matter, and of primary and secondary minerals (Likens and Bormann 1971, cited by Smith 1974). It has been demonstrated that in many agricultural plants the rate of photosynthesis is reduced by pollutants (many sources cited by Smith 1974). Another effect of emissions is reduced reproduction, which may be the result of direct damage to the fruit and flowers, or of inhibition of seedlings. Emissions may affect pollinators, which in turn reduce reproductive success (references cited by Smith 1974). In areas of the Flathead National Forest adjacent to an aluminum smelter, elevated levels of fluoride were found in pine needles. This led to a build-up of the pine needle scale, *Phenocaspis pinifoliae* (Fitch) (Carlson and Dewey 1971, cited by Smith 1974). Lodgepole pines in this area also appeared to be predisposed by fluoride injury to attack by a pitch mass borer, a needle miner, a needle sheath miner, and the sugar pine tortrix (C.E. Carlson, personal communication, cited by Smith 1974).

The most severe level of forest damage, Class III, occurs under high pollution loads. The result is a simplified ecosystem, with forest species often being replaced by resistant grasses. Smith (1974) reviewed many articles on forests destroyed by airborne pollutants. Of these pollutants, SO_2 and O_3 appeared to be primary causes of severe morbidity and mortality.

Gaseous effluents may have an indirect effect on tree mortality through attacks by bark beetles. Forest entomologists have long recognized an association between diseased trees and bark beetle infestations, and have speculated that disease is a factor predisposing forest trees to bark beetle attack (Furniss and Carolin 1977). Populations of bark beetles have been known to build up on dying trees to levels where healthy trees are subsequently attacked and killed. Whole areas of forests have been devastated by such attacks (Borden 1971; Bright 1976). Consequently, this group of insects has received particular attention in air pollution studies.

The most frequently cited published article on a bark beetle-air pollution link is that of Stark et al. (1968). Researchers had examined ponderosa pine in the San Bernardino mountains and found that many trees had "chlorotic decline". This condition, noted on many trees in the Los Angeles basin since the early 1950's, was determined to be associated with photochemical air pollutants, including ozone. Stark's group investigated the relationship between chlorotic decline and levels of bark beetle attack. They found that chlorotic trees were heavily attacked compared to healthy trees, and concluded that atmospheric pollution injury predisposed ponderosa pine to attacks by the western pine beetle (*Dendrotonus brevicomis* Leconte) and the mountain pine beetle [*D. ponderosae* (Hopkins)].

Donald Dahlsten of the University of California, Berkeley campus, is currently involved in follow-up research on bark beetle populations in the San Bernardino mountains (Dahlsten 1978). He was interviewed for this report and provided some relevant insights to the bark beetle question.

Bark beetle populations in the San Bernardino mountains have not increased dramatically, nor have these beetles killed large numbers of trees. Ponderosa pines continue to be affected by smog-induced chlorosis. By examining beetle galleries on infested trees, Dahlsten found that fewer eggs were being laid, and fewer larval miners were produced, than normal for both *Dendroctonus* species. Hence, the chronic poor health of the trees reduced their nutritive value to individual beetles, limiting the expansion rate of beetle populations.

This implies that bark beetles will not pose a significant threat to trees in the AOSERP study area. Dahlsten felt that research time spent on this problem would not yield significant results.

3.2 EFFECTS OF POLLUTION ON ARTHROPODS

In contrast to the volume of literature dealing with plant injury and the use of plants as bioindicators, literature on the use of insects is comparatively limited. Hay (1977) recently published a bibliography on arthropods and air pollution. In many papers dealing with plants (Heagle 1973; Smith 1974), insect infestations are mentioned as a symptom of damage present. They do not discuss pollution as having a direct influence on the insects. Philosophical reasons for choosing invertebrates, particularly aquatic and terrestrial insects, as biomonitor organisms were discussed at a recent symposium (King and Elfner 1975). Insects as a whole are sensitive indicators of pollutants, both those of a deliberate nature, such as pesticides (biocides), and those of a passive nature, such as industrial wastes and other man made products.

3.2.1 Sulphur Emissions

Oil extraction plants in the AOSERP study area are producing, and will continue to produce, large volumes of SO_2 emissions, so it is perhaps best to start with sulphur compounds, then proceed to other pollutants.

Atmospheric pollution (SO_2) from industrial sources in Tarnobrzeg, Poland, has had a considerable impact on the surrounding countryside. Przybylski (1974) observed plants and animals around this polluted centre in 1966, 1968, and 1971, primarily to determine the extent of damage caused by sulphur compounds. For the study of arthropods, Przybylski chose three locations: Chmielow, 0.5 km east of the industrial centre; Ocice, 2 km northeast of the centre; and Zarebki, 30 km from the centre. At each locality, four similar wheat field and grassland sites were chosen. A sweep net was used to sample each field (100 sweeps per field). These collections were used to calculate the average number of insect taxa in the wheat fields and grasslands.

Przybylski concluded that sulphur gasses exert a noxious influence on plants and animals (one must accept, without clear documentation, that the fallout near the plant consisted of 20 kg of sulphur dust, 10 kg H_2S, and 4250 kg of SO_2 per hectare). Przybylski concluded that: (1) thrips, polyphagous Coleoptera, curculionids, elaterids, and Hymenoptera were more abundant in the wheat field near the factory than farther away; (2) tettigoniids, adephagous Coleoptera, cantharids, coccinellids, and halictines were found mainly in wheat fields far from the factories; (3) the insect fauna was impoverished in grasslands situated less than 2 km to the northeast and east of the chemical centre; and (4) no carabids, cantharids, and tettigoniids were found in wheat fields or grasslands near the factories. Przybylski stated that the observation of insects over a long period of time could provide an index (bio-indicator) to the presence of sulphur emissions in the atmosphere. He concluded that aphids were least sensitive, while the natural enemies of harmful insects were extremely sensitive, to sulphur dioxide.

Around the same time that Przybylski conducted his studies, Freitag (Freitag in press; Freitag and Hastings 1973; Freitag et al. 1973; Hastings et al. 1972; Hastings and Freitag 1972) examined the effects of airborne emissions from a Kraft mill in Thunder Bay, Ontario, to evaluate leaf litter habitat alteration as a consequence of fallout from flue exhausts. During these studies, sulphate fallout was measured by analysis of snow packs and accumulation of rainwater in collection tubs along a transect. Average fallout rates were calculated as a function of the distance from the plant. These were then correlated to sampling station results. Freitag used five pitfall trap stations, each consisting of 100 traps, located along the same transect used to sample SO_4 fallout. Specimens of 20 species of carabids and 1 species of silphid were collected. Freitag plotted the relative numbers of beetles collected versus distance from the mill and the annual rate of sulphate fallout on a composite graph, shown in Figure 3. Beetle numbers were negatively correlated with fallout. Freitag concluded that the emissions from the Kraft mill effectively reduced the size of ground beetle populations near the mill and that the toxic agent may be sulphate, or related compounds, released from the mill stack.

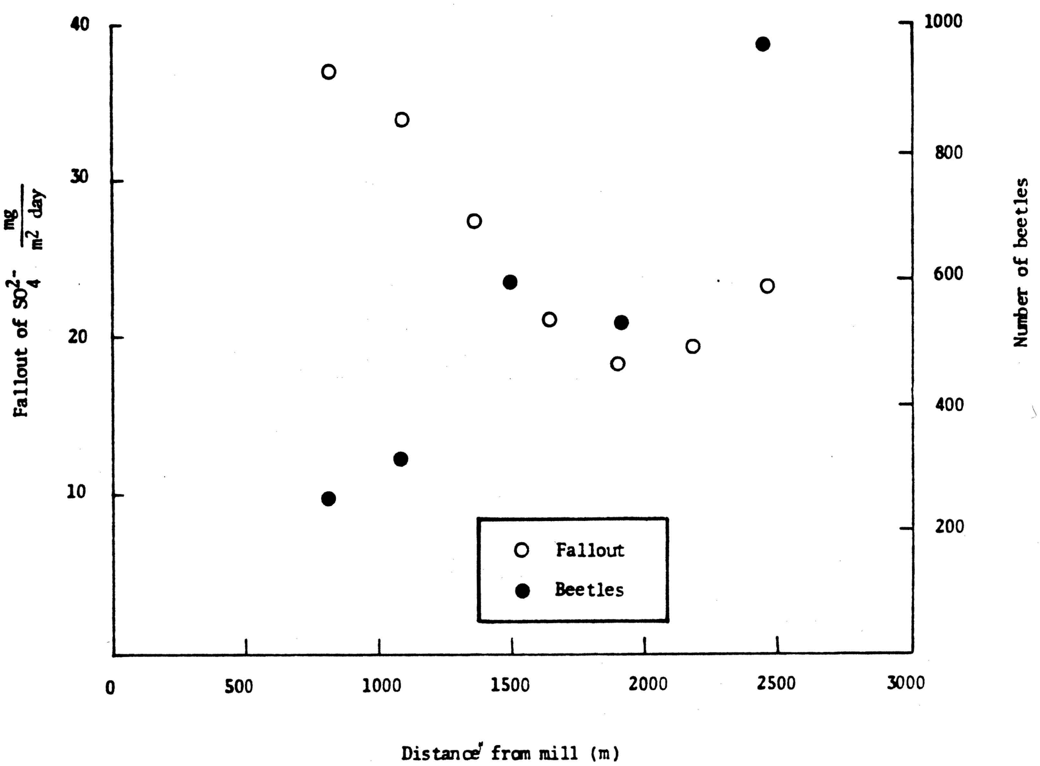

Figure 3. Composite plot of beetle populations and sulphate fallout. Average annual 1970 and 1971 $SO_4{}^{2-}$ fallout and size of summer beetle population samples (1971) versus distance from a kraft mill in Thunder Bay Ontario are plotted (after Freitag and Hastings 1973).

3.2.2 Ozone

Levy et al. (1972) examined the effects of ozone on laboratory cultures of *Musca domestica* L., *Stomoxys calcitrans* (L.), and *Drosophila melanogaster* Meigen. Results showed little influence on egg hatch, larval molting, pupation, and adult emergence. Exposure of adults to ozone seemed to stimulate oviposition. Beyond this noted effect, no detrimental effects were observed. In another study, Levy et al. (1973) examined the effects of ozone on the cockroaches *Periplaneta americana* (L.) and *Nauphoeta cinerea* (Oliver) and the red imported fire ant *Solenopsis invicta* Bureun. Mortality, fecundity, molting, egg hatch, and behaviour were observed. No differences in ozone sensitivity were observed between control and exposed groups.

Under laboratory conditions it appears that ozone has little or no effect. In the field the situation may be different if other chemical emissions have a detrimental, synergistic effect.

3.2.3 Fluorides

Dewey (1973) examined the effects of fluoride emissions on four groups of insects: pollinators, predators, foliage feeders, and cambial region feeders. Data showed that pollinators accumulated the highest fluoride levels, followed by predators, then foliage feeders, with the lowest concentrations being found in cambial feeders. Dewey speculated that the high concentrations of fluoride are either accumulated by respiration or passed along the food chain.

Fluoride emissions are not expected in the AOSERP study area, but pollinators and carnivorous insects are. By analogy to the results of this fluoride study, pollinators and carnivorous insects appear to be prone to accumulate emissions, either by direct exposure or via bio-concentration.

3.2.4 Heavy Metals

The commonest toxic heavy metal pollutant encountered in the terrestrial environment is lead. Giles et al. (1973) published a note on the accumulation of atmospheric lead by insects in areas of high traffic density 4 km north of Baltimore. Insects were collected by sweep netting. Giles et al. observed that species of insects caught close to a freeway had significantly higher concentrations of lead than did insects in a control area.

In another study, Price et al. (1974) observed in areas of high lead emissions from vehicle exhausts that lead levels varied for different guilds of insects. Plant sucking insects had the lowest average lead concentration, 10.3 ppm, while plant chewing and predatory insects had average lead levels of 15.5 and 25.0 ppm, respectively. In areas of low lead emissions, insects in the same feeding guilds had lower average lead counts of 4.7, 3.4, and 3.3 ppm, respectively. These concentrations were not significantly different.

A third study conducted by Maurer (1974) also compared areas of high and low traffic volume. Instead of measuring uptake of lead, Maurer examined the diversity (Shannon Weaver index) of the beetle and spider faunas near a busy road, a quiet road, and in the middle of a field. Maurer observed, near the busy road, that there were fewer species and lower numbers of trapped carabid beetles. A reduction in spider numbers and species was also observed. No significant differences were observed between busy and quiet roads for staphylinid beetles.

3.2.5 Hydrocarbons

The danger of pollution by oil and its by-products is often thought of in relation to oil spills at sea, but there is also a real danger of damage to the terrestrial environment.

On 28 January 1969, an oil spill occurred off the coast of Santa Barbara, California. Evans (1970) surveyed the high littoral zone crevice fauna for damage, choosing a species of carabid beetle, *Thalassotrechus barbarae* (Horn), as a representative indicator of the crevice community. Evans surveyed the coast line in a zone 120 km north to 80 km south of Santa Barbara. Beetles of *T. barbarae* were not found in localities of moderate to heavy oil deposition, but had been killed with other members of the crevice fauna by oil.

On 13 July 1971, liquid condensate was accidently released into the atmosphere near Strachan, Alberta. Wong and Melvin (1973) surveyed the effects of this release and its consequences on insect populations. Severe damage to the forest occurred up to 0.4 km from the release point. Condensate covered the vegetation with an oily sheen and soaked into the duff in many places. Of the large number of insects sampled, bark and wood boring insects did the most damage to injured trees. These were found to occur in a succession pattern similar to that on fire damaged trees. Wong and Melvin concluded that hydrocarbon condensate damages trees and increases susceptibility to attack by bark and wood inhabiting insects.

3.2.6 Biocide Pollutants

These are usually the most toxic and among the most abundant of the contentious chemicals released into the environment.

Insecticides are toxic to all insects. A problem with non-specificity of toxicity is that desirable elements of the insect fauna, notably predators and parasites, are killed. Applications of insecticide disrupt natural controls more readily than pest populations, making pest problems worse in time. Responses of arthropod natural enemies to insecticides have been summarized by Croft and Brown (1975). Specific examples of effects of insecticide treatments, mostly in crop situations, are found in Freitag and Poulter (1970), Herne (1963), Menhinick (1962), Sellers and Dahm (1975), Coaker (1966), Doane and Schaeffer (1971), Dempster (1968), Edwards and Thompson (1975), and others.

Insects have been used as biomonitors for insecticides primarily because these chemicals were developed to control pest insects. The papers surveyed here deal mainly with toxic effects on non-target insects (primarily carabid beetles).

The effects of insecticides on carabids are varied. Coaker (1966) and Critchley (1972a, b) observed that, in some studies, the application of sublethal doses of insecticide increased the number of carabids caught in pitfall traps. They speculated that this increase was due to increased motor activity. Dempster (1968) observed the termination of feeding by *Harpalus rufipes* when exposed to sublethal doses of DDT; however, the beetles recovered quickly when removed from contact with the insecticide. Tomlin (1975) found that larvae of *Pterostichus melanarius* Illiger and adults of *Stenolophus comma* Fabricius could tolerate high doses of p, p'-DDT. Tomlin concluded that this may be innate, or evolved as a result of continuous exposure to DDT residues in the soil. Esau and Peters (1975) regarded chlorinated hydrocarbons as having both negative and positive effects on carabids in corn fields. The more usual response of carabids to the application of insecticides is negative. In an orchard studied by Menhinick (1962), fewer carabids were present than in untreated orchards. Herne (1963) found fewer *P. melanarius* in an orchard recently sprayed with DDT, but the populations persisted in spite of the use of DDT for 10 years. Freitag et al. (1969) and Freitag and Poulter (1970) examined the effects of the organophosphorous insecticides sumithion and phosphamidon on ground beetles near Lake Shebandowan, Ontario. These insecticides were used for control of the spruce budworm, *Choristoneura fumiferana* (Clements). Carabid populations were examined the year of spraying and the following year. The control area contained more beetles, with the greatest differences in populations in the year following spraying, implying a persistence in disturbance.

These reports, and the book by Thiele (1977) on carabid beetles in their environments, illustrate that carabid beetles are the most frequently used terrestrial insect group in biomonitoring studies of habitat disturbance through exposure to insecticides.

3.2.7 Low Frequency Electromagnetic Fields

Electric current may be an environmental pollutant. To test this hypothesis, populations of soil dwelling Collembola and mites were monitored to determine the effects of ground current flow, electromagnetic fields, and extremely low frequency radiations from a power station antenna (Greenberg 1972). Initial results seemed to confirm that populations of these soil dwelling invertebrates were suppressed by magnetic fields. A more thorough sampling program revealed no significant differences in test versus control populations in 14 of 16 tests. The two cases where significant differences were found were rejected due to the large variance of the extracted populations.

This was the only study found which used soil arthropod populations as bioindicators of pollution.

4. BIOMONITORING OF AOSERP STUDY AREA ARTHROPODS

Jenkins (1971) suggested that major environmental pollutants of global importance should be monitored, including toxic or abundant hydrocarbons (chlorinated, biphenyls, crude oil, and petroleum products) and toxic metals (Hg, Pb, As, Cd). This author specified six criteria that should be used to select any group of organisms used in biological monitoring programs: (1) abundance, (2) cosmopolitan, (3) sensitive to pollution (i.e., fragile), (4) show a well-defined response (i.e., change or mutate, die or population decrease, replacement), (5) non-target species (i.e., not objects of control programs), and (6) changes visible by remote sensing. In addition, a biomonitoring program should be cost effective for purposes proposed. It should be based on firm theoretical principles as well as being practically augmentable.

The criteria proposed by Jenkins (1971) for biomonitoring can be applied to the selection of arthropod groups suitable for biomonitoring study in the AOSERP study area through data found in surveys of terrestrial insects there (Ryan and Hilchie 1980; Porter and Lousier 1975). There are 178 insect families known to be represented (Table 2) in the AOSERP study area, and more are expected to be present. Of those families listed, only a few families were found to be abundant, Jenkins' first criterion. In the soil surface zone these included: carabid and staphylinid beetles, spiders, and Collembola. Fungivorid and chironomid fly larvae were abundant within the soil. On vegetation, psocids, aphids, cicadellids, and spiders were abundant. The above groups are cosmopolitan in distribution. The third criterion, sensitivity to pollution, is poorly known. Tolerance levels to certain pollutants are known in a few groups of insects: in Diptera (ozone) and carabid beetles (pesticides, sulphur compounds, lead). The fourth criterion, showing a well-defined response to a pollutant, has been documented for one species of scale insect and for carabid beetles. Organisms which are not targets of control (criterion 5) encompass virtually all arthropods in the AOSERP study area. Several groups, including carabid beetle, spiders, and parasitic wasps, are viewed as being beneficial in pest control programs. The last criterion proposed by Jenkins involves the

Table 2. Families of insects in terrestrial habitats within the AOSERP study area.[a]

Taxon	Ryan & Hilchie 1980	Porter & Lousier 1975		Ryan & Hilchie 1980	Porter & Lousier 1975
COLLEMBOLA			HOMOPTERA		
Entomobryidae	+		Aphididae	+	+
Isotomidae	+	+	Cercopidae	+	+
Onychiuridae	+	+	Chermidae	+	+
Poduridae	+	+	Cicadellidae	+	+
Sminthuridae	+	+	Cicadidae	+	+
EPHEMEROPTERA			Cixiidae		+
Ephemerellidae	+	+	Coccidae	+	
ODONATA			Delphacidae	+	
Aeshnidae		+	Fulgoridae	+	
Coenagrionidae	+	+	Pseudococcidae	+	
Libellulidae	+	+	Psyllidae	+	+
ORTHOPTERA			COLEOPTERA		
Acrididae	+	+	Anobiidae	+	
Tetrigidae	+	+	Anthicidae	+	+
PLECOPTERA			Anthribidae	+	
Nemouridae	+	+	Buprestidae	+	+
Taeniopterygidae	+		Byrrhidae	+	+
PSOCOPTERA			Cantharidae	+	+
Pseudocaeciliidae	+		Carabidae	+	+
Psocidae	+	+	Cerambycidae	+	+
THYSANOPTERA			Chrysomelidae	+	+
Phlaeothripidae	+		Cicindelidae	+	
Thripidae	+		Cleridae		+
HEMIPTERA			Coccinellidae	+	+
Aradidae	+	+	Colydiidae	+	+
Gerridae	+		Cryptophagidae	+	
Lygaeidae	+		Cucujidae	+	+
Miridae	+	+	Curculionidae	+	+
Nabidae	+		Dytiscidae	+	
Pentatomidae	+	+	Elateridae	+	+
Saldidae	+		Eucnemidae		+
Tingidae	+	+	Helodidae	+	+
			Histeridae	+	+

Continued ...

Table 2. Continued.

Taxon	Ryan & Hilchie 1980	Porter & Lousier 1975		Ryan & Hilchie 1980	Porter & Lousier 1975
Hydrophilidae	+		DIPTERA		
Lampyridae	+	+	Agromyzidae	+	
Lathridiidae	+		Anisopodidae		+
Leptodiridae	+		Anthomyiidae	+	+
Lycidae		+	Anthomyzidae	+	
Melandryidae	+		Asilidae	+	+
Mordellidae	+	+	Bibionidae	+	+
Mycetophagidae	+		Bombyliidae	+	+
Nitidulidae	+	+	Calliphoridae	+	
Orthoperidae	+		Cecidomyiidae	+	+
Pedilidae		+	Ceratopogonidae	+	+
Phalacridae	+		Chamaemyiidae	+	
Pselaphidae	+		Chaoboridae	+	+
Scaphidiidae	+		Chironomidae	+	+
Scarabaeidae	+	+	Chloropidae	+	+
Scolytidae	+		Clusiidae	+	
Silphidae	+		Conopidae		+
Staphylinidae	+	+	Culicidae	+	+
Tenebrionidae	+	+	Cuterebridae	+	
NEUROPTERA			Dixidae	+	+
Chrysopidae	+		Dolichopodidae	+	+
Hemerobiidae	+	+	Drosophilidae	+	
TRICHOPTERA			Empididae	+	+
Limnephilidae	+	+	Ephydridae	+	
LEPIDOPTERA			Heleomyzidae	+	
Arctiidae	+		Lonchopteridae	+	
Cosmopterygidae	+		Milichiidae	+	
Geometridae	+	+	Muscidae	+	+
Gracilariidae	+	+	Mycetophilidae	+	+
Hepialidae		+	Otitidae	+	
Lycaenidae		+	Phoridae	+	+
Nepticulidae		+	Piophilidae	+	
Noctuidae	+	+	Pipunculidae	+	+
Notodontidae	+		Psychodidae	+	+
Nymphalidae	+		Ptychopteridae	?	
Olethrutidae		+	Rhagionidae	+	
Pieridae	+	+	Sarcophagidae	+	
Pterophoridae	+	+	Scatopsidae	+	
Pyralidae	+		Sciaridae	+	+
Tineidae	+				
Tortricidae	+				

Continued ...

Table 2. Concluded.

Taxon	Ryan & Hilchie 1980	Porter & Lousier 1975
Sciomyzidae	+	+
Sepsidae	+	+
Simuliidae	+	+
Stratiomyidae	+	+
Syrphidae	+	+
Tabanidae	+	+
Tachinidae	+	+
Therevidae	+	+
Tipulidae	+	+
Trichoceridae	+	
Trixoscelididae	?	
SIPHONAPTERA		
Leptosyllidae	+	
Ceratophyllidae	+	
HYMENOPTERA		
Apidae	+	+
Argidae		+
Braconidae	+	+
Ceraphronidae	+	
Chalcididae		+
Chrysididae	+	+
Colletidae		+
Cynipidae	+	
Diapriidae	+	+
Diprionidae	+	+
Dryinidae	+	
Encyrtidae	+	
Eucharitidae		+
Eulophidae	+	+
Eupelmidae	+	
Eurytomidae	+	
Formicidae	+	+
Halictidae	+	+
Ichneumonidae	+	+
Megachilidae	+	+
Mymaridae	+	
Perilampidae		+
Platygasteridae	+	
Pompilidae	+	+
Proctotrupidae	+	+
Pteromalidae	+	+
Scelionidae		+
Sphecidae	+	+
Tenthredinidae	+	+
Torymidae	+	+
Trichogrammatidae	+	
Vespidae	+	
Orders	16	14
Families	161	111
Total Families	178	

[a] After Ryan and Hilchie (1980).

use of remote sensing. This criterion refers specifically to plant species and does not readily apply to studies of arthropods. Its intent is that individuals of biomonitored organisms should be easily and clearly detectable.

The groups of insects which could be considered for a biomonitoring program in the AOSERP study area are carabid beetles, bark beetles, ground dwelling spiders, scale insects, soil dwelling flies, psocids, and plant bugs (aphids, cicadellids). Appropriate techniques to monitor several of these arthropod groups are discussed in Sections 4.2 to 4.7.

It must be realized that there is no standardized insect biomonitoring system which can be applied to the AOSERP study area. The whole biomonitoring field is still in its infancy. The projects treated here are the authors' own deliverations on studies which have been published, and the authors' recommendations of techniques which they consider are appropriate to the AOSERP study area.

4.1 SAMPLING CONSIDERATIONS

Insect population sampling procedures can be broadly categorized into two types: absolute and relative methods (Southwood 1971). Absolute procedures are designed to collect all the individuals within a defined sample unit. Procedures to extract insects from blocks of soil are absolute methods, although different methods will yield unequal estimates of the true population due to variations in the extraction efficiency of each method (Edwards and Fletcher 1971; Willard 1972). Relative sampling procedures remove an uncertain portion of the individuals in a population. Furthermore, the area from which individuals are drawn is usually not discrete. Light traps are a relative sample method. They collect an uncertain portion of night flying insects from an unidentified area. The catch of a light trap will vary with the weather each night and the trapping radius will vary with the presence of other light sources. It is critical to the success of any biomonitoring program to realize the significance of the differences between these approaches to population sampling.

Sampling programs used for insect pests of cotton in California offer an important lesson about population sampling. Cotton is an economically important crop in California and consequently research monies have been available to researchers for investigations of cotton insect pests for years. An early priority was to devise methods to quickly survey cotton fields for insect pests in order to advise farmers to spray insecticides. Relative sampling devices, such as the insect sweep net and D-vac sampler, were used for extensive surveys (Dietrick et al. 1959). Later, the distribution patterns of Lygus bugs and other pests in cotton fields were examined through the use of relative sampling techniques (Sevacherian and Stern 1972). Recently, these relative sampling techniques were compared to an absolute population sampling method in two cotton fields (Byerly et al. 1978). This study showed that the relative sweep net and D-vac methods did not give the same trends in populations numbers as the absolute sample method.

This well-studied population problem illustrates an inherent danger of relative sampling methods. An assumption by early researchers was that the sample results reflected the true populations of pest insects. These relative sampling techniques collected an inconsistent proportion of the true population. Results which are only approximately reliable in the year that they are collected offer a weak base from which to compare results between years. Weather and other environmental variables will exert as much influence on this type of data as the variable whose effect is to be measured, in this case air pollution. Przybylski's (1974) sweep net data, cited earlier in this report, is challengeable on the basis that sweep net data do not necessarily reflect the true populations of the sampled insects.

Relative sampling techniques are useful to accumulate specimens for an index, such as the diversity of species inhabiting an area. This index then becomes the absolute measure against which comparisons can be made. Numerical results from relative sample techniques are more acceptable for within year comparisons than between year comparisons. For example, ground beetles will be subject to similar weather conditions over a large area, so populations can be pitfall trapped on a localized scale to compare local populations (other environmental factors being equal). However, trap records should not be compared from year to year, except when climatic factors are proven to be similar and the results are drastically different.

Absolute sampling procedures are not totally efficient. These techniques generally require more equipment and labour than relative methods. However, absolute methods provide a more sound theoretical basis for comparison of events from year to year. Population increases of scale insects, for example, can be quantified and compared between years, with measurements of variance to establish probable validity.

Insects change their activity (especially during molting) and form (i.e., pterygote insects) during development, which affect the efficiency of all sampling procedures. Populations in which the age of individuals is distributed with respect to time will have only a portion of their numbers subject to sampling at any point in time for any method which does not sample all age classes (Fulton and Hayes 1977). Biomonitoring techniques should be highly efficient for at least one developmental stage of an arthropod if they are to accurately reflect actual population levels.

Insect sampling in the AOSERP study area should involve methods which have been tested and shown to be effective. Pitfall traps have been proven effective as a relative sampling method for determining activity, abundance, and species diversity in ground dwelling insects (carabids, spiders). Emergence traps have not been previously used in biomonitoring programs for terrestrial insects, but have been tested and used to quantitatively sample adult insect production. Several insect taxa have potential for use as bioindicators; there are drawbacks for others. Economically important insects (bark beetles) could be subjects for study, in addition to insects studied for their potential as bioindicators (scale insects, honey bees). All sampling programs must have spatially isolated sites and be continuous through time (years) to provide a solid data base. This is necessary to allow valid interpretations of the impact of emissions on bioindicator organisms.

4.2 PITFALL TRAPS

A popular, inexpensive, and effective insect sampling technique is the use of pitfall traps. A simple pitfall trap can be a jar buried in the ground with the upper rim flush to the surface. Many modifications have been made to this basic design including funnels soldered onto baby food jars (Esau and Peters 1975), plastic storage containers with slits cut in the lid (Ryan and Hilchie 1980), elaborate molded plastic traps with ramps and a collecting tray (Goulet 1973), and eavestroughs. These traps operate over an extended period of time in a wide variety of habitats and are used by ecologists to sample soil surface faunas (Greenslade 1964; Southwood 1971; McFadyen 1962). Pitfall traps collect both nocturnal and diurnal forms, do not select for rare species or against common species, and give a good indication of surface activity.

Pitfall traps are used to sample active surface dwelling insects, principally carabid and staphylinid beetles, and ground dwelling spiders. Other groups of insects, mostly beetles and some flies, are also collected but less regularly.

Because pitfall traps are highly efficient in collecting ground beetles, many authors (Freitag et al. 1969; Freitag and Hastings 1973; Esau and Peters 1975; Herne 1963; and others) have used this method in biomonitoring programs. The number of traps used in these studies depended on the researcher. Freitag and Hastings used five sites with 100 traps per site, whereas Esau and Peters (1975) used four to five traps per site.

The present authors recommend the use of pitfall traps in an AOSERP biomonitoring program. This type of sampling is effective and comparable between similar sites. The arthropods captured will be primarily carabid beetles, which are well-known both taxonomically and in their response to pollution, and ground dwelling spiders. An expert on spiders is available locally for consultation and species determinations.

In the AOSERP study area, it would be best to use about 10 pitfall traps per site. Extra traps may be laid to anticipate damage caused by wildlife [e.g., several traps were damaged during the insect inventory study of Ryan and Hilchie (1980)]. Results from surplus traps would be used only in the event of damage, thus keeping the sample size constant.

Following the example set by Freitag et al. (1973), a transect of sample sites should be laid through the emission affected area, with a control site beyond the influence of most airborne emissions. The first site would ideally be in the reclaimed area with the remainder placed in natural areas at various prescribed distances from oil extraction plants. Site spacing should be based on a log scale of the distance from the emission source (e.g., 1.0 km, on reclaimed area, 2 km, 4 km, 8 km, 16 km, 32 km, and 64 km in natural areas). The site farthest from the emission source should be designated the control plot; when field data are available it may be decided to use the 32 km site as a second control. This transect should proceed northward from the oil sands plant in order to reduce the effect of any additional emissions and influences from the town of Fort McMurray. This would also permit sample site access by vehicle. Only the control site would require other means of transportation for access. Restricting the sites to a constant elevation and a single type of plant community should reduce between site variation to within acceptable limits. An aspen spruce community is suggested for all but the first sample site. The aspen spruce association is a large, moderately productive floral unit in the AOSERP study area (Peterson and Levinsohn 1977) with a relatively diverse insect fauna (Ryan and Hilchie 1980; Porter and Lousier 1975). Physical constraints (flooding) limit the usefulness of sampling bogs, fens, and other wetland areas with pitfall traps.

Information obtained from pitfall traps will include species composition, relative abundance, and indications of activity periods during the year. Comparisons can be made with the control site inferences drawn as to whether or not emissions from the oil extraction plants are having a positive or negative effect on the insect/arthropod fauna. Comparisons between years will be tenuous until a data bank of information is obtained for within site variation from several years of field work.

Diptera larvae, particularly members of the Chironomidae and Fungivoridae, were the most abundant soil insects in the AOSERP study area, as was revealed by the aquatic O'Connor funnel extractions (Ryan and Hilchie 1980). These larvae were poorly represented in the dry Tullgren funnel extractions. This, and finding the greatest populations of these larvae at the wettest habitats, shows that these insects are semi-aquatic within the soil. Chironomid larvae are usually regarded as aquatic insects. Therefore, this group of insects should be particularly susceptible to any effects of H_2SO_3 and H_2SO_4 in soils due to effects on their food supply and on the insects themselves. It would be difficult to demonstrate anything less than a catastrophic effect on larval populations with soil core extractions because the soil cores sampled are small and time consuming to count, and the results are quite variable. Shifts in the mean numbers and mean biomass of soil insects are difficult to interpret, particularly in view of the known inefficiency of extraction procedures.

The rate of emergence of adult flies from soil reflects the accumulated effects of pollution and natural processes on their larval stages. These emergence rates are clearly revealed by emergence traps. Reductions in the overall emergence rates, or in the emergence rates of members of certain Diptera families, should be quantifiable and subject to statistical validation. The soil area trapped can be large enough to reduce some of the variation found with soil core size samples.

Emergence traps would need to be designed and built for the AOSERP project. Six 1 m^2 traps in two habitats within close proximity to the Syncrude and GCOS plants, and at two similar sites located outside of the normal emission plumes, would provide a suitable data base. These traps should be monitored at about five-day intervals to minimize data losses due to trap damage. Emergence rates should be compared on a short time interval as well as seasonal basis. Insects caught in the traps should be sorted, counted, dried, and weighed.

4.6 HONEY BEES

Honey bees, one of the few types of domesticated insects, can be found in pastures far from pollution sources to rooftop apiaries in urban and industrial areas. The association with man, wide range foraging behaviour, and the large number of individuals per hive have prompted investigators to use honey bees as subjects for pollution studies. Toshkow et al. (1974) used bees to investigate environmental pollution. Tong et al. (1975) conducted analyses of honey from industrial and mining areas as an indicator of pollution. They detected 47 elements in the honey. In relation to SO_2 fumes, Hillmann (1972) reported a reduction in brood rearing and hence a reduction in pollen collection. Hillmann's study is inconclusive: data from the first year showed increased mortality, but this was not found the following year. Bromenshenk (1978) studied the effects of SO_2 on honey bee colonies. Beehives were placed near experimental fumigation plots. From the results, he found no evidence to conclusively support the hypothesis that honey bees are sensitive to SO_2 fumes. Part of the problem with the experiment was that the hives were not placed on the experimental fumigation plots due to incompatability of bees and investigators.

In light of the literature reviewed, honey bees do not appear to be suitable for use in a biological monitoring program in the AOSERP study area. Bees may be useful in the analysis of trace elements collected in nectar, but they appear to show no conclusive response when exposed to SO_2 fumes. An additional serious problem with the use of honey bees in the AOSERP study area would be the probability of destruction of hives by bears.

4.7 SPECIES DIVERSITY INDICES

Insect species diversity can be a useful indicator of changes in environmental conditions. In any given area, insects are represented by a great many species with diverse habits and life histories, which evolved under the natural (normal) conditions of the area. If any change occurs in the environment, some species of insects will be directly affected. This will lead to reductions in the diversity of insect faunas in the affected area.

A program to determine all the insect species inhabitants of the AOSERP study area would provide data to compare with the future fauna of the area. This comparison would permit measurements of any reduction in species diversities, such as the reduction in oligochaete species diversity found in polluted versus unpolluted California estuaries (Howmiller and Scott 1977). However, a broad-scale undertaking will be unlikely to succeed. The systematic relationships of many insect taxa are not well understood, and are continually being reviewed and revised. The total diversity of insects in the AOSERP study area is so great that a broad-scale project would tax the resources of systematists at the Biosystematics Research Institute in Ottawa.

Some taxa have received more attention than others and hence their classification is more stable. Carabid beetles (Lindroth 1961-69), butterflies, and spiders are among the group of arthropods which have been adequately reviewed and stabilized. Experts are readily available to make species determinations for these taxa. It is suggested that individuals in these three taxa should be diligently collected and identified, and a list of the present fauna should be compiled.

4.8 LABORATORY STUDIES

At present there are no laboratory demonstrations of harmful effects of SO_2 and other atmospheric pollutants produced by oil sands extraction procedures. Conclusive links should be established at some stage. Fruit flies (*Drosophila melanogaster* Meigen) reared for several generations in an SO_2 atmosphere could show reduced fecundity compared to control flies. Activity and longevity of adult insects may be impaired by exposure to SO_2. Development could be affected at critical stages, or weight gain may be inhibited. Such responses of test insect populations can be statistically analyzed following repetitions of suitable experiments.

This biomonitoring evaluation emphasizes the detection of changes within the natural ecosystems of the AOSERP study area. Laboratory studies should be considered as a supplement to such ecosystem studies.

5. SUMMARY

A review of the AOSERP literature revealed that the two presently operating oil sands extraction plants are licensed to emit up to 635 t of SO_2 per day into the atmosphere. In addition, large quantities of N_xO_x gas and 72 t of fly ash are being added to the atmosphere daily. More plants will be built which will dramatically increase local atmospheric pollution (unless better emission control devices are installed). The atmospheric transformations, especially of SO_2, and plume patterns of these emissions have been investigated. Fallout concentrations fluctuate and exceed Clean Air Act tolerances at times. Exposure to these higher concentrations is thought to be more biologically harmful than chronic exposure to lower levels.

Most plants are damaged by SO_2 concentrations of 0.2 to 2.5 ppm for 8 h. Ozone is also known to damage plants at concentrations of 0.08 to 0.2 ppm for 8 h. Lichens are known to be sensitive to air pollution and, consequently, a biomonitoring system using lichens has been undertaken in the AOSERP study area. Ecosystems tend to act like a sink for emissions until damage levels are reached, which in highly polluted situations can clear forests and leave only grasses. Insects may be involved as agents in the destruction of injured trees, but their development may also be adversely affected by the unhealthy condition of the trees.

There are few published papers on the effects of pollution on terrestrial arthropods, and some contain more speculation than substantiated experimental results. Pitfall traps have been used to demonstrate that carabid beetle populations have been adversely affected by SO_2 pollution. Ozone did not harm insects in laboratory tests. Lead, fluoride, and hydrocarbons have been shown to adversely affect insect populations. Biocides disrupt insect populations, having their greatest impact on parasites and predators, such as carabid beetles.

Criteria for an effective biomonitoring program at the AOSERP study area are discussed in relation to insect groups known from the area. Sampling techniques which yield relative information about populations are expected to be less useful for long-term comparisons

than absolute population indices. Biomonitoring programs are proposed for carabid beetles and spiders (using pitfall traps), for scale insects, and for pterygote soil insects (using emergence traps). Species lists of carabid beetles, butterflies, and spiders would also provide a biomonitor index to show reductions in diversity. Biomonitoring programs with bark beetles and honey bees are considered but tentatively rejected. Laboratory studies, particularly with SO_2, should supplement ecological research.

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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.		
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.		Alberta Oil Sands Environmental Research Program Interim Report to 1978 covering the period April 1975 to November 1978
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 1.5.2	Air System Winter Field Study in the AOSERP Study Area, February 1977.
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
40.	WS 3.3	Mixing Characteristics of the Athabasca River below Fort McMurray - Winter Conditions
41.	AF 3.5.1	Acute and Chronic Toxicity of Vanadium to Fish
42.	TF 1.1.4	Analysis of Fur 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
45.	VE 3.3	Interim Report on Physiology and Mechanisms of Air-Borne Pollutant Injury to Vegetation, 1975 to 1978
46.	VE 3.4	Interim Report on Ecological Benchmarking and Biomonitoring for Detection of Air-Borne Pollutant Effects on Vegetation and Soils, 1975 to 1978.
47.	TF 1.1.1	A Visibility Bias Model for Aerial Surveys for Moose on the AOSERP Study Area
48.	HG 1.1	Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta
49.	WS 1.3.3	The Ecology of Macrobenthic Invertebrate Communities in Hartley Creek, Northeastern Alberta
50.	ME 3.6	Literature Review on Pollution Deposition Processes
51.	HY 1.3	Interim Compilation of 1976 Suspended Sediment Date in the AOSERP Study Area
52.	ME 2.3.2	Plume Dispersion Measurements from an Oil Sands Extraction Plan, June 1977

53.	HY 3.1.2	Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray
54.	WS 2.3	A Preliminary Study of Chemical and Microbial Characteristics of the Athabasca River in the Athabasca Oil Sands Area of Northeastern Alberta
55.	HY 2.6	Microbial Populations in the Athabasca River
56.	AF 3.2.1	The Acute Toxicity of Saline Groundwater and of Vanadium to Fish and Aquatic Invertebrates
57.	LS 2.3.1	Ecological Habitat Mapping of the AOSERP Study Area (Supplement): Phase I
58.	AF 2.0.2	Interim Report on Ecological Studies on the Lower Trophic Levels of Muskeg Rivers Within the Alberta Oil Sands Environmental Research Program Study Area
59.	TF 3.1	Semi-Aquatic Mammals: Annotated Bibliography
60.	WS 1.1.1	Synthesis of Surface Water Hydrology
61.	AF 4.5.2	An Intensive Study of the Fish Fauna of the Steepbank River Watershed of Northeastern Alberta
62.	TF 5.1	Amphibians and Reptiles in the AOSERP Study Area
63.	ME 3.8.3	Analysis of AOSERP Plume Sigma Data
64.	LS 21.6.1	A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Large Mammals in the AOSERP Study Area
65.	LS 21.6.2	A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Black Bears in the AOSERP Study Area
66.	AS 4.3.2	An Assessment of the Models LIRAQ and ADPIC for Application to the Athabasca Oil Sands Area
67.	WS 1.3.2	Aquatic Biological Investigations of the Muskeg River Watershed
68.	AS 1.5.3 AS 3.5.2	Air System Summer Field Study in the AOSERP Study Area, June 1977
69.	HS 40.1	Native Employment Patterns in Alberta's Athabasca Oil Sands Region
70.	LS 28.1.2	An Interim Report on the Insectivorous Animals in the AOSERP Study Area
71.	HY 2.2	Lake Acidification Potential in the Alberta Oil Sands Environmental Research Program Study Area
72.	LS 7.1.2	The Ecology of Five Major Species of Small Mammals in the AOSERP Study Area: A Review
73.	LS 23.2	Distribution, Abundance and Habitat Associations of Beavers, Muskrats, Mink and River Otters in the AOSERP Study Area, Northeastern Alberta
74.	AS 4.5	Air Quality Modelling and User Needs
75.	WS 1.3.4	Interim Report on a Comparative Study of Benthic Algal Primary Productivity in the AOSERP Study Area
76.	AF 4.5.1	An Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
77.	HS 20.1	Overview of Local Economic Development in the Athabasca Oil Sands Region Since 1961.
78.	LS 22.1.1	Habitat Relationships and Management of Terrestrial Birds in Northeastern Alberta

79. AF 3.6.1 The Multiple Toxicity of Vanadium, Nickel, and Phenol to Fish.

80. HS 10.2 & HS 10.1 History of the Athabasca Oil Sands Region, 1980 to 1960's. Volumes I and II.

81. LS 22.1.2 Species Distribution and Habitat Relationships of Waterfowl in Northeastern Alberta.

82. LS 22.2 Breeding Distribution and Behaviour of the White Pelican in the Athabasca Oil Sands Area.

83. LS 22.2 The Distribution, Foraging Behaviour, and Allied Activities of the White Pelican in the Athabasca Oil Sands Area.

84. WS 1.6.1 Investigations of the Spring Spawning Fish Populations in the Athabasca and Clearwater Rivers Upstream from Fort McMurray; Volume I.

85. HY 2.5 An intensive Surface Water Quality Study of the Muskeg River Watershed. Volume I: Water Chemistry.

86. AS 3.7 An Observational Study of Fog in the AOSERP Study Area.

87. WS 2.2 Hydrogeological Investigation of Muskeg River Basin, Alberta

88. AF 2.0.1 Ecological Studies of the Aquatic Invertebrates of the Alberta Oil Sands Environmental Research Program Study Area of Northeastern Alberta

89. AF 4.3.2 Fishery Resources of the Athabasca River Downstream of Fort McMurray, Alberta. Volume 1

90. AS 3.2 A Wintertime Investigation of the Deposition of Pollutants around an Isolated Power Plant in Northern Alberta

91. LS 5.2 Characterization of Stored Peat in the Alberta Oil Sands Area

92. WS 1.6.2 Fisheries and Habitat Investigations of Tributary Streams in the Southern Portion of the AOSERP Study Area. Volume I: Summary and Conclusions

93. WS 1.3.1 Fisheries and Aquatic Habitat Investigations in the MacKay River Watershed of Northeastern Alberta

94. WS 1.4.1 A Fisheries and Water Quality Survey of Ten Lakes in the Richardson Tower Area, Northeastern Alberta. Volume I: Methodology, Summary, and Discussion.

95. AS 4.2.6 Evaluation of the Effects of Convection on Plume Behaviour in the AOSERP Study Area

96. HS 20.3 Service Delivery in the Athabasca Oil Sands Region Since 1961

97. LS 3.4.1 Differences in the Composition of Soils Under Open and Canopy Conditions at Two Sites Close-in to the Great Canadian Oil Sands Operation, Fort McMurray, Alberta

98. LS 3.4.2 Baseline Condition of Jack Pine Biomonitoring Plots in the Athabasca Oil Sands Area; 1976 and 1977

99. LS 10.1 Synecology and Autecology of Boreal Forest Vegetation in the AOSERP Study Area

100. LS 10.2 Baseline Inventory of Aquatic Macrophyte Species Distribution in the AOSERP Study Area

101. LS 21.1.3 Woodland Caribou Population Dynamics in Northeastern Alberta

102. LS 21.1.4 Wolf Population Dynamics and Prey Relationships in Northeastern Alberta