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THE RELATIONSHIP OF AN INSECT INFESTATION ON LODGEPOLE PINE TO FLUORIDES EMITTED FROM A NEARBY ALUMINUM PLANT IN MONTANA

by

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ABSTRACT

Stepwise multiple regression techniques were used to statistically analyze the relationships between damage caused by the pine needle sheath miner *Zellaria haimbachi* (Busck); a needle miner, *Ocnerostoma strobivorum* (Zeller); sugar pine tortrix, *Choristoneura lambertiana* (Busck); and ambient and foliar concentrations of fluoride in lodgepole pine (*Pinus contorta* v. *latifolia* Engelm.) near the Anaconda Aluminum Company at Columbia Falls, Montana. Foliar fluoride concentration was significantly related (0.01 level) to needle miner damage and to damage caused by the pine needle sheath miner. The data strongly indicate that fluoride is a contributing factor in predisposing pines to damage by these insects.

INTRODUCTION

The Environmental Protection Agency (1973) in 1970 studied fluoride emissions from the Anaconda aluminum plant near Columbia Falls, Montana. They showed that fluorides were carried in the air from the aluminum plant northeastward toward Glacier National Park. Injury to vegetation was observed throughout the area in which airborne fluorides were found. Gordon (1972) showed that forest vegetation over a wide

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area from Columbia Falls, Montana, to Logan Pass in Glacier National Park accumulated abnormally high amounts of fluoride and showed varying amounts of injury. In addition, he showed that animals feeding on contaminated vegetation accumulated high quantities of fluoride in skeletal tissue. Carlson and Dewey (1971) showed that excessively high amounts of fluoride were found in vegetation over about 200,000 acres in the area, and that visible fluoride injury could be found over about 69,000 acres. The most severe injury was found on lodgepole pine (*Pinus contorta* var *latifolia* Engelm.), ponderosa pine (*Pinus ponderosa* Laws.), and western white pine (*Pinus monticola* Dougl. ex D.). Within 30,000 acres of the 30 isopol[2/] east of Teakettle Mountain, a severe insect infestation was detected on the lodgepole pine. It was estimated in 1970 that about 50 percent of the visible injury on lodgepole in this area was caused by fluoride and about 50 percent was caused by insects. The defoliating insects were identified as pine needle sheath miner, *Zellaria haimbachi* (Busck); a needle miner, *Ocnerostoma strobivorum* (Zeller); pine needle scale, *Phenacaspis pinifoliae* (Fitch); and the sugar pine tortrix, *Choristoneura lambertiana* (Busck).[3/]

This complex infestation began with sugar pine tortrix reaching epidemic levels in 1967 (McGregor, 1968, 1969). He noted that although tortrix populations and resultant defoliation decreased from 1967 to 1968, populations of the pine needle sheath miner increased. This occurred during the same period that the Anaconda Company increased their capacity by two potlines resulting in more than 7,500 pounds of fluoride per day being emitted to the atmosphere and carried directly by the prevailing wind currents to the area infested by insects.

The association between the insects and fluoride was quite striking. The infestation expanded to nearly 150,000 acres in 1973 and was contained primarily within the area in which vegetation accumulated fluoride emitted by the aluminum plant. The most serious insect damage appeared to be within the area moderately influenced by fluorides. Interestingly, little insect damage was found close to the aluminum plant where high amounts of fluoride prevailed in the atmosphere and vegetation.

Lodgepole pine forms nearly pure stands over nearly 50 percent of the area influenced by insects and fluoride. Much of the land east of Teakettle Mountain is highly productive and capable of growing

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2/ That area over which foliage contained more than 30 parts per million fluoride, dry weight basis.

3/ Identified by W. D. Duckworth and R. W. Hodges, U. S. National Museum, Beltsville, Maryland.

valuable commercial timber in a relatively short period of time.[4/] It was important to know what relationship, if any, existed between the insects and fluoride. The objective of this study was to determine if significant correlations existed between atmospheric fluoride, pine needle tissue fluoride concentration, fluoride injury on needles, and damage caused by four insect species.

MATERIALS AND METHODS

Thirty-six plots were randomly distributed in lodgepole pine stands throughout the area moderately and lightly influenced by fluorides (between the 10 and 100 isopols as shown by Carlson and Dewey, 1971) (fig. 1). No plots were put within the area included by the 100 or greater isopols because of a lack of lodgepole pine stands. Four control plots were placed in areas not influenced by airborne fluorides: two 30 miles south of Columbia Falls in the Swan River valley and two 20 miles west of Kalispell, Montana, near Rogers Lake. All plots were referenced to existing road systems. At each plot location five lodgepole pine between 20 and 40 feet in height (dominant and codominant trees on the site) were selected as sample trees. The nearest neighbor technique (Gabriel, 1972) was used in tree selection to reduce personal bias. In all, 200 trees were sampled. Sample trees at each plot were then classified, based on condition as affected by both insects and fluoride:

Tree class	Vigor description
0	No apparent insect feeding or fluoride damage. Needle retention normal in appearance.
1	Some damage evident; tree crowns becoming thin or light insect activity visible. Needle retention below normal.
2	Damage by insect feeding quite evident or crown thin. Needle retention may be poor.
3	Heavy insect damage evident. Excessive insect feeding visible. Crowns thin and needle retention poor.

From each of the sample trees on each plot four branches 18-20 inches in length were removed from midcrown with extendable pole pruners equipped with a basket just below the cutting head to catch the

4/ Personal communication with the Flathead National Forest, 1973.

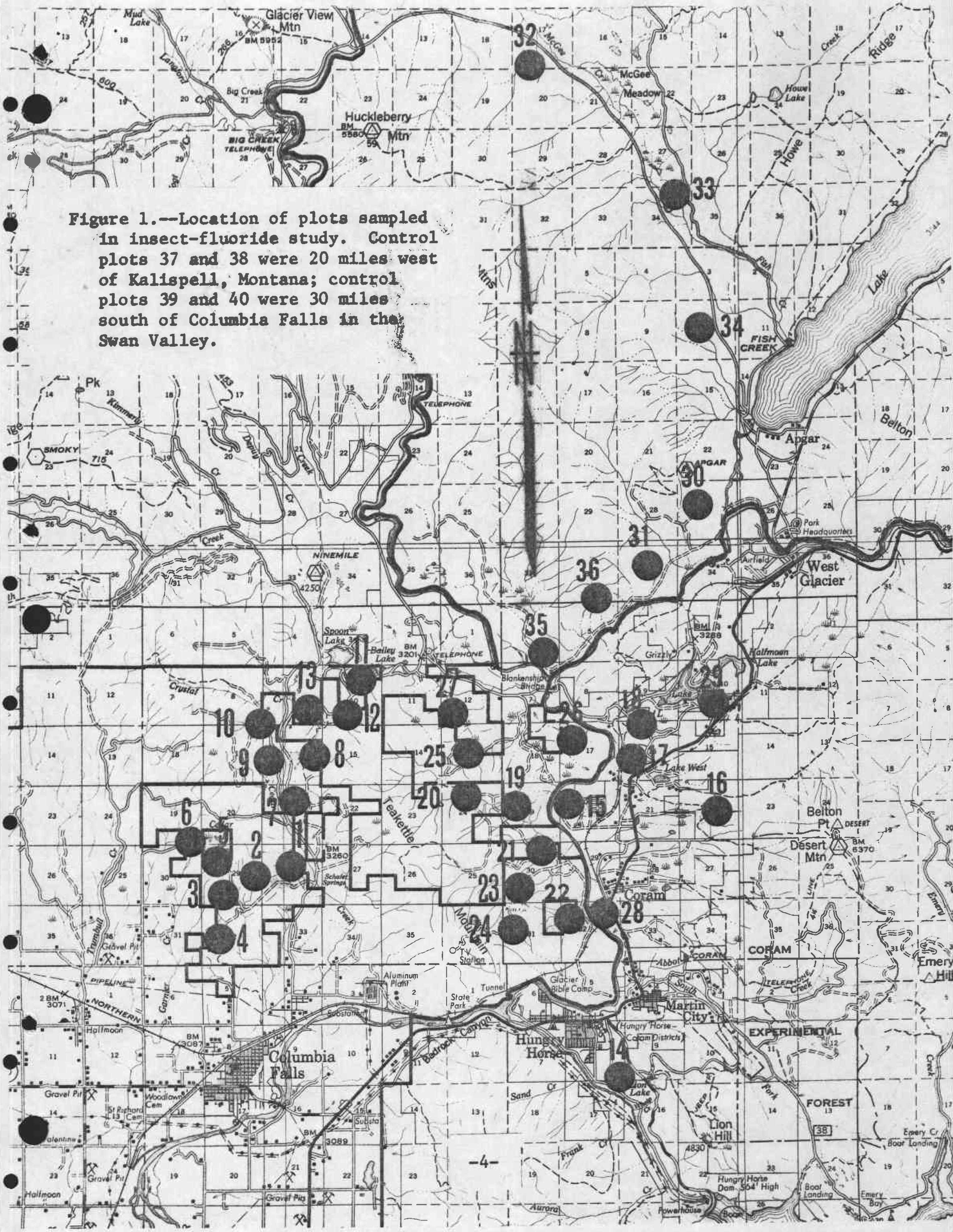

Figure 1.--Location of plots sampled in insect-fluoride study. Control plots 37 and 38 were 20 miles west of Kalispell, Montana; control plots 39 and 40 were 30 miles south of Columbia Falls in the Swan Valley.

branch samples and insects dislodged during the cutting process. Branches and basket contents collected from each tree were placed separately into plastic bags which in turn were placed in large canvas bags to eliminate heat damage to foliage and insects. Each plastic bag was labeled as to date, plot, and tree number. All samples were put in cold storage at the end of each collection day.

Foliage samples were transferred from cold storage to the U. S. Forest Service, Region 1, Insect and Disease Laboratory. Here estimates of the populations of tortrix, pine needle scale, needle miner, and needle sheath miner were made. Total insect counts were made on each sample tree for each insect species following procedures described by McGregor (1969) and Fischer (1950). The sugar pine tortrix and sheath miner had completed their feeding and some were in the pupal stage, whereas the needle miners had pupated and started to emerge as moths. The pine scale appeared as conspicuous white tufts on the needle.

Next, the relative amount of foliar damage caused by each insect and by fluoride was estimated. Needles were stripped from each sample branch and kept separate by year of origin: 1973, 1972, or 1971. Then, for each tree, 100 needles from each growth period were randomly selected and examined individually. From these 100 needles, the number sustaining damage caused by the pine needle sheath miner, pine needle scale, needle miner, and fluoride was determined based on the characteristic damage of each current tortrix and sheath miner damage was confined to the 1973 growth because of their feeding habits. Needles mined by the sheath miner were discolored and hollow but the tortrix confined its feeding to elongating needles of the candles. However, because of difficulty in separating sheath miner damage from that caused by tortrix, these variables were lumped. The needle miner fed on 2- and 3-year-old needles and damage was easily recognized by the hollow needles and exit holes of mature larvae. Pine needle scale damage was obvious by the chlorosis and necrosis it caused. Fluoride damage was identified by necrotic needle tips and dark brown band appearing at the junction of healthy and necrotic tissue.

Approximately 10 grams (fresh weight) of needles from each growth period on each sample tree were prepared and analyzed in our laboratory for fluoride content by the specific ion method described by Gordon (1971). The 10 grams included healthy needles and needles damaged by various agents. Fluoride concentrations were given in parts per million (p.p.m.) based on the dry weight of the tissue.

Static monitors to estimate the amount of gaseous airborne fluoride were placed on trees No. 1 and No. 3 of each plot. Each monitor consisted of a small circular filter paper saturated with sodium formate attached to the inside of a small Petri dish. Atmospheric fluoride reacted with sodium formate and was retained by the plate, permitting quantitative analysis to be made. Each plate was placed inverted in a plastic holder attached at breast height on the respective sample trees, left out for a 2-month period, and then changed. All plates were provided by the State of Montana, Department of Health and Environmental Services, Helena, Montana, but were analyzed in our laboratory by the specific ion method. Procedures for plate preparation and analysis are given in Appendix 1 and are the same as used by the State of Montana. Ambient concentrations of fluoride were given in micrograms of fluoride per square centimeter per day.

RESULTS

Stepwise multiple regression was used to statistically analyze the data. Means and standard errors for each variable measured are given in table 1. The average concentration of fluoride in the 1971 and 1972 foliage was computed and used for regression purposes. Fluoride concentration in 1973 foliage was not used because that foliage had been exposed to ambient air for only 1 month prior to collection and would have accumulated little fluoride.[5/] Because virtually no pine needle scale was found on any of the samples and because of limitations in the dimensions of the computer program, scale was not included as a variable. Data from plot 29 were discarded because no information on ambient fluoride concentrations was obtained. Therefore, the analysis was done on data from 195 trees instead of 200. All standard errors were less than 25 percent of their respective means; thus we considered the sampling adequate.

Stepwise multiple regression computes regressions selectively based on a predetermined level of significance. Different independent variables are entered or deleted in a stepwise fashion based on the selected "F" ratio level. We selected $F = 2.0$ as the minimum acceptable level for any independent variable entering the regression ($t^2 = F$, $t = 1.41$). Values of t at the 0.05 and 0.01 levels for 195 degrees of freedom are 1.97 and 2.35, respectively. We selected the slightly lower value of 1.41 so as to include as many independent variables as reasonably possible in the regression. Results are given in table 2. All of the independent variables entered in each of the

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5/ Data for the variables measured is presented in Appendix 2. Simple correlation coefficients are given in Appendix 3.

Table 1.--Means and standard errors for independent and dependent variables

Variable	Code[a]	Mean	Standard error	Standard error as percent of mean
Tortrix population	X_1	0.9330[b]	0.1770	0.19
Ambient fluoride	X_2	.0027[c]	.0002	.07
Average F concentration	X_3	10.2000[d]	.9300	.09
Needle miner population	X_4	39.3000[b]	7.0400	.18
Sheath miner population	X_5	2.8100[b]	.3600	.13
Tree rating	Y_1	1.1200	.0500	.04
1971 needle miner damage	Y_2	11.0400[e]	.8100	.07
1971 fluoride damage	Y_3	1.3600[e]	.3000	.22
1972 needle miner damage	Y_4	9.3600[e]	.6700	.07
1972 fluoride damage	Y_5	.6200[e]	.1500	.24
Sheath miner and tortrix damage	Y_6	11.7300[e]	.9000	.08

a/ X = independent; Y = dependent.

b/ Tortrix, needle miner, and needle sheath miner populations are expressed as total insects per four-branch sample per tree.

c/ $\mu gF^-/CM^2/day$.

d/ Parts per million fluoride, dry weight basis.

e/ Damaged needles per 100 observed.

Table 2.--Regression coefficients, t ratios, and coefficients of multiple determination and correlation for six dependent variables

Dependent variable	Independent variable	B[a]	t ratio	R^2	R
Y_1	X0[b]	0.540		0.51	0.71**
(tree rating)	X2 ambient F^-	119.500	5.41**[c]		
	X3 av. F^- content	.023	5.96**		
	X5 sheath miner population	.003	4.01**		
Y_2 (1971	X0	6.600		.45	.69**
miner damage)	X3 av. F^- content	.150	3.28**		
	X4 needle miner population	.070	11.71**		
Y_3 (1971	X0	-.530		.15	.39**
fluoride	X2 ambient F^-	692.200	5.92**		
damage)					
Y_4 (1972	X0	6.110			
needle miner	X3 av. F^- content	.170	2.89**	.14	.38**
damage)	X4 needle miner population	.037	4.70**		
Y_5 (1972	X0	.250		.04	.20**
fluoride	X3 av. F^- content	.036	3.09**		
damage)					
Y_6 (sheath	X0	6.250			
miner/tortrix	X1 tortrix population	.830	2.55**		
damage)	X3 av. F^- content	.310	4.97**		
	X4 needle miner population	-.020	-2.18**		
	X5 sheath miner population	.800	4.90**		

a/ B = partial regression coefficient.
b/ XO = Y intercept.
c/ ** = significance at 0.01 level.

regressions were statistically significant either at the 0.05 or 0.01 probability levels. Statistically, visual rating of tree condition (Y_1) was dependent on ambient fluoride, needle concentration of fluoride, and sheath miner populations. Needle miner damage to 1971 needles (Y_2) was dependent on needle fluoride concentration and the needle miner populations. Fluoride damage to 1971 needles (Y_3) was dependent only on ambient fluoride. Needle miner damage to 1972 needles (Y_4) was dependent on needle fluoride concentration and needle miner populations. The 1972 fluoride damage (Y_5) was dependent only on needle tissue fluoride. Sheath miner damage (Y_6) was dependent on tortrix population, needle tissue fluoride, needle miner population, and sheath miner population. Coefficients of multiple correlation for each of the regressions were significant at the 0.01 level.

Two sodium formate plates were placed at each plot location and exposed for a 2-month period before changing. A paired "t" test between plate pairs gave nonsignificant "t" values, showing the consistency of plates on the same plot to record atmospheric fluoride (table 3). This indicates that plates on the same plot were collecting equivalent amounts of fluoride. The correlation coefficient of 0.96 was significant at the 0.01 level.

Table 3.--Paired t test on sodium-formate plates

Sampling period	Mean X	Mean Y	Mean difference	t	r
July-September 1973	0.0027[a/]	0.0027	0.000	0.03	0.96

a/ Micrograms fluoride per square centimeter per day.

DISCUSSION AND CONCLUSIONS

Populations of insects are usually quite mobile and difficult to measure. However, the feeding injury caused by the same insects remains for a period of time and the amount can be estimated with a reasonable degree of accuracy. This is supported by the data in table 1. Standard errors for 1971 and 1972 needle miner damage, sheath miner and tortrix damage, and percent damaged candles are much less than standard errors for population estimates. For this reason, damage caused by the different insects at Columbia Falls was used dependently in regression analyses even though populations were measured. Insect populations, along with ambient and foliar concentrations of fluoride, were used as independent variables.

Visual rating of pines was significantly affected by ambient fluoride, foliar fluoride, needle miner populations, and sheath miner populations, although this effect was primarily caused by the insects. However, presence of ambient and foliar fluoride in the regression at substantially higher "t" values than computed for insect populations indicates a strong relationship between the insects and fluoride. This relationship is supported in that for each of the cases in which insect feeding damage on needles was a dependent variable, foliar fluoride concentration contributed in a positive highly significant way to the regression as indicated by the "t" ratio for partial regression coefficients. For the cases in which fluoride injury was the dependent variable, only atmospheric fluoride and needle concentration and not insect populations contributed significantly to the regression, indicating the tests were definitive.

Consistency of the 1971 and 1972 needle miner regressions is striking. Foliar fluoride concentration and needle miner populations were highly significant and had roughly the same coefficients in both regressions. This consistency was not found in relation to fluoride damage. Fluoride injury to 1971 needles was related to ambient fluoride, but for 1970 needles was related to foliar fluoride. The simple correlation coefficient between ambient and foliar fluoride was 0.67 (appendix 3), indicating a high association. Standard errors of fluoride damage estimates, however, were relatively large (table 1), and this variability probably affected the independent variable entering the regressions. Nevertheless, fluoride damage was related to either ambient or foliar fluoride and not to some other variable.

Pine needle sheath miner damage was negatively related to needle miner populations, as indicated by the regression equations. Populations of pine needle sheath miner or sugar pine tortrix could reduce subsequent needle miner populations, because both of the former destroy current year's needles. During heavy populations of either or both insects, the complete needle complement can be destroyed for several consecutive years, leaving no oviposition or feeding sites for the needle miner. Also, needle miner populations could indirectly affect pine needle sheath miner damage if parasites of the needle miner were also parasitizing the pine needle sheath miner. Sheath miner was about three times as numerous as tortrix, and little feeding damage by tortrix was found during laboratory work. Thus, even though we lumped tortrix and sheath miner damage, most of it must be attributed to sheath miner.

It is recognized that many so-called "indicator" organisms show that traces of toxic substances can cause harmful effects in the environment. Entomological literature, both published and unpublished, during the last half century contains numerous references to suspected or documented associations of airborne toxicants and outbreaks of forest insects (Johnson, 1969). In a majority of these outbreaks, toxicants either preconditioned coniferous host trees making them more susceptible to attack of insect pests, or they induced the buildup of epidemic populations of arthropods by killing important invertebrate parasites, predators, or competing species that normally cause these populations to be endemic.

Several outbreaks of forest insects have been tied to airborne pollutants in the western United States and Canada (Evenden 1923; Keen and Evenden 1929; Johnson 1950; and Struble and Johnson 1964) and many species of insects were shown to be secondary in nature, confining their attacks to unhealthy and weakened trees. In 1929, F. P. Keen and J. C. Evenden studied the effects of either smelter fumes or a combination of smelter fumes and other destructive agents on rather large volumes of timber near Northport, Washington. After examining 1,000 trees, they concluded that it was nearly impossible to separate the importance of insects from other factors that might have contributed to death of the trees. They also found that the two or three previous dry years might have weakened ponderosa pine within the study area making them more susceptible to western pine beetle attacks. This same condition might have precipitated population buildup of various defoliators in their respective hosts also. They also found that many Douglas-fir infested with bark beetles were dying principally from *Armillaria mellea*. Keen and Evenden (1929) concluded that in lodgepole pine, insects (defoliators, bark beetles, and wood borers) appeared to be entirely secondary although contributing to mortality of many trees which were severely defoliated by fume damage in the vicinity of a smelter at Northport, Washington.

During our study, pine needle scale, *Phenacaspis pinifoliae,* populations occurred at such a low level that they were not included in the statistical analysis. At Spokane, Washington, from 1948 to 1950, a massive infestation of the black pine leaf scale, *Aspidiotus californica* Coleman, was first thought to be associated with heavy, widespread concentrations of airborne fluoride from an aluminum reduction processing plant, but was subsequently found to be associated with heavy concentrations of aerially suspended cement, silicon, and other dusts (Johnson, 1950). Struble and Johnson (1964) state that infestations of the black pine leaf scale are commonly associated with environmental conditions such as smelter fumes, smog, smoke, and dusts from roads, trails, excavations, cement plants, and poultry yards.

We have demonstrated a strong statistical relationship between industrially emitted fluorides and damage caused by a complex infestation of insects on lodgepole pine. Mechanisms for this relationship were not studied but research on the effect of different foliar and/or ambient fluoride concentrations on insect feeding habits, fecundity, parasites and predators, or other factors affecting population dynamics is warranted. Dewey (1972) reported that foliage feeding insects collected near the Anaconda aluminum plant at Columbia Falls, Montana, accumulated from 21 to 255 p.p.m. fluoride compared to 3.5 to 16.5 p.p.m. for his controls, but effects of fluoride on the insects was not studied.

In conclusion, we believe the data collected in this study strongly indicate that fluorides from the Anaconda Aluminum Company have in some way triggered the insect complex in the polluted area to become epidemic, contributing significantly to widespread damage of lodgepole pine.

The data substantiates previous observations that the insects and resultant damage were more than coincidental with the fluoride pollution. Our interest is more than academic--over 150,000 acres of forested lands, including private, State of Montana, Flathead National Forest, and Glacier National Park are involved. Damage to ecosystems on these lands is not of little concern. Already on the east side of Teakettle Mountain, large numbers of lodgepole pine are dead and many more are in a state of severe decline.

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APPENDIX 1

SODIUM FORMATE PAPERS

Fabrication

The fluoride collection media used is a Whatman 41 filter paper (4.7 cm diameter) attached to a Millipore Petri dish with three drops of acetone. The filter discs are immersed in a 50 percent ethyl alcohol solution containing 10 percent sodium formate. These discs are air dried at room temperature.

Reagents:

Fluoride standard (10 mg F^-/ml)

TISAB

Analysis:

1. Remove the exposed filter paper from the Petri dish and place in a test tube. Cover the filter paper with 20 ml of TISAB.

2. Stopper the tube and place on a Vortex-mixer for 2-4 minutes or let sample sit for 2 hours.

3. Transfer the sample solution to a 25 ml polyethylene beaker and measure the fluoride potential with the specific ion electrode on an expanded range pH meter. (Ten minutes is adequate for the electrode to stabilize.)

Standard curve:

Dilute fluoride standard solutions (0.5, 1.0, 10.0 and 100 mg F^-/liter) buffered to pH 7.5 with 0.1 M sodium citrate are prepared from the stock solution by appropriate dilutions.

Plot fluoride content of the standards against the millivolt readings from the expanded scale pH meter.

Calculations:

The fluoridation rate in $\mu g\ F^-/cm^2$/day is calculated accordingly.

$$F = \frac{AB}{CD}$$

F = fluoridation rate in $\mu g\ F^-/cm^2$/day.
A = $\mu g\ F^-$ from standard curve and millivolt measurement.
B = volume of filtrate used to obtain fluoride potential reading.
C = area of plate in cm^2.
D = exposure time in days.

APPENDIX 2. -- DATA ENTERED FOR MULTIPLE REGRESSION ANALYSIS

PLOT	INDEPENDENT VARIABLES A	B	C	D	E	DEPENDENT VARIABLES F	G	H	I	J	K
1	0	0.0044	4.6	0	0	2	6	0	4	1	2
	0	0.0044	7.2	0	2	2	4	0	5	0	1
	0	0.0044	7.8	3	1	2	5	0	11	0	2
	0	0.0044	11.7	0	0	1	3	0	5	0	8
	0	0.0044	9.2	0	1	1	11	0	0	0	6
2	0	0.0022	10.6	5	0	1	8	0	5	3	19
	0	0.0022	5.9	0	1	1	27	0	13	0	12
	0	0.0022	10.8	0	1	1	3	0	4	0	18
	0	0.0022	10.9	2	0	1	14	2	17	0	5
	0	0.0022	9.8	0	0	1	11	1	14	0	8
3	0	0.0018	8.4	0	1	1	10	0	4	0	7
	0	0.0018	5.2	0	0	1	4	0	2	0	0
	0	0.0018	0.7	18	1	1	2	0	8	0	4
	0	0.0018	2.7	17	0	1	2	0	1	0	2
	0	0.0018	2.7	0	0	1	3	0	6	0	1
4	0	0.0020	5.0	0	0	1	4	0	7	0	5
	0	0.0020	10.0	1	0	1	6	0	0	0	3
	0	0.0020	7.6	3	0	1	1	0	9	0	1
	0	0.0020	2.8	0	0	1	3	0	3	0	11
	0	0.0020	6.6	1	0	1	3	0	3	0	2
5	1	0.0012	5.1	0	2	1	12	0	7	0	16
	1	0.0012	1.5	0	1	1	3	0	7	0	11
	1	0.0012	5.6	0	3	1	14	0	14	0	1
	0	0.0012	5.2	0	8	1	5	0	2	1	21
	1	0.0012	6.7	0	5	1	20	4	8	0	11
6	0	0.0005	3.3	0	0	0	0	6	0	3	22
	0	0.0005	7.9	2	2	0	8	4	12	21	8
	0	0.0005	4.6	0	1	0	4	0	3	0	7
	0	0.0005	1.6	0	0	0	3	0	1	0	7
	0	0.0005	1.2	0	0	0	3	0	4	0	9
7	0	0.0052	15.4	0	3	2	2	3	2	1	23
	2	0.0052	10.7	12	4	2	9	2	8	0	41
	0	0.0052	19.6	3	18	2	5	2	6	3	22
	0	0.0052	10.6	12	11	2	7	0	10	0	37
	1	0.0052	14.8	7	4	2	5	0	4	1	6
8	3	0.0024	4.2	0	16	1	17	0	11	0	14
	0	0.0024	0.4	0	8	2	18	0	20	0	2
	0	0.0024	10.6	0	9	1	34	0	11	0	5
	0	0.0024	9.1	0	3	2	6	0	11	0	5
	0	0.0024	7.4	0	2	1	11	0	15	0	15

A TORTRIX POPULATION/4 BRANCH SAMPLE
B AMBIENT FLUORIDE LEVELS (MICROGRAMS FLUORIDE/SQ.CM/DAY)
C AVERAGE PPM OF FLUORIDE IN 1971 AND 1972 NEEDLES
D NEEDLE MINER POPULATION/4 BRANCH SAMPLE
E SHEATH MINER POPULATION/4 BRANCH SAMPLE
F TREE RATING
G 1971 NEEDLES DAMAGED BY NEEDLE MINER/100 OBSERVED
H 1971 NEEDLES DAMAGED BY FLUORIDE/100 OBSERVED
I 1972 NEEDLES DAMAGED BY NEEDLE MINER/100 OBSERVED
J 1972 NEEDLES DAMAGED BY FLUORIDE/100 OBSERVED
K 1973 NEEDLES DAMAGED BY SHEATH MINER/100 OBSERVED

APPENDIX 2. -- DATA ENTERED FOR MULTIPLE REGRESSION ANALYSIS, CONT.

PLOT	INDEPENDENT VARIABLES					DEPENDENT VARIABLES					
	A	B	C	D	E	F	G	H	I	J	K
9	0	0.0019	3.3	25	4	1	10	0	6	0	16
	0	0.0019	3.5	6	9	1	10	0	19	0	23
	0	0.0019	5.0	2	4	1	23	0	13	0	24
	2	0.0019	0.0	4	11	1	1	3	5	1	15
	0	0.0019	5.0	8	14	1	7	1	3	1	33
10	0	0.0019	5.7	3	9	2	4	0	8	0	15
	0	0.0019	0.0	0	0	2	6	0	12	0	24
	1	0.0019	5.4	1	17	2	5	0	11	0	11
	6	0.0019	3.2	0	24	2	8	0	18	0	24
	3	0.0019	3.5	0	3	2	14	0	10	0	28
11	0	0.0006	2.8	0	0	0	15	8	18	13	9
	0	0.0006	3.2	0	0	0	15	0	1	0	6
	1	0.0006	0.8	0	0	0	5	2	3	0	6
	0	0.0006	5.8	0	0	0	4	4	4	0	4
	0	0.0006	0.0	0	0	0	8	0	6	0	0
12	0	0.0020	4.2	3	2	0	7	1	3	1	0
	1	0.0020	0.8	0	0	0	5	0	8	1	0
	1	0.0020	8.8	0	2	0	0	0	2	0	7
	1	0.0020	0.6	0	0	0	1	3	1	1	0
	2	0.0020	1.1	1	0	0	3	2	1	0	0
13	0	0.0004	0.4	0	2	0	7	0	11	0	3
	0	0.0004	3.4	0	1	0	6	0	3	0	1
	2	0.0004	2.6	0	1	0	7	0	3	0	2
	0	0.0004	3.5	12	2	0	8	2	22	2	3
	1	0.0004	1.4	5	2	0	3	1	1	0	11
14	0	0.0016	2.8	4	1	1	6	0	0	0	20
	0	0.0016	9.9	0	3	1	7	0	3	2	22
	0	0.0016	11.2	0	0	1	4	0	3	0	37
	0	0.0016	13.5	0	0	1	13	0	6	0	25
	0	0.0016	14.1	0	0	1	4	1	5	1	13
15	0	0.0092	14.8	46	0	1	5	29	3	0	1
	0	0.0092	20.9	374	18	1	20	0	4	0	5
	0	0.0092	19.0	206	0	1	32	20	9	5	4
	0	0.0092	16.8	332	0	1	30	0	13	0	4
	2	0.0092	6.6	386	0	1	47	40	21	0	3
16	0	0.0019	4.7	211	10	1	12	0	11	0	10
	0	0.0019	8.2	130	2	1	11	3	6	0	9
	0	0.0019	4.6	87	1	2	17	0	5	0	10
	1	0.0019	4.7	99	1	2	9	4	11	2	12
	0	0.0019	10.8	96	2	1	17	0	4	0	6
17	1	0.0036	12.2	19	1	2	29	0	30	0	31
	0	0.0036	5.9	24	1	2	30	0	36	0	40
	0	0.0036	25.8	13	1	2	40	3	42	0	20
	0	0.0036	31.4	37	1	2	47	8	41	3	47
	2	0.0036	20.3	0	1	2	18	4	43	0	26
18	0	0.0016	10.5	275	0	1	12	6	11	3	5
	0	0.0016	7.0	391	1	1	15	0	11	0	0
	1	0.0016	4.8	336	5	1	23	1	14	0	0
	0	0.0016	12.4	193	0	1	35	2	22	0	4
	1	0.0016	17.8	468	6	1	34	0	26	0	4

APPENDIX 2. -- DATA ENTERED FOR MULTIPLE REGRESSION ANALYSIS, CONT.

PLOT	INDEPENDENT VARIABLES					DEPENDENT VARIABLES					
	A	B	C	D	E	F	G	H	I	J	K
19	1	0.0054	36.1	3	1	3	0	12	0	3	34
	1	0.0054	93.4	1	1	3	4	3	15	0	23
	1	0.0054	31.5	5	1	2	13	4	19	3	16
	0	0.0054	55.0	10	0	2	7	10	10	6	15
	1	0.0054	83.0	2	0	3	16	3	16	6	25
20	3	0.0088	24.9	12	2	2	10	6	4	0	25
	1	0.0088	27.4	44	1	2	11	0	4	0	12
	1	0.0088	29.8	8	3	2	16	0	7	0	8
	5	0.0088	31.7	7	4	2	6	0	4	0	2
	2	0.0088	40.7	0	1	2	6	0	3	0	12
21	0	0.0060	18.2	10	1	2	11	4	14	0	4
	0	0.0060	12.0	58	2	2	25	0	0	0	0
	0	0.0060	22.0	59	3	2	13	0	7	0	2
	2	0.0060	10.8	1	0	3	10	0	3	0	6
	0	0.0060	12.8	0	0	2	8	0	5	0	5
22	0	0.0030	5.4	130	2	1	26	0	9	0	7
	0	0.0030	9.7	93	1	1	28	0	16	0	6
	1	0.0030	2.1	143	4	1	10	0	20	0	25
	0	0.0030	7.2	185	3	1	15	0	14	0	16
	3	0.0030	6.0	414	3	1	42	0	17	0	3
23	1	0.0068	61.2	2	2	3	25	14	30	2	50
	1	0.0068	36.5	6	2	3	11	0	19	0	20
	0	0.0068	32.8	6	0	3	12	2	13	2	32
	5	0.0068	28.2	15	0	3	1	0	0	0	62
	3	0.0068	35.2	0	0	3	33	0	16	0	21
24	5	0.0080	39.4	125	0	2	12	2	42	2	11
	1	0.0080	31.5	641	4	2	80	0	44	0	6
	1	0.0080	38.5	87	1	2	29	4	12	2	0
	3	0.0080	24.7	6	5	2	17	8	16	9	1
	3	0.0080	18.3	515	6	2	59	3	60	5	16
25	7	0.0051	16.3	2	7	1	2	0	1	0	10
	8	0.0051	18.1	35	7	1	8	0	2	0	23
	4	0.0051	20.0	0	2	1	1	0	1	0	11
	2	0.0051	21.2	6	4	1	6	0	1	0	9
	10	0.0051	11.0	10	1	1	4	0	0	0	11
26	2	0.0030	10.6	65	3	2	15	2	13	8	20
	4	0.0030	14.8	65	3	3	25	0	16	0	80
	1	0.0030	14.8	148	2	2	32	1	8	1	31
	0	0.0030	14.2	112	4	2	19	0	8	0	29
	28	0.0030	13.6	0	4	1	28	0	7	0	37
27	0	0.0018	5.2	0	6	1	5	4	5	0	15
	1	0.0018	6.8	0	5	1	11	0	7	0	6
	0	0.0018	9.2	0	1	1	5	0	9	0	4
	3	0.0018	1.8	0	4	1	0	0	0	0	10
	0	0.0018	7.5	0	4	1	1	0	0	0	3
28	0	0.0036	11.5	6	1	1	10	0	5	0	9
	0	0.0036	5.0	6	2	1	2	2	10	0	7
	1	0.0036	7.6	15	1	1	3	0	4	0	4
	0	0.0036	13.1	6	0	1	5	0	1	0	5
	0	0.0036	9.1	18	2	1	12	0	5	0	9

APPENDIX 2. -- DATA ENTERED FOR MULTIPLE REGRESSION ANALYSIS, CONT.

PLOT	A	B	C	D	E	F	G	H	I	J	K
	INDEPENDENT VARIABLES					DEPENDENT VARIABLES					
30	0	0.0020	5.8	4	1	1	4	0	8	0	3
	0	0.0020	7.9	0	1	1	13	0	6	1	26
	0	0.0020	6.4	3	0	1	5	0	6	0	9
	0	0.0020	4.0	4	1	1	4	0	2	0	7
	0	0.0020	11.5	1	0	1	5	0	8	0	12
31	0	0.0022	7.9	31	0	1	8	0	10	0	22
	1	0.0022	3.9	42	4	1	8	0	3	0	24
	1	0.0022	6.7	58	4	1	7	0	4	0	24
	1	0.0022	2.8	75	6	1	7	0	10	0	26
	2	0.0022	4.5	40	8	1	5	0	6	0	45
32	0	0.0001	0.0	0	0	0	1	0	5	0	0
	0	0.0001	1.2	0	0	0	8	0	6	0	2
	0	0.0001	1.2	0	0	0	9	0	8	0	0
	0	0.0001	2.6	0	0	0	3	0	8	0	0
	0	0.0001	0.3	0	0	0	6	1	2	0	2
33	0	0.0002	1.7	1	0	0	2	0	3	0	2
	0	0.0002	1.4	0	1	0	15	3	0	0	4
	0	0.0002	0.6	0	3	0	5	1	3	0	2
	0	0.0002	2.7	0	0	0	7	0	9	0	15
	1	0.0002	2.0	0	0	0	7	0	7	0	2
34	0	0.0006	0.7	13	15	1	0	3	0	0	20
	0	0.0006	0.0	11	15	1	2	2	3	1	30
	1	0.0006	1.8	4	41	2	5	0	6	0	41
	0	0.0006	1.2	1	20	1	1	0	0	0	23
	0	0.0006	0.0	2	7	1	0	0	0	0	16
35	0	0.0018	14.6	99	0	1	5	0	5	0	0
	0	0.0018	6.2	70	0	1	5	0	3	0	0
	0	0.0018	11.2	61	0	1	5	0	10	0	1
	0	0.0018	6.0	45	0	1	12	0	2	0	0
	0	0.0018	7.0	78	0	1	4	0	2	0	0
36	0	0.0024	9.7	3	0	1	13	0	14	0	2
	0	0.0024	12.3	4	0	1	16	0	53	0	6
	0	0.0024	10.2	9	0	1	6	0	5	0	9
	0	0.0024	1.4	1	0	1	13	0	5	0	2
	0	0.0024	0.9	29	0	1	15	0	100	0	2
37	3	0.0002	0.0	10	10	1	3	0	6	0	3
	2	0.0002	0.6	0	7	1	11	0	10	0	7
	5	0.0002	4.0	0	7	1	0	0	0	0	8
	2	0.0002	1.2	0	2	1	3	0	2	0	8
	4	0.0002	0.5	0	5	1	5	0	4	0	7
38	1	0.0010	0.0	1	2	1	0	0	3	0	6
	0	0.0010	1.8	0	0	0	2	0	4	0	8
	0	0.0010	2.2	0	0	1	0	0	1	0	0
	1	0.0010	1.6	0	0	1	2	0	6	0	2
	1	0.0010	1.6	3	1	1	5	0	2	0	3
39	1	0.0002	0.0	0	0	1	2	0	5	0	0
	0	0.0002	2.0	0	1	1	4	0	5	0	2
	0	0.0002	0.0	0	1	1	6	0	2	0	6
	0	0.0002	1.2	0	0	1	23	0	19	0	0
	0	0.0002	2.4	0	0	1	7	0	9	0	3

APPENDIX 2. -- DATA ENTERED FOR MULTIPLE REGRESSION ANALYSIS,CONT.

PLOT	INDEPENDENT VARIABLES					DEPENDENT VARIABLES					
	A	B	C	D	E	F	G	H	I	J	K
40	0	0.0000	1.8	0	0	1	17	0	7	0	6
	0	0.0000	1.1	0	0	1	3	0	1	0	5
	0	0.0000	0.3	1	0	1	28	0	15	0	8
	0	0.0000	0.0	0	0	1	33	0	9	0	2
	0	0.0000	1.0	0	0	1	3	0	2	0	1

APPENDIX 3. - CORRELATION COEFFICIENTS FOR THE REGRESSION

VARIABLES	COEFFICIENTS			
	1	.1859	.1282	7.538E-3
A	.1342	.1289	9.135E-2	-1.241E-2
	-1.133E-3	-2.023E-2	.2466	
	.1859	1	.6677	.3159
B	-1.752E-2	.6234	.3492	.3919
	.2075	.1051	.1741	
	.1282	.6677	1	.1149
C	-9.294E-2	.635	.2484	.2371
	.23	.2173	.2968	
	7.538E-3	.3159	.1149	1
D	6.141E-2	8.385E-2	.6496	.2079
	.3375	.033	-8.181E-2	
	.1342	-1.752E-2	-9.294E-2	6.141E-2
E	1	.1524	-3.224E-2	-8.307E-2
	-3.453E-2	-2.813E-2	.299	
	.1289	.6234	.635	8.385E-2
F	.1524	1	.2683	9.372E-2
	.259	.0376	.4872	
	9.135E-2	.3492	.2484	.6496
G	-3.224E-2	.2683	1	.2307
	.5785	9.252E-2	.1163	
	-1.241E-2	.3919	.2371	.2079
H	-8.307E-2	9.372E-2	.2307	1
	.1197	.2742	.0431	
	-1.133E-3	.2075	.23	.3375
I	-3.453E-2	.259	.5785	.1197
	1	.1366	.1279	
	-2.023E-2	.1051	.2173	.033
J	-2.813E-2	.0376	9.252E-2	.2742
	.1366	1	.0627	
	.2466	.1741	.2968	-8.181E-2
K	.299	.4872	.1163	.0431
	.1279	.0627	1	

APPENDIX 3.--CORRELATION COEFFICIENTS FOR THE REGRESSION, cont.

Coefficients are listed for variables A-K horizontally, line by line, for a given variable listed vertically. For example, the correlation coefficient for variable pair A-C is 0.1282.