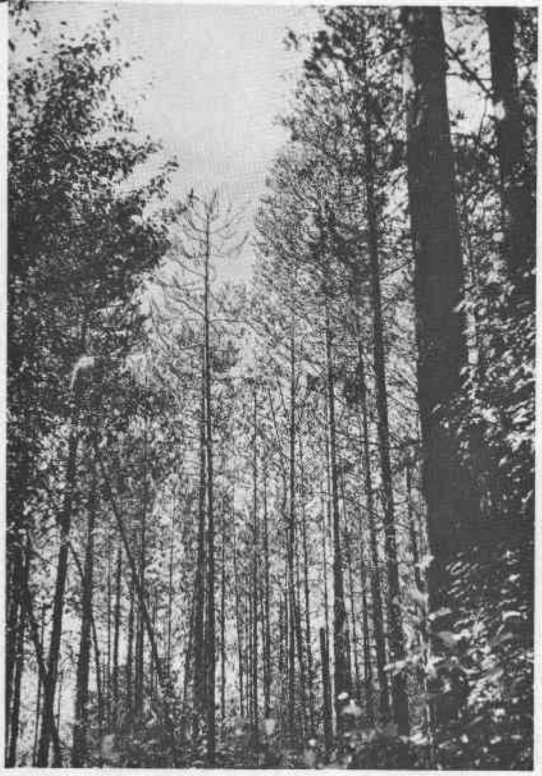
[redacted]

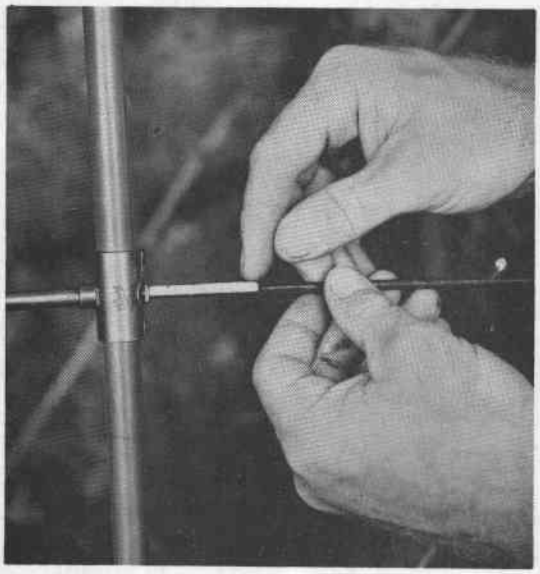
REPORT NO. 74-25



Impact of Fluorides and Insects on Radial Growth of Lodgepole Pine

near an Aluminum Smelter in Northwestern Montana

A PRELIMINARY INQUIRY



FOREST ENVIRONMENTAL PROTECTION
USDA · FOREST SERVICE · NORTHERN REGION
State & Private Forestry · Missoula, MT 59801

Cover photos: Lower right: Anaconda Aluminum Company. Gaseous fluorides are emitted from the roof vents and impact vegetation over a wide area. Upper: Lodgepole pine stands have been heavily damaged by a combination of fluoride and insects. Lower left: Increment cores extracted from damaged trees showed a substantial growth loss since the aluminum plant expanded in 1968.

December 1974

IMPACT OF FLUORIDES AND INSECTS ON RADIAL GROWTH OF LODGEPOLE PINE NEAR AN ALUMINUM SMELTER IN NORTHWESTERN MONTANA

- A Preliminary Inquiry -

Clinton E. Carlson and William P. Hammer[1]
Forest Environmental Protection

ABSTRACT

A study was conducted in summer of 1973 to assess impact of fluoride-insect damage on radial growth of lodgepole pine near the Anaconda Aluminum Company at Columbia Falls, Montana. Statistically significant growth losses attributed primarily to the effects of fluorides were found in 14 of 17 unmanaged stands for the period 1968-1973 in the polluted area. Radial growth reductions, estimated by comparison with a prediction model, ranged from 0.002 to 0.071 inch. Radial growth loss was transformed to volume loss, averaging 57 board feet per acre per year for the stands examined. Potential height growth losses and observed mortality were not considered. Hand-thinned stands in which growth acceleration should have occurred had not responded as expected. In fact, radial growth losses from 9 to 22 percent were found. Volume losses were not computed for the thinned stands.

INTRODUCTION

Fluoride-induced injury to vegetation near the Anaconda Aluminum Company at Columbia Falls, Montana, is well documented (Carlson and Dewey 1971, Gordon 1972, Carlson 1972, EPA 1973, Carlson 1974). A severe insect infestation on lodgepole pine *(Pinus contorta* v. *latifolia Engelm.)* was concurrent with the fluoride problem and covered much of same area. Carlson et al. (1974) recently showed a highly significant positive relationship between damage caused by a needle miner, *Ocnerostoma strobivorum* (Zeller) and pine needle sheath miner, *Zellaria haimbachi* (Busck), two insect species epidemic in the polluted area, and ambient and foliar concentrations of fluoride on lodgepole pine. The evidence suggested the pines were predisposed by fluorides to insect attack. Defoliated, brown lodgepole pine affected by the fluoride-insect complex were evident over nearly 150,000 acres of private, State, and Federally administered lands including Glacier National Park.

---

[1] Plant pathologist and biological aid, respectively, USDA, Forest Service, Northern Region, State and Private Forestry, Missoula, Montana.

Reduction of the foliar complement of trees by fluoride and insects logically would cause a reduction in radial growth because the photosynthetic base would be diminished. Also "invisible" effects of insidious fluoride accumulation on certain biochemical processes may reduce carbohydrate production. Lynch (1951) studied diameter growth of ponderosa pine (*Pinus ponderosa* laws) near the Kaiser Aluminum Plant north of Spokane, Washington and found significant growth reductions in the fluoride polluted area. He could not relate this observation to weather, soils, or other environmental factors commonly affecting tree growth. Treshow, et al. (1967) studied radial growth of Douglas-fir near a phosphate fertilizer plant in southern Idaho. They found that radial growth decreased with increasing foliar fluoride concentrations. Greatest reduction occurred when foliar fluorides exceeded 100 p.p.m. (parts per million) but statistically significant decreases were found at lower concentrations, even when no leaf necrosis appeared.

The Anaconda Aluminum Company reached maximum capacity and was emitting the greatest amount of fluoride (7,500 pounds per day) in 1968. The purpose of this study was to determine if hand-thinned, dozer-thinned, or unmanaged lodgepole pine stands within the fluoride-polluted area have experienced abnormal radial growth reduction since 1968.

METHODS

The area within the 30 isopol [2/] (Carlson and Dewey, 1971) was stratified by stand type based on 1972 1:63000 aerial photography. Seventeen unmanaged lodgepole pine stands 50± 10 years old within or close to the 30 isopol were selected for study (Figure 1). These stands originated following a series of severe forest fires in the 1920's, and were in a natural condition, save for the influence of fluorides from the aluminum plant. Three stands of the same age class but hand-thinned to about 14 by 14 feet spacing and one dozer-thinned stand of the same age in the polluted area were selected for study. Five control stands were selected from the same age class and fire history but outside the 10 isopol, removed from the influence of airborne fluorides. Three were in an unmanaged state, one was hand thinned to 14 by 14 feet, and the other was dozer thinned.

Habitat types (h.t.) in all stands were similar and included only *Thuja plicata/Clintonia uniflora* h.t. and *Tsuga heterophylla/Clintonia uniflora* h.t. (Pfister, et al., 1972).

[2/] Area in which average fluoride concentration in foliage was greater than 30 parts per million, dry weight basis.

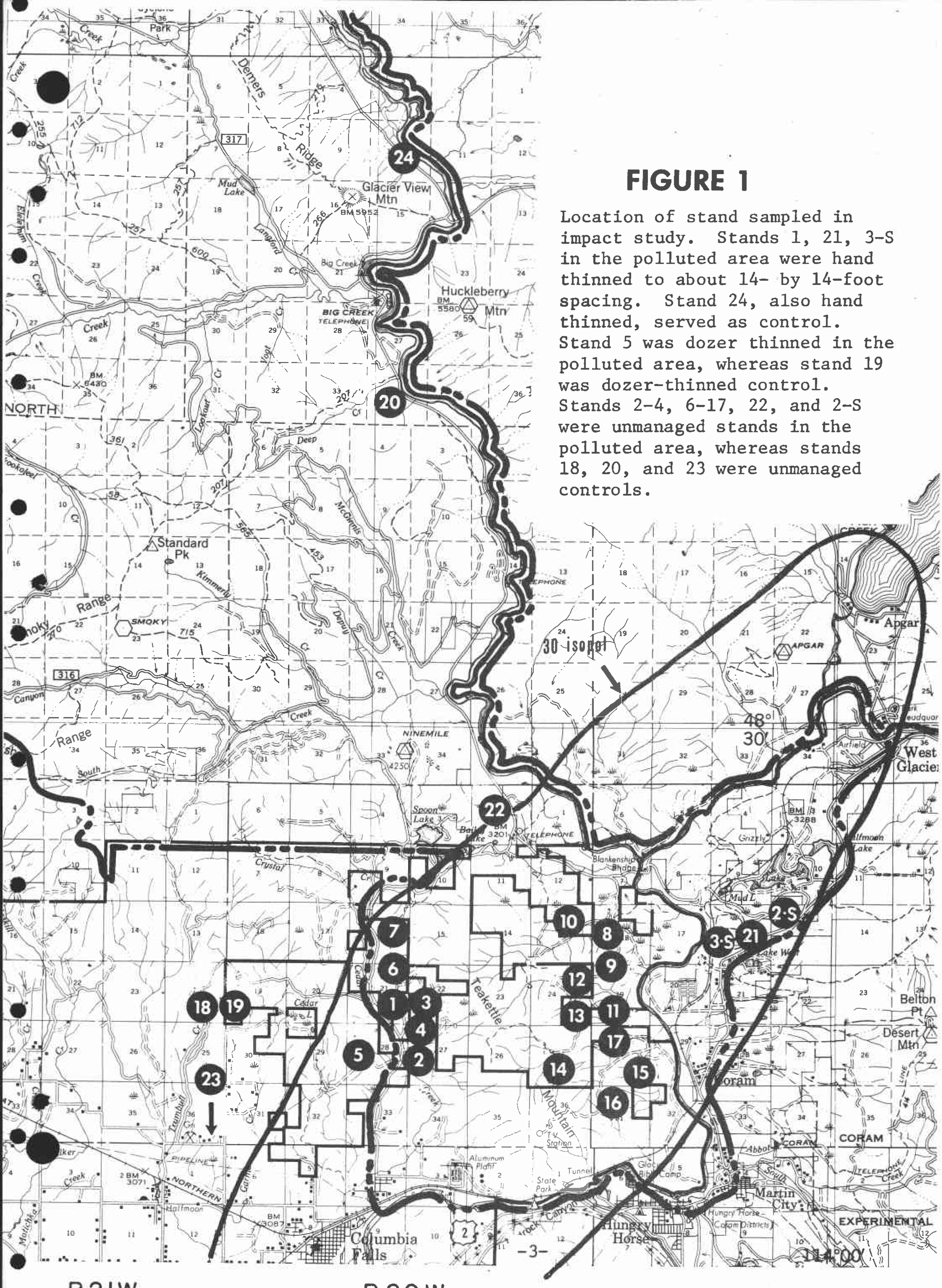


FIGURE 1

Location of stand sampled in impact study. Stands 1, 21, 3-S in the polluted area were hand thinned to about 14- by 14-foot spacing. Stand 24, also hand thinned, served as control. Stand 5 was dozer thinned in the polluted area, whereas stand 19 was dozer-thinned control. Stands 2-4, 6-17, 22, and 2-S were unmanaged stands in the polluted area, whereas stands 18, 20, and 23 were unmanaged controls.

An intensive Stage II stand examination was then done in each stand (Timber Management Handbook, Region 1, USDA, Forest Service) and estimates of basal area per acre, trees per acre (crop and excess), cubic foot and board foot volume per acre, etc., were obtained. Fifteen plots were sampled in each stand. Then using a Swedish increment borer, one increment core was extracted from each of four crop trees per plot selected in the Stage II examination. Cores were taken at 4.5 feet above ground level on the north side of the trees. If the plot contained less than the desired four crop trees, the remaining cores were obtained from other potential crop trees outside the Stage II plot. Thus, 60 cores were collected from each stand. Age, total height, and d.b.h. (diameter breast height) were recorded for each core-sampled tree. Following extraction, all cores were put in plastic straws, labeled as to stand-plot-tree number, sealed, and transferred to cold storage to prevent dehydration.

A growth analysis of each core was made in the Forest Environmental Protection laboratory, USDA, Forest Service, at Missoula, Montana. It was assumed that if fluoride reduced radial growth of pines, then the greatest effect would have occurred since 1968, 5 years ago, when the aluminum plant reached full production. Also, recognizing that year-to-year natural variability in radial growth due to weather and other environmental factors can be significant, we believed that periodic growth increment rather than annual increment would be stable as a growth indicator. Therefore, growth on each core was marked off in 5-year intervals, beginning with 1973, back to 1948. This included the 5-year period since the plant reached maximum capacity, the full 18 years since the plant was built in 1955, and one 5-year period prior to construction of the facility. Five-year periodic growth on each core was measured to the nearest 0.01 inch and was recorded.

To detect abnormal changes in growth rate, a predictive model was necessary. Unmanaged, healthy pine stands experience a natural radial growth reduction due to competition and other factors, and the model must account for this. Also, radial growth in stands thinned 6 to 8 years previous would be expected to accelerate. Our predictive models were developed from the five control stands (three unmanaged, one hand thinned, one dozer thinned) on habitat types similar to those of stands studied in the polluted area. However, stand densities and average stem diameters differed. From work done by Stage (1970) and Bousfield, et al. (1973), we know that diameter/height and the preceding 10 years' periodic growth can be used with confidence to predict future or current diameter or height growth. Using stepwise multiple regression techniques, we used diameter/height, age, and 20-25, 15-20, 10-15, 5-10, 5-15 year periodic growth as independent variables to develop a predictive model for the 0-5 year (1973-1968) growth period separately for hand-thinned, dozer-thinned, and unmanaged control lodgepole pine stands. The model was represented as $\hat{Y} = a+b_{x1}...+b_{xn}$ where $\hat{Y}$ = predicted radial growth for the period 1973-1968, and x1 through xn = age, diameter/height, and growth for different growth periods.

RESULTS AND DISCUSSION

Regression analysis indicated that diameter/height and 5-15 year growth period were the best predictors of the 0-5 year periodic growth in unmanaged control stands and dozer-thinned stands whereas diameter/height and 10-15 year growth were best in the hand-thinned control stands (Table 1).

Table 1.--Regression analysis of growth predictors for control stands

Stand No.	Stand type	Variable	Coefficient	T-ratio	n[a]
18	Unmanaged	Y-intercept	0.096		51
		D/H	- .546	-1.71 NS[b]	
		5-15 periodic growth	.407	8.35**[c]	
19	Dozer thinned	Y-intercept	.015		49
		D/H	- .032	.068 NS	
		5-15 periodic growth	.395	5.44**	
18+19	Combination	Y-intercept	.047		100
		D/H	- .253	-1.46 NS	
		5-15 periodic growth	.397	10.88**	
24	Hand thinned	Y-intercept	.039		59
		D/H	1.135	2.65*[d]	
		10-15 periodic growth	2.70	2.42*	

[a] n = number of cores used for analysis
[b] NS = nonsignificant
[c] ** = significant at 0.01 level
[d] * = significant at 0.05 level

Preliminary analyses indicated the models for dozer-thinned and unmanaged stands were basically the same for a given set of data would predict equivalently the 0-5 year growth. In other words, dozer thinning resulted in no growth acceleration in the control stand we sampled. Therefore, core data from stands 18 and 19 were combined in developing a final single regression equation applicable to both dozer-thinned and unmanaged stands. The equation was $Y = 0.047 - 0.253X_1 + .397X_2$, where Y = predicted 0-5 year periodic growth, X_1 = D/H, and X_2 = 5-15 year growth period. The equation for hand-thinned stands was $Y = 0.039 + 1.135X_1 + 2.7X_2$ where X_1 = D/H and X_2 = 10-15 year growth. T-ratios of the partial regression coefficients for the 5-15 year periodic growth in the combined regression and for the 10-15 year periodic growth in the hand-thinned stand were significant at the 0.01 and 0.05 levels, respectively. The T-ratio for D/H in the combined regression was not significant at the 0.01 or 0.05 levels, but was better than for other variables tested. However, D/H was significant in the hand-thinned analysis. Thus, D/H ratio was retained as a variable in the final equations.

The combined equation was tested on the two control stands from which it was derived and on two additional unmanaged lodgepole pine control stands. Actual growth for the 0-5 year period was compared to predicted growth of the same period by means of a paired T test. Similarly, the equation for hand-thinned stands was tested on the stand from which is was derived (Table 2).

Table 2.--Comparison of actual vs. predicted growth in control stands

Stand No.	Stand type	Mean growth 0-5 year period Actual (inch)	Predicted	T-ratio
18	Unmanaged	0.291	0.286	0.384 NS
19	Dozer thinned	.206	.210	.224 NS
20	Unmanaged	.217	.210	1.342 NS
23	Unmanaged	.078	.089	-1.905 NS
24	Hand thinned	.587	.587	-0.007 NS

Results indicated that the models would predict the 0-5 year growth within reasonable limits as computed T-ratios for differences were nonsignificant. That the combined equation was tested on two additional control stands which were not used in developing the equation, and was able to predict accurately the 0-5 year growth added support to its reliability. However, this additional support was not gained for hand-thinned stands as an additional control stand in which to test the equation could not be found.

It is important to recognize that these models were designed to compare predicted radial growth to actual growth within stands but not between stands. Predicted growth is based on previous stand performance (growth and D/H). Because the model accurately predicted growth in control stands varying in stand density and average d.b.h., it is assumed these variables have little influence on the within-stand predictive capabilities of the models.

These equations were then applied to various stands within the fluoride polluted area. Predicted growth of the 0-5 year period was compared to actual growth and differences were statistically tested using a paired T-test (Table 3, Figure 2).

Table 3.--Comparison of predicted and actual radial growth for the 0-5 year period for stands within the fluoride-polluted area

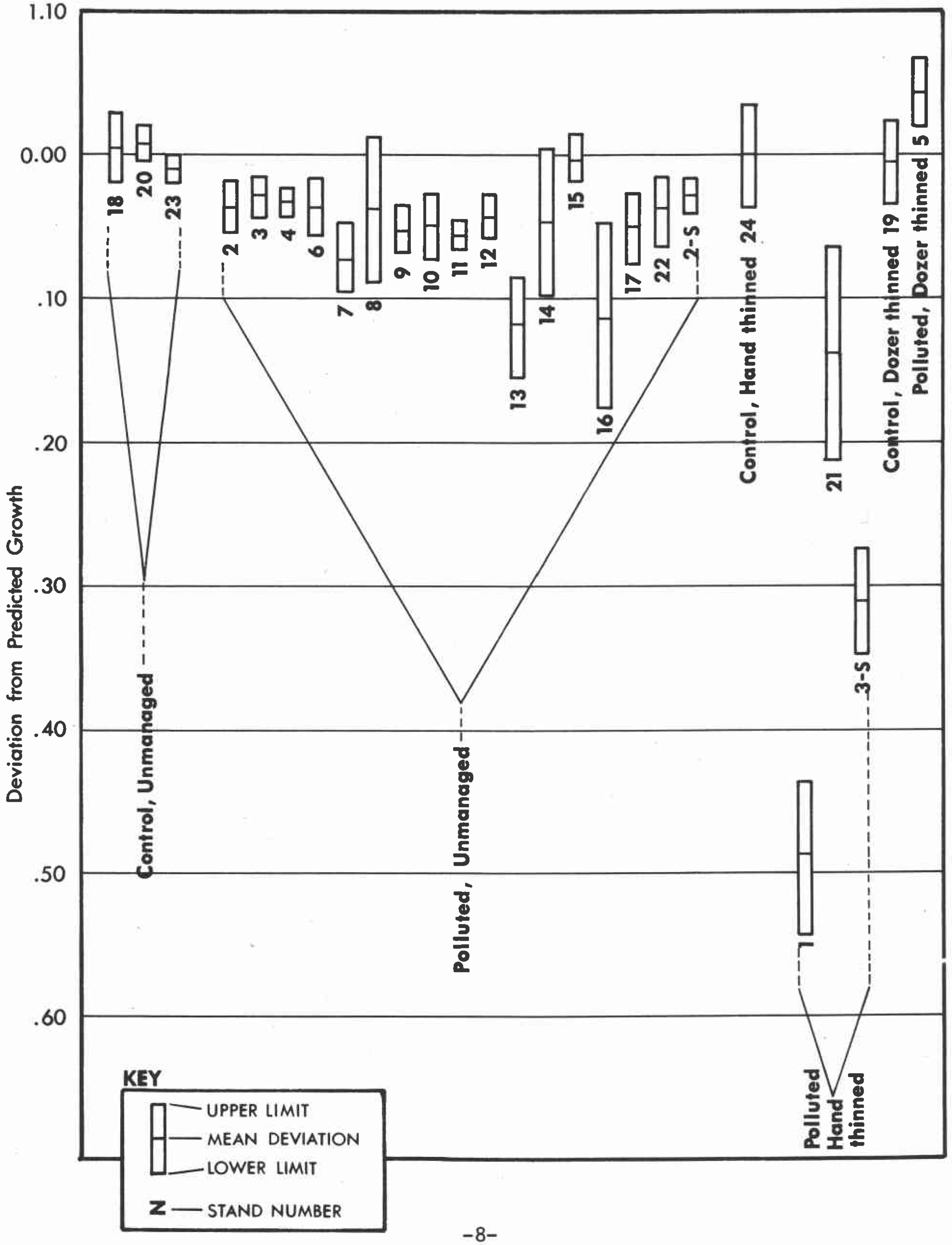
		Mean growth inches 0-5 year period				
Stand No.	Stand type	Actual	Predicted	Difference	T	N[1]
2	Unmanaged	0.186	0.221	-0.035	- 4.32**[2]	60
3	Unmanaged	.158	.188	- .029	- 4.07**	58
4	Unmanaged	.157	.187	- .030	- 5.97**	49
6	Unmanaged	.165	.201	- .036	- 3.48**	36
7	Unmanaged	.224	.295	- .071	- 6.13**	39
8	Unmanaged	.390	.430	- .039	- 1.55NS[3]	36
9	Unmanaged	.223	.276	- .053	- 6.46**	56
10	Unmanaged	.262	.312	- .051	- 4.56**	44
11	Unmanaged	.088	.143	- .055	-13.58**	57
12	Unmanaged	.169	.211	- .042	- 6.16**	51
13	Unmanaged	.335	.454	- .119	- 7.13**	59
14	Unmanaged	.280	.328	- .047	- 1.83NS	21
15	Unmanaged	.147	.149	- .002	- 2.37NS	40
16	Unmanaged	.241	.352	- .111	- 3.58**	20
17	Unmanaged	.182	.233	- .050	- 4.11**	31
22	Unmanaged	.316	.354	- .037	- 3.04**	40
2-S	Unmanaged	.157	.186	- .028	- 4.79**	48
1	Hand thinned	.250	.737	- .487	-17.85**	44
21	Hand thinned	.520	.657	- .137	- 3.74**	20
3-S	Hand thinned	.300	.611	- .310	-15.96**	40
5	Dozer thinned	.238	.193	+ .044	+ 3.55**	35

[1] N = Numbers of observations
[2] ** = Significant at 0.01 level
[3] NS = Nonsignificant

Fourteen of the seventeen unmanaged stands showed depressed radial growth significant at the 0.01 level of probability. The remaining three stands had nonsignificant growth reduction. Greatest negative deviation from predicted growth was found in hand-thinned stands. Although they showed some response to thinning done 6 to 8 years ago, the increase was nominal. The only stand to exhibit a significant increase in radial growth was stand No. 5, a dozer-thinned area. As discussed previously, the prediction model for dozer-thinned stands was similar to that for unmanaged, so the two were combined. Actually one would expect the models to be different because thinning should cause a positive growth response. However, in the control stand examined shrubs (willow, alder) proliferated following soil disturbance caused by the dozer thinning and likely offered considerable competition for water and nutrients to the remaining pines, thus limiting diameter growth. Stand No. 5, dozer thinned in the polluted area, did not have near the

FIGURE 2

95 Percent Confidence Intervals of Deviations from Predicted Growth



amount of competing undergrowth as the control and showed accelerated growth following thinning. Therefore, we do not believe that we have developed a proper model for predicting growth in dozer-thinned stands. However, soil disturbance during thinning was minimal in hand-thinned stands, nonexistent in unmanaged areas, and differences in competing understory vegetation were negligible and probably had little influence on growth differences in these stands. We believe the models worked well for these areas.

There is little question that significant reduction in radial growth of lodgepole pine in the polluted area has occurred. This reduction was converted to board foot and cubic foot loss. Impact on crop trees[3] is shown in Table 4, excess and mature trees in Table 5, and a summary is given in Table 6. Using the data from the Stage II survey and from the growth reduction shown in Table 3, mean actual diameters (D_1), and mean predicted diameters (D_2) of each stand were obtained. Percent diameter reduction (D_w) was computed as $\frac{D_2 - D_1}{D_2}$. It can be shown that proportion volume reduction (V_r) of a cylinder, which approximates the shape of a lodgepole stem, is related to proportion diameter reduction (D_w) by the formula $V_r = D_w (2 - D_w)$. Knowing the proportion volume reduction relative to diameter reduction, cubic foot and board foot losses were computed. Because of the young age and small diameters of the trees, little board foot volume was computed. Most volume was computed in terms of cubic feet, a feature contained in the Stage II computer program. Information for stand No. 5, the dozer-thinned example, was not computed because of uncertainties concerning the modeling data, as mentioned before. On a few other stands, including the hand-thinned stands, Stage II information was not available, and volume losses could not be computed. Crop tree losses ranged from 0 to 52 cubic feet per acre. Losses on excess and mature trees ranged from 2 to 56 cubic feet and from 6 to 279 board feet per acre. In Table 6 the total impact is shown on 1,424 acres for which Stage II information was available. This amounted to 69,031 cubic feet and an additional 59,540 board feet. Assuming a 1:5 ratio of cubic feet:board feet, the total impact in terms of board feet was 404,695 or 284 board feet per acre. These values represent losses over the 5-year period 1968-73. Expressed on a yearly basis, the average loss was 57 board feet per acre per year.

This evaluation was only a preliminary inquiry of the impact of fluoride and insects on lodgepole pine growth in the Columbia Falls, Montana, area. The total area affected by these stresses (within the 10 isopol) is estimated at 150,000 acres of State, private, and Federal lands--we

---

[3] Crop trees are those trees that would be saved and managed to rotation. Excess and mature trees would be eliminated in commercial or precommercial thinnings under normal forest management practices.

studied only 1,424. If the average growth loss can be applied to the total area affected, including lands outside the 30 isopol, the total growth impact becomes quite large--slightly over 8½ million board feet per year. For the last 5 years this approaches nearly 43 million board feet. Admittedly, this is speculative, but even if the real impact is only one-half or one-fourth of that, it is still significant.

Two other points need to be considered: First, height growth may or may not have been affected by the fluoride-insect complex; we did not study it. If a reduction in height has occurred, then our estimates of growth loss are conservative. Second, we made no attempt to assess mortality. Fluoride-caused mortality is extensive within 2 miles east and northeast of the aluminum plant, and certainly would contribute substantially to the total impact.

Although no volume information was available for hand-thinned stands 1, 21, and 3-S, stand growth following the management action was reduced 9 to 22 percent. This raises serious questions as to whether stand improvement measures should be attempted in the area as long as fluoride pollution continues.

Carlson et al. (1974) demonstrated a significant statistical relationship of fluorides to epidemic populations of two insects in the fluoride-polluted area. If this is a biologically true event, then fluorides must be considered the primary cause of radial growth rediction in the polluted area.

In conclusion, this evaluation shows that diameter growth within the area affected by fluoride and insects at Columbia Falls, Montana, has been significantly reduced. Translated to volume, the average reduction is 57 board feet per acre per year. Furthermore, growth increases expected following thinning are not realized. To assess the total impact on the timber resource in the affected area, it is recommended that the survey be expanded using the same techniques, and that mortality estimates be made. The preliminary study indicates that a significant economic loss has occurred and will continue to occur if fluoride emissions are not controlled.

ACKNOWLEDGEMENTS

Special appreciation is given to Wayne Bousfield for his help in programing and data analysis; to the Flathead National Forest for aid in collecting field data; to Dr. Gerhardt Shreuder, Dr. Don Davis, and others for reviewing the manuscript; and to Bob Neaves for doing the illustrations.

Table 4.--Lodgepole pine crop tree statistics - actual and predicted volumes for fluoride polluted area

Stand No.	Radial growth reduction inches	D_r Diameter growth reduction inches	D_1 Mean actual diameter inches	D_2 Mean predicted diameter inches	D_w Percent diameter reduction	V_r Percent volume reduction	Cu. ft. vol/acre actual	Cu. ft. vol/acre predicted	Bd. ft. vol/acre actual	Bd. ft. vol/acre predicted	Cu. ft. vol/acre loss	Bd. ft. vol/acre loss
2	0.035	0.070	6.2	6.3	1.11	2.21	1,257	1,285	--[1]	--	28	--
3	.029	.058	4.3	4.4	1.32	2.62	695	714	--	--	19	--
4	.030	.060	7.2	7.3	.85	1.69	1,513	1,539	642	653	26	11
6	.036	.072	4.0	4.1	1.76	3.52	535	557	--	--	22	--
7	.071	.142	6.6	6.7	2.12	4.20	796	831	917	957	35	40
8	.039	.078	5.1	5.2	1.50	2.98	575	593	--	--	18	--
9	.053	.106	6.8	6.9	1.54	3.06	1,636	1,688	--	--	52	--
10	.051	.102	6.5	6.6	1.52	3.02	1,333	1,375	--	--	42	--
11	.055	.110	5.2	5.3	2.08	4.12	252	263	--	--	11	--
12	.042	.084	5.9	6.0	1.40	2.78	818	841	--	--	23	--
13	.119	.238	6.9	7.1	3.35	6.59	574	614	--	--	40	--
14	.047	.094	6.2	6.3	1.49	2.96	NA[2]	--	--	--	--	--
15	.002	.004	6.9	6.9	.06	.12	135	135	--	--	0	--
16	.111	.222	6.6	6.8	3.26	5.12	490	516	--	--	26	--
17	.050	.100	6.4	6.5	1.54	3.06	896	924	--	--	28	--
22	.037	.074	6.7	6.8	1.09	2.17	NA	--	--	--	--	--
25	.028	.056	6.5	6.6	.85	1.69	NA	--	--	--	--	--
1	.467	.974	7.0	8.0	12.20	22.81	NA	--	--	--	--	--
21	.137	.274	5.8	6.1	4.50	8.80	NA	--	--	--	--	--
35	.310	.620	6.4	7.0	8.80	16.83	NA	--	--	--	--	--

---

[1] Diameters too small for board foot computations.
[2] NA - Stage II information not available.

Table 5.--Lodgepole pine excess and mature tree statistics actual and predicted volumes for fluoride-polluted area

Stand No.	Radial growth reduction inches	Diameter growth reduction inches	D_1 Mean actual diameter inches	D_2 Mean predicted diameter inches	D_w Percent diameter reduction	V_r Percent volume reduction	Cu. ft. vol/acre actual	Cu. ft. vol/acre predicted	Bd. ft. vol/acre actual	Bd. ft. vol/acre predicted	Cu. ft. vol/acre loss	Bd. ft. vol/acre loss
2	0.035	0.070	5.4	5.5	1.27	2.52	874	897	217	223	23	6
3	.029	.058	3.2	3.3	1.76	3.49	270	280	166	172	10	6
4	.031	.062	5.4	5.5	1.13	2.65	1,346	1,383	221	227	37	6
6	.036	.072	3.2	3.3	2.18	4.31	19	20	--1/	--	1	--
7	.071	.142	9.8	9.9	1.43	2.84	337	349	1,394	1,435	12	41
8	.039	.078	7.5	7.6	1.03	2.05	840	858	3,463	3,535	18	72
9	.053	.106	4.8	4.9	2.16	4.27	1,247	1,303	536	560	56	24
10	.050	.100	6.6	6.7	1.49	2.96	394	406	1,514	1,560	12	46
11	.055	.110	2.3	2.4	4.58	8.95	--	--	--	--	--	--
12	.042	.084	3.2	3.3	2.55	5.04	136	143	256	270	7	14
13	.119	.238	9.4	9.6	2.48	4.90	1,148	1,207	5,417	5,696	59	279
14	.047	.094	5.5	5.6	1.68	3.33	NA2/	--	--	--	--	--
15	.002	.004	1.6	1.6	.25	.50	NA	--	--	--	--	--
16	.111	.222	2.3	2.5	8.88	16.97	NA	--	--	--	--	--
17	.050	.100	3.4	3.5	2.94	5.79	53	55	--	--	2	--
22	.037	.074	NA	--	--	--	--	--	--	--	--	--
25	--	--	--	--	--	--	--	--	--	--	--	--
1	.487	.974	--	--	--	--	--	--	--	--	--	--
21	.137	.274	--	--	--	--	--	--	--	--	--	--
35	.310	.620	--	--	--	--	--	--	--	--	--	--

1/ Diameters too small for board foot computations or information not on Stage II printout.
2/ NA - Stage II information not available.

Table 6.--Summary of fluoride-insect impact on lodgepole pine growth

		Crop trees		Excess and mature trees		Crop trees		Excess and mature trees		Total impact	
Stand No.	Number of acres	Cu. ft. loss/ acre	Bd. ft. loss/ acre	Cu. ft. loss/ acre	Bd. ft. loss/ acre	Cu. ft. loss/ stand	Bd. ft. loss/ stand	Cu. ft. loss/ stand	Bd. ft. loss/ stand	Cu. ft. loss/ stand	Bd. ft. loss/ stand
2	58	28		23	6	1,624		1,334	348	2,958	348
3	22	19		10	6	418		220	132	638	132
4	50	26	11	37	6	1,300	550	1,850	300	3,150	850
6	75	22		1	--	1,650		75		1,725	--
7	162	35	40	12	41	5,670	6,480	1,944	6,642	7,614	13,122
8	132	18		18	72	2,376		2,376	9,504	4,752	9,504
9	184	52		56	24	9,568		10,304	4,416	24,288	4,416
10	112	42		12	46	4,704		5,152	1,344	9,856	1,344
11	122	11		--	--	134				1,342	--
12	21	23		7	14	483		147	294	630	294
13	70	40		59	279	2,800		4,130	19,530	6,930	19,530
14	76	--								--	--
15	154	0		0		0				0	--
16	108	26				2,808				2,808	--
17	78	28		2	--	2,184		156		2,340	--
22	NA	--									
25	NA	--									
1	23										
21	NA										
35	NA										
Total acres	1,424 1/								Total impact	69,031	59,540

Total board foot impact, assuming 5:1 ratio of board foot:cubic foot = 404,695
Per acre board foot impact = 284
Per acre per year board foot impact = 57

1/ Acres on which Stage II information was available.

REFERENCES CITED

Bousfield, W., R. Lood, R. Miller, and S. Haglund, 1973. Observations on the impact of western spruce budworm in the Valley Creek drainage, Flathead Indian Reservation, Montana. USDA, Forest Serv., Northern Region, Missoula, Mont., Insect and Dis. Rept. 73-17, 8 pp.

Carlson, C. E., and J. E. Dewey, 1971. Environmental pollution by fluorides in Flathead National Forest and Glacier National Park. USDA, Forest Serv., Northern Region, Missoula, Mont., 57 pp.

Carlson, C. E., 1972. Monitoring fluoride pollution in Flathead National Forest and Glacier National Park. USDA, Forest Serv., Northern Region, Missoula, Mont., 25 pp.

Carlson, C. E., 1974. Monitoring fluoride pollution in Flathead National Forest and Glacier National Park - 1972. USDA, Forest Serv., Northern Region, Missoula, Mont., Insect and Dis. Rept. 74-5, 7 pp.

Carlson, C. E., Wayne E. Bousfield, and Mark D. McGregor, 1974. The relationship of an insect infestation on lodgepole pine to fluoride emitted from a nearby aluminum plant in Montana. USDA, Forest Serv., Northern Region, Missoula, Mont., Insect and Disease Rept. 74-14, 21 pp.

Environmental Protection Agency, 1973. Fluoride in Glacier National Park: a field investigation. U.S. Environ. Prot. Agency, Region VII, Air and Water Prog. Div., Denver, Colo., 69 pp.

Gordon, C. C., 1972. 1970 Glacier National Park Study. Environ. Studies Lab., Univ. of Mont., Missoula, Mont.

Lynch, D. W., 1951. Diameter growth of ponderosa pine in relation to the Spokane pine-blight problem. Northwest Science 25: 157-163.

Pfister, R. D., S. F. Arno, R. C. Presby, and B. L. Kovalchik, 1972. Preliminary forest habitat types of western Montana. USDA, Intermountain Forest and Range Expt. Sta. and Region 1, Missoula, Mont., 71 pp.

Stage, A., 1970. Program changes implemented in Trend 1 and HGF. Subroutine for growth and PAI computations. USDA, Intermountain Forest and Range Expt. Sta., Moscow, Idaho.

Treshow, M., F. K. Anderson, and F. Harner, 1967. Responses of Douglas-fir to elevated atmospheric fluorides. Forest Science 13(2): 114-120.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1974—696-255 106