forestry report

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Toxic substances and the forest environment

Affected understory of a lodgepole pine forest in a particulate elemental sulfur deposition area. Note the yellow block of elemental sulfur in the background (See article page 2.)

The Canadian Forestry Service has had a long-standing interest in industrial emissions and their effects on forest productivity. These effects have been actively investigated by the Northern Forest Research Centre (NoFRC) since the early 1970s. Initially, assessments were carried out by staff of the Forest Insect and Disease Survey, but as public interest in air pollution and the number of sources increased, specialists in air pollution research were recruited.

The first studies were impact assessments that relied almost exclusively on photographically recording the visible symptoms caused by specific pollutants. Much of the symptomology work was synthesized into a manual for the diagnosis of air pollution and natural stress symptoms on forest vegetation in western Canada (Malhotra and Blauel 1980). Gradually, a more quantitative approach was adopted that depended far less on visible symptom development and instead used measured biological and chemical parameters. A laboratory program was developed to investigate biochemical and physiological phenomena associated with air pollution stress.

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In this issue:

Elemental sulfur affects plants

Elemental sulfur is a byproduct that results when hydrogen sulfide is removed from natural gas. Historically, most of the elemental sulfur was poured into blocks for storage, but since the world demand for sulfur increased in 1978, these blocks have been reclaimed by mechanical breakup and melting. Large amounts of particulate elemental sulfur result from block breakup and the production and handling of sulfur products (i.e., prills and slate). This particulate elemental sulfur is deposited in forests downwind of sulfur handling facilities. The sulfur is inert, but through microbial action it forms sulfate and hydrogen ions, which can kill vegetation.

In the Rocky Mountain foothills of west-central Alberta, a lodgepole pine forest adjacent to a particulate elemental sulfur source had 55 times more total sulfur in its soil litter horizon than did the forest of the surrounding region. While the trees do not appear affected, the understory vegetation is dead. The moss is eliminated first, then the forbs and shrubs.

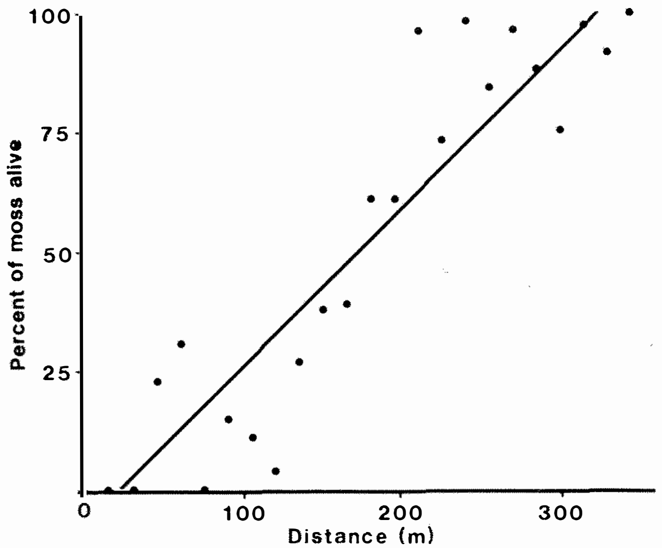
The early death of moss suggested that measurement of the moss might be a potential biomonitoring tool for evaluating the impact and extent of particulate elemental sulfur deposition in a forest. Monitoring the moss involved determining the percentage of moss that was alive and measuring the total sulfur content of the litter soil horizon in a deposition area. The percentage of moss alive increased and the percentage of sulfur in the litter decreased with distance from the particulate elemental sulfur source. The change in the percentage of moss alive was closely related to changes in the total sulfur content of the litter and in fact could be predicted from the total sulfur content of the litter.

These results indicate that moss may be used to monitor the extent of particulate elemental sulfur deposition in a lodgepole pine forest. Use of moss as a biomonitoring tool may also serve to warn of potential damage to forbs and shrubs in these deposition areas.

K.A. Kennedy

Declining percentage cover of vegetation in a particulate elemental sulfur deposition area, 1981-83

Year	Moss	Forb	Shrub	Total
1981	1	10	5	18
1982	0	5	3	8
1983	0	0.1	0.2	0.6



Increasing percentage of moss that is alive with increasing distance from the particulate elemental sulfur source.

Toxic

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Detailed measurements have provided insight into the mechanisms of pollutant impact and the threshold levels of plant response. This combination of laboratory and field studies has made it possible not only to detect and monitor the influence of several large-scale developments in the region but also to determine some of the causes for the responses seen in the field. The laboratory experimentation and analyses have proven to be essential to the interpretation of field observations.

Surveys and assessments of impacts have been carried out at a number of locations in the prairies and Northwest Territories. Detailed studies have been confined to a few types of industrial activity at several specific locations. Virtually all projects have been or are being carried out in cooperation with either provincial governments, industry, or other federal agencies. The Province of Manitoba has supported studies in the vicinity of Thompson and Flin Flon to examine the influence of the mining and smelting industry on the forest ecosystem. A similar study in the Athabasca Oil Sands area was supported by the Province of Alberta. Other projects have also been carried out in cooperation with the oil and gas industry (Canterra Energy Ltd. and Gulf Canada Resources Inc.) near Rocky Mountain House, Alberta, and with Environment Canada's Environmental Protection Service at Uranium City, Saskatchewan.

Study areas of the toxic substances—long-range transport of air pollutants project.

This Forestry Report describes studies of the Northern Forest Research Centre to determine the present and future impacts of industrial development on the native forests of the prairie provinces and Northwest Territories.

P.A. Addison

Reference

Malhotra, S.S; Blauel, R.A. 1980. Diagnosis of air pollutant and natural stress symptoms on forest vegetation in western Canada. Environ. Can., Can. For. Serv., North. For. Res. Cent. Inf. Rep. NOR-X-228.

Acid rain can damage forest systems

Acid rain is a widely acknowledged phenomenon in many industrialized regions of the world. It arises from the emission of sulfur dioxide and nitrogen oxides associated with the combustion of sulfide ores and fossil fuels. The smelting of sulfide ores and the burning of fossil fuels that currently occur within the prairies-Northwest Territories region are sufficient to acidify regional precipitation. Depending on the atmospheric conditions at the time of release, these gases may be transported over many hundreds of kilometres to be eventually deposited as acid rain. The two chief components of the rain are nitric acid and sulfuric acid, which form when gaseous oxides of nitrogen and sulfur are dissolved in rain water.

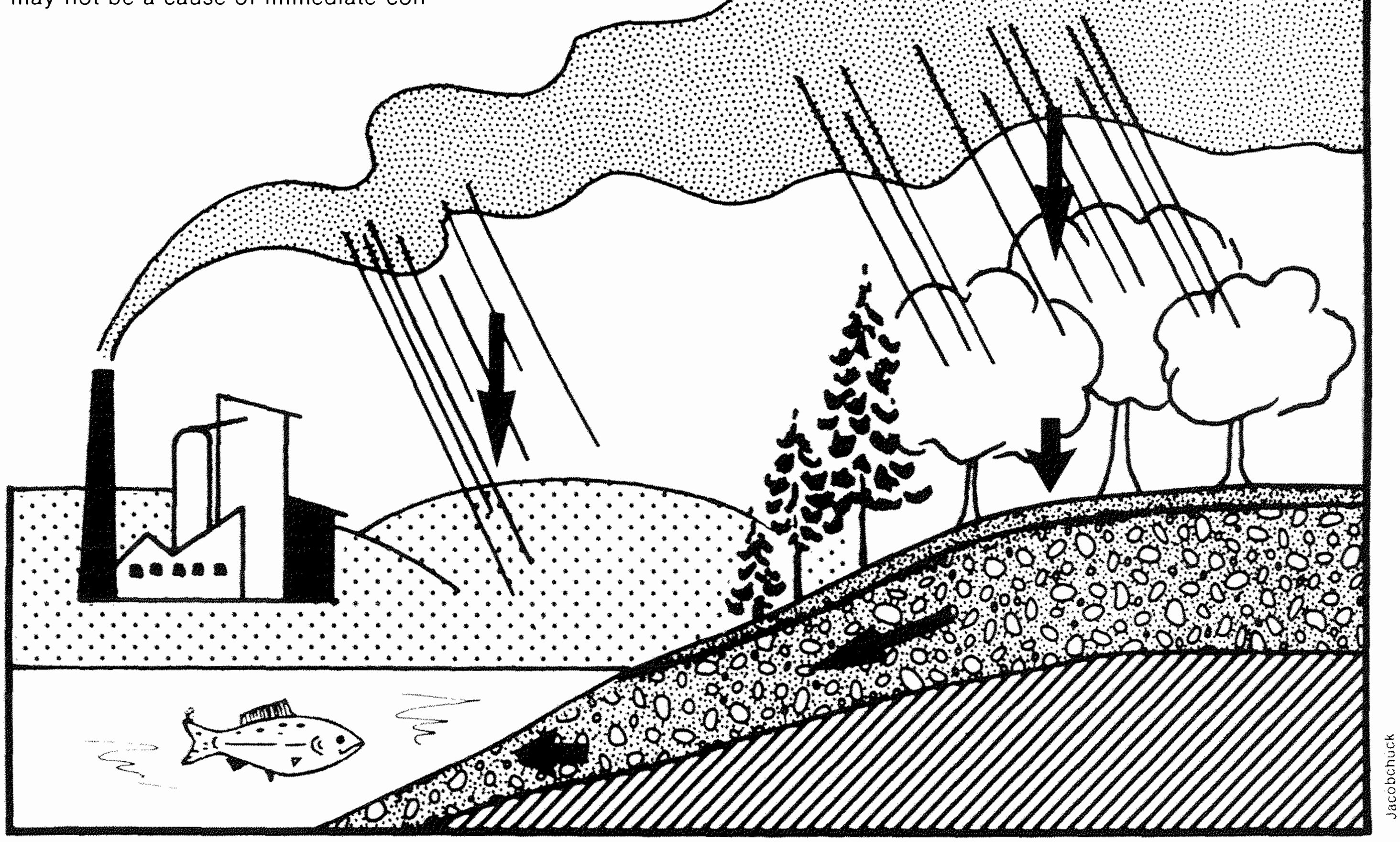
Information from the CANSAP network (Canadian Network for Sampling Precipitation) shows that acid precipitation is not yet widespread within the region. Precipitation acidity is highest in northeastern Alberta and northern Saskatchewan in an area where the sulfate and nitrate deposition is the lowest. These results tend to indicate that the high acidities reported for these areas are not related to industrial emissions but to some other factor. While acid rain may not be a cause of immediate concern in western Canada, it is of national concern because of high acidities in the eastern and Maritime provinces. In these regions, acid deposition levels are 10-50 times greater than the levels experienced in the prairies and Northwest Territories.

Unlike many other pollutants (i.e., sulfur dioxide and ozone), which produce alien stresses that are easily recognized, acid rain affects forests largely by accelerating a number of natural processes. Acid rain has been implicated as an agent that can lead to the increased loss of calcium and magnesium and the mobilization of soil aluminum and iron. This loss of nutrients from the soil system may ultimately bring about changes in forest nutrient status and in this way could have a direct effect on plant growth.

Experimental studies have also shown that it is possible to cause direct injury to trees and shrubs. This injury, which is often related to erosion of the leaf surface, could lead to a loss of forest growth. Acid rain induced injury is currently being investigated at NoFRC and other Canadian Forestry Service laboratories. Recent findings from the Maritimes Forest Research Centre in Fredericton, N.B., indicate that under experimental conditions several economically important tree species are considerably more sensitive to simulated acid rain than was previously thought. This work should obviously be confirmed by further studies, but the conclusions seem to point to a greater potential for direct impact on forest vegetation.

Two factors are currently limiting the potential for damage to forests within our region: first, the low acidity of the rainfall, particularly in the south; and secondly, the low incidence of rainfall in comparison to eastern North America. As the industrial base within the region increases and emissions increase concomitantly, however, the potential for acid rain induced injury will increase.

G.D. Hogan



Emissions of sulfur dioxide and nitrogen oxide from smelters and power plants are deposited as acid rain, which may affect the forest environment.

Biomonitoring of air pollution impacts in the Athabasca Oil Sands forests

In the past, many studies have examined the impact of air pollution on vegetation or vegetational components such as tree growth or chemical composition of plant material. Although there have been hundreds of such studies, almost all have dealt with severely degraded areas. In the Athabasca Oil Sands area of northeastern Alberta, there appears to be very little obvious damage to the forest ecosystem that can be attributed to air pollution. Since there is considerable potential for air pollutants (especially sulfur dioxide) to injure forest ecosystems, it is important that monitoring of forest conditions be carried out in order to assess pollutant impact on the vegetation and soils of the area.

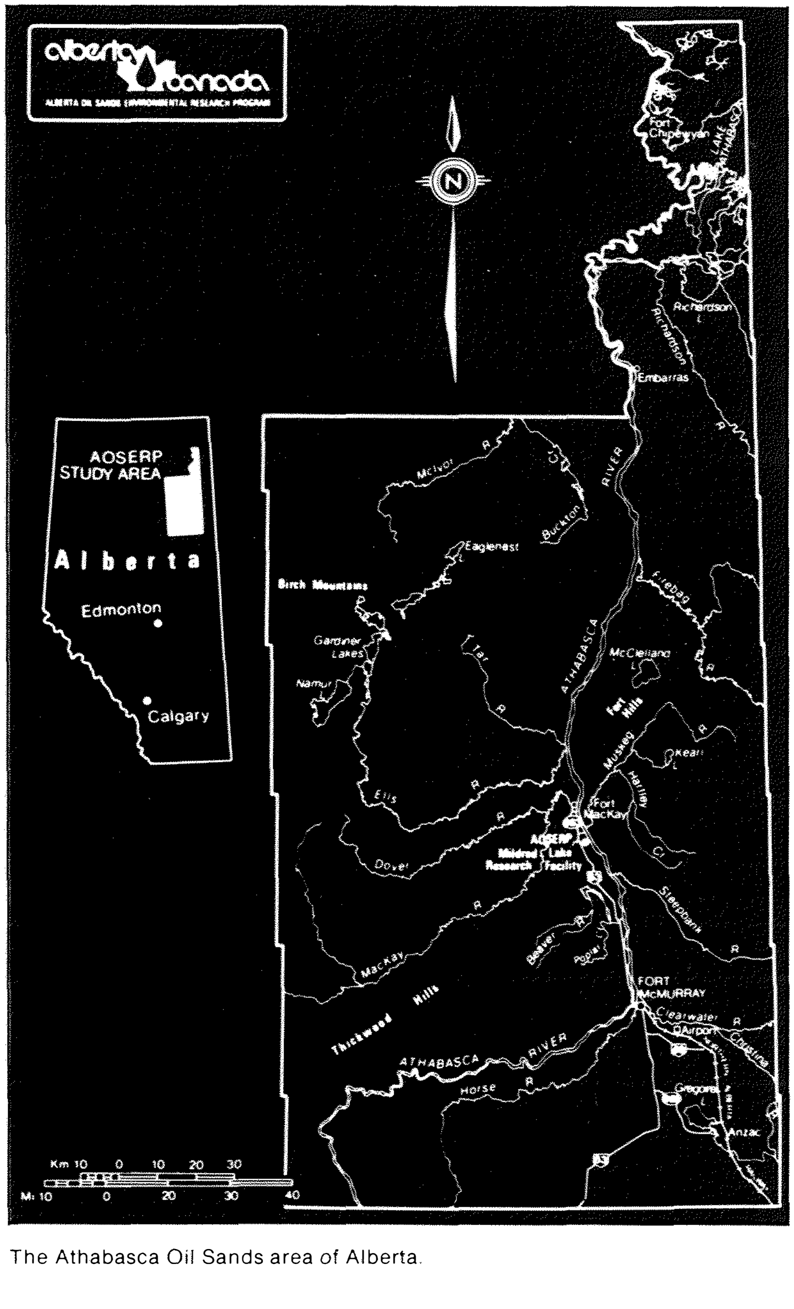
Biomonitoring is a technique whereby biological samples are used as indicators of pollution impingement and as measures of air pollution impact. Obviously, the health of any organism is the best measure of air pollution impact on that species. Biomonitoring may also utilize specific processes or formations of the ecosystem. As with an organism, a process such as decomposition or a plant community response may be the most effective way to assess pollutant impact on these ecosystem components.

Several plant groups, particularly mosses and lichens, have been shown to be sensitive to as well as very efficient in taking up and storing pollutants. If the ecosystem in an area can provide a reliable and consistent measure of both the impingement (deposition) and impact (response) of a specific pollutant or pollutant mixture, the expense of establishing and maintaining high technology monitoring instrumentation can be eliminated in certain cases. This does not mean that air quality measurements will be out of date; quite the opposite. These types of measurements, along with deposition studies, will still be essential for pollution regulation and for testing the reliability of biomonitoring techniques.

Several studies have attempted to use components of the terrestrial ecosystem as indicators of pollution deposition and impact in the Athabasca Oil Sands area. These studies have included the examination of particular groups of organisms such as insects (Hilchie and Ryan 1980) or lichens (Addison and Puckett 1980) as well as soils (Takyi and Nyborg 1977) and vegetation (Addison 1980). The Athabasca Oil Sands area is of particular interest in biomonitoring because of both the potential for long-range transport of air pollutants to Saskatchewan and the large amount of information on air quality and pollution deposition that has been generated by the Alberta Oil Sands Environmental Research Program.

To date, the approach of the Northern Forest Research Centre has been to work with well-defined, permanently marked, and well-documented sites. The advantages of this approach are as follows:

1. It permits simultaneous assessment of numerous factors that may respond to pollutants. This results in greater reliability, because it substantially reduces the possibility of a chance occurrence being interpreted as a meaningful response.
2. It permits the interpretation of one factor through the use of others. For example, discussion of the exposure of a target organism would be meaningless, as would discussion of plant pollutant content without soil analyses and physical measurements of pollutant deposition.
3. It reduces the natural variability that has to be dealt with in all ecosystems by allowing measurements of the same site over time.
4. It permits the establishment of a system that takes into consideration different types and rates of response. Biomonitoring, if it is to be used to provide early warning of pollutant injury to a forest, must use a combination of techniques of differing sensitivities with known relationships between them so that both "What has happened?" and "What will happen?" can be answered.



The Athabasca Oil Sands area of Alberta.

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Changes in soil chemistry influence forest productivity

Soils possess certain chemical, physical, and biological properties unique to the conditions under which they are developed. They are also relatively stable and resistant to short-term changes. Measurable changes in soil properties as a result of weathering or other natural processes may take thousands of years to occur because of the soil's capability to buffer or resist change. The deposition of acid material on forest soils as a result of man's activities may accelerate changes in soil properties that could ultimately affect forest productivity.

Eluviated Dystric Brunisol soil profile.

Field studies are being carried out in lodgepole pine forests of the lower foothills region of the boreal forest where large amounts of elemental sulfur have been deposited onto the surface organic horizon. Elemental sulfur, when oxidized by soil microorganisms, produces sulfuric acid.

In the area of heaviest deposition of elemental sulfur, differences have been observed in the pH and total sulfur concentrations of the litter. The pH is approximately 2 units lower at sites with high levels of elemental and total sulfur. Associated with decreasing pH is a reduction in the concentration of most cations. The cations are more readily leached from the surface organic horizons because of their increased solubility at lower pH and their replacement by hydrogen ions.

Soil nutrients are one of several environmental factors that can exert a significant influence on forest productivity. The litter horizon is important for the long-term supply of nutrients, even though trees may have deep roots. The effective or active roots are probably concentrated in the litter horizon. Although the soil chemical changes observed are not significantly affecting tree growth to date, the loss of nutrients may reduce the long-term productivity and ultimately the survival of the trees at these contaminated sites. In addition, the lowered pH may reduce forest productivity directly through acid effects or indirectly by increasing the availability of elements such as Fe, Al, or certain micronutrients to toxic levels. At this time, observable changes are limited to the surface litter horizon and have not been observed in the mineral soil horizons with the exception of increased sulfur concentrations.

D.G. Maynard

The pH and concentration of sulfur and other elements in the litter horizon of a lodgepole pine forest in west-central Alberta

Distance from S dust source (m)	pH	Elemental S	Total S	Ca	Mg	K	Mn	Al
				(mg/kg)				
50	2.4	35 618	36 500	1 586	421	876	379	4 285
250	3.6	5 881	8 993	7 623	771	1 331	333	5 494
700	4.4	6 109	7 455	15 094	839	1 815	985	5 104

Biomonitoring

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5. It permits comparison of different types of responses and allows testing of the reliability and reproducibility of specific techniques.

The approach, however, is not without disadvantages. Only a small number of sites (<30) can be handled, since the technique is labor intensive. Sites must also be representative of the area. This is a particularly difficult requirement to satisfy in heterogeneous areas. A team approach, which is often difficult to maintain, is essential because of the multidisciplinary nature of the work.

In general, this approach was only partly successful when applied to the Athabasca Oil Sands area of Alberta. It was possible to demonstrate that pollutants characteristic of industrial operations were not distributed evenly (Addison and Puckett 1980). Distinct gradients in soil LFH horizon, native plant element content, and sulfation plates were observed in the vicinity of oil sands operations (Addison 1980). It is expected that precipitation measurements would have also shown the same pattern if it were not for the technical problems encountered.

Demonstration of plant response to the pollutants was much more difficult, however. Long-term measures such as vascular plant community change, soil nutrient change, and tree growth could not be related to pollutant deposition. Some plant responses (such as lichen condition and pollutant content, jack pine seed germination, and lichen community change) were influenced by industrial emissions, but the magnitude of response was not great enough to be of alarm. Vascular plant and lichen physiological responses that were expected to be sensitive were far too variable to be useful without further refinement.

P.A. Addison

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Addison, P.A. 1980. Ecological benchmarking and biomonitoring for the detection of airborne pollutant effects on vegetation and soils. Alberta Oil Sands Environmental Research Program (AOSERP), Edmonton, Alberta. AOSERP Rep. 111.

Addison, P.A.; Puckett, K.J. 1980. Deposition of atmospheric pollutants as measured by lichen element content in the Athabasca Oil Sands area. Can. J. Bot 58:2323-2334.

Hilchie, G.J.; Ryan, J.K. 1980. Approaches to the design of a biomonitoring program using arthropods as bioindicators for the AOSERP study area. Alberta Oil Sands Environmental Research Program, Edmonton, Alberta. AOSERP Rep. 105.

Takyi, S.K.; Nyborg, M. 1977. Sulphur dioxide and acidification of soils in the oil sands area. Pages 1-50 *in* Soil research related to revegetation of oil sands area. Alberta Oil Sands Environmental Research Program, Edmonton, Alberta.

Natural radionuclides part of the environment

The environment has always been exposed to radiation from a variety of sources such as cosmic rays originating deep in space, natural radioactive elements in soils, rocks, and water, and the radionuclides produced continually by cosmic ray interactions in the upper atmosphere. To this natural radioactive background—some of it harmful, some useful and necessary, but all of it present whether man is or not—all living species are exposed.

Industrial activity can add to this natural background. In assessing such activities, the question "What additional amounts of radioactive exposure can people and their surroundings tolerate without harm?" becomes paramount. One such activity, the mining and processing of uranium, is under investigation by the Northern Forest Research Centre. In the mining and milling processes, no radionuclides are actually produced, but the naturally occurring radioactive elements of uranium are physically redistributed and chemically atlered.

Saskatchewan has experienced two periods of intense uranium development. The first, relatively localized in the Uranium City area, came to a close in the early 1960s with the shutdown of more than 24 small mines and two processing mills. Neither environmental awareness nor regulatory standards were highly developed at that time, and most of the closed operations, including the two mills and about 35 ha of exposed tailings, were abandoned with little or no mitigation of their potential impact.

Increased world demand for new energy resources and the discovery of very rich deposits in the Athabasca sandstone formation pushed Saskatchewan into a second growth period in the mid-1970s. The opening of the Rabbit Lake mine just west of Wolloston Lake in 1975 has been followed by a number of other projects, and it is expected that by 1990 as much as 75% of Canada's uranium will come from Saskatchewan.

Development of uranium deposits is now preceded by extensive environmental reviews, regulated by both federal and provincial authorities, and subject to ongoing environmental monitoring. Nevertheless, with such intensified activity, a number of questions about the long-term effects on the forest environment have been raised.

Uranium operations contribute many of the same environmental stresses as other mining operations but have the addition of radiological implications. The tailings that contain the radioactive decay products of uranium, and sometimes thorium, are classified as low-level radioactive wastes. As a consequence, uranium operations are perceived to have a relatively high potential impact on natural ecosystems.

The operations abandoned in the early 1960s provide a clear worst case setting for studying some of these questions. Over the past 20 years, no attempts have been made to reclaim the affected areas. They thus afford an opportunity to study three main mechanisms for uranium-related contaminant interaction with the terrestrial ecosystem:

1. airborne transport to soil and foliage of both wind-eroded particulate matter and gaseous radon-222 with its decay products of polonium-210 and lead-210,
2. surface and groundwater runoff carrying leached radionuclides and heavy metals from exposed waste rock and tailings into the rooting zone of native plants, and
3. bioaccumulation and possible increased availability of radionuclides in the forest vegetation and soils.

Concern for this last mechanism has been expressed with regard to current proposals to revegetate waste areas as a means of reducing the effects of the first two mechanisms.

A review of the current literature resulted in the publication "Airborne radioactive materials and plants: a review" (Joshi 1982). This has been followed by the development of radioanalytical facilities at NoFRC and the initiation of an active field study. These current studies have two objectives:

1. to determine the distribution pattern of material from uranium tailings areas in adjacent forests, and
2. to determine the magnitude of vegetation uptake and accumulation of radionuclides in the vicinity of abandoned mill tailings.

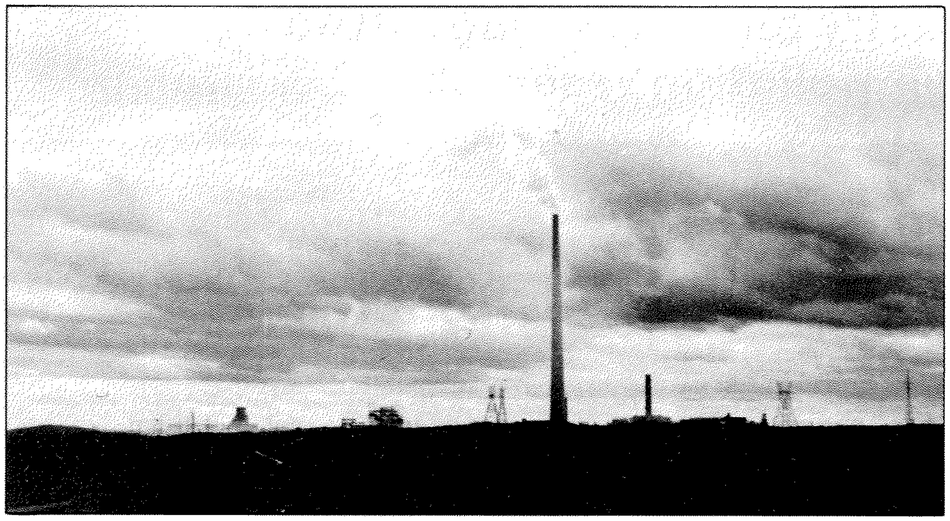
It is expected that this descriptive phase of the study will delineate the critical contaminants associated with the uranium mining industry. The research focus will then be on assessing the potential long-term impact these can have on the boreal forest ecosystem.

M.J. Apps

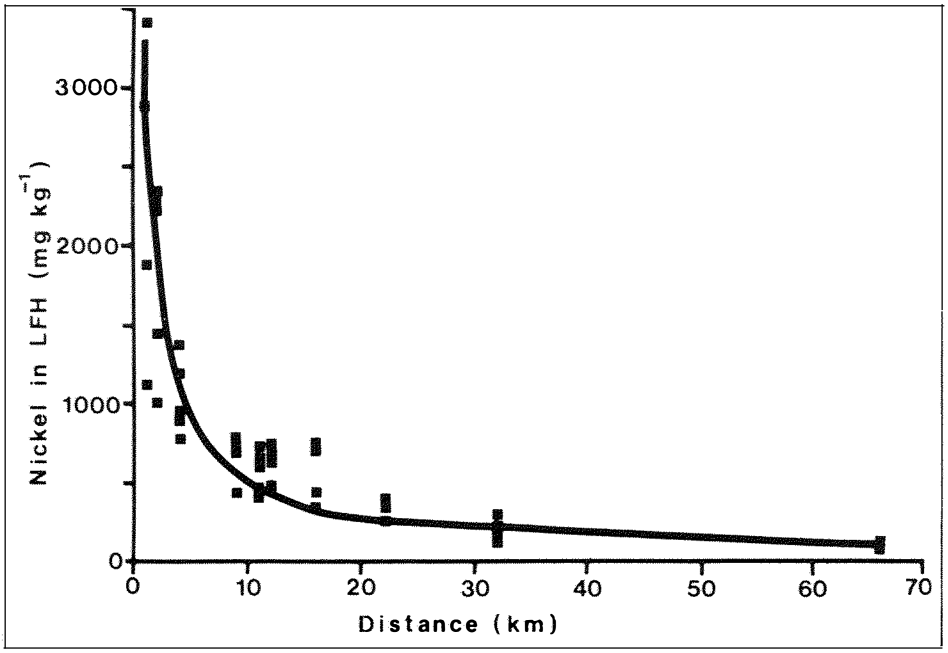
Reference

Joshi, S.R. 1982. Airborne radioactive material and plants: a review. Sci. Total Environ. 24:101-117.

Abandoned Lorado mill and tailings area in northern Saskatchewan.



Smelter and affected vegetation around Flin Flon, Manitoba.



Nickel concentration in the surface litter of the soil drops off quickly with distance from the smelter at Thompson, Manitoba.

Copper and nickel levels near Thompson, Manitoba, are high enough to reduce the growth of jack pine seedlings.

Metal particulate emissions affect forest systems

Smelter stacks are usually associated with sulfur dioxide or acid, but these are not the only pollutants that originate from these sources. Metal particulates are a group of pollutants that are emitted from smelter stacks as fine dusts along with sulfur gases during the smelting of metallic ores. Mining and smelting companies are required to capture particulates from their stack gases. The equipment used, however, and the operating conditions often do not allow for the complete recovery of these substances. Typical emissions of particulates from smelter stacks may be in the region of 10 to 30 tonnes/day. The particulates are usually greater than 5 to 10 μm in size, but a significant portion are less than 5 μm. This is a characteristic that allows them to travel great distances when released from the stack.

Most particulates do not travel great distances, however, but fall onto vegetation and soil surfaces within a few kilometres of the smelter. The second figure shows the accumulation of nickel within the surface soil around a smelter at Thompson, Manitoba. The levels of nickel within a radius of 5 km of the stack are 20 to 30 times higher than the levels found in normal soils.

The presence of high levels of metals such as cadmium, copper, lead, nickel, and zinc (sometimes referred to as the heavy metals) is a real threat to forest communities adjacent to major mining and smelting operations. Research has shown that high accumulations of these metals in soils can cause reductions in tree growth through tree root mortality and reduced nutrient turnover. The high levels of nickel and copper in soils from Thompson (Plot 10) can cause seedling toxicity, thereby inhibiting the ability of seedlings to regenerate these sites. If emissions continue at the present rate, the forests in these areas would become overmature and could not be replaced by a younger productive forest without extensive site treatment. Investigations by NoFRC staff at Thompson and Flin Flon, Manitoba, have shown that areas within a 5 km radius of the stacks would be extremely difficult to regenerate because of high soil metal levels.

G.D. Hogan

Biochemistry and physiology used in air pollution research

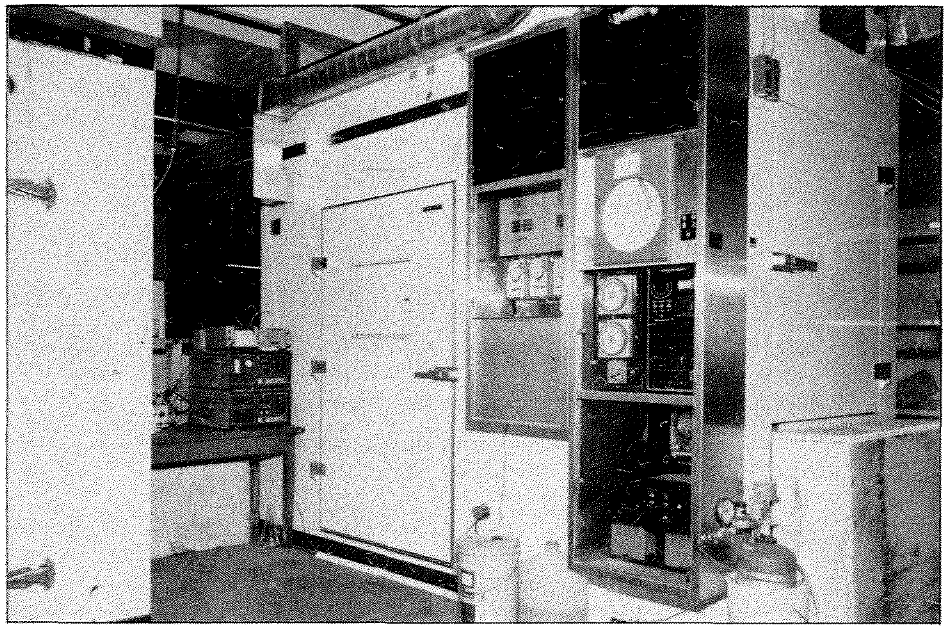
Laboratory examination of physiological and biochemical responses of tree seedlings to sulfur dioxide fumigation is a necessary step in understanding the potential effects of sulfur dioxide pollution on trees in the boreal forest. Under controlled conditions, trees can be selectively exposed to various concentrations of sulfur dioxide for predetermined lengths of time. Their responses can be easily measured and related to conditions they might experience in the field. Some of the responses that have been measured include enzyme activities, sugar content, sulfur uptake, chlorophyll content, photosynthesis, and leaf conductance to water loss. All of these variables have some effect on the metabolic functioning of trees and therefore influence growth rates and survival.

The response of four variables to short-term sulfur dioxide fumigation is shown in the table. Leaf conductance, which decreased as sulfur dioxide concentration increased, controls the entry of gases into pine needles as well as the exit of water vapor (transpiration). When leaf conductance is low, the stomata (pores) on the needles are closed, stopping transpiration and preventing entry of carbon dioxide for photosynthesis. Xylem tension reflects the internal water status of seedlings. The decrease in xylem tension after sulfur dioxide fumigation is a result of the decrease in transpiration caused by stomatal closure but may also indicate cell damage.

Photosynthetic activity and breakdown of carbohydrates control the levels of fructose (a simple sugar) in leaf tissue. Increased sulfur dioxide concentrations resulted in lower fructose levels, mainly because of lower photosynthetic rates after stomatal closure. Sulfur content in leaf tissue increased as sulfur dioxide concentration increased, but as the stomata closed, the increases were not as large. The relationships among these variables show how short-term sulfur dioxide fumigation can result in a series of responses that determines how much damage the plants will suffer.

When relationships among physiological responses have been quantified in the laboratory, this information can be used to predict the response to air pollution of trees in the field. Estimation of the amount of past damage can also be made, keeping in mind that all field measurements must be done carefully and with enough replication to reduce the problem of natural variation.

S.J. L'Hirondelle



Controlled environment facilities allow monitoring of temperature, light, relative humidity, and pollutant concentration.

Effect of 24 hours of sulfur dioxide exposure on physiological responses of 10-week-old jack pine

SO_2 concentration (ppm)	Leaf conductance (cm/s)	Xylem tension (kPa)	Fructose content (mg/g DW[a])	Sulfur content (mg/g DW)
0	0.200	1040	18.1	2.08
0.1	0.188	1020	15.5	1.92
0.4	0.158	700	13.2	2.75
0.6	0.038	310	11.8	3.04
1.0	0	230	11.1	3.11

[a] DW = dry weight.

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