REGIONAL COPPER-NICKEL STUDY:

THE EFFECTS OF SMELTER EMISSIONS ON FOREST TREE PRODUCTIVITY

MINNESOTA ENVIRONMENTAL QUALITY BOARD
REGIONAL COPPER-NICKEL STUDY

Author: Barbara Coffin

Contributing Editors: Gerald A. Lieberman
William A. Patterson

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INTRODUCTION TO THE REGIONAL COPPER-NICKEL STUDY

The Regional Copper-Nickel Environmental Impact Study is a comprehensive examination of the potential cumulative environmental, social, and economic impacts of copper-nickel mineral development in northeastern Minnesota. This study is being conducted for the Minnesota Legislature and state Executive Branch agencies, under the direction of the Minnesota Environmental Quality Board (MEQB) and with the funding, review, and concurrence of the Legislative Commission on Minnesota Resources.

A region along the surface contact of the Duluth Complex in St. Louis and Lake counties in northeastern Minnesota contains a major domestic resource of copper-nickel sulfide mineralization. This region has been explored by several mineral resource development companies for more than twenty years, and recently two firms, AMAX and International Nickel Company, have considered commercial operations. These exploration and mine planning activities indicate the potential establishment of a new mining and processing industry in Minnesota. In addition, these activities indicate the need for a comprehensive environmental, social, and economic analysis by the state in order to consider the cumulative regional implications of this new industry and to provide adequate information for future state policy review and development. In January, 1976, the MEQB organized and initiated the Regional Copper-Nickel Study.

The major objectives of the Regional Copper-Nickel Study are: 1) to characterize the region in its pre-copper-nickel development state; 2) to identify and describe the probable technologies which may be used to exploit the mineral resource and to convert it into salable commodities; 3) to identify and assess the impacts of primary copper-nickel development and secondary regional growth; 4) to conceptualize alternative degrees of regional copper-nickel development; and 5) to assess the cumulative environmental, social, and economic impacts of such hypothetical developments. The Regional Study is a scientific information gathering and analysis effort and will not present subjective social judgements on whether, where, when, or how copper-nickel development should or should not proceed. In addition, the Study will not make or propose state policy pertaining to copper-nickel development.

The Minnesota Environmental Quality Board is a state agency responsible for the implementation of the Minnesota Environmental Policy Act and promotes cooperation between state agencies on environmental matters. The Regional Copper-Nickel Study is an ad hoc effort of the MEQB and future regulatory and site specific environmental impact studies will most likely be the responsibility of the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency.

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ABSTRACT

The literature is reviewed concerning the effects of atmospheric pollutants on forest productivity. This issue is particularly important for northeastern Minnesota where a large percentage of the land is currently being managed for timber by the USFS. Research has been conducted both in North America and northern Europe. Results from these studies suggest a direct relationship exists between decrease in forest productivity and proximity to a pollutant source. Most studies cannot be considered conclusive, it is difficult to experimentally control all potentially influential variables. There is a need for carefully designed studies that would conclusively define the type of relationship that exists between atmospheric pollutants and forest productivity.

INTRODUCTION

The interaction between atmospheric pollutants and forest productivity is a concern both ecologically and economically. This issue is of particular importance because of the high percentage of land that is forested in northeastern Minnesota (approximately 82 percent in the Regional Copper-Nickel Study Area). Timber production is the prime economic use of these forested lands.

The effects of emissions from smelter stacks on forest growth is poorly understood. Research has been conducted both in North America and in northern Europe. Studies have been of two kinds: regional (e.g. eastern United States, southern Sweden); and local (i.e. a study of the area adjacent to a pollutant source). The results from these studies are used in this paper as indicators of general trends. In most instances the investigations are based on phenomena that occurred before the start of the investigation in a situation where few, if any, potentially influential variables were experimentally controlled. Thus, the studies are of a nonexperimental nature with all the implied statistical problems (Jonsson and Sundberg 1972). Causal relationships based on these data cannot be considered conclusive. However, the evidence thus far gathered should not be ignored. The inference suggests a potential for direct relationship between decrease in forest productivity and proximity to a pollutant source.

HISTORICAL BACKGROUND

Studies of Local Effects

One of the first studies to relate the presence of air pollutants to forest productivity was conducted by Lathe and McCallum (1939). The effect of sulfur dioxide (SO_2) on the diameter increment of conifers was studied in an area surrounding two smelters located in British Columbia, Canada. Three conifers, douglas fir (Pseudotsuga menziesii [Mirb.] Franco), yellow pine (Pinus ponderosa Laws.), and lodgepole pine (Pinus contorta Dougl.) were monitored. Increment cores were obtained from the trees and annual rings were measured and correlated with emission levels and climatic variables. The growth of all three species was found to be substantially reduced in areas where the effect of smoke from both smelters had been clearly observed.

Linzon (1966) found eastern white pine (Pinus strobus L.) to be severely damaged by atmospheric SO_2 up to distances of 25 miles northeast of copper smelters in Sudbury, Ontario. The damage to white pine was assessed by chemical analysis of foliage and bark, observation of biological injuries, tree mortality, and measurement of radial and volume growth decrement. The increment boring studies demonstrated a decrease in growth in the trees sampled in areas adjacent to the smelters while control trees maintained a constant pattern. The locations of the trees sampled is described according to the distance and direction from the town of Sudbury, Ontario (Table 1). The economic implications of this study are discussed in more detail in the section titled "Economic Implications."

Growth-damage to conifers in northern Sweden caused by atmospheric pollution from a sulfite plant was studied by Westman (1974). The change in annual growth rings was estimated by using growth quotients and multiple regression analysis for both spruce and pine. The growth quotient relates natural growth rates (determined by such factors as age, heredity, space, site-quality, and local climate) to the observed growth rates. The quotient is determined by relating growth during a period of high pollution to a reference period when pollution is low. The multiple regression analysis was designed to rate the importance of many different variables (e.g. pollutants, altitude, exposure, density, site quality, height and age of trees) to the growth patterns. Reduction in plant growth could be detected up to ten km from the sulfite plant. The growth reduction was most dramatic in the areas immediately adjacent to the plant. However, there were some discrepancies that complicate this pattern. The spruce located in plots to the west of and closest to the sulfite plant showed an increase in growth. Westman hypothesized that smoke from the factory's bark furnaces may contribute substances which stimulate growth.

The effects on tree growth of low-level sulfur dioxide emissions from a copper smelter in White Pine, Michigan, were studied by Kotar (manuscript). Growth patterns were determined for balsam fir (*Abies balsamea* [L.] Mill.), white spruce (*Picea glanca* [Moench] Voss), and trembling aspen (*Populus tremuloides* Mich.). Measurements showed a substantial reduction in the growth of balsam fir and white spruce on sites located downwind from the smelter. Trembling aspen, a species known to be sensitive to SO_2, demonstrated no particular change from its expected growth pattern. These results must be considered inconclusive until more comprehensive research can be conducted.

There are two radial growth studies being conducted in Minnesota. Grether (1975) is studying radial growth of white pine in the environs of the Allen S. King generating plant at Stillwater. To date he has found no relationship between decreased growth and proximity to the generating plant.

A study of red pine (Pinus resinosa Ait.) radial growth is being conducted in the vicinity of the Clay Boswell Station at Cohasset, Minnesota (MPCA, 1977). The results indicate that emissions for this plant have not significantly affected the growth rate compared with other influencing factors.

Studies of Regional Effects

Jonsson and Sundberg (1972) conducted a study to determine if acidification due to atmospheric pollution has caused a growth reduction in forests of southern Sweden. Their studies showed that trees growing on sites more susceptible to acidification (i.e. a soil type that is susceptible to acidification and is close to a pollution source) did show a poorer growth development than did trees on less susceptible soils during the two decades immediately before 1965. Statistical analysis indicated that the observed differences cannot be explained by random variation. Other explanations for the difference in growth between these two regions were studied (e.g. different natural growth trends, different microclimate, different silvicultural practices), and care was taken to control as many variables as possible. The investigators felt it valid to give only an impression of the order of magnitude of the average annual growth reduction during the period 1951 to 1965. Jonsson and Sundberg proposed values of 0.3 and 0.6 percent as a reasonable approximation, and concluded that acid rainfall probably is decreasing forest productivity. It is not yet possible to establish quantitatively the magnitude of this effect, however, and the authors suggest that further studies are needed to clarify this question.

Air pollution and its effect on the forests of California have been the object of considerable study. As in most other studies of forest productivity, the loss has not yet been quantified, but there has been considerable work done (Miller and Millecan 1971; Miller 1969) on identifying the symptoms and the extent of damage.

The mixed conifer forest of the San Bernadino Mountains outside of Los Angeles are being damaged by photochemical oxidant air pollution. Ponderosa pines are showing symptoms including needle drop, yellow mottle, and dying branches. Distinct growth reductions have been observed on trees that are less severely affected. Additional complications arise because trees weakened by pollutant damage are easy prey for natural enemies (i.e. several species of pine bark beetle).

The effect of acid precipitation on tree growth in eastern North America was studied by Cogbill (1976). Trees were sampled in the White Mountain National Forest of New Hampshire and the Great Smokey Mountains National Park of Tennessee. Trees were cored for tree-ring analysis and measured for diameter class. Data were analyzed by multiple-regression using precipitation and temperature parameters as independent variables. The pattern and historical trends of acid precipitation were compared to measured growth trends. The radial increment studies showed no regional, synchronized decrease. The basal area increment did show a slight recent decrease which was neither dramatic nor without precedent, but acid precipitation cannot be dismissed as a possible causal agent. Cogbill concludes that, due to the unknown initiation date of acid precipitation and the large variation of tree growth estimates, a correlation of forest growth and acid precipitation in eastern North America cannot at present be established.

Methods for Analyzing Nonclimatic Variations in Radial Tree Growth

Methods for analyzing nonclimatic variations in radial tree growth are discussed by Lathe and McCallum (1939), Linzon (1966), Jonsson and Sundberg (1972), Westman (1974), Cogbill (1976), and Kotar (manuscript). Both Holm and Sundberg (1975) and Nash et al. (1975) have published papers specifically describing a technique for examining nonclimatic variations in widths of annual tree rings. The method of Holm and Sundberg (1975) is based on a multiplicative model of growth, determining the change that has occurred since the onset of the interference in growth by estimated growth quotients. The method used by Nash et al. (1975) involves making adjustments for climate as inferred from a chronology developed for the surrounding region.

ECONOMIC IMPLICATIONS

To date there has been only one study that has attempted to quantify decreases in forest growth in terms of economic loss. Linzon (1971) studied the effects and economic impact of SO_2 on forest growth in the Sudbury, Ontario area. Eastern white pine was chosen as an indicator species because of its known sensitivity to sulfur dioxide and its high commercial value as a timber crop. Inner, intermediate, and nonfume zones were established for the Sudbury area based both on degree of tree injury and concentration of SO_2 (Table 1). Study plots were distributed throughout the three zones. In the inner fume zone trees died at an average annual rate that is three times greater than in the outer fume zone and two times greater than in the intermediate zone. Radial increment growth studies showed that white pines in areas adjacent to the smelters exhibited a gradual growth decline, whereas a constant pattern was maintained in control areas. Determinations of volume growth of white pine supported the patterns of tree mortality and radial growth. There was a net average annual loss in volume growth.

The loss in income to people involved in the wood industry was estimated by utilizing the volume growth data.

> ...In the Inner Fume Zone there was a net average annual loss in total volume of 0.10 cu ft per white pine tree in the 7-12 in DBH class due to the combination of trees dying from unknown causes and reduced growth of surviving trees. In the Non-Fume Zone each tree added 0.30 cu ft in total volume per year. Together this represents a loss of 0.40 cu ft in total volume per tree per year in the Inner Fume Zone. Since net merchantable volume is estimated to be approximately 50% of gross total volume for sawlogs, the white pine trees experienced a loss of 0.20 cu ft per tree per year in the Inner Fume Zone ... White pine stands exist on only 7.6% of the total productive forest area in the Sudbury district ... Using the figure of 7.6%, then 27.6 sq mi, or 17,510.5 acres of the total productive forest area in the Inner Fume Zone is composed of white pine. On each acre it is assumed that there would be 50 white pine trees in the 7-12 in DBH class. Since it was found that each white pine tree lost 0.20 cu ft in net merchantable volume per year; this would be equivalent to a loss of 10 cu ft per acre per year in the Inner Fume Zone. On 17,510 acres, this would represent a loss for white pine of 175,104 cu ft, net merchantable volume. Assuming 5.35 board ft/cu ft, this would represent a loss of 936,806 board ft, net merchantable volume, per year, for white pine ... In the Sudbury area stumpage dues are $0.08/cu ft. Since 175,104 net merchantable cu ft of white pine were estimated to be lost each year in the Inner Fume Zone, this would represent a loss of $14,008 annually in stumpage dues. If a valuation of $125 per 1000 board ft was assumed as a white pine lumber price f.o.b. mill, then $117,100 was lost each year to producers, or $1,171,000 was lost during the 10-year period 1953-1963 (Linzon 1976).

Thus, for white pine alone, there is an estimated loss of $117,000 annually within the Inner Fume Zone.

This study and the figures calculated must be viewed in the appropriate historical framework. The study was conducted in the Sudbury region during the 1950s and 1960s, before the installation of tall smelter stacks. It is most likely that emission levels from a smelter built in northeastern Minnesota would differ greatly from those at Sudbury. There are many factors which make extrapolation from Linzon's study to a prediction of what might happen in northeastern Minnesota very difficult. New technology has dramatically reduced the emission levels of smelters. In addition, Linzon's conclusions were based on SO_2 measurements averaged over a ten-year period. Thus, the results do not distinguish between the importance of low long-term levels of atmospheric pollution and high short-term levels of atmospheric pollution. This makes it difficult to determine which concentration level is important in understanding damage to forest trees.

A study was conducted to estimate growth response of spruce and pine in the forests surrounding an oil-shale industrial plant in Kvarrntorp, Sweden. Estimates of growth reduction were made on three separate occasions, 1948-1950, 1953, and 1958 (Statens Skogsforskiringsinstitut, 1950 in Tamm and Aronsson 1972). Average monthly SO_2 concentrations were correlated with annual growth patterns. Tamm and Aronsson (1972) analyzed the data and concluded that growth is reduced by 3 percent when ambient concentrations of SO_2 range between 39 $\mu g/m^3$ and 52 $\mu g/m^3$ and by about 20 percent when the concentration is about 79 $\mu g/m^3$. These estimates of annual percent loss in forest productivity have been used in a separate report (see Regional Copper-Nickel Study: Forest Productivity in the Superior National Forest Outside of the BWCA) to estimate, on a general level, the loss that might be anticipated in northeastern Minnesota.

CONCLUSION

The interaction between atmospheric pollutants and forest productivity is a complex issue, requiring knowledge of emission levels and dispersion patterns of atmospheric pollutants and the physiological response of tree species to these pollutants. It is useful to look at forests for several reasons: 1) they are widespread; 2) they can be indicators of contamination and alteration of an ecosystem; and 3) they are an economically important crop.

An understanding of the potential effect of emitted pollutants from smelters located in northeastern Minnesota on forest productivity is dependent on careful interpretation of dispersion and deposition models and as a means for quantitatively predicting the growth response of trees to varying pollutant levels. Dispersion and deposition models are available for the proposed mining developments (see Regional Copper-Nickel Study: Air Quality Report). However, the data for predicting the physiological responses of trees are not readily available.

The literature on this subject is scanty and not without experimental problems. The research that has been conducted cannot be accurately applied to northeastern Minnesota. For these reasons, predictions as to the extent of economic loss that would occur due to the interaction of pollutants and forest systems must be interpreted only as trends. General estimates of the potential for decrease in forest growth due to copper-nickel mining in northeastern Minnesota have been calculated and summarized in a separate report (see Regional Copper-Nickel Study: Forest Productivity in the Superior National Forest Outside of the BWCA) based on the results of a Swedish study. This issue is particularly important for northeastern Minnesota, where a large percentage of the land is currently being managed for timber by the USFS. It is clear that there is a need for carefully designed studies that would conclusively define the type of relationship that exists between atmospheric pollutants and forest productivity.

Table 1. Location of sample areas and their arrangement according to distance and direction from Sudbury, Ontario.

SAMPLE AREA	NUMBER OF PERMANENT SAMPLE PLOTS, ACRES	TOWNSHIP LOCATIONS	DISTANCE AND DIRECTION FROM SUDBURY
West Bay	3	Norman	19 miles NE
Portage Bay	4	Rathbun	25 miles NE
McCarthy	2	McCarthy	32 miles NE
Emerald Lake	10	Afton, Clement, and Scholes	43 miles NE
Bear Island	4	Joan	58 miles NE
Goward	2	Strathy	71 miles NE
Lake Panache	3	83 and Indian Reserve No. 6	23 miles SW
Lake Matinenda	4	161	93 miles W
Mattawa	10	Mattawan, Papineau, and Calvin	110 miles E

Table 2. Average half-hour sulfur dioxide concentration over total period of machine operation (1954-63).

MACHINE LOCATION	DISTANCE AND DIRECTION FROM SUDBURY	YEARS OF OPERATION	SULFUR DIOXIDE MEAN, PPM
Skead	16 miles NE	10	0.045
Garson	4.8 miles NE	10	0.034
Kukagami	26.8 miles NE	10	0.017
Burwash	17.2 miles SE	10	0.016
Callum	18.2 miles E	2	0.014
Rayside	9.0 miles NW	7	0.012
Panache	22.2 miles SW	10	0.009
Grassy	40.4 miles NE	10	0.008
Morgan	15.4 miles NW	3	0.005
St. Charles	30.0 miles SE	7	0.004

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