Technical Report Documentation Page

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Highway Operation And Plant Damage

5. REPORT DATE

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7. AUTHOR(S)

Andrew T. Leiser, Ravindran Palaniyandi, Jack L. Paul, Robert Raabe (Dept. Plant Pathology, U.C. Berkeley)

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Davis, CA 95616

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16. ABSTRACT

A five year study investigated the relationship between highway operation and plant damage in the Tahoe Basin and adjacent highways. These studies included field surveys, greenhouse studies, soil salt application trials, foliar salt application trials, an Armillaria root rot inoculation study, a seasonal fluctuation of salt study, the effect of temperature on salt uptake and a bark absorption of salt study. Highway deicing salt is a cause of damage on conifers, usually limited to 30 feet from the pavement edge. Drainage patterns and salt carried by aerosols may extend damage farther from the pavement. Beetles were an important cause of damage along highway corridors in the study area. Depth of fill and Armillaria root rot had little apparent effect.

Of the four principal conifers in the study area, Jeffrey pine and lodgepole pine appeared the most tolerant of salt and incense cedar was the most susceptible. The true firs were intermediate in sensitivity. Symptoms and estimated critical threshold levels of leaf Na and Cl are given. The soils of the study area appear to leach well and there was no evidence of salt build-up during the course of the study.

Root uptake of salt is low when air temperatures are low. There did not appear to be uptake of salt through the bark of trees.

17. KEYWORDS

Deicing Salt, Leaf sodium, Tree damage, Leaf chloride, Beetles, Damage symptoms, Terrestrial vegetation, Soil salts

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The findings of this study are compared to those of Scharpf and Srago for the Tahoe Basin.

17. KEY WORDS		18. DISTRIBUTION STATEMENT
Deicing Salt	Leaf sodium	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161
Tree damage	Leaf chloride	
Beetles	Damage symptoms	
Terrestial vegetation	Soil salts	

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English to Metric System (SI) of Measurement

Quanity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic yards (yd^3)	3.785 .02832 .7646	litres (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time			
(Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour(mph) feet per second(fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity(G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^2)
Force	pounds (lbs) kips (1000 lbs)	4.448 4.448	newtons(N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds(ft-lb) foot-kips (ft-k)	1.356 1.356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds(ft-lbs) foot-pounds(ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi) pounds per square foot (psf)	6895 47.88	pascals (Pa) pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

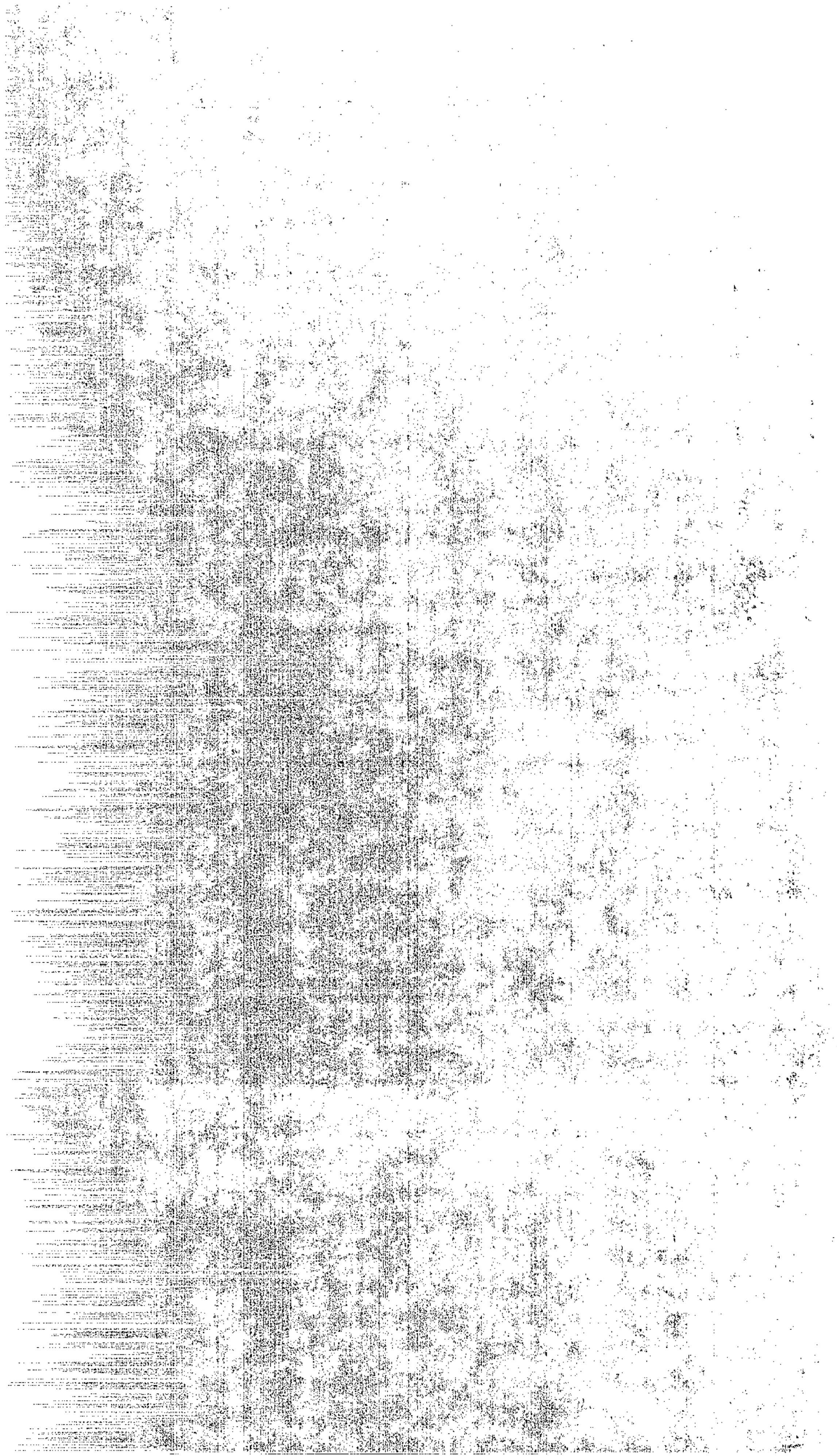

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TABLE OF CONTENTS

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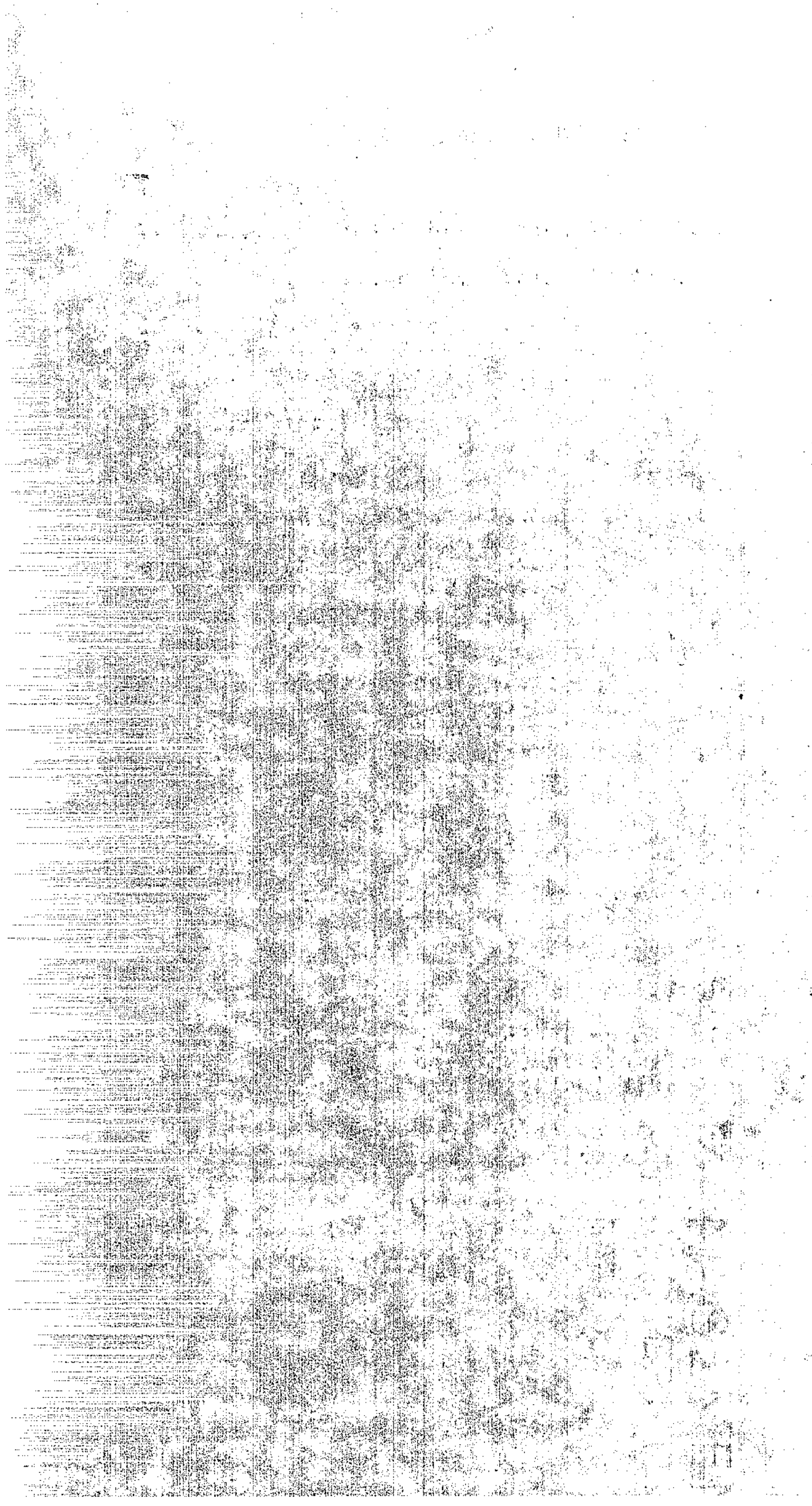


TABLE OF CONTENTS (Cont.)

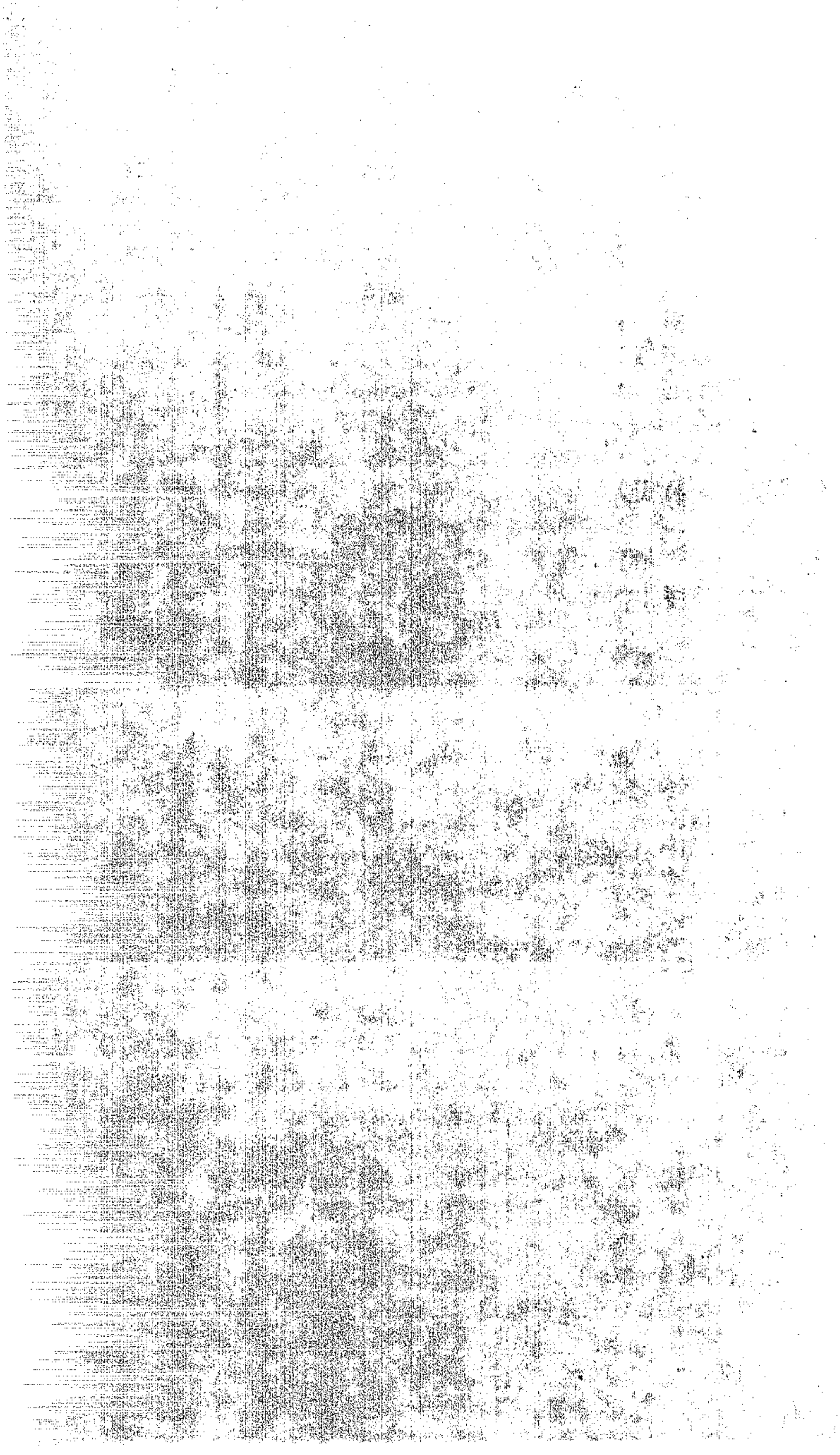
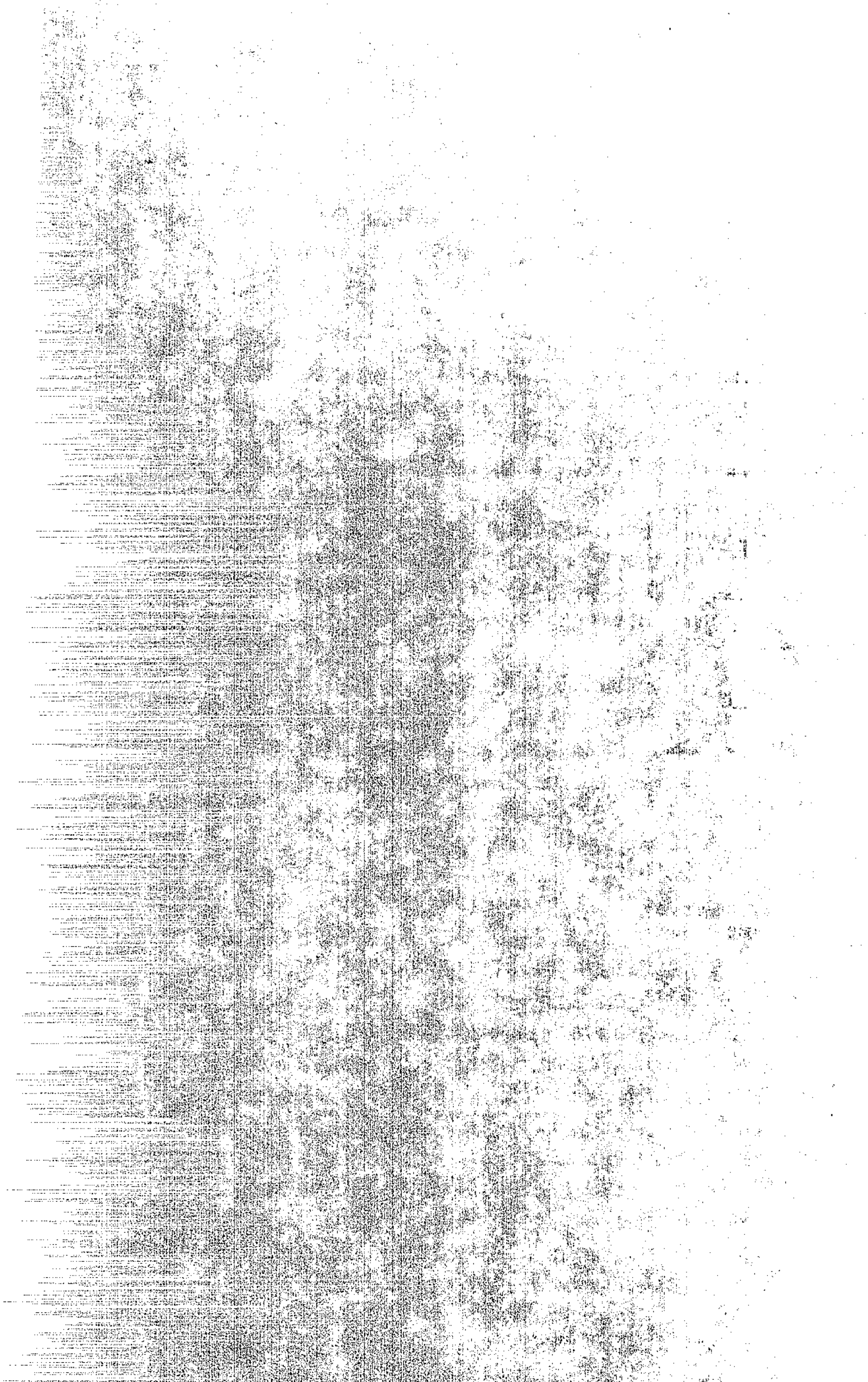


TABLE OF CONTENTS (Cont.)

LIST OF FIGURES



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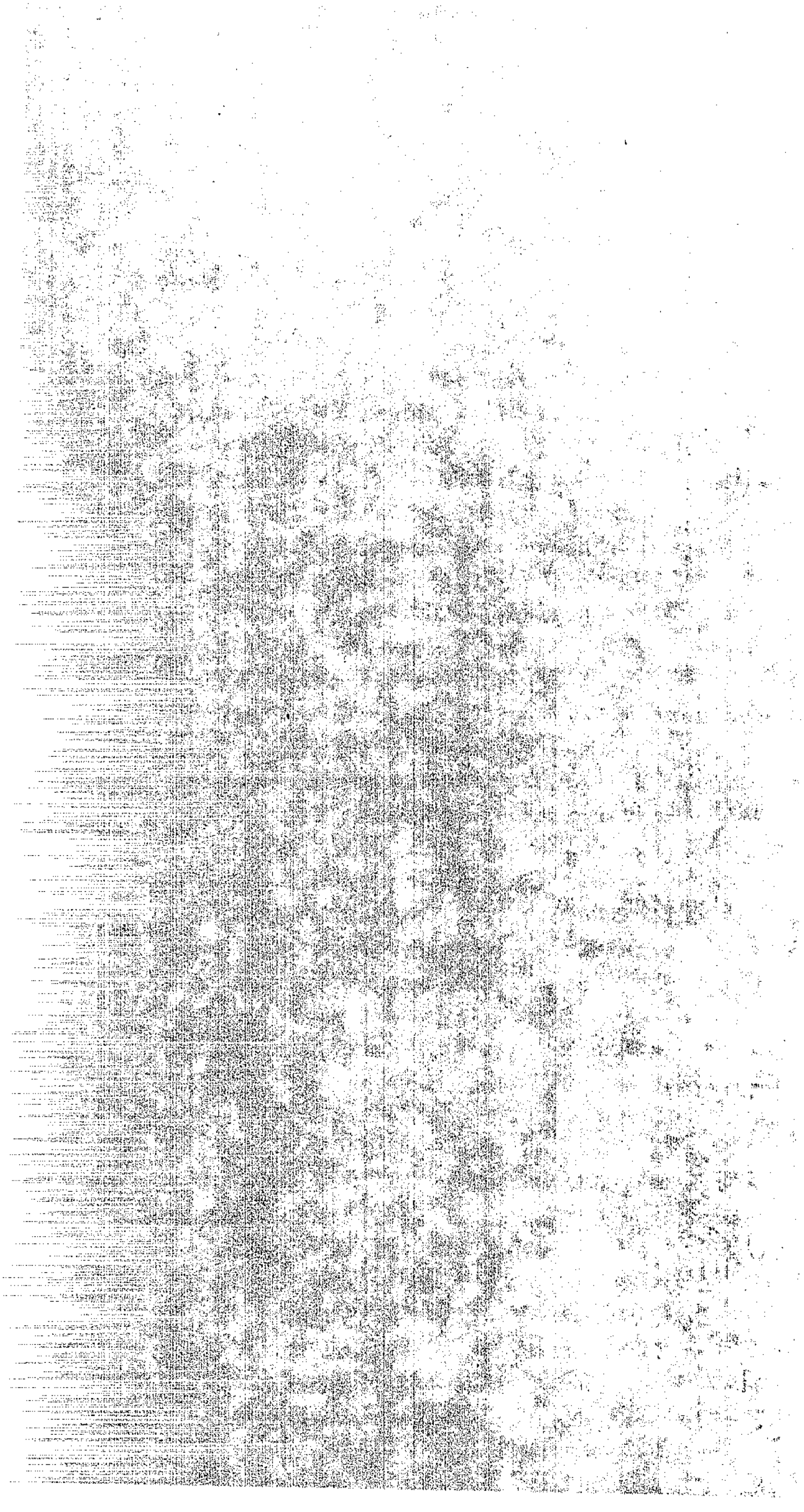

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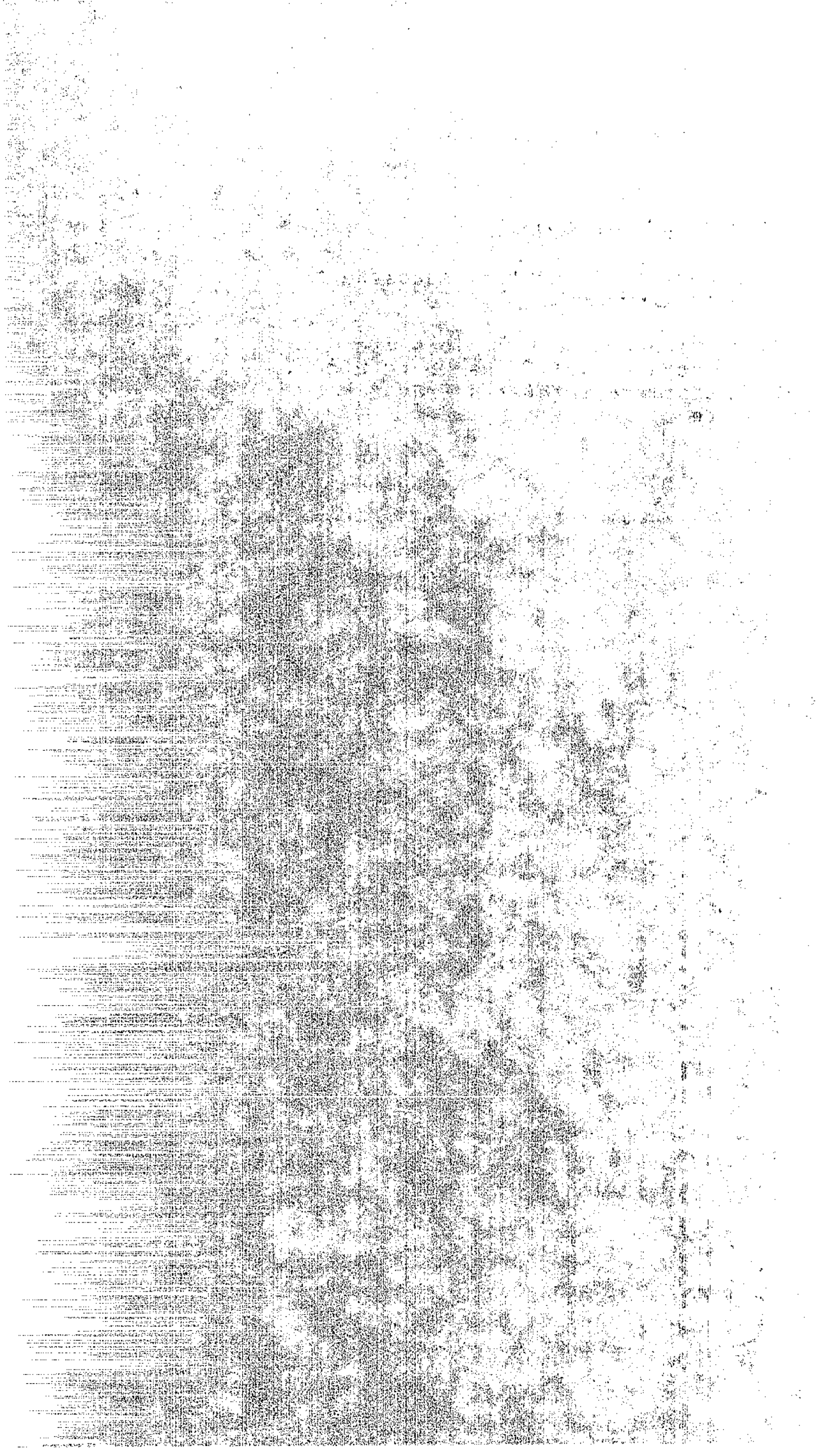

LIST OF TABLES

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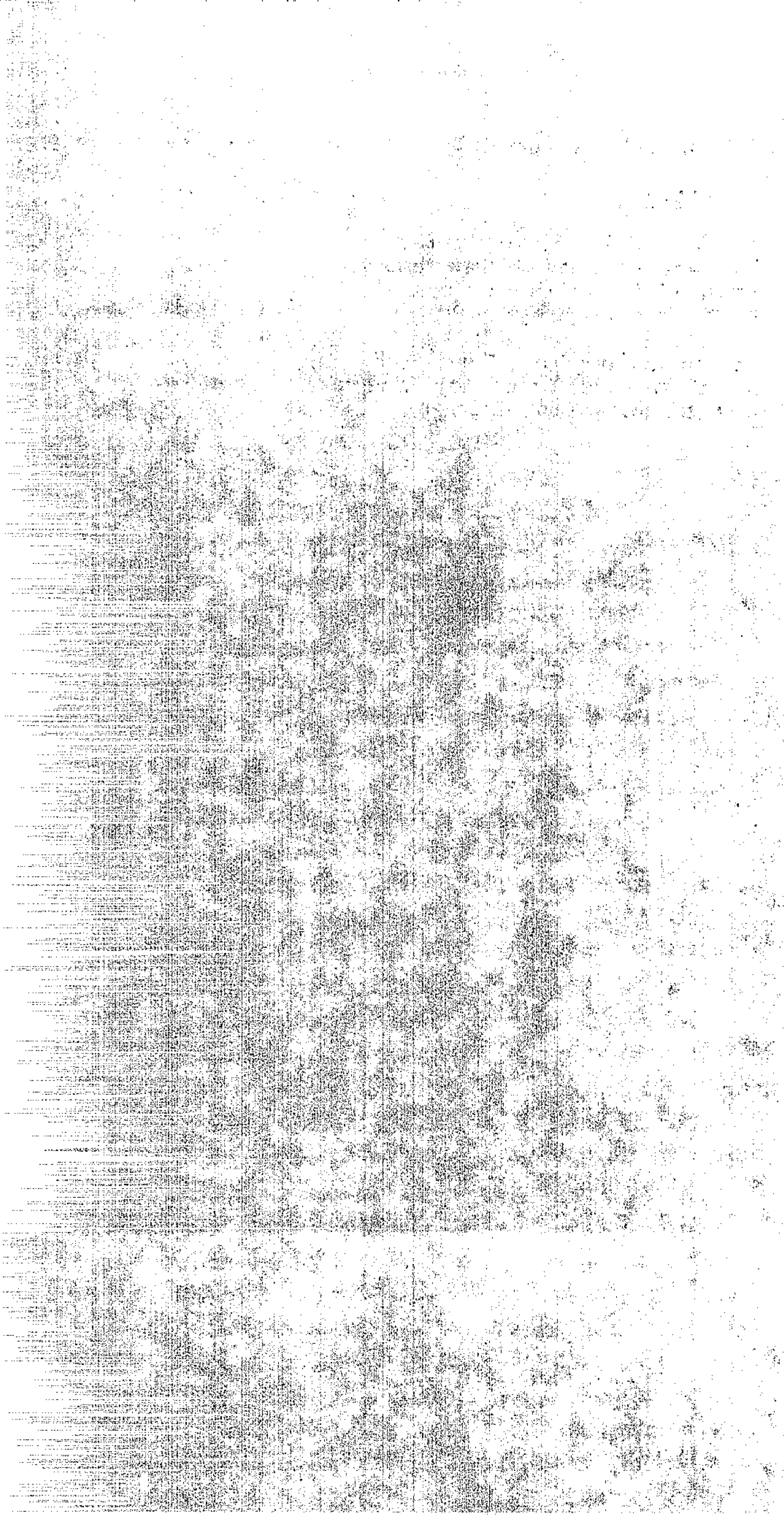


1. INTRODUCTION

In the Lake Tahoe Basin, California, deicing of highways with salt (sodium chloride) mixed with sand and cinder was begun in the early 1950's. Between 1965 and 1975, on an average, 1,460 tons of salt per year were used in deicing highways around the basin. In the early 1970's several species of coniferous trees were observed to be dying along these highways. Plant pathologists of the U.S. Forest Service (USFS) reported in 1971 that the decline of pine and fir in several hundred acres in the vicinity of Camp Richardson and Echo Summit were caused by fungi - *Elytroderma deformis* and *Melampsorella cerastii*. Local foresters suspected highway deicing salt also as a cause of damage especially in areas where these fungi were absent. Several investigations (1,8,9,10,11, 14,18,24,25) conducted in the eastern and midwestern states have shown that deicing salt caused damage to roadside vegetation, but in California information on the impact of salt on the roadside vegetation was scanty.

In the spring of 1973 the Pacific Southwest Forest and Range Experiment Station and the Pacific Southwest Region, USFS conducted a study to determine the effect of salt on the coniferous trees in the Lake Tahoe Basin and concluded that some 3,000 trees were dying or dead within 60 feet of the highways due to salt (21). This study did not attempt to correlate the extent of damage to the amount of salt applied in different sections of the highways nor did it take into account other possible causes of plant damage. The California State Department of Transportation (Caltrans), the USFS and the Tahoe Regional Planning Agency (TRPA) recognized the need for more detailed studies which would partition the amount of plant damage among different casual agents, establish threshold levels of sodium (Na) and chloride (Cl) causing phytotoxicity, and delineate salt damage symptoms from those caused by other factors. The relation between highway application rates of salt, salt in the soil adjacent to the highway, and tissue levels of Na and Cl, at threshold levels of damage was needed to implement a successful mitigation program.

A research program initiated and financed by Caltrans and the Federal Highway Administration (FHWA), and conducted by the Department of Environmental Horticulture of the University of California at Davis was begun in 1973. This report presents and discusses the research findings of this program.

2. BACKGROUND

Sand or cinders, and salt are used as safety measures on some California highways subjected to snowfall. The sand or cinders are used for increased traction and the salt is used primarily as a bond breaker between the pavement and the snow and ice. The rate of application of salt varies according to storm frequency and site aspect.

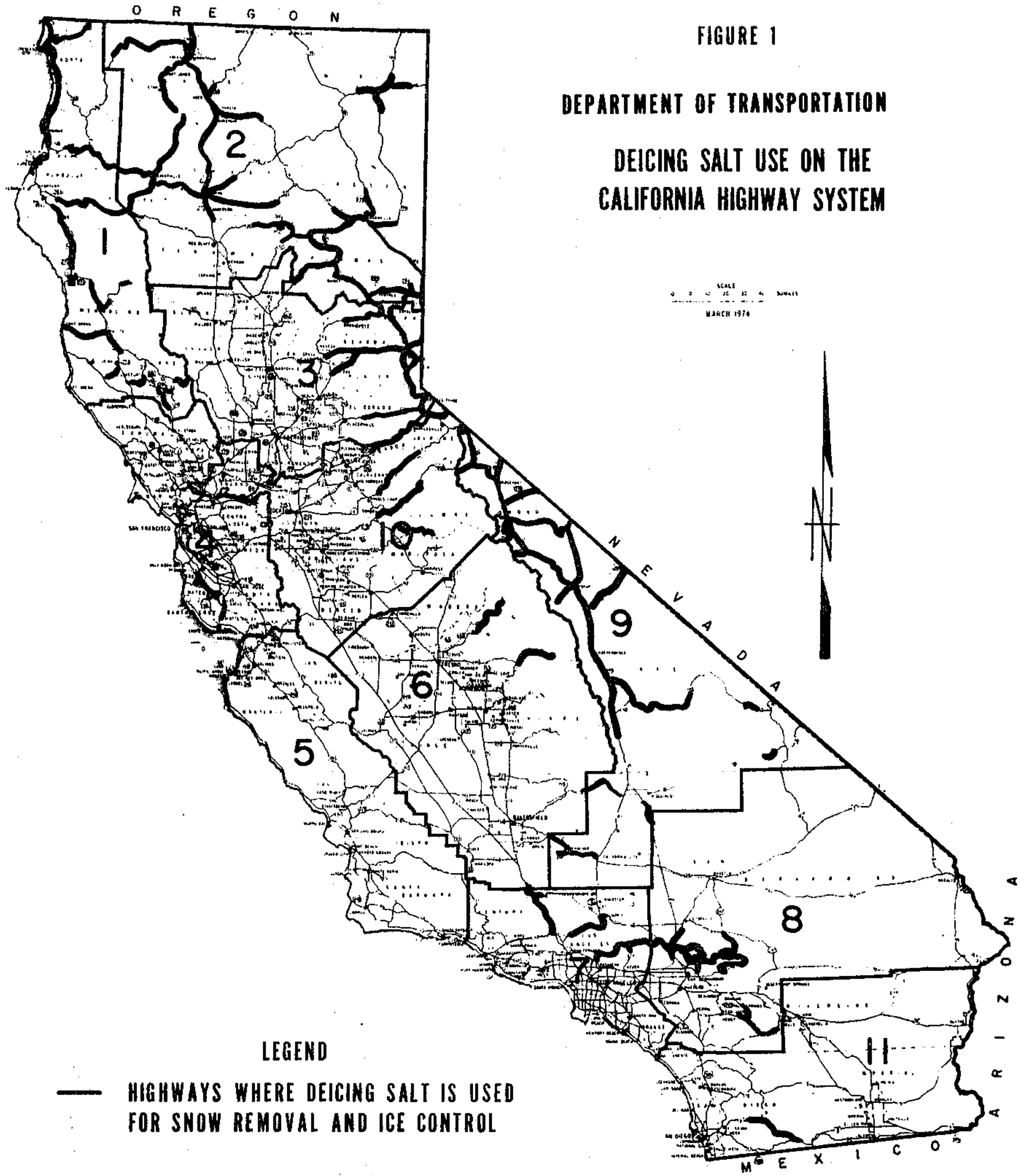
Between 1970 and 1975, the total annual use of salt on the state highway system ranged from about 18,000 to 31,000 tons depending on the severity of the season (7). Approximately half of the total annual tonnage was used on State Route 50 and I-80 in Transportation District 03 (Fig. 1).

During these years typical annual salt application rates per lane mile in District 03 ranged from 15-25 tons on

FIGURE 1

DEPARTMENT OF TRANSPORTATION

DEICING SALT USE ON THE CALIFORNIA HIGHWAY SYSTEM



LEGEND

—— HIGHWAYS WHERE DEICING SALT IS USED FOR SNOW REMOVAL AND ICE CONTROL

State Route 50 over Echo Summit (7,000 ft), 7-12 tons on I-80 over Donner Summit (7,240 ft), to a low of 1.5 - 5.8 tons on State Route 89 in the Lake Tahoe Basin (7). These roads lie in regions of heavy snowfall and traverse coniferous forests of the Sierra Nevada mountains. They are routes of heavy winter traffic.

An environmental impact report was prepared and circulated by Caltrans in 1975 covering the use of deicing salt on state highways in California. This report covered specific issues of salt usage impact on the roadside environment and the established Caltrans approach to handling snow and ice removal along state routes. The report compilation resulted in a re-definition of statewide objectives of snow and ice removal, namely "......to use the minimal amount of salt necessary to maintain highways in a condition that is safe......"

Caltrans has directed its efforts since 1975 to the reduction of salt usage through:

1. Uniform logging of salt application;
2. Identification of highway segments of typical salt usage;
3. Re-evaluation of snow and ice control levels throughout the system to determine when reduced salt usage will give equivalent adequacy;
4. Improved training of field personnel;
5. Securing better electronic metering for improved mixing and application of salt and abrasives;
6. Identifying environmentally sensitive segments where further downward adjustment of salt applications might be made.

An experimental no-salt section of 10 miles on State Route 89 is currently being monitored by Caltrans in an effort to relate safety, maintenance costs, road closure, etc., to similar areas where salt is used.

Salt leaves the highway surface in three ways. Snow plows remove large quantities of salt-laden snow and deposit it in the median or along the roadway shoulder. Dissolved salt leaves the roadway as runoff. Aerosols created by traffic may deposit salt on foliage. The quantities of salt that leave the road depend on the amount applied but the distance the salt is transported and the concentration in the soil from place to place depends on other factors. The topography, presence of berms, highway slope (super) and grade, wind velocity and direction, presence of vegetation, location of roadside ditches and drainage channels, volume of traffic and variations in snow accumulation (affecting dilution) influence the distribution of soil salt adjacent to the highway.

Many studies have shown that deicing salt can have an adverse effect on vegetation near highways because of the toxicity of high concentrations of Na and Cl in the tissue. The damage is manifested in mild form by tip browning of foliage, premature defoliation in conifers, retardation of growth and, in severe cases, death of the plant, (8,9,10, 11,14,24,25).

Plant damage along highways can be caused by a number of other agents. Various fungous diseases, plant parasites and insects occur in the study area.

Needle blight (Elytroderma spp.) in Jeffrey pine and lodgepole pine, brown rust (Melampsorella spp.) in white fir and red fir, both in epidemic proportions in certain localities, commandra blister rust (Cronartium spp.) in the native pines, canker (Cytospora sp.) in white fir and leaf rust (Gymnosporangium sp.) in incense cedar and species of Armillaria, Fomes and Polyporus. which cause root and heart rot and pocket dry rot in pines, firs and incense cedars are known to be present in the Lake Tahoe Basin.

Dwarf mistletoes (Arceuthobium spp.) which causes extensive damage in sugar pine, white and red firs and especially in Jeffrey and lodgepole pines are also prevalent in the area.

The mountain pine beetle (Dendroctonus ponderosae (Syn.: D. monticolae)) in sugar pine and lodgepole pine, Jeffrey pine beetle (Dendroctonus jeffreyi) in Jeffrey pine, fir engraver beetle (Scolytis sp.) in white fir and red fir are known to be destructive in these areas.

Changes in the micro-environments by men's activities may contribute to plant damage. The activities include: the opening of the forest canopy by highway and other construction; altering runoff and drainage patterns, dumping fill material around trees during construction or clean-up activities, severing portions of the root systems during road and sewer construction, and compaction from traffic and parking along highway rights-of-way. Most of these factors are difficult to evaluate but this study did attempt to assess the effects of fill around trees.

In the study area where roads are uniformly salted, the damage pattern is erratic. This suggests that there may be genetic variability and that variations in tree size and vigor may affect susceptibility to salt damage. The adverse biotic agents and changes in micro-environments could act independently or have an additive effect on plant damage. A careful examination of the etiology of plant disorders along highway corridors seemed desireable.

The geography and hydrology of the research areas are similar but vary somewhat.

Lake Tahoe, at an elevation of about 6,200 feet, is encircled by mountains. The soils are formed from a complex admixture of volcanic, metamorphic and granitic rocks. The annual snowfall is between 200 and 300 inches. The summer day-time temperatures range from 70-90°F and the growing season between killing frosts varies from 8-12 weeks depending upon the year.

The three Trans-Sierra highways have, at the elevations of the study sites, somewhat similar soil and vegetation patterns. The soils at the sites are described in Caltrans Data Appendix (17). Precipitation at the weather stations in the project area are given in Table 1. At lower elevation sites the plant spectrum begins to change. The true firs and the lodgepole and Jeffrey pine give way to Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) and ponderosa pine (Pinus ponderosa Dougl. ex P. Laws. & C. Laws.) and the deciduous poplars give way to California black oak (Quercus Kellogii Newb.) and big-leaf maple (Acer macrophyllum Pursh). There is change in diversity and kinds of shrub species.

The following are the predominant tree and shrub species in the Tahoe Basin and adjacent study areas:

Table 1. Annual precipitation in the study area (inches, July through June).[1]

Year	Blue Canyon		Truckee Ranger Station		Tahoe City		Twin Lakes	
	Normal	Actual	Normal	Actual	Normal	Actual	Normal	Actual
1974-75	67.58	68.92	32.82	31.56	33.13	27.33	51.13	49.96
1975-76	"	34.75	"	17.42	"	14.32	"	29.14
1976-77	"	26.98	"	17.91	"	12.16	"	26.68
1977-78	"	87.87	"	33.47	"	28.71	"	55.00

[1]From Nakao et al (17).

Trees

Abies concolor (Gord.) Lindl. ex Hildebr.	White fir
A. magnifica A. Murr.	Red fir
Calocedrus decurrens (Torr.) Florin	Incense cedar
Pinus jeffreyi Grev. & Balf.	Jeffrey pine
P. lambertiana Dougl	Sugar pine
P. murryana Grev. & Balf.	Lodgepole pine
P. ponderosa Dougl. ex P. Laws & C. Laws	Ponderosa pine
Populus tremuloides Michx.	Quaking aspen
P. trichocarpa Torr. & Gray	Cottonwood

Shrubs

Arctostaphylos nevadensis	Pinemat manzanita
A. patula Greene	Greenleaf manzanita
Artemisia tridentata Nutt.	Bigbasin sagebrush
Ceanothus cordulatus Kell.	Mountain whitethorn, snowbush
C. prostratus Benth.	Squaw carpet, mahala mat
C. velutinus Dougl. ex Hook.	Tobacco brush, buckbrush
Chrysolepis sempervirens (Kell.) Hjelmquist	Chinquapin
Cornus stolonifera Michx. (Syn.: C. sericea)	American dogwood, creek dogwood
Penstemon newberryi Gray	Newberry penstemon, mountain pride

Shrubs (Cont.)

<u>Prunus emarginata</u> (Dougl.) Walp.	Bitter cherry
<u>Quercus vaccinifolia</u> Kell.	Huckleberry Oak
<u>Salix</u> spp.	Willow
<u>Sambucus microbotrys</u> Rydb.	Mountain elderberry

Numerous other shrub species occur in varying numbers in the study areas and at the lower elevations on the trans-Sierran highways a few additional tree species are found.

3. OBJECTIVES

This five-year study was inaugurated by Caltrans in 1973 to assess the extent and causes of damage to roadside vegetation in Transportation Districts 03 and portions of District 10 caused by highway operations; to investigate the role of other possible agents that might contribute to damage; and to develop operational procedures to minimize or alleviate plant damage.

The project was divided into two phases: I - soil salt analysis and II - vegetation damage assessment and recommendation for mitigation.

Phase I was conducted by Caltrans staff with the following objectives: to quantify salt concentrations of soils at selected sites along roadways, to determine typical ozone concentrations in the Basin and to develop methods to minimize or alleviate plant damage. The task was completed in June 1975. In January 1976, Caltrans published an interim report discussing their findings.

Phase II, conducted by the Department of Environmental Horticulture, UCD, had the following objectives:

1. To survey the extent of plant damage in the study areas, identify the causes of damage (salt in the soil and foliage, pathogens, bark beetles and altered micro-environment, etc.), and when possible, quantify the damage caused by each agent, and delineate plant damage symptoms;

2. To determine the seasonal fluctuation of salt in roadside vegetation and soils;

3. To develop salt damage symptoms in shrubs and trees native to the study area and to determine the threshold toxicity levels in the leaf tissue;

4. To determine the symptoms and threshold levels of damage from salt applied to the foliage;

5. To determine the influence of temperature on salt uptake by roots of at least one tree species;

6. To determine the role of root rot pathogens in damage to conifers in the study sites;

7. To determine whether salt can enter the tree through the bark at the base of the trunk. (This area is often covered by deicing sand or cinders near the highway.): and

8. To assist Caltrans in developing alternative highway operational procedures, to minimize or alleviate plant damage, based on the results of the research.

4. RESEARCH STUDIES

A number of separate studies were devised to meet these objectives. These were:

1) Field Surveys - objectives 1, 2, and 6 (in part),

2) Soil Salt Application Trials - objective 3,
3) Foliar Salt Application Trials - objective 4,
4) *Armillaria* Root Rot Study - objectives 1 (in part) and 6,
5) Seasonal Fluctuation of Salt Study - objectives 1 (in part), and 2,
6) Temperature Influence on Salt uptake - objective 5,
7) Bark Absorption of Salt - objective 7.

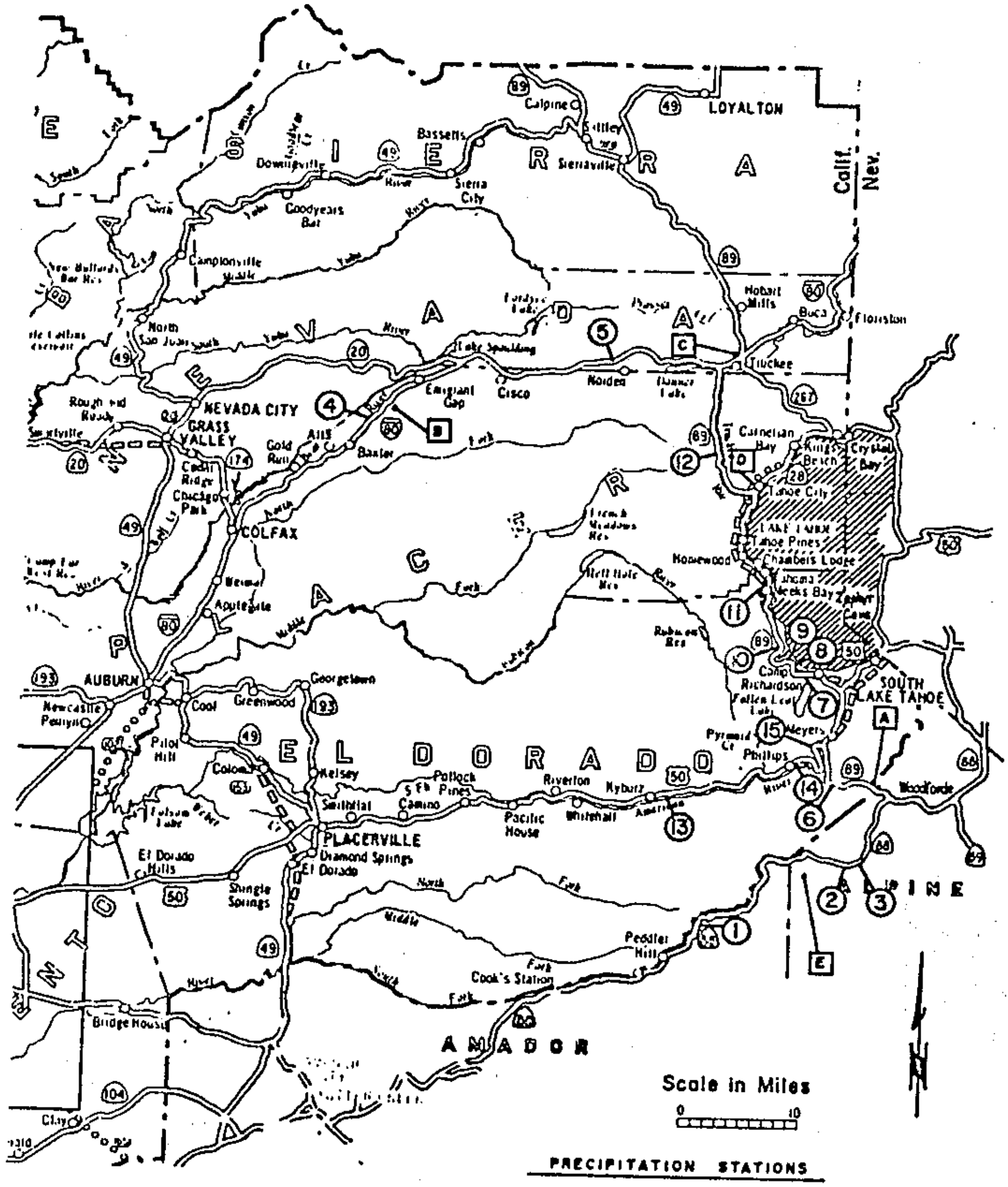
5. FIELD SURVEYS

5.1 Selection of Study Areas

Potential study areas were selected in the fall of 1973 by visiting the highway corridors involved, State routes 28, 88, and 89, U.S. 50, and I-80 in the areas in which snow removal and salting operations are conducted. Fifteen sites were selected for intensive study, based on: deicing salt application rates, soil types, topography, roadway drainage patterns, and type and severity of plant damage. The objectives were to select representative sites with a range of salt application rates, soil types and as complete a spectrum of vegetation, of suitable size for sampling, as possible. Locations of these sites are shown in Fig. 2. The soil types, topography, drainage patterns, etc., of the sites are described in a Caltrans Interim Report. (16) The salt application rates adjacent to the sites (Caltrans data) are shown in Figs. 3A,B,C, and D.

The preliminary survey in the summer of 1974, included an inventory of all tree and major shrub vegetation on each site and initial sampling of tissues of four shrub species.

Figure 2 . PLANT DAMAGE STUDY SITES



PRECIPITATION STATIONS

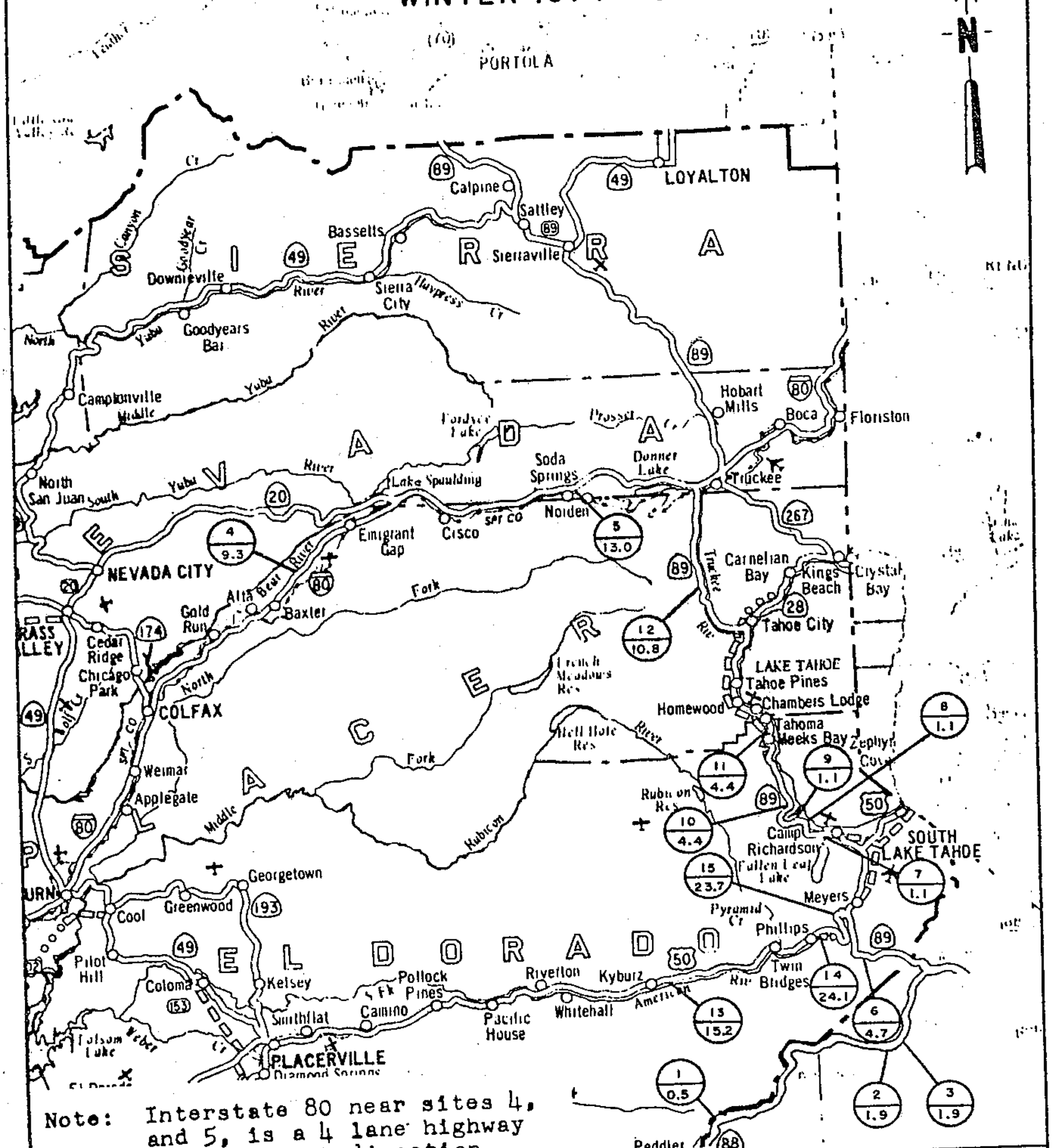
- A LUTHER PASS
- B BLUE CANYON
- C TRUCKEE RANGER STATION
- D TAHOE CITY
- E TWIN LAKES

SITE	LOCATION	
1	10-Ama-88	PM 60.5
2	10-Alp-88	PM 4.53
3	10-Alp-88	PM 5.05
4	03-Pla-80	PM 50.26
5	03-Nev-80	PM 3.53
6	03-ED-89	PM 3.98
7	03-ED-89	PM 10.43
8	03-ED-89	PM 14.32

SITE	LOCATION	
9	03-ED-89	PM 15.47
10	03-ED-89	PM 18.10
11	03-ED-89	PM 26.4
12	03-Pla-89	PM 13.49
13	03-ED-50	PM 51.43
14	03-ED-50	PM 62.63
15	03-ED-50	PM 69.44

Taken from Nakao et al (17).

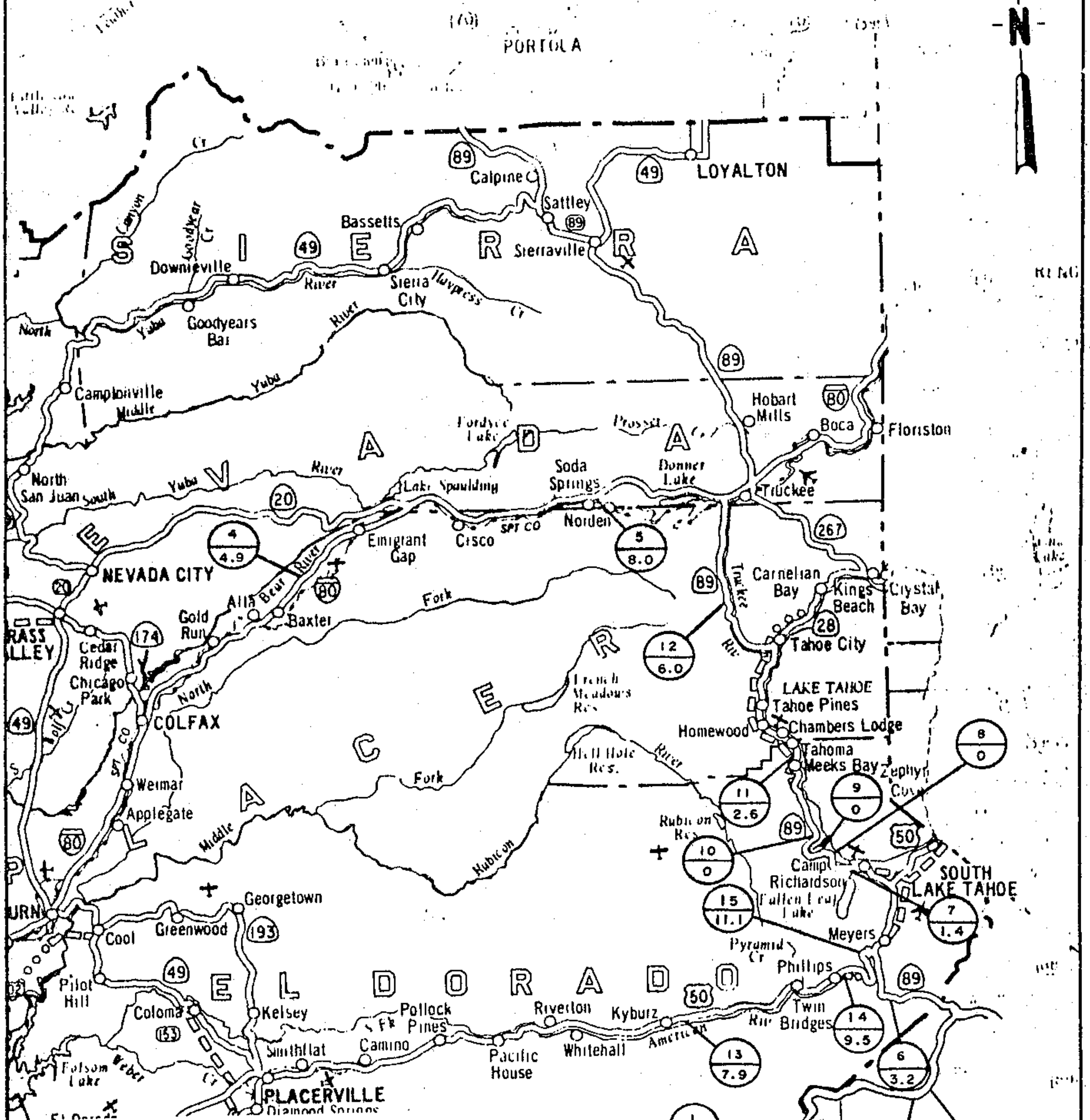
FIGURE 3A. DEICING SALT APPLICATION RATES AT THE TERRESTRIAL VEGETATION STUDY SITES WINTER 1974-75



Note: Interstate 80 near sites 4, and 5, is a 4 lane highway (2 lanes each direction, separated by a wide median). All other highways in the vicinity of the sites are 2 lanes.

SITE NO. — Deicing salt application tons/lane mile

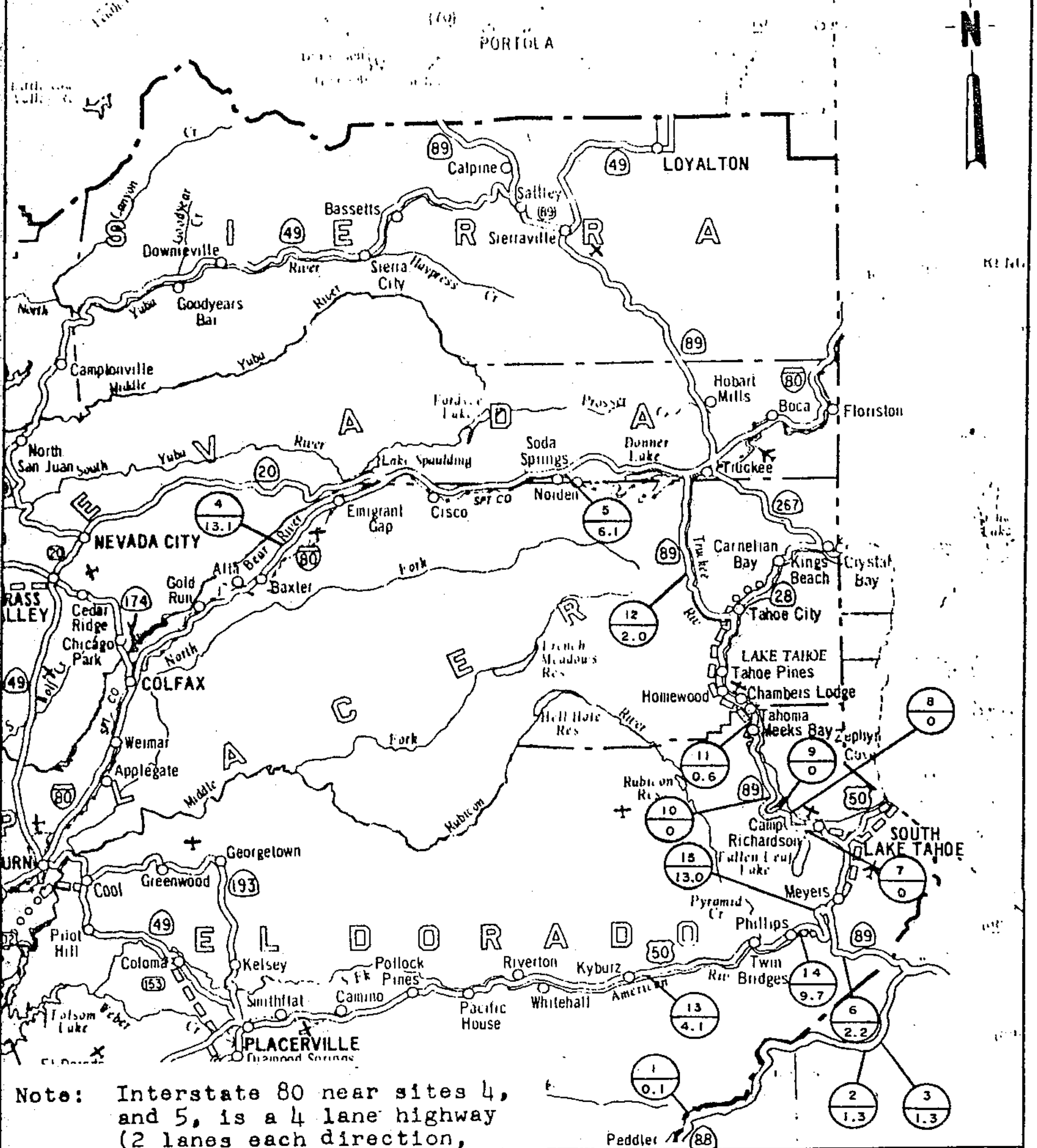
FIGURE 3B. DEICING SALT APPLICATION RATES AT THE TERRESTRIAL VEGETATION STUDY SITES WINTER 1975-76



Note: Interstate 80 near sites 4, and 5, is a 4 lane highway (2 lanes each direction, separated by a wide median). All other highways in the vicinity of the sites are 2 lanes.

SITE NO. / Deicing salt application tons/lane mile

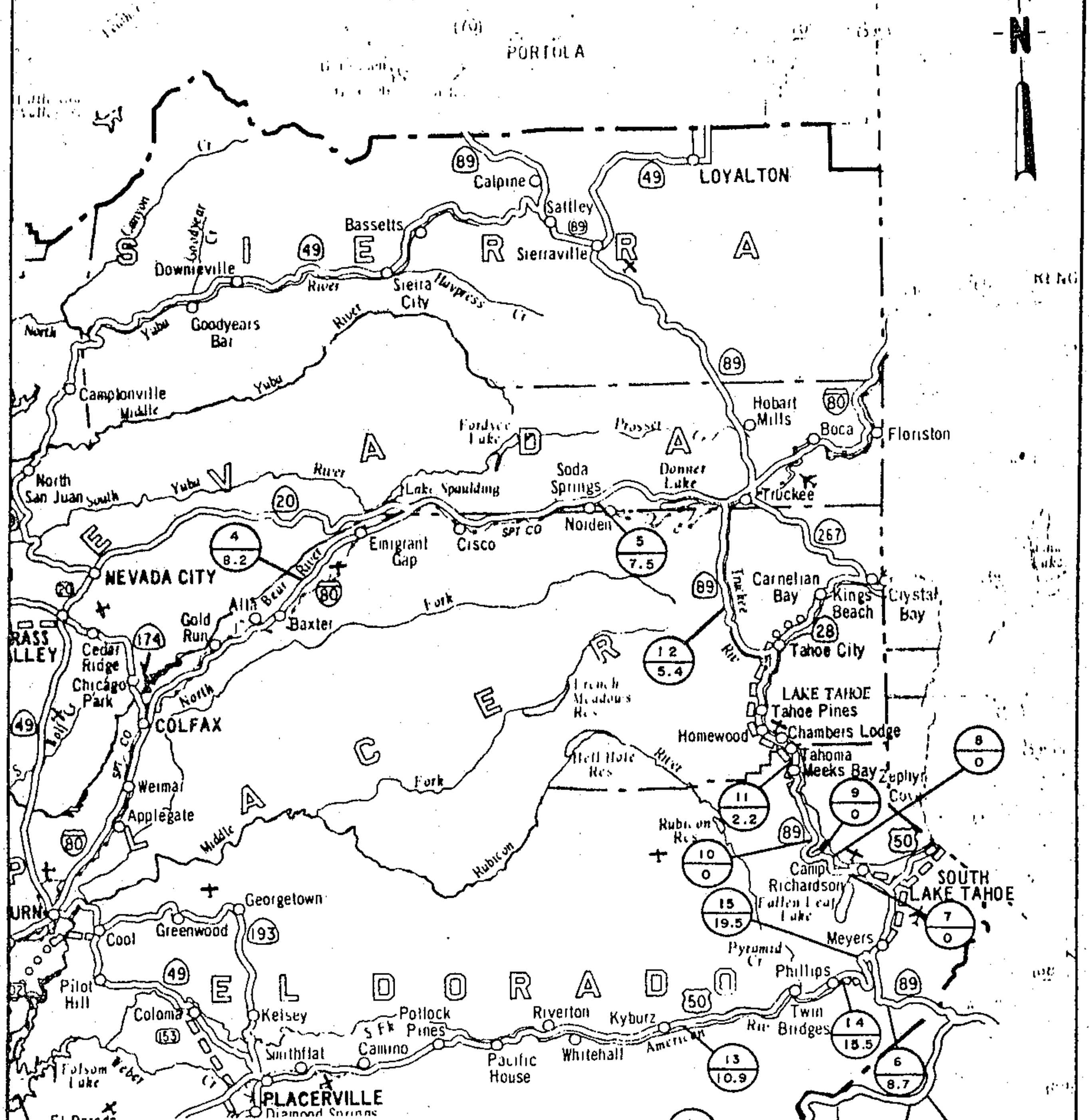
FIGURE 3C. **DEICING SALT APPLICATION RATES AT THE TERRESTRIAL VEGETATION STUDY SITES WINTER 1976-77**



Note: Interstate 80 near sites 4, and 5, is a 4 lane highway (2 lanes each direction, separated by a wide median). All other highways in the vicinity of the sites are 2 lanes.

SITE NO. — Deicing salt application tons/lane mile

FIGURE 3D. DEICING SALT APPLICATION RATES AT THE TERRESTRIAL VEGETATION STUDY SITES WINTER 1977-78



Note: Interstate 80 near sites 4, and 5, is a 4 lane highway (2 lanes each direction, separated by a wide median). All other highways in the vicinity of the sites are 2 lanes.

SITE NO. / Deicing salt application tons/lane mile

Additional preliminary survey work was done in 1975 and early 1976. It was apparent from these studies that changes in vegetation were not occurring at a rate which would supply the data needed to accomplish the objectives within the time constraints of the project. A more intensive survey was begun in August 1976 on three of the 15 original sites.

5.2 General Methods

5.21 Chemical Analysis: Sodium and chloride contents of leaf tissue were taken as a measure of damage due to salt.

The sodium (Na) and chloride (Cl) contents of the leaf tissue were determined by the following procedures. For Na, dried, ground tissue was leached with a neutral normal NH_4Ac (ammonium acetate) solution. This solution effectively removes all Na from the tissue. Sodium is then determined in the leachate. For Cl, dried, ground tissue is extracted with hot dilute nitric acid, and Cl is then determined in the extract. Results for both Na and Cl are reported as percent by weight of dried leaf tissue.

The salt content of soil samples was obtained by measuring the electrical conductivity of the saturation extract (18). The electrical conductivity (EC_e) is given in millimhos/cm. Na and Cl analysis of the saturation extract are reported as milliequivalents/liter (meq l^{-1}).

For both tissue and soil analysis, Na was determined by flame photometry and Cl was determined by potentiometric titration.

5.22 Beetle Damage: The number of beetle holes (including pitch tubes) detected around a 6" band of bark at breast height was counted. These data were converted to holes per square foot of surface area and were taken as an index of beetle damage. The species of beetles were not identified.

5.23 Fungous Damage: The base of the trunk and the bark of the crown roots of each tree were examined for the presence of fungus especially Armillaria root rot fungus, and when present, a sample was taken and cultured in the laboratory for identification.

5.24 Fill Material: One of the easily measured modification of the micro-environment of roadside trees is the presence of fill material around the trunk. The depth of fill around each tree in the intensive survey was measured in inches.

5.25 Miscellaneous Observations: The presence of mistletoe, leaf diseases, altered drainage patterns, etc., were recorded when observed. Because of the random occurrence, their contribution to plant damage could not be quantified.

5.26 Damage Rating: Damage of trees was assessed on the extent of browning and defoliation of the whole tree. This was expressed as % damage in the Intensive Survey of 1976. The pattern of leaf browning caused by deicing salt was different from that caused by other factors such as beetle and fungus and was noted. However, in damage assessment, the overall browning of the tree was considered regardless of the pattern or the cause. Damage on shrubs was not rated.

5.3 Preliminary Surveys

5.31 Survey of 1974: During the summer and fall of 1974, the 15 sites selected in the fall of 1973 were staked and vegetation inventories made (the inventory on site 9 was completed in the spring of 1975). The inventories included the number and size of trees by species and the percentage of shrub cover by species. Qualitative data included observations on health and vigor of tree species. Tissue samples of four shrub species were collected to correlate Na and Cl levels with the soil salt levels found in the Caltrans Translab studies (16).

These inventories indicated that, in general, there was somewhat more damage adjacent to the highways, but the pattern of injury was erratic and trees distant from the highways also often exhibited damage symptoms.

The four shrub species sampled were pinemat manzanita, squaw carpet, Newberry penstemon and mountain elderberry. These plants were growing at various distances from the highway in sites 1 and 11 which received low quantities of salt, and site 15, which received large quantities of salt. Tissue samples from these plants were collected and analyzed for Na and Cl. Both green and damaged leaves were obtained from the manzanita and the penstemon.

The concentrations of Na and Cl in the samples are listed in Table 2. Sodium concentration in mountain elderberry varied from 0.45 to 0.56% and in other shrubs from 0.07 to 0.26%. Chloride concentrations in all these samples ranged from less than 0.003 to 0.05%. Thus, except for mountain elderberry, Na and Cl in foliage within each shrub at different distances

Table 2. Preliminary Survey - Leaf Na and Cl concentration of 4 shrub species growing in sites, 1, 11 and 15; sampled in August, 1974.

Species	Site	Distance from highway feet	% dry weight Na	Cl
Pinemat manzanita	11	70	0.14	<0.005
	11	70	0.09	<0.005
	11	70	0.08	<0.005
	11+	70	0.09	<0.003
	11+	70	0.07	<0.005
	11+	70	0.09	<0.005
	15	230	0.13	<0.05
	15	230	0.14	<0.05
	15	230	0.12	<0.05
	15	--	0.13	<0.05
	15	--	0.12	<0.05
	15	--	0.13	<0.05
	15+	--	0.11	<0.05
	15+	--	0.10	<0.05
	15+	--	0.11	<0.05
Squaw carpet	11	30	0.25	<0.05
	11	30	0.25	<0.05
	11	30	0.25	<0.05
	11	200	0.23	<0.05
	11	200	0.25	<0.05
	11	200	0.24	<0.05
	11	325	0.26	<0.05
	11	325	0.25	<0.05
	11	325	0.25	<0.05
Newberry penstemon	15	10	0.09	0.017
	15	10	0.14	<0.003
	15+	10	0.15	0.006
	15+	10	0.14	0.002
	15+	40	0.13	0.006
	15	40	0.09	<0.015
	15+	40	0.14	0.004
	15+	40	0.14	0.003
	15	100	0.15	<0.015
	15	100	0.14	0.003
Mountain elderberry	1	100	0.46	0.006
	1	100	0.56	--
	1	100	0.46	0.006
	1	220	0.47	0.003
	1	220	0.45	0.003
	1	220	0.47	0.003

+Brown leaves.

from the highway did not vary widely though soil data of Spring 1974 at corresponding distances, furnished by Caltrans, showed that Na and Cl concentrations differed widely with distances from the highway (16). Also Na levels encountered in these shrubs were much lower than the levels that caused damage in these shrubs under greenhouse conditions (Appendix 1).

In November, roots of dead or dying conifers were examined for presence of root rot. These trees were at varying distances from the highway and included some trees in sites 7,8,10,11, and 13.

At 03-Ed-50, PM 51.40 (site 13) an incense cedar with limbs dying on one side was sampled. A water mold, possibly a species of *Pythium* was isolated.

At Site 7, Camp Richardson 03-Ed-89, PM 10.43 many trees of Jeffrey pine were dead, most over 100 feet from the road. All dead trees examined were found to have *Armillaria mellea* in the large roots and below-ground portion of main trunk. Some roots of several unthrifty trees were examined but no *Armillaria* was found on these. Trees on the steep bank at Site 8, 03-Ed-89, PM 14.32 had excessive soil pushed around the lower portions of the main trunk, one of which was covered more than 5-6 feet. Soil was removed to the root crown on two white fir and *Armillaria* was found in the larger roots and below-ground portion of main stems of both trees.

At the snow gate, north approach to Emerald Bay, Site 10, 43-Ed-89, PM 18.10, stumps of several trees were examined.

No fungus was found on the very large Jeffrey pine removed earlier. Several declineing trees across the road were examined. No fungus was found on these.

Two trees on the downhill side of the road were examined a few hundred yards north of the Bliss State Park entrance. Soil level had been raised on these trees. On one, a white fir, Armillaria was found but not on the other, a lodgepole pine. Across the road, Armillaria was found on one large red fir but not on two others.

North of Tahoma, (03-PLA-89) two large white fir stumps (sporophores from near one) were examined but no Armillaria was isolated. The sporophores were not those of Armillaria.

Just north of Site 11, 03-Ed-89, PM 26.4, Sugar Pine Point State Park, two trees on the west side of the roadway were examined. Both had beetle infestation, one had mechanical damage at the base and possible Armillaria mycelia appeared to be present on one, a red fir. The other, a white fir, did not show Armillaria mycelia.

At the time of the survey it could not be determined whether the Armillaria was a contributing cause of death or invaded the roots as a saprophyte. Inoculation studies will be reported later.

Green and brown leaf tissue samples of white fir and incense cedar were collected in November from different limbs of the same tree or from carefully selected paired trees growing 20' from the highway at site 11.

Na and Cl levels were determined (Table 3). Sodium concentrations in green as well as brown tissues were essentially

Table 3. Preliminary Survey - Leaf Na and Cl concentration of white fir and incense cedar growing 20 feet from highway in site 11; sampled in Nov. 1975.

Species	Same tree or pair*	% dry weight			
		Na		Cl	
		Green	Brown	Green	Brown
White fir	Pair	0.02	0.03	0.56	1.26
"	Same tree	0.03	0.02	0.61	0.62
"	Same tree	0.02	0.03	0.62	0.64
"	Pair	0.02	0.13	0.40	0.99
Incense cedar	Same tree	0.01	0.02	0.62	0.94

*Green and brown leaves were collected from the same tree or from a selected pair of trees.

the same, ranging from 0.01% to 0.3% except in one white fir brown tissue sample which showed a higher value, 4.13%. However, in 3 pairs, concentrations of chloride in brown needles were higher than those of the green needles. In all samples, the chloride was near or above the levels later determined to be toxic.

5.32 Snow Removal Operations: Trees adjacent to highways where rotary plows are used for snow removal often have dead limbs on the side facing the road and live limbs on the side away from the road to a height of 30 feet or more. On February 7, 1975, a survey was made of snow removal operations on I-80 between Kingvale and Donner Lake interchange to assess the effects of the operation on this plant damage. Removal of snow pack does not appear to be the major factor in the damage to branches on the highway side of trees. The snow is pulverized so finely that it probably has little abrasive force. It is suspected that the removal of the ice crust or pack and cinders from the pavement may be the principle cause of this injury. Measurements of impact force would be required to verify this conclusion.

5.33 Survey of May 1976: In this survey, trees and shrubs in all the sites were carefully examined for damage symptoms caused by various agents. Tissue samples from several plants were collected and analyzed for Na and Cl. Damage of trees was rated (Table 4).

In conifers, based on the preliminary data in Tables 4 and 5, and field observations, older foliage appeared to be the first indicator of salt stress. The symptoms generally developed within an individual needle basipetally, (from

Table 4. Preliminary Survey - Leaf Na and Cl concentration of different tree and shrub species growing in different sites and damage rating of trees; surveyed in May 1976.

Species	Site	Transect[1]	Dist.[2]	Nature of tissue[3]: Green Na	Green Cl	50:50 Green/Brown (% dry weight) Na	50:50 Green/Brown Cl	Brown Na	Brown Cl	Tree damage[4]
Jeffrey Pine	4	B	20	0.111	0.129					2
	4	A	75	0.019	0.011					1
	7	B	200	0.017	0.048					4
	9	A	10	0.036	0.672	0.020	0.322			2
	9	B	10			0.029	0.693			2
	13	B	10	0.065	0.370	0.299	0.874	0.259	0.725	2
	13	B	10	0.081	0.403	0.109	0.506	0.234	0.966	2
	13	B	10	0.105	0.338	0.348	0.667	0.106	0.370	3
	13	B	30	0.027	0.037	0.070	0.518	0.115	0.467	2
	13	B	30	0.037	0.046	0.071	0.851	0.079	0.628	2
	13	B	30	0.053	0.282	0.063	0.575	0.105	1.047	2
	15	B	5	0.204	0.213	0.285	0.589	0.426	0.564	3
	15	B	10	0.184	0.364	0.354	0.725	0.351	0.757	3
	15	B	200	0.026	0.055	0.025	0.069	0.033	0.064	4
	15	B	200	0.036	0.048			0.029	0.040	4
Sugar Pine	3	-	250	0.022	0.011					
Lodgepole Pine	1	B	20	0.023	0.030					1
	1	B	500	0.016	0.030					1
	5	C	15	0.101	0.177	0.411	0.634			2
	5	C	90	0.031	0.225	0.048	0.805			2
	5	C	110	0.050	0.097					1
	5	C	130	0.023	0.058					1
White fir	4	A	40	0.018	0.040					1
	4	A	100	0.017	0.010					1
	8	B	10	0.047	0.170					1
Red fir	1	B	20	0.021	0.045					1
	1	B	300	0.020	0.041					1
	14	A	10	0.155	0.179			1.390	1.087	3
	14	B	10	0.167	0.386			0.432	0.758	3
	14	B	100	0.020	0.097					1
	14	A	150	0.017	0.105					1
	14	B	200	0.016	0.193					1
Incense cedar	2	-	30	0.026	0.870	0.040	1.079	0.042	0.853	2
	13	B	30	0.016	0.547	0.032	1.047	0.049	0.483	2
	13	B	30	0.035	0.886	0.076	1.272	0.259	1.401	3
	13	B		0.147	1.095	0.283	1.771	0.299	1.417	3
Newberry penstemon	15	B	20	0.235	0.274			0.422	0.362	
	15	B	200	0.029	0.011					
Huckleberry oak	15	B	20	0.119	0.177			0.213	0.242	
	15	B	200	0.063	0.055					
Greenleaf manzanita	15	B	20	0.092	0.097			0.125	0.322	
	15	B	200	0.026	0.032					
Chinquapin	15	B	200	0.043	0.064			0.062	0.056	

[1]A = uphill transect; B = downhill transect; C = middle transect (between roads).
[2]Distance from highway in feet.
[3]Samples were collected from the same plant and composed of 1-5 year old needles.
[4]Damage rating key: based on the entire foliage of the tree, % browning and defoliation; 0 = 0%, 1 = 1-25%, 2 = 26-50%, 3 = 51-75%, 4 = 76-100%.

tip to base). Yellowing or deep reddening of foliage, browning of youngest foliage, and top kill where the top of the tree was damaged while the bottom of the crown remained healthy were usually associated with insects (leaf miners and bark beetles), diseases (leaf and root fungi) and parasites (mistletoe). These observations were confirmed in later studies.

Trees and shrubs, closer to the highway (within 30 feet) showed higher concentrations of Na and Cl in leaves than those further from the road (Table 4).

In shrubs, based on the preliminary data in Table 4, it appeared that salt damage symptoms began as leaf tip burn and progressed downward. Damage due to other agents such as fungi and insects were negligible. On the whole, damage was minimal.

Irrespective of the distance from the roadway, trees in many sites, especially Jeffrey pines, showed evidence of bark beetle attack. Leaf fungi and mistletoe were widely prevalent in sites 7,8,9,10,11 and 12, and stem and root fungi were present in sites 11,13, and 14.

Damage was not confined to trees that were within 30 feet of the highway but extended further into the forest. The damage further than 30 feet from the roadside was usually associated with agents other than salt. Damage was not particularly higher in sites that were exposed to greater quantities of deicing salt than those exposed to low quantities.

Two trees were sampled at site 12 to determine the change in Na and Cl with age of tissue to be used as a guide in future sampling (Table 5). In a Jeffrey pine 10 feet away from the road, Na and Cl concentrations consistently increased with age of the needle. Four year old needles showed 5.5 and 3.3 fold increases in Na and Cl concentrations respectively when compared to 1 year old needles. In a white fir 25 feet away from the road, only sodium concentration increased with age. Only one set of samples was collected.

5.4 Intensive Survey, 1976

Salt damage to plants was reported to extend up to 60 feet from highways at Lake Tahoe (21) and in some midwestern states and Canada up to 100 feet (1,10,23,24,25). Soil analysis data from the Caltrans study showed that salt usually reached ambient levels within 20 to 100 feet from the roadway (17). The Preliminary Surveys indicated coexistence of salt, biotic agents, and modified micro-environment, within 200 feet of the roadside. With this background information, an intensive survey was conducted in Aug./Sept. 1976 with the objective of quantifying the share of salt, root rot fungus, bark beetles, fill around the trunk and other causes of plant damage.

Four sites, 9 on State Route 89, 4 on I-80, and 13 and 14 on U.S. 50 were chosen because of the plant spectrum and the previous deicing salt application levels. The salt applications (tons/lane mile) to the highways traversing these sites for the two previous seasons are summarized in Table 6. In order to obtain sufficient numbers of trees to sample, sites 13 and 14 were pooled and are hereafter referred to as site 14. The overall maps of these sites are shown in Figures 4A, 5A. and 6A and C. The tree

Table 5. Preliminary Survey - Leaf Na and Cl concentration in different age green needles of Jeffrey pine and white fir collected from the downhill transect of Site 12, May 1976.

Species	Distance from highway (feet)	Age of needle (years)	% dry weight Na	Cl	Tree damage rating*
Jeffrey pine	10	1	0.081	0.290	2
		2	0.121	0.338	
		3	0.368	0.628	
		4	0.449	0.950	
White fir	25	1	0.026	0.161	1
		2	0.037	0.126	
		3	0.040	0.145	
		4	0.038	0.129	
		5	0.046	0.161	

*Damage rating based on entire foliage of tree, % browning and defoliation: 0 = 0%, 1 = 1 -25%, 2 = 26-50%, 3 = 51 - 75%, 4 = 76 - 100%.

Table 6. Summary of deicing salt applications (tons/lane mile) on intensive survey sites 13, 14, 4, and 9.

Site	Applications prior to survey 1974-75	1975-76	Total	Applications during study 1976-77	1977-78	Total
9	1.1	0	1.1	0	0	0
4	9.3	4.9	14.2	13.1	8.2	21.3
13	15.2	7.9	23.1	4.1	10.9	15.0
14	24.1	9.5	33.6	9.7	15.5	25.2
Average 13 + 14	19.7	8.7	28.4	6.9	13.2	20.1

Figure 4A. Intensive Survey, 1976. Map of Site 9.

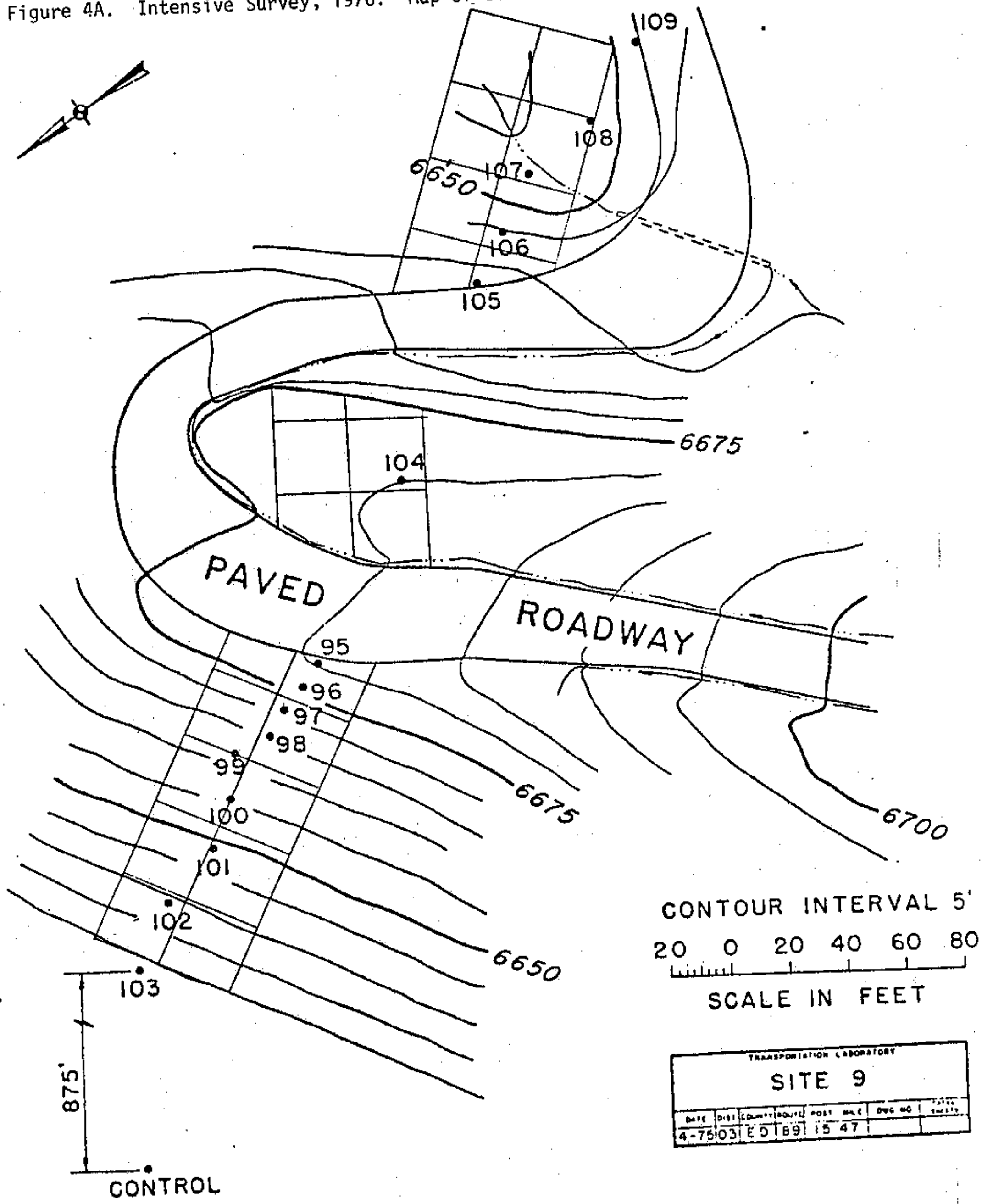


Figure 5A. Intensive Survey, 1976. Map of Site 4.

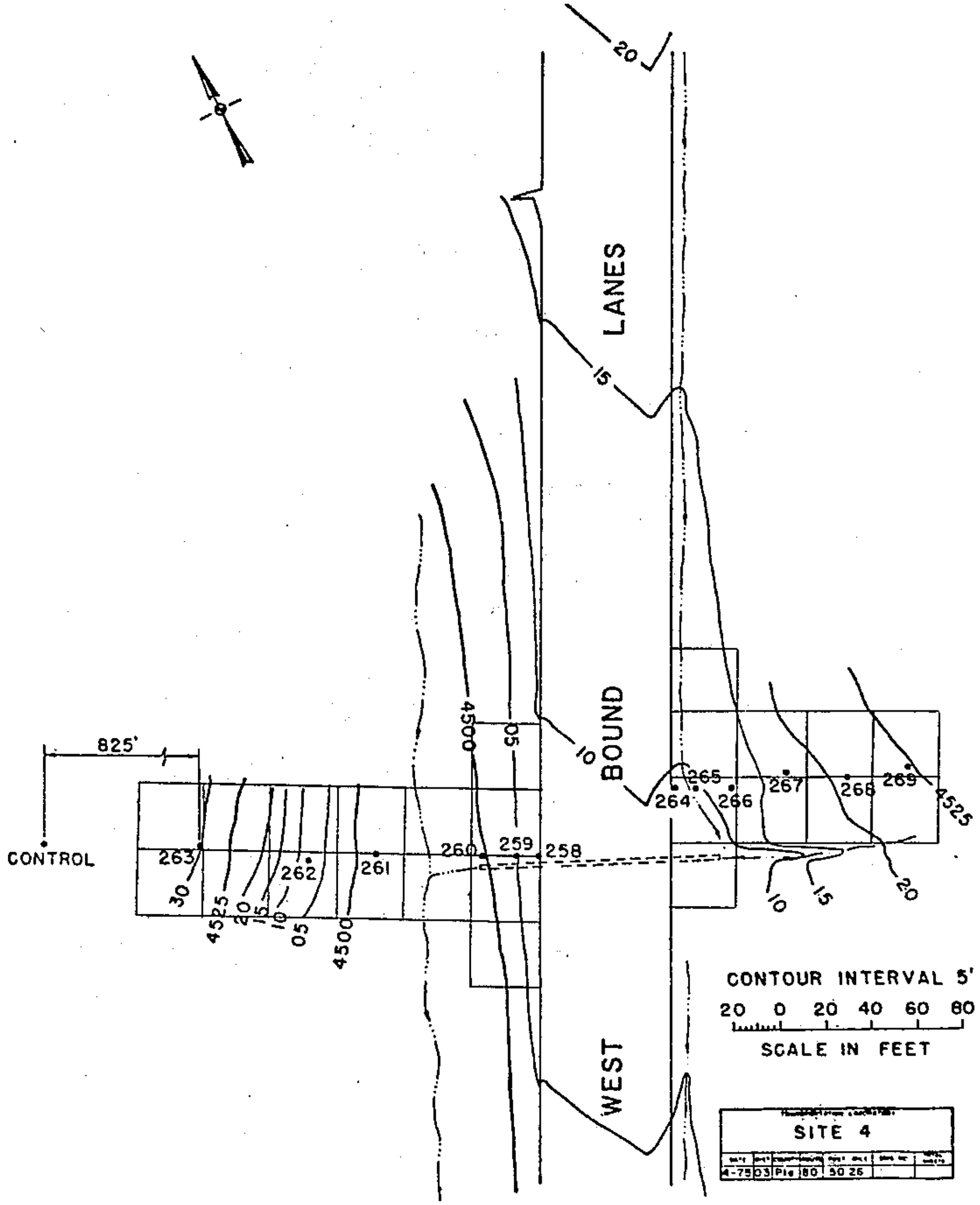


Figure 6A. Intensive Survey, 1976. Map of Site 13.

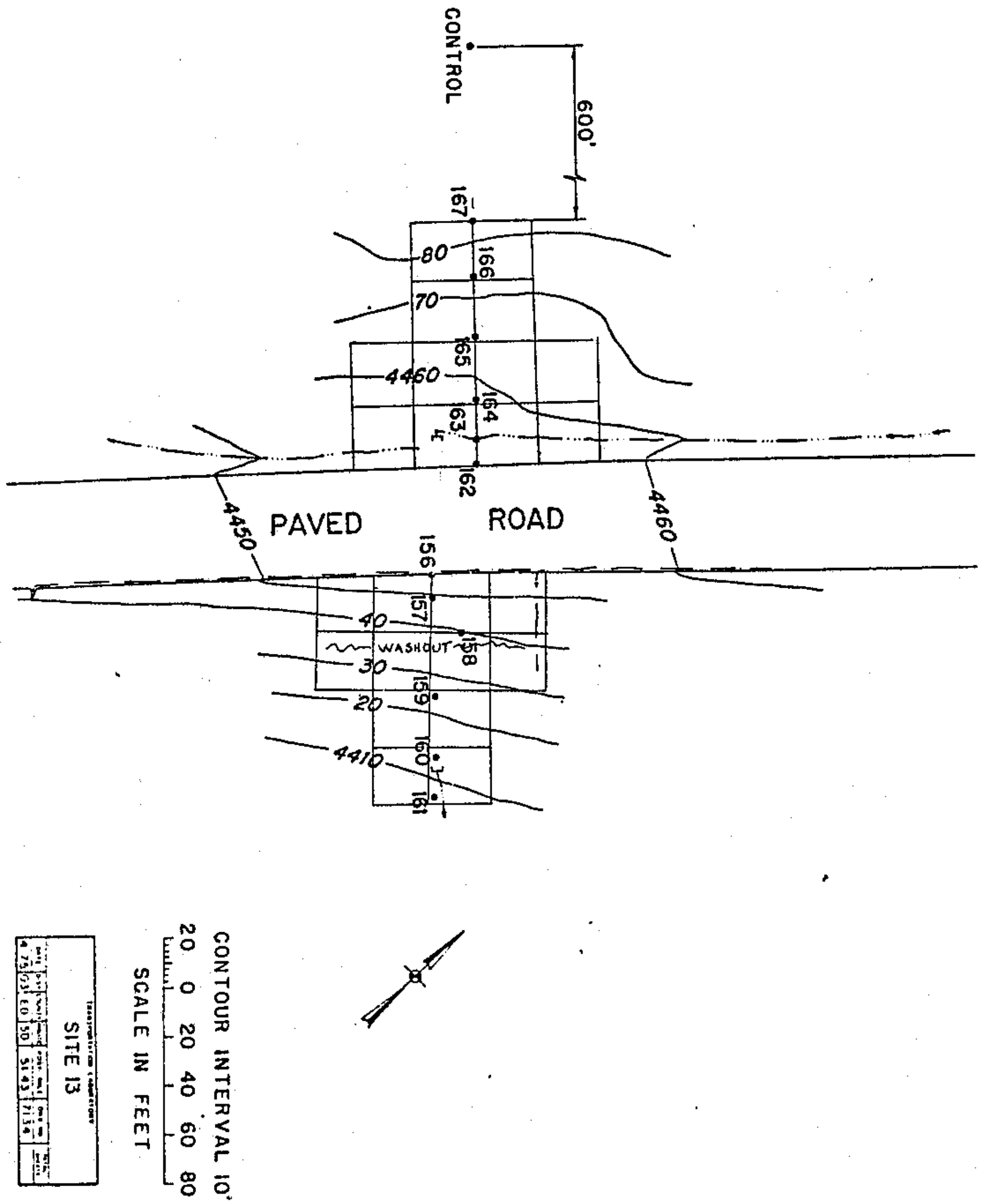
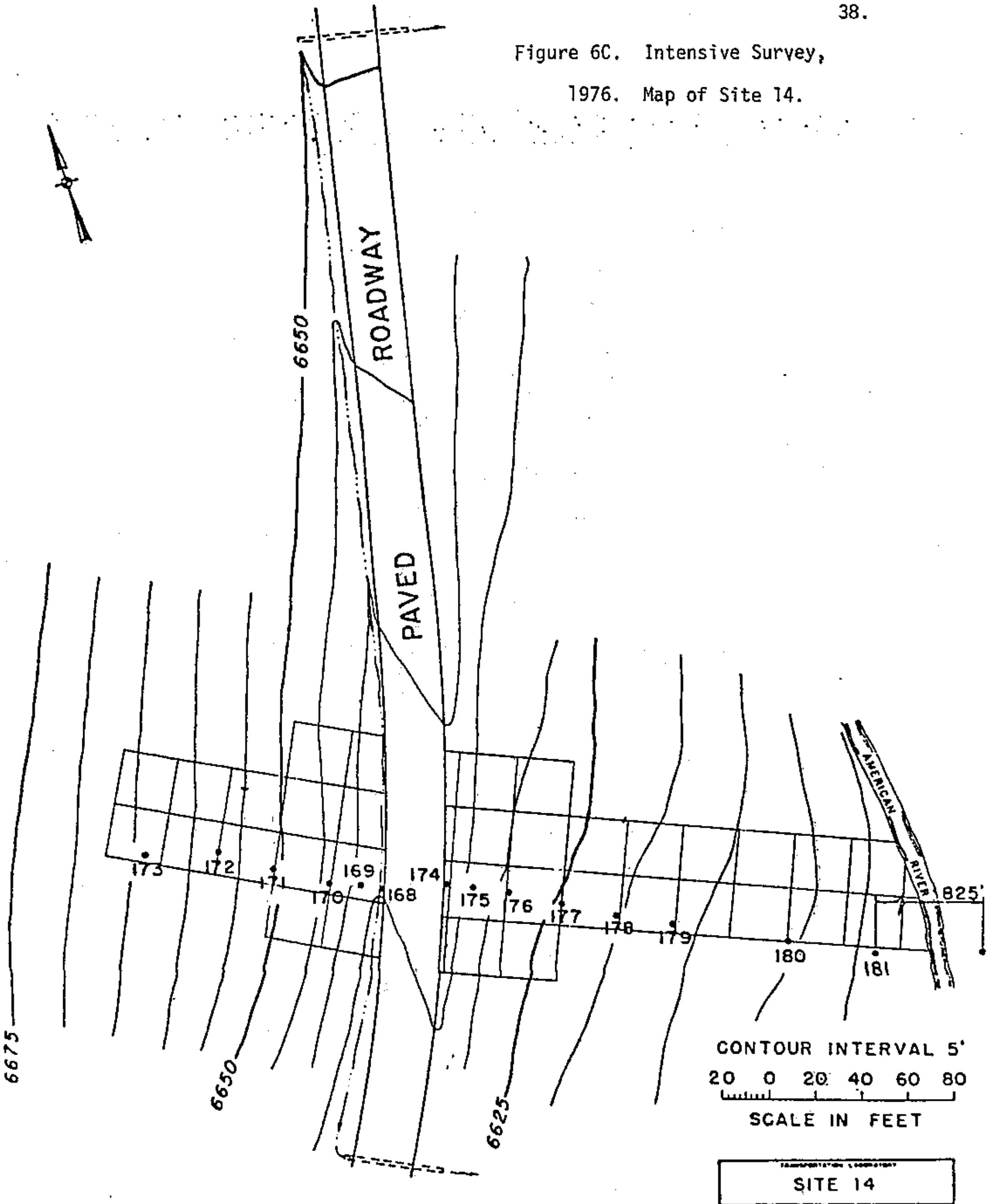


Figure 6C. Intensive Survey, 1976. Map of Site 14.



spectrum as mapped in the Preliminary Survey are shown in Figures 4B and C. 5B and C, and 6B, D and E respectively for these sites.

Four plant species, Jeffrey pine, white fir, incense cedar and greenleaf manzanita growing in or adjacent to these sites were evaluated. For each species at each site, 5 to 9 plants (2 of which were on the uphill transect) were rated for damage at three distance intervals from the pavement edge: 0-20 (Group I); 50-100 (Group II); and 150-200 feet (Group III).

The trees ranged in height from 8-20 feet with circumference at breast height (cbh) of 1-38 in. Tissue samples consisting of the oldest green leaves were collected from each tree and analyzed for Na and Cl. Brown leaves of the same age were also collected when available. The Na and Cl analyses of paired green and brown samples were compared to determine whether samples of green leaves would give reliable estimates of the Na and Cl levels in the plants prior to death of the tissues. Soil samples were collected for EC_e, Na and Cl analyses under some of the trees at two depths, 0-12, and 13-24 in. For each tree beetle holes, including pitch tubes were counted in a 6 in. band at breast height. The circumference (cbh) was recorded for calculation of beetle numbers per square foot. The depth of fill around the trunk was measured and the existence of fungi or other potential causes of damage were noted.

Means and standard errors of the means of the variables were calculated for each species, site, and group (distance intervals). The data were subjected to correlation analysis.

KEY TO SYMBOLS ON

Figures 4B and C; 5B and C; 6B, D and E

Ac	Abies concolor	White fir
Am	A. magnifica	Red fir
Cd	Calocedrus decurrens	Incense cedar
Jo	Juniperus occidentalis	Sierra juniper
Pj	Pinus jeffreyi	Jeffrey pine
Pl	P. lambertiana	Sugar pine
Pm	P. murrayana	Lodge pole pine
Qk	Quercus kelloggii	California black oak
Qw	Q. wislizenii	Interior live oak

Figure 4B. Intensive Survey, 1976. Plant inventory of transect A, Site 9.

SITE 9
03-ED-89 PM 15.47

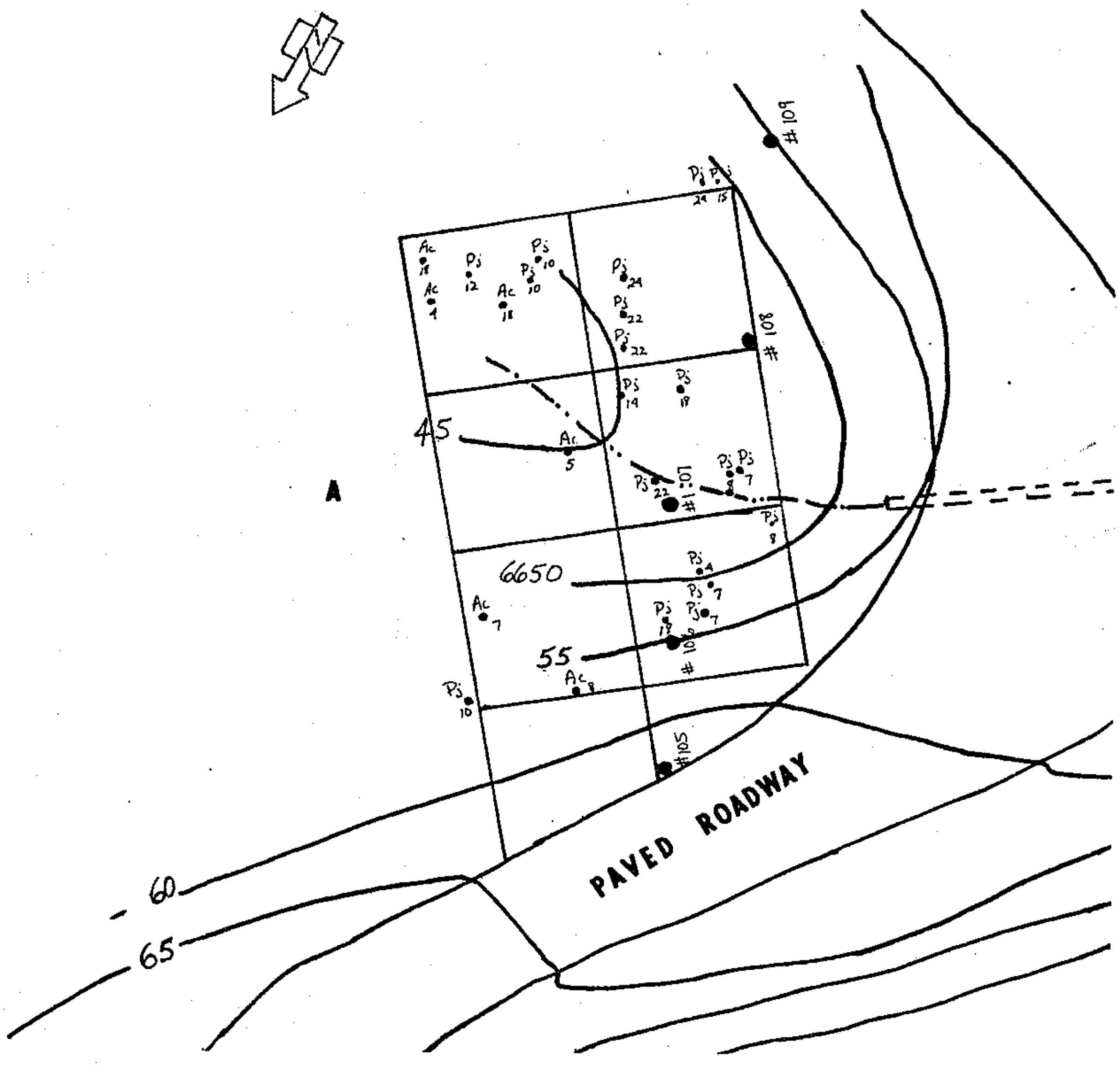
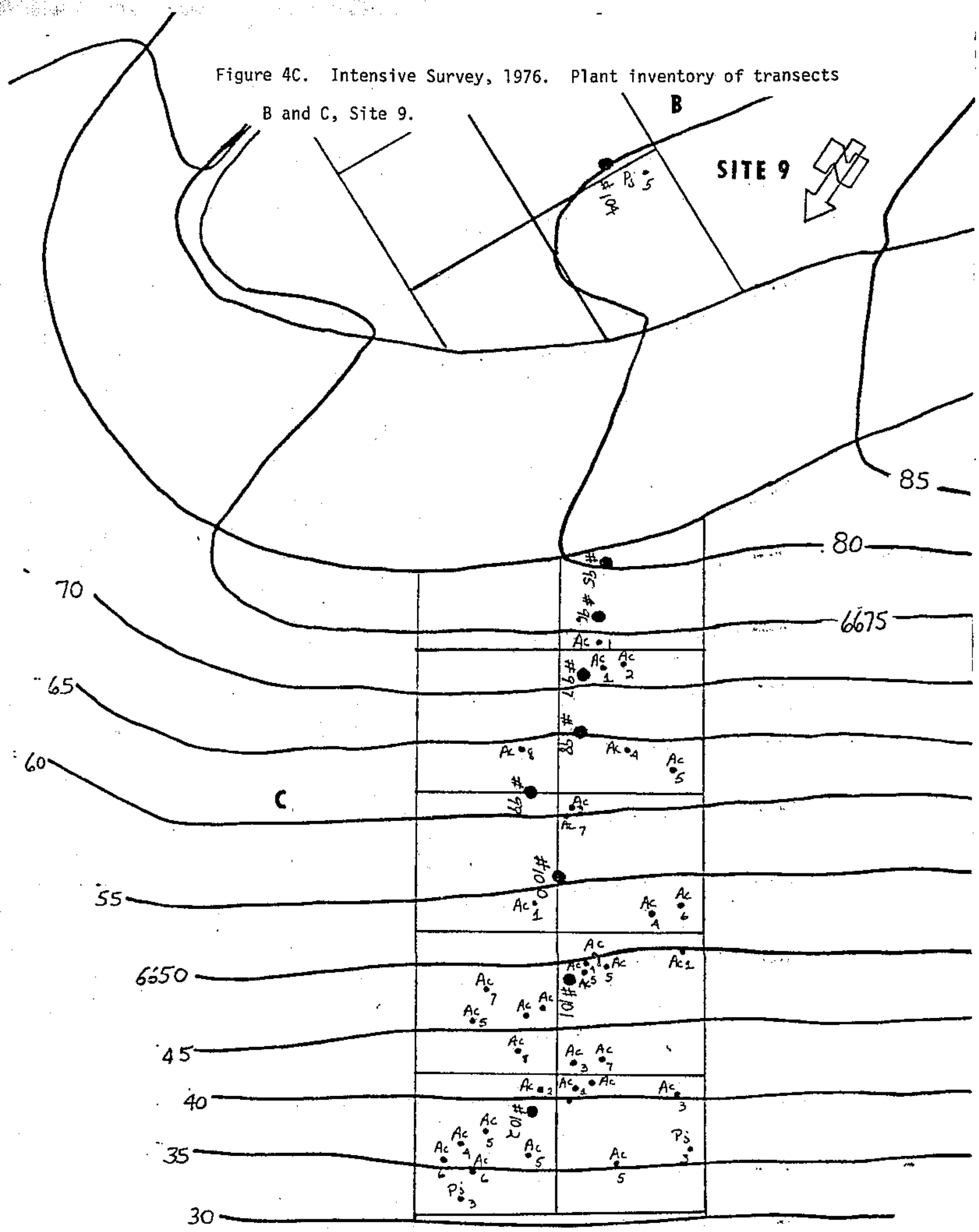
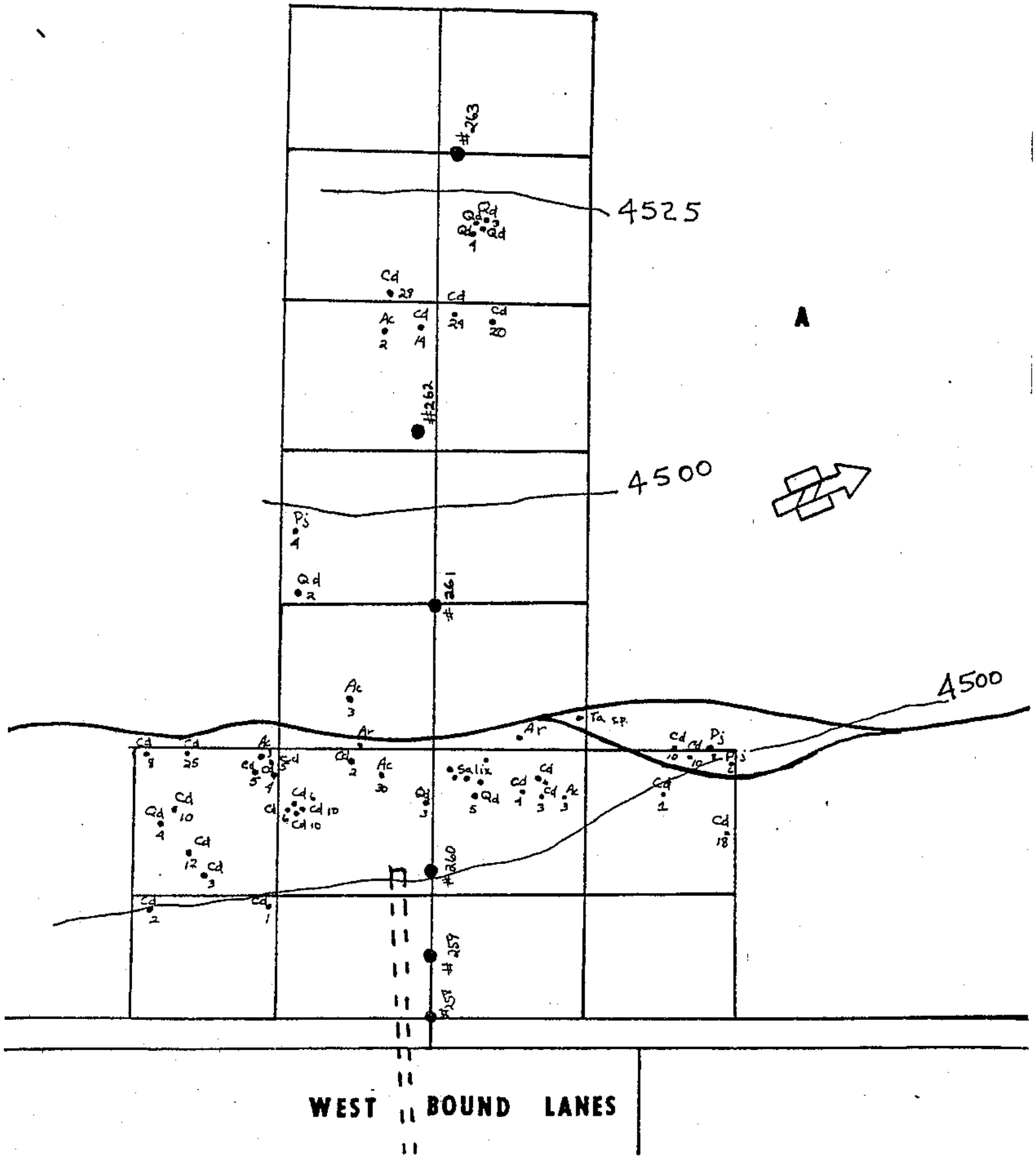


Figure 4C. Intensive Survey, 1976. Plant inventory of transects B and C, Site 9.



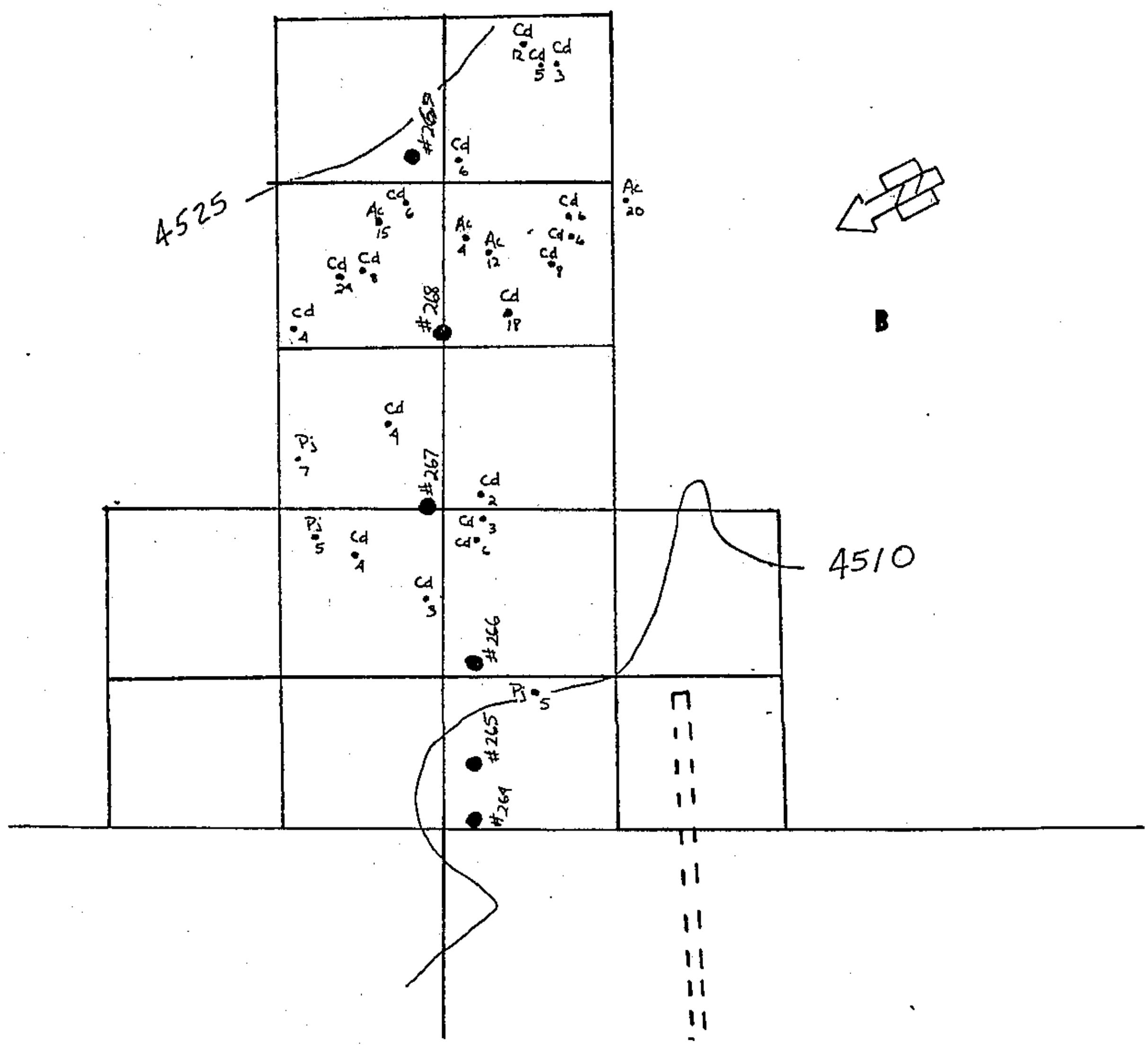
SITE 4
03-PLA-80 PM 50.26

Figure 5B. Intensive Survey, 1976. Plant inventory of transect A, Site 4.



SITE 4

Figure 5C. Intensive Survey, 1976. Plant inventory of transect B, Site 4.



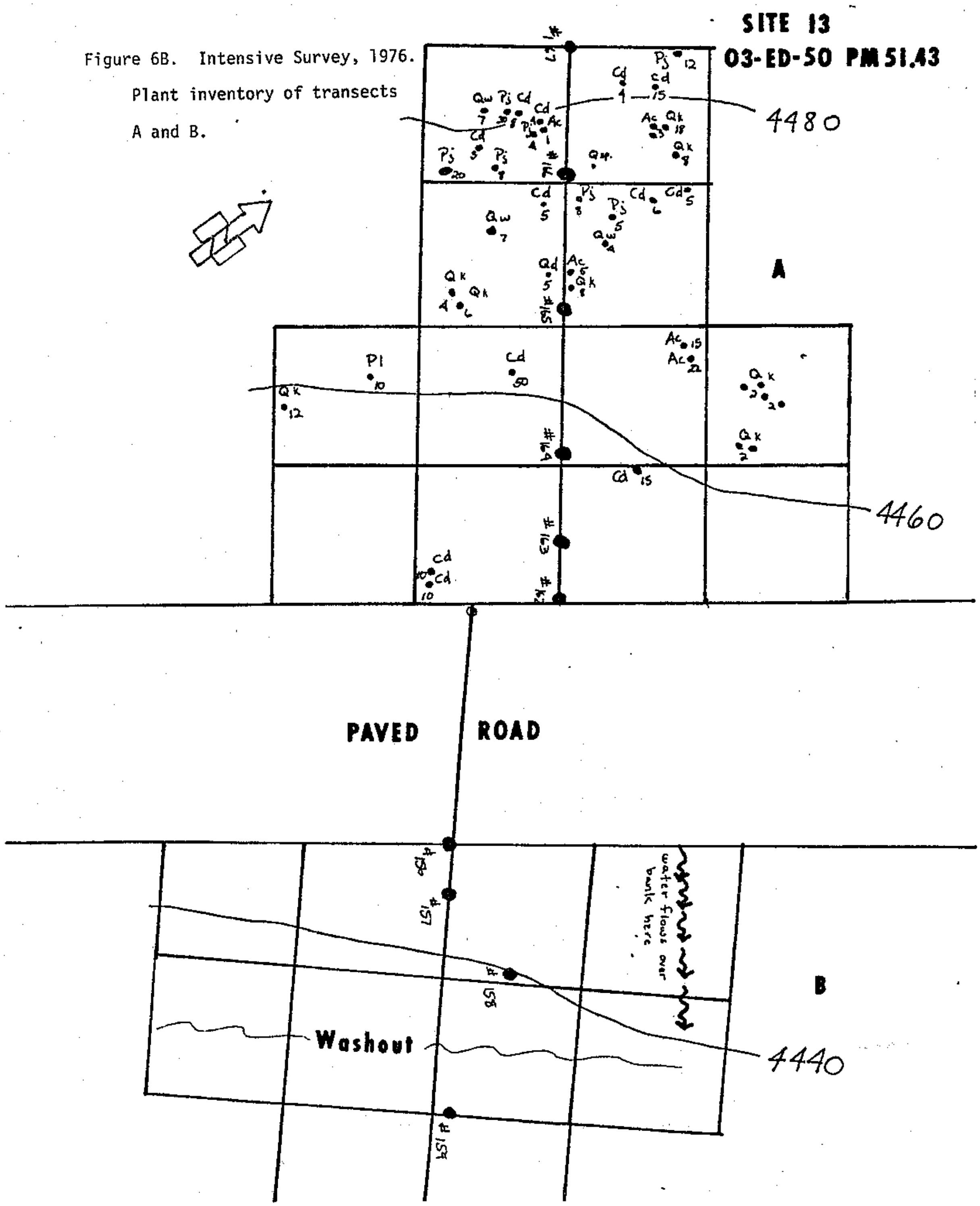
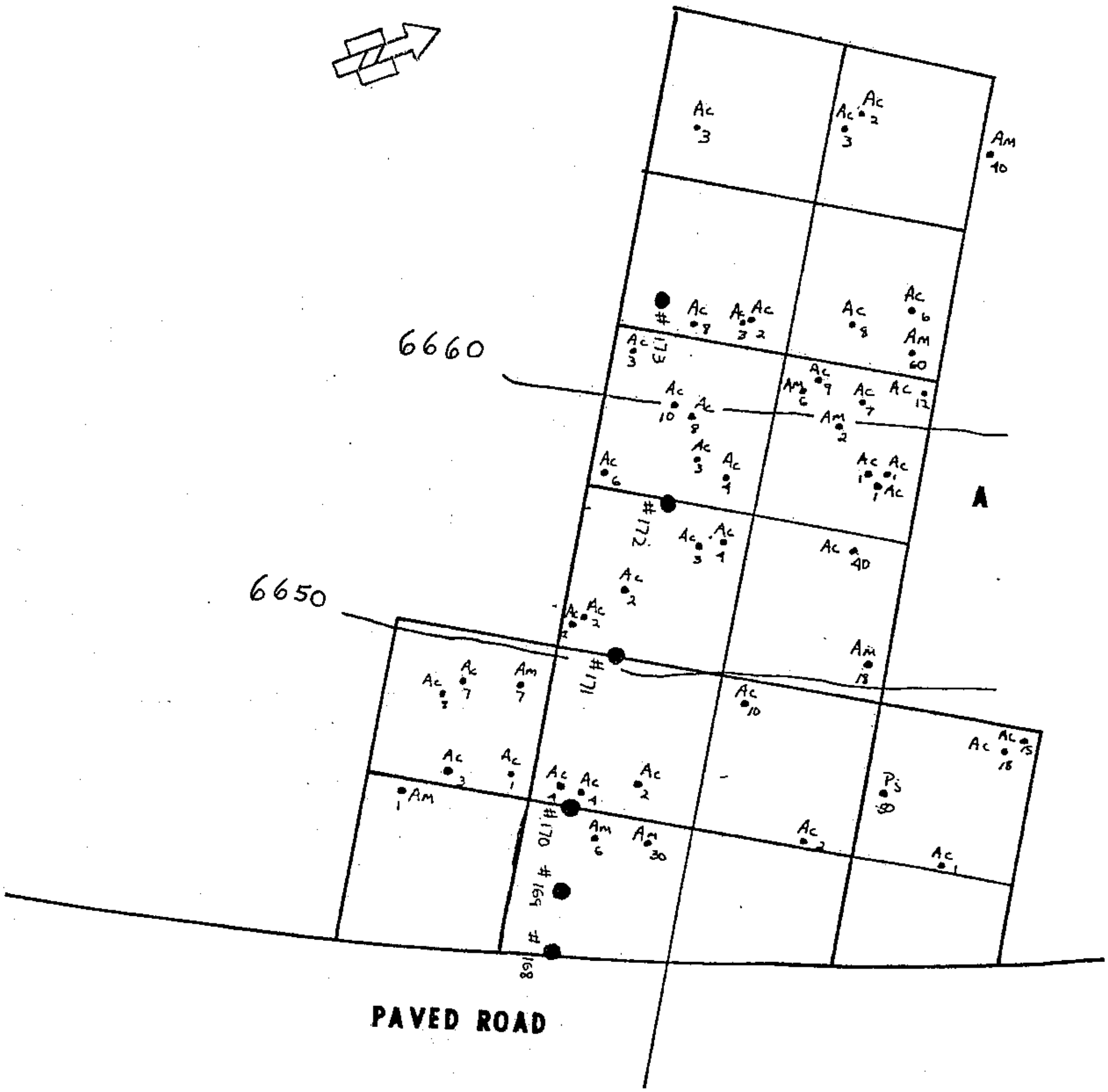


Figure 6B. Intensive Survey, 1976. Plant inventory of transects A and B.

SITE 14

03-ED-50 PM 62.63

Figure 6D. Intensive Survey, 1976. Plant inventory of transect A, Site 14.



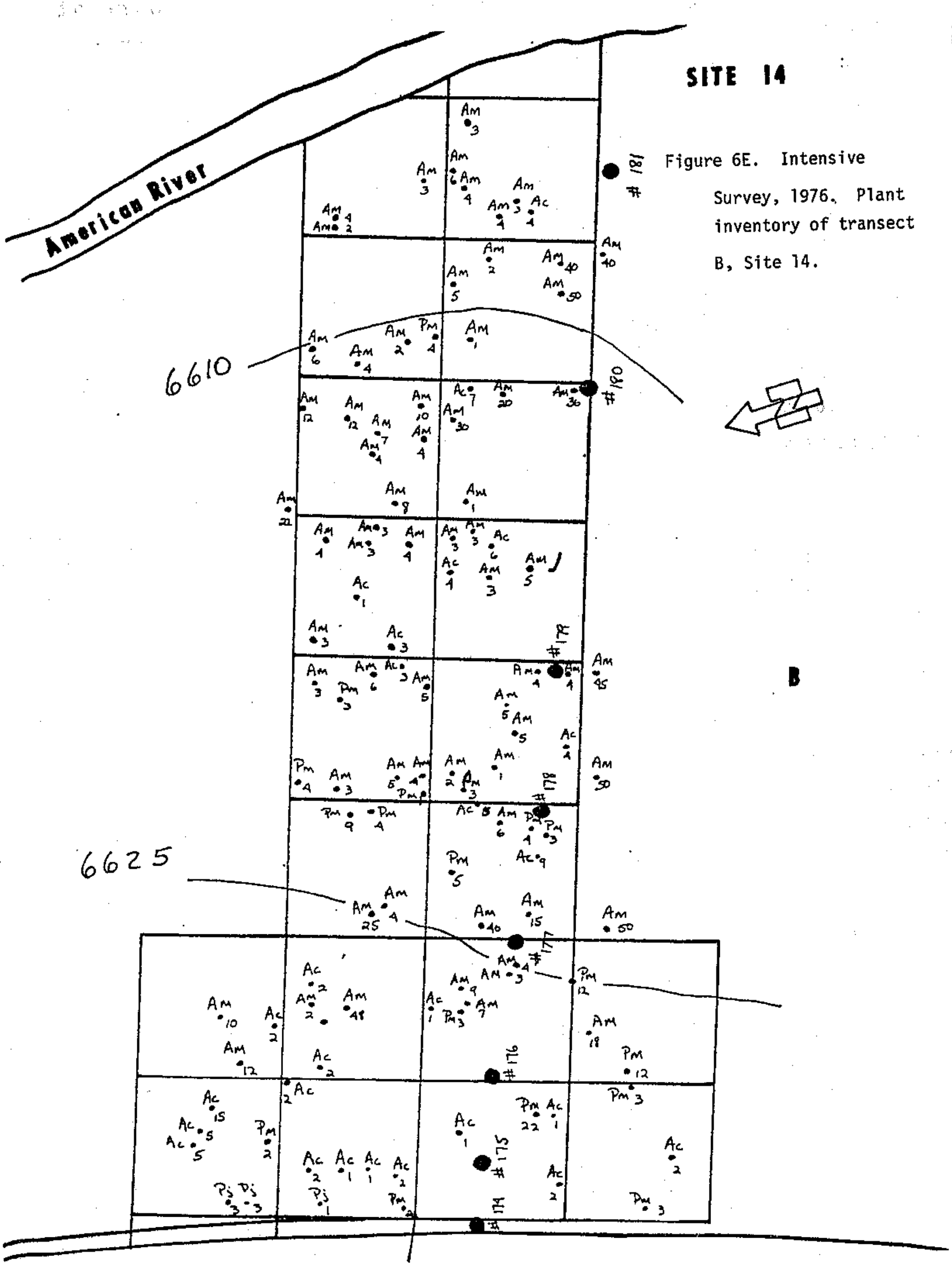


Figure 6E. Intensive Survey, 1976. Plant inventory of transect B, Site 14.

5.41 Results: Neither fungi nor mistletoe were found with sufficient frequency in these three sites to warrant inclusion in the statistical analysis. Trees were free of Armillaria and only a few trees were found to be infected with other fungi. The effect of these fungi on the trees could not be determined. Mistletoe can cause extensive damage and death in trees in the study area but in these sites the frequency was low.

Leaf Na and Cl and fill around the trunk of trees growing in uphill transects were somewhat lower than those growing in downhill transect. However, the differences were not significant. Therefore, the data were analyzed without distinguishing between the uphill and downhill transects.

The agreement between Na and Cl content of green and brown leaf tissue taken from the same tree varied with tree species (Table 7).

Agreement was close for both Na and Cl between green and brown samples from Jeffrey pine. Na was 0.095 and 0.109% dw, and Cl was 0.102 and 0.105% dw, respectively, in green and brown tissue. Comparison in individual trees showed Na highest in 33, equal in 5 and lowest in 11 and Cl highest in 16 and lowest in 33 in brown samples of 49 tissue pairs. Both correlation coefficients, 0.948 for Na and 0.957 for Cl were significant at the 99% level.

The greatest divergence between Na and Cl content of green and brown tissue was in white fir. Na was 0.40 and 0.66% dw, and Cl was 0.114 and 0.149%, respectively, in green and brown tissue. Na was highest in 20, equal in 2, and lowest in 3, and Cl was highest in 17 and lowest in 8

Table 7. Comparison of Na and Cl in green and brown leaves of 3 conifer species. Intensive Survey, 1976.

Site	Group	Number of samples	$\bar{x}$ [a] Na, % dw green	$\bar{x}$ [a] Na, % dw brown	$\bar{x}$ [a] Cl, % dw green	$\bar{x}$ [a] Cl, % dw brown
A. Jeffrey pine						
14	I	7	0.304	0.317	0.307	0.311
	II	7	0.041	0.042	0.039	0.027
	III	7	0.027	0.029	0.037	0.028
4	I	5	0.237	0.311	0.165	0.243
	II	3	0.055	0.062	0.031	0.036
	III	5	0.046	0.047	0.035	0.029
9	I	15	0.035	0.050	0.213	0.193
	II	4	0.038	0.046	0.027	0.028
	III	6	0.031	0.036	0.006	0.006
Grand total: $\bar{x}$			0.095	0.109	0.102	0.105
$s_{\bar{x}}$			0.016	0.018	0.018	0.020
Correlation coefficient:			0.948**		0.957**	
B. White fir						
14	I	5	0.100	0.206	0.277	0.105
	II	7	0.020	0.027	0.069	0.083
	III	7	0.019	0.027	0.054	0.076
4	I	1	0.050	0.087	0.107	0.049
	II	1	0.034	0.036	0.160	0.259
	III	4	0.036	0.034	0.087	0.110
9	I	0				
	II	0				
	III	0				
Grand total: $\bar{x}$			0.040	0.067	0.114	0.149
$s_{\bar{x}}$			0.007	0.017	0.024	0.029
Correlation coefficient:			0.915**		0.934**	
C. Incense cedar						
14	I	5	0.106	0.199	0.471	0.463
	II	6	0.025	0.038	0.090	0.154
	III	6	0.024	0.035	0.060	0.089
4	I	4	0.094	0.160	0.519	0.525
	II	6	0.036	0.074	0.225	0.249
	III	4	0.034	0.045	0.080	0.104
9	I	3	0.044	0.059	0.254	0.199
	II	3	0.036	0.039	0.074	0.093
	III	3	0.024	0.027	0.033	0.034
Grand total: $\bar{x}$			0.047	0.077	0.209	0.216
$s_{\bar{x}}$			0.005	0.011	0.033	0.032
Correlation coefficient:			0.885**		0.832**	

[a] All means computed from original data.
**Significant at the 1% level.

brown samples of 25 tissue pairs. Both correlation coefficients, 0.915 for Na and 0.934 for Cl, was significant at the 99% level.

Agreement was intermediate for Na and Cl content of green and brown tissue in incense cedar. Na was 0.047 and 0.077, and Cl was 0.202 and 0.244% dw, respectively, in green and brown tissue. Na was highest in 33, equal in 2 and lowest in 5 and Cl was highest in 21 and lowest in 19 brown samples of 40 tissue pairs. Both correlation coefficients, 0.885 for Na and 0.832 for Cl, were significant at the 99% level.

The Na and Cl levels of tissues killed by salt would be expected to be higher than that of tissues not yet dead, if excessive leaching by rain had not occurred. The overall agreement of Na and Cl levels in green and brown pairs of samples was good. When levels were low in brown tissue they were low in green tissues and when high in brown tissues they were high in green tissues. Because these studies were to investigate the status of many trees, both apparently healthy and distressed, it was impossible to obtain brown tissues on many of the trees. It was concluded that green samples would reflect the relative Na and Cl content of the leaf tissues of trees in the study area.

5.41.1 <u>Damage</u>: Damage was rated as the percent of brown foliage and defoliation in the crown of the tree (Table 8).

5.41.11 Jeffrey pine

Jeffrey pine in site 9, the low salt site, exhibited considerable damage. Mean damage (43.3%) was highest in

Table 8. Intensive Survey, 1976. Damage rating (% browning and defoliation) in Jeffrey pine, white fir, and incense cedar, on three sites exposed to different levels of deicing salts, and at three distance intervals from the highway. Means, standard errors of the means and ranges. Correlation coefficients of damage rating x distance from the road (r) are also given.

Species	Parameter	Site 9: 1.1 ton/lane mile[1] Groups[2]				Site 4: 14.2 ton/lane mile[1] Groups[2]				Site 14: 28.4 ton/lane mile[1] Groups[2]			
		I	II	III	All	I	II	III	All	I	II	III	All
Jeffrey pine	$\bar{x}$	29.2	24.0	43.3	32.6	31.0	5.5	17.2	17.9	25.6	14.0	16.8	19.0
	$s_{\bar{x}}$	7.1	9.7	9.1	5.1	10.8	2.3	6.0	4.7	4.1	4.0	5.2	2.7
	Range	10-60	5-50	20-85	5-85	6-75	1-15	0-35	0-35	15-50	1-35	2-40	1-50
	r^3	-0.63	-0.61	0.09	0.26	0.65	0.43	0.78*	-0.16	0.37	-0.25	-0.80*	-0.32
White fir	$\bar{x}$	5.0	8.3	0.3	4.6	3.9	0.8	3.2	2.75	9.6	5.0	3.1	5.9
	$s_{\bar{x}}$	3.2	8.3	0.3	2.9	1.5	0.5	1.7	0.8	3.6	0.6	1.2	1.4
	Range	0.20	0-50	0-2	0-50	0-10	0-3	0-11	0-11	1-30	3-8	1-10	1-30
	r^3	-0.82*	0.07	$-0.74^{.1}$	-0.20	0.57	0.68	-0.30	-0.04	-0.92**	-0.21	0.47	$-0.41^{.1}$
Incense cedar	$\bar{x}$	10.4	17.6	5.4	11.1	15.4	5.4	2.7	8.0	25.3	5.2	1.7	10.7
	$s_{\bar{x}}$	5.1	6.3	1.2	2.8	6.8	1.7	0.6	2.6	8.3	0.7	0.3	3.6
	Range	0-25	3-40	2-8	0-40	0-60	1-15	1-6	0-60	3-50	3-8	1-3	1-50
	r^3	$0.81^{.1}$	0.84*	0.48	-0.20	0.02	-0.09	0.52	$-0.37^{.1}$	-0.82*	0.87*	-0.25	-0.60**

[1]Total Salt Application, 1974-75 and 1975-76.
[2]Group I, 0-20'; Group II, 50-100'; and Group III, 150-200' from edge of pavement.
[3].1 = 90%, * = 95%, ** = 99% levels of significance.

Group III, 150-200 feet from the road, intermediate (29.2%) in Group I and lowest (24.0%) in Group II. These damage ratings were not significantly different because of the large range in ratings. Overall damage was 32.6% with a range of 5 to 85% browning and defoliation.

Damage in site 4, the intermediate salt site, was highest in Group I (31.0%), intermediate in Group III (17.2%), and lowest (5.5%) in Group II. Damage in Group II was significantly lower than in the other two groups. Overall damage was 17.9% with a range of 0 to 75% browning and defoliation.

Damage in site 14, the high salt site, was greatest in Group I (25.6%), intermediate in Group III (16.8%), and lowest in Group II (14.0%). Two trees had ratings of 15% and seven had ratings of 20 to 50% in Group I. In Group II, three trees of eight had damage ratings of 20% or more and five had 15% or less. In Group III, four trees of eight had 20% or more damage. Differences between Groups I and III and between Groups III and II were not significant, but were significant between Groups I and II. Overall damage was 19.0% with a range of 1 to 50% browning and defoliation.

The overall damage on site 9 was significantly greater than on the two other sites with higher salt application rates. In this site, damage was highest in Group III while in sites 4 and 14 it was highest in Group I. Damage on sites 4 and 14 were similar although there was a slightly different pattern of damage within sites. In site 4, the lowest damage was in Group II and in site 14 damage was not significantly different in Groups II and III.

5.41.12 White fir

Mean damage ratings in site 9 were low (5.0, 8.3, and 0.3) in all three groups. The range was 0 to 50% browning and defoliation in this site, but only two trees out of eighteen showed damage of 20% or more. Three trees had ratings of 2-5% and the remainder were zero. Overall damage was insignificant at 4.6% browning and defoliation.

Damage was low on site 4 in all groups. Although the mean damage rating in Group II was significantly different than in Groups I and III, the highest rating (3.9%) and the overall mean of 2.75% browning and defoliation was very small. The maximum damage on any tree in this site was only 11%.

The damage in site 14 was highest in Group I (9.6%), with a range of 1 to 30% browning and defoliation. Only one tree had 30% damage, all the others were below 10%. Damage in Groups II and III was small and scarcely different between the two groups. Overall damage was 5.9% with a range of 1 to 30% browning and defoliation.

The overall damage on site 14 was significantly greater than on site 4 but not different than on site 9. However, only one tree was severely damaged in each of sites 9 and 14 and there was little real difference among sites. Overall, there was a trend for greater damage in Group I but the data were not statistically significant.

5.41.13 Incense cedar

Damage in site 9 was highest in Group II (17.6%), in Group I (10.4%), and lowest in Group III (5.4%).

Differences between Groups I and II and between Groups I and III were not significant but those between Groups II and III were. Two trees out of five each in Groups I and II had 20% or more damage. Overall damage was 11.1% with a range of 0 to 40% browning and defoliation.

Damage was highest in site 4 in Group I (15.4%). Damage was low in both Groups II (5.4%) and III (2.7%). Overall damage was 8.0% with a range of 0 to 60% browning and defoliation.

Damage in site 14 was highest in Group I (25.3%) with three of six trees having 25 to 50% browning and defoliation. Damage was low in Groups II (5.0%) and III (1.7%). Overall damage was 10.7% with a range of 0 to 50% browning and defoliation.

The differences in damage among the three sites were not significant. Damage was most severe in Group I except on site 9 where damage was slightly higher in Group II. Overall the damage correlation with distance was significant at the 1% confidence level with r = 0.400.

5.41.14 Species comparison

Jeffrey pine exhibited the most damage on all sites, incense cedar had intermediate damage and white fir had the least damage on these three sites.

Damage was negligible on greenleaf manzanita on all sites.

5.41.2 Depth of fill: The depth of fill was generally greatest in Group I and lowest in Group III (see Table 9).

Table 9. Intensive Survey, 1976. Depth of fill (in inches) in Jeffrey pine, white fir, and incense cedar on three sites exposed to different levels of deicing salt, and at three distance intervals from the highway. Means, standard errors of the means and ranges. Correlation coefficient of damage ratings x depth of fill (r) are also given.

		Site 9: 1.1 ton/lane mile[1] Groups[2]				Site 4: 14.2 ton/lane mile[1] Groups[2]				Site 14: 28.4 ton/lane mile[1] Groups[2]			
Species	Parameter	I	II	III	All	I	II	III	All	I	II	III	All
Jeffrey pine	$\bar{x}$	10.0	3.0	2.0	5.1	2.8	3.8	1.7	2.8	5.4	1.8	1.6	3.0
	$s_{\bar{x}}$	1.4	0.9	0.5	1.1	0.7	1.4	0.2	0.5	1.0	0.4	0.3	0.5
	Range	5-15	1-6	1-4	1-15	1-6	1-10	1-2	1-10	2-12	1-4	1-3	1-12
	r[3]	0.81*	0.43	-0.11	0.06	-0.02	-0.17	0.56	-0.09	0.24	-0.17	-0.22	0.30
White fir	$\bar{x}$	6.5	3.0	2.7	4.1	2.1	2.3	1	1.9	4.1	1.9	1.4	2.5
	$s_{\bar{x}}$	2.1	0.4	0.5	0.8	0.2	0.8	-	0.3	1.1	0.7	0.3	0.5
	Range	2-14	2-4	1-4	1-14	1-3	1-6	-	1-6	1-10	1-6	1-3	1-10
	r[3]	0.32	-0.45	-0.27	0.04	0.22	-0.05	-	-0.02	0.21	-0.59	0.92**	0.37
Incense cedar	$\bar{x}$	6.5	2.8	1.6	3.5	2.6	8.0	1.4	4.1	3.3	1.0	1.3	1.9
	$s_{\bar{x}}$	1.2	1.3	0.4	0.7	0.6	4.0	0.3	1.5	0.8	-	0.2	0.4
	Range	3-10	1-4	1-3	1-10	1-6	1-34	1-3	1-34	1-6	-	1-2	1-6
	r[3]	0.45	-0.79[1]	-0.45	0.32	0.83**	0.31	-0.39	0.12	0.70[1]	-	0.79*	0.82**

[1]Total salt application, 1974-75 and 1975-76.
[2]Group I, 0-20'; Group II, 50-100'; and Group III, 150-200' from edge of pavement.
[3]·1 = 90%, * = 95%, ** = 99% levels of significance

Fill was rarely over 12 in. in depth and usually under 5 in. In four cases there was a significant correlation with damage ratings. However, because of the nature of the fill, primarily sand and cinders, and because of the negligible depth in most cases, it is felt that the correlations were not of biological importance. The highest correlation occurred with white fir in site 14, Group III where damage was almost non-existent. The fill around incense cedar in site 4, Group I was 2.6 in. (range 1-6 in.) did not seem to be sufficient to be important biologically. On the other hand, one tree in Group II on this site had 34 in. of fill and only 10% damage.

5.41.3 Beetle holes per square foot: No number of beetle holes per square foot can be cited as a critical level for tree damage or death (see Table 10). The number will vary with the species of beetle, the vigor of the tree and other factors (2,12,15). The only sure way to assess tree damage from beetles is by destructive sampling which was not possible in this study. However, Cole (2) states that 12 pairs of mountain pine beetle (*Dendroctonus ponderosae*) per square foot at breast height would be sufficient to infest and kill a lodgepole pine. Keen (12) gives the same value for western pine beetle (*D. brevicomis*) on ponderosa pine. Both species will attack Jeffrey pine. Twelve pairs of beetles would result in twelve entry holes because the males enter through the holes made by females. In any case, once a "pioneer beetle" is successful it creates an attraction for others to attack. Damage to the tree is both by girdling and the introduction of fungus spores which destroys the phloem and cambium (5,6,13).

Table 10. Intensive Survey, 1976. Beetle holes (per ft^2) in Jeffrey pine, white fir, and incense cedar on three sites, exposed to different levels of deicing salt, and at three distance intervals from the highway. Means, standard errors of the means and ranges. Correlation coefficients of damage ratings x beetle hole numbers (r) are also given.

Species	Parameter	Site 9: 1.1 Ton/Lane Mile[1] Groups[2] I	II	III	All	Site 4: 14.2 Ton/Lane Mile[1] Groups[2] I	II	III	All	Site 14: 28.4 Ton/Lane Mile[1] Groups[2] I	II	III	All
Jeffrey pine	$\bar{x}$	33.6	17.7	40.0	31.2	6.3	8.2	19.1	11.2	10.4	17.6	14.5	14.0
	$s_{\bar{x}}$	8.5	5.8	10.0	5.2	2.7	2.6	6.2	2.6	3.6	3.4	4.3	2.2
	Range[3]	5-65	4-32	13-77	4-77	0-15	4-21	0-38	0-38	0-34	5-31	5-31	5-34
	r[4]	0.12	0.95**	0.41	0.49*	0.28	0.80*	0.94*	0.33	0.61*	0.65*	0.94*	0.56**
White fir	$\bar{x}$	4.9	2.0	3.4	3.5	0	0	0.7	0.2	0.9	1.8	1.4	1.4
	$s_{\bar{x}}$	2.3	0.7	1.1	0.9	-	-	0.7	0.2	0.4	0.8	0.9	0.4
	Range[3]	0-16	0-4	0-7	0-16	-	-	0-4	0-4	0-3	0-5	0-5	0-5
	r[4]	0.98**	0.41	0.17	0.33	-	-	-0.02	-0.02	-0.16	-0.65[1]	0.77**	-0.02
Incense cedar	$\bar{x}$	11.8	32.9	26.7	23.8	3.9	2.3	1.1	2.5	1.0	1.2	0.8	1.0
	$s_{\bar{x}}$	8.2	27.3	8.9	9.5	3.0	1.3	0.8	1.1	0.7	1.2	0.6	0.5
	Range[3]	0-44	3-142	6.-58	0-142	0-24	0-9	0.-6	0-24	0.-4	0.-7	0.-3	0-7
	r[4]	0.65	0.90*	0.21	0.69**	0.06	-0.04	0.87**	0.15	-0.48	-0.05	-0.58	-0.15

[1]Total salt application, 1974-75 and 1975-76.
[2]Group I; 0-20, Group II, 50-100; and Group III, 150-200' from edge of pavement.
[3]Range = Rounded to nearest whole number.
[4].1 = 90%, * = 95%, ** = 99% levels of significance

5.41.31 Jeffrey pine

Beetle holes in site 9 were highest in Groups III and I and intermediate in Group II at 40.0, 33.6 and 17.7 respectively. The range in Group III was 12.7 to 77.1, all above the critical levels given by Cole and Keen. In Group I, the range was 5.3 to 64.9 with four of five trees having 24.0 or more holes per ft^2. In Group II (range 3.5 to 32.0), three of five trees had 14.4 or more beetle holes per ft^2. Correlation with damage ratings was significant at the 99% level in Group II and at the 95% level overall. The overall mean was 31.2 holes/ft^2.

Means for beetle hole numbers in site 4 was the lowest of the three sites. The number of holes was highest in Group III and about equal in Groups I and II. In Group III, four of six trees had 14.4 or more beetle holes (range 0.0 to 37.6). Group I (range 0-14.6) had two trees of six with 14.4 or more holes and Group II (range 4.0 to 20.6) only had one tree with more than 8.7 holes/ft^2. The overall mean was 11.2 holes/ft^2. Corrlation with damage was significant at the 95% level in Group II and at the 99% level in Group III.

Beetle holes in site 14 were intermediate between sites 9 and 4. There were no significant differences between Groups II and III or between Groups I and III, but there was a significant difference between Groups I and II. Four of nine trees in Group I had 12 or more, six of eight trees in Group II had 16.0 or more and four of eight trees in Group III had 18.5 or more beetle holes. For the site overall, fourteen of twenty-five trees had more than twelve beetle holes/ft^2. Correlation coefficients with damage were significant at the 95% level in Groups I and II and at the 99% level in Groups III and for the site, overall. The overall mean was 14.0 holes/ft^2.

Beetle holes in jeffrey pine were highest in site 9, intermediate in site 14 and lowest in site 4. In all sites and groups, one or more trees had twelve or more beetle holes/ft^2. Correlation of damage x beetle holes was significant in six of the nine groups, two of the three sites, and was significant at the 99% level ($r = 0.54$) for all sites.

5.41.32 White fir

Mean beetle holes in white fir in site 9 was not significantly different among groups. One tree in Group I had 15.6 holes/ft^2 and five had 5.0 or fewer. The highest number of holes in Group II was 4.2/ft^2 and Group III was 7.0. Correlation with damage rating was only significant in Group I at the 99% level.

No beetle holes were found in site 4 in Groups I and II. The maximum number of holes in Group III was 4.0/ft^2. Five of six trees had no holes.

Beetle hole numbers were low in site 14. In Group I the mean was 0.9 with a range of 0-2.7/ft^2. No holes were found in four of seven trees. The mean in Group II was 1.8 with a range of 0 to 5.1 holes/ft^2. No holes were found in three of seven trees. The mean in Group III was 1.4 with a range of 0.53 holes/tree. No holes were found in four of seven trees. The correlation with damage ratings was significant at the 90% level in Group II and at the 95% level in Group III. Correlations for the site overall was not significant. At this very low number of holes/ft^2, the damage on this site cannot be attributed to beetle attack with any degree of certainty.

Beetle holes in all sites were low in number. The greatest number were in site 9 and the lowest number in site 4. Only one tree in site 9 had more than 12 holes/ft^2. Although correlation with damage for all sites was significant at the 90% level, because of the relatively low number of holes per ft^2, the damage to white fir on these sites cannot, with any degree of certainty, be attributed to beetle attack. However, during the preliminary surveys many dead and dying white fir were found with extensive beetle damage in the overall study area.

5.41.33 Incense cedar

Beetle attacks on incense cedar may be largely a matter of secondary invasion of weakened trees (Bedard, 1980).

The beetle holes/ft^2 in site 9 were highest in Group II (32.9), intermediate in Group III, and lowest in Group I (11.8). Because of the variation in beetle numbers, these means are not significantly different. Two trees in Group I had 10.3 and 43.6 holes and none were found in two of the five trees. In Group II, four trees had fewer than ten holes and the high mean was due to a single tree with 142 holes/ft^2. Group III had only one tree with 6.4 holes and four trees with 14.7 to 58.3 holes. Correlation with damage ratings was significant at the 95% level.

The number of beetle holes in site 4 were relatively low, 3.9, 2.3, and 1.1 in Groups I, II, and III respectively.

In Group I, one tree had 24, one 7.2, and six trees zero holes. No holes were found in four of eight trees in Group II. Only two of seven trees in Group III were found to have beetle holes. Although correlation with damage ratings was significant at the 99% level in Group III, the small number of beetle holes suggest that this correlation is meaningless biologically.

In site 14, the numbers of beetle holes were small in all groups. The maximum number was $6.9/ft^2$. No holes were found in thirteen of eighteen trees on this site.

The number of beetle holes was high in site 9 and very low in sites 4 and 14. For all sites and groups, correlation with damage ratings was significant at the 95% level. In view of the reports in the literature that beetles only attack weakened, dying or dead trees, in this species it cannot be concluded that the beetle holes (beetles) numbers, per se were a cause of damage in this species.

5.41.34 Species comparisons

Jeffrey pine had the highest numbers, incense cedar, an intermediate number, and white fir the fewest number of beetle holes on these study sites. The beetle hole numbers in Jeffrey pine suggest that beetles may be contributing to the damage of this species. Where Na and Cl levels are also high it is impossible to determine which is the primary cause of damage. There is no evidence on these sites that Na or Cl increases susceptibility to beetle attack.

5.41.4 Leaf sodium and chloride: Leaf sodium and chloride concentrations are expressed on a percent dry weight basis.

Threshold levels for these two elements were estimated from tissue sampling carried out in 1977 and 1978 on the Soil Salt Application Study. The threshold level was defined as the tissue concentration of either element where necrosis or browning of leaf tissue ranged from tip burn (about 12 to 15% necrosis) to 25%. These threshold levels were estimated three ways. One set of estimates was derived from samples of individual needles just showing tip burn, 25, 50, 75, and 100% browning. A second estimate was made using treatment means of Na and Cl and the mean damage rating for the treatments when damage was rated 1 (25% damage). The third estimate was derived from data for individual trees which had damage ratings of 1. This third estimate was selected because it was generally intermediate between the other two estimates and appeared to most closely match the leaf concentrations and damage ratings in the individual trees in this intensive survey. These estimates of threshold levels are graphed and discussed at greater length in the Soil Salt Application Study.

5.41.41 Leaf sodium

Refer to Table 11 for leaf sodium values.

5.41.41.1 Jeffrey pine: Estimated threshold level, 0.15-0.20% dry weight.

Leaf Na was low in site 9 in Jeffrey pine in all three groups. The overall mean was 0.035% D.W. Although the correlation with damage in Group I and overall for the site was significant at the 90% level, the range of 0.027 to 0.049% was well below the estimated threshold level.

Table 11. Intensive Survey, 1976. Leaf sodium (% dry weight) in Jeffrey pine, white fir, and incense cedar on three sites exposed to different levels of deicing salt, and at three distance intervals from the highway. Means, standard errors of the means and ranges. Correlation coefficients of damage ratings x leaf sodium (r) are also given.

		Site 9: 1.1 Ton/lane mile[1] Groups[2]				Site 4: 14.2 Ton/lane mile[1] Groups[2]				Site 14: 28.4 Ton/lane mile[1] Groups[2]			
Species	Parameter	I	II	III	All	I	II	III	All	I	II	III	All
Jeffrey pine	$\bar{x}$	0.037	0.037	0.031	0.035	0.228	0.055	0.043	0.109	0.277	0.042	0.024	0.121
	$s_{\bar{x}}$	0.003	0.003	0.001	0.001	0.020	0.005	0.010	0.022	0.030	0.011	0.002	0.027
	Range	0.027	0.032	0.028	0.027	0.184-	0.046-	0.027-	0.027-	0.115	0.023	0.017-	0.017-
		0.043	0.049	0.034	0.049	0.289	0.073	0.092	0.289	0.414	0.115	0.032	0.414
	r^3	-0.074	-0.21	0.08	0.47.1	0.19	-0.06	0.41	0.50*	-0.05	-0.38	-0.44	0.30
White fir	$\bar{x}$	0.036	0.036	0.032	0.035	0.080	0.048	0.034	0.057	0.088	0.020	0.019	0.043
	$s_{\bar{x}}$	0.002	0.001	0.001	0.001	0.019	0.004	0.004	0.009	0.013	0.001	0.002	0.008
	Range	0.029-	0.034-	0.029-	0.029-	0.050-	0.034-	0.025-	0.025-	0.046-	0.014-	0.014-	0.014-
		0.042	0.039	0.035	0.042	0.202	0.059	0.055	0.202	0.147	0.023	0.027	0.147
	r^3	-0.52	-0.36	-0.58	-0.13	-0.41	-0.33	0.08	-0.15	0.71.1	-0.19	0.67.1	0.68**
Incense cedar	$\bar{x}$	0.046	0.035	0.023	0.035	0.102	0.037	0.036	0.059	0.107	0.025	0.024	0.052
	$s_{\bar{x}}$	0.003	0.001	0.001	0.003	0.013	0.002	0.003	0.008	0.016	0.003	0.003	0.011
	Range	0.036-	0.032-	0.020-	0.020-	0.059-	0.027-	0.026-	0.026-	0.050-	0.014-	0.017-	0.014-
		0.055	0.039	0.025	0.055	0.179	0.043	0.046	0.179	0.161	0.034	0.032	0.161
	r^3	0.011	0.86*	0.60	0.28	-0.43	-0.01	0.26	0.16	0.77.1	-0.59	-0.48	0.86**

[1]Total salt application, 1974-75 and 1975-76.
[2]Group I, 0-20'; Group II, 50-100'; and Group III, 50-200' from edge of pavement.
[3].1 = 90%, * = 95%, ** = 99% levels of significance.

Leaf Na in site 4 was highest in Group I (0.228%). The statistical calculations did not give significant correlation with the damage rating. However, the range of 0.184 to 0.289% would indicate that nearly all of the trees in this group were at a Na level which could be expected to result in damage. Groups II and III had low Na levels (0.055 and 0.043%) and ranges below that at which damage could be expected. Overall, there was correlation with damage rating at the 95% level for the site.

Leaf Na was also highest in site 14 in Group I (0.277%). The range was 0.115 to 0.414%. Eight of nine trees had leaf Na above 0.230%, one had 0.115%. The leaf Na in Group II was intermediate at 0.042% with a range of 0.23 to 0.115%. Group III had low Na at 0.024% with a range of 0.017 to 0.032%. The damage ratings and Na levels did not correlate well on this site.

Leaf Na levels increased from the low to the high salt sites. The correlation with damage ratings was poor in all groups and was not significant when calculated for all sites combined. However, in sites 4 and 14 in Group I, Na levels in individual trees were near or above that which could be considered damaging.

5.41.41.2 <u>White fir</u>: Estimated threshold level, 0.07-12% dry weight.

Leaf Na was low and almost identical in site 9 in all three groups. The mean Na level for the site was 0.035% with a range of 0.029 to 0.042%. Correlations with damage levels were not significant.

In site 14, Na levels were highest in Group I (0.088) with a range of 0.046 to 0.147%). Two trees of seven had levels over 0.100% Na, three had levels of 0.073 to 0.096% and two had levels of 0.064 or below. The levels in Groups II and III were almost identical and very low. The maximum value was 0.027%. The correlation with damage rating was significant at the 90% level in Groups I and III and at the 99% level for the site as a whole.

Leaf Na increased from the low to the mid-level salt site. Levels were slightly (but not significantly) lower in the high salt site than in the mid-salt site. Only four trees had leaf Na levels above 0.100 and three trees had leaf Na levels between 0.070 and 0.100% for all sites. Correlation with damage ratings were not significant for all sites combined.

5.41.41.3 <u>Incense cedar</u>: Estimated threshold level, 0.05% dry weight.

Leaf Na in site 9 decreased from 0.046 in Group I to 0.023 in Group III. The maximum Na in Group I was 0.055%. Two trees of five had Na levels above 0.05%. The correlation with damage rating was only significant in Group II where the mean was 0.035% D.W. This has little meaning because the Na levels (range 0.032-0.039%) were below those expected to cause damage.

Leaf Na in site 4 was highest in Group I (0.102%). Five of eight trees had leaf Na between 0.059 and 0.100% and one each had 0.126, 0.130 and 0.179% Na. The Na levels in Groups II and III were almost identical (0.037 and 0.036%) with a maximum level in Group II of 0.43% and in

Group III of 0.046%. There was no significant correlation with damage ratings. However, all trees in Group I had Na levels which could be considered damaging.

The leaf Na levels in site 14 were essentially the same as in site 4. The maximum levels were in Group I (0.107%) with a range of 0.050 to 0.161%. One tree had levels of 0.160%, three were between 0.115 and 0.126%, one was 0.073 and one was 0.050%. Correlation with damage was significant at the 90% level in Group I. The mean Na in Groups II and III were 0.025 and 0.024 with ranges of 0.014 to 0.034 and 0.017 to 0.032% respectively. Correlation with damage ratings was significant at the 99% level for the site overall.

Leaf Na increased from the low to the mid-salt site but remained at about the same level in the high salt site. The correlation with damage rating was significant at the 99% level when all sites were combined. Sodium in sites 4 and 14, Group I were approaching or at estimated threshold levels.

5.41.41.4 Species comparisons: Sodium accumulation was highest in Jeffrey pine and about equal between white fir and incense cedar. In general, the correlation between Na and content and damage was poor for all three species.

Leaf sodium concentration in all samples of greenleaf manzanita were very low.

5.41.42 Leaf chloride

Refer to Table 12 for leaf chloride values.

Table 12. Intensive Survey, 1976. Leaf chloride (% dry weight) in Jeffrey pine, white fir , and incense cedar on three sites exposed to different levels of deicing salts, and at three distance intervals from the highway. Means, standard errors of the means, and ranges. Correlation coefficients of damage rating x leaf chloride (r) are also given.

		Site 9: 1.1 Ton/lane mile[1] Groups[2]				Site 4: 14.2 Ton/lane mile[1] Groups[2]				Site 14: 28.4 Ton/lane mile[1] Groups[2]			
Species	Parameter	I	II	III	All	I	II	III	All	I	II	III	All
Jeffrey pine	$\bar{x}$	0.179	0.023	0.006	0.072	0.152	0.027	0.030	0.070	0.280	0.036	0.034	0.123
	$s_{\bar{x}}$	0.070	0.004	0.001	0.030	0.030	0.006	0.010	0.017	0.038	0.007	0.011	0.028
	Range	0.010-0.450	0.007-0.033	0.003-0.010	0.003-0.450	0.090-0.292	0.009-0.044	0.006-0.070	0.006-0.292	0.129-0.481	0.017-0.073	0.011-0.105	0.011-0.481
	r^3	0.91**	0.65	0.22	0.23	0.57	0.25	-0.16	0.61**	0.65*	0.82**	0.69*	0.57**
White fir	$\bar{x}$	0.131	0.040	0.026	0.065	0.120	0.072	0.070	0.090	0.261	0.069	0.054	0.128
	$s_{\bar{x}}$	0.059	0.008	0.006	0.022	0.034	0.020	0.018	0.016	0.083	0.022	0.010	0.035
	Range	0.013-0.324	0.024-0.074	0.010-0.048	0.010-0.034	0.043-0.347	0.023-0.160	0.024-0.132	0.023-0.347	0.085-0.550	0.016-0.186	0.031-0.108	0.016-0.550
	r^3	0.77*	-0.05	-0.36	0.24	0.59	0.57	0.04	0.47*	-0.07	-0.14	0.96**	0.24
Incense cedar	$\bar{x}$	0.295	0.077	0.037	0.136	0.484	0.180	0.058	0.249	0.464	0.140	0.060	0.221
	$s_{\bar{x}}$	0.078	0.008	0.012	0.039	0.072	0.043	0.015	0.047	0.065	0.061	0.018	0.051
	Range	0.154-0.545	0.048-0.095	0.008-0.077	0.008-0.545	0.087-0.756	0.090-0.383	0.013-0.113	0.013-0.756	0.311-0.704	0.044-0.151	0.014-0.143	0.014-0.704
	r^3	0.012	-0.079[.1]	-0.13	-0.02	0.42	0.63[.1]	0.70[.1]	0.59**	0.94**	0.90**	-0.43	0.86**

[1]Total salt application, 1974-75 and 1975-76.
[2]Group I, 0-20'; Group II, 50-100'; and Group III 150-200' from edge of pavement.
[3].1 = 90%, * = 95%, ** = 99% levels of significance.

5.41.42.1 Jeffrey pine: Estimated threshold level, 0.25-0.40% dry weight.

Leaf Cl in site 9 was highest in Group I (0.179%) with a range of 0.010 to 0.450%. Of six trees, one had 0.450 and one had 0.317% and four were below 0.153%. Two trees were at or above the estimated threshold level. Leaf chloride in Group II was 0.023% with a maximum of 0.033%. The mean in Group III was 0.006% with a maximum of 0.010%. The correlation with damage rating ($r = 0.91$) was significant at the 99% level for Group I but not for the site overall.

Leaf Cl in site 4 was highest in Group I (0.152%) with a range of 0.090 to 0.292%. One tree had 0.292%, in the estimated threshold level range, three had between 0.138 and 0.156% and two had below 0.100% Cl. Groups II and III had low leaf Cl (0.027 and 0.030% respectively) and with a range of 0.009 to 0.044% in Group II and 0.006 to 0.070 in Group III. Only one tree in this site was at the estimated critical level of Cl. Correlation with damage rating were not significant in any group but were significant at the 99% level for the site overall.

Leaf Cl was also highest in site 14 in Group I (0.280) with a range of 0.129 to 0.481%. Two of nine trees had Cl levels of 0.416% or more, one had 0.340, two were between 0.253 and 0.300, two were between 0.23 and 0.24, and one was below 0.200% Cl. Chloride levels in Groups II and III were low and essentially the same (0.036 and 0.034 respectively) with ranges of 0.017 to 0.073 and 0.011 to 0.105 respectively. Correlation with damage ratings were significant in all three groups and for the site overall. The level was at 95% in Groups I and III and at 99% in Group II and for the site overall.

Leaf chloride was higher in site 9, the low salt site, than in site 4, the mid-salt site. This was thought to be due to the topography and drainage patterns in site 9. The southerly half of the pavement drains downhill for at least a quarter of a mile, crosses the road in a culvert and collects in a portion of this site. See Fig. 4A. The highest chloride levels were in the high salt site. Correlation with damage rating was significant at the 99% level for all sites combined.

5.41.42.2 <u>White fir</u>: Estimated threshold level, 0.45-0.60% dry weight.

Leaf Cl in site 9 was highest in Group I (0.131%) and low in Groups II and III (0.040 and 0.26% respectively). The range in Group I was 0.013 to 0.324%. Two of six trees had leaf Cl of 0.311% or more but these levels were about two-thirds the estimated threshold level. The ranges in Groups II and III were 0.024 to 0.74 and 0.010 to 0.48% respectively. Correlation with damage rating was significant (at the 90% level) in Group I only.

Leaf Cl in site 4 was highest in Group I (0.120%) with a range of 0.043 to 0.347%. All but one tree had levels below 0.142% Cl. The Cl in Groups II and III was very similar to 0.072 and 0.070% respectively. The ranges were 0.023 to 0.160 for Group II and 0.024 to 0.132 for Group III. Correlation with damage rating was not significant in groups but was significant at the 95% level for the site overall. However, only two trees on the site near the highway manifested symptoms at a slightly lower leaf Na and Cl concentration when compared to those in the Soil-Salt Application Study.

5.5 Salt Application Trials

A greenhouse study with shrubs and a field experiment with conifers were conducted in order to produce salt damage symptoms and determine threshold salt levels causing damage.

5.51 Salt Damage in Shrubs: Shrubs constitute a conspicuous portion of the ground cover along roadsides in the Lake Tahoe Basin. The effect of deicing salt on growth and survival of these shrubs is unknown. As part of the preliminary survey, a greenhouse study was conducted in 1974 to produce salt damage symptoms in four shrub species native to the Tahoe region, and to develop guidelines to identify salt damage on these plants in the field. This experiment was done by Dr. Robert P. Doss. The results of this study are given in Appendix 1.

The original plan had been to extend these greenhouse studies to include the native conifers of the study area. The results of the greenhouse studies on the four shrub species indicated that threshold levels developed in this manner might be unrealistically high because of the higher humidities and lack of water stress compared to field conditions. A second question was whether threshold levels and symptom development would be similar in the 2-3 year old trees suitable for greenhouse studies as for more mature trees. It was decided, therefore, to conduct salt application experiments in the study area.

were 0.048 to 0.095 and 0.008 to 0.077% respectively. The only correlation between Cl and damage rating was a negative value at the 90% level in Group II. This correlation appears to be biologically meaningless because of the low leaf Cl levels and because of the negative value.

Leaf Cl in site 4 was 0.484 in Group I, 0.180 in Group II and 0.058 in Group III. The range in Group I was 0.087 to 0.756 with values for three trees of eight exceeding 0.600%, one exceeding 0.500%, two exceeding 0.400% and one, 0.300%. All trees in Group I had Cl levels at or exceeding the estimated threshold level. The range in Group II was 0.090 to 0.383%, with one tree at 0.383%, and two trees between 0.270 and 0.280%. Five trees had levels below 0.175%. The range in Group III was 0.013 to 0.113%. Correlation with damage rating was significant at the 90% level for Groups II and III and at the 99% level overall.

Leaf Cl in site 14 was 0.464% in Group I, 0.140% in Group II, and 0.060% in Group III. The range in Group I was 0.311 to 0.704%. One tree was above 0.700%, one had 0.612%, one 0.426%, and three had between 0.311 and 0.400% Cl. Group II range was 0.044 to 0.151% and Group III was 0.014 to 0.143%. Correlation with damage rating was significant at the 99% level for Groups I and II and for the site overall. The Cl levels in all trees in Group I were at or above the estimated threshold levels.

Leaf Cl was at intermediate levels in site 9, the low salt site, and at higher and similar levels in both sites 4 and 14. The pattern in Groups I, II, and III, were very similar in these latter two sites. Leaf Cl levels were approaching or above estimated threshold levels in Group I in both these two sites. The leaf Cl in site 4, Group II, was somewhat higher than in site 14, Group II. Correlation with damage ratings were significant at the 99% level when all sites were combined.

5.41.42.4 Species comparisons: The overall comparison of chloride tissue concentration among these species indicated that Jeffrey pine and white fir contained about the same concentration in the area nearest the roadway. In Groups II and III, which were more distant from the roadway, the white fir leaves contained more Cl than the pine. In general, the incense cedar contained more Cl with levels sometimes nearly twice that of the other species.

Leaf Cl concentrations in all samples of greenleaf manzanita were very low.

5.41.43 Comparison of leaf sodium and chloride concentrations in relation to tree damage ratings

Significant correlations (90% level and above) of damage rating x leaf Na concentration by species and site occurred in four of nine cases (Table 11). These were, for Jeffrey pine in site 9 at the 90% level ($r = 0.47$), and in site 4 at the 95% level ($r = 0.50$), for white fir in site 14 at the 99% level ($r = 0.68$), and for incense cedar in site 14 at 99% level ($r = 0.86$). Significant correlations of damage rating x leaf Ca concentrations occurred in five of nine cases (Table 12). These were, for Jeffrey pine in sites 4 and 14 at the 99% level (r = 0.61 and 0.57 respectively), for white fir in site 4 at the 95% level (r = 0.47), and for incense cedar in sites 4 and 14 at the 99% level (r = 0.59 and 0.86 respectively).

Significant correlation of damage ratings x leaf Na concentrations for species (all sites combined) (Table 13) occurred only with incense cedar, at the 99% level (r = 0.45). However, for damage rating x leaf Cl concentrations, correlation coefficients were significant for all three species (Table 13). For Jeffrey pine, significance was at the 99% level (r = 0.35), for white fir at the 90% level (r = 0.24), and for incense cedar at the 99% level (r = 0.56).

For these three species, leaf Cl concentration appears to be a better indicator of the salt status of the plant, relative to damage rating than does the leaf Na concentration.

5.41.44 Soil salt levels and leaf sodium and chloride

Soil analyses for EC_e, Na and Cl were made for a portion of the trees in the Intensive Survey Study. (Appendix II, Tables 1-3.) The values were generally higher in Group I in all sites and increased from site 9 to site 14. However, they were relatively low even in Group I, site 14, the high salt site. Correlations with corresponding tree tissue levels of Na and Cl were poor. It is probable that by the time of sampling, the soil salts had been mostly leached from the top 2 ft of the soil profile. The soil sampling was done in mid-summer.

Table 13. Intensive Survey 1976. Correlation Coefficients of Distance, Depth of Fill, Beetle Holes per Square Foot, Leaf Na and Cl, and Damage for Jeffrey Pine, White Fir and Incense Cedar for all Sites combined.

Correlation	Jeffrey Pine		White Fir		Incense Cedar	
	r	Sig.	r	Sig.	r	Sig.
Fill vs. Distance	-0.52	**	-0.38	**	-0.29	*
Beetle vs. Distance	0.15		0.004		0.08	
Leaf Na vs. Distance	-0.58	**	-0.48	**	-0.49	**
Leaf Cl vs. Distance	-0.60	**	-0.40	**	-0.63	**
Damage vs. Distance	-0.07		-0.20		-0.40	**
Beetle vs. Fill	0.15		0.38	**	-0.01	
Leaf Na vs. Fill	0.18		0.09		-0.03	
Leaf Cl vs. Fill	0.55	**	0.55	**	-0.21	
Damage vs. Fill	0.19		0.13		0.15	
Damage vs. Beetle	0.54	**	0.24	0.1	0.29	*
Beetle vs. leaf Na	-0.30	*	-0.17		-0.13	
Damage vs. leaf Na	0.12		0.15		0.45	**
Leaf Na vs. leaf Cl	0.65	**	0.29	*	0.83	**
Beetle vs. leaf Cl	-0.06		0.11		-0.16	
Damage vs. leaf Cl	0.35	**	0.24	0.1	0.56	**

0.1 = 90% level of significance
* = 95% level of significance
** = 99% level of significance

5.41.5 Summary: Both beetles and chloride are probable causes of damage to Jeffrey pine in Group I in sites 9 and 14. In site 4, Group I damage may be in part due to beetles. The Cl levels are such that it is difficult to determine the contribution of Cl to damage. The Cl levels are well below the estimated critical levels.

Damage levels were relatively low in all sites and groups for white fir. Maximum Cl concentrations in Group I, sites 9 and 14 were only about two-thirds the estimated threshold levels. Beetle hole numbers were relatively low in site 9 and zero in site 4 in Group I. From the data available, the damage rating of 50% in one tree in Group I, site 9 cannot be accounted for. Damage in Group I, site 14 was probably related to Cl concentration. The beetle hole count was very low.

The leaf Cl concentrations in Group I at all sites was sufficient to be the suspected cause of damage in incense cedar. Beetle hole numbers were sufficiently high in all groups in site 9 and in Group I, site 14 to be suspected of causing damage except that the literature indicates that beetles are only secondary invaders in this species (6). In Groups II and III, site 9, leaf Cl concentrations are not high enough to be suspected of being primary cause of damage. If beetles are indeed only secondary invaders, it becomes difficult to attribute a cause of damage, particularly in Group II.

When both leaf chloride concentration and beetle hole numbers are high in one group, it is impossible to assign a percentage of damage due to each factor unless individual tree data show one factor high and one low.

There was no evidence in this survey that high leaf chloride levels made the trees more susceptible to beetle attack. This was surprising in view of the statements made in the literature that trees weakened by any environmental factors were more susceptible to attack (4,5,6,13,22).

5.42 Survey of June, 1977: After becoming familiar with foliar salt damage symptoms based on observations from the Intensive Survey and the Soil-Salt Application Study (discussed later), a small scale follow up survey was undertaken in June 1977. The objectives were to compare the salt levels in trees and soil with those of the Intensive Survey where samples were collected in Aug./Sept. of 1976 and to determine whether the different degrees of damage observed along the highway occur at a similar leaf Na and Cl concentration as in the Soil-Salt Application Study. Trees growing 20 feet from the highway in sites 6 and 14 were examined. Seven comparisons each in Jeffrey pine and lodgepole pine, and 4 each in white fir and incense cedar were made. These trees were given a damage rating of 2 on a scale of 0-4. From each tree, tip browned, half green and half brown and dead needles were collected separately. Soil samples at three depths (0-12", 12-24" and 24-36") under these trees were also collected. Leaf samples were analyzed for Na and Cl and soils for EC_e, Na and Cl.

The data showed that as Na and Cl concentrations increased in the leaves so did the damage (Table 14). The June levels of Na and Cl in the foliage and soil were higher than those recorded in Aug./Sept. of 1976 (Table 14 and 15).

The soils data are relatively low and suggest that by the time of sampling, leaching had taken place. Trees growing

Table 14. Survey of June 1977: Leaf Na and Cl concentrations (% dry weight) of conifers. Sampled trees were within 20' of highway near sites 6 and 14.

Species	Nature of tissue					
	Green (tip burned)		Half green/ half dead		Dead	
	Na	Cl	Na	Cl	Na	Cl
Jeffrey pine (7)+	0.237	0.389	0.453	0.616	0.547	0.704
Lodgepole pine (7)	0.228	0.396	0.481	0.637	0.653	0.853
White fir (4)	0.302	0.529	0.451	0.790	0.647	0.888
Incense cedar (4)	++	0.923	++	0.968	++	1.177

+: # of samples in each mean.
++: not analysed.

Table 15. Survey of June 1977: Electrical Conductivity, EC_e, Na and Cl concentrations of the saturation extract of soil samples at different depths. Samples correspond to the trees in Table 14.

Species	Depth	EC_e mmhos/cm	Na meq l^{-1}	Cl meq l^{-1}
Jeffrey pine	1st foot	1.14	7.2	5.3
	2nd foot	1.15	9.2	4.8
	3rd foot	1.51	12.3	7.7
Lodgepole pine	1st foot	0.80	7.5	3.5
	2nd foot	0.72	6.5	4.2
	3rd foot	1.40	10.3	7.1
White fir	1st foot	1.24	10.9	6.8
	2nd foot	1.37	11.0	5.8
	3rd foot	1.24	10.2	6.2
Incense cedar	1st foot	1.58	10.0	7.7
	2nd foot	1.18	11.8	7.0
	3rd foot	1.51	12.3	7.7

near the highway manifested symptoms at a slightly lower leaf Na and Cl concentration when compared to those in the Soil-Salt Application Study.

5.5 Salt Application Trials

A greenhouse study with shrubs and a field experiment with conifers were conducted in order to produce salt damage symptoms and determine threshold salt levels causing damage.

5.51 Salt Damage in Shrubs: Shrubs constitute a conspicuous portion of the ground cover along roadsides in the Lake Tahoe Basin. The effect of deicing salt on growth and survival of these shrubs is unknown. As part of the preliminary survey, a greenhouse study was conducted in 1974 to produce salt damage symptoms in four shrub species native to the Tahoe region, and to develop guidelines to identify salt damage on these plants in the field. This experiment was done by Dr. Robert P. Doss. The results of this study are given in Appendix 1.

The original plan had been to extend these greenhouse studies to include the native conifers of the study area. The results of the greenhouse studies on the four shrub species indicated that threshold levels developed in this manner might be unrealistically high because of the higher humidities and lack of water stress compared to field conditions. A second question was whether threshold levels and symptom development would be similar in the 2-3 year old trees suitable for greenhouse studies as for more mature trees. It was decided, therefore, to conduct salt application experiments in the study area.

5.52 Salt Damage in Conifers: From the field survey it was recognized that salt is one of the two major causes for the decline of conifers near highways in the Tahoe Basin. From preliminary field observations and leaf analyses, it appeared that the salt damage symptoms (tip burn) develop in these conifers in a similar manner as described in trees of the midwest and northeast: from base to tip within a branch or a tree and from tip to base within a leaf. Threshold levels for damage in these conifers (Jeffrey pine, white fir, and incense cedar) based on the May 1976 survey was tentatively set at 0.25% (dry weight) for Na and 0.4% for Cl. However, in order to establish these more precisely, two field trials were performed to observe the onset and development of symptoms and to determine the corresponding leaf Na and Cl concentrations at various damage levels. These trials were also designed to observe the differences, if any, between damage resulting from salt taken up through foliage and salt absorbed by roots. These experiments, initiated in the winter of 1976-77, were conducted in the Tahoe Basin, near sites 7 and 15. The first trial was to determine plant response to salt application to the soil. The second, was to determine plant response to salt application to foliage.

5.53 Soil Salt Application Study: This study was conducted during the winters of 1976-77 and 1977-78. Two locations were selected where four of the conifer species native to the study area were available of such sizes that leaf sampling could be done and where they were spaced far enough apart so that treatments could be separated. Location I was near site 15 and location II was near site 7. Both locations were isolated from any influence of highway deicing salt by distance and terrain.

The salt application rates were selected to be representative of rates that might occur adjacent to deicing operations. Caltrans research (16) had shown that soil salt levels were highest within 25-50 ft of the pavement edge and that beyond this distance, salt levels were negligible. If all the salt from one lane mile moved to a strip 25 ft wide adjacent to that lane, it would be dispersed over 3.03 A. A 50 ft dispersal would cover 6.06 A. On a roadway with super, the salt from two lanes would largely be dispersed to a strip on one side (unless removed in the plowing operation). One and one-half tons of salt per lane mile transported to a 25 ft strip would equal a salt application rate of 0.5 T/A., and to a 50 ft strip, would equal 0.25 T/A. The rates planned for this experiment ranged from 0 to 8.0 T/A or 0 to 24 T/lane mile for a 25 ft dispersal zone, 0 to 48 T/lane mile for a 50 ft zone, or 0-12 T/lane mile for a 25 ft zone where highway super caused melt from both lanes to disperse on one side of the highway.

The experimental details are given in the following table.

Table 16. Salt application rates, species used and location of the soil-salt application study, 1976-77 and 1977-78.

Species	Salt treatment, Tons/acre[a]			Number of replications and locations
	Planned	Actual		
		1976-77	1977-78	
Jeffrey pine and White fir	0 0.5 1.0 2.0 4.0 8.0	0 0.33 0.66 1.33 2.67 5.33	0 0.5 1.0 2.0 4.0 8.0	Jeffrey pine: 3 in Location I, 3 in II White Fir: 5 in Location II
Lodgepole pine and Incense cedar	0 0.5 1.0 2.0 4.0	0 0.33 0.66 1.33 2.67	0 0.5 1.0 2.0 4.0	Lodgepole pine: 4 in Location I Incense cedar 4 in Location II

a. To convert to Kg/ha, multiply by 1.12.

All trees selected were healthy and ranged in height from 8-20 feet. The ground around each tree was level and most trees were isolated from other forest trees. Each replication contained trees of similar heights and consisted of six trees for Jeffrey pine, five trees for white fir, and four trees for lodgepole pine and incense cedar. One tree within each replication received each level of treatment.

The height, circumference at breast height, crown spread, density, and possible surface runoff were recorded before salt application.

For the purposes of salt application it was assumed, from general horticultural knowledge, that feeder roots occupy an area slightly more than twice the area of the spread of the crown. The crown spread of the selected trees of Jeffrey pine, white fir, and incense cedar averaged 10 feet. Salt was broadcast in an area of 400 square feet around these trees [$(\frac{22}{2})^2 \times \pi = 380$, rounded to 400 square feet]. The average crown spread of lodgepole pine was 7 feet and salt was applied in an area of 200 square feet [$(\frac{16}{2})^2 \times \pi = 201$, rounded to 200 square feet]. Salt was applied in equal doses, twice in 1977 (mid January and mid April), and three times in 1978 (mid January, February, and March). The third application was omitted in 1977 because of the very low snowfall.

Leaf samples were collected from all trees in January 1977 before the first salt application.

From May through October 1976 and January through September 1977, leaf samples were collected from each tree, except those trees that were completely defoliated. Samples were analyzed for Na and Cl. The leaf tissue sample consisted of oldest "green" leaves on a branch. On trees with no damage symptoms, these leaves were the oldest leaves (e.g. 4 year old on Jeffrey pine). On trees where there was moderate damage, samples were taken just above severely damaged leaves. These leaf samples may or may not have had tip burn. On heavily damaged trees, the samples were again taken above severely damaged leaves and in this case, the sampled leaves may have been partially brown. The objective was to obtain a leaf sample whose Na and Cl concentration most sensitively reflected the damage status of the entire tree, yet sampling criteria in the field were subjective, and there was a degree of sampling error and variability which could not be avoided.

Another study involved the relation between the Na and Cl concentration and extent of damage of the leaf. Therefore, leaves with tip burn or which were 1/4, 1/2, 3/4 and totally brown were analyzed for Na and Cl. In this study, we wished to obtain the minimal Na and Cl concentration associated with individual leaf damage.

At the time of sampling, trees were assessed for damage on a scale of 0-4 where 0 = no damage, 1 = first visible symptoms-25, 2 - 26-50, 3 = 51-75, and 4 = 76-100% browning and defoliation.

Soil samples from four replications in Jeffrey pine, three in white fir, two each in lodgepole pine and incense cedar at three increment depths (0-12", 13-24", 25-36") were collected in June and October, 1977, and June 1978 before leaf sampling.

Photographs showing the sequence of symptoms in these plants were included in the Quarterly Report for June-August 1977.

5.53.1 <u>Description of Damage Symptoms</u>:

5.53.11 Jeffrey pine

In this species, only trees treated with 5.28 tons of salt per acre showed visual damage symptoms in 1977. By July, five out of six trees were distressed. One of the six exhibited injury on the lowest branch as early as mid-April.

Damage progression in this tree was as follows: The four year old annual whorl of needles on the affected branch were green from base to middle and brown from the middle to the tip. In the individual needles there was a distinct though narrow chlorotic band between the green and the brown portion. As much as one centimeter of the tips of needles of the third annual whorl were brown. The two and one year old needles and the dormant buds did not show any visual symptoms.

The damage had spread almost half-way up the tree by May. In the lower branches that showed symptoms in April, the four year old annual whorl was totally brown, and the needles could easily be stripped from the branch. Needles of the three year old annual whorl were three-quarters brown and the two year old one-half brown. The one year old needles showed one-quarter browning. There was no damage in the current year's growth which had just begun. In the branches above, damage in individual needles varied from tip burn to three-quarters dead, depending upon the age of the needles, the oldest needles showing the most injury. Between two adjacent tiers of branches, the lower tier showed greater damage.

The damage had progressed to the upper crown by June, in the same pattern as in the lower crown. By then the needles of the lowest branch, except for the current growth which now was about one-half brown, were totally dead. The older whorls of the branches above were also dead or almost dead.

The damage had progressed in intensity by July and was so apparent that the tree was dominated by a brownish hue, despite the active, green current growth. By this time, the three and four year old needles even in the topmost branches were almost totally brown and the younger needles tip brown to one-half brown. The lower branches showed distinct defoliation. The damage rating was raised to three.

By August, there was severe defoliation of the brown needles resulting in a very sparse crown. The current growth was at its peak, and once again, the green needles became prominent.

This is the typical progression of damage in this species although the onset of injury and the exact stage at which it leveled off varied in some cases. In two trees, exhibiting minimum damage (rating in July = 1) there was a spiral pattern of injury; however, within a branch the symptoms progressed in the pattern described above.

5.53.12 White fir

One tree each in 1.33 T/A and 2.67 T/A and three out of the five white firs in 5.33 T/A salt treatments showed moderate (rating = 2) to terminal (rating = 4) damage symptoms. The general pattern of spread of symptoms was identical to that of Jeffrey pine, basi-petally within a needle and acropetally within a branch.

The first visual symptoms were noticed in April in one of the trees receiving the highest treatment. The damage appeared among the oldest needles (over 5 years) in the lower branches and then progressed upward to the younger needles. At this point, the oldest needles were one-half green (from base to middle) and one-half brown (from tip downwards). Tip die-back had begun in the younger needles (3-5 years). The youngest needles (1-2 years) and dormant buds were unaffected.

The oldest needles, depending upon their age, turned brown and fell off in May. The younger needles, except current seasons growth, showed varying degrees of die-back ranging from tip die-back to three-quarters browning. All these needles could easily be peeled from the branches.

There was marked defoliation of all the brown needles by June. In several branches only current to three year old needles were retained. In a few of the defoliated branches the tender current growth was scorched or burned, resulting in an upward curl while the one to three year old growth remained green.

Severe defoliation continued through July and August. The scorched current season's growth succumbed. Damage progressed to the younger needles as usual in those branches where the current growth was not affected.

5.53.13 Incense cedar

Until July, only two of the four incense cedars at the highest salting rate (2.67 T/A) showed damage symptoms. The oldest foliage in the lower branches of these trees turned bronze and the branchlet tips were necrotic in May.

Distinct browning of foliage appeared in June. The lower half of the branchlets turned brown while the upper half remained green, thus conforming to the general salt damage pattern. There was no defoliation.

Damage progressed only in one tree by July, where the previous and current season's growth were also killed.

A third tree began to show symptoms of salt injury in August and this continued through September.

5.53.14 Lodgepole pine

One of the four lodgepole pines in the maximum salt treatment (2.67 T/A) showed a moderate amount of damage in July. The pattern of damage was essentially the same as in Jeffrey pine. The remainder showed no symptoms even until the end of October.

5.53.2 <u>Leaf Na and Cl Concentrations and Damage Rating</u>:

Tables 17, 19, 21 and 23 contain plant data for the salt application study for 1977 and 1978. The data presented are Na and Cl concentrations of leaf tissue and the tree damage rating; the values given are the mean values and standard errors for each treatment. Selected data are given in graphs in Fig. 7, 8, 10, 11, 13, 14, 16 and 17. Soil data are presented in Tables 18, 20, 22 and 24 and also in Figs. 9, 12, 15 and 18.

5.53.21 Jeffrey pine

Damage in 1977 appeared only in plots that received the highest level of salt (5.33 T/A). In 1978, damage appeared at lower rates but not until late in the year (see Table 17 for results).

The background leaf concentration of Na and Cl for this species are about 0.02% and 0.01% dry weight respectively. These values are for samples taken from the 0 T/A treatment. Accumulation of Na and Cl following the addition of salt at the highest rate (5.33 T/A. 1977 and 8 T/A, 1978) as a function of time is shown in Fig. 7. While the pattern of increase was somewhat irregular, both Na and Cl followed a similar course. Damage rating increased in a manner very similar to that of Na and Cl. There was no increase in Na during the first year in the lowest three application rates (0.33, 0.67, and 1.33 T/A). During the second year, increases in Na were small at these rates. Leaf Cl, however, increased gradually at these rates and then increased sharply at the 2.67 and 5.33 T/A rates. Increases in Cl at the lower application rates were substantial the second year. A marked increase in leaf Na occurred in the 5.33 T/A treatment. This is shown in Fig. 8 where Na and Cl leaf concentrations are plotted as a function of applied

Table 17. Soil Salt Application Study. Leaf sodium and chloride concentation (% DW) and damage ratings in Jeffrey pine following the addition of various rates of salt.

		Salt Treatment - Tons/A																	
1977		0			0.33			0.67			1.33			2.67			5.33		
1978		0			0.5			1			2			4			8		
	Para-	% DW		Dam-	% DW		Dam-	% DW		Dam-	% DW		Dam-	% DW		Dam-	% DW		Dam-
Date	meter	Na	Cl	age	Na	Cl	age	Na	Cl	age	Na	Cl	age	Na	Cl	age	Na	Cl	age
Jan. 77	$\bar{x}$	0.037	0.011	-	0.033	0.012	-	0.034	0.013	-	0.034	0.011	-	0.029	0.010	-	0.034	0.007	-
	$s_{\bar{x}}$	0.004	0.002	-	0.004	0.002	-	0.003	0.002	-	0.004	0.002	-	0.002	0.002	-	0.003	0.001	-
May 77	$\bar{x}$	0.013	0.011	-	0.017	0.030	-	0.016	0.039	-	0.015	0.064	-	0.025	0.112	-	0.100	0.343	0.17
	$s_{\bar{x}}$	0.001	0.003	-	0.002	0.005	-	0.002	0.013	-	0.002	0.007	-	0.002	0.027	-	0.024	0.071	0.17
June 77	$\bar{x}$	0.009	0.004	-	0.009	0.019	-	0.009	0.038	-	0.014	0.059	-	0.040	0.139	-	0.248	0.495	0.83
	$s_{\bar{x}}$	0.001	0.000	-	0.001	0.008	-	0.001	0.013	-	0.002	0.020	-	0.010	0.031	-	0.065	0.104	0.31
July 77	$\bar{x}$	0.013	0.007	-	0.011	0.031	-	0.026	0.042	-	.024	0.065	-	0.051	0.136	-	0.309	0.512	1.33
	$s_{\bar{x}}$	0.002	0.002	-	0.000	0.012	-	0.001	0.016	-	0.002	0.017	-	0.013	0.026	-	0.079	0.085	0.33
Aug. 77	$\bar{x}$	0.021	0.018	-	0.021	0.021	-	0.026	0.046	-	0.024	0.025	-	0.051	0.107	-	0.309	0.438	1.50
	$s_{\bar{x}}$	0.002	0.000	-	0.001	0.003	-	0.001	0.016	-	0.002	0.006	-	0.013	0.030	-	0.079	0.125	0.43
Sept. 77	$\bar{x}$	0.019	0.010	-	0.016	0.020	-	0.019	0.043	-	0.020	0.053	-	0.046	0.116	-	0.223	0.543	-
	$s_{\bar{x}}$	0.001	0.002	-	0.002	0.007	-	0.002	0.013	-	0.004	0.022	-	0.012	0.035	-	0.092	0.157	-
Oct. 77	$\bar{x}$	0.016	0.008	-	0.015	0.019	-	0.017	0.060	-	0.016	0.060	-	0.063	0.248	-	0.490	0.807	1.83
	$s_{\bar{x}}$	0.001	0.000	-	0.001	0.006	-	0.003	0.030	-	0.002	0.022	-	0.020	0.070	-	0.163	0.214	0.54
Jan. 78	$\bar{x}$	0.013	0.008	-	0.016	0.028	-	0.017	0.047	-	0.024	0.083	-	0.080	0.256	0	0.316	0.633	1.83
	$s_{\bar{x}}$	0.001	0.000	-	0.002	0.011	-	0.002	0.016	-	0.004	0.023	-	0.020	0.054	-	0.094	0.231	0.54
May 78	$\bar{x}$	0.031	0.026	-	0.034	0.077	-	0.039	0.116	-	0.079	0.253	-	0.097	0.357	0.5	0.352	0.846	2.67
	$s_{\bar{x}}$	0.003	0.004	-	0.004	0.015	-	0.006	0.014	-	0.019	0.060	-	0.280	0.077	0.22	0.087	0.237	0.62
June 78	$\bar{x}$	0.030	0.018	-	0.037	0.047	-	0.062	0.136	-	0.050	0.166	-	0.107	0.365	-	0.457	0.907	-
	$s_{\bar{x}}$	0.001	0.007	-	0.003	0.016	-	0.021	0.024	-	0.011	0.052	-	0.033	0.103	-	0.140	0.252	-
Sept 78	$\bar{x}$			-			-			-			0.17			0.83			2.83
	$s_{\bar{x}}$			-			-			-			0.17			0.40			0.60

Figure 7. Soil-Salt Application Study. Sodium and chloride concentrations and damage ratings for Jefferey pine as a function of time at the high salt rate. Salt Applications were 5.33 T/A in 1977 and 8 T/A in 1978.

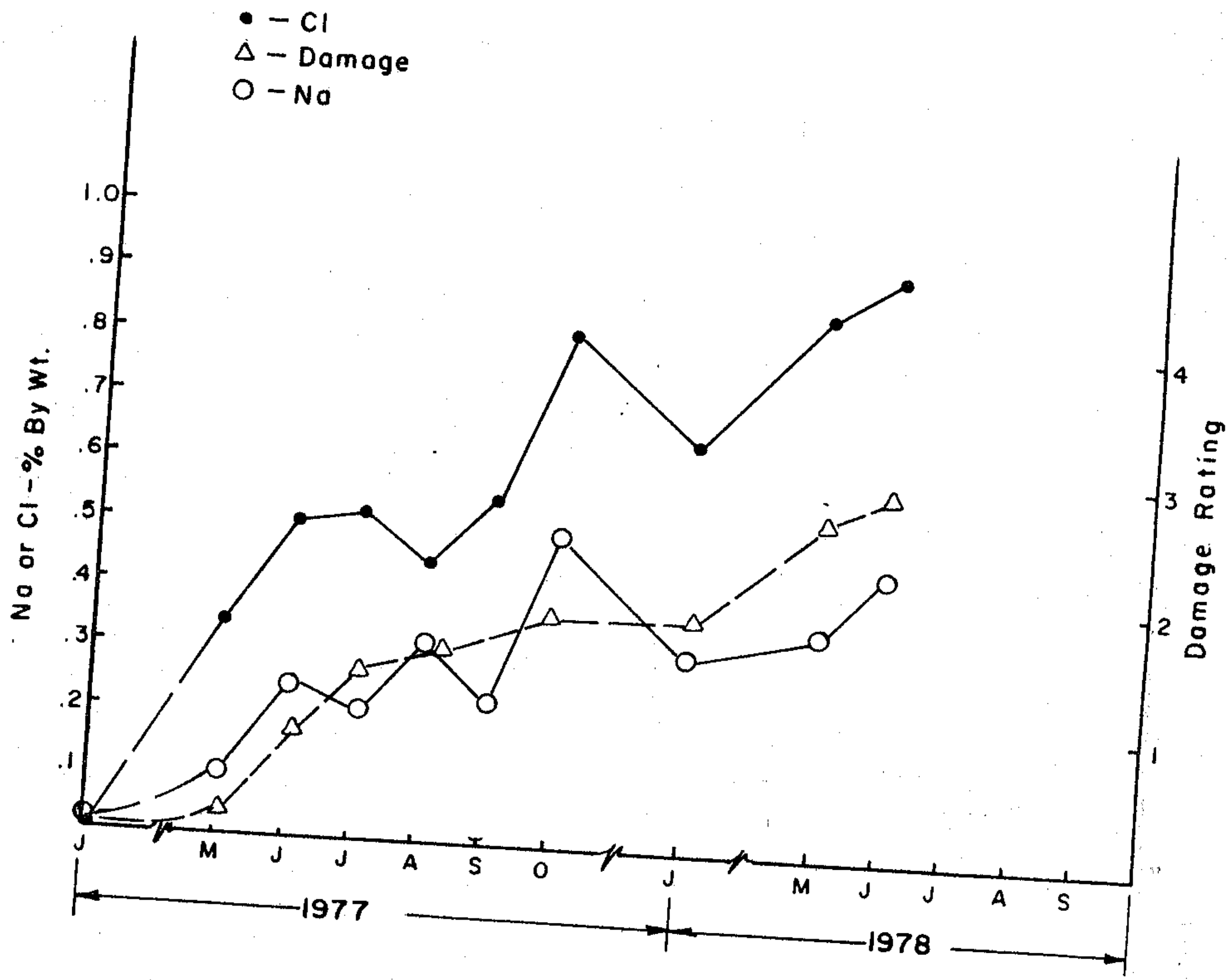
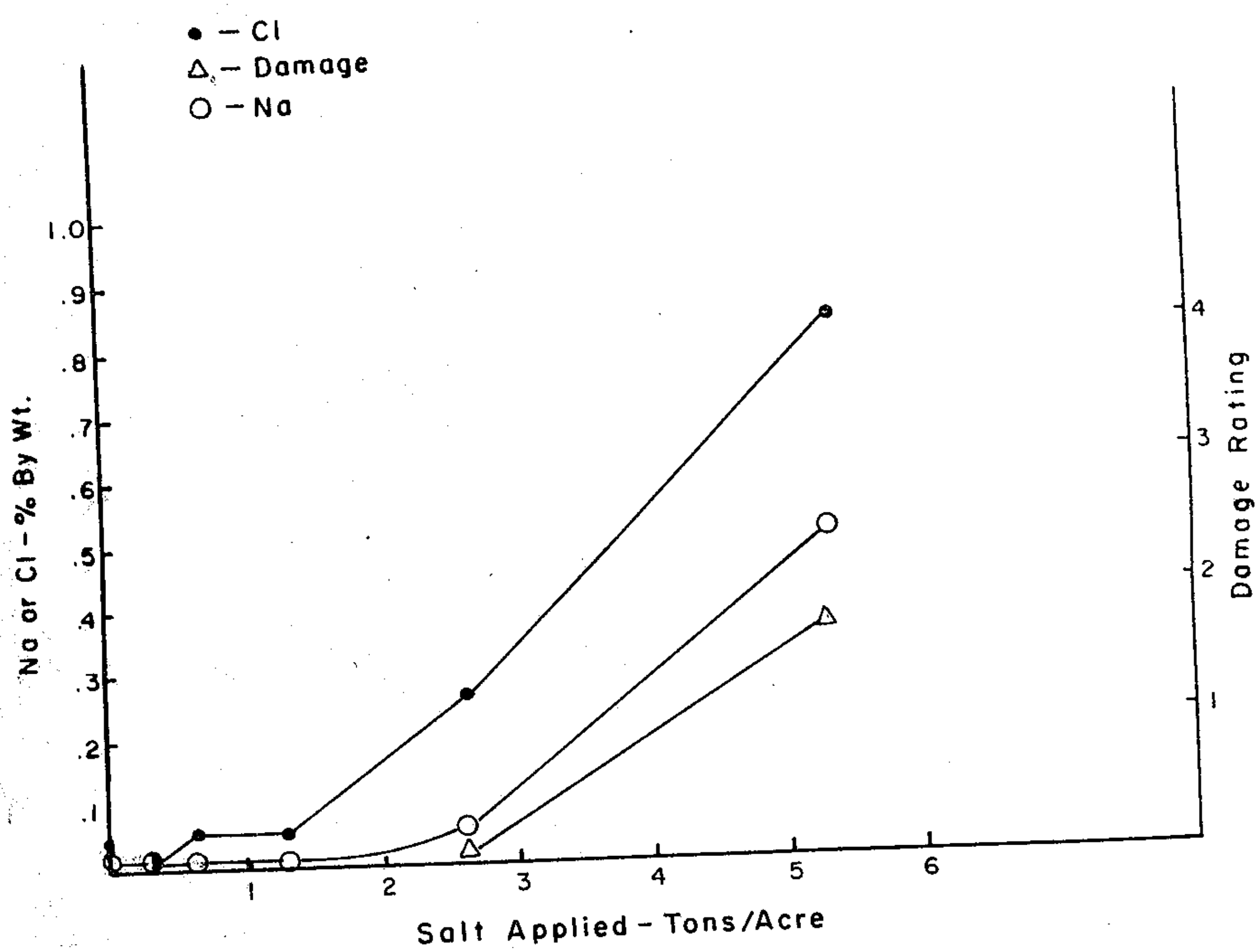


Figure 8. Soil Salt Application Study. Sodium and chloride concentrations and damage ratings for Jeffrey pine in October 1977 as a function of applied salt.



salt. At low salt application rates, Jeffrey pine appears to be a Na excluder. The data are for the October 1977 sampling only, but the pattern is typical for other months as well.

Detailed soil data are given in Table 18. It is apparent that applied salt reached a depth of 36" on all sampling occasions. During 1977, the salt remaining in the soil was much greater than that remaining in the soil in 1978. This is shown clearly in Fig. 9. The reason for the marked decrease in soil salt is most likely that 1976 and 1977 were drought years and the normal to above normal precipitation in 1978 resulted in leaching of salt from the soil profile. This indicates that salt does not accumulate but is readily leached under 'normal' precipitation.

5.53.22 White fir

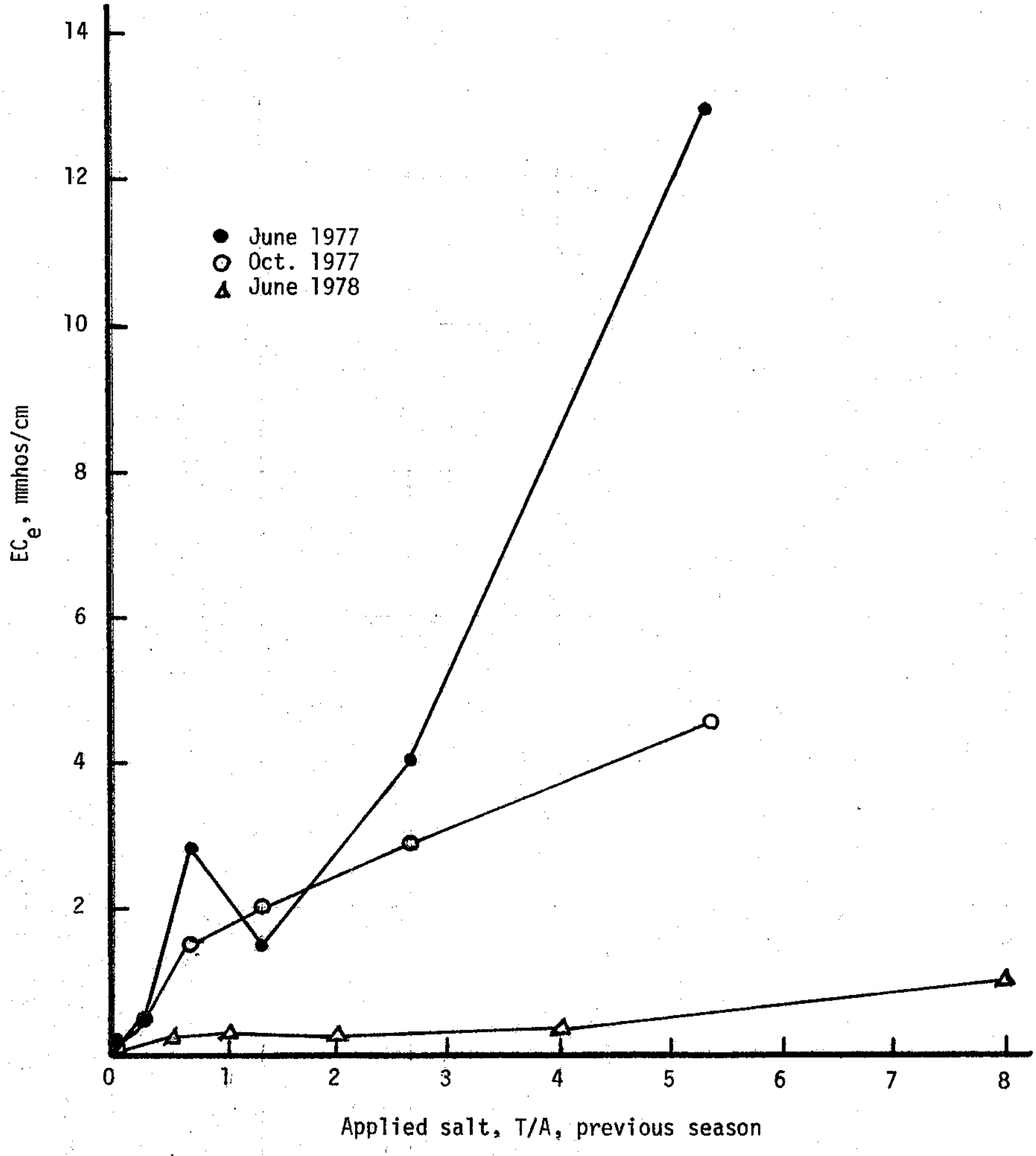
The response of white fir to controlled application of salt was similar to that of Jeffrey pine. One tree in the 1.33 T/A treatment showed severe damage symptoms and very high tissue levels of Na and Cl as early as May 1977. Because none of the other trees in this treatment behaved in this way, we concluded that there was either an error in application or that particular tree was more sensitive to salt than other specimens. In the discussion of results for this species, this tree is not included.

In general, this species appeared to be more sensitive to salt than Jeffrey pine. Three out of five trees in the 5.33 T/A treatment were killed by salt by October 1977. In 1978, damage occurred in the 2, 4 and 8 T/A treatments.

Table 18. Soil Salt Application Study. Soil EC_e (millimhos/cm), sodium and chloride (meq l^{-1}) under Jeffrey pine following the adddition of various rates of salt.

			Salt Treatment - Tons/A																	
1977			0			0.33			0.67			1.33			2.67			5.35		
1978			0			0.5			1			2			4			8		
				meq l^{-1}			meq l^{-1}			meq l^{-1}			meq l^{-1}			meq l^{-1}			meq l^{-1}	
Date	Depth	Parameter	EC_e	Na	Cl	EC_e	Na	Cl	EC_e	Na	Cl	EC_e	Na	Nl	EC_e	Na	Cl	EC_e	Na	Cl
June 77	0-1	$\bar{x}$	0.16	0.5	0.1	0.41	2.7	1.2	2.83	21.1	15.0	1.58	10.9	8.3	4.03	33.8	26.7	12.92	98.3	109.3
		$s_{\bar{x}}$	0.03	0.0	0.1	0.12	1.0	0.7	1.00	6.8	5.2	0.55	4.6	3.8	1.37	14.1	10.4	7.71	57.9	69.2
	1-2	$\bar{x}$	0.38	0.9	1.2	0.46	3.7	2.6	2.19	5.9	9.5	2.19	10.6	14.9	3.87	24.9	22.2	11.11	91.6	87.3
		$s_{\bar{x}}$	0.18	0.5	1.0	0.11	1.2	1.4	0.89	1.5	3.4	0.78	3.6	5.8	1.26	9.0	7.5	5.85	53.5	54.7
	2-3	$\bar{x}$	0.19	0.6	0.3	0.39	1.9	1.5	0.59	2.2	2.5	0.94	5.4	4.1	2.42	8.5	14.7	5.39	31.6	30.9
		$s_{\bar{x}}$	0.09	0.2	0.3	0.11	1.0	0.6	0.09	0.4	0.4	0.12	1.2	0.6	0.45	1.9	2.5	1.27	5.8	9.5
Oct. 77	0-1	$\bar{x}$	0.17	0.4	0.3	0.50	4.7	3.2	1.54	14.4	13.7	2.06	15.7	18.9	2.90	29.3	23.5	4.56	41.4	41.4
		$s_{\bar{x}}$	0.05	0.1	0.1	0.12	1.4	1.4	0.53	4.8	4.8	0.79	4.6	8.3	1.12	10.8	10.1	1.27	11.7	12.3
	1-2	$\bar{x}$	0.09	0.5	0.2	0.44	2.6	3.1	1.66	13.0	13.9	2.03	19.2	17.0	3.40	40.0	37.0	5.86	40.2	50.3
		$s_{\bar{x}}$	0.02	0.2	0.0	0.11	0.5	0.8	0.67	4.7	6.0	0.75	8.2	6.7	1.29	23.3	22.3	2.25	10.8	19.5
	2-3	$\bar{x}$	0.09	0.4	0.3	0.34	2.4	2.3	1.56	12.3	13.8	1.60	12.8	13.1	4.27	38.3	36.9	5.12	41.0	48.2
		$s_{\bar{x}}$	0.02	0.0	0.1	0.06	0.9	0.7	0.50	4.9	4.7	0.73	7.0	6.5	0.65	4.2	6.6	1.45	11.1	14.5
June 78	0-1	$\bar{x}$	0.09	0.3	0.1	0.29	3.0	0.6	0.32	3.3	0.5	0.26	2.4	0.2	0.34	2.9	0.6	1.02	9.8	8.4
		$s_{\bar{x}}$	0.02	0.0	0.0	0.08	0.9	0.2	0.06	0.8	0.2	0.06	0.6	0.1	0.12	1.5	0.3	0.43	4.6	5.0
	1-2	$\bar{x}$	0.11	0.5	0.2	0.25	2.1	0.6	0.33	3.1	1.9	0.38	3.8	2.5	1.72	11.9	15.5	1.43	12.8	10.9
		$s_{\bar{x}}$	0.03	0.1	0.1	0.07	0.5	0.1	0.09	0.7	1.2	0.10	0.6	1.5	1.53	10.2	15.0	0.56	4.3	4.7
	2-3	$\bar{x}$	0.07	0.3	0.1	0.24	1.9	1.3	0.34	3.3	2.0	0.34	3.7	2.5	1.12	11.0	9.5	2.84	25.9	26.8
		$s_{\bar{x}}$	0.01	0.1	0.0	0.04	0.4	0.6	0.19	2.0	1.7	0.08	0.8	0.7	0.83	8.6	8.5	1.58	13.9	15.6

Figure 9. Soil Salt Application Study. Soil EC_e (millimhos/cm) in upper one foot of profile under Jeffrey pine as a function of salt applied the previous season.



Using the background level of 0.02% dry weight Na as a reference concentration, it is apparent that very little Na accumulated in leaf tissue except at the 2.67 and 5.33 T/A rates in 1977 and 4 and 8 T/A rates in 1978 (Table 19). As with Jeffrey pine, Cl accumulation was much greater than Na. The background Cl concentration was 0.04% dry weight. Cl concentration had reached 0.08% dry weight in the lowest application rate (0.33 T/A) as early as May 1977 and at the highest rate (5.33 T/A) tissue concentrations had risen to 1.3% Cl, dry weight, by September 1977.

The time course of Na and Cl accumulation in the highest salt application treatment (5.33 T/A) is shown in Fig. 10. The concentration of both elements increase with time and reached a maximum by October 1977. Mean damage rating increased in a fashion similar to that of Cl tissue concentration. At the lower rates of salt application (0.33, 0.67, 1.33 and 2.67 T/A), Cl absorption was much greater than that of Na (Fig. 11). This reduced tendency of Na accumulation compared to Cl suggests that Na is excluded by this species relative to Cl absorption.

The soil salt concentration increased more or less linearly with the increased in applied salt (Table 20, Fig. 12). The salt was distributed fairly evenly in the first three feet of the soil profile. Data in Fig. 12 show that the salt content of the soil was much lower in 1978 than in 1977 owing to the higher precipitation in 1978 than in 1977.

5.53.23 Incense cedar

Prior to this study it was felt that incense cedar and lodgepole pine were very sensitive to salt and that

Table 19. Soil Salt Application Study. Leaf sodium and chloride concentration (% DW) and damage ratings in white fir following the addition of various rates of salt.

		Salt Treatment - Tons/A																	
1977		0			0.33			0.67			1.33			2.67			5.33		
1978		0			0.5			1			2			4			8		
	Para-	% DW		Dam-	% DW		Dam-	% DW		Dam-	% DW		Dam-	% DW		Dam-	% DW		Dam-
Date	meter	Na	Cl	age	Na	Cl	age	Na	Cl	age	Na	Cl	age	Na	Cl	age	Na	Cl	age
Jan. 77	$\bar{x}$	0.037	0.017		0.042	0.032		0.032	0.023		0.039	0.027		0.036	0.017		0.038	0.011	
	$s_{\bar{x}}$	0.005	0.005	-	0.005	0.007		0.003	0.002		0.004	0.005		0.004	0.003		0.004	0.002	
May 77	$\bar{x}$	0.013	0.044	-	0.014	0.079	-	0.017	0.119	-	0.011	0.103	-	0.026	0.196	-	0.144	0.460	0.80
	$s_{\bar{x}}$	0.002	0.008	-	0.003	0.019	-	0.004	0.019	-	a	a	-	0.001	0.028	-	0.038	0.107	0.37
June 77	$\bar{x}$	0.009	0.044	-	0.008	0.086	-	0.009	0.159	-	0.011	0.165	-	0.053	0.341	0.40	0.162	0.550	1.40
	$s_{\bar{x}}$	0.001	0.008	-	0.001	0.027	-	0.001	0.030	-	a	a	-	0.027	0.052	0.40	0.052	0.126	0.75
July 77	$\bar{x}$	0.016	0.050	-	0.015	0.135	-	0.013	0.182	-	0.017	0.192	-	0.058	0.371	0.60	0.230	0.805	1.60
	$s_{\bar{x}}$	0.003	0.011	-	0.003	0.051	-	0.001	0.050	-	a	a	-	0.020	0.048	0.60	0.109	0.182	0.75
Aug. 77	$\bar{x}$	0.022	0.025	-	0.021	0.117	-	0.030	0.214	-	0.025	0.207	-	0.195	0.541	0.60	0.572	1.074	2.00
	$s_{\bar{x}}$	0.001	0.004	-	0.002	0.048	-	0.005	0.042	-	a	a	-	0.120	0.206	0.60	0.259	0.291	0.84
Sept. 77	$\bar{x}$	0.017	0.055		0.020	0.177		0.023	0.240		0.122	0.239		0.109	0.569		0.511	1.275	
	$s_{\bar{x}}$	0.003	0.010		0.002	0.057		0.002	0.047		a	a		0.048	0.064		0.242	0.380	
Oct. 77	$\bar{x}$	0.016	0.029	-	0.015	0.147	-	0.027	0.284	-	0.031	0.260	-	0.130	0.564	1.20	0.551	1.346	2.40
	$s_{\bar{x}}$	0.003	0.001	-	0.002	0.047	-	0.006	0.072	-	a	a	-	0.064	0.070	0.74	0.212	0.374	0.98
Jan. 78	$\bar{x}$	0.016	0.033	-	0.017	0.182	-	0.016	0.316	-	0.017	0.339	0.2	0.122	0.644	1.40	0.432	1.305	2.80
	$s_{\bar{x}}$	0.003	0.006	-	0.003	0.057	-	0.001	0.037	-	a	a	a	0.043	0.115	0.68	0.123	0.180	0.74
May 78	$\bar{x}$	0.020	0.050	-	0.035	0.213	-	0.054	0.442	0.400	0.042	0.338	0.50	0.239	1.063	2.20	-	-	3.00
	$s_{\bar{x}}$	0.002	0.003	-	0.004	0.062	-	0.016	0.092	0.245	0.010	0.092	a	0.078	0.191	0.58	-	-	0.63
June 78	$\bar{x}$	0.020	0.045		0.027	0.257		0.053	0.450		0.061	0.298		0.090	0.769		-	-	
	$s_{\bar{x}}$	0.002	0.008		0.005	0.078		0.022	0.078		0.031	0.077		0.043	0.124		-	-	
Sept. 78	$\bar{x}$			-			-			0.40			0.75			2.40			3.60
	$s_{\bar{x}}$			-			-			0.25			-			0.68			0.24

[a] Means recomputed without data of one aberrant tree, $s_{\bar{x}}$ unavailable.

Figure 10. Soil Salt Application Study. Sodium and chloride concentrations and damage ratings for white fir as a function of time at the high salt rate. Salt applications were 5.33 T/A in 1977 and 8 T/A in 1978.

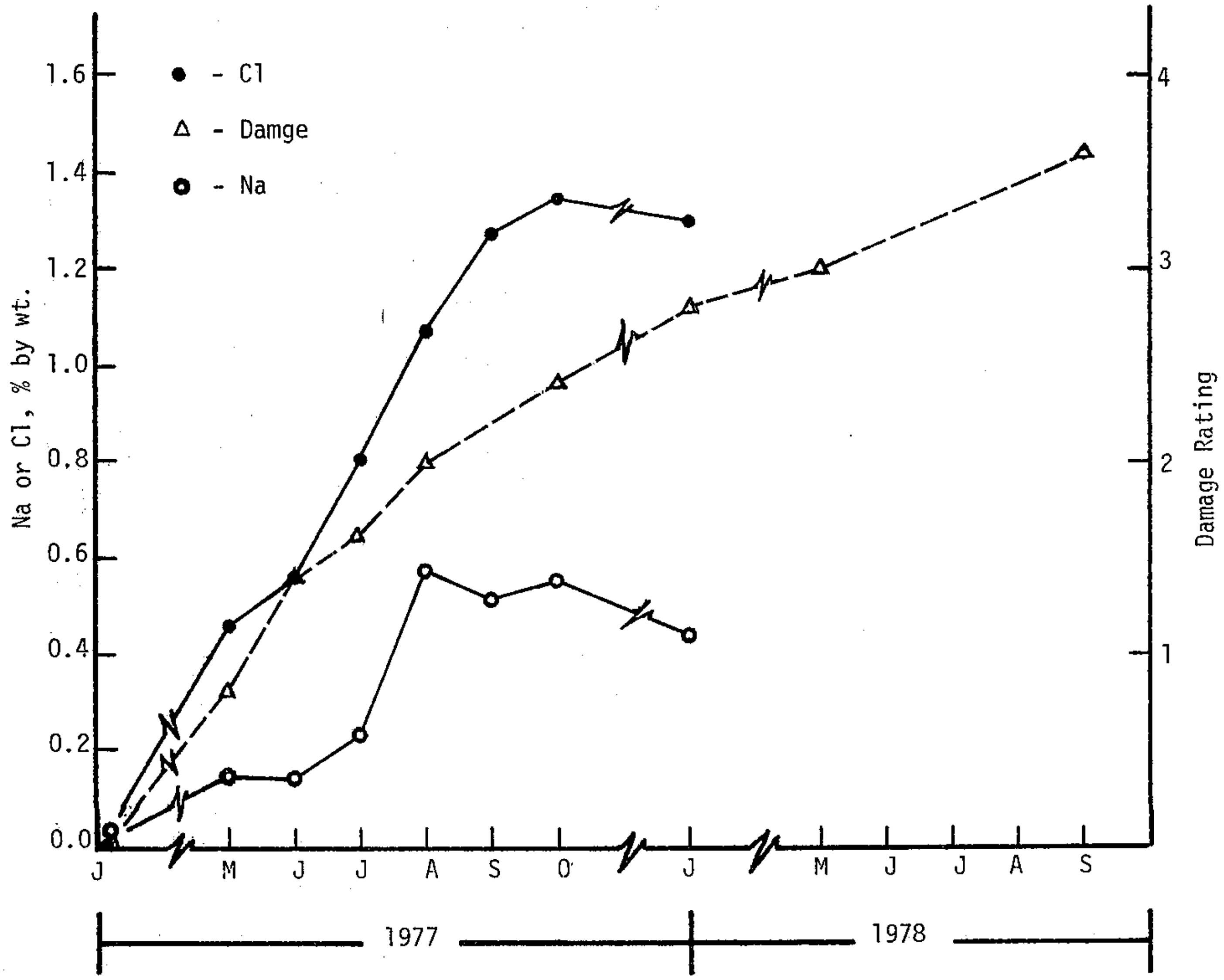


Figure 11. Soil Salt Application Study. Sodium and chloride concentrations and damage ratings for white fir on October 1977 as a function of applied salt.

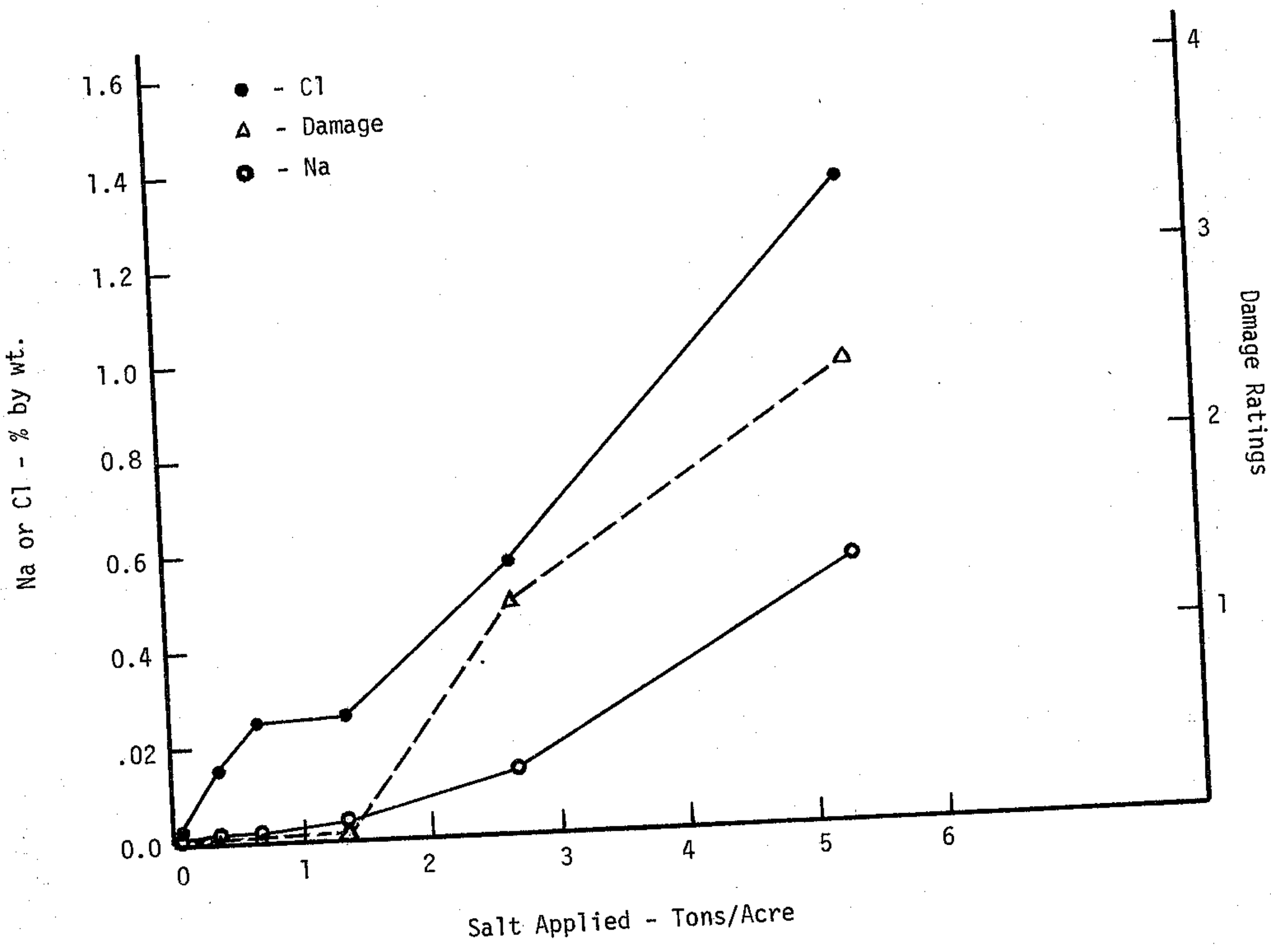
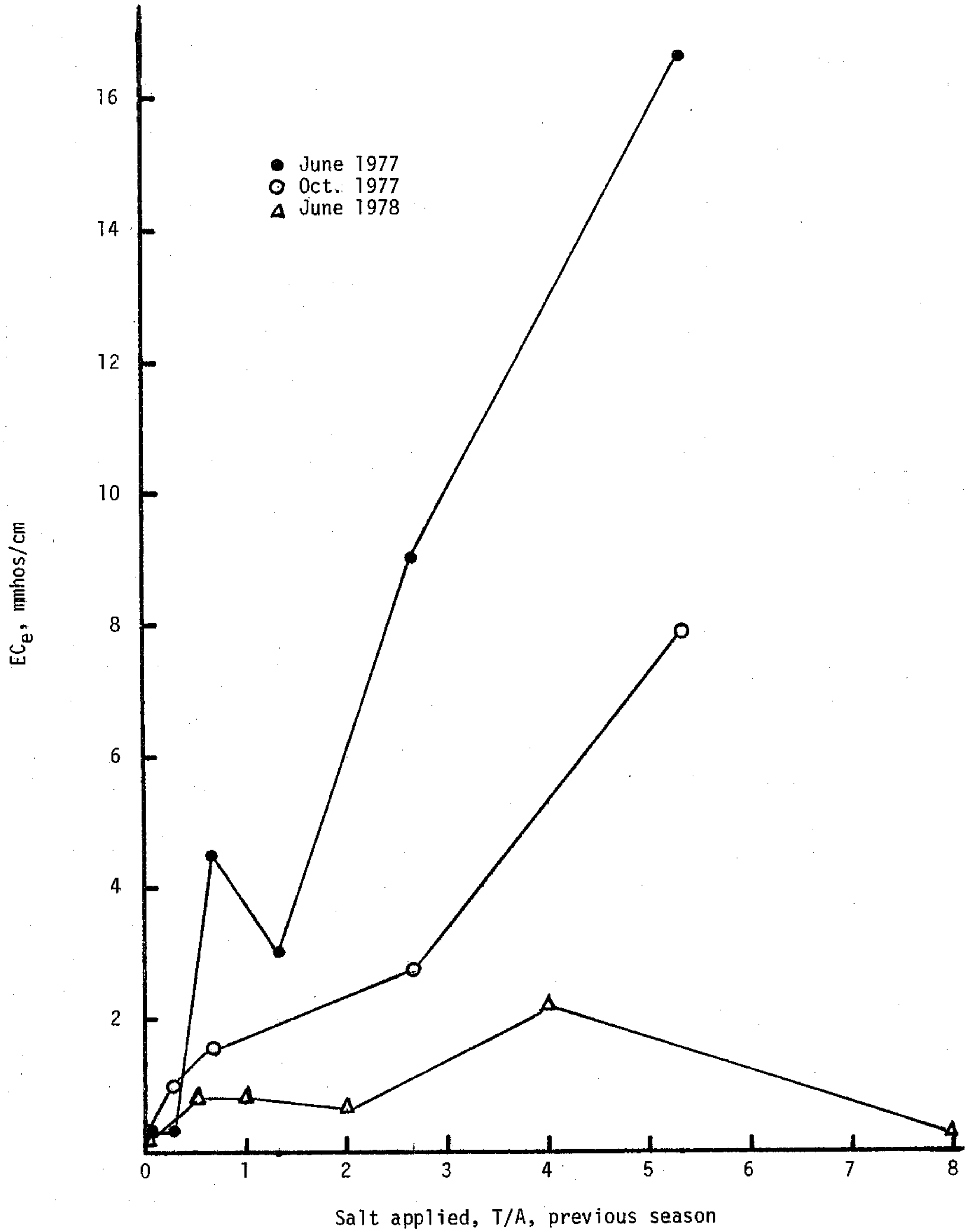


Table 20. Soil Salt Application Study. Soil EC_e (millimhos/cm), sodium and chlroide (meq 1^{-1}) under white fir following the addition of various rates of salt.

Date	Depth	Parameter	Salt Treatments - Tons/A																	
1977			0			0.33			0.67			1.33			2.67			5.33		
1978			0			0.5			1			2			4			8		
			EC_e	meq 1^{-1} Na	meq 1^{-1} Cl	EC_e	meq 1^{-1} Na	meq 1^{-1} Cl	EC_e	meq 1^{-1} Na	meq 1^{-1} Cl	EC_e	meq 1^{-1} Na	meq 1^{-1} Cl	EC_e	meq 1^{-1} Na	meq 1^{-1} Cl	EC_e	meq 1^{-1} Na	meq 1^{-1} Cl
June 77	0-1	$\bar{x}$	0.29	0.8	0.8	0.29	1.9	2.4	4.49	34.1	26.7	3.07	22.8	19.8	9.04	68.9	65.0	16.61	138.0	148.1
		$s_{\bar{x}}$	0.08	0.1	0.4	0.11	0.8	1.1	1.79	13.5	10.7	1.27	8.6	9.0	4.30	35.5	34.3	2.82	17.9	18.4
	1-2	$\bar{x}$	0.18	0.6	0.4	0.56	1.9	3.4	4.88	36.1	34.1	2.50	10.4	11.1	7.42	50.2	56.5	11.89	76.0	62.1
		$s_{\bar{x}}$	0.02	0.1	0.1	0.22	0.8	1.2	1.34	7.8	11.1	0.78	1.9	2.4	2.22	14.5	24.6	3.15	9.7	4.9
	2-3	$\bar{x}$	0.13	0.6	0.1	0.62	2.1	2.5	2.67	12.3	17.2	1.44	9.1	8.2	4.08	15.5	18.0	8.62	57.2	66.1
		$s_{\bar{x}}$	0.04	<0.1	0.1	0.11	0.7	1.0	1.31	6.5	9.9	0.67	3.7	5.2	0.67	4.5	5.8	2.39	18.0	29.2
Oct. 77	0-1	$\bar{x}$	0.27	0.8	0.5	1.04	7.4	8.3	1.61	13.9	14.6	1.92	16.9	19.6	2.77	26.3	21.8	7.89	70.7	71.6
		$s_{\bar{x}}$	0.06	0.1	0.1	0.48	3.2	4.5	0.50	5.5	6.0	0.54	4.6	5.3	0.24	0.9	2.8	0.85	4.1	8.5
	1-2	$\bar{x}$	0.26	0.8	0.3	0.79	3.9	5.8	1.48	12.3	12.7	2.78	21.1	22.6	3.45	30.3	27.2	11.82	108.5	114.0
		$s_{\bar{x}}$	0.13	0.2	0.2	0.29	1.5	2.1	0.70	7.9	6.2	0.79	7.4	8.2	1.44	14.7	12.4	2.61	26.2	36.0
	2-3	$\bar{x}$	0.25	0.6	0.4	1.05	5.4	8.1	1.28	11.3	9.5	2.82	23.4	27.0	2.00	16.7	18.2	9.83	83.0	82.7
		$s_{\bar{x}}$	0.04	0.1	0.1	0.52	2.2	4.0	0.17	2.4	1.3	0.69	9.7	8.7	0.31	3.9	2.8	1.97	20.5	16.6
June 78	0-1	$\bar{x}$	0.16	0.7	0.3	0.85	9.0	7.9	0.82	7.1	5.3	0.65	4.5	5.1	2.28	18.1	14.9	0.26	2.7	0.7
		$s_{\bar{x}}$	0.01	0.1	0.1	0.24	2.5	4.5	0.22	1.7	2.0	0.25	2.5	3.1	1.80	13.3	12.6	0.14	1.5	0.5
	1-2	$\bar{x}$	0.12	0.5	0.3	0.57	4.9	3.4	1.85	14.9	15.2	0.81	4.0	5.4	1.99	19.6	16.7	0.68	6.8	4.0
		$s_{\bar{x}}$	0.03	0.1	0.1	0.31	2.3	2.4	0.88	7.7	8.2	0.43	0.7	3.6	1.28	13.9	12.3	0.51	5.1	3.3
	2-3	$\bar{x}$	0.14	0.6	0.2	0.78	7.5	7.1	0.99	7.6	7.7	1.67	10.9	16.5	2.42	19.6	21.6	0.45	5.5	2.1
		$s_{\bar{x}}$	0.02	0.1	0.1	0.18	1.6	3.0	0.35	1.6	3.5	1.41	8.4	14.8	1.30	9.2	13.1	0.33	4.3	1.8

Figure 12. Soil Salt Application Study. Soil EC_e (millimhos/cm) in upper one foot of profile under white fir as a function of salt applied the previous season.



sufficient information regarding their response to salt application could be obtained by using lower rates of salt application. Thus, the highest rate of 5.33 T/A (1977) and 8 T/A (1978) was eliminated for these species.

In 1977, damage occurred only in the 2.67 T/A treatment but in 1978, damage was present in both the 2 and 4 T/A treatments. The data did not confirm the assumption that incense cedar was more sensitive to salt than the other species.

This species readily absorbs Cl, but appears to exclude Na. This is suggested by data in Table 21 and in Figs. 13 and 14. In Fig. 13, Cl content of the leaf tissue increases steadily with time and at a rate about 10 times greater than that of Na. Chloride and Na accumulation are sharply contrasted in Fig. 14. Here we note that Cl uptake is much greater than that of Na. As with Jeffrey pine (at low salt rates), and white fir, incense cedar appears to have the ability to exclude Na uptake relative to Cl uptake; thus, Cl is probably mainly responsible for damage in this species.

The soil salt levels found in June and October 1977 were very similar to those found for Jeffrey pine for the same rates (0-2.67 T/A) (Table 22). In 1978, the soil salt levels were significantly lower than those of 1977, presumably due to greater leaching (Fig. 15).

5.53.24 Lodgepole pine

Damage was negligible in this species. We believe that this is due to the very low level of salt in the treated plots and not due to this species being less sensitive to

Table 21. Soil Salt Application Study. Leaf sodium and chloride concentration (% DW) and damage ratings in incense cedar following the addition of various rates of salt.

		Salt Treatment - Tons/A														
1977		0			0.33			0.67			1.33			2.67		
1978		0			0.5			1			2			4		
		% DW			% DW			% DW			% DW			% DW		
Date	Parameter	Na	Cl	Damage	Na	Cl	Damage	Na	Cl	Damage	Na	Cl	Damage	Na	Cl	Damage
Jan. 77	$\bar{x}$	0.020	0.023		0.025	0.038		0.020	0.042		0.024	0.036		0.023	0.043	
	$s_{\bar{x}}$	0.002	0.004		0.002	0.009		0.002	0.008		0.001	0.004		0.001	0.011	
May 77	$\bar{x}$	0.011	0.049		0.028	0.092		0.019	0.104		0.019	0.116		0.046	0.254	
	$s_{\bar{x}}$	0.001	0.012		0.007	0.008		0.008	0.009		0.005	0.015		0.010	0.058	
June 77	$\bar{x}$	0.015	0.014	-	0.020	0.065	-	0.023	0.092	-	0.030	0.127	-	0.079	0.397	0.50
	$s\bar{x}$	0.004	0.007	-	0.002	0.013	-	0.008	0.015	-	0.006	0.009	-	0.043	0.166	0.29
July 77	$\bar{x}$	0.014	0.022	-	0.016	0.101	-	0.016	0.131	-	0.018	0.200	-	0.072	0.408	0.75
	$s_{\bar{x}}$	0.002	0.002	-	0.003	0.024	-	0.002	0.032	-	0.003	0.037	-	0.049	0.132	0.48
Aug. 77	$\bar{x}$	0.014	0.025	-	0.017	0.106	-	0.021	0.186	-	0.017	0.249	-	0.037	0.530	0.75
	$s_{\bar{x}}$	0.001	0.004	-	0.000	0.025	-	0.001	0.058	-	0.002	0.058	-	0.025	0.125	0.48
Sept. 77	$\bar{x}$	0.014	0.022		0.018	0.122		0.021	0.253		0.018	0.366		0.025	0.525	
	$s_{\bar{x}}$	0.002	0.006		0.002	0.027		0.003	0.052		0.002	0.089		0.006	0.081	
Oct. 77	$\bar{x}$	0.017	0.021	-	0.020	0.149	-	0.025	0.286	-	0.031	0.425	-	0.058	0.785	1.25
	$s_{\bar{x}}$	0.002	0.009	-	0.002	0.020	-	0.003	0.055	-	0.005	0.141	-	0.013	0.203	0.63
Jan. 78	$\bar{x}$	0.016	0.046	-	0.022	0.186	-	0.027	0.297	-	0.029	0.679	0.25	0.060	0.848	1.75
	$s_{\bar{x}}$	0.003	0.006	-	0.002	0.041	-	0.003	0.102	-	0.005	0.242	0.25	0.025	0.121	0.48
May 78	$\bar{x}$	0.014	0.104	-	0.022	0.206	-	0.035	0.387	-	0.032	0.866	1.25	0.114	1.001	2.25
	$s_{\bar{x}}$	0.004	0.016	-	0.001	0.033	-	0.011	0.074	-	0.002	0.268	0.63	0.062	0.249	0.75
June 78	$\bar{x}$	0.016	0.055		0.030	0.193		0.028	0.319		0.036	0.653		0.113	1.043	
	$s_{\bar{x}}$	0.002	0.011		0.005	0.038		0.002	0.067		0.004	0.088		0.066	0.223	
Sept. 78	$\bar{x}$			-			-			-			1.50			2.50
	$s_{\bar{x}}$			-			-			-			.50			0.87

Figure 13. Soil-Salt Application Study. Sodium and chloride concentrations and damage ratings for incense cedar as a function of time at the high salt rate. Salt applications were 2.67 T/A in 1977 and 4 T/A in 1978.

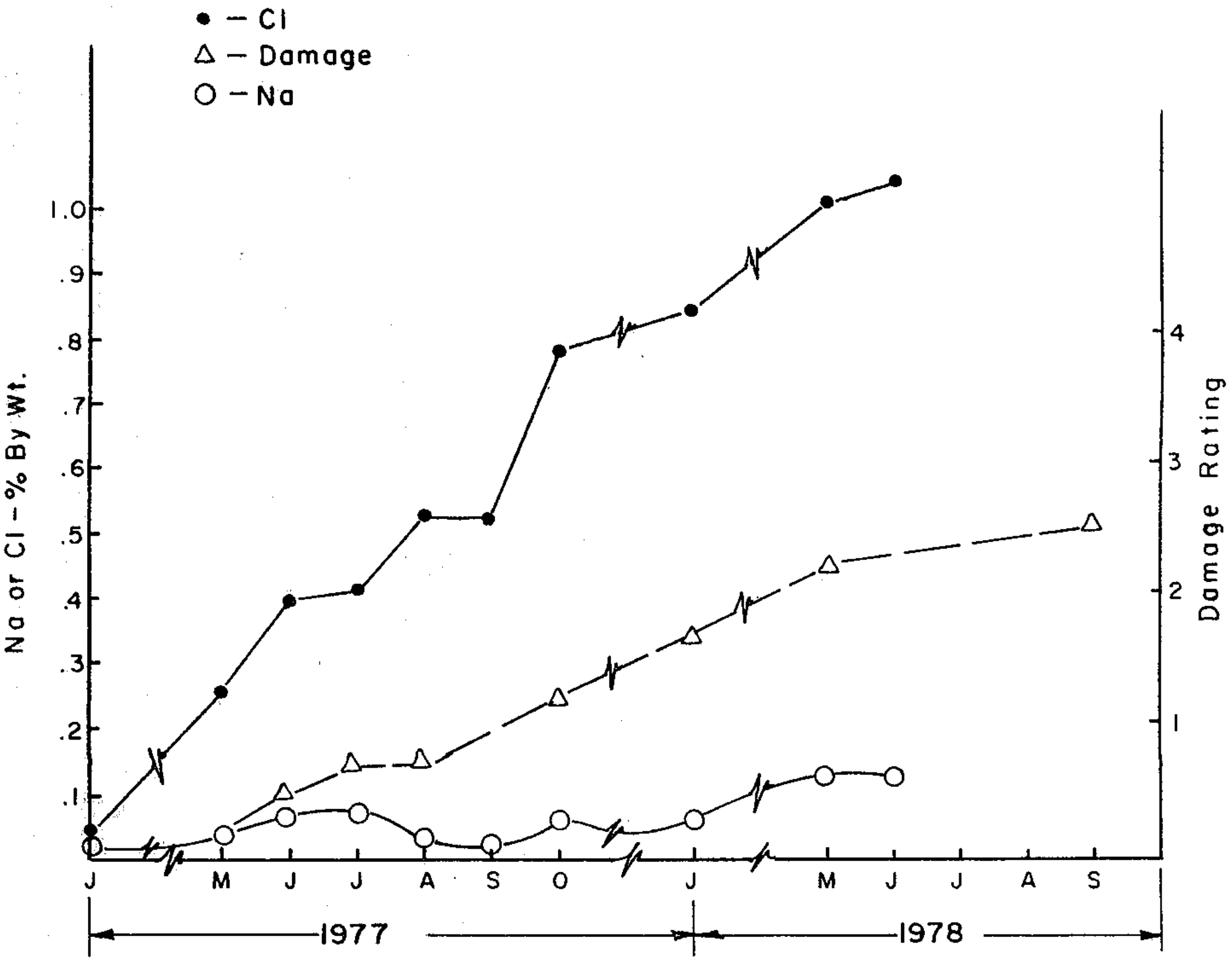


Figure 14. Soil Salt Application Study. Sodium and chloride concentrations and damage ratings for incense cedar in October 1977 as a function of applied salt.

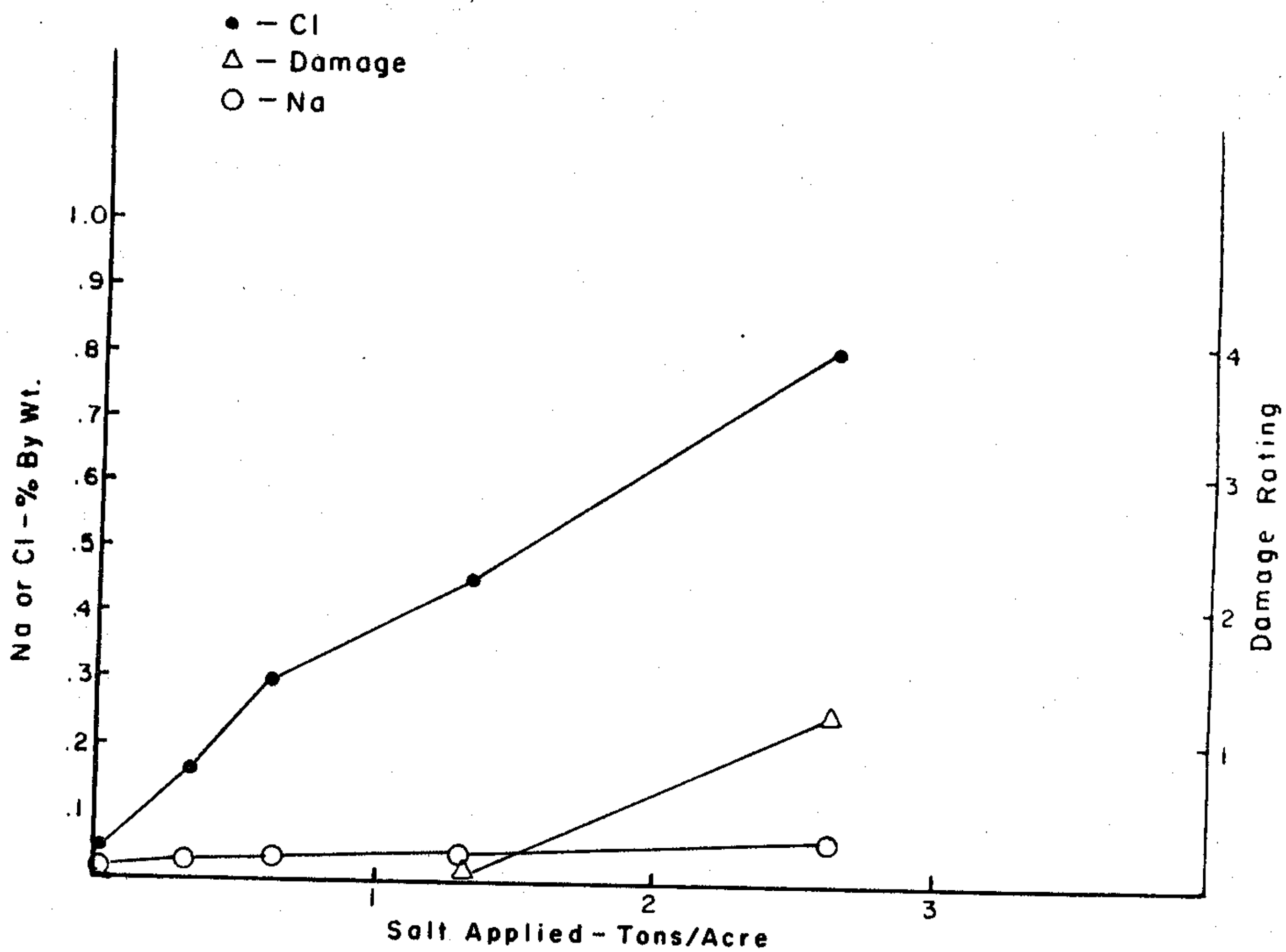
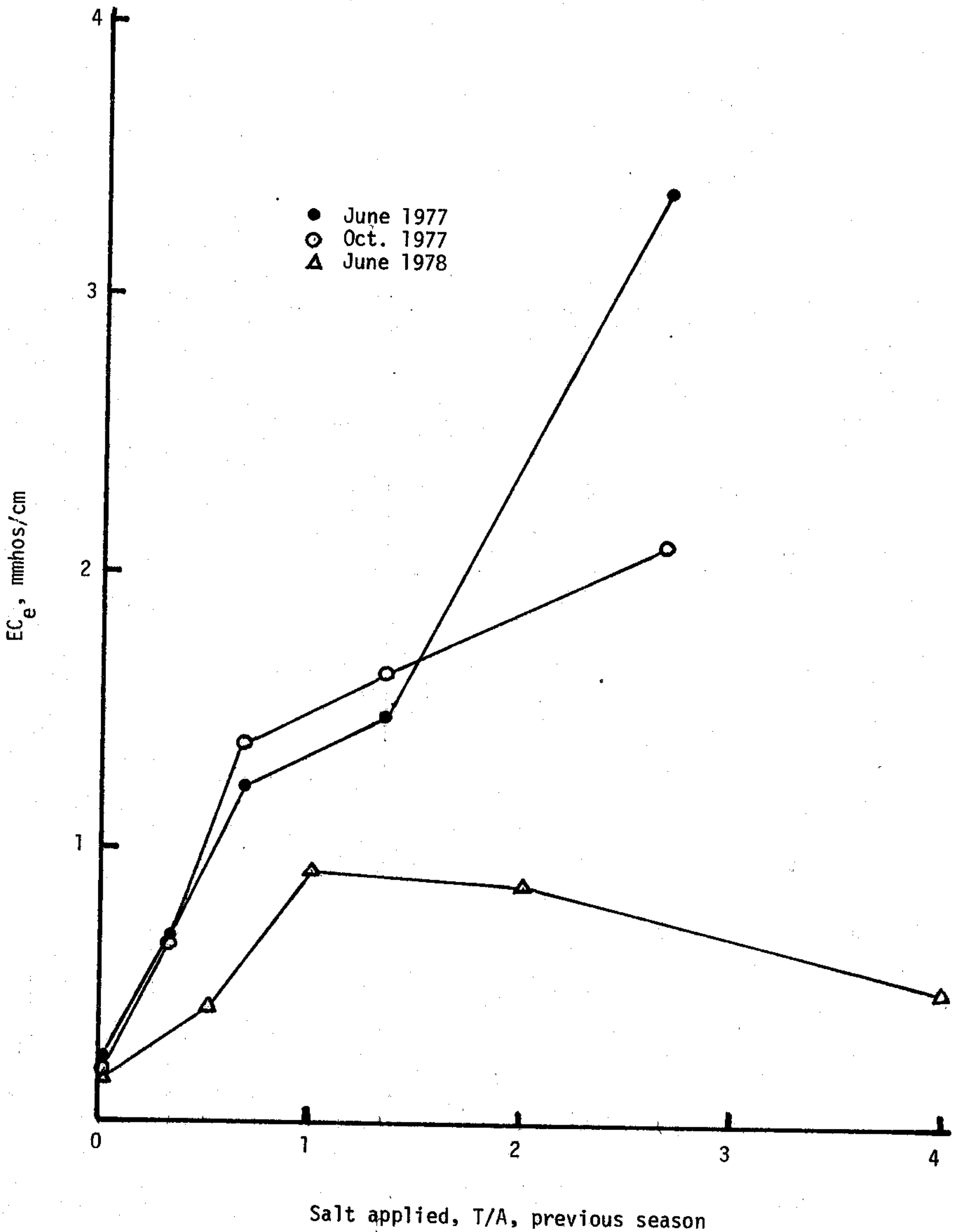


Table 22. Soil Salt Application Study. Soil EC_e (millimhos/cm), sodium and chloride (meq l^{-1}) under incense cedar following the addition of various rates of salt.

			Salt Treatments - Tons/A														
1977			0			0.33			0.67			1.33			2.67		
1978			0			0.5			1			2			4		
				meq l^{-1}			meq l^{-1}			meq l^{-1}			meq l^{-1}			meq l^{-1}	
Date	Depth	Parameter	EC_e	Na	Cl	EC_e	Na	Cl	EC_e	Na	Cl	EC_e	Na	Cl	EC_e	Na	Cl
June 77	0-1	$\bar{x}$	0.24	0.6	0.3	0.68	5.5	5.9	1.24	6.5	6.7	1.48	9.6	8.6	3.39	28.6	23.6
		$s_{\bar{x}}$	0.10	0.1	0.2	0.11	1.1	3.8	0.90	5.7	6.3	0.90	3.6	6.6	0.26	6.0	<0.1
	1-2	$\bar{x}$	0.18	0.6	0.4	0.71	3.9	3.6	1.71	7.0	11.2	1.36	12.1	7.4	3.15	12.0	11.4
		$s_{\bar{x}}$	0.02	0.1	0.2	0.23	1.3	1.5	1.38	5.8	10.0	0.18	1.1	0.8	1.41	7.5	7.2
	2-3	$\bar{x}$	0.26	0.7	0.2	0.82	3.1	3.2	1.50	4.4	10.2	2.72	11.7	11.2	1.70	3.6	9.8
		$s_{\bar{x}}$	0.04	0.2	0.1	0.02	0.7	0.1	1.14	3.4	9.3	1.29	2.5	3.4	0.80	1.5	3.8
Oct. 77	0-1	$\bar{x}$	0.18	0.4	0.2	0.66	6.2	4.2	1.39	11.6	10.0	1.65	12.2	10.8	2.12	22.5	19.4
		$s_{\bar{x}}$	0.02	0.2	0.1	0.29	1.7	2.8	1.12	8.8	8.5	1.06	5.4	7.9	0.33	4.2	7.4
	1-2	$\bar{x}$	0.13	0.4	0.2	0.92	6.0	6.2	1.07	7.7	9.6	3.13	19.2	24.4	4.95	40.6	44.8
		$s_{\bar{x}}$	0.04	0.1	0.0	0.63	3.6	4.5	0.74	4.9	6.6	2.44	12.1	19.7	0.19	1.3	5.8
	2-3	$\bar{x}$	0.12	0.5	0.2	0.70	4.4	5.1	0.56	3.2	4.0	2.53	21.0	21.4	2.13	16.4	17.8
		$s_{\bar{x}}$	0.01	0.1	0.1	0.20	1.9	2.0	0.44	2.3	3.9	1.33	12.0	12.1	1.33	13.0	12.8
June 78	0-1	$\bar{x}$	0.15	0.4	0.3	0.42	3.8	1.7	0.93	9.8	3.8	0.88	9.0	2.7	0.49	5.0	1.7
		$s_{\bar{x}}$	0.05	0.2	0.1	0.20	1.8	1.0	0.13	1.8	1.7	0.27	2.7	1.0	0.15	1.7	1.0
	1-2	$\bar{x}$	0.11	0.4	0.1	0.30	2.4	1.4	1.22	12.1	11.3	0.41	5.2	1.5	0.45	4.0	2.5
		$s_{\bar{x}}$	0.01	0.0	0.0	0.10	0.7	0.4	1.05	10.7	10.5	0.03	0.7	0.2	0.05	0.7	0.4
	2-3	$\bar{x}$	0.09	0.5	0.3	0.25	1.7	0.7	1.61	12.2	12.3	0.30	4.3	1.7	0.50	2.9	2.3
		$s_{\bar{x}}$	0.01	0.1	0.1	0.10	0.8	0.3	0.84	8.6	8.2	0.07	1.7	0.9	0.02	0.6	0.9

Figure 15. Soil Salt Application Study. Soil EC_e (millimhos/cm) in upper one foot of profile under incense cedar as a function of salt applied the previous season.



salt. The soil salt levels found in June 1977 were much lower than anticipated (Fig. 18). The maximum levels (Table 24) found were 1.5 mmhos/cm, much lower than the levels found for incense cedar, Jeffrey pine and white fir for the same application rates. The reason for lower salt found under lodgepole pine is because of higher leaching that occurred where lodgepole grew. It was present only on site 1 and trees were immediately adjacent to a fire trail into which snow drifted and thus, snow depth was much deeper than around the other species. Very little Na and Cl accumulated in the leaves of lodgepole pine except for the highest application rates (1.33 and 2.67 T/A) (Table 23, Figs. 16 and 17) in 1977 or 1978. Sodium did not accumulate much except at the highest rate of applied salt (Fig. 17). Where Na and Cl accumulation are plotted as a function of time for the 2.67 T/A treatment (Fig. 16), the rate of accumulation of both ions is very similar. In any case, too little Na or Cl was absorbed to cause much damage.

5.53.25 Relation between Na and Cl tissue concentration and damage rating

A correlation between tree damage rating and Cl and Na tissue concentrations was found for three of the four species tested. Damage in lodgepole pine was too low to obtain a correlation.

The correlation was obtained in the following way: the Na or Cl tissue concentration of trees having the same damage rating, regardless of treatment or length of treatment, was plotted against damage rating. In this instance damage rating was the dependent variable. The relationship

Table 23. Soil Salt Application Study. Leaf sodium and chloride concentration (% DW) and damage ratings in lodgepole pine following the addition of various rates of salt.

		Soil Treatment - Tons/A														
1977		0			0.33			0.67			1.33			2.67		
1978		0			0.5			1			2			4		
	Para-	% DW		Dam-	% DW		Dam-	% DW		Dam-	% DW		Dam-	% DW		Dam-
Date	meter	Na	Cl	age	Na	Cl	age	Na	Cl	age	Na	Cl	age	Na	Cl	age
Jan. 77	$\bar{x}$	0.025	0.010		0.024	0.011		0.025	0.015		0.024	0.019		0.024	0.011	
	$s_{\bar{x}}$	0.002	0.002		0.001	0.003		0.001	0.004		0.001	0.003		0.001	0.005	
May 77	$\bar{x}$	0.011	0.006		0.012	0.027		0.012	0.043		0.012	0.086		0.021	0.128	
	$s_{\bar{x}}$	0.001	0.002		0.001	0.006		0.001	0.006		0.001	0.021		0.005	0.035	
June 77	$\bar{x}$	0.008	0.004	-	0.008	0.017	-	0.010	0.029	-	0.014	0.054	-	0.061	0.133	0.25
	$s_{\bar{x}}$	0.001	0.001	-	0.001	0.009	-	0.001	0.007	-	0.005	0.023	-	0.027	0.058	0.25
July 77	$\bar{x}$	0.013	0.010	-	0.012	0.019	-	0.020	0.055	-	0.018	0.109	-	0.059	0.137	0.25
	$s_{\bar{x}}$	0.001	0.002	-	0.002	0.006	-	0.003	0.005	-	0.002	0.034	-	0.026	0.045	0.25
Aug. 77	$\bar{x}$	0.021	0.013	-	0.029	0.016	-	0.032	0.040	-	0.034	0.102	-	0.090	0.167	0.25
	$s_{\bar{x}}$	0.002	0.003	-	0.007	0.002	-	0.007	0.008	-	0.011	0.029	-	0.031	0.053	0.25
Sept. 77	$\bar{x}$	0.022	0.007		0.024	0.008		0.027	0.038		0.040	0.140		0.111	0.175	
	$s_{\bar{x}}$	0.002	0.001		0.002	0.001		0.003	0.021		0.004	0.026		0.041	0.066	
Oct. 77	$\bar{x}$	0.015	0.011	-	0.018	0.013	-	0.019	0.027	-	0.028	0.131	-	0.113	0.200	0.25
	$s_{\bar{x}}$	0.002	0.002	-	0.003	0.004	-	0.003	0.012	-	0.002	0.043	-	0.026	0.049	0.25
Jan. 78	$\bar{x}$	0.018	0.013	-	0.021	0.018	-	0.038	0.036	-	0.076	0.258	-	0.147	0.250	0.25
	$s_{\bar{x}}$	0.002	0.004	-	0.002	0.009	-	0.006	0.003	-	0.031	0.080	-	0.038	0.100	0.25
May 78	$\bar{x}$	0.061	0.081	-	0.040	0.060	-	0.059	0.111	-	0.110	0.311	0.25	0.180	0.308	0.50
	$s_{\bar{x}}$	0.040	0.062	-	0.003	0.009	-	0.003	0.021	-	0.035	0.098	0.25	0.047	0.096	0.29
June 78	$\bar{x}$	0.022	0.007	-	0.042	0.028	-	0.054	0.087	-	0.110	0.270	0.25	0.135	0.280	0.50
	$s_{\bar{x}}$	0.002	0.000	-	0.002	0.010	-	0.012	0.023	-	0.031	0.067	0.25	0.047	0.123	0.29
Sept. 78	$\bar{x}$			-			-			-			0.25			0.50
	$s_{\bar{x}}$			-			-			-			0.25			0.29

Figure 16. Soil-Salt Application Study. Sodium and chloride concentrations and damage ratings for lodgepole pine as a function of time at the high salt rate. Salt applications were 2.67 T/A in 1977.

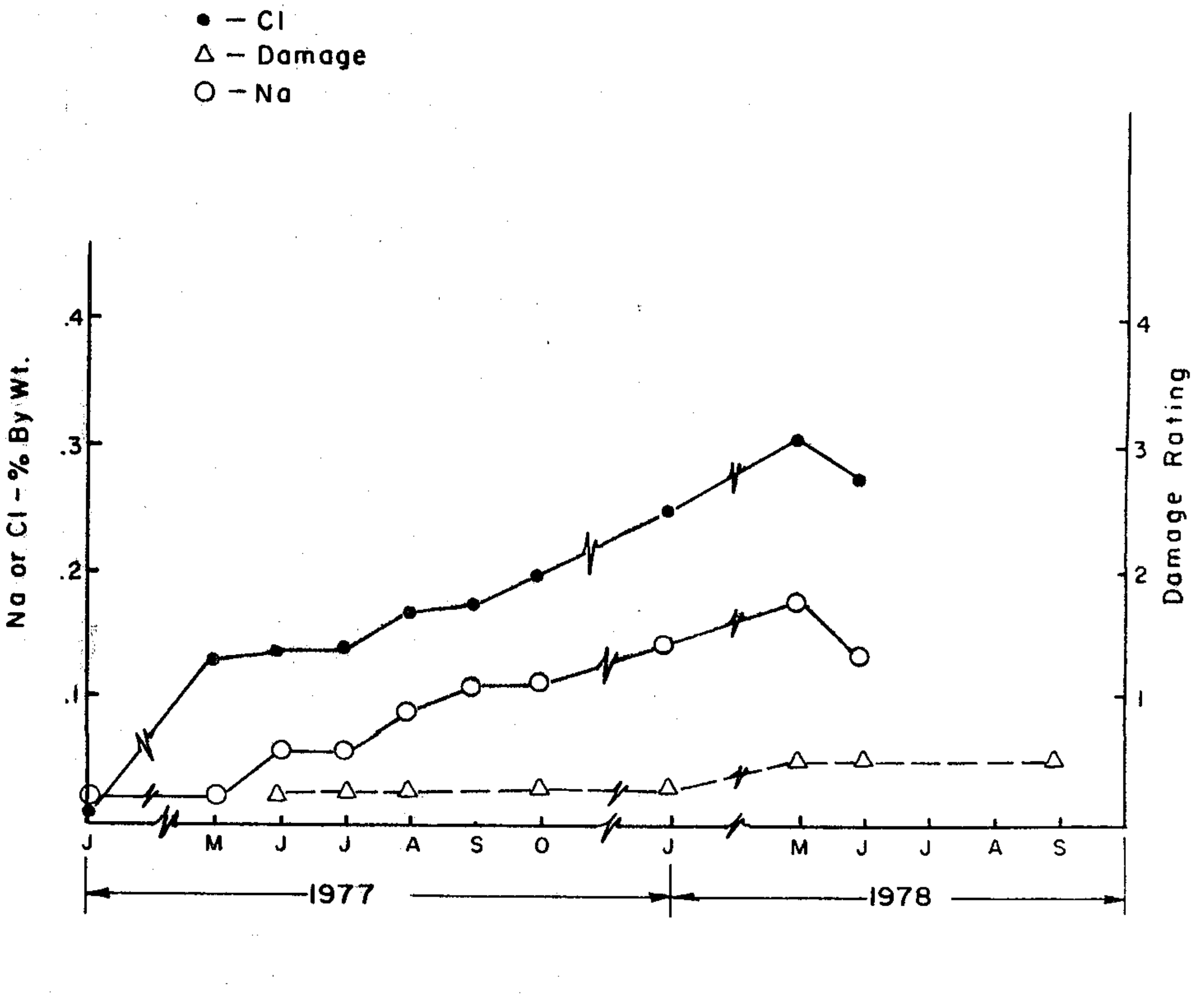


Figure 17. Soil Salt Application Study. Sodium and chloride concentrations and damage ratings for lodgepole pine in October 1977 as a function of applied salt.

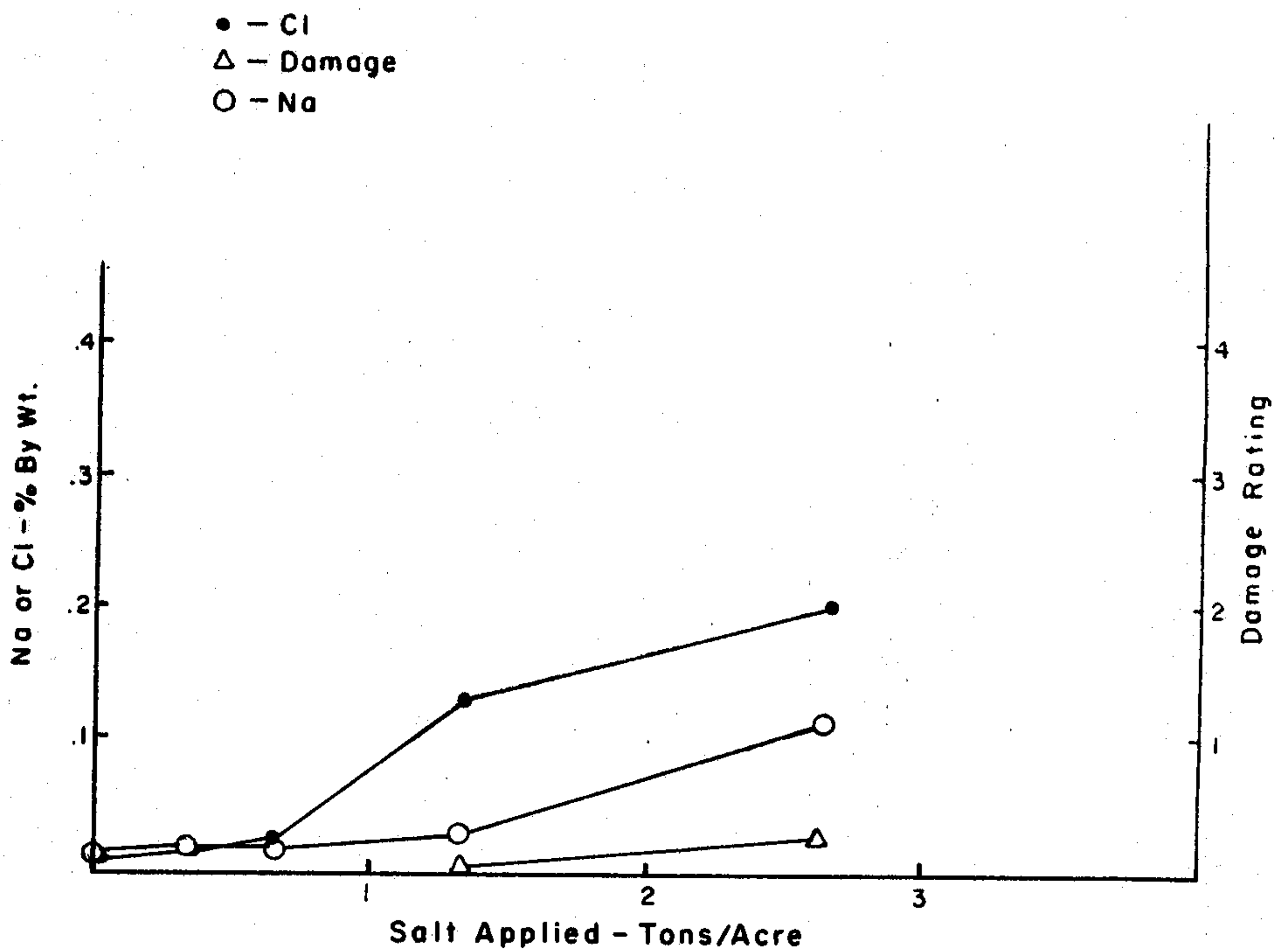
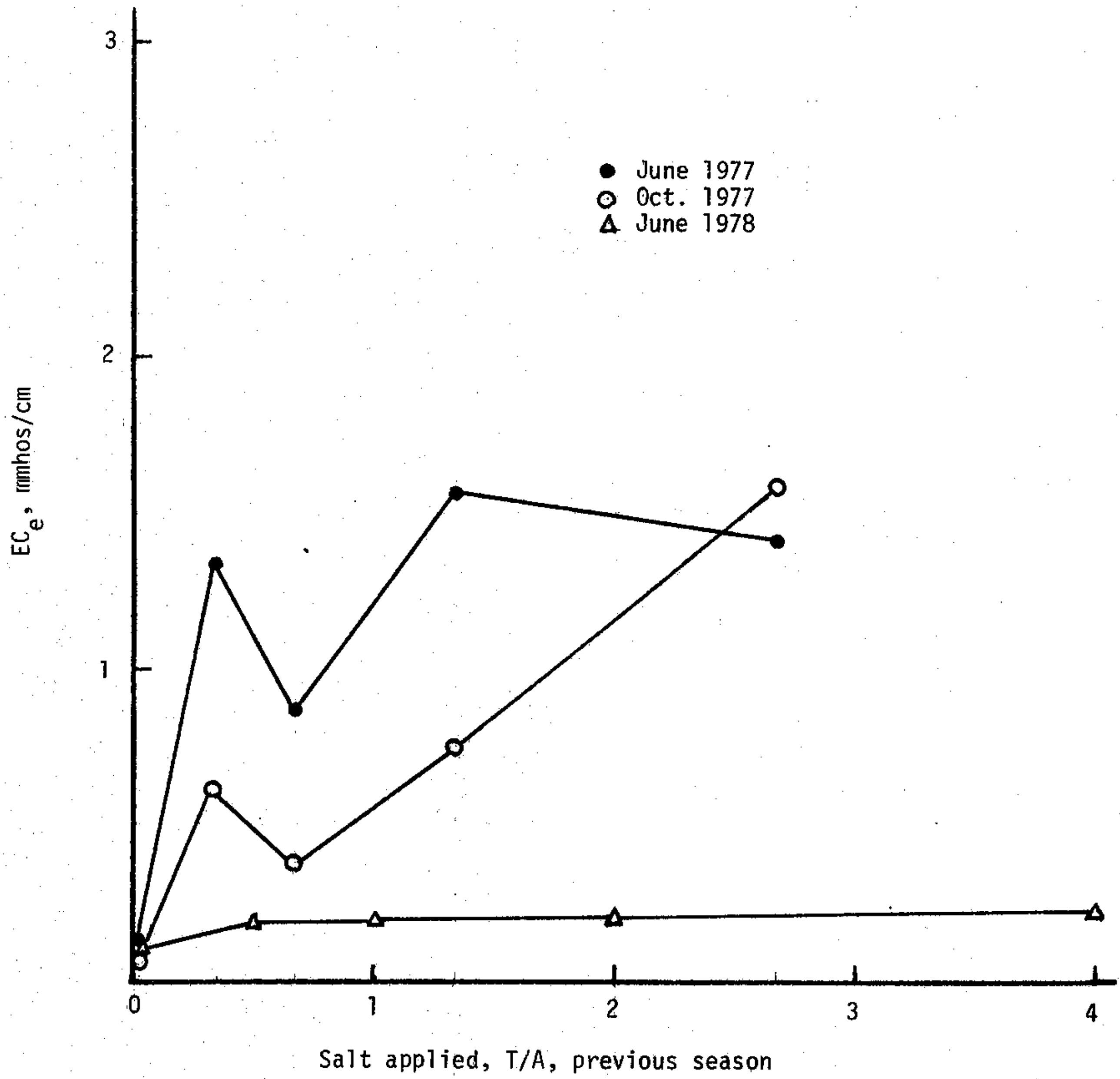


Table 24. Soil Salt Application Study. Soil EC_e (millimhos/cm), sodium and chloride (meq l^{-1}) under lodgepole pine following the addition of various rates of salt.

			Salt Treatments - Tons/A														
1977			0			0.33			0.67			1.33			2.67		
1978			0			0.5			1			2			4		
				meq l^{-1}			meq l^{-1}			meq l^{-1}			meq l^{-1}			meq l^{-1}	
Date	Depth	Parameter	EC_e	Na	Cl	EC_e	Na	Cl	EC_e	Na	Cl	EC_e	Na	Cl	EC_e	Na	Cl
June 77	0-1	$\bar{x}$	0.10	0.5	0.1	1.35	2.6	1.5	0.87	6.2	4.1	1.57	9.4	8.0	1.40	11.7	7.3
		$s_{\bar{x}}$	0.01	0.0	0.0	0.47	1.4	1.2	0.68	6.0	3.5	1.22	6.7	6.8	0.49	3.9	3.0
	1-2	$\bar{x}$	0.07	0.4	<0.1	0.42	2.6	1.3	0.69	4.0	3.8	1.17	6.6	4.9	2.14	16.5	13.5
		$s_{\bar{x}}$	0.01	0.0	<0.1	0.08	0.7	0.1	0.42	2.6	2.8	0.83	4.2	3.7	0.14	2.5	1.9
	2-3	$\bar{x}$	0.08	0.4	0.1	0.72	4.7	5.2	0.90	5.4	3.8	1.45	12.4	6.8	1.06	13.6	10.2
		$s_{\bar{x}}$	0.01	0.0	0.0	0.41	3.1	4.0	0.56	3.8	2.0	1.05	10.8	5.5	0.76	0.4	0.5
Oct. 77	0-1	$\bar{x}$	0.07	0.3	0.2	0.62	5.6	5.1	0.38	4.0	3.1	0.72	6.4	4.7	1.59	15.4	14.8
		$s_{\bar{x}}$	0.02	0.1	0.1	0.49	4.1	4.9	0.06	0.2	0.0	0.09	0.5	0.9	0.85	8.3	9.1
	1-2	$\bar{x}$	0.08	0.2	0.1	0.71	6.2	5.6	0.40	3.4	2.8	0.45	4.4	2.7	1.50	11.1	11.6
		$s_{\bar{x}}$	0.00	0.0	0.0	0.54	4.4	4.6	0.14	1.0	0.9	0.21	1.6	2.0	0.77	5.9	5.5
	2-3	$\bar{x}$	0.08	0.3	0.2	0.62	5.9	4.6	0.34	1.7	2.3	0.46	4.3	3.7	2.86	25.1	27.1
		$s_{\bar{x}}$	0.00	0.1	0.1	0.34	3.3	2.9	0.05	0.8	0.2	0.31	2.4	2.3	2.71	24.5	26.9
June 78	0-1	$\bar{x}$	0.10	0.4	0.1	0.20	1.7	0.7	0.20	2.3	0.9	0.21	2.0	0.4	0.22	2.5	0.8
		$s_{\bar{x}}$	0.01	0.0	0.0	0.01	0.1	0.1	0.07	0.2	0.5	0.03	0.5	0.0	0.08	1.1	0.3
	1-2	$\bar{x}$	0.08	0.3	0.2	0.18	1.5	1.0	0.22	1.6	1.1	0.22	2.1	1.3	0.18	1.9	0.8
		$s_{\bar{x}}$	0.02	0.0	0.1	0.04	0.1	0.8	0.08	0.7	0.5	0.10	1.1	0.9	0.07	1.0	0.4
	2-3	$\bar{x}$	0.08	0.5	0.2	0.16	1.3	0.5	0.30	1.3	1.7	0.17	1.4	0.7	0.19	1.7	0.7
		$s_{\bar{x}}$	0.01	0.1	0.1	0.02	0.1	0.0	0.20	0.4	1.5	0.06	0.4	0.3	0.10	1.0	0.3

Figure 18. Soil Salt Application Study. Soil EC_e (millimhos/cm) in upper one foot of profile under lodgepole pine as a function of salt applied the previous season.



for Jeffrey pine is shown in Fig. 19. Trees having a damage rating of 1 have a mean Cl tissue concentration of 0.4% and a mean Na tissue concentration of about 0.18%. As damage rating increases, Na and Cl leaf concentration increase linearly. White fir (Fig. 20) behaves similarly to Jeffrey pine, however, incense cedar shows (Fig. 21) a much lower Na level than either white fir or Jeffrey pine.

It should be remembered that the tissue sampled and analyzed in this study represents the oldest green or partly green leaves on a branch. When trees are sampled in this fashion and tissues are found to contain Na and Cl concentrations at or exceeding the levels given in the following table, then the tree is very likely suffering from salt stress.

Table 25. Sodium and chloride concentration of oldest leaves associated with a tree damage rating of 1 in Jeffrey pine, white fir and incense cedar.

Species	% dry wt.		Damage Rating
	Na	Cl	
<u>Jeffrey pine</u>	0.18	0.4	1
<u>White fir</u>	0.13	0.65	1
<u>Incense cedar</u>	0.05	0.65	1

5.53.3 <u>Relation between individual leaf damage and Cl and Na content</u>: One of the objectives of this study was to obtain an estimate of the Na and Cl leaf concentration that resulted in damage (necrosis) of individual leaves. Specifically, we were interested in the minimum Na and Cl tissue level associated with necrosis. To do this, samples with

Figure 19. Soil Salt Application Study. Damage rating in Jeffrey pine as a function of leaf sodium and chloride concentrations for individual tree data. Concentrations at 0.5-1 damage ratings are estimated threshold levels.

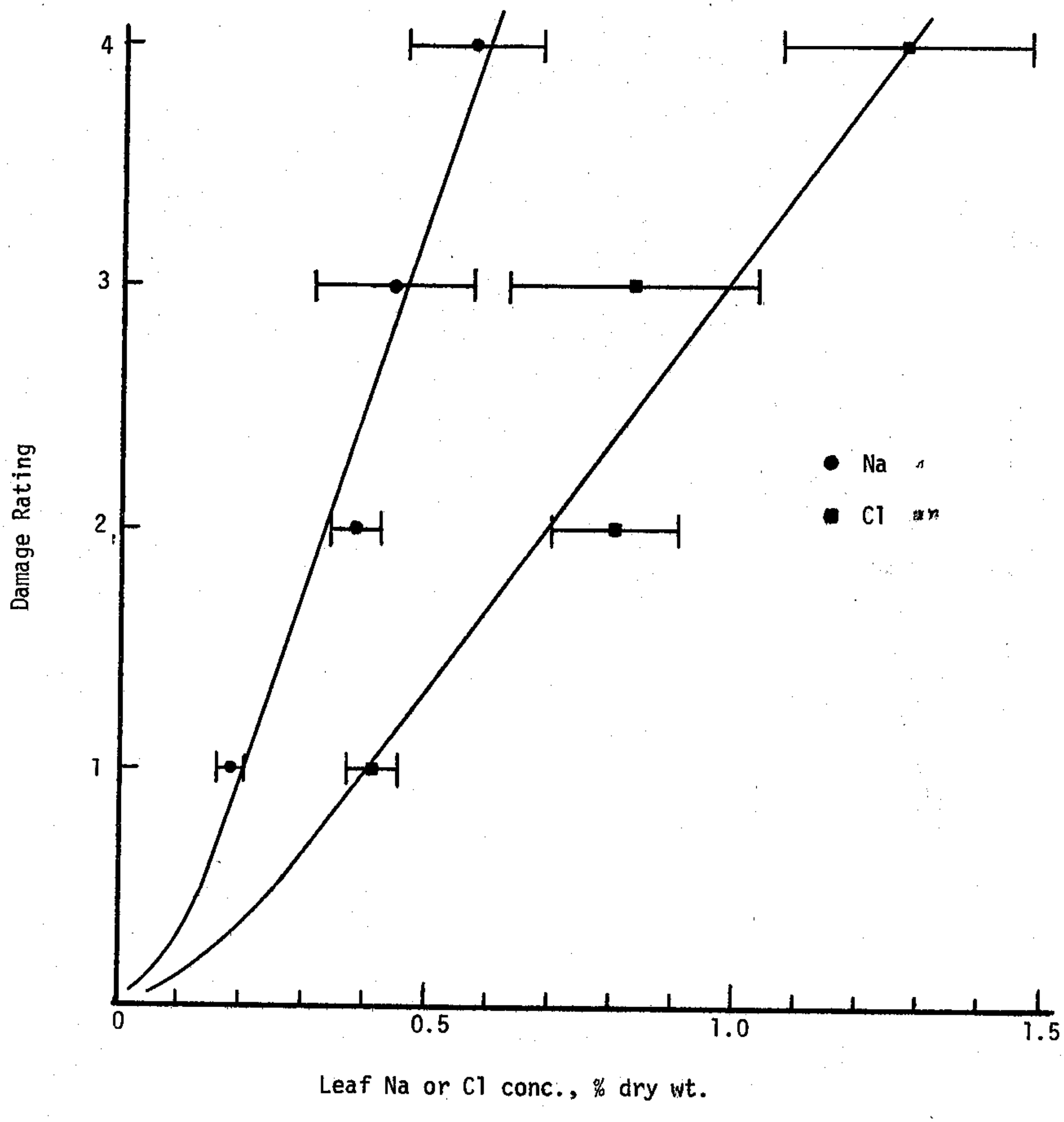


Figure 20. Soil Salt Application Study. Damage rating in white fir as a function of leaf sodium and chloride concentrations for individual tree data. Concentrations at 0.5-1 damage ratings are estimated threshold levels.

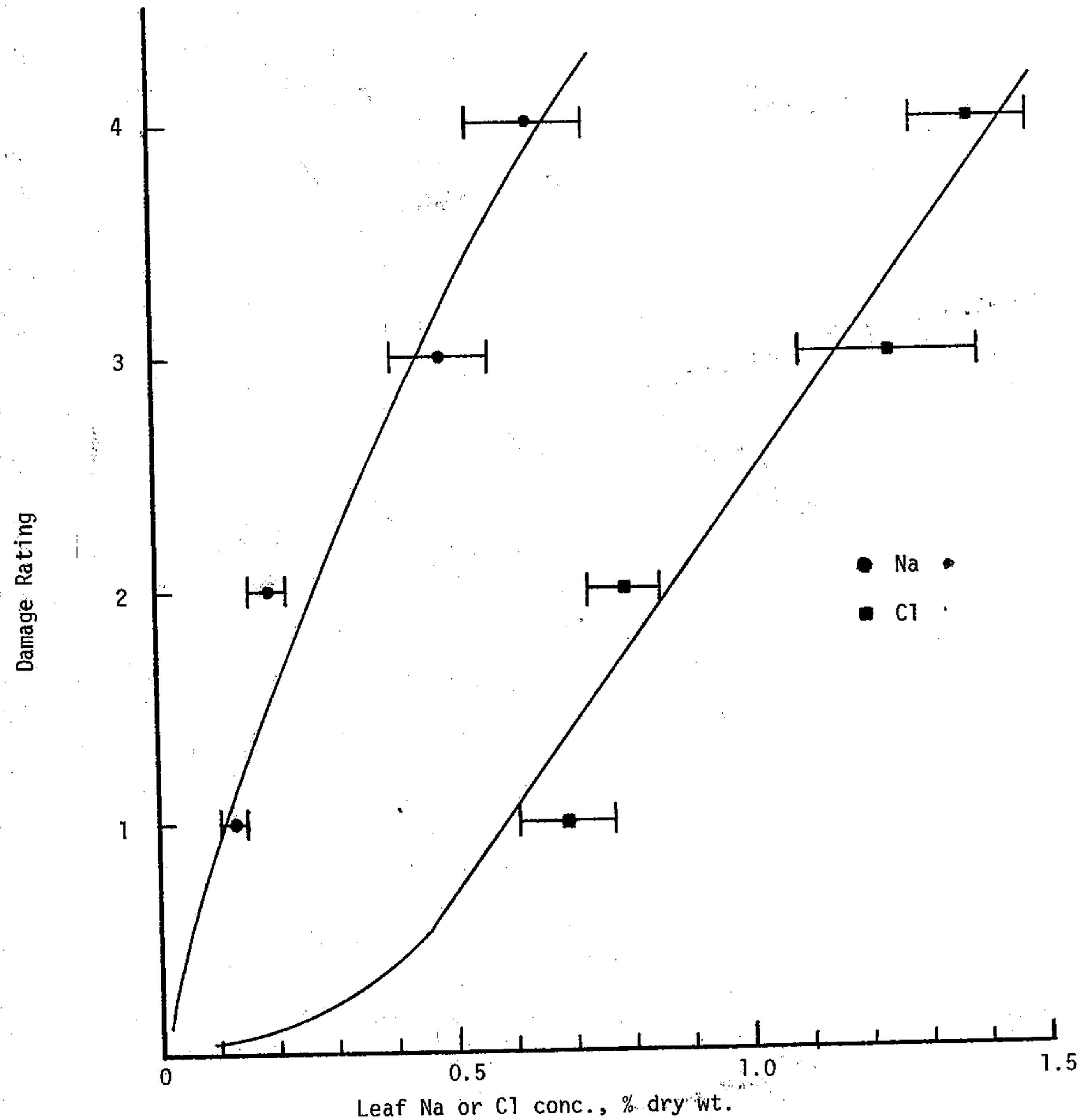
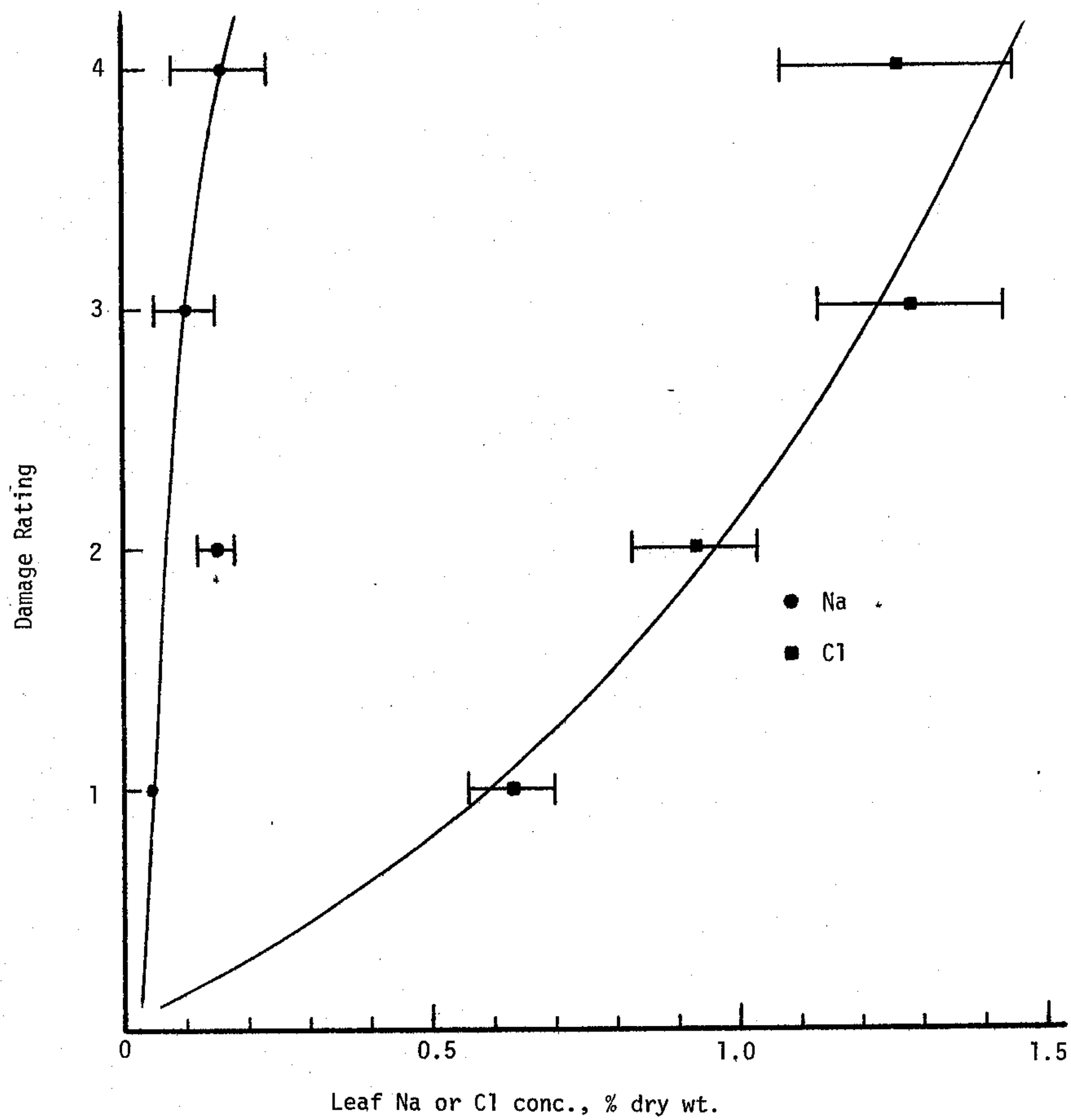


Figure 21. Soil Salt Application Study. Damage rating in incense cedar as a function of leaf sodium and chloride concentrations for individual tree data. Concentrations at 0.5-1 damage ratings are estimated threshold levels.



varying degrees of necrosis (i.e., tip burn, 1/4 brown, 1/2 brown, 3/4 brown and fully brown) were collected from the plots receiving salts. Samples were collected in 1977 and also in 1978. The results are shown in Figs. 22 through 25. From these figures an estimate of Na and Cl associated with varying degrees of leaf necrosis can be obtained. In the following table, Na and Cl leaf concentrations associated with tip burn (about 10% browning) and completely dead tissue (100% browning) is presented.

Table 26. Sodium and chloride concentration of leaves with tip burn and complete necrosis in Jeffrey pine, white fir, incense cedar and lodgepole pine.

	Tip burn		Complete necrosis	
	% dry wt.			
Species	Na	Cl	Na	Cl
Jeffrey pine	0.15-0.23	0.44-0.50	0.90	1.10-1.40
White fir	0.14	0.43-0.50	0.95	1.56-1.98
Incense cedar	0.06	0.44	0.30	1.80
Lodgepole pine	0.14-0.22	0.37-0.56	0.40-0.70	0.09-1.12

These estimates can assist in ascertaining whether tissue damage (necrosis) is due to salt or to other factors.

5.53.4 <u>Summary</u>: Controlled application of sodium chloride to four species of trees growing in the Tahoe Basin has allowed us to: 1) to record and note the development of symptoms and tree damage as a result of excessive salt

Figure 22. Soil Salt Application Study. Leaf sodium and chloride concentrations in Jeffrey pine at different fractions of leaf browning.

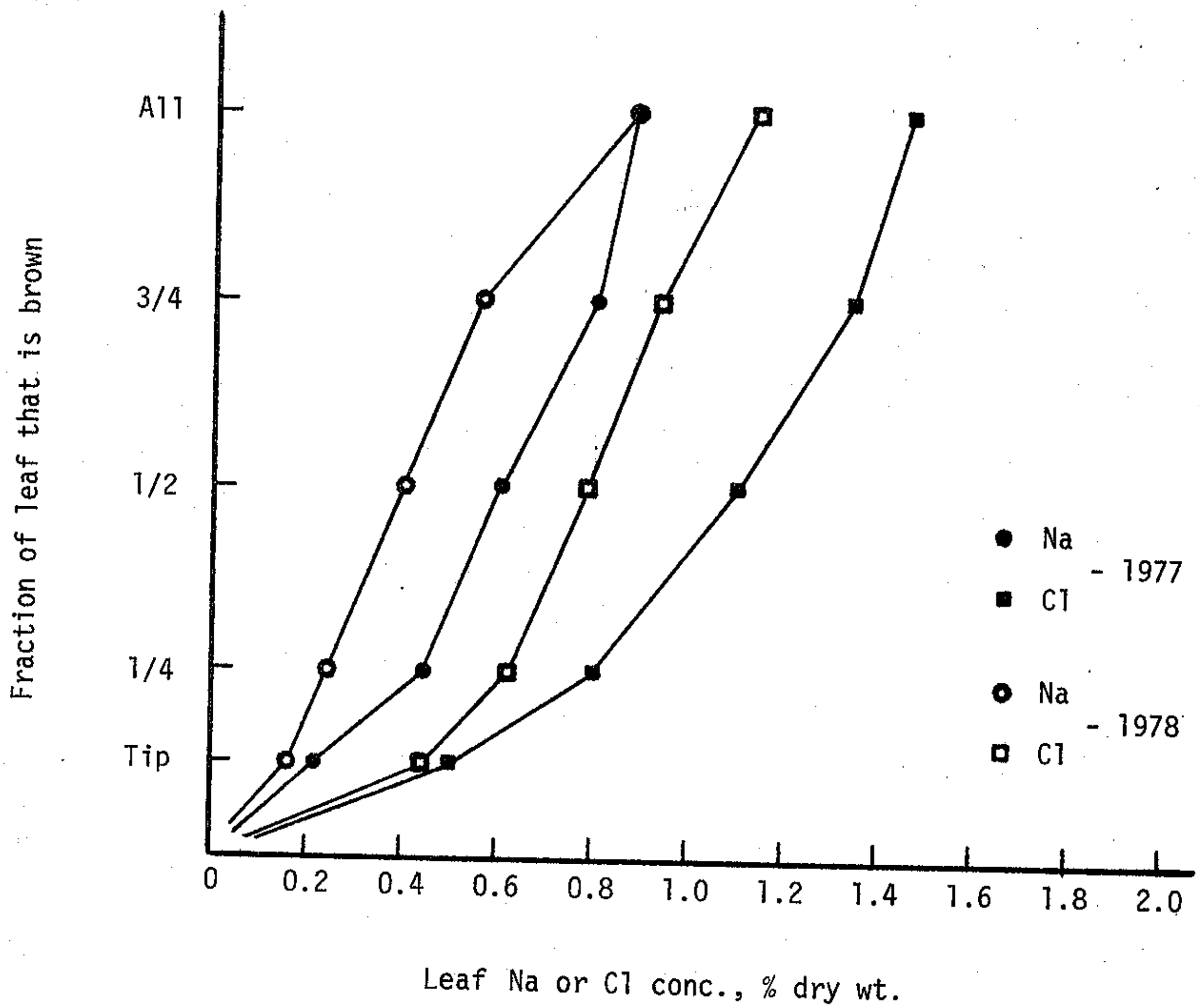


Figure 23. Soil Salt Application Study. Leaf sodium and chloride concentrations in white fir at different fractions of leaf browning.

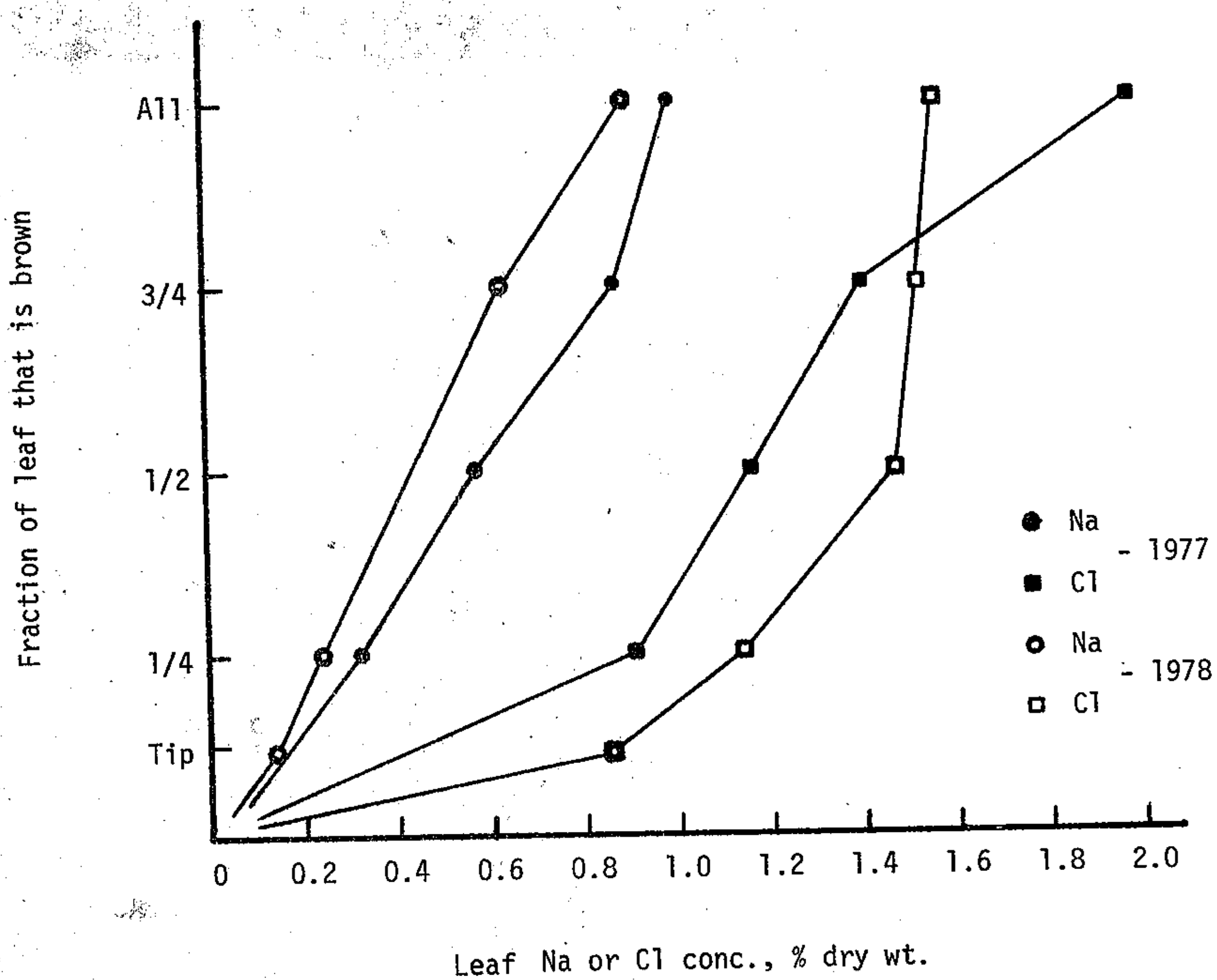


Figure 24. Soil Salt Application Study. Leaf sodium and chloride concentrations in incense cedar at different fractions of leaf browning.

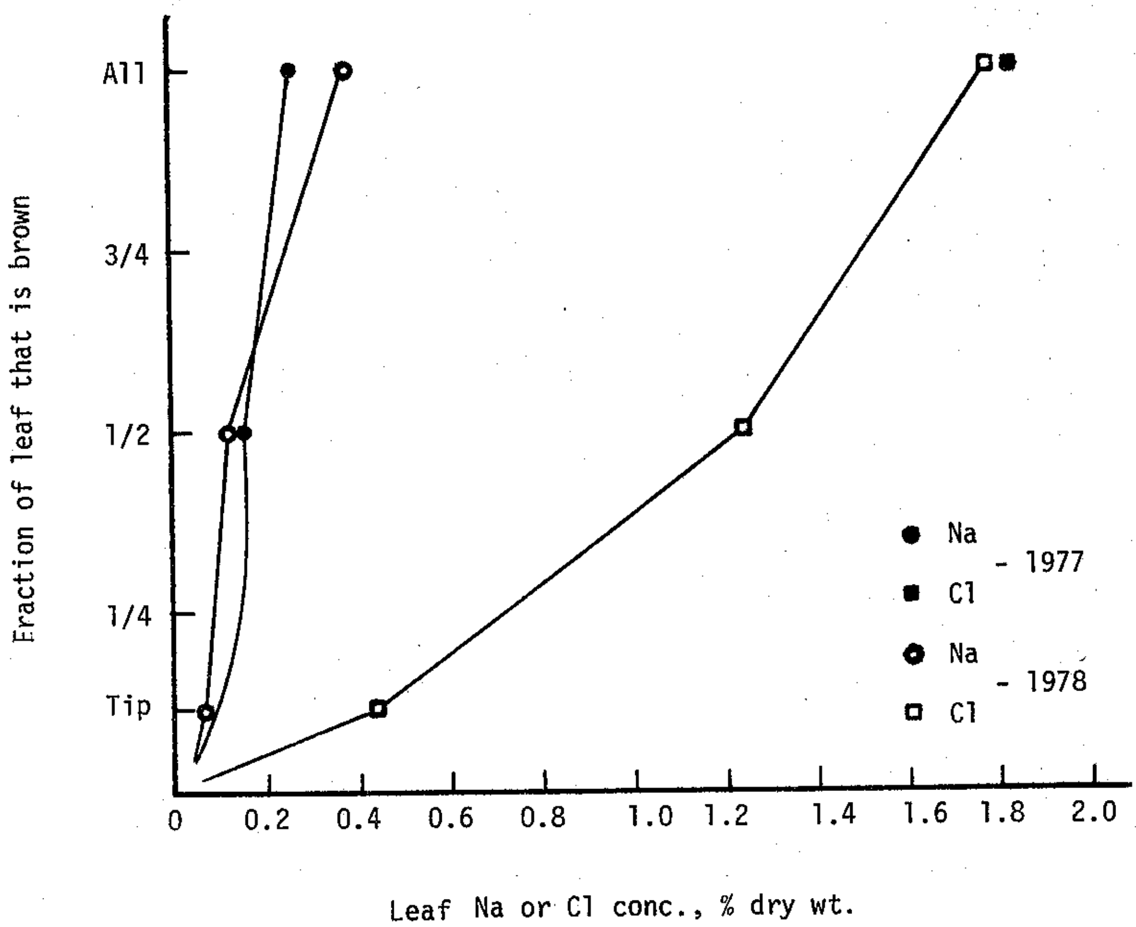
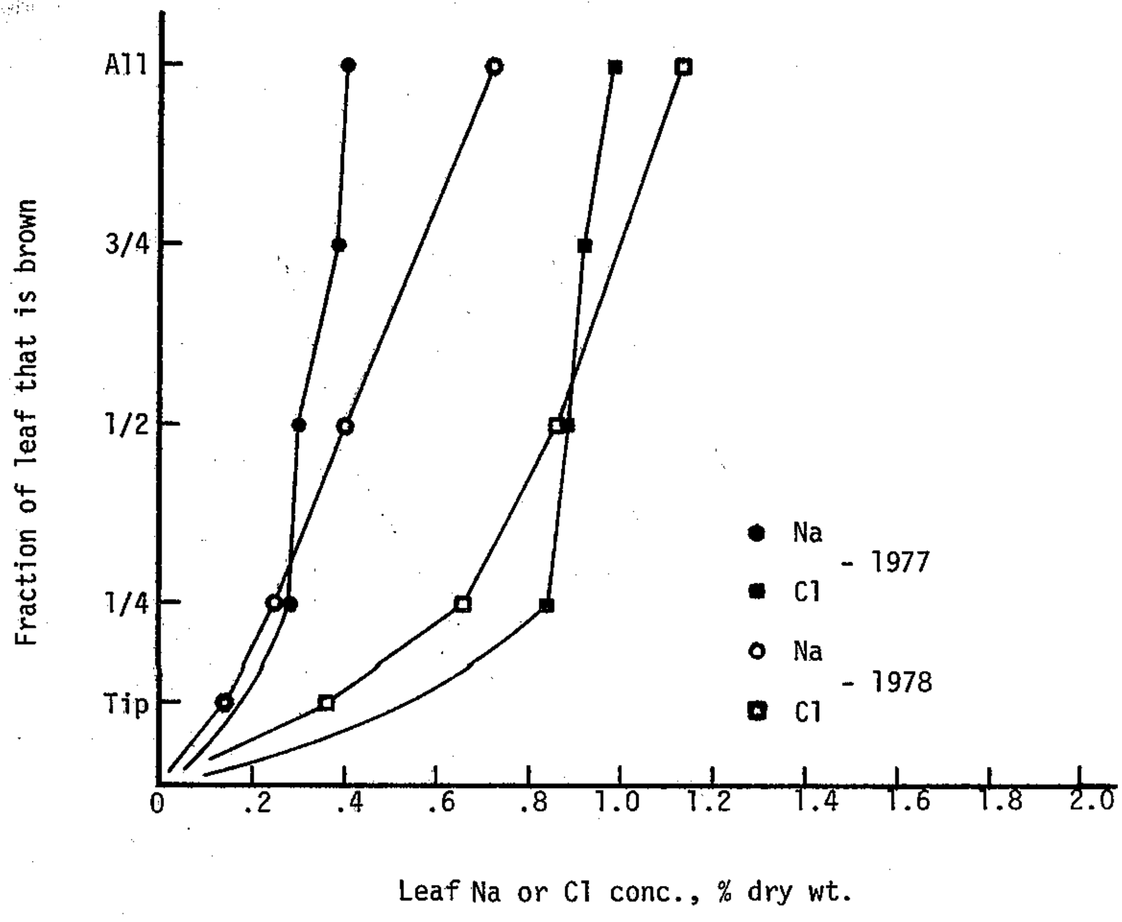


Figure 25. Soil Salt Application Study. Leaf sodium and chloride concentrations in lodgepole pine at different fractions of leaf browning.



in the soil; 2) to obtain leaf tissue Na and Cl concentrations associated with varying degrees of overall tree damage; and 3) to obtain leaf tissue Na and Cl concentrations associated with varying degrees of leaf necrosis.

5.6 Foliar Salt Application Study

Some portion of the salt applied to highways is dispersed as spray or aerosols whipped up by traffic and blown onto adjacent vegetation. Vegetation can absorb salt through the foliage and suffer damage. The objectives of this study were to induce damage symptoms on conifers to determine: 1) concentrations of salt spray which might cause damage; 2) whether the symptoms differed from those resulting from root uptake; 3) relative sensitivity of species; and 4) concentration of salt in leaves which causes damage.

5.61 Materials and methods: The foliar salt application study was conducted from January 1977 till June 1978. Four species of trees, Jeffrey pine, white fir, lodgepole pine and incense cedar were chosen at two sites, removed from the highway environment in the Tahoe National Forest, Lake Tahoe basin. Three replications of Jeffrey pine and five of lodgepole pine were in Location I of the Soil Salt Application Study near site 15. Three replications of Jeffrey pine, five of white fir and five of incense cedar were at Location II of the Soil Salt Application Study near site 7.

There were five NaCl concentrations used as a foliar spray: 0, 0.1, 0.5, 1.0, and 5.0 molar (M) NaCl, made from deicing salt. The 0.5 M solution is slightly more concentrated than the salt concentration in sea water. These concentrations bracket the salt concentrations found in pavement runoff by an earlier Caltrans study (16). Five healthy branches of similar size and condition, 6 ft above the ground on the same tree, received one treatment each. Thus, every tree was a single replication. There were six replications of Jeffrey pine and five each of the other three species.

The treatment solutions were sprayed to runoff on January 24, March 22 and April 12, in 1977. A snowstorm occurred the day after the March 22, 1977 application. The treatments were reapplied in January, February, and March, 1978. The air temperatures were between 28 and 36°F on the days of application.

From May 1977 to June 1978, the treated branches were observed for salt damage symptoms. Damage was rated on a scale of 0-4, where: 0 = no damage; 1 = first visible symptoms to 25; 2 = 26-50; 3 = 51-75; 4 = 76-100% browning or defoliation.

Depending upon availability, oldest green leaves and varying grades of brown foliage (tip brown, 1/4, 1/2, 3/4 and fully brown leaves) were sampled from each treatment in January and August 1977 and January and June 1978 for determining their Na and Cl concentrations.

The leaf samples were washed in distilled water to remove surface salt and oven-dried at 70° for 72 hours. They were ground through a 40 mesh screen in a Wiley mill and Na and Cl concentrations were determined as described previously.

5.62 Results: Means and Standard errors of the means are given in Table 27.

5.62.1 Jeffrey and lodgepole pine: Jeffrey and lodgepole pines did not show any salt damage symptoms even at the 5M treatment after two years although in the interval, concentrations of Na and Cl in the leaves had increased significantly. They did not, however, exceed the threshold levels, as determined by the Soil Salt Application Study.

5.62.2 White fir: Damage occurred in white fir in the 5M treatment as early as June 1977 in one branch. This branch received a damage rating of 2 in August. Symptoms were no different from those resulting from the uptake of salt by roots. Tip browning in a second branch became visible in August and was rated 1 on the damage scale. These two branches had damage ratings of 2 in January 1978. By June 1978, the damage rating on these two branches were 3 and 2, respectively. Branches on two other replicates were rated 1 on the scale and one replicate did not show visible damage. No damage symptoms developed in the 1.0M and lower treatments. Leaf Na and Cl concentrations increased over initial levels in most of the treatments but did not exceed the estimated threshold of the Soil Salt Application Study by June 1978. However, there was damage at the damage rating of 1 (25% level) in several trees at the highest application rate. From the data, the estimated threshold levels for injury (25% damage) to white fir from foliar-applied salt were 0.30% for Na (range 0.16-0.38%) and 0.42% for Cl (range 0.28-0.49%).

Table 27. Foliar Salt Application Study, 1977-78. Leaf and sodium chloride concentrations in four conifer species, Jeffrey pine, lodgepole pine, white fir, and incense cedar sprayed with 0, 0.1, 0.5, 1 and 5 molar (M) salt solutions.

Species and sampling date	Para-meter	0 M meq l^{-1} Na	0 M meq l^{-1} Cl	0 M Dam-age[1]	0.1 M meq l^{-1} Na	0.1 M meq l^{-1} Cl	0.1 M Dam-age[1]	0.5 M meq l^{-1} Na	0.5 M meq l^{-1} Cl	0.5 M Dam-age[1]	1 M meq l^{-1} Na	1 M meq l^{-1} Cl	1 M Dam-age[1]	5 M meq l^{-1} Na	5 M meq l^{-1} Cl	5 M Dam-age[1]
Jeffrey pine																
Jan. 77	$\bar{x}$	0.034	0.011	-	0.034	0.011	-	0.034	0.011	-	0.034	0.011	-	0.034	0.011	-
	$s_{\bar{x}}$	0.004	0.002	-	0.004	0.002	-	0.004	0.002	-	0.004	0.002	-	0.004	0.002	-
Jan. 78	$\bar{x}$	0.031	0.005	-	0.045	0.006	-	0.056	0.009	-	0.066	0.011	-	0.049	0.014	-
	$s_{\bar{x}}$	0.004	0.001	-	0.006	0.000	-	0.004	0.001	-	0.010	0.002	-	0.014	0.005	-
June 78	$\bar{x}$	0.046	0.033	-	0.077	0.030	-	0.088	0.055	-	0.123	0.084	-	0.133	0.077	-
	$s_{\bar{x}}$	0.008	0.004	-	0.018	0.002	-	0.016	0.015	-	0.014	0.017	-	0.026	0.020	-
Loddepole pine																
Jan. 77	$\bar{x}$	0.026	0.010	-	0.026	0.010	-	0.026	0.010	-	0.026	0.010	-	0.026	0.010	-
	$s_{\bar{x}}$	0.004	0.003	-	0.004	0.003	-	0.004	0.003	-	0.004	0.003	-	0.004	0.003	-
Jan. 78	$\bar{x}$	0.027	0.006	-	0.045	0.006	-	0.053	0.008	-	0.067	0.023	-	0.072	0.030	-
	$s_{\bar{x}}$	0.002	0.001	-	0.003	0.001	-	0.005	0.001	-	0.006	0.009	-	0.006	0.012	-
June 78	$\bar{x}$	0.034	0.017	-	0.045	0.038	-	0.062	0.059	-	0.088	0.076	-	0.132	0.111	-
	$s_{\bar{x}}$	0.002	0.008	-	0.010	0.013	-	0.005	0.015	-	0.013	0.018	-	0.007	0.026	-

(Continued)

Table 27. (Continued)

Species and sampling date	Parameter	0 M meq l^{-1} Na	0 M meq l^{-1} Cl	0 M Damage[1]	0.1 M meq l^{-1} Na	0.1 M meq l^{-1} Cl	0.1 M Damage[1]	0.5 M meq l^{-1} Na	0.5 M meq l^{-1} Cl	0.5 M Damage[1]	1M meq l^{-1} Na	1M meq l^{-1} Cl	1M Damage[1]	5 M meq l^{-1} Na	5 M meq l^{-1} Cl	5 M Damage[1]
White fir																
Jan. 77	$\bar{x}$	0.036	0.019	-	0.036	0.019	-	0.036	0.019	-	0.036	0.019	-	0.036	0.019	-
	$s_{\bar{x}}$	0.004	0.002	-	0.004	0.002	-	0.004	0.002	-	0.004	0.002	-	0.004	0.002	-
Aug. 77	$\bar{x}$	0.021	0.071	-	0.029	0.080	-	0.056	0.115	-	0.062	0.123	-	0.173	0.222	0.60
	$s_{\bar{x}}$	0.003	0.009	-	0.004	0.009	-	0.007	0.013	-	0.008	0.012	-	0.063	0.058	0.40
Jan. 78	$\bar{x}$	0.029	0.012	-	0.054	0.037	-	0.055	0.069	-	0.089	0.193	-	0.120	0.220	0.80
	$s_{\bar{x}}$	0.005	0.003	-	0.007	0.009	-	0.017	0.012	-	0.023	0.032	-	0.068	0.073	0.49
June 78	$\bar{x}$	0.036	0.090	-	0.045	0.149	-	0.079	0.147	-	0.131	0.396	-	0.365	0.571	1.40
	$s_{\bar{x}}$	0.009	0.018	-	0.004	0.063	-	0.015	0.021	-	0.022	0.160	-	0.136	0.161	0.51
Incense cedar																
Jan. 77	$\bar{x}$	0.023	0.032	-	0.023	0.032	-	0.023	0.032	-	0.023	0.032	-	0.023	0.032	-
	$s_{\bar{x}}$	0.001	0.007	-	0.001	0.007	-	0.301	0.007	-	0.001	0.007	-	0.001	0.007	-
Aug. 77	$\bar{x}$	0.021	0.115	-	0.087	0.217	0.40	0.163	0.396	0.60	0.250	0.523	0.60	0.365	0.771	1.60
	$s_{\bar{x}}$	0.004	0.009	-	0.011	0.021	0.25	0.010	0.018	0.25	0.041	0.061	0.25	0.073	0.097	0.25
Jan. 78	$\bar{x}$	0.028	0.127	-	0.062	0.243	0.40	0.167	0.446	0.80	0.341	0.824	1.60	0.424	0.815	2.40
	$s_{\bar{x}}$	0.004	0.016	-	0.009	0.023	0.25	0.043	0.074	0.37	0.148	0.174	0.40	0.116	0.098	0.25
June 78	$\bar{x}$	0.039	0.186	-	0.117	0.384	0.80	0.316	0.775	2.00	0.727	1.225	3.00	1.542	2.337	4.00
	$s_{\bar{x}}$	0.008	0.025	-	0.020	0.034	0.20	0.095	0.115	0.32	0.158	0.203	0.32	0.269	0.312	0.00

[1]0 = no damage, 1 = first visible symptoms to 25%, 2 = 26-50%, 3 = 51-75%, and 4 = 76-100% growing and defoliation.

The leaf Na and Cl concentrations in white fir are plotted as a function of time in Figure 26. Sodium concentration in leaves increased gradually to January 1978 in the 5 and 1 M treatments then increased again after the 1978 applications. Chloride concentrations increased by August 1977 and held steady or dropped slightly by January 1978 in all except the 1 M treatments. The level increased in all treatments following the 1978 applications.

5.62.3 Incense cedar: Incense cedar was the most susceptible conifer in this study. Even at the lowest concentration (0.1 M) NaCl spray caused damage in incense cedar. Foliar symptoms were identical to those resulting from root uptake. By August, all five branches that received the 5 M spray showed damage, two received a rating of 1 and three received a damage rating of 2. Three branches each in the 1 M and 0.5 M treatments received a damage rating of 1. One branch in the 0.1 M treatment received a damage rating of 1. Damage increased progressively until June 1978 when all the branches in the 5 M treatment were dead (damage rating of 4). One branch in the 1 M treatment was dead, three were rated 2, and one was rated 1. One branch in the 0.5 treatment was rated 3, three were rated 2, and one was rated 1. Four of five branches in the 0.1 M treatment were rated 1. Estimated threshold levels for injury (25% damage) to incense cedar from foliar-applied salt were 0.16% (range 0.062-0.265%) and 0.45% for Cl (range 0.20-0.79%). The data (means) for sodium and chloride concentrations at all damage levels are plotted in Figure 27.

The leaf Na and Cl concentrations in incense cedar are plotted as a function of time in Figure 28. The pattern

Figure 26. Foliar-Salt Application Study. Leaf sodium and chloride concentrations in white fir as a function of time at several application rates.

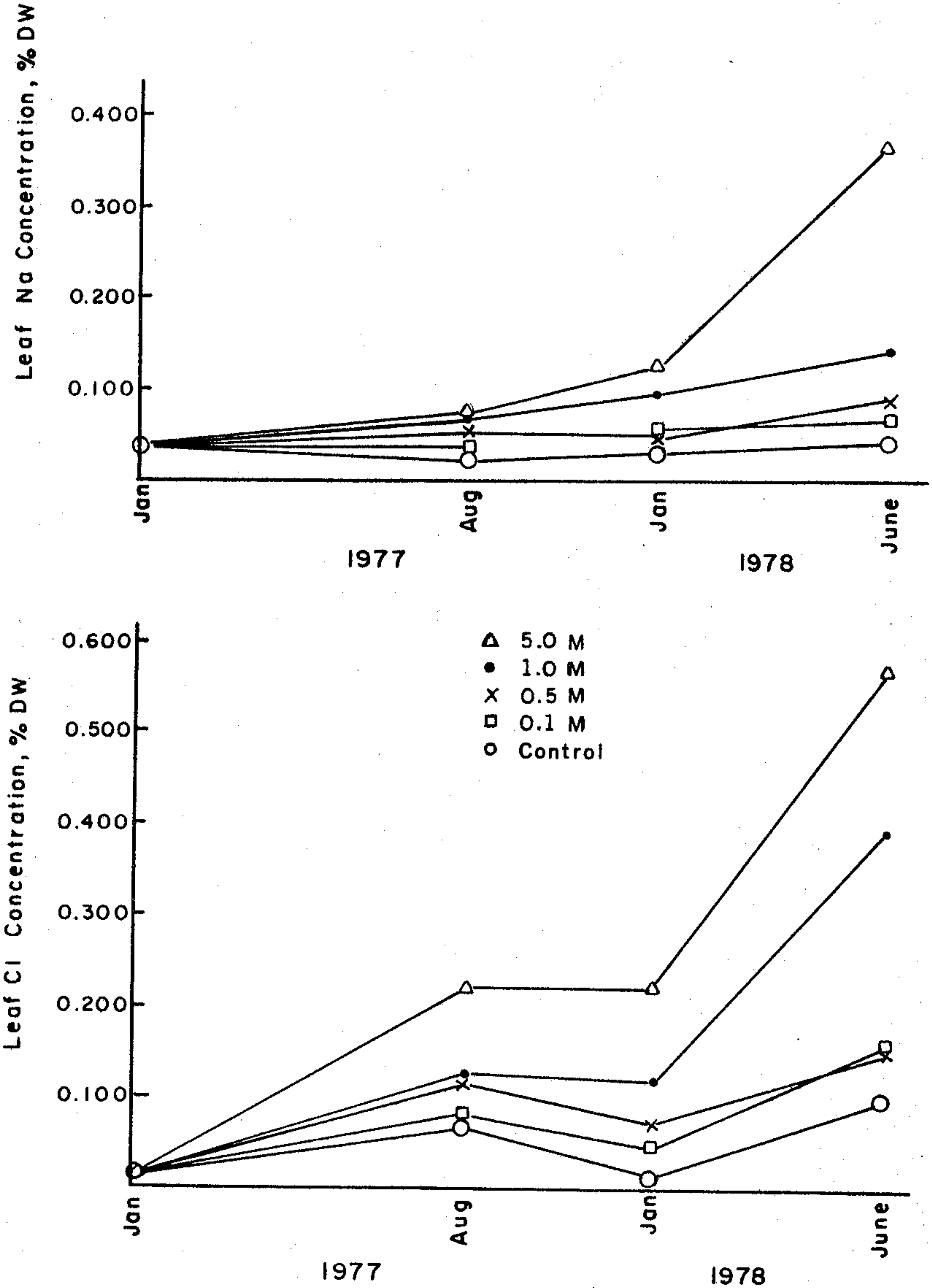


Figure 27. Foliar Salt Application Study. Damage ratings as a function of leaf sodium and chloride concentrations in incense cedar from foliar applied salt.

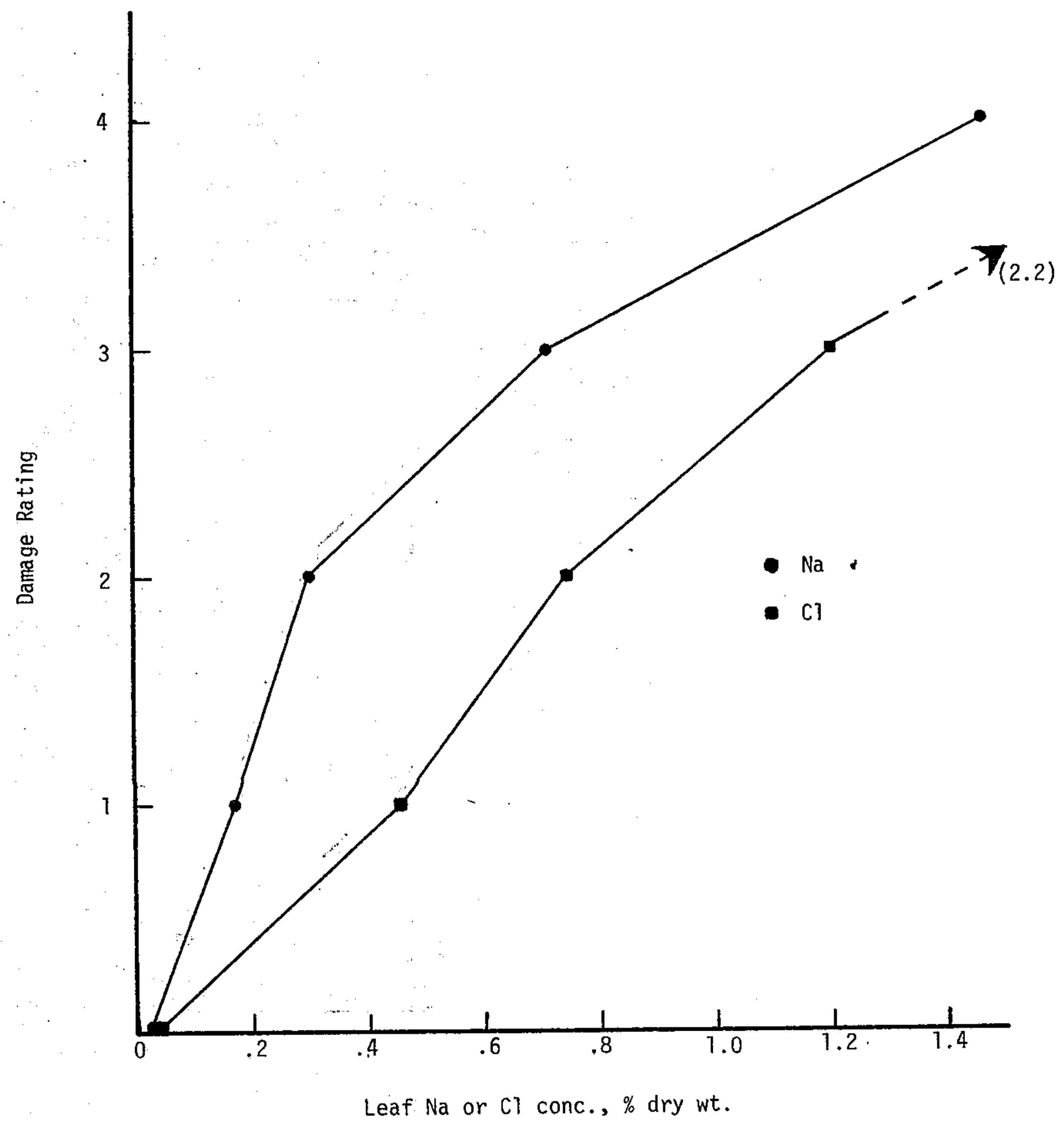
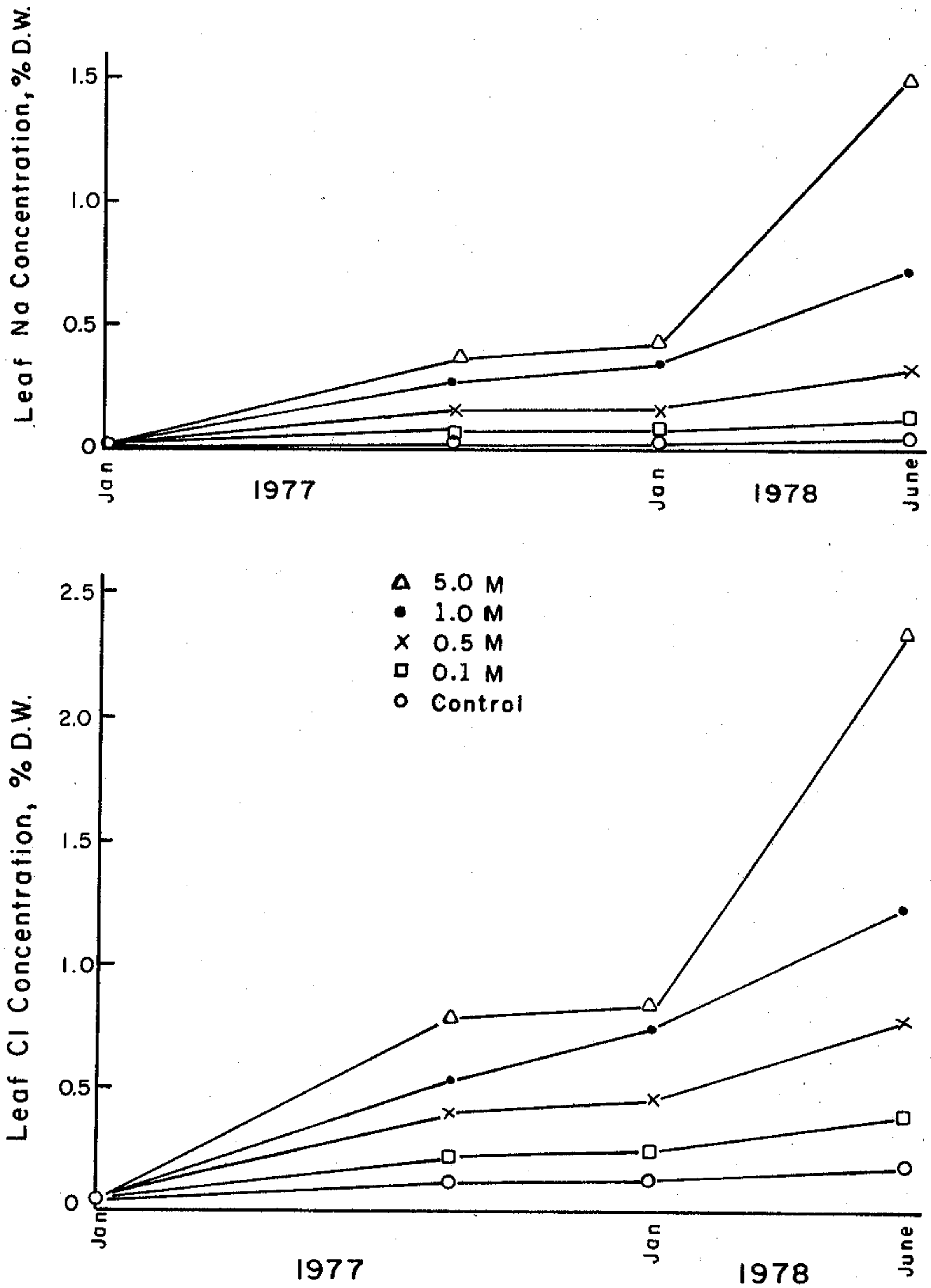


Figure 28. Foliar-Salt Application Study. Leaf sodium and chloride concentrations in incense cedar as a function of time at several application rates.



of accumulation is very similar for both ions. However, the concentration of both elements was about 4-fold higher in incense cedar than in white fir at the two highest concentrations (5 and 1 M) and 2- to 4-fold in the lower concentrations (0.5 and 0.1 M). Slight increases in leaf Cl in both species may have been due to translocation within the plant.

5.63 Summary: It is very probable that some of the plant damage from deicing operations, at least in white fir and incense cedar, is from salt spray of aerosols. Although damage symptoms were not visible in the pine species, a portion of leaf Na and Cl may come from aerosols.

Accumulation of foliar applied salts was additive for the two years of this study. For three to five or more years, leaves remain on a tree salt accumulation through foliage could be a major cause of damage. This could be particularly important in incense cedar which absorbed up to four times as much Na and Cl as did the second most sensitive species, white fir. However, the typical one-sided pattern (more damage on the side of the tree nearest the highway) reported by some workers in the eastern United States were not observed in the surveys of the original 15 sites.

5.7 Temperature Influence Study

5.71 Materials and methods: This experiment was conducted between January and May 1978. Forty-eight three year old white fir seedlings established in gallon cans were acquired from Christensen Nurseries, Saratoga, California. These seedlings were acclimatized to the Lake Tahoe environment for three weeks in January. The plants were then placed in a wooden frame outdoors, in an area well protected from direct snowfall at a private homesite in North Lake Tahoe. Each can was fully insulated with redwood sawdust.

There were eight salt treatments viz. 0, 10, 20, 40, 60, 80, 100, and 120 meq l^{-1}. This experiment was a complete randomized block design with six replications.

Treatments were applied five times in February, on the 3rd, 7th, 10th, 16th, and 23rd. One hundred ml of solution were applied per can at each application. On February 3, treatments above 40 meq l^{-1}, were not used, instead those plants received the 40 meq l^{-1} solutions, so that they could be gradually conditioned to the higher dosages. Likewise, on February 7th, treatments above 80 meq l^{-1} received only the 80 meq l^{-1} solution. But from February 10th onwards, the plants in higher treatments (100 and 120 meq l^{-1}) received their designated dosages. In March, the treatments were applied on the 6th, 11th, and 29th, and in April, on the 12th, and 26th. Each time, 100 ml of the treatment solution was applied to the soil except for February 16th when a 150 ml was used. The container media never became dry. Some leaching occurred from drip snow melt.

At the end of February, March, April, and May, oldest needles were sampled from these seedlings to determine their Na and Cl content. Plants were observed for salt damage symptoms and rated on a scale of 0-4 where: 0 = no damage, 1 = first visible symptoms -25, 2 = 26 to 50, 3 = 51 to 75, 4 = 76 to 100% browning and defoliation.

The leaf samples were washed in distilled water to remove surface contamination and oven dried at 70° for 72 hours. Na and Cl concentrations were determined as described previously.

Daily maximum and minimum temperatures from January through May recorded by National Weather Forecasting Service of the National Oceanic and Atmospheric Agency at Tahoe City, about six miles from the test site, were obtained to determine the influence of temperature on Na and Cl uptake (Table 28).

5.72 Results: The average minimum and low maximum air temperatures were low during the course of this experiment and had relatively narrow ranges. The average minimum temperature varied between 23 and 31°C, the high minimum between 32 and 37°F and the low maximum between 27 and 40°F. However, the average maximum and the high maximum temperatures had a greater range. The average maximum temperatures were 33°F in January and February and reached 60°F in May. The high maximum in January was 46°F, in February, 47°F, in March and April, 58°F, and in May, 76°F.

Leaf Na increased only slightly from the end of February until the end of April in the 90 and 120 meq l^{-1} treatments and then increased 4- to 5-fold by the end of May (Table 29, Fig. 29). The uptake of the Na somewhat parallels the maximum temperature levels.

Leaf Cl increased somewhat more during March and April than did the Na, about 2-fold, and then increased very rapidly by the end of May, another 2- to 3-fold increase

Table 28. Temperature data for Tahoe City, 6 miles S.W. of the experimental site[1].

	MAXIMUM TEMPERATURES ° F		MINIMUM TEMPERATURES °F	
Month	Range	Average	Range	Average
January	46-27	33	32-4	24
February	47-30	33	37-12	23
March	58-36	45	35-18	29
April	58-34	47	33-15	26
May	76-40	60	35-24	31

[1]Provided by: National Oceanic and Atmospheric Administration, Reno, Nevada, U.S. Department of Commerce.

Table 29. Temperature Influence Study. Leaf sodium and chloride concentrations of white fir treated with 0-80 meq l^{-1} soil salt applications in February and March 1978. Samples were collected monthly from February to May.

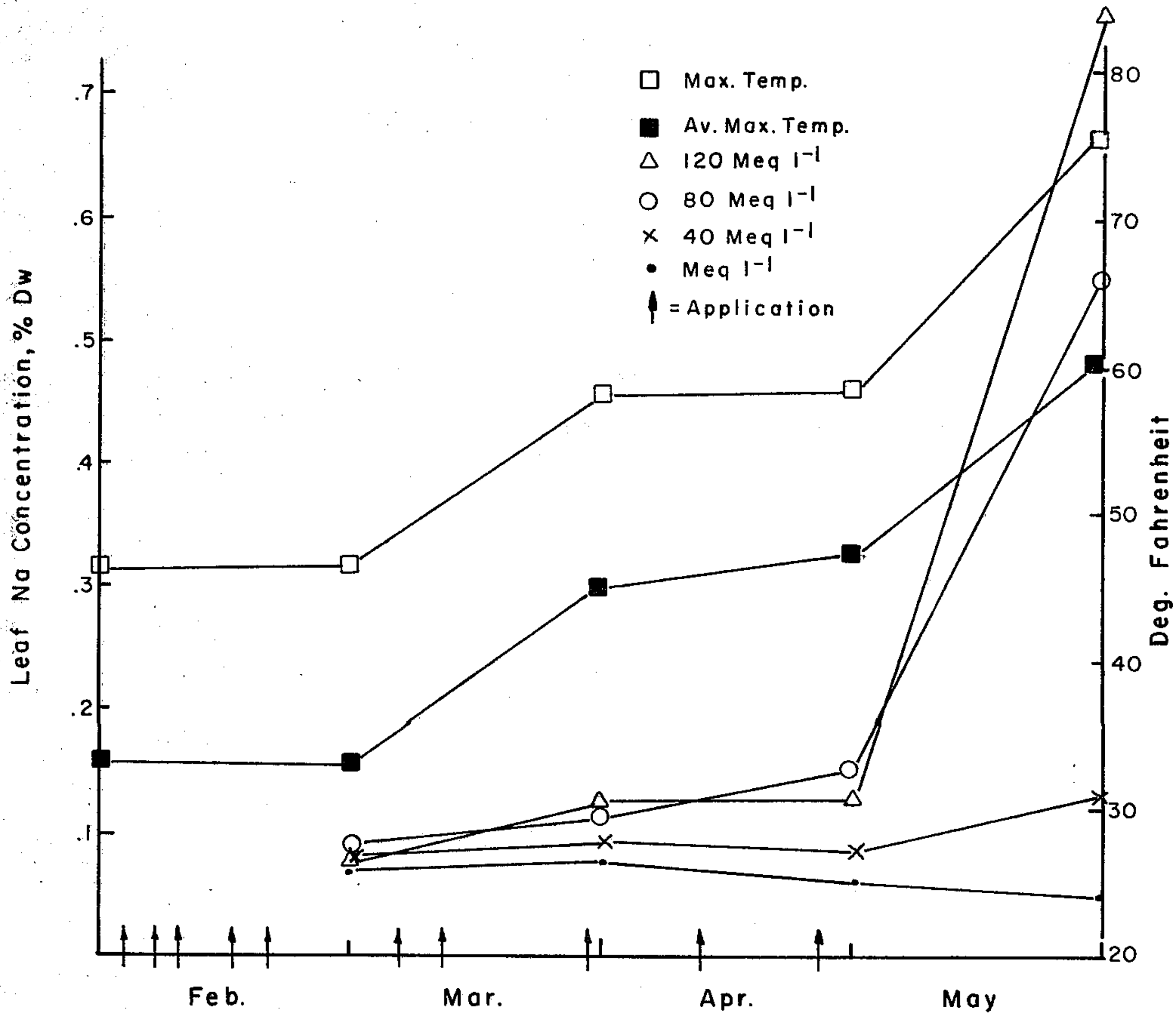
Treatment	Parameter	February % DW		March % DW		April % DW		May % DW		Damage rating
		Na	Cl	Na	Cl	Na	Cl	Na	Cl	
0 meq l^{-1}	$\bar{x}$	0.067	0.082	0.075	0.085	0.058	0.106	0.047	0.118	
	Range	0.050-0.080	0.043-0.128	0.041-0.091	0.042-0.109	0.042-0.084	0.074-0.139	0.036-0.080	0.094-0.148	
	$s_{\bar{x}}$									
10 meq l^{-1}	$\bar{x}$	0.088	0.118	0.103	0.100	0.077	0.192	0.076	0.272	
	Range	0.063-0.175	0.064-0.187	0.054-0.195	0.073-0.165	0.042-0.154	0.098-0.274	0.036-0.123	0.157-0.561	
	$s_{\bar{x}}$									
20 meq l^{-1}	$\bar{x}$	0.076	0.101	0.089	0.095	0.059	0.177	0.082	0.226	
	Range	0.060-0.087	0.064-0.149	0.047-0.120	0.048-0.136	0.036-0.072	0.139-0.261	0.042-0.150	0.115-0.365	
	$s_{\bar{x}}$									
40 meq l^{-1}	$\bar{x}$	0.080	0.103	0.089	0.134	0.082	0.236	0.127	0.455	0.17
	Range	0.063-0.090	0.064-0.170	0.042-0.132	0.098-0.178	0.033-0.136	0.183-0.343	0.058-0.250	0.220-0.713	
	$s_{\bar{x}}$									
60 meq l^{-1}	$\bar{x}$	0.083	0.131	0.089	0.215	0.105	0.377	0.420	0.804	1.33
	Range	0.060-0.113	0.106-0.170	0.072-0.126	0.083-0.348	0.047-0.212	0.235-0.539	0.144-0.684	0.435-1.692	
	$s_{\bar{x}}$									
80 meq l^{-1}	$\bar{x}$	0.084	0.159	0.114	0.220	0.150	0.383	0.547	0.956	1.50
	Range	0.063-0.116	0.035-0.249	0.077-0.168	0.052-0.710	0.106-0.202	0.224-0.851	0.342-0.978	0.463-2.133	
	$s_{\bar{x}}$									

(continued)

Table 29. (Continued)

Treatment	Parameter	February % DW Na	February % DW Cl	March % DW Na	March % DW Cl	April % DW Na	April % DW Cl	May % DW Na	May % DW Cl	Damage rating
100 meq l^{-1}	$\bar{x}$	0.086	0.136	0.104	0.217	0.221	0.621	0.814	1.625	2.0
	Range	0.054-0.116	0.035-0.249	0.058 0.220	0.056-0.426	0.053 0.426	0.091 1.553	0.265-1.160	0.526-3.113	
	$s_{\bar{x}}$									
120 meq l^{-1}	$\bar{x}$	0.080	0.184	0.126	0.282	0.127	0.476	0.766	1.345	2.17
	Range	0.060-0.099	0.022-0.320	0.070-0.190	0.035-0.530	0.023-0.201	0.161-0.731	0.469-1.035	0.382-2.619	
	$s_{\bar{x}}$									

Figure 29. Temperature Influence Study. Leaf sodium concentrations at four sampling dates at four levels of applied Na Cl. maximum and average maximum air temperatures during the study are also given.



in one month (Table 29, Fig. 30). The uptake of Cl and the maximum temperature levels as plotted are strikingly similar.

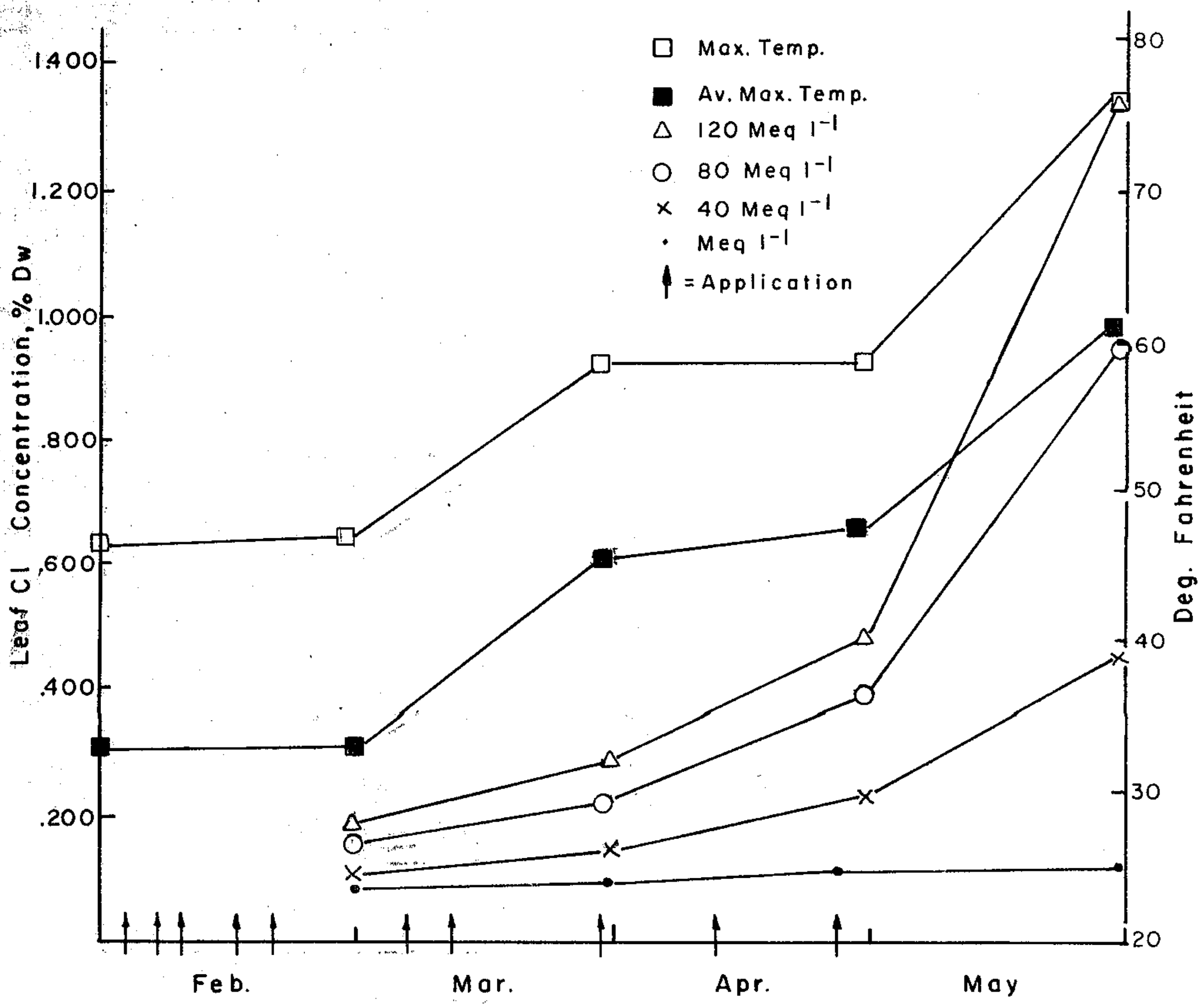
These results are similar to those of other workers who have shown that uptake of salts and development of damage symptoms occur more rapidly in the spring than in the winter (20). This suggests that the addition of salt during late winter and early spring months may be more detrimental to the roadside vegetation than the midwinter applications. There is less uptake of salt when temperatures are low. At this time the roots are relatively inactive. Salts applied in midwinter would have more time to be diluted by additional snowfall and early spring rains and to be leached from the soil than salts applied later in the season.

5.8 Bark Uptake Study

5.81 Materials and methods: This study was conducted from March to August 1978. Seventeen white firs, eleven Jeffrey pines, and five incense cedars, established in five gallon cans were placed in a lathhouse. These plants obtained from Christensen Nursery, Saratoga, California, were more than 10 years old and 30-36 in. high.

An aluminum foil cup, 4" diameter and 1" cm deep (10.6 x 2.54 cm) was attached around the base of the stem of each plant. These cups were waterproofed so that there would not be any leakage of salt solution into the root zone. Fill material, 300 gm cup, with a content of 11 meq l^{-1} Na and 14 meq l^{-1} Cl collected near a highway in Lake Tahoe Basin, was added.

Figure 30. Temperature Influence Study. Leaf chloride concentration at four sampling dates at four levels of applied Na Cl. maximum and average maximum air temperatures during the study are also given.



There were three treatments of 30, 100, and 300 meq l^{-1} NaCl with five replications for white fir. Treatments for Jeffrey pine and incense cedar were 30 and 300 meq l^{-1} with five and two replications respectively. Four seedlings, two of white fir and one each of Jeffrey pine and incense cedar received no salt. The cups were kept covered with aluminum foil until the end of April to prevent entry of rain water. However, on May 2nd, roots were observed which had been initiated from the area surrounded by fill material in three white fir, two in the 30 meq l^{-1} treatment and one in the 100 meq l^{-1} treatment. Subsequently, the cups were left uncovered to discourage further root initiation and the treatments were added more frequently to keep the fill saturated. During the entire course of this experiment, plants were watered with tap water. No fertilizer was added. The experiment was terminated in June because of the possibility of further root initiation and of breakdown of the seals between the cups and trunks.

Oldest leaves were collected from each seedling in February, April, and June to determine their Na and Cl concentrations. The samples were oven-dried at 70° for 72 hours and ground through a 40 mesh screen in a Wiley Mill. Na and Cl concentrations were determined as described previously. The plants were observed every month for salt damage. None was observed through the June sampling date.

5.82 Results: The mean leaf Na and Cl concentrations are given in Table 30. Initial levels of both Na and Cl were low in Jeffrey pine and these remained low through the experiment.

Table 30. Bark Uptake Study. Mean leaf sodium and chloride (% DW) in Jeffrey pine, white fir, and incense cedar on four sampling dates. Fill materials around the stem was treated with NaCl solutions from March onward.

Species	Treatment meq l^{-1}	Feb. 1978		April 1978 % DW		June 1978	
		Na	Cl	Na	Cl	Na	Cl
Jeffrey pine	30	0.041	0.036	0.039	0.021	0.023	0.014
	300	0.041	0.023	0.028	0.014	0.023	0.039
White fir	30	0.033	0.050	0.036	0.029	0.028	0.091
	100	0.038	0.046	0.049	0.034	0.059	0.183
	300	0.028	0.063	0.040	0.050	0.084	0.365
Incense cedar	30	0.065	0.342	0.038	0.323	0.039	0.342
	100	0.057	0.599	0.049	0.448	0.100	0.852

The initial levels of Na and Cl were low in white fir. By June there were somewhat higher levels of Na in the 100 and 300 meq l^{-1} treatments but these were below 0.05% dry weight even in the 300 meq l^{-1} treatment. Leaf Cl levels in April were low but there was an increase in all treatments on the June sampling date (Fig. 31). It could not be determined whether this was due to bark uptake or the beginnings of root initiation.

Leaf Na concentration in incense cedar was low initially and on the April sampling date. In the 100 meq l^{-1} treatment the level had reached 0.1% by June but was unaffected in the lower salt treatment. Initial leaf chloride levels were fairly high in this species. They remained nearly constant for the 30 meq l^{-1} treatment throughout the experiment. In the 300 meq l^{-1} the chloride level dropped on the April sampling date and then increased somewhat on the June sampling date. The data for incense cedar are plotted in Fig. 32.

The data indicate that bark uptake of salt was negligible from March through May or June. In the study area, much of the salt would be leached out of the sand-cinder side castings by June. It is concluded that these materials are not a serious stress factor in the study area.

5.9 Seasonal Salt Fluctuation Study

5.91 Materials and methods: This study, conducted from October 1977 to August 1978, was initiated to supplement the Intensive Survey of 1976 by giving a greater diversity of sampling distances between 10 and 100 feet of the highway, and, through more frequent sampling times, to study

Figure 31. Bark Uptake Study. Leaf chloride concentration (% dry wt.) in white fir treated with 30, 100, and 300 meq l^{-1} NaCl as a function of time.

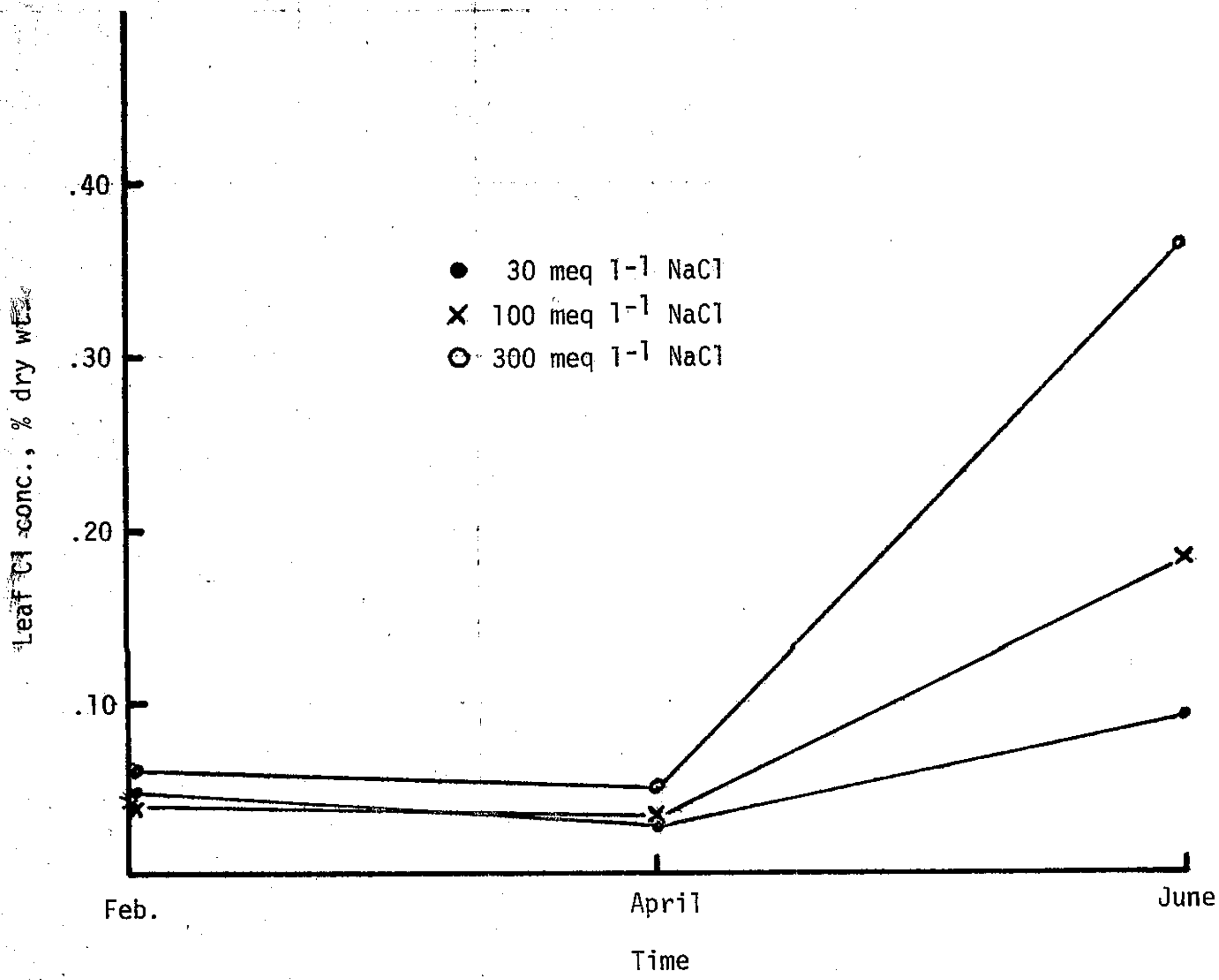
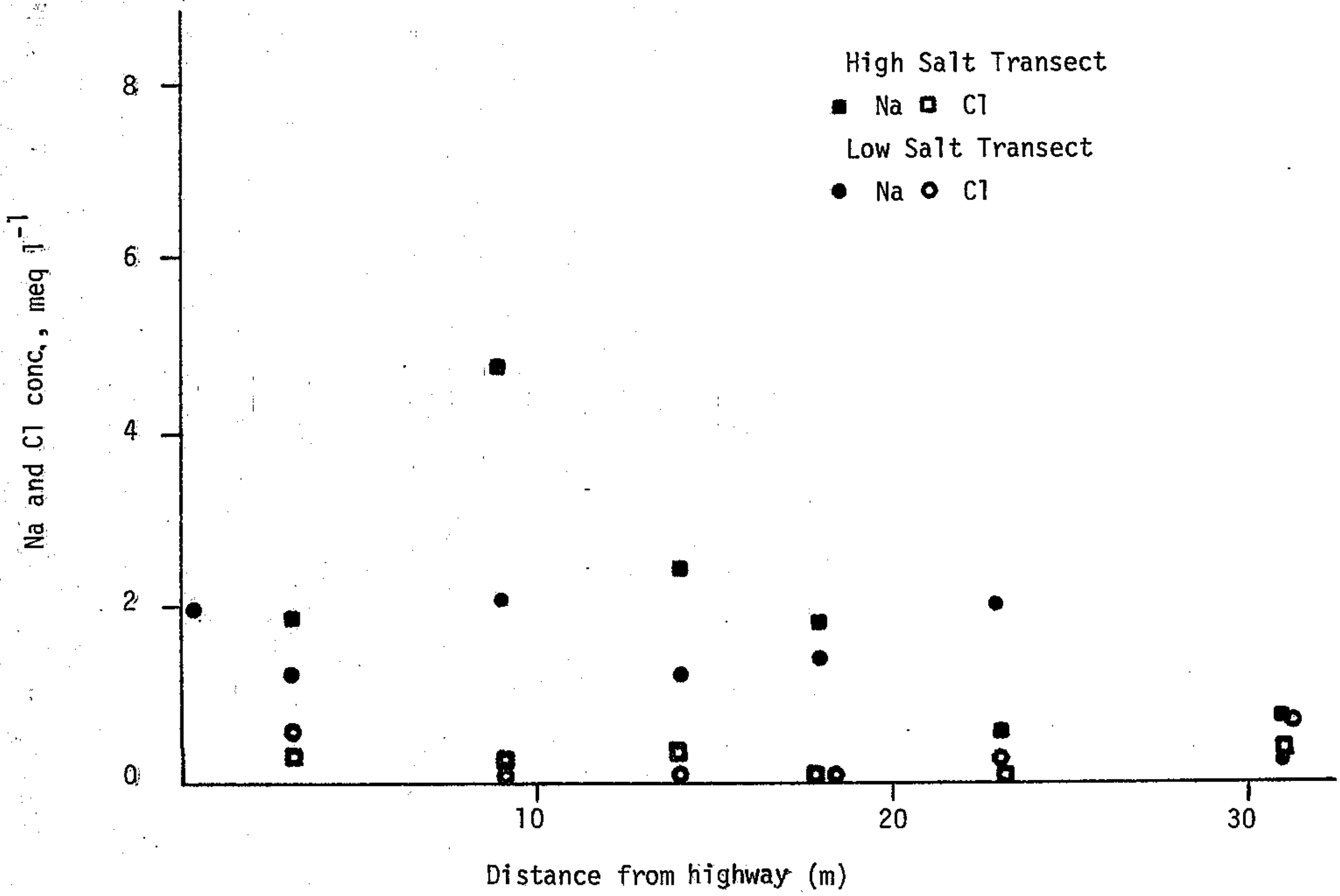


Figure 4. Salt concentration of the soil solution as a function of the distance from the paved roadway. Data provided by State of California, Division of Highways, Transportation Laboratory. Samples were collected in spring, 1974. High salt transect was at site 15 and low salt transect was at site 1.



seasonal trends in soils and tissue salt levels, and in damage ratings.

Three of the original 15 study sites were selected for this study: Site 11 in Sugar Pine Point State Park (03-ED-89, PM 26.4); Site 4, immediately west of the Baxter Maintenance Station (03-Pla-80, PM 50.26); and Site 13, east of Kyburz (03-ED-50, PM 51.43). (See Fig. 2.) This salt application rates in previous years on these sites are given in Table 31.

Two species of trees were studied, Jeffrey pine and incense cedar. Transects were taken: four at Site 11, six at Site 4, and 10 at Site 13. One tree of each species was sampled at each of seven distance intervals in each transect. Distance intervals were 10, 20, 30, 40, 60, 100, and 200 feet (3.1, 6.1, 9.1, 12.2, 18.3, 30.5, and 61 meters) from the pavement edge. Each transect was considered a replication. There were, of each species, 28 trees at Site 11, 42 at Site 4, and 70 at Site 13, a total of 140 trees. Trees were 7-15 feet tall and located downhill from the pavement edge.

Damage was rated on a scale of 0-4 where: 0 = no damage, 1 = first, observable symptoms to 25, 2 = 26-50, 3 = 51-75, and 4 = 76-100% browning and defoliation. These ratings were taken in October 1977, May, June, and August 1978.

Oldest green tissues (usually three year old needles) of Jeffrey pine and the oldest leaf tissue of incense cedar, without and sometimes with symptoms were collected from each tree to determine the Na and Cl levels. Sampling

Table 31. Salt Application Rate (Tons/lane mile) on Seasonal Fluctuation Study Sites.

Site	1974-75	1975-76	1976-77	1977-78
11	4.4	2.6	0.6	2.2
4	9.3	4.9	13.1	8.2
13	15.2	7.9	4.1	10.9

was in October 1977, April, May, June, and August 1978.

Leaf samples were oven-dried at 70°F for 72 hours and ground through a 40-mesh screen in a Wiley mill. Sodium and chloride were determined as described previously.

One soil sample per tree was taken in October 1977, May and August 1978 at 0-12 in. Soil EC_e, and Na and Cl levels were determined as described previously.

5.92 Results:

5.92.1 General Patterns: The overall seasonal fluctuation patterns of leaf Na and Cl, and of soil analyses for EC_e, Na and Cl were very similar for both species studied and among all sites (Tables 32-43, Figs. 33-46). The quantitative values varied, of course, between species, and among sites, and for distance intervals within sites.

Leaf Na and Cl (Tables 32, 34, 36, 38, 40 and 42, Figs. 33, 35, 37, 41, 43, 45), were always highest at the 10 ft. distance interval and usually decreased as distance from the highway increased. In a few cases the leaf Na and Cl concentrations at one distance interval were higher than those at a distance interval nearer the highway, e.g. in Jeffrey pine at Site 11, levels at 40 feet were higher than those at 20 and 30 feet. For trees 60 or more feet from the highway, in most cases, these levels were below the estimated toxicity threshold levels. At all but the 100 and 200 foot distance intervals, levels were usually lowest in October 1977, highest in May 1978, and had decreased somewhat by August 1978. However, August 1978 levels were almost always higher than those in October

1977. Thus, one can conclude that except where NaCl in the soil is at or near background levels there will be an increase in leaf Na and Cl with time, until either the leaves are damaged or they abcise normally.

The soil parameters EC_e, Na and Cl had, for each site and distance interval, almost identical patterns as a function of time (Tables 33, 35, 37, 39, 41, 43, Figs. 34, 36, 38, 42, 44, 46). The October 1977 sampling was at the end of two years of severe drought (see Table 1). The levels of EC_e, Na and Cl at the distance intervals nearest the road were highest at this sampling date. Even though additional salt was applied during the winter of 1977-78, soil salt levels dropped dramatically by May 1978 after a season of normal or above normal precipitation. They dropped even further by August 1978. The levels of these parameters at 100, 200, and sometimes at 60 feet changed very little because they were already at or near background levels.

5.92.2 <u>Species, Sites and Distance Comparisons</u>: The concentration of leaf Cl and soil EC_e will be discussed by species and by site and distance intervals. Soil Na and Cl patterns were very similar to those for EC_e (Tables 33, 35, 37, 39, 41, 43) and therefore are not discussed separately.

5.92.21 Jeffrey pine

Site 11, 2.2 T salt/lane mile. Tables 32 and 33, Figures 33 and 34. On this site, the leaf Cl concentration at 40 feet was intermediate between that at 10, and at 20 and 30 feet. The higher levels at 40 feet, compared to 20 and 30

Table 32. Seasonal Fluctuation Study: Leaf sodium and chloride concentrations in Jeffrey pine from October 1977 to August 1978 at varying distances from the highway. Damag ratings are also given. Data include means, range and standard errors of the means.

Site[1]	Distance	Parameter	Oct. 1977 % DW Na	Oct. 1977 % DW Cl	Oct. 1977 Damage	April 1978 % DW Na	April 1978 % DW Cl	May 1978 % DW Na	May 1978 % DW Cl	May 1978 Damage	June 1978 % DW Na	June 1978 % DW Cl	June 1978 Damage	August 1978 % DW Na	August 1978 % DW Cl	August 1978 Damage
11	10 ft	$\bar{x}$	0.148	0.267	1.25	0.186	0.329	0.135	0.459	1.75	0.159	0.437	2	0.152	0.366	2
2.2T		Range	0.161	0.385	1	0.116	0.373	0.173	0.523	1	0.059	0.621	2	0.066	0.576	2
n = 4		$s_{\bar{x}}$	0.037	0.083	0.25	0.025	0.088	0.036	0.119	0.25	0.012	0.134	0.41	0.017	0.131	0.41
	20 ft	$\bar{x}$	0.121	0.110	0.5	0.126	0.142	0.117	0.202	0.5	0.128	0.161	0.5	0.101	0.107	0.5
		Range	0.094	0.304	1	0.081	0.221	0.065	0.328	1	0.067	0.390	1	0.064	0.284	1
		$s_{\bar{x}}$	0.019	0.071	0.29	0.017	0.049	0.014	0.069	0.29	0.016	0.089	0.29	0.014	0.066	0.29
	30 ft	$\bar{x}$	0.065	0.116	0.25	0.073	0.178	0.085	0.226	0.25	0.062	0.166	0.25	0.059	0.174	0.25
		Range	0.072	0.345	1	0.114	0.407	0.062	0.416	1	0.062	0.453	1	0.034	0.603	1
		$s_{\bar{x}}$	0.017	0.081	0.25	0.024	0.098	0.014	0.096	0.25	0.014	0.111	0.25	0.008	0.149	0.25
	40 ft	$\bar{x}$	0.032	0.169	0.50	0.033	0.257	0.062	0.279	0.75	0.038	0.343	0.75	0.043	0.262	0.75
		Range	0.041	0.616	2	0.024	0.827	0.041	0.891	3	0.046	1.291	3	0.017	1.004	3
		$s_{\bar{x}}$	0.010	0.151	0.50	0.005	0.195	0.008	0.219	0.75	0.010	0.319	0.75	0.004	0.250	0.75
	60 ft	$\bar{x}$	0.028	0.026	0	0.035	0.042	0.044	0.103	0	0.033	0.081	0	0.034	0.065	0
		Range	0.041	0.076	-	0.024	0.064	0.007	0.159	-	0.022	0.186	-	0.009	0.133	-
		$s_{\bar{x}}$	0.010	0.018	-	0.006	0.015	0.002	0.034	-	0.005	0.040	-	0.002	0.033	-
	100 ft	$\bar{x}$	0.025	0.050	0	0.028	0.050	0.040	0.080	0	0.028	0.069	0	0.036	0.065	0
		Range	0.025	0.183	-	0.010	0.173	0.010	0.159	-	0.012	0.222	-	0.007	0.213	-
		$s_{\bar{x}}$	0.006	0.046	-	0.002	0.043	0.002	0.038	-	0.003	0.054	-	0.001	0.053	-
	200 ft	$\bar{x}$	0.020	0.005	0	0.024	0.006	0.038	0.030	0	0.024	0.009	0	0.032	0.011	0
		Range	0.006	0.004	-	0.004	0.002	0.011	0.054	-	0.016	0.001	-	0.009	0.009	-
		$s_{\bar{x}}$	0.002	0.001	-	0.001	<0.001	0.003	0.012	-	0.003	<0.001	-	0.002	0.002	-

[1]Site number, salt application 1977-1978, number of replications.

Table 33. Seasonal Fluctuation Study: Soil EC_e, sodium and chloride under Jeffrey pine at several distances from the highway on three sampling dates.

			Oct. 1977			May 1978			August 1978		
				meq l^{-1}			meq l^{-1}			meq l^{-1}	
Site[3]	Distance	Parameter	EC_e[1,2]	Na[1]	Cl[1]	EC_e	Na	Cl	EC_e	Na	Cl
11	10 ft	$\bar{x}$	0.405	3.090	2.100	0.325	2.980	1.775	0.207	1.752	1.000
2.2T		range	0.340	4.160	2.800	0.360	3.400	2.800	0.210	1.160	1.500
n = 4		$s_{\bar{x}}$	0.075	1.097	0.642	0.077	0.698	0.650	0.044	0.294	0.324
	20 ft	$\bar{x}$	0.290	2.905	1.950	0.152	1.070	0.575	0.215	1.100	0.325
		range	0.460	5.720	5.800	0.090	1.180	1.000	0.250	1.240	0.400
		$s_{\bar{x}}$	0.104	1.279	1.373	0.022	0.271	0.225	0.054	0.266	0.085
	30 ft	$\bar{x}$	0.265	1.500	1.150	0.207	1.000	0.625	0.210	0.777	0.525
		range	0.130	1.840	1.800	0.110	2.040	1.500	0.280	1.420	1.300
		$s_{\bar{x}}$	0.032	0.386	0.419	0.027	0.488	0.359	0.065	0.319	0.325
	40 ft	$\bar{x}$	0.197	0.760	0.800	0.167	0.660	0.500	0.097	0.370	0.100
		range	0.200	0.920	0.500	0.120	0.200	0.500	0.100	0.220	0
		$s_{\bar{x}}$	0.043	0.207	0.108	0.025	0.049	0.122	0.021	0.052	0
	60 ft	$\bar{x}$	0.202	0.705	0.575	0.160	0.565	0.325	0.102	0.430	0.125
		range	0.210	0.620	0.300	0.160	0.700	0.600	0.030	0.120	0.100
		$s_{\bar{x}}$	0.045	0.147	0.075	0.038	0.152	0.144	0.006	0.025	0.025
	100 ft	$\bar{x}$	0.227	0.990	0.875	0.145	0.535	0.250	0.157	0.535	0.275
		range	0.390	0.740	1.500	0.170	0.280	0.500	0.120	0.520	0.400
		$s_{\bar{x}}$	0.085	0.167	0.330	0.037	0.066	0.119	0.025	0.122	0.103
	200 ft	$\bar{x}$	0.125	0.407	0.500	0.190	0.615	0.150	0.190	0.430	0.125
		range	0.020	0.280	1.200	0.230	1.140	0.100	0.320	0.180	0.100
		$s_{\bar{x}}$	0.005	0.058	0.274	0.054	0.264	0.029	0.072	0.040	0.025

[1]saturation paste extract
[2]millimhos/cm.
[3]Site number, salt application 1977-1978, number of replications.

Figure 33. Seasonal Fluctuation Study. Leaf chloride concentration (%DW) in Jeffrey pine as a function of time, site 11, 2.2T salt/lane mile.

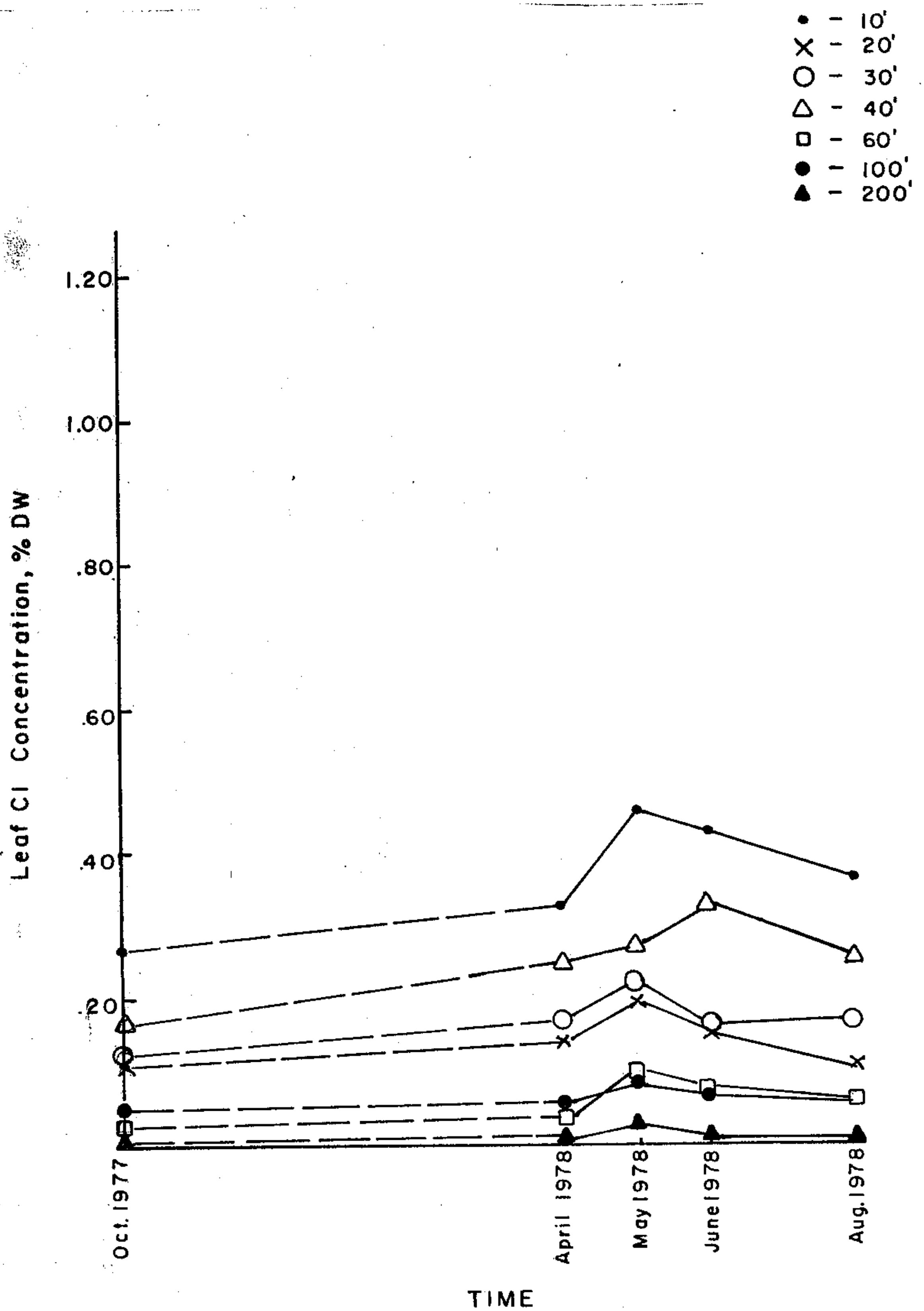
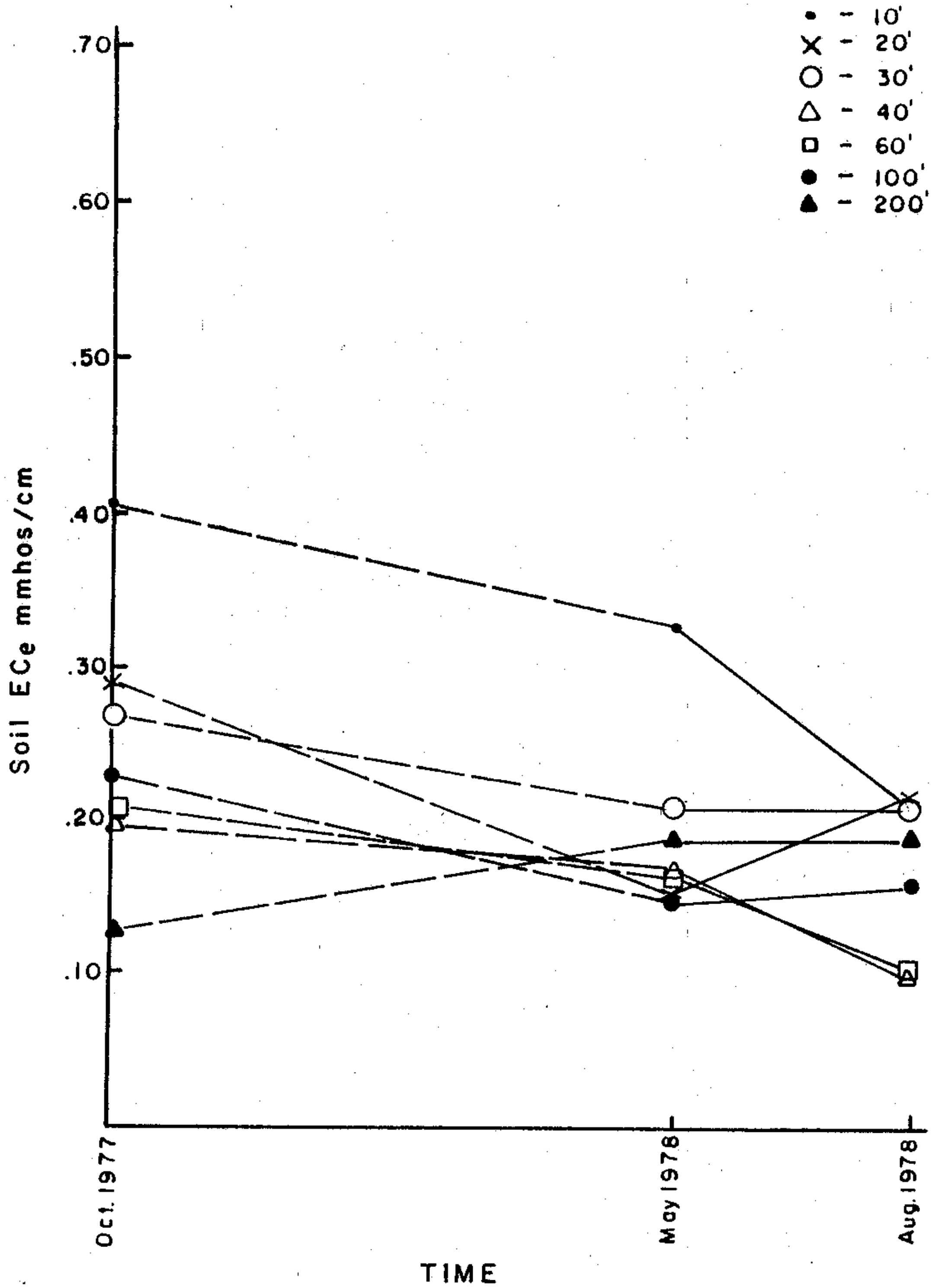


Figure 34. Seasonal Fluctuation Study. Soil EC_e(millimhos/cm) under Jeffrey pine as a function of time, site 11, 2.2T salt/lane mile.



feet could not be explained by the estimates of spray or runoff possibilities. At 60 feet and beyond, levels were low. Leaf Cl at 10 feet was 0.27%, below the estimated threshold level (0.4%) in October 1977, increased to slightly above the level in May and June 1978, (0.46 and 0.44%), and decreased to slightly below the level (0.37%) by August.

The EC_e data of October 1977 and May 1978 at different distance intervals did not correlate well with the leaf Cl concentrations. At 40 feet, EC_e was lower than at 20 and 30 feet and were almost identical to those at 60 feet. This lack of correlation may have been due to leaching of soils that may have occurred prior to sampling and/or to differences in exposure to salt from aerosols.

Site 4, 8.2 T salt/lane mile. Table 34 and 35 and Figures 35 and 36. Leaf Cl concentrations at 10 and 20 feet were essentially the same and very similar to those at 10 feet on Site 11. These peaked in April and May 1978 at about 0.47% and declined to at or just below the estimated threshold level by August. At 30 feet and beyond the levels were all below 0.16% Cl.

The EC_e data and leaf Cl concentrations generally were arrayed in the same order on this site. However, the EC_e was higher at 10 and 20 feet than at 10 feet in Site 11 but the leaf Cl levels at 10 feet were almost the same on both sites.

Site 13, 10.9 T salt/lane mile. Table 36 and 37, Figures 37 and 38. Leaf Cl concentrations were above estimated threshold levels at 10 and 20 feet on all sampling dates,

Table 34. Seasonal Fluctuation Study: Leaf sodium and chloride concentrations in Jeffrey pine from October 1977 to August 1978 at varying distances from the highway. Damage ratings are also given. Data include means, range and standard errors of the means.

Site[2]	Distance	Parameter	Oct. 1977 % DW Na	Oct. 1977 % DW Cl	Oct. 1977 Damage	April 1978[1] % DW Na	April 1978[1] % DW Cl	May 1978 % DW Na	May 1978 % DW Cl	May 1978 Damage	June 1978 % DW Na	June 1978 % DW Cl	June 1978 Damage	August 1978 % DW Na	August 1978 % DW Cl	August 1978 Damage
4	10 ft	$\bar{x}$	0.248	0.263	1.5	0.343	0.433	0.388	0.476	2.7	0.333	0.416	2.83	0.457	0.330	2.83
8.2T		Range	0.210	0.314	1	0.194	0.137	0.261	0.293	1	0.297	0.280	1	0.342	0.142	1
n = 6		$s_{\bar{x}}$	0.034	0.049	0.22	0.057	0.040	0.040	0.049	0.21	0.049	0.047	0.17	0.050	0.021	0.17
	20 ft	$\bar{x}$	0.282	0.291	1.5	0.481	0.473	0.383	0.453	2.17	0.380	0.407	2.33	0.531	0.402	2.5
		Range	0.119	0.310	1	0.229	0.149	0.183	0.328	1	0.358	0.585	1	0.227	0.363	1
		$s_{\bar{x}}$	0.016	0.045	0.22	0.076	0.047	0.031	0.060	0.17	0.059	0.086	0.21	0.036	0.060	0.22
	30 ft	$\bar{x}$	0.091	0.068	0.5	0.086	0.074	0.162	0.157	0.5	0.162	0.141	0.5	0.224	0.101	0.5
		Range	0.117	0.166	1	0.042	0.054	0.282	0.310	1	0.357	0.310	1	0.453	0.284	1
		$s_{\bar{x}}$	0.020	0.030	0.22	0.012	0.017	0.050	0.059	0.22	0.057	0.053	0.22	0.079	0.046	0.22
	40 ft	$\bar{x}$	0.092	0.047	0	0.131	0.122	0.124	0.150	0	0.139	0.098	0	0.111	0.060	0
		Range	0.088	0.094	-	0.026	0.114	0.149	0.248	-	0.297	0.133	-	0.143	0.089	-
		$s_{\bar{x}}$	0.014	0.013	-	0.008	0.034	0.022	0.035	-	0.048	0.023	-	0.023	0.016	-
	60 ft	$\bar{x}$	0.057	0.032	0	0.067	0.086	0.072	0.062	0	0.057	0.032	0	0.053	0.017	0
		Range	0.041	0.065	-	0.047	0.080	0.059	0.107	-	0.037	0.045	-	0.030	0.018	-
		$s_{\bar{x}}$	0.006	0.012	-	0.014	0.023	0.008	0.016	-	0.005	0.008	-	0.004	0.002	-
	100 ft	$\bar{x}$	0.052	0.012	0	0.041	0.020	0.052	0.025	0	0.039	0.008	0	0.040	0.009	0
		Range	0.030	0.016	-	0.014	0.038	0.030	0.035	-	0.030	0.002	-	0.029	0.001	-
		$s_{\bar{x}}$	0.005	0.003	-	0.005	0.013	0.005	0.006	-	0.005	<0.001	-	0.004	<0.001	-
	200 ft	$\bar{x}$	0.040	0.010	0	0.057	0.036	0.046	0.035	0	0.038	0.008	0	0.043	0.010	0
		Range	0.026	0.012	-	0.028	0	0.033	0.057	-	0.020	0.002	-	0.036	0.010	-
		$s_{\bar{x}}$	0.005	0.002	-	0.008	0	0.005	0.011	-	0.003	<0.001	-	0.006	0.002	-

[1]Three samples only in April.
[2]Site number, salt application 1977-1978, number of replications.

Table 35. Seasonal Fluctuation Study: Soil EC_e, sodium and chloride under Jeffrey pine at several distances from the highway on three sampling dates.

Site[3]	Distance	Parameter	Oct. 1977 EC_e[1,2]	Oct. 1977 Na[1] (meq l^{-1})	Oct. 1977 Cl[1] (meq l^{-1})	May 1978 EC_e	May 1978 Na (meq l^{-1})	May 1978 Cl (meq l^{-1})	August 1978 EC_e	August 1978 Na (meq l^{-1})	August 1978 Cl (meq l^{-1})
4	10 ft	$\bar{x}$	0.638	5.830	2.700	0.253	2.335	0.617	0.248	2.080	0.517
8.2T		range	0.850	8.810	6.000	0.130	3.060	0.500	0.140	0.940	0.300
n = 6		$s_{\bar{x}}$	0.113	1.211	0.998	0.021	0.474	0.095	0.018	0.177	0.048
	20 ft	$\bar{x}$	0.567	4.960	1.622	0.333	2.473	1.467	0.232	2.033	0.700
		range	0.630	6.280	2.030	0.220	2.480	2.600	0.150	0.800	1.100
		$s_{\bar{x}}$	0.094	1.040	0.345	0.032	0.414	0.428	0.024	0.109	0.155
	30 ft	$\bar{x}$	0.228	2.012	1.317	0.333	2.797	1.650	0.188	1.307	0.650
		range	0.280	2.940	2.900	0.200	1.480	1.200	0.120	1.260	1.700
		$s_{\bar{x}}$	0.047	0.497	0.457	0.033	0.226	0.238	0.020	0.239	0.262
	40 ft	$\bar{x}$	0.273	1.893	1.233	0.205	1.317	0.667	0.153	1.010	0.267
		range	0.220	2.380	2.400	0.040	0.940	0.500	0.060	0.880	0.300
		$s_{\bar{x}}$	0.033	0.362	0.359	0.008	0.156	0.071	0.010	0.160	0.049
	60 ft	$\bar{x}$	0.198	1.038	0.533	0.182	1.107	0.483	0.100	0.720	0.200
		range	0.200	1.040	0.600	0.140	1.140	0.700	0.050	0.360	0.300
		$s_{\bar{x}}$	0.030	0.161	0.088	0.024	0.177	0.111	0.009	0.058	0.045
	100 ft	$\bar{x}$	0.163	0.733	0.467	0.118	0.490	0.233	0.103	0.527	0.100
		range	0.120	0.360	1.100	0.090	0.360	0.500	0.070	0.440	0
		$s_{\bar{x}}$	0.017	0.049	0.167	0.013	0.060	0.076	0.012	0.078	0
	200 ft	$\bar{x}$	0.142	0.638	0.333	0.122	0.515	0.150	0.107	0.438	0.100
		range	0.150	0.900	1.200	0.090	0.160	0.100	0.010	0.050	0
		$s_{\bar{x}}$	0.022	0.139	0.196	0.013	0.028	0.022	0.002	0.007	0

[1]saturation paste extract
[2]millimhos/cm.
[3]Site number, salt application 1977-1978, number of replications.

Figure 35. Seasonal Fluctuation Study. Leaf chloride concentration (%DW) in Jeffrey pine as a function of time, site 4, 8.2T salt/lane mile.

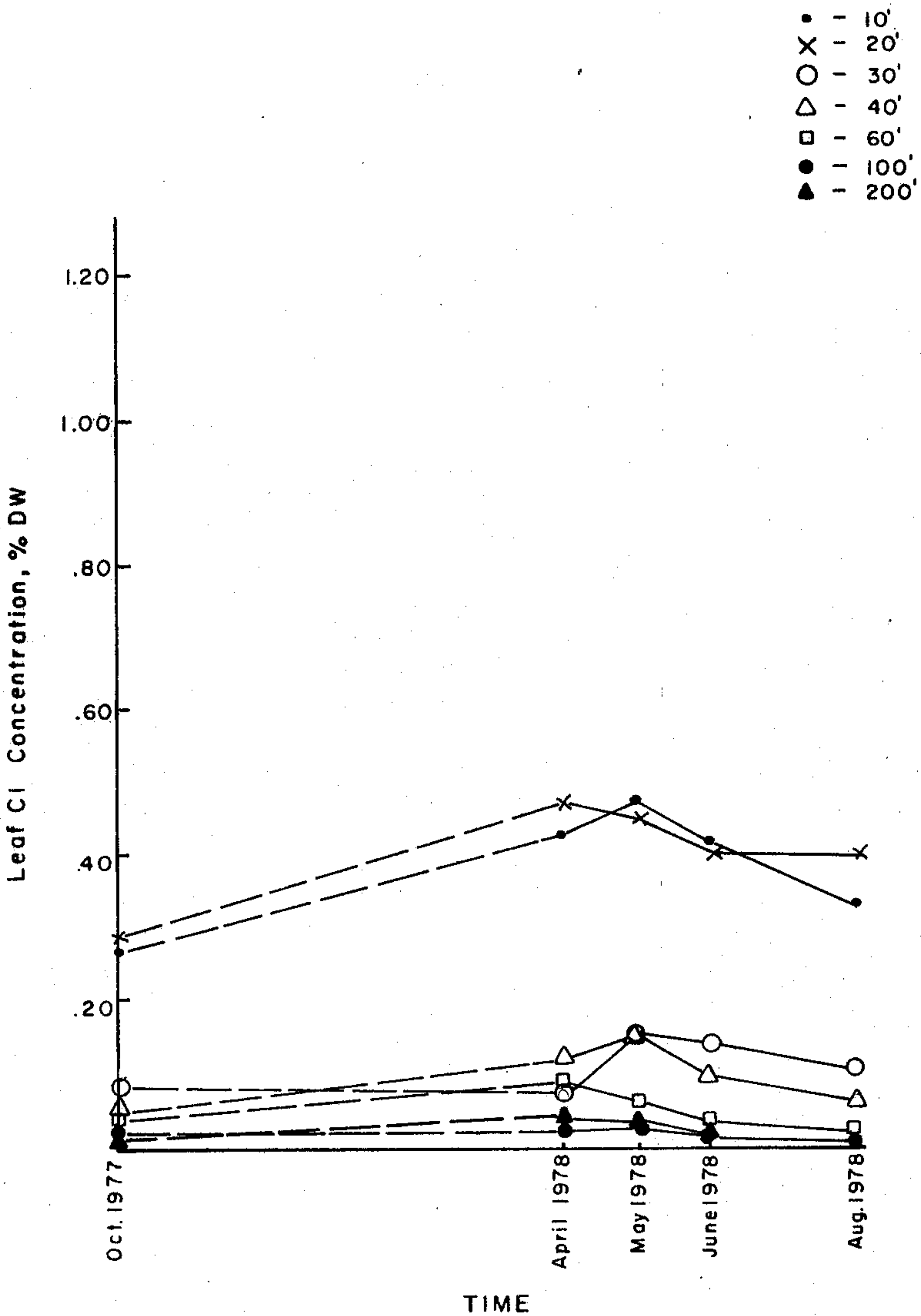


Figure 36. Seasonal Fluctuation Study. Soil EC_e(Millimhos/cm) under Jeffrey pine as a function of time, site 4, 8.2T salt/lane mile.

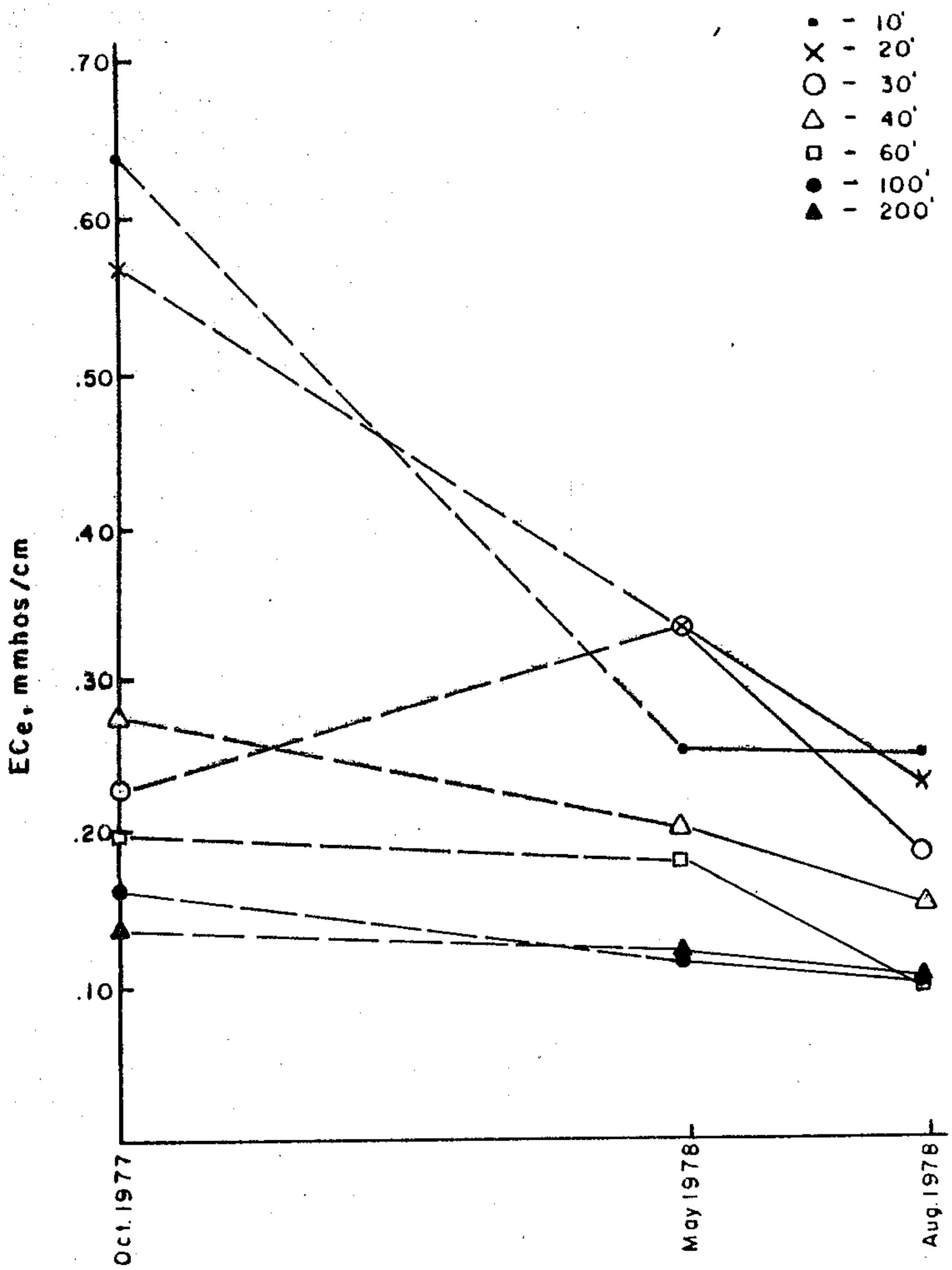


Table 36. Seasonal Fluctuation Study: Leaf and chloride concentrations in Jeffrey pine from October 1977 to August 1978 at varying distances from the highway. Damage ratings are also given. Data include means, range and standard errors of the means.

			Oct. 1977			April 1978		May 1978			June 1978			August 1978		
			% DW			% DW		% DW			% DW			% DW		
Site[1]	Distance	Parameter	Na	Cl	Damage	Na	Cl	Na	Cl	Damage	Na	Cl	Damage	Na	Cl	Damage
13	10 ft	$\bar{x}$	0.443	0.696	2.5	0.583	0.892	0.629	0.993	3	0.509	0.910	3.5	0.631	0.898	3.8
10.9T		Range	0.679	0.674	1	0.736	0.555	0.846	0.666	2	0.662	0.533	2	0.448	0.603	1
n = 10		$s_{\bar{x}}$	0.059	0.074	0.17	0.071	0.060	0.091	0.073	0.15	0.052	0.058	0.22	0.040	0.058	0.13
	20 ft	$\bar{x}$	0.306	0.570	1.8	0.316	0.698	0.351	0.853	2.5	0.327	0.717	2.6	0.326	0.716	2.8
		Range	0.548	0.861	3	0.428	0.745	0.602	1.252	3	0.585	0.781	2	0.572	1.153	2
		$s_{\bar{x}}$	0.051	0.079	0.29	0.042	0.067	0.059	0.105	0.27	0.057	0.080	0.22	0.068	0.108	0.25
	30 ft	$\bar{x}$	0.116	0.245	0.8	0.150	0.360	0.162	0.412	0.8	0.172	0.417	0.9	0.106	0.302	0.9
		Range	0.135	0.479	2	0.270	0.515	0.435	0.622	2	0.480	0.665	2	0.165	0.497	2
		$s_{\bar{x}}$	0.015	0.049	0.2	0.027	0.055	0.041	0.060	0.2	0.048	0.064	0.23	0.018	0.050	0.23
	40 ft	$\bar{x}$	0.068	0.171	0.3	0.077	0.212	0.092	0.209	0.2	0.072	0.189	0.2	0.061	0.144	0.2
		Range	0.072	0.479	1	0.108	0.453	0.280	0.435	1	0.114	0.537	1	0.088	0.417	1
		$s_{\bar{x}}$	0.009	0.051	0.15	0.012	0.049	0.027	0.043	0.13	0.012	0.053	0.13	0.010	0.045	0.13
	60 ft	$\bar{x}$	0.040	0.036	0	0.041	0.090	0.048	0.166	0	0.047	0.075	0	0.045	0.044	0
		Range	0.085	0.189	-	0.072	0.195	0.077	0.302	-	0.052	0.135	-	0.059	0.107	-
		$s_{\bar{x}}$	0.008	0.018	-	0.007	0.018	0.008	0.029	-	0.005	0.015	-	0.006	0.014	-
	100 ft	$\bar{x}$	0.040	0.113	0.1	0.035	0.165	0.040	0.177	0.1	0.040	0.173	0.1	0.039	0.155	0.1
		Range	0.049	0.615	1	0.043	0.468	0.039	0.462	1	0.028	0.417	1	0.026	0.683	1
		$s_{\bar{x}}$	0.005	0.060	0.1	0.004	0.050	0.004	0.049	0.1	0.003	0.050	0.1	0.003	0.068	0.1
	200 ft	$\bar{x}$	0.028	0.037	0	0.025	0.068	0.029	0.085	0	0.036	0.067	0	0.031	0.036	0
		Range	0.024	0.085	-	0.022	0.097	0.019	0.142	-	0.024	0.161	-	0.031	0.143	-
		$s_{\bar{x}}$	0.002	0.011	-	0.002	0.010	0.002	0.014	-	0.003	0.016	-	0.003	0.014	-

[1]Site number, salt application 1977-1978, number of replications.

Table 37. Seasonal Fluctuation Study: Soil EC_e, sodium and chloride under Jeffrey pine at several distances from the highway on three sampling dates.

			Oct. 1977			May 1978			August 1978		
				meq l^{-1}			meq l^{-1}			meq l^{-1}	
Site[3]	Distance	Parameter	EC_e[1,2]	Na[1]	Cl[1]	EC_e	Na	Cl	EC_e	Na	Cl
13	10 ft	$\bar{x}$	0.823	7.435	5.040	0.510	4.176	2.820	0.602	5.482	3.930
10.9T		Range	1.250	14.670	7.500	1.160	8.580	8.300	0.960	6.720	7.900
n=10		$s_{\bar{x}}$	0.125	1.432	0.810	0.125	0.930	0.841	0.094	0.654	0.754
	20 ft	$\bar{x}$	0.343	3.572	1.330	0.323	2.928	1.330	0.272	2.684	1.010
		Range	0.390	4.340	2.300	0.370	4.040	2.300	0.310	3.780	1.800
		$s_{\bar{x}}$	0.033	0.421	0.248	0.033	0.384	0.217	0.034	0.387	0.191
	30 ft	$\bar{x}$	0.409	3.034	2.010	0.300	2.188	1.200	0.293	1.729	0.860
		Range	0.890	6.050	4.600	0.480	2.940	4.400	0.420	3.980	2.400
		$s_{\bar{x}}$	0.084	0.593	0.521	0.040	0.244	0.395	0.053	0.372	0.257
	40 ft	$\bar{x}$	0.243	1.855	0.700	0.139	0.866	0.240	0.134	1.170	0.390
		Range	0.330	3.610	1.600	0.150	1.400	0.500	0.160	1.840	0.900
		$s_{\bar{x}}$	0.037	0.395	0.160	0.017	0.133	0.054	0.021	0.200	0.123
	60 ft	$\bar{x}$	0.232	1.456	0.850	0.163	0.984	0.210	0.140	0.928	0.220
		Range	0.350	2.470	1.900	0.110	1.160	0.300	0.260	2.340	1.000
		$s_{\bar{x}}$	0.044	0.307	0.248	0.014	0.118	0.038	0.025	0.232	0.099
	100 ft	$\bar{x}$	0.222	1.103	0.620	0.138	0.676	0.230	0.097	0.626	0.100
		Range	0.180	1.710	1.100	0.070	0.630	0.400	0.070	0.980	0
		$s_{\bar{x}}$	0.019	0.189	0.096	0.008	0.074	0.050	0.008	0.108	0
	200 ft	$\bar{x}$	0.204	0.652	0.660	0.177	0.731	0.340	0.109	0.390	0.240
		Range	0.180	0.720	1.200	0.170	1.420	0.700	0.130	0.620	0.400
		$s_{\bar{x}}$	0.025	0.084	0.153	0.024	0.170	0.087	0.016	0.074	0.060

[1]saturation paste extract
[2]millimhos/cm
[3]Site number, salt application 1977-1978, number of replications.

Figure 37. Seasonal Fluctuation Study. Leaf chloride concentration (%DW) in Jeffrey pine as a function of time, site 13, 10.9T salt/lane mile.

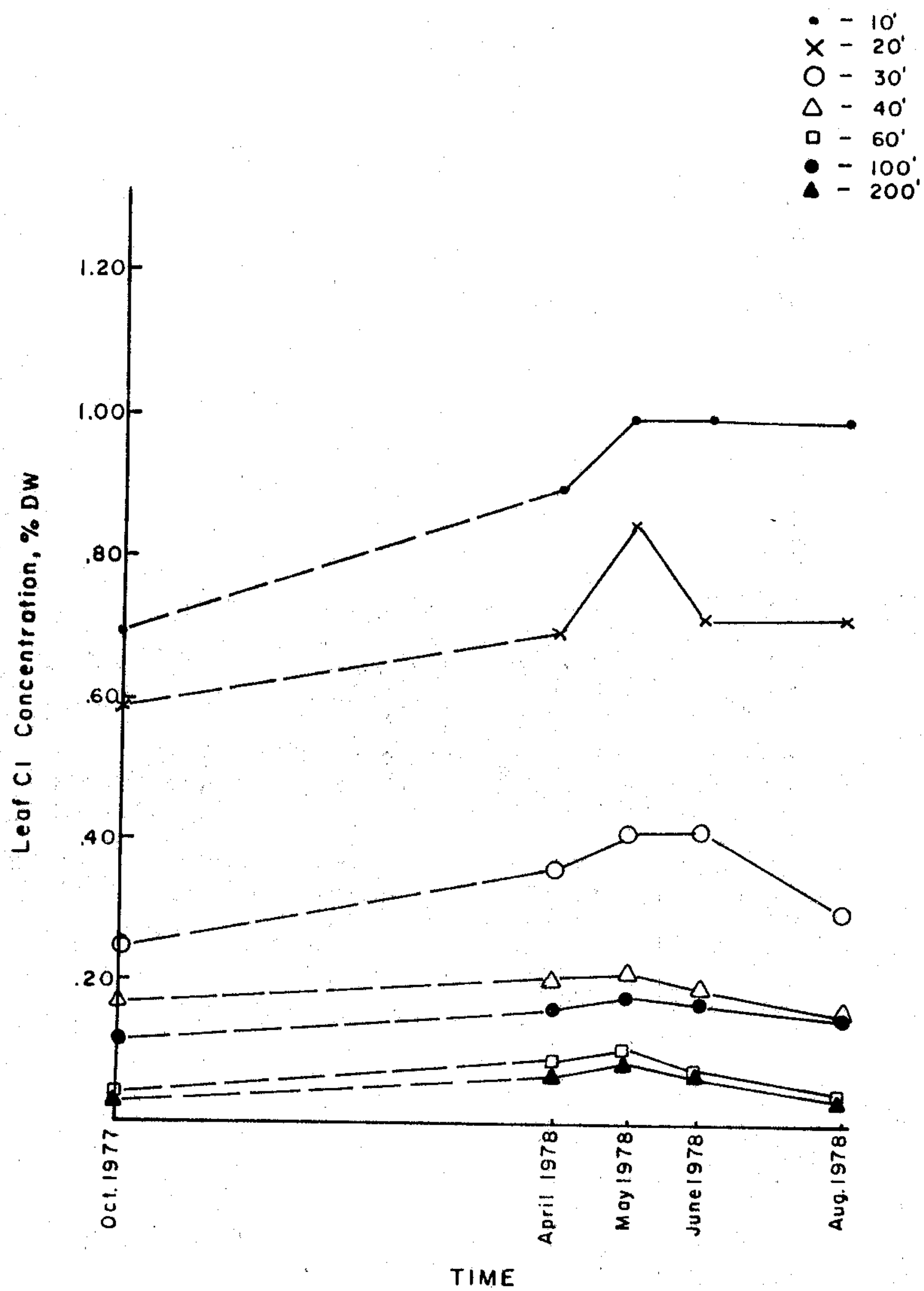
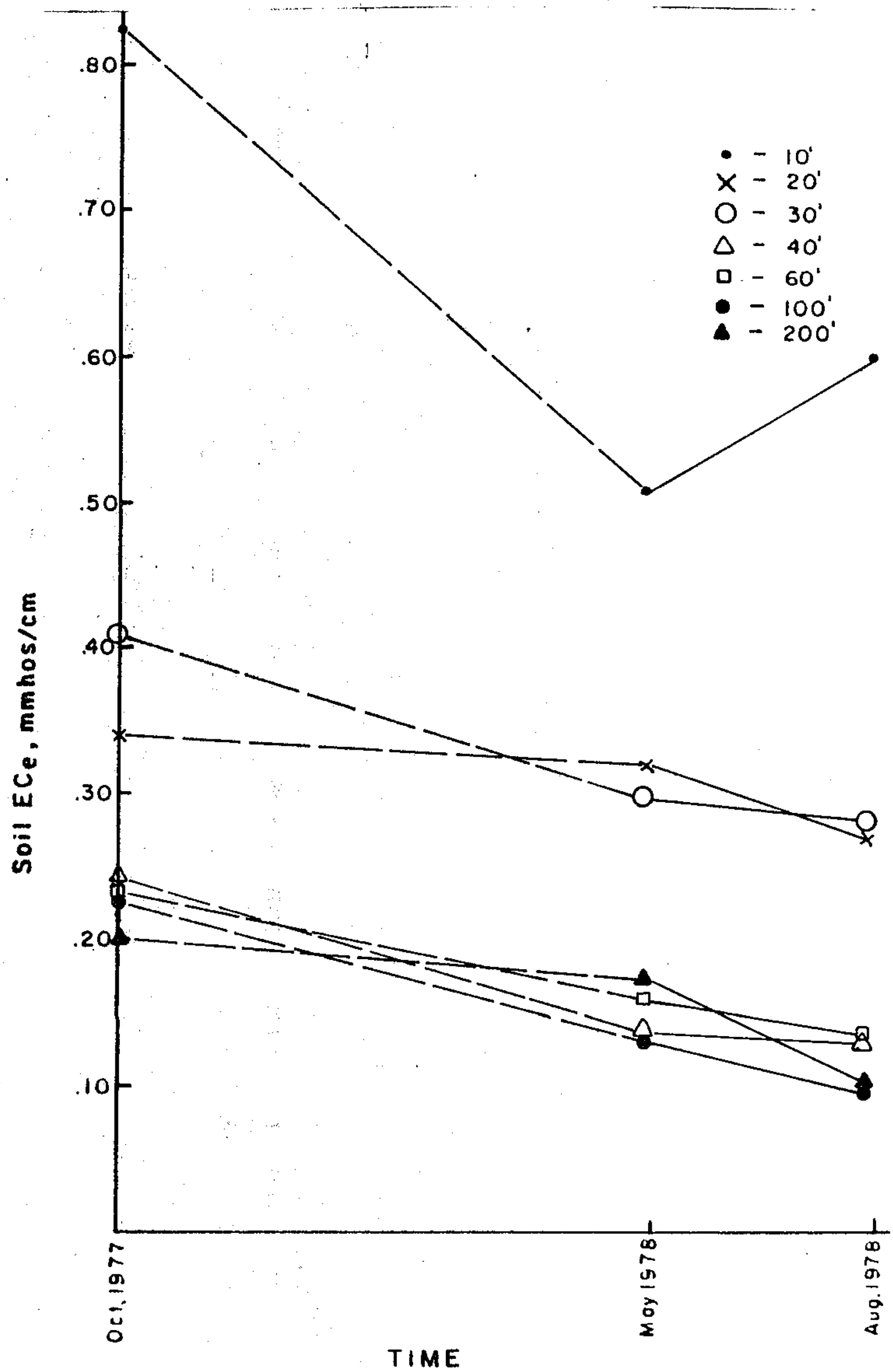


Figure 38. Seasonal Fluctuation Study. Soil EC_e(Millimhos/cm) under Jeffrey pine as a function of time, site 13, 10.9T salt/lane mile.



peaking at 0.99 and 0.85% respectively. Leaf Cl concentrations at 30 feet peaked in May and June at 0.42%, at the estimated threshold level. At 40 feet, the maximum Cl level was 0.21%. The levels at 100 feet were slightly lower than at 40 feet while the levels at 60 and 200 feet were very low.

The EC_e on this site at 10 feet was about twice that at Site 11. Values at 20 and 30 feet were almost identical and similar to those at 10 feet on Site 11. However, leaf Cl concentrations at 20 feet were almost twice those at 30 feet on this site and equal to those at 10 feet on Site 11. This may again have been due to differences in leaching or exposure to aerosols.

All sites, Figures 39 and 40. The leaf Cl concentrations in May 1978 are plotted as a function of distance from the highway in Figure 39. Maximum levels in Sites 11 and 4 were very similar even though the salt application rates were quite different. Levels were below the estimated threshold levels at all sites 40 feet from the highway and were near background levels at 60 feet and beyond.

Soil EC_e in May 1978 plotted as a function of distance from the highway for all sites are shown in Figure 40. These were at or near background levels at 20 feet on Site 11 and at 40 feet for the other two sites.

5.92.22 Incense cedar

Site 11, 2.2 T salt/lane mile. Tables 38 and 39, Figures 41 and 42. Leaf Cl concentrations were above estimated threshold levels at both 10 and 20 feet and just below this

Figure 39. Seasonal Fluctuation Study. Leaf chloride concentration (%DW) in Jeffrey pine as a function of distance from the highway on three sites in May 1978.

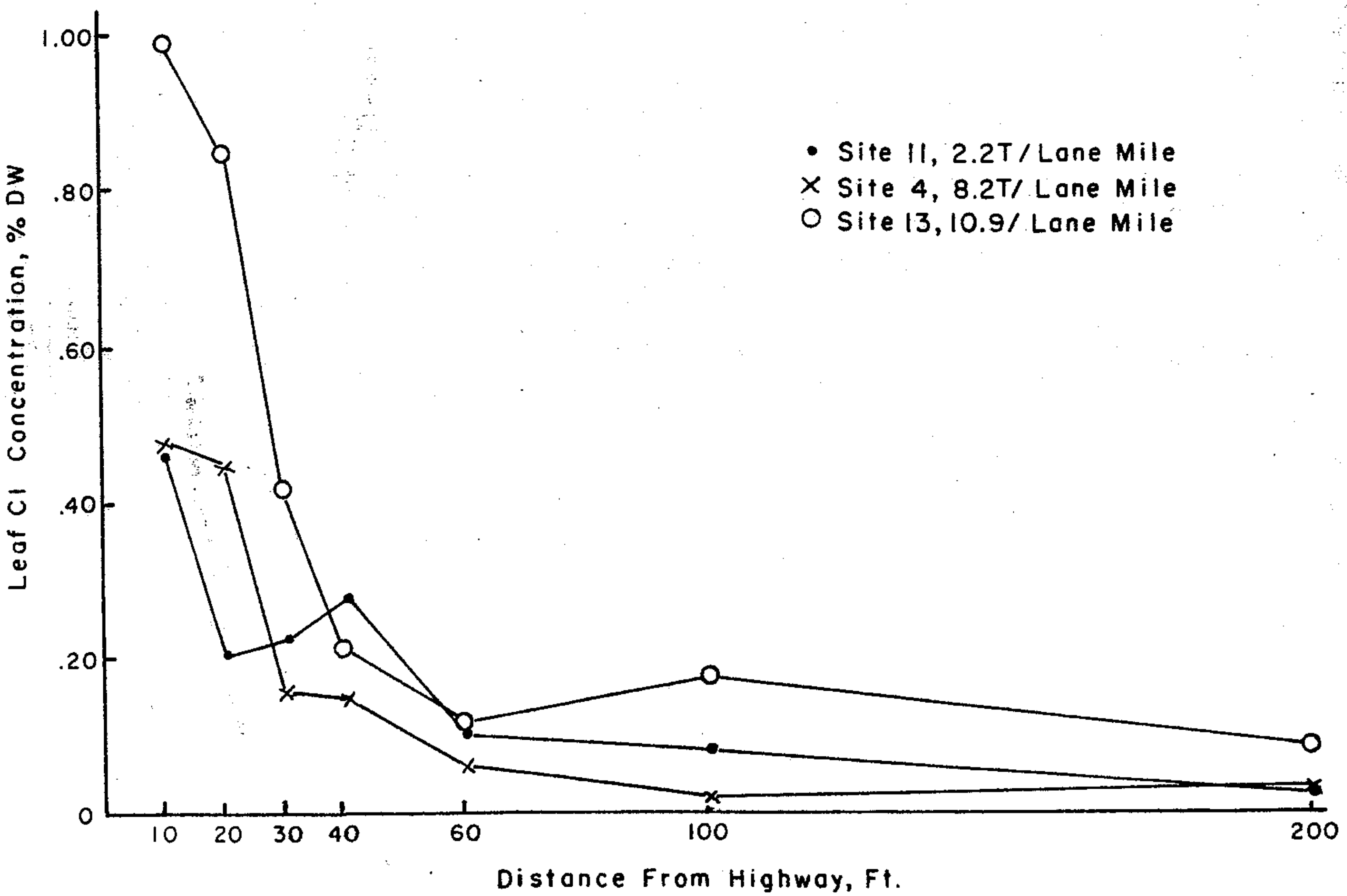


Figure 40. Seasonal Fluctuation Study. Soil EC_e (Millimhos/cm) under Jeffrey pine as a function of distance from the highway on three sites in May 1978.

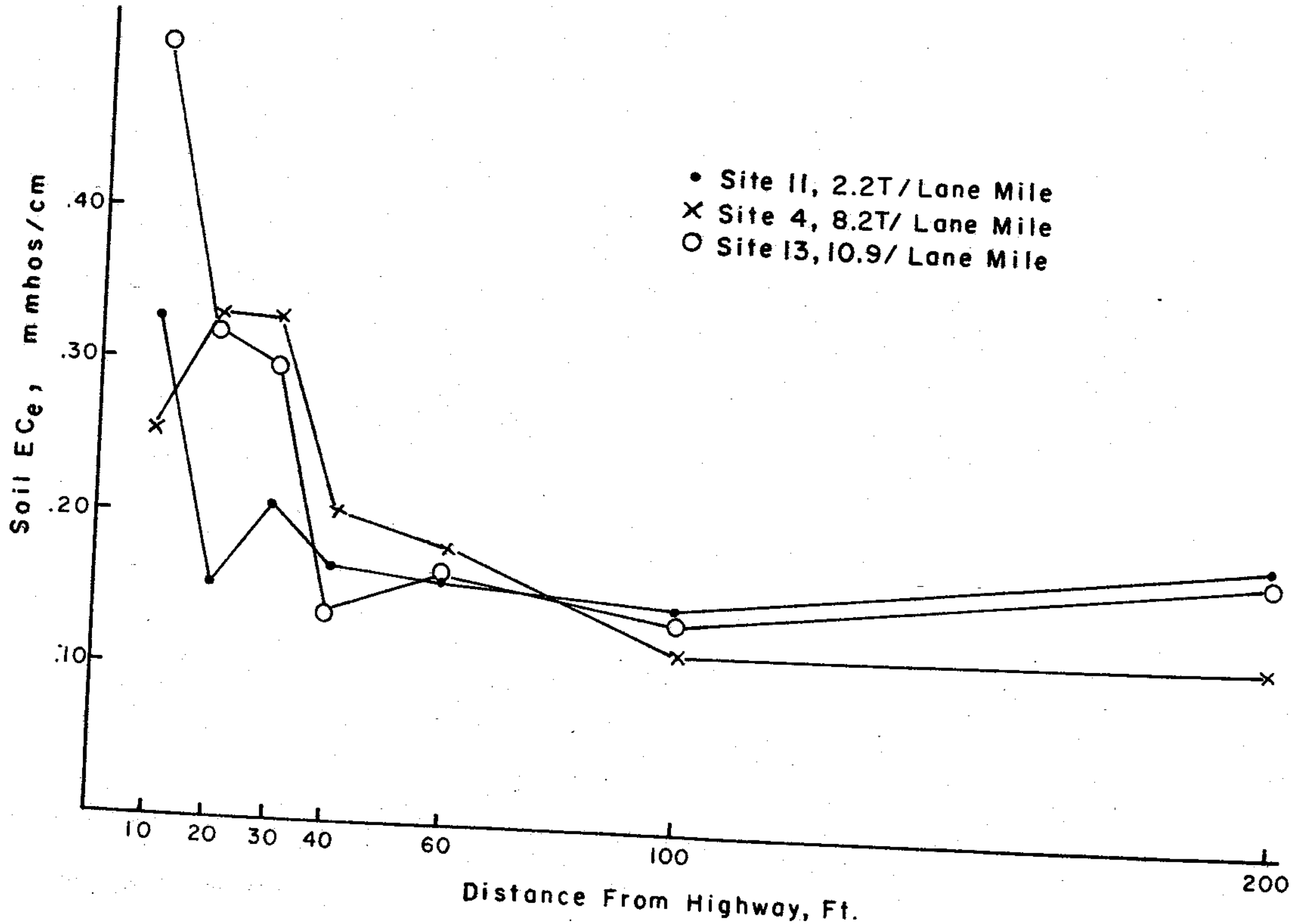


Table 38. Seasonal Fluctuation Study: Leaf sodium and chloride concentrations in incense cedar from October 1977 to August 1978 at varying distances from the highway. Damage ratings are also given. Data include means, range and standard errors of the means.

			Oct. 1977			April 1978		May 1978			June 1978			August 1978		
			% DW			% DW		% DW			% DW			% DW		
Site[1]	Dis-tance	Para-meter	Na	Cl	Damage	Na	Cl	Na	Cl	Damage	Na	Cl	Damage	Na	Cl	Damage
11	10 ft	$\bar{x}$	0.190	1.273	2.5	0.140	1.319	0.157	1.369	3.25	0.101	1.223	3.25	0.136	1.123	3.25
2.2T		Range	0.357	0.746	1	0.092	0.804	0.223	0.710	1	0.128	0.908	1	0.218	0.781	1
n = 4		$s_{\bar{x}}$	0.077	0.164	0.29	0.024	0.185	0.048	0.149	0.25	0.026	0.202	0.25	0.046	0.182	0.25
	20 ft	$\bar{x}$	0.090	0.947	1.75	0.084	0.994	0.081	1.061	2.5	0.118	0.987	2.5	0.079	0.901	2.5
		Range	0.071	0.724	1	0.123	1.037	0.040	0.826	2	0.195	0.701	2	0.040	0.781	2
		$s_{\bar{x}}$	0.018	0.160	0.25	0.026	0.213	0.009	0.194	.05	0.044	0.145	0.5	0.010	0.169	0.5
	30 ft	$\bar{x}$	0.057	0.367	0.25	0.042	0.384	0.043	0.402	0.25	0.040	0.339	0.25	0.040	0.364	0.25
		Rage	0.098	0.627	1	0.068	0.440	0.062	0.515	1	0.052	0.603	1	0.069	0.559	1
		$s_{\bar{x}}$	0.022	0.136	0.25	0.015	0.107	0.015	0.133	0.25	0.013	0.144	0.25	0.016	0.140	0.25
	40 ft	$\bar{x}$	0.026	0.312	0	0.027	0.291	0.027	0.293	0	0.029	0.268	0	0.030	0.258	0
		Range	0.007	0.421	-	0.025	0.398	0.007	0.400	0	0.012	0.475	-	0.013	0.488	-
		$s_{\bar{x}}$	0.002	0.110	-	0.006	0.103	0.001	0.104	-	0.003	0.118	-	0.003	0.115	-
	60 ft	$\bar{x}$	0.028	0.367	0	0.031	0.363	0.022	0.380	0	0.027	0.333	0	0.027	0.329	0
		Range	0.022	0.373	-	0.040	0.313	0.029	0.436	-	0.025	0.364	0	0.013	0.336	-
		$s_{\bar{x}}$	0.005	0.085	-	0.009	0.067	0.006	0.089	-	0.005	0.080	-	0.003	0.083	-
	100 ft	$\bar{x}$	0.024	0.142	0	0.026	0.160	0.021	0.153	0	0.027	0.122	0	0.026	0.113	0
		Range	0.010	0.213	-	0.019	0.199	0.016	0.195	-	0.010	0.275	-	0.007	0.234	-
		$s_{\bar{x}}$	0.002	0.050	-	0.004	0.043	0.004	0.043	-	0.002	0.058	-	0.002	0.048	-
	200 ft	$\bar{x}$	0.020	0.120	0	0.024	0.122	0.020	0.153	0	0.025	0.099	0	0.026	0.112	0
		Range	0.010	0.235	-	0.010	0.113	0.006	0.182	-	0.004	0.229	-	0.004	0.169	-
		$s_{\bar{x}}$	0.003	0.054	-	0.002	0.027	0.002	0.038	-	0.001	0.049	-	0.001	0.040	-

[1]Site number, salt application 1977-1978, number of replications.

Table 39. Seasonal Fluctuation Study: Soil EC_e, sodium and chloride under incense cedar at several distances from the highway on three sampling dates.

Site[3]	Distance	Parameter	Oct. 1977 EC_e[1,2]	Oct. 1977 Na[1] (meq l^{-1})	Oct. 1977 Cl[1] (meq l^{-1})	May 1978 EC_e	May 1978 Na (meq l^{-1})	May 1978 Cl (meq l^{-1})	August 1978 EC_e	August 1978 Na (meq l^{-1})	August 1978 Cl (meq l^{-1})
11	10 ft	$\bar{x}$	0.670	5.415	3.850	0.395	3.325	1.975	0.260	2.755	1.200
2.2T		Range	0.750	5.500	6.300	0.630	4.180	4.700	0.190	2.680	2.400
n = 4		$s_{\bar{x}}$	0.172	1.185	1.308	0.140	0.873	1.036	0.047	0.609	0.574
	20 ft	$\bar{x}$	0.412	3.460	-	0.192	1.590	0.700	0.155	1.145	0.250
		Range	0.530	5.500	-	0.250	2.600	1.800	0.140	1.020	0.300
		$s_{\bar{x}}$	0.110	1.253	-	0.057	0.569	0.436	0.034	0.230	0.087
	30 ft	$\bar{x}$	0.440	3.935	1.925	0.342	1.920	1.325	0.177	1.135	0.525
		Range	0.990	7.440	5.600	0.800	5.100	4.100	0.260	2.280	1.600
		$s_{\bar{x}}$	0.231	1.922	1.310	0.190	1.219	0.966	0.056	0.495	0.392
	40 ft	$\bar{x}$	0.197	0.735	0.400	0.242	1.080	0.900	0.127	0.587	0.175
		Range	0.210	0.820	0.200	0.140	1.620	1.100	0.090	0.380	0.200
		$s_{\bar{x}}$	0.044	0.180	0.041	0.029	0.365	0.268	0.021	0.081	0.048
	60 ft	$\bar{x}$	0.252	1.612	0.725	0.142	0.580	0.425	0.125	0.607	0.175
		Range	0.300	3.230	1.500	0.070	0.600	0.600	0.080	0.290	0.300
		$s_{\bar{x}}$	0.064	0.716	0.325	0.019	0.124	0.125	0.019	0.063	0.075
	100 ft	$\bar{x}$	0.182	1.390	0.275	0.177	0.575	0.350	0.137	0.575	0.200
		Range	0.310	4.040	0.300	0.170	0.320	0.500	0.170	0.540	0.400
		$s_{\bar{x}}$	0.066	0.973	0.075	0.037	0.084	0.119	0.038	0.128	0.100
	200 ft	$\bar{x}$	0.120	0.320	0.225	0.165	0.615	0.300	0.090	0.370	0.100
		Range	0.130	0.350	0.400	0.130	0.820	0.700	0.030	0.140	0
		$s_{\bar{x}}$	0.030	0.076	0.095	0.033	0.180	0.168	0.007	0.029	0

[1]saturation paste extract
[2]millimhos/cm.
[3]Site number, salt application 1977-1978, number of replications.

Figure 41. Seasonal Fluctuation Study. Leaf chloride concentration (%DW) in incense cedar as a function of time, site 11, 2.2T salt/lane mile.

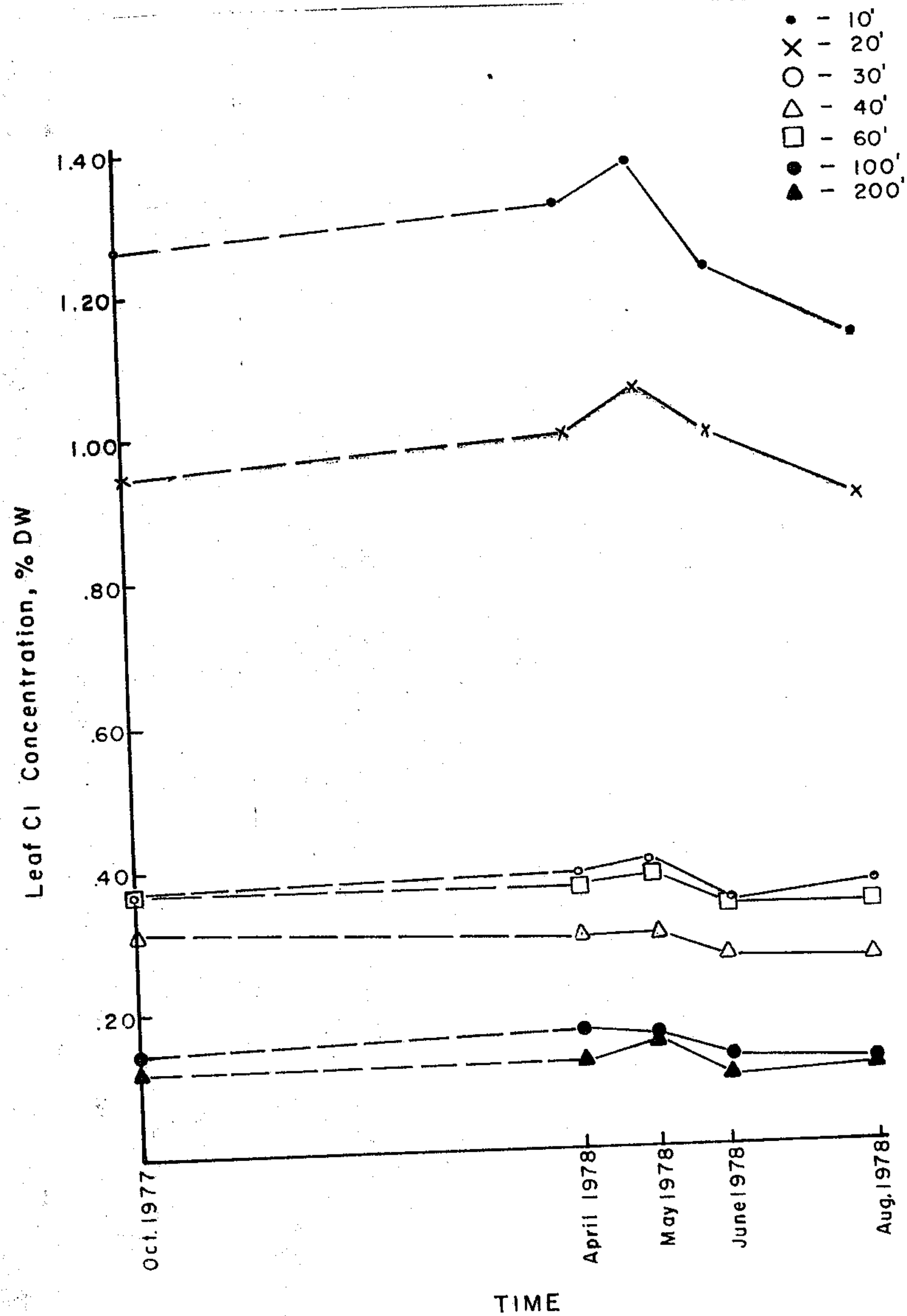
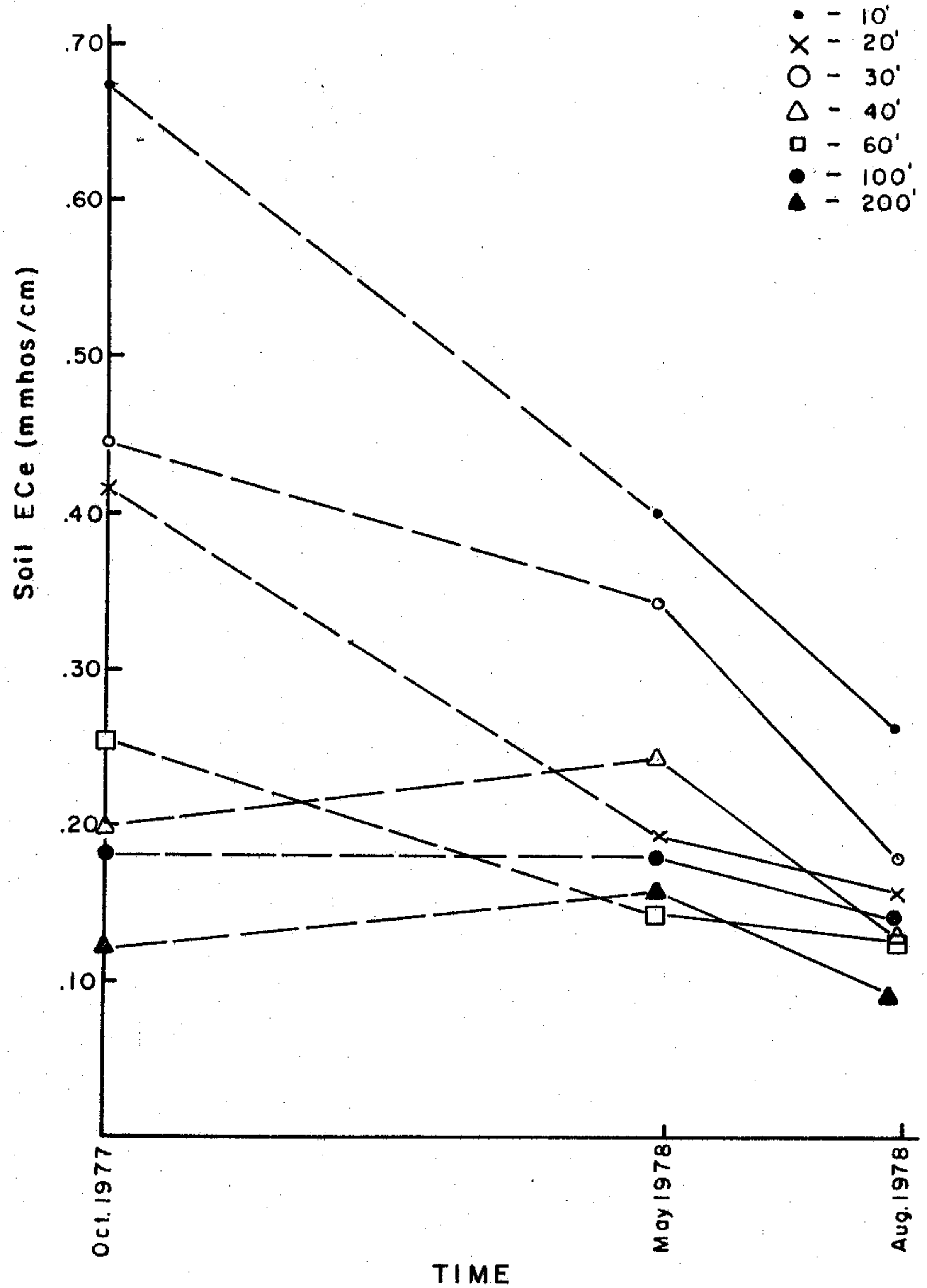


Figure 42. Seasonal Fluctuation Study. Soil EC_e(Millmhos/cm) under incense cedar as a function of time, site 11, 2.2T salt/lane mile.



level at 30, 40, and 60 feet on this site. At 100 and 200 feet, levels were low and relatively constant with time.

The EC_e data did not match leaf Cl concentrations very well. The value at 20 feet was lower than that at 30 feet while leaf Cl at 20 feet was twice that at 30 feet. This species was found to be very susceptible to foliar applied salt in an earlier study. This fact and the data seem to suggest that much of the leaf Cl in this species may have come from aerosols.

Site 4, 8.2 T salt/lane mile. Tables 40 and 41, Figures 43 and 44. Leaf Cl concentrations at 10 and 20 feet on this site were below those at 10 feet and similar to those at 20 feet on Site 11. Levels at 30 and 40 feet were above, and those at 60 feet were at estimated threshold levels. At 100 and 200 feet leaf Cl was low and relatively constant with time.

The EC_e values generally decreased as distance from the highway increased. The values at 20 feet were slightly more than half those at 10 feet although leaf Cl was essentially the same at the two distances. Again, this suggests that salt carried by aerosols may have been an important source of Cl in this species.

Site 13, 10.9 T salt/lane mile. Tables 42 and 43, Figures 45 and 46. Leaf Cl was high and similar at both 10 and 20 feet. At 30 and 40 feet, Cl was well above the estimated threshold levels and of about the same order of magnitude. At 60 feet, the Cl levels were above the estimated threshold levels on all sampling dates and at 100 feet on two

Table 40. Seasonal Fluctuation Study: Leaf sodium and chloride concentrations in incense cedar from October 1977 to August 1978 at varying distances from the highway. Damage ratings are also given. Data include means, range and standard errors of the means.

Site[1]	Dis- tance	Para- meter	Oct. 1977 % DW			April 1978 % DW		May 1978 % DW			June 1978 % DW			August 1978 % DW		
				Cl	Damage	Na	Cl	Na	Cl	Damage	Na	Cl	Damage	Na	Cl	Damage
4	10 ft	$\bar{x}$	0.110	0.837	2.3	0.373	0.957	0.335	0.959	2.83	0.219	0.832	2.83	0.165	0.821	2.83
8.2T		Range	0.067	0.256	1	0.245	0.341	0.285	0.357	1	0.133	0.373	1	0.130	0.328	1
n = 6		$s_{\bar{x}}$	0.010	0.039	0.21	0.039	0.052	0.045	0.049	0.17	0.025	0.059	0.17	0.020	0.051	0.17
	20 ft	$\bar{x}$	0.088	0.864	2	0.219	0.943	0.176	1.000	2.33	0.153	0.907	2.33	0.144	0.949	2.33
		Range	0.131	0.255	-	0.294	0.256	0.308	0.293	1	0.164	0.418	1	0.225	0.364	1
		$s_{\bar{x}}$	0.022	0.040	-	0.053	0.041	0.048	0.043	0.21	0.028	0.065	0.21	0.034	0.050	0.21
	30 ft	$\bar{x}$	0.077	0.675	0.83	0.136	0.699	0.099	0.631	1	0.118	0.618	1	0.093	0.658	1
		Range	0.091	0.488	1	0.227	0.511	0.111	0.426	2	0.139	0.488	2	0.129	0.533	2
		$s_{\bar{x}}$	0.015	0.078	0.17	0.042	0.076	0.020	0.075	0.26	0.025	0.069	0.26	0.023	0.074	0.26
	40 ft	$\bar{x}$	0.075	0.524	0.5	0.143	0.500	0.105	0.549	0.5	0.102	0.490	0.5	0.093	0.530	0.5
		Range	0.090	0.506	2	0.212	0.526	0.101	0.533	2	0.111	0.417	2	0.088	0.550	2
		$s_{\bar{x}}$	0.014	0.086	0.34	0.038	0.079	0.021	0.077	0.34	0.020	0.069	0.34	0.014	0.098	0.34
	60 ft	$\bar{x}$	0.036	0.432	0.17	0.034	0.405	0.037	0.449	0.17	0.038	0.402	0.17	0.040	0.431	0.17
		Range	0.041	0.556	1	0.090	0.596	0.090	0.674	1	0.060	0.719	1	0.054	0.710	1
		$s_{\bar{x}}$	0.006	0.080	0.17	0.014	0.091	0.014	0.098	0.17	0.008	0.104	0.17	0.009	0.102	0.17
	100 ft	$\bar{x}$	0.024	0.138	0	0.020	0.135	0.031	0.147	0	0.031	0.136	0	0.028	0.086	0
		Range	0.010	0.197	-	0.016	0.187	0.035	0.212	-	0.016	0.187	-	0.016	0.168	-
		$s_{\bar{x}}$	0.002	0.030	-	0.002	0.028	0.005	0.036	-	0.003	0.028	-	0.003	0.022	-
	200 ft	$\bar{x}$	0.020	0.086	0	0.013	0.085	0.017	0.070	0	0.027	0.045	0	0.025	0.064	0
		Range	0.006	0.150	-	0.006	0.125	0.012	0.088	-	0.019	0.026	-	0.016	0.233	-
		$s_{\bar{x}}$	0.001	0.023	-	0.001	0.018	0.002	0.012	-	0.003	0.004	-	0.002	0.037	-

[1]Site number, salt application 1977-1978, number of replications.

Table 41. Seasonal Fluctuation Study: Soil EC_e, sodium and chloride under incense cedar at several distances from the highway on three sampling dates.

Site[3]	Distance	Para-meter	Oct. 1977 EC_e[1,2]	Oct. 1977 Na (meq l^{-1})	Oct. 1977 Cl (meq l^{-1})	May 1978 EC_e	May 1978 Na (meq l^{-1})	May 1978 Cl (meq l^{-1})	August 1978 EC_e	August 1978 Na (meq l^{-1})	August 1978 Cl (meq l^{-1})
4	10 ft	$\bar{x}$	0.670	6.043	2.700	0.387	3.048	1.267	0.330	2.272	0.783
8.2T		Range	0.560	6.110	6.200	0.490	4.880	3.800	0.290	1.830	1.700
n = 6		$s_{\bar{x}}$	0.085	1.029	0.958	0.070	0.707	0.591	0.041	0.276	0.275
	20 ft	$\bar{x}$	0.413	3.908	0.983	0.273	1.703	0.550	0.188	1.450	0.367
		Range	0.370	3.900	1.500	0.300	2.460	1.000	0.190	1.200	0.600
		$s_{\bar{x}}$	0.063	0.712	0.233	0.044	0.340	0.150	0.027	0.203	0.092
	30 ft	$\bar{x}$	0.373	3.273	1.733	0.303	2.105	1.400	0.175	1.400	0.433
		Range	0.380	3.620	2.600	0.210	2.610	2.200	1.140	1.480	0.800
		$s_{\bar{x}}$	0.060	0.580	0.357	0.039	0.456	0.353	0.025	0.246	0.141
	40 ft	$\bar{x}$	0.347	2.022	1.150	0.197	1.007	0.667	0.123	0.827	0.217
		Range	0.510	4.520	1.700	0.040	0.820	0.900	0.100	1.140	0.400
		$s_{\bar{x}}$	0.074	0.716	0.279	0.007	0.138	0.128	0.017	0.167	0.065
	60 ft	$\bar{x}$	0.162	0.880	0.567	0.178	0.897	0.500	0.112	0.593	0.250
		Range	0.140	1.330	1.700	0.050	1.040	0.600	0.100	0.480	0.400
		$s_{\bar{x}}$	0.020	0.193	0.262	0.007	0.192	0.113	0.019	0.076	0.067
	100 ft	$\bar{x}$	0.168	0.585	0.267	0.130	0.510	0.167	0.102	0.690	0.200
		Range	0.180	0.290	0.400	0.050	0.240	0.100	0.200	2.100	0.600
		$s_{\bar{x}}$	0.035	0.043	0.067	0.010	0.039	0.021	0.030	0.342	0.100
	200 ft	$\bar{x}$	0.228	0.492	0.117	0.137	0.447	0.167	0.090	0.593	0.183
		Range	0.360	0.270	0.100	0.090	0.140	0.100	0.040	0.660	0.200
		$s_{\bar{x}}$	0.072	0.040	0.017	0.013	0.025	0.021	0.005	0.106	0.031

[1]saturation paste extract
[2]millimhos/cm.
[3]Site number, salt application 1977-1978, number of replications.

Figure 43. Seasonal Fluctuation Study. Leaf chloride concentration (%DW) in incense cedar as a function of time, site 4, 8.2T salt/lane mile.

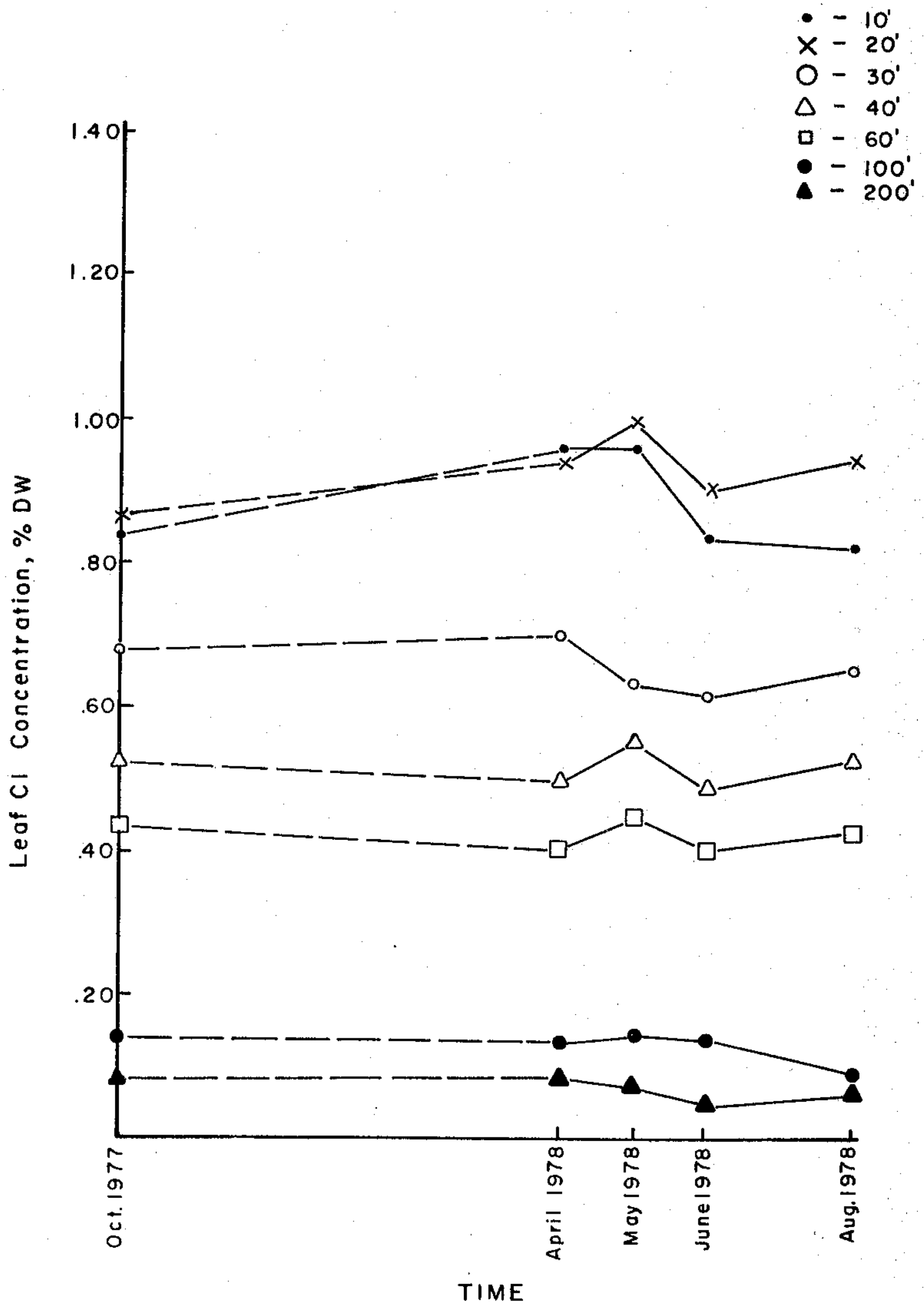


Figure 44. Seasonal Fluctuation Study. Soil EC_e(Millimhos/cm) under incense cedar as a function of time, site 4, 8.2T salt/lane mile.

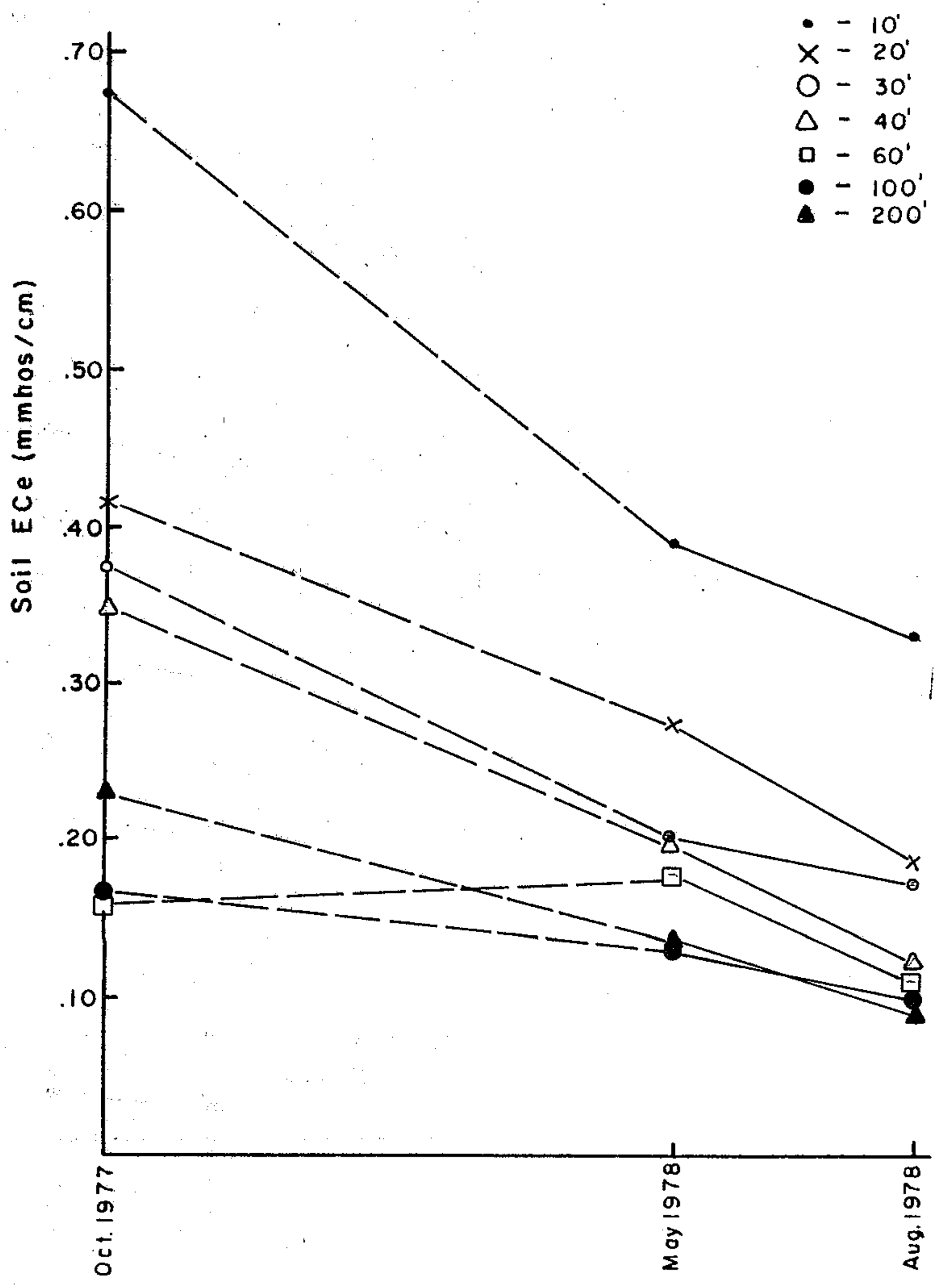


Table 42. Seasonal Fluctuation Study: Leaf and chloride concentrations in incense cedar from October 1977 to August 1978 at varying distances from the highway. Damage ratings, are also given. Data include means, range and standard errors of the means.

Site[1]	Dis-tance	Para-meter	Oct. 1977 % DW Na	Oct. 1977 % DW Cl	Oct. 1977 Damage	April 1978 % DW Na	April 1978 % DW Cl	May 1978 % DW Na	May 1978 % DW Cl	May 1978 Damge	June 1978 % DW Na	June 1978 % DW Cl	June 1978 Damge	August 1978 % DW Na	August 1978 % DW Cl	August 1978 Damge
13	10 ft	$\bar{x}$	0.126	1.165	2.9	0.265	1.223	0.189	1.279	3.2	0.192	1.230	3.6	0.137	1.313	3.8
10.9T		Range	0.148	0.491	1.	0.403	0.498	0.228	0.426	2.	0.320	0.870	1	0.121	0.728	1
n = 10		$s_{\bar{x}}$	0.013	0.053	0.1	0.042	0.055	0.023	0.042	0.2	0.035	0.088	0.16	0.012	0.075	0.13
	20 ft	$\bar{x}$	0.087	1.082	2.7	0.209	1.200	0.190	1.184	3.1	0.126	1.115	3.2	0.099	1.182	3.2
		Range	0.160	0.753	1	0.301	0.781	0.357	0.843	2	0.203	0.917	2	0.146	0.683	2
		$s_{\bar{x}}$	0.016	0.072	0.15	0.037	0.069	0.035	0.086	0.18	0.022	0.098	0.2	0.015	0.080	0.2
	30	$\bar{x}$	0.058	0.744	1.4	0.088	0.800	0.093	0.898	1.9	0.105	0.833	2	0.059	0.773	2
		Range	0.179	0.948	2	0.209	0.952	0.401	1.200	3	0.404	1.002	3	0.146	0.901	3
		$s_{\bar{x}}$	0.017	0.099	0.267	0.018	0.093	0.038	0.131	0.38	0.039	0.105	0.33	0.013	0.098	0.33
	40 ft	$\bar{x}$	0.029	0.644	1.2	0.031	0.684	0.037	0.748	1.5	0.038	0.632	1.6	0.032	0.779	1.6
		Range	0.042	0.731	3	0.041	0.994	0.050	1.053	3	0.043	0.870	4.	0.036	1.109	4
		$s_{\bar{x}}$	0.004	0.079	0.36	0.004	0.110	0.005	0.120	0.37	0.004	0.094	0.43	0.004	0.122	0.43
	60 ft	$\bar{x}$	0.029	0.456	0.4	0.030	0.523	0.033	0.465	0.5	0.033	0.465	0.5	0.031	0.464	0.5
		Range	0.059	0.894	2	0.045	0.994	0.039	1.100	2	0.039	1.340	2.	0.039	1.050	2
		$s_{\bar{x}}$	0.005	0.097	0.22	0.005	0.115	0.004	0.113	0.27	0.004	0.131	0.27	0.003	0.118	0.27
	100 ft	$\bar{x}$	0.018	0.386	0.6	0.020	0.409	0.027	0.439	0.6	0.031	0.510	0.7	0.025	0.385	0.7
		Range	0.022	1.101	3	0.022	1.139	0.032	1.136	3	0.078	1.251	3	0.036	1.216	3
		$s_{\bar{x}}$	0.002	0.106	0.34	0.002	0.109	0.004	0.116	0.34	0.007	0.129	0.34	0.003	0.129	0.34
	200 ft	$\bar{x}$	0.015	0.332	0.1	0.015	0.302	0.023	0.307	0.1	0.021	0.329	0.1	0.024	0.346	0.1
		Range	0.012	0.623	1	0.012	0.628	0.025	0.753	1	0.010	0.691	1	0.019	0.807	1
		$s_{\bar{x}}$	0.001	0.069	0.1	0.001	0.064	0.003	0.079	0.1	0.001	0.078	0.1	0.002	0.085	0.1

[1]Site number, salt application 1977-1978, number of replications.

Table 43. Seasonal Fluctuation Study. Soil EC_e, sodium and chloride under incense cedar at several distances from the highway on three sampling dates.

Site[3]	Distance	Parameter	Oct. 1977 $EC_e^{1,2}$	Oct. 1977 meq l^{-1} Na^1	Oct. 1977 meq l^{-1} Cl^1	May 1978 EC_e	May 1978 meq l^{-1} Na	May 1978 meq l^{-1} Cl	August 1978 EC_e	August 1978 meq l^{-1} Na	August 1978 meq l^{-1} Cl
13	10 ft	$\bar{x}$	0.648	5.234	3.560	0.484	3.994	2.140	0.406	3.810	2.620
10.9T		range	1.680	10.090	11.800	0.880	6.900	5.000	1.910	15.460	14.900
n = 10		$s_{\bar{x}}$	0.163	0.940	1.159	0.108	0.863	0.618	0.182	1.465	1.433
	20 ft	$\bar{x}$	0.415	4.008	1.800	0.268	2.524	0.860	0.221	2.011	0.870
		range	0.660	6.000	3.500	0.380	3.520	2.300	0.370	4.180	1.900
		$s_{\bar{x}}$	0.064	0.602	0.398	0.039	0.422	0.222	0.033	0.440	0.215
	30 ft	$\bar{x}$	0.293	2.174	1.150	0.225	1.726	0.810	0.229	1.572	0.690
		range	0.400	4.210	3.800	0.280	3.300	3.100	0.410	4.120	2.400
		$s_{\bar{x}}$	0.038	0.374	0.346	0.029	0.318	0.301	0.050	0.370	0.258
	40 ft	$\bar{x}$	0.295	2.077	1.200	0.163	1.137	0.260	0.131	0.920	0.250
		range	0.580	3.880	4.100	0.250	2.180	0.500	0.210	2.260	0.400
		$s_{\bar{x}}$	0.056	0.424	0.373	0.027	0.245	0.054	0.020	0.199	0.050
	60 ft	$\bar{x}$	0.226	1.418	0.720	0.234	1.398	0.490	0.146	0.881	0.360
		range	0.370	2.440	1.900	0.530	3.940	1.600	0.260	1.630	1.000
		$s_{\bar{x}}$	0.044	0.285	0.208	0.046	0.356	0.154	0.029	0.169	0.120
	100 ft	$\bar{x}$	0.211	1.006	0.650	0.176	0.720	0.380	0.162	1.216	0.570
		range	0.230	1.620	1.200	0.160	1.080	1.100	0.390	4.240	3.300
		$s_{\bar{x}}$	0.024	0.151	0.119	0.019	0.105	0.110	0.038	0.405	0.321
	200 ft	$\bar{x}$	0.170	0.509	0.410	0.128	0.531	0.230	0.130	0.482	0.350
		range	0.090	0.880	0.700	0.080	0.760	0.800	0.340	1.600	2.300
		$s_{\bar{x}}$	0.009	0.083	0.060	0.008	0.075	0.076	0.031	0.156	0.229

[1]saturation paste extract
[2]millimhos/cm.
[3]Site number, salt application 1977-1978, number of replications.

Figure 45. Seasonal Fluctuation Study. Leaf chloride concentration (%DW) in incense cedar as a function of time, site 13, 10.9T salt/lane mile.

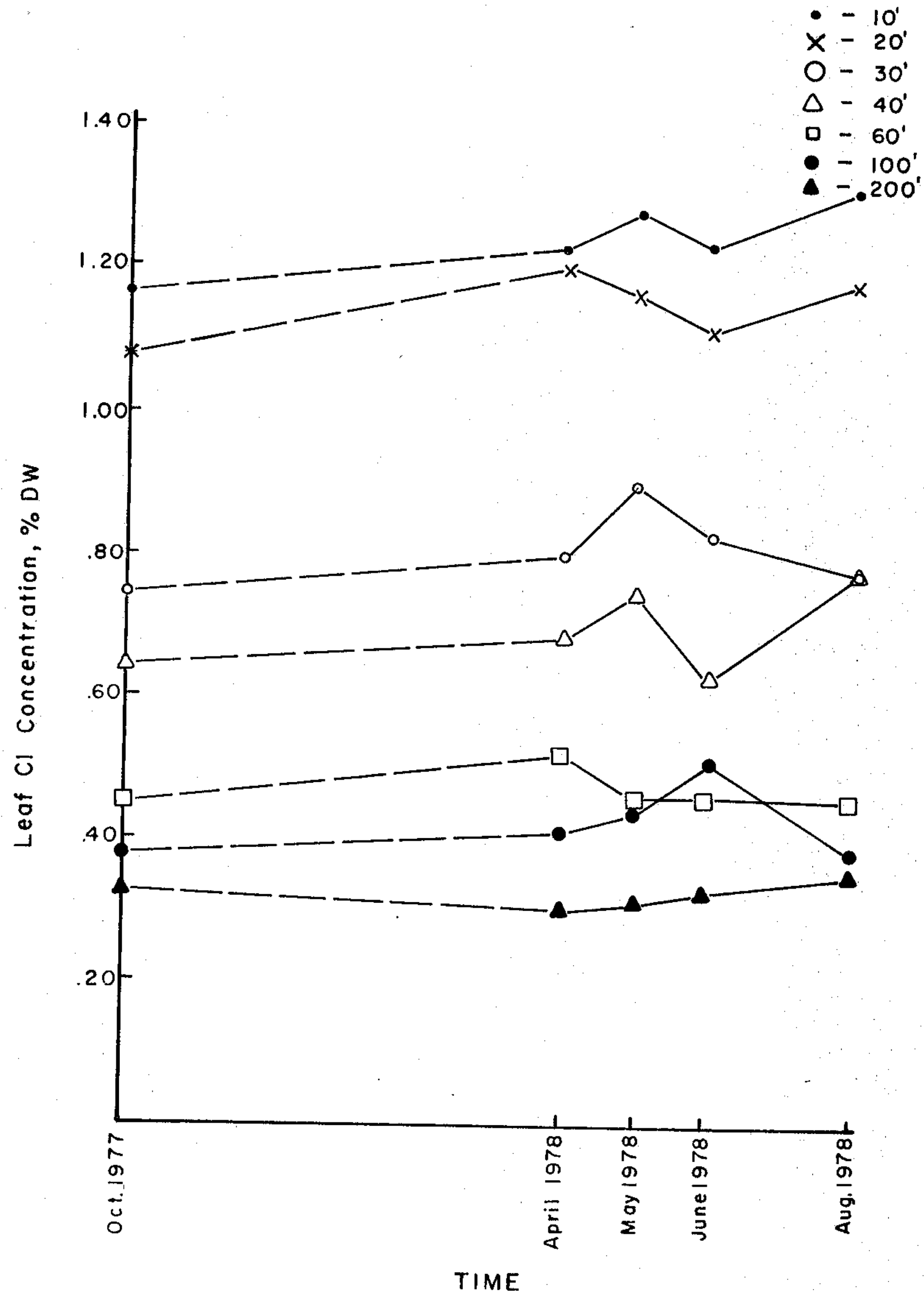
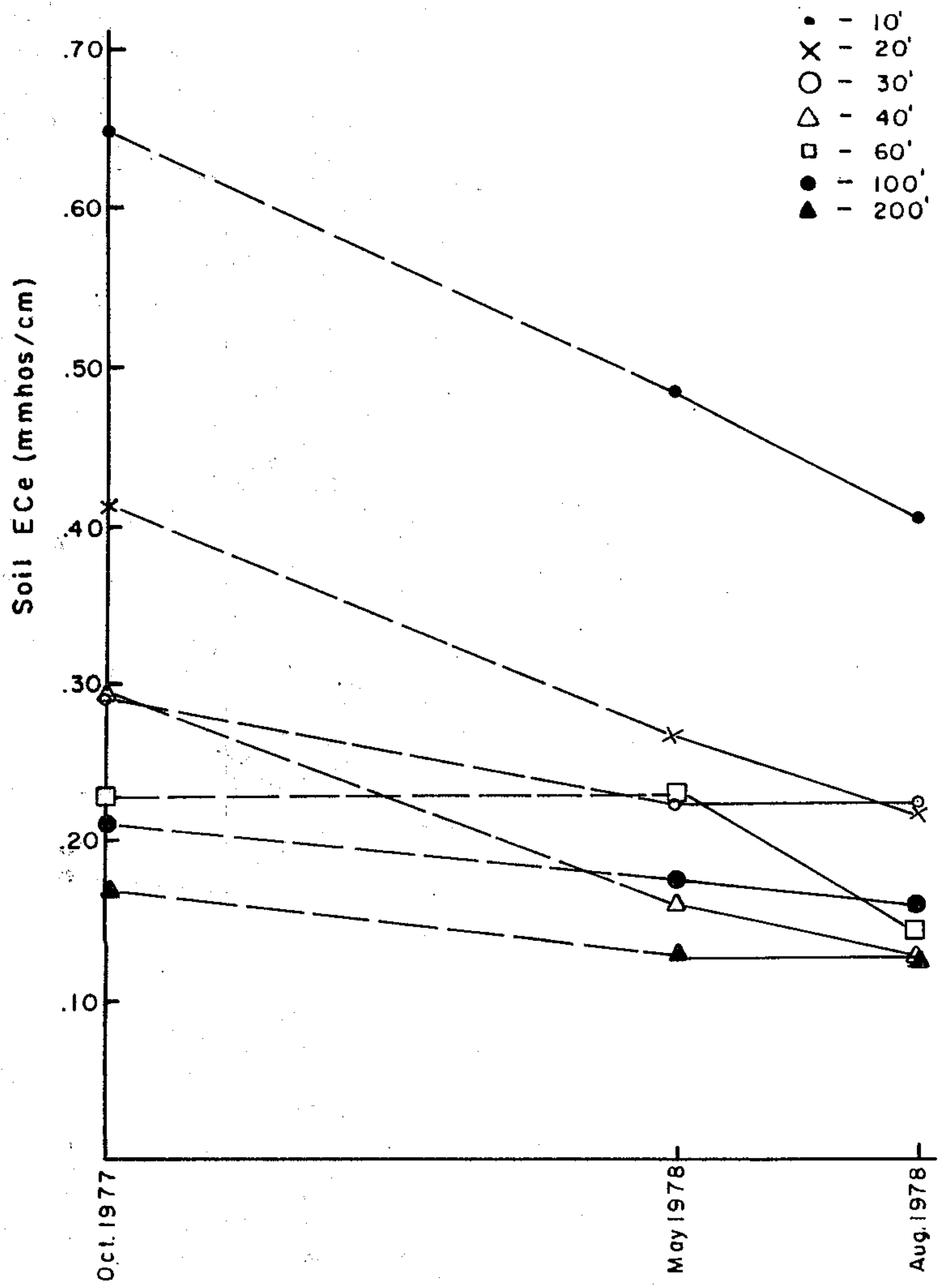


Figure 46. Seasonal Fluctuation Study. Soil EC_e (Millimhos/cm) under incense cedar as a function of time, site 13, 10.9T salt/lane mile.



sampling dates. Even at 200 feet, Cl was above 0.3% on all sampling dates. This was considerably higher than the Cl level at either 100 or 200 feet on the other two sites.

The high leaf Cl levels on this site at the points more distant from the highway could not be explained on the basis of EC_e which had a pattern very similar to that of Site 4, and at the greater distances on Site 11, the low salt site. Again, air-borne salt seems to be a reasonable explanation for at least a part of these differences.

5.92.3 <u>All sites</u>: The leaf Cl concentration in May 1978, plotted as a function of distance from the highway, are given in Figure 47. They are consistently higher than those of Jeffrey pine. In both the Soil Salt and Foliar Salt Application studies, this species was shown to accumulate more of Cl than Jeffrey pine. A portion of this greater accumulation in this study may be to both soil and foliar sources of salt. At 60 feet from the highway, these levels are just below estimated threshold levels for Site 11 and above these levels for Sites 4 and 13. On Site 13 they remain above the estimated threshold level to 100 feet and were still above background level at 200 feet. Yet EC_e (Figure 48) was at or approaching background levels at 40 and 60 feet on all sites and the EC_e levels as well as soil Na and Cl levels were similar for both incense cedar and Jeffrey pine. It seems most likely that the differences in leaf Cl on Site 13 at 100 and 200 feet compared to the levels at those distances in Sites 11 and 4 are due to salt that reaches and enters the leaf as a result of salt carried in aerosols.

Figure 47. Seasonal Fluctuation Study. Leaf chloride concentration (%DW) in incense cedar as a function of distance from the highway on three sites in May 1978.

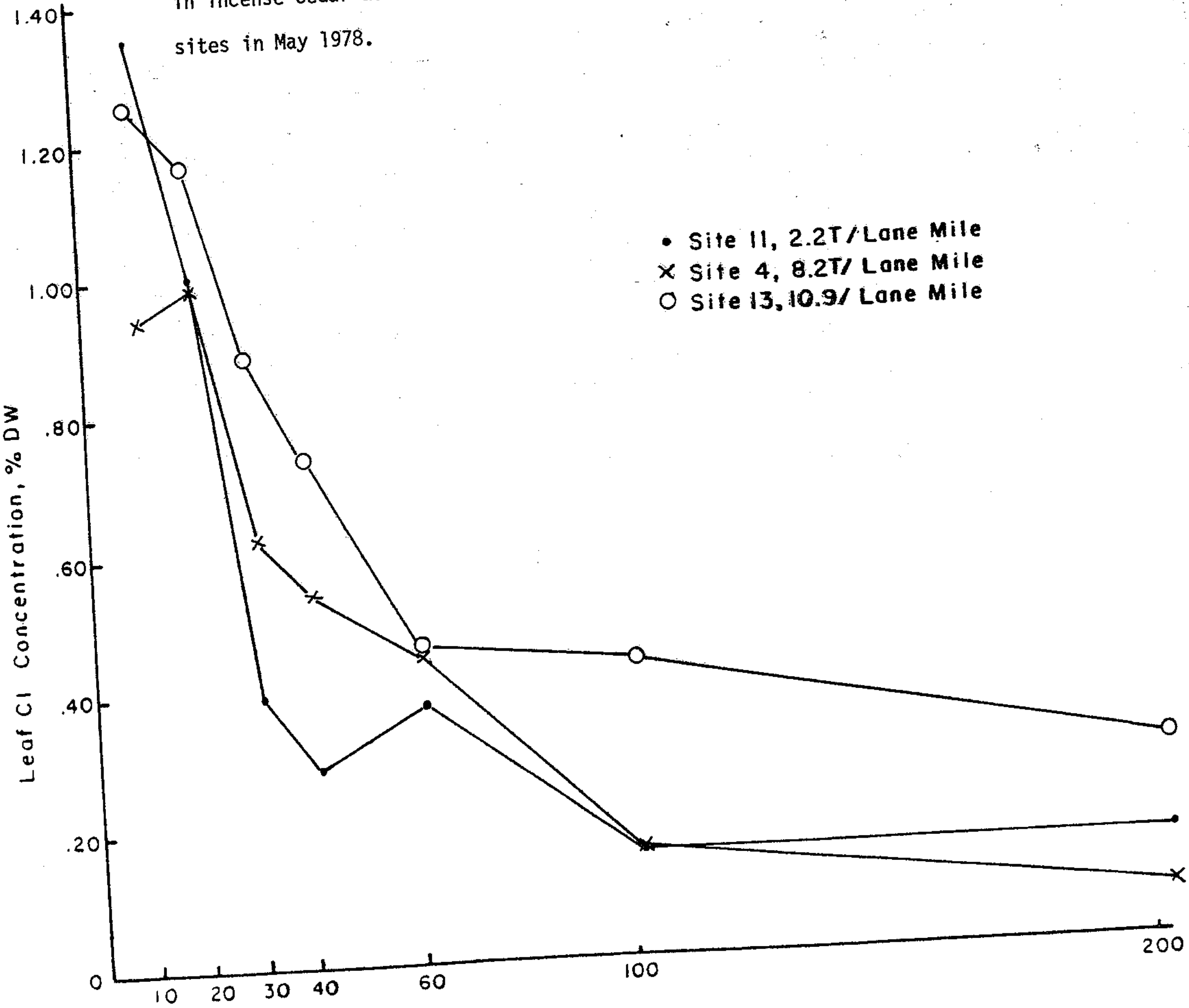
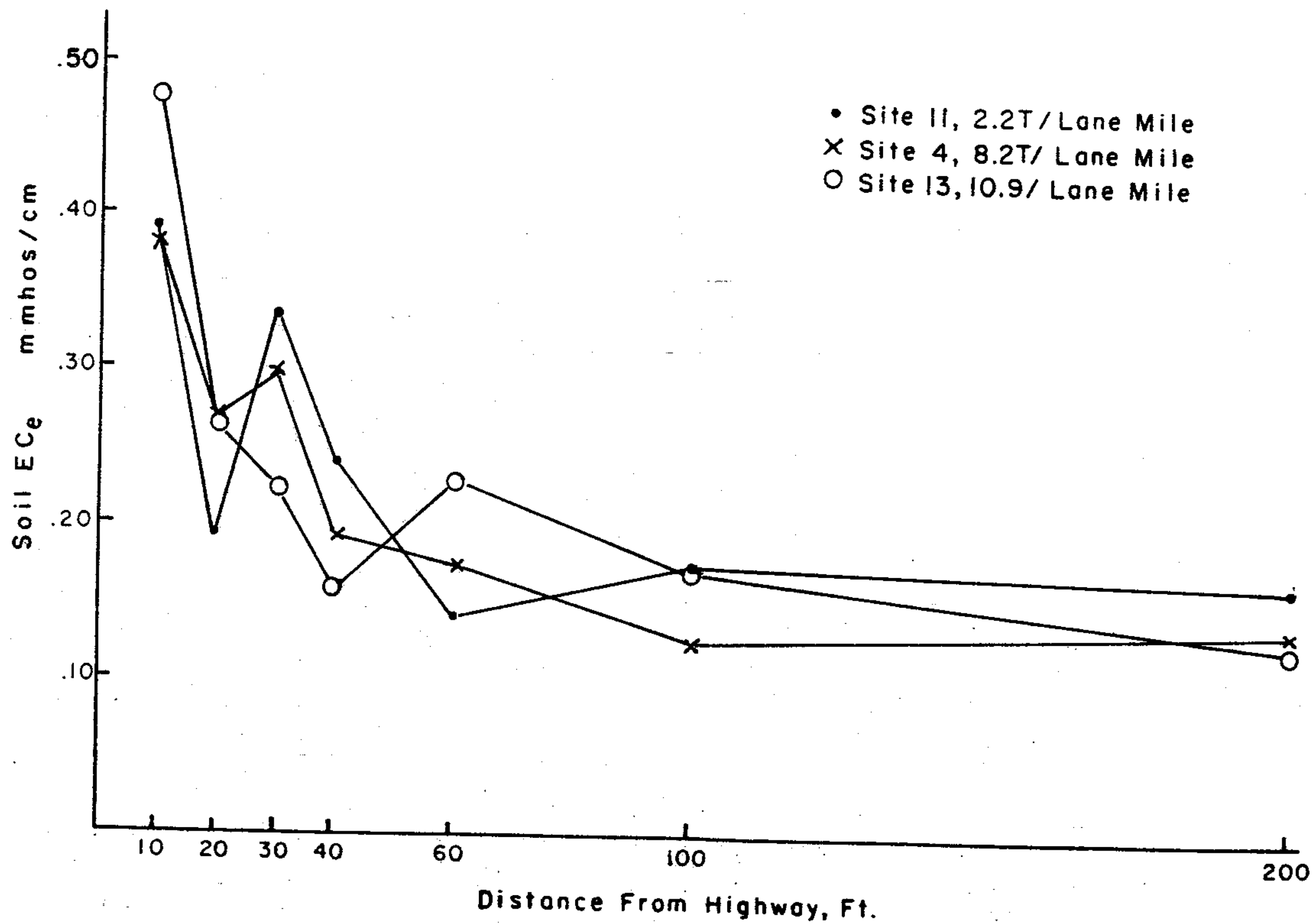


Figure 48. Seasonal Fluctuation: Soil EC_e (Millimhos/cm) under incense cedar as a function of distance from the highway on three sites in May 1978.



5.10 Armillaria Root Rot Study

During the preliminary surveys, Armillaria root rot (causal organism, Armilleria mellea) was observed on a number of white fir, red fir, and Jeffrey pines in the study area. This root rot may be either a virulent pathogen or little more than a saprophytic invader of dying tissue, depending upon the strain of the fungus involved.

5.101 Materials and methods: Six isolates of this fungus were collected in the Tahoe Basin in the summer of 1976. These were cultured and purified in the laboratory during the winter of 1976-77 and a supply of inoculum of each was obtained. A seventh isolate of proven virulence was used for a control. On June 21, 1977, 21 red fir seedlings were inoculated with each of the seven isolates. Successful inoculation should occur in 4-10 months.

5.102 Results: At the end of 16 months, 18 of the 21 trees inoculated with the known virulent strain of the fungus were dead. None of the trees inoculated with the isolates obtained in the Tahoe Basin were dead even though the fungus was still alive in most of the containers. The fact that the known virulent strain was effective in killing the trees proved that conditions for infection were correct. It must be concluded that the six isolates from the Tahoe Basin were nonvirulent strains of the fungus.

6. COMPARISONS WITH U.S. FOREST SERVICE STUDY OF 1973

Comparisons of the findings of this study with those of the U.S. Forest Service Study of 1973 "Conifer Damage and Death Associated with the Use of Highway Deicing Salt in the Lake Tahoe Basin of California and Nevada" by R. F. Scharpf and M. Srago, (21), show similar findings and are useful in putting the extent of conifer damage in perspective.

The damage ratings Scharpf and Srago used were similar but not identical to those used in this report. Their rating "light damage" corresponded to the upper range of "1" and the lower range of "2" as used in this report. The rating "moderate damage" corresponded to the upper range of "2" and lower range of "3" of this report. The rating of "severe damage" corresponded to the upper range of "3" and all of rating "4" of this report.

Symptom development and descriptions of the two reports are very similar except that dieback of youngest foliage was rarely observed in this study until all older foliage was affected, whereas Scharpf and Srago reported it as "the most conspicuous and distinctive symptom of salt damage" in pine.

The relationship between damage, location along the highways and distance from them was very similar in both studies. The majority of the damage was on downhill transects and within the first 20-25 feet of the pavement. At 60 feet leaf Na and Cl concentrations were usually near background or control levels. The principal exception was in our study, where, in our Seasonal Fluctuation Study, high leaf Cl concentrations were sometimes found up to 100 feet from the pavement.

The levels of Na and Cl in foliage at various damage ratings were very similar (Tables 25, 26 and 44). The estimated threshold damage levels of this report ($\pm$ 25% damage) were intermediate between those of "light" and "moderate" damage reported by Scharpf and Srago.

It is not possible to make exact comparisons of total or percentages of tree damage between the two studies. The study of Scharpf and Srago did not contain any total population estimates nor did our study estimate total numbers of trees damaged. The Forest Service study was limited to the Lake Tahoe Basin while ours included portions of highways outside the Tahoe Basin. However, it is possible to make some models using the data and certain assumptions to illustrate the extent of conifer damage in the study area. These models should not be taken as estimates of the total tree damage in the study areas. They will help to set the problem of tree damage in perspective so that decisions relating to the cost (tree damage)/benefits (highway access and safety) may be made more rationally.

Scharpf and Srago surveyed approximately 80 miles of highway and reported 321 sites with one or more trees showing symptoms of salt damage, (Fig. 49). Although not counted precisely, they estimated 3,000 conifers, six feet or taller that were dead or damaged. Of these, 75% were estimated to be on downhill transects. It was not clear whether the 3,000 trees were an estimate of those

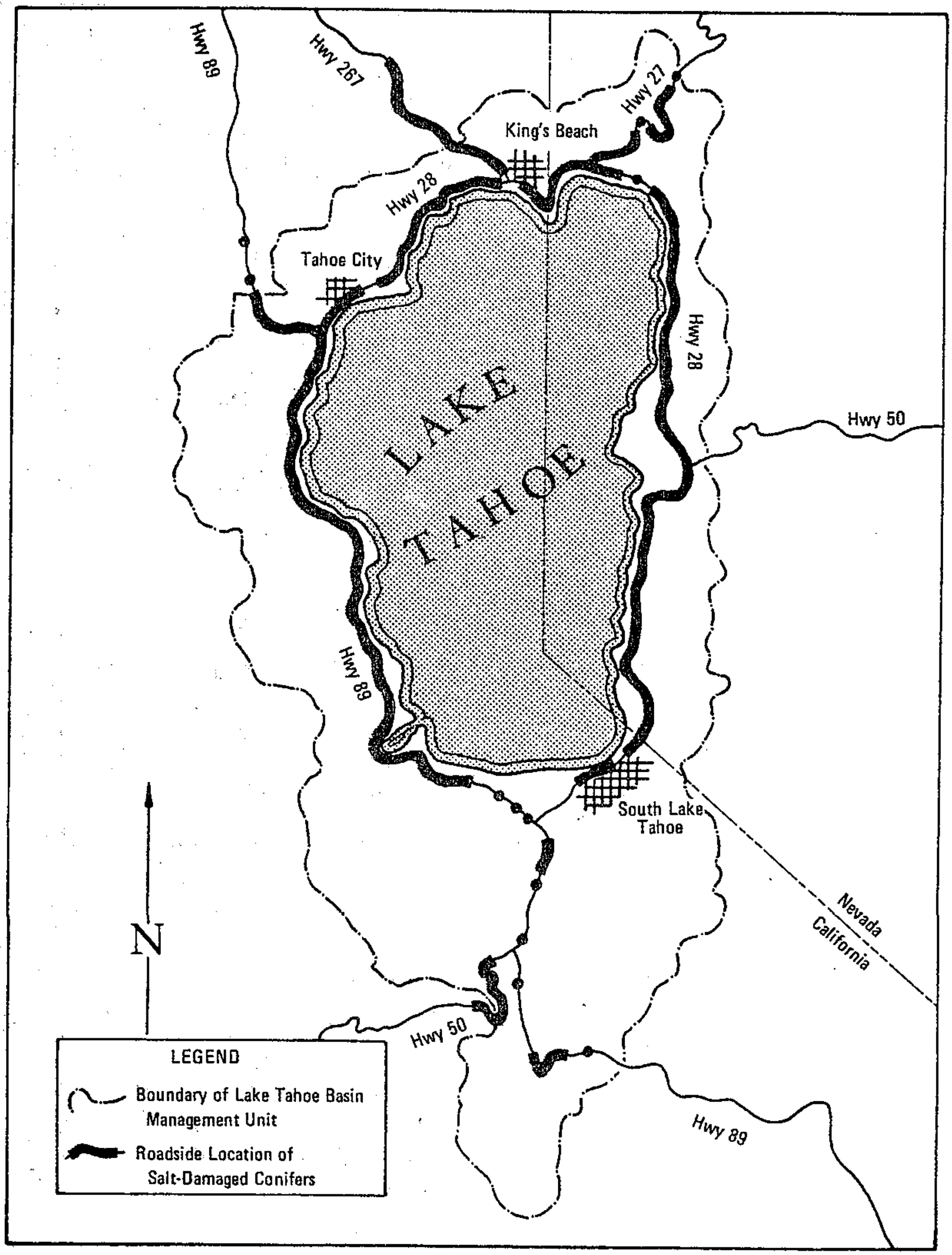
TABLE 44. The means of percent dry weight of sodium and chloride found in the foliage of three major conifers growing beside highways deiced with salt, and the 95 percent confidence intervals around the means.[1]

	DAMAGE RATING	JEFFREY PINE	WHITE FIR	INCENSE-CEDAR
SODIUM	Control	.002 ± .001	.002 ± .001	.001 ± .001
	None	.027 ± .011	.023 ± .016	.014[1]
	Light	.042 ± .011	.022 ± .010	.037 ± .041[2]
	Moderate	.034 ± .007	.036 ± .005[2]	.062 ± .042[2]
	Severe	.077 ± .035	.192 ± .085	.072 ± .044
CHLORIDE	Control	.020 ± .025	.047 ± .062	.097 ± .103
	None	.094 ± .022	.185 ± .073	.330[1]
	Light	.271 ± .081	.302 ± .210	.503 ± .297[2]
	Moderate	.535 ± .131	.853 ± .082[2]	.990 ± .831[2]
	Severe	.855 ± .150	1.204 ± .199	1.387 ± .083

[1]Not enough observations to determine confidence intervals.
[2]Small sample (2-3 observations).

[1] From Scharpf and Srago, 1974, p. 10.

FIGURE 49. The locations of salt-damaged roadside confiers at Lake Tahoe, April 1973.[1]



[1]From Scharpf and Srago, 1974, p. 8.

only on the 321 sites or in the total survey area. However, they stated "All trees or groups of trees growing within 200 feet of highways and appearing to have been damaged by salt were recorded and plotted on a map.", and "Damage was not uniform along the highways. In some locations, only scattered trees showed damage. In others, groups of trees were damaged, and in some cases, nearly all the trees were damaged in a continuous strip of from one to three-tenths of a mile along one or both sides of the highway."

The discussion will be limited to the downhill transects where damage is concentrated to illustrate the most severe cases. Scharpf and Srago estimated 3,000 trees damaged or dead in the study area indicated in Fig. 49, with 75% or 2,250 located on downhill transects. The mean number of trees showing damage symptoms would be about 28 per mile, or one every 188 feet. On a site basis, the estimate would be between 9 and 10 per site. Mean site size was not stated, however.

In the Preliminary Survey of this study there were 419 trees in the 0-50 foot distance interval on 14 sites. There were 1,413 lineal feet of frontage in these sites or about 3,060 trees per mile. Using the data from Scharpf and Srago of 28 damaged or dead trees per mile, slightly less than 1% of trees would have been affected.

The sites in the Preliminary Survey of this study averaged 100 lineal feet along the highways for the first 25 feet from the pavement edge and 88 lineal feet for the 25-50 foot distance interval (Table 45). There were 12 trees per site in the 0-25 foot distance interval, 18 trees in the

TABLE 45. Preliminary Survey. Plant spectrum, description and densities at 0-25 and 25-50 feet from highway on 14 sites.

Distance Interval	Lineal feet	25x25' blocks	ft²		Species[1] Ac	Am	Cd	Jo	Pj	Pl	Pm	Total
0-25'	1,500	67.5	42,188	Nbr.	64	4	19	0	47	1	32	167
				%	38	2	11	-	28	<1	19	40%
25-50'	1,325	52.5	32,813	Nbr.	107	28	41	1	20	0	55	252
				%	42	11	16	<1	8	-	22	60%
0-50'	1,413	120	75,000	Nbr.	171	32	60	1	67	1	89	419
				%	41	8	14	<1	16	<1	21	

Summary

Distance Interval	Trees/Site	Trees/25x25 Plot	lineal ft/tree	ft²/tree	tree/acre
0-25'	12	2.5	9	253	192
25-50'	18	4.8	5	130	335
0-50'	T.=30	$\bar{x}$ =3.5	3	179	243

1. Ac = Abies concolor, white fir; Am = A. magnifica, red fir; Cd = Calocedrus decurrens, incense cedar; Jo = Juniperus occidentalis, western juniper; Pj = Pinus jeffreyi, Jeffrey pine; Pl = P. lambertiana, sugar pine; Pm - P. murryana, lodgepole pine.

25-50 foot interval for a total of 30 trees in the first 50 feet from the pavement edge. Most of the trees in the 25 foot strip nearest the highway were located at a distance beyond 10-15 feet from the pavement edge. This is probably mainly due to highway construction activities, e.g. cuts and fills, berms, culverts, etc., which may occupy much of the first 10 feet. There was one tree per nine lineal feet in the 0-25 foot distance interval, one tree per five lineal feet in the 25-50 foot distance interval, and one tree per three lineal feet in the 0-50 foot distance interval.

A conservative estimate (from the standpoint of tree preservation) of potential damage or death of trees on these sites may be made from the leaf Cl concentration levels found in the Intensive Survey of 1976. These estimated critical levels were based on observations that when damage approached 25%, trees often lost progressively more foliage and might eventually die. Observations in the Seasonal Fluctuation Study indicated that trees with leaf Cl concentrations somewhat below the estimated threshold levels would continue to accumulate Cl and eventually reach these threshold levels. To illustrate the most extreme possibilities, leaf Cl concentrations of 1/2 estimated threshold levels, or more, will be used. In this illustration, numbers of trees of Jeffrey and lodgepole pine and of white and red fir are combined.

In the Intensive Survey study, 47.6% of the Jeffrey pine and 73.7% of the incense cedar had levels of Cl at or above 1/2 the estimated threshold levels. (Percentage of trees at or above leaf Cl concentration of estimated threshold levels were 14.3 and 10.5% respectively, and

0% for white fir.) Because the values for Cl concentration in white fir seemed abnormally low in this study compared to the findings in the Soil Salt and Foliar Salt Application Studies, the leaf Cl concentrations for this species is estimated as the mean between the Jeffrey pine and incense cedar, i.e. 60.6%. This estimate is based on the findings of these later two studies which indicated that white fir is intermediate in sensitivity between Jeffrey pine and incense cedar.

Using these percentages of leaf Cl concentrations an estimate of the number of trees which may eventually have serious damage or death for trees in the downhill transects on the 14 sites is given in Table 46. These values give a frequency of potential damage or death of about one tree in 16 lineal feet, in the first 25 feet.

TABLE 46. Estimate of potential for serious damage or death in 14 sites of the Preliminary Survey for three genera of conifers within 25 feet of the highway.

Genus	Number of trees	%[1]	Number of trees	
			Moderate damage or death	0-light damage
Pine (2 spp.)	79	47.6	38	41
Fir (2 spp.)	68	60.6	41	27
Incense cedar	19	73.7	14	5

[1]Percent with 1/2 estimated threshold level or more of leaf Cl Concentration.

If 75% of the damage (93 trees) is in the first 20-25 feet and estimate of serious damage or death in the 25-50 foot distance interval would be 15% or ±23 (of 252). This averages about one tree in 12 feet or about 16 times more frequent than the data of Scharpf and Srago indicate. This is perhaps the most severe illustration of potential damage.

Recalculating for tree distribution in the 50 foot strip along the highway based on assumed removal of all trees with serious damage or death gives the estimates in Table 47. Of course, real damage is in an irregular pattern as pointed out by Scharpf and Srago.

TABLE 47. Tree distribution on 14 survey sites as originally surveyed and after removal of trees estimated to suffer severe damage or death from highway salt.

Distance interval	Original distribution[1]	Estimated distribution[1]
0-25 ft	9	20.5
25-50 ft	5	6
0-50 ft	3	4.6

[1]Lineal feet per tree.

It is regrettable that any trees die from highway deicing operations. Gross numbers as "3,000 dead or dying trees" may give a picture of devastation along highway corridors. In perspective, however, even a 50-60% mortality within 20 feet of the pavement edge (or a 27% for the first 50 feet) as the above estimate is, would have a relatively minor effect on the visual quality of the first fifty feet of highway corridor where tree density may change from one tree per three lineal feet to one tree per four to five lineal feet. This illustration is far more severe than that depicted by Scharpf and Srago.

7. SUMMARY AND CONCLUSIONS

Tree damage and death along mountain highways of the study area is due to several factors: highway deicing salt, beetle attack, and, although not found in significant amounts in this study, mistletoe and fungous infestations, and purposely avoided in this study, construction activities and natural attrition. In the selection of study sites, those areas of known epidemics of leaf fungi, extensive construction activity and old mature trees were avoided because of the difficulty of obtaining uniform sampling or of separating confounded causes of decline. Furthermore, sampling was limited to trees of such size that leaf tissue samples could be obtained by reaching from the ground. Beetles, fungous infection and dwarf mistletoe may be more serious on trees of a more mature age.

The several studies do indicate that deicing activities cause tree damage and death mostly within 25 but up to

30 to 60 feet of the pavement edge in Jeffrey pine (Pinus jeffreyi) and white fir (Abies concolor) and perhaps to 100 feet or more in incense cedar (Calocedrus decurrens). This is in contrast to reports for California and other areas of death at up to 100 feet or more from deicing operations. However, this damage was very spotty with many trees remaining apparently undamaged. These studies also indicate that beetle attack may be serious at any distance from the highway. In the Intensive Survey of 1976, for example, Jeffrey pine near the road on some sites were heavily infested with beetles. There was no indication, however, that trees weakened by salt were more susceptible to beetle attack. This is contrary to reports that trees weakened by other stresses are more susceptible to beetle attack (4,5,6,13,23).

Beetle attack has been reported to be serious, usually on trees of moderate size, e.g. 10-12 in. trunk diameter at breast height (dbs) or larger, and especially to mature and over-mature trees. Many trees in this study, particularly of Jeffrey pine, with trunk diameters as small as three inches (dbs) were found with heavy infestation.

In the Intensive Survey Study of 1976, there was little beetle infestation in white fir (Abies concolor) however, in spot surveys, including those where dead trees were being removed, heavy beetle infestation was observed in this species.

Although Armillaria root rot (also known as mushroom, shoestring, or oak root rot) was observed frequently, inoculation studies indicated that the isolates collected were nonvirulent strains, acting more as a saprophyte on dying trees rather than as a primary pathogen. This does not rule out other pathogens as cause of tree decline.

Dwarf mistletoe can be a cause of tree decline and death. On the selected sites it was present in varying amounts, but infestations appeared to be limited. Although this parasite may seriously weaken and kill trees, it was impossible to quantify the contribution it was making to tree decline in the study area.

The importance of dispersal or concentration of runoff of snow melt from the highway was demonstrated by the Intensive Survey of 1976 where, on the lowest salt application site, tissue Na and Cl levels were abnormally high in certain areas. This appeared to be due to the drainage pattern for the site where runoff from one quarter mile or more of pavement was concentrated in one spot.

Soil and foliar salt application studies allowed an estimate of threshold levels of tissue Na and Cl where about 1/4 of the needles were brown (25% damage). These threshold levels varied from species to species. Incense cedar appeared to be the most sensitive, white fir intermediate, and Jeffrey pine the most tolerant species to salt when both rate of uptake and leaf damage were considered. Threshold level estimates for incense cedar were higher than those for white fir and Jeffrey pine, but this species absorbed chloride much more readily than did white fir and Jeffrey pine. This was true whether salt was applied to the soil or to the foliage.

The uptake by white fir of salt applied to the soil was temperature dependent. Little uptake occurs in months with low air temperatures, but the rate of absorption increased rapidly in April and May when air temperatures increased.

Salt uptake through bark seems unlikely on the basis of one study. Young trees of three species were used and there was little change in leaf Na and Cl from February through April. By June, leaf Na and Cl were increasing but there was evidence of some root initiation in the treated area in one species and of breakdown of the sealing materials around some of the trees by this date.

A study on seasonal patterns of salt in soils and tissues indicated that soils in the study area do not continue to accumulate salt but that the salts are readily leached. Soil salt levels were relatively high in October 1977 after two years of drought but by May 1978, even after an additional year of salt application, the normal to above normal precipitation had reduced salt levels to one-half or more. This leaching was also observed in the Soil Salt Application Study. However, tissue Na and Cl continued to increase during the course of the study at distances near the road.

In the Seasonal Salt Fluctuation Study on Jeffrey pine and incense cedar, the latter species accumulated higher levels of Cl and accumulated potentially damaging levels at greater distances from the highways than did Jeffrey pine. Because of the low levels of soluble soil Na and Cl at 60 feet and beyond and because of the low levels of leaf Cl in Jeffrey pine, it is believed that the Cl accumulation in incense cedar at 60 to 200 feet from the highway was due largely to aerosol borne salt.

The results of these studies regarding damage symptom development and damage descriptions, and of leaf Na and Cl levels at different stages of damage symptom development correlate very well with those of Scharf and Srago. In putting tree damage in a proper perspective comparison of the findings of the Scharf and Srago study and of this study were made.

These comparisons indicated that as few as 1%, or under extreme assumptions, as many as 27% of the trees in the 50 feet adjacent to the highways may ultimately be damaged. Even with the maximum estimates of losses, the visual quality, as measured by tree density in the first 50 feet of the highway, would only be reduced from one tree per three lineal feet to one tree per 4.6 lineal feet. The use of mitigation measures already in effect and which might be implemented should reduce both actual tree damage and mortality and the visual impact of such damage and mortality.

8. MITIGATION MEASURES

Reduction in salt applications is an obvious mitigation measure. This reduction will be effective primarily in those species which absorb salt through the roots. It will be less effective in reducing damage in incense cedar, and to some extent in white fir, which absorb salt readily through the foliage. Incense cedar was found to have high levels of salt in the Seasonal Fluctuation Study even on the site where the salting rate was only 2.2 T lane/mile. However, even with this species, a reduction in salt use should reduce absorption of salt distributed in aerosols.

Continuation of revised salting practices, e.g. accurate logging of salt application, calibration of equipment, etc., is recommended.

The estimated critical levels of salt applied in the Soil Salt Application Study (tons/acre) may be related to highway salt applications (tons/lane mile) with the help of Table 48 and Figure 50. It must be remembered that these are theoretical distribution patterns. Usually there will be a continuous gradient of salt levels, decreasing as the distance from the pavement edge increases, and also altered by roadside ditches, AC dikes, culverts and highway grade and super.

A reduction in soil salt levels may also be accomplished in other ways. Highway runoff may be channeled to live streams or to areas with little vegetation by use of AC dikes, culverts, roadside ditches or berm configuration. Conversely, a reduction in soil salt in localized areas may be accomplished by more uniform dispersion of runoff over a large area by the removal of AC dikes, more frequent use of culverts of diversion techniques which minimize the concentration of runoff. These efforts would be of particular value when specific problem areas are identified or in areas where the existing vegetation is of particular importance to the visual quality of the site.

The use of other deicing chemicals cannot be recommended at the present time. Nitrogen containing compounds such as urea are apt to be more deleterious to the environment than is NaCl because of their effects on stream and lake water quality. The use of $CaCl_2$ would probably be no better from a biological standpoint because the conifers in the study

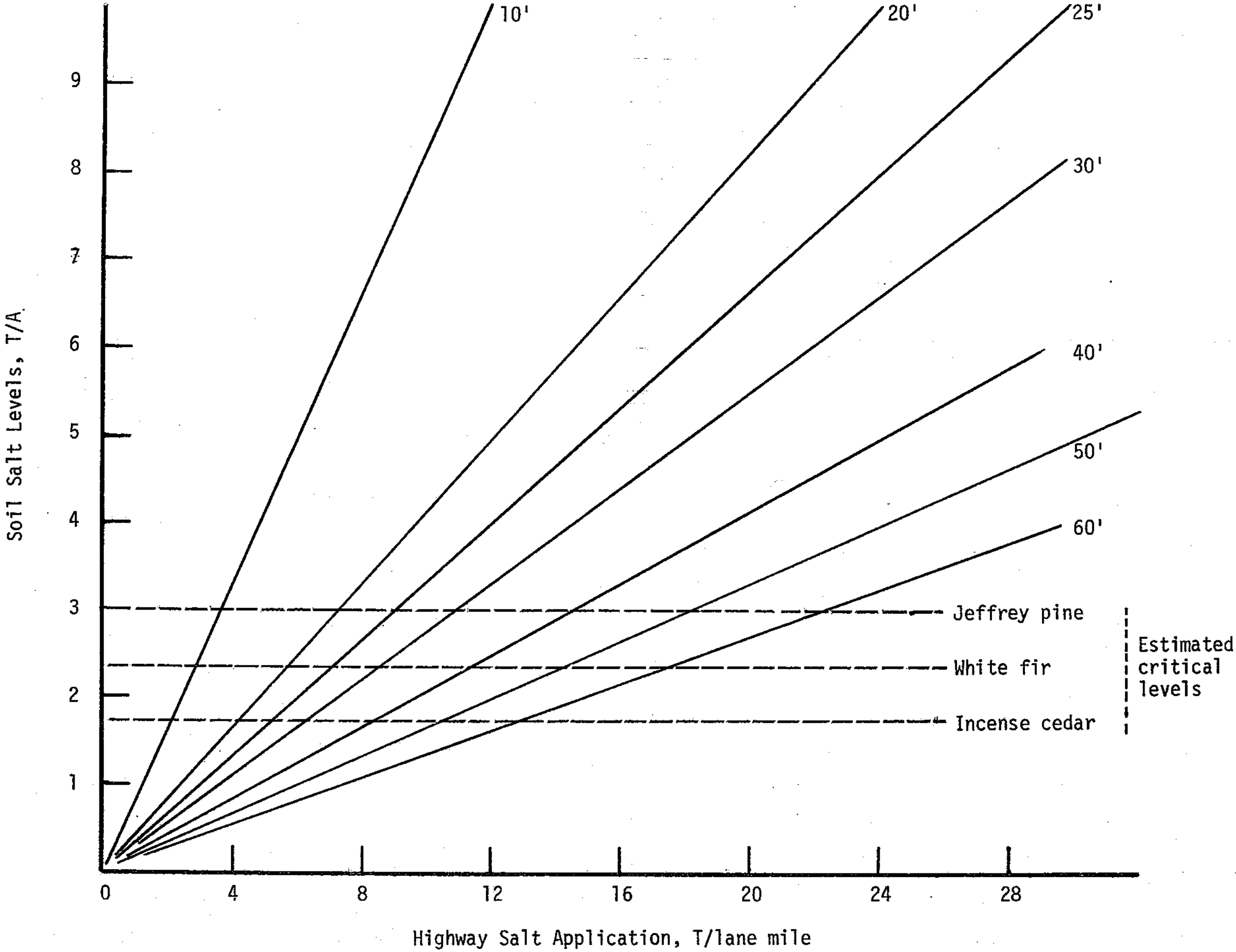
Table 48. Salt application conversion, tons per lane mile equated to tons per acre for several distribution distances from edge of pavement.

Tons/ lane mile	Tons/Acre[1,2] Distance Distributed, Feet						
	10	20	25	30	40	50	60
1	0.83	0.41	0.33	0.28	0.21	0.17	0.14
2	1.65	0.83	0.67	0.55	0.41	0.33	0.28
3	2.48	1.24	1.00	0.83	0.62	0.50	0.41
4	3.30	1.65	1.33	1.10	0.83	0.66	0.55
6	4.95	2.48	2.00	1.65	1.24	0.99	0.83
8	6.60	3.30	2.67	2.20	1.65	1.32	1.10
9	7.43	3.71	3.00	2.48	1.86	1.49	1.24
10	8.25	4.13	3.33	2.75	2.06	1.65	1.38
12	9.90	4.95	4.00	3.30	2.48	1.98	1.65
14	11.55	5.78	4.67	3.85	2.89	2.31	1.93
15	12.38	6.19	5.00	4.13	3.09	2.48	2.06
16	13.20	6.60	5.33	4.40	3.30	2.64	2.20
18	14.85	7.43	6.00	4.95	3.71	2.97	.248
20	16.50	8.25	6.67	5.50	4.13	3.30	2.75
21	17.33	8.66	7.00	5.78	4.33	3.47	2.89
22	18.15	9.08	7.33	6.05	4.54	3.63	3.03
24	19.80	9.90	8.00	6.60	4.95	3.96	3.30
26	21.45	10.73	8.67	7.15	5.36	4.29	3.58
27	22.28	11.14	9.00	7.43	5.57	4.46	3.71
28	23.10	11.55	9.33	7.70	5.70	4.62	3.85
30	24.75	12.38	10.00	8.25	6.19	4.95	4.13

[1]If salt from more than one lane is dispersed on one side of the pavement, multiply by the number of lanes.

[2]Salt will not be distributed evenly throughout the distances but usually will be more concentrated nearest the highway.

distance intervals from the pavement edge. Estimated critical levels for three conifer species are indicated.



area absorb Cl as readily, and with some species, more readily than Na. The Cl ion was found to be extremely well correlated with plant damage. The fact that the soils of the study area are mostly coarse textured and leach readily negates any advantage $CaCl_2$ might have over NaCl.

Applications of gypsum ($CaSO_4.2H_2O$) have been recommended in the east to counteract the deflocculating effect of Na ions. This chemical is only effective on soils with sufficient clay fractions to permit flocculation or aggregation. The soils of the study area are largely sandy soils with little or no aggregation, hence the Na ion does not appear to materially alter the percolation rates in these soils. In general, we do not recommend the use of this chemical as a mitigation measure. Its use would only add to the "salt" load in the study area without any predictable advantages. However, there may be small areas of clay soils along roadsides where Na ions would adversely affect percolation. If such areas are specifically identified, the use of $CaSO_4$ may be justified in these localized areas.

Although perhaps not strictly a mitigation measure, the prompt removal of trees which have been injured beyond the point of recovery, whether by salt, beetle infestion, infection by fungi or mistletoe or other causes, will lessen the visual impact on the traveling public. This removal should occur before the tree is completely dead. The point at which removal is accomplished should be determined by individual diagnosis, e.g., extent of beetle damage, leaf Cl concentrations, etc.

The visual impact of branches defoliated or mechanically damaged by snow removal operations could be reduced by removal of the damaged branches. The economics of removal may not be justified on economic considerations. These dead limbs have little adverse effect on the survival of trees.

Beetle infestations can be controlled by sanitation logging and by use of insecticides. The economics of chemical control on the extensive mountain highway system is very questionable.

Any revegetation with conifers along the highways subject to deicing salts should use the most resistant tree species. Jeffrey pine, lodgepole pine and Western juniper (<u>Juniper occidentalis</u>) appear to be the best trees for most of this study area. Shrub species native to the study area should be used in the first 10 to 20 feet from the pavement edge. In this study we could not confirm death of any shrub species due to highway deicing salts, although some of the foliage burn observed may have been due to this cause.

There is, of course, the possibility that a long term testing and screening program might find individual trees in some of the native species which might be more tolerant of salt than the average tolerance of the species. Propagation would have to be by vegetative means. This would make planting stock quite costly compared to bare root seedlings now used. It is very questionable whether the economics of such a program would be justified.

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10. APPENDIX

10.1 Salt Tolerance of Four Shrub Species of the Sierra Nevada - Potential Impact of Highway Deicing

Robert P. Doss[1], John Law[2], Jack L. Paul, Andrew T. Leiser
Department of Environmental Horticulture
University of California,
Davis, California 95616

Abstract

Arctostaphylos nevadensis Gray, *Ceanothus prostratus* Benth., *Penstemon newberryi* Gray, and *Sambucus microbotrys* Rydb. were grown with varying soil salt concentrations in the greenhouse. The objective was to obtain information about the possible response of these species to increased salinity in the roadside environment resulting from the application of highway deicing salt. *A. nevadensis*, *C. prostratus*, and *P. newberryi* had visible salt damage symptoms after less than a six week exposure to a soil solution containing a salt concentration of 40 milliequivalents liter $^{-1}$ (meq l^{-1}). Symptoms appeared in *S. microbotrys* after 30 days exposure to a salt concentration of 80 meq l^{-1}. With the onset of salt damage symptoms, the concentration of sodium varied from 0.54 to 2.01 and of chloride from 2.55 to 7.74 percent of dry weight in these shrubs. Leaves of these shrubs collected from several locations contiguous to highways subjected to heavy deicing salt application did not show potentially damaging levels of chloride or sodium.

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[1]Present address: USDA, ARS Ornamental Plants Lab, Extension Center, Puyallup, Washington 98371

[2]Present address unknown

Introduction

Numerous workers have suggested that plants growing in roadside environments can experience damage resulting from the application of highway deicing salts (7, 13, 14, 15, 17, 18, 19, 20, 21, 23, 24, 25, 26). Others have concluded that, in at least some locations winter road salting does not harm roadside trees (8, 9).

Scharpf and Srago (17) found many conifers in the Lake Tahoe Basin of California and Nevada exhibited damage symptoms that correlated with high leaf concentrations of sodium (Na) and chloride (Cl). The work reported here grew out of an attempt to duplicate these findings using native shrub species. Shrubs were chosen because of the ease of propagation and maintenance. These characteristics allowed extensive testing within the relatively controlled environment of the greenhouse. Moreover, shrubs constitute a conspicuous portion of the roadside vegetation, and are important with respect to erosion control (13), snow screening (10), and soil fertility (4).

Materials and Methods

Greenhouse studies:

Rooted cuttings of the evergreen shrubs *Arctostaphylos nevadensis* Gray, Pinemat manzanita, *Ceonothus prostratus* Benth., squaw carptet, and *Penstemon newberryi* Gray, Newberry Penstemon and the deciduous shrub, *Sambucus microbotrys* Rydb., mountain elderberry, were transplanted into one gallon nursery cans with a soil mix containing equal parts (by volume) of medium sand, ground peat, and redwood sawdust. The plants were grown under photoperiods (July and August, Davis, California) in a greenhouse with a maximum day temperature of 21°C and a minimum night temperature of 16°C.

The shrubs were irrigated to runoff daily with half strength Hoagland's solution. Equinormal amounts of $CaCl_2$ and NaCl were added to the basic irrigation solution to give added salt concentrations of 0, 20, 40, 80, 120, and 160 meq l^{-1}. Final soil salt concentrations greater than 40 meq l^{-1} were reached by stepwise increase from 40 meq l^{-1} using a 40 meq l^{-1} step up every third day[1]. The treatments in each shrub species were replicated at least ten times.

The character and the time of onset of salt damage symptoms were noted for each species. After 40 to 59 days, the treatments were discontinued and the fresh and dry weights of the plant tissue formed during the treatment intervals were measured. Leaf concentrations of Cl were determined by potentiometric titration and of Na by flame photometry using a Beckman Model DU Flame Spectrophotometer.

Field studies:

Three sites, 1, 11, and 15 in the Sierra Nevada either near or within Lake Tahoe Basin were chosen for collection of field grown shrub tissue. Site 15 had been exposed to large, and sites 1 and 11 to low quantities of deicing salts. Healthy (green) and dead (brown) leaves were collected

[1]This preliminary experiment was started before any field soil data were available. All salt levels except 20 meq l^{-1} were higher than actual field levels.

separately and analyzed for chloride and sodium content using procedures identical to those used for the greenhouse grown plants. The State of California, Division of Highways, Transportation Laboratory provided soil and water analysis data used in the field study.

Results and Discussion

Greenhouse studies:

Table 1 describes the salt damage symptoms seen with greenhouse grown plants. Visible symptoms of salt damage did not appear on any of the plants which received the 0 or the 20 meq l^{-1} salt treatment (Table 2). Longer treatment periods would probably have caused an increase in the number of plants showing symptoms as well as an increase in the number of plants killed.

Figure 1 indicates the relative fresh weight yield of the four shrub species as a function of soil salt concentration. The dry weight yields followed an identical pattern.

Sambuces microbotrys exhibited a severe depression of growth at the 20 and 40 meq l^{-1} salt concentrations. Visible symptoms of salt damage were not apparent at the lower concentrations except that plants periodically dropped leaves and new growth flushes appeared (Fig. 1, Tables 1 and 2). This species was a low Na accumulator but was the highest Cl accumulator (Figs. 2 and 3).

Ceanothus prostratus and *Penstemon newberryi*, on the other hand, showed visible signs of salt damage at soil salt levels not associated with a marked inhibition of growth.

Table 1. Salt damage symptoms in four Sierran shrub species developed in greenhouse study.

Species	Symptoms
Arctostaphylos nevadensis	Reddening of leaf tips followed by necrosis which develops basipetally on the leaf. No particular starting place on the plant.
Ceanothus prostratus	Chlorosis of leaf tips followed by necrosis which develops basipetally. Leaves in center of plant (i.e. neither least nor most mature leaves) are affected first.
Penstemon newberryi	Increase in succulence accompanied by pronounced decrease in size of newly formed leaves. Leaves later take on a dull silvery cast and chlorotic areas develop on tip and along midvein. Necrosis follows same pattern as chlorosis with necrotic areas bordered by chlorotic tissue.
Sambucus microbotrys	Leaf roll in younger leaves is followed by slight yellowing. Leaves later lose turgidity and undergo senescence. At lower salt levels affected leaves abscise and are replaced by new leaves which appear normal.

Table 2. Time to appearance of salt damage symptoms in four Sierran shrub species.

Species	Salt level meq l[1]	Minimum days to appearance of symptoms after beginning of treatment[2]	Fraction of plants showing symptoms at harvest	Fraction of plants dead at harvest
A. nevadensis	0	-	0/10	0
	20	-	0/10	0
	40	20	3/10	0
	80	20	10/10	3/10
	120	10	10/10	5/10
	160	0	10/10	9/10
C. prostratus	0	-	0/10	0/10
	20	-	0/10	0/10
	40	14	3/10	0/10
	80	11	10/10	3/10
	120	2	10/10	8/10
	160	0	10/10	6/10
P. newberryi	0	-	0/11	0/11
	20	-	0/11	0/11
	40	37	1/11	0/11
	80	26	4/11	0/10
	120	18	11/11	4/11
	160	11	11/11	6/11
S. microbotrys	0	-	0/10	0/10
	20	-	0/10	0/10
	40	-	0/10	0/10
	80	30	8/10	0/10
	120	25	10/10	7/10
	160	16	10/10	3/10

[1]Treatment periods were: *Arctostaphylos nevadensis*-59 days, *Ceanothus prostratus*-40 days, *Penstemon newberryi*-49 days, and *Sambucus microbotrys*-50 days.

[2]Zero value indicates that symptoms were already present at time of step up in salt concentrations.

Figure 1. Relative yield of four Sierran shrub species as a function of the salt concentration of the soil solution. Average fresh weight yields at 0 meq l^{-1} salt concentration were: Arctostaphylos nevadensis (A.n.), 5.41 ± 0.83 g: Ceanothus prostratus (C.p.), 21.3 ± 3.17 g; Penstemon newberryi (P.n.), 43.45 ± 3.00 g; and Sambucus microbotrys (S.m.), 170.04 ± 28.8 g. Each point represents the average of either 10 or 11 (P. newberryi) values. Standard errors were similar in magnitude to those listed above for most of the points. See Table 3 for treatment periods.

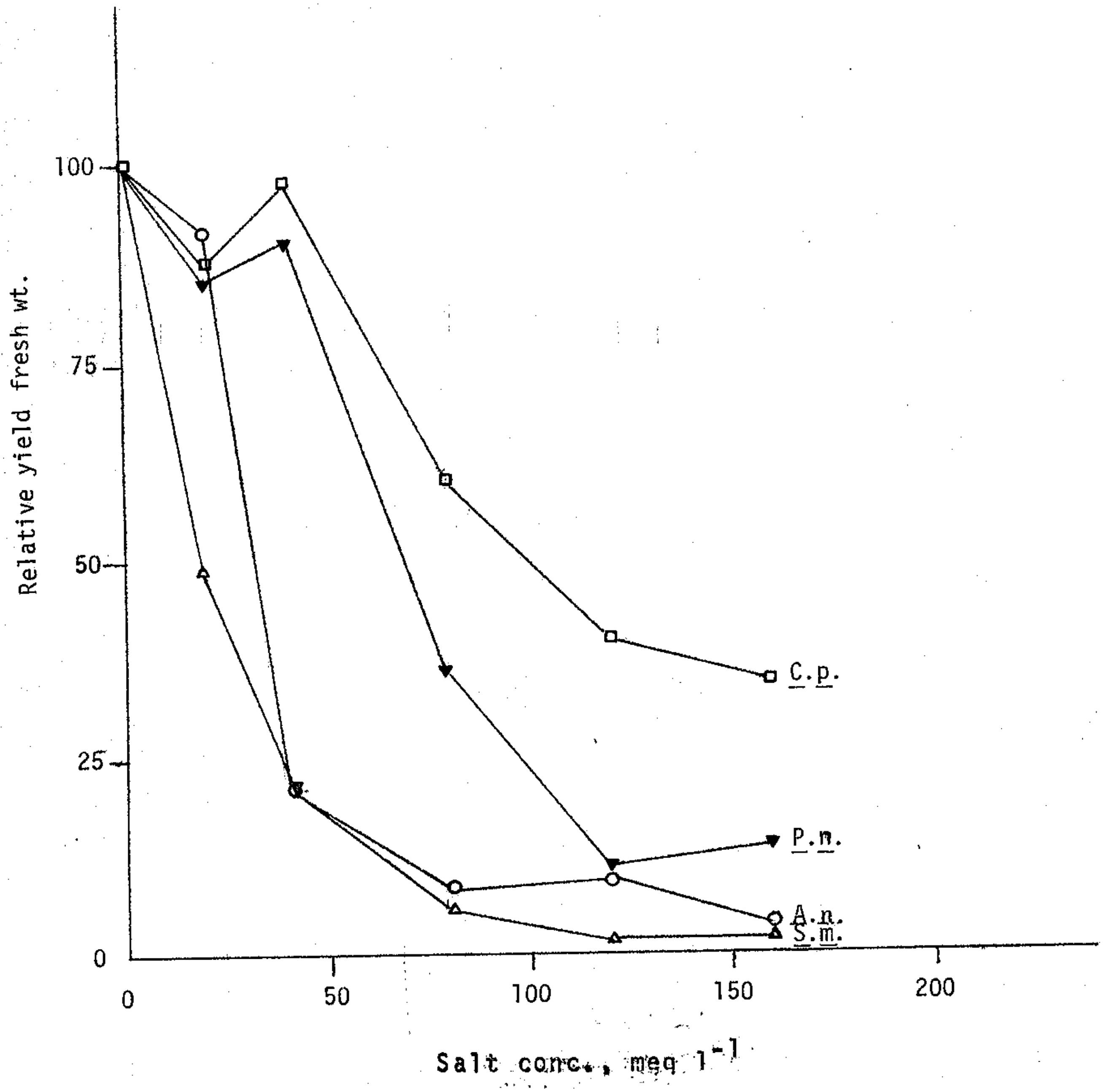


Figure 2. Leaf Na concentration of four Sierran shrub species, *Arctostaphylos nevadensis* (A.n.), *Ceanothus prostratus* (C.p.), *Penstemon newberryi* (P.n.), and *Sambucus microbotrys* (S.m.) as a function of salt concentration of the soil solution. Each point represents the mean of three determinations.

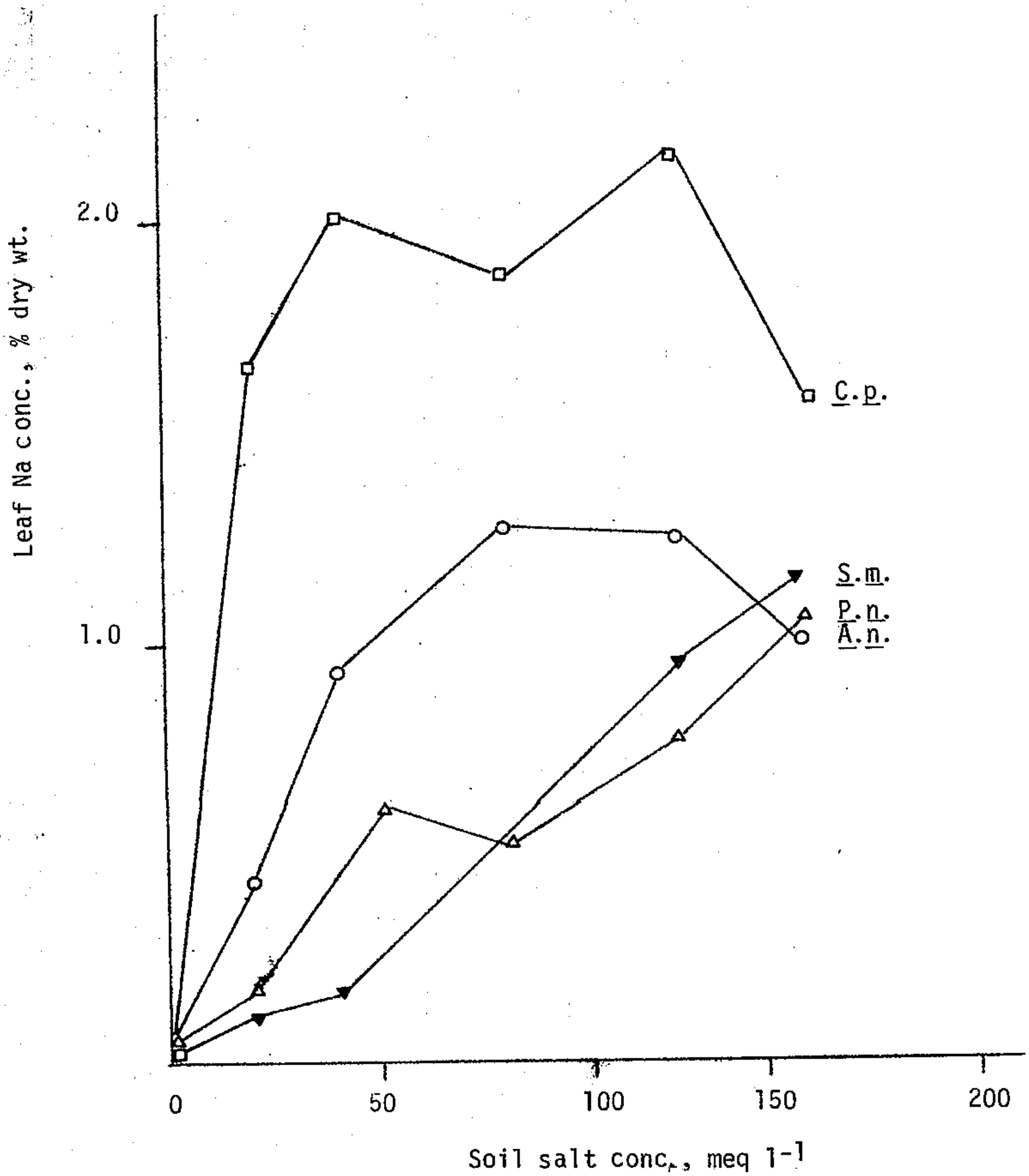
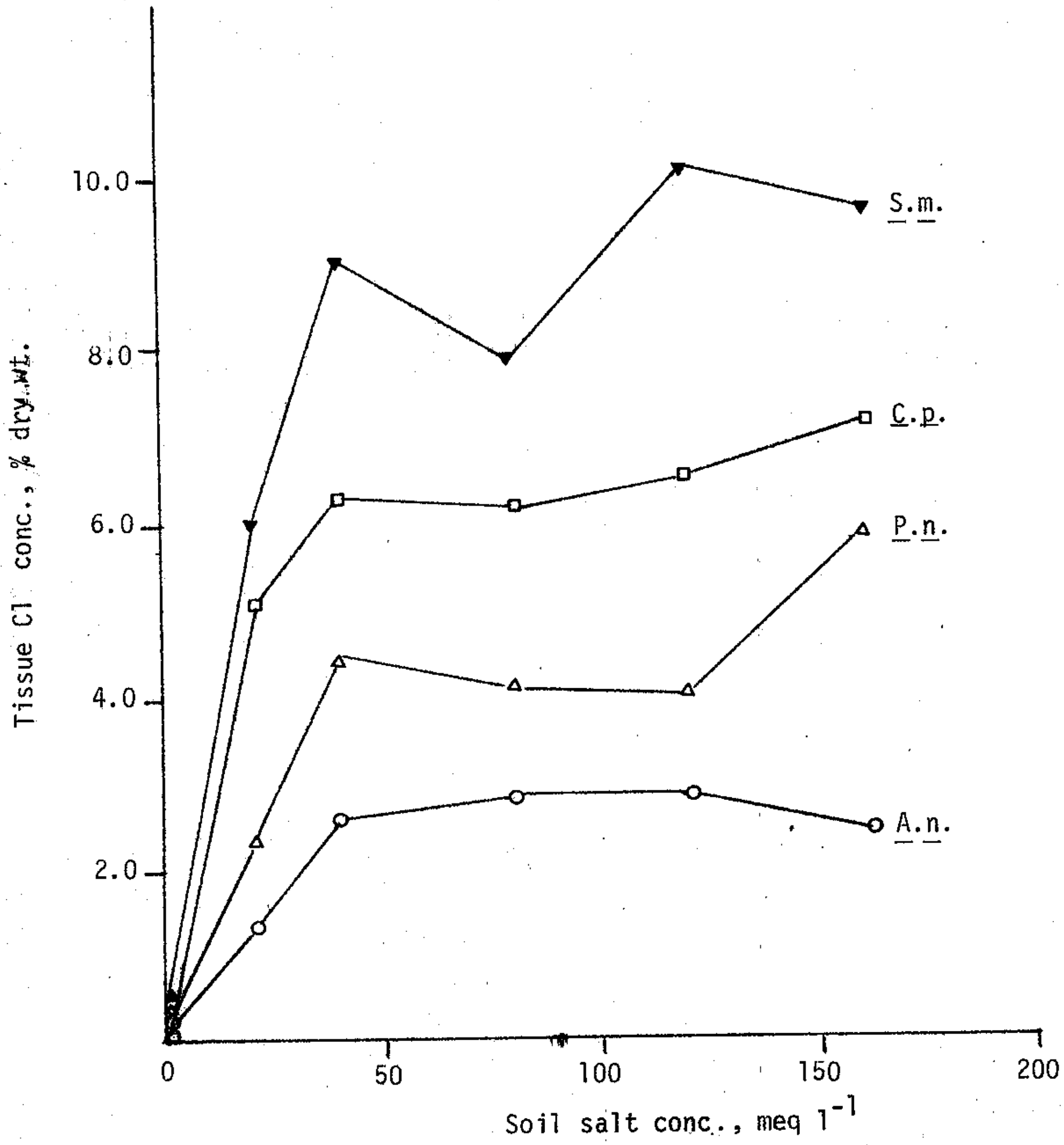


Figure 3. Leaf Cl concentration of four Sierran shrub species, *Arctostaphylos nevadensis* (A.n.), *Ceanothus prostratus* (C.p.), *Penstemon newberryi* (P.n.), and *Sambucus microbotrys* (S.m.), as a function of salt concentration of the soil solution. Each point represents the mean of three determinations.



C. prostratus, a relatively slow grower, had the highest relative yield, the highest Na and second highest Cl levels. P. newberryi, a relatively strong grower, had a relative yield, low Na and intermediate Cl levels.

Arctostaphylos nevadensis, a slow grower, had the second lowest relative yield, an intermediate Na level, and the lowest Cl level of the four species.

Table 3 lists the leaf concentrations of Na and Cl found in plants which showed incipient symptoms of salt damage. The values reported here are generally higher than those reported to be excessive by other workers who have related Na levels of from 0.5 to greater than 9.0 percent of dry weight to damage symptoms in a number of plants (1, 7, 8, 14, 17, 21, 22, 26). Similarly minimum leaf Cl levels of from 0.3 to 8.5 percent of dry weight have been correlated with damage symptoms (1, 3, 5, 7, 8, 17, 18, 22, 23, 26).

Figures 2 and 3 show the leaf concentrations of Na and Cl as a function of the salt concentrations of the soil solution. This information, taken along with the data shown in Table 1 should provide rough guidelines for relating symptoms to salt damage in the field.

Field studies:

Neither Na nor Cl were found at potentially damaging levels in any leaves from plants growing naturally in the field except Na levels (Table 4) in S. microbotrys.

Sodium concentrations in samples from the field varied from 0.45 to 0.56 percent of dry weight in the six samples of

Table 3. Minimum leaf salt concentration of four Sierran shrub species with onset of salt damage symptoms. Each value represents the mean of three replicates, shown with standard errors.

Species	Tissue concentration (% dry weight) Na	Cl
Arctostaphylos nevadensis	0.92 ± 0.15	2.55 ± 0.48
Ceanothus prostratus	2.01 ± 0.18	6.33 ± 0.47
Penstemon newberryi	0.61 ± 0.17	4.55 ± 0.73
Sambucus microbotrys	0.54 ± 0.24	7.75 ± 0.45

Table 4. Leaf salt content of shrubs growing in the field.

Species	Site[1]	Distance from highway[2]	% of dry weight Na	% of dry weight Cl
Arctostaphylos nevadensis	11	72	0.14	<0.005
	11	72	0.09	<0.005
	11	72	0.08	<0.005
	11[3]	72	0.09	<0.003
	11[3]	72	0.07	<0.005
	11[3]	72	0.09	<0.005
	15	250	0.13	<0.05
	15	250	0.14	<0.05
	15	250	0.12	<0.05
	15	-	0.13	<0.05
	15	-	0.12	<0.05
	15	-	0.13	<0.05
	15[3]	-	0.11	<0.05
	15[3]	-	0.10	<0.05
	15[3]	-	0.11	<0.05
Ceanothus prostratus	11	36	0.25	<0.05
	11	36	0.25	<0.05
	11	36	0.25	<0.05
	11	113	0.23	<0.05
	11	113	0.25	<0.05
	11	113	0.24	<0.05
	11	354	0.26	<0.05
	11	354	0.25	<0.05
	11	354	0.25	<0.25
Penstemon newberryi	15	13	0.09	0.017
	15	13	0.14	<0.003
	15[3]	13	0.15	0.006
	15[3]	13	0.14	0.002
	15	43	0.13	0.006
	15	43	0.09	<0.015
	15[3]	43	0.14	0.004
	15[3]	43	0.14	0.003
	15	108	0.15	<0.015
	15	108	0.14	0.003
Sambucus microbotrys	1	43	0.46	0.006
	1	43	0.56	--
	1	43	0.46	0.006
	1	243	0.47	0.003
	1	243	0.45	0.003
	1	243	0.47	0.003

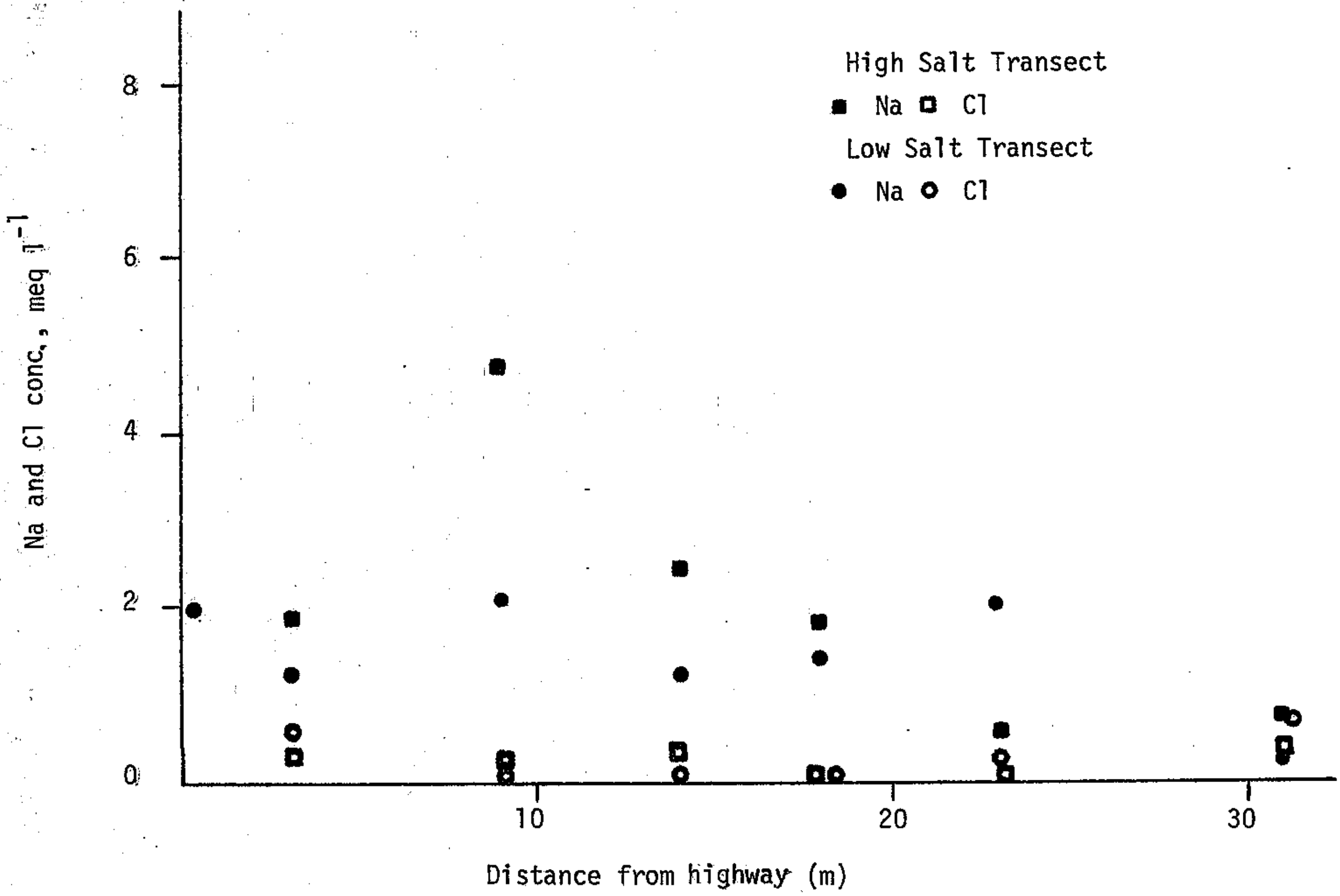
[1]Site 1, State Route 88, (Carson Pass Highway), Amador Co., P.M. 60.5; Site 11, State Route 89, El Dorado Co., P.M. 26.4 (Sugar Pine State Park, Lake Tahoe); Site 15, U.S. 50, El Dorado Co., P.M. 69.4, (foot of Meyer's Grade, Tahoe Basin).
[2]Measured from edge of paved roadway, in feet.
[3]Dead tissue.

tissue from S. microbotrys, and from 0.11 to 0.26 percent in the 34 tissue samples from the remainder of the plants. Again, these concentrations, except for S. microbotrys are below those associated with sodium toxicity symptoms in any but Na sensitive plants (1, 26).

Chloride concentrations in the samples ranged from less than 0.003 to 0.017 percent of dry weight. These values are several orders of magnitude below the minimum toxic concentrations found in the greenhouse studies and are also far below any values reported to be excessive by other workers (1, 3, 5, 17, 22, 23). The lowest levels found in field grown plants would be considered to be below the critical concentration for Cl in a number of plants (6, 22). Therefore, the death of these tissues is probably due to factors other than excessive salt.

The lack of excessive levels of salt in plants growing in the field may be explained when soil concentrations of Na and Cl are considered. Investigators have found that soil concentrations of Cl must reach from 3 to 25 meq l^{-1} in the soil solution before damage symptoms are seen, even in perennial plants (2, 18). In the greenhouse studies it was found that damage symptoms did not appear in shrubs growing in soil containing 20 meq l^{-1} chloride and 10 meq l^{-1} sodium. Such levels of salt were not often detected in field soil even at locations heavily treated with deicing salt. Figure 4 indicates that, as reported by others (18, 26), chloride and sodium concentrations are highest immediately next to a salted highway where few plants are found. Thus, the number of shrubs exposed to excessively high levels of salt in the soil solution is small. Moreover, the data shown in Figure 4 were obtained

Figure 4. Salt concentration of the soil solution as a function of the distance from the paved roadway. Data provided by State of California, Division of Highways, Transportation Laboratory. Samples were collected in spring, 1974. High salt transect was at site 15 and low salt transect was at site 1.



from soil samples collected in the Spring when salt levels are usually at their highest (23) and over-estimate the average salt levels experienced by the plants during the entire growing season. Another possible explanation is that rain may have leached Na and Cl from the leaves prior to the summer sampling date.

Summary

Although Scharpf and Srago (17) had found that conifers adjacent to highways in the Lake Tahoe Basin exhibited damage symptoms that were correlated with high leaf concentrations of Na and Cl, the data for the four shrub species did not show high Na or Cl concentrations. The high Na levels for *Sambucus microbotrys* were at both 43 and 343 feet from the pavement edge. In the greenhouse studies, this species was the lowest accumulator of Na, thus the results are difficult to explain.

Two explanations for the differences between reported salt damage on conifers and these data for shrub species are possible. These conifer species may be more sensitive to salt than the associated shrub species. Differences in species sensitivity to salt have been reported (7, 19, 20, 21). Much of the salt accumulation in conifers might be due to salt spray generated by traffic. The associated shrub species would be covered by snow and thus protected from spray drift.

Further greenhouse studies were abandoned in favor of more extensive field studies because of the poor relationship between these preliminary experiments. The symptoms of salt damage developed in the greenhouse are valuable but the threshold levels at which these symptoms occurred may be unrealistically high.

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Appendix II

Table IA. Intensive Survey, 1976. Jeffrey pine data by sites and groups. Site 9.

Tree no.	Damage %	Fill, inches	CBH, inches	Beetle holes /ft^2	Green Tissue, % D.W. Na	Green Tissue, % D.W. Cl	Brown Tissue, % D.W. Na	Brown Tissue, % D.W. Cl	Soils 0-12" EC_e	Soils 0-12" meq l^{-1} Na	Soils 0-12" meq l^{-1} Cl	Soils 12-24" EC_e	Soils 12-24" meq l^{-1} Na	Soils 12-24" meq l^{-1} Cl
							Group I							
74	10	9	18	34.7	.040	.089	.043	.007	-	-	-	-	-	-
75	30	12	31	48.0	.041	.153	.051	.107	0.23	1.26	0.81	-	-	-
49	20	5	27	5.3	.040	.055	.058	.078	-	-	-	0.20	1.04	0.79
52	60	15	19	24.0	.029	.450	.048	.481	0.29	2.50	0.83	0.24	2.12	1.34
67	35	11	17	64.9	.027	.317	.051	.290	0.17	1.76	0.46	0.15	1.22	0.52
82	20	8	26	24.9	.043	.010	-	-	-	-	-	-	-	-
							Group II							
62	50	2	27	32.0	.037	.028	.040	.049	0.09	0.36	0.34	0.06	0.24	0.09
78	45	6	29	30.6	.034	.033	.051	.026	-	-	-	0.06	0.24	0.44
53	10	4	34	3.5	.032	.031	.029	.023	0.12	1.00	0.38	0.15	0.80	0.31
84	5	1	9	8.0	.035	.007	-	-	-	-	-	-	-	-
87	10	2	15	14.4	.049	.017	.062	.014	-	-	-	0.20	0.50	0.51
							Group III							
43	30	2	17	12.7	.034	.006	.029	.004	0.16	0.40	0.47	0.10	0.36	0.43
65	85	1	28	46.3	.031	.006	.046	.022	0.07	0.36	0.27	0.08	0.14	0.30
30	40	3	19	35.4	.032	.003	.039	.002	0.09	0.16	0.42	0.05	0.36	0.43
34	40	1	17	77.1	.032	.007	.032	.002	0.14	0.36	0.57	0.09	0.40	0.49
35	45	4	16	54.0	.029	.010	.028	.003	0.11	0.40	0.42	0.06	0.16	0.28
38	20	1	38	14.5	.028	.004	.039	.002	0.14	0.36	0.57	0.09	0.40	0.49

Appendix II

Table 1B. Intensive Survey, 1976. Jeffrey pine data by sites and groups. Site 4.

					Green tissue % DW		Brown tissue % DW		Soils 0-12"			Soils 12-24"		
Tree no.	Damage %	Fill, inches	CBHC inches	Beetle holes /ft^2	Na	Cl	Na	Cl	EC_e	Na meq l^{-1}	Cl meq l^{-1}	EC_e	Na meq l^{-1}	Cl meq l^{-1}
Group I														
113	6	2	18	5.3	.188	.098	.345	.156	0.56	4.70	3.13	0.97	9.80	5.61
120	15	1	8	0.0	.289	.138	.322	.157	0.42	3.60	2.97	0.29	2.76	2.19
111	75	2	5	14.4	.262	.156	.368	.317	-	-	-	-	-	-
112	50	3	10	0.0	.184	.292	.184	.415	-	-	-	-	-	-
117	25	6	13	3.7	.262	.141	.335	.169	0.50	4.00	3.03	0.70	6.40	3.96
126	15	3	23	14.6	.184	.090	.381	-	0.58	5.20	3.96	0.69	6.40	4.99
Group II														
141	4	1	27	5.3	.059	.009	-	-	-	-	-	-	-	-
147	10	3	24	6.0	.046	.044	.055	.032	0.22	1.76	1.04	-	-	-
106	1	4	20	4.8	.073	.038	.074	.071	-	-	-	-	-	-
135	1	10	24	4.0	.046	.011	.057	.005	-	-	-	-	-	-
136	2	1	33	8.7	.046	.031	-	-	0.11	0.50	0.66	-	-	-
143	15	4	14	20.6	.059	.026	-	-	-	-	-	-	-	-
Group III														
150	8	1	27	6.2	.028	.070	.034	.050	-	-	-	0.08	0.64	0.32
170	30	2	23	37.6	.036	.038	.036	.032	0.10	0.16	0.20	0.09	0.16	0.42
154	25	2	27	21.3	.092	.031	.086	.055	0.14	0.64	0.64	0.10	0.96	0.32
158	35	2	26	35.1	.040	.006	.048	.005	0.20	0.24	0.33	-	-	-
162	5	1	15	14.4	.036	.029	.029	.004	-	-	-	0.10	0.24	0.47
166	0	2	6	0.0	.027	.007	-	-	0.10	0.86	0.58	0.05	0.24	0.11

Appendix II

Table 1C. Intensive Survey, 1976. Jeffrey pine data by sites and groups. Site 14.

Tree no.	Damage %	Fill, inches	CBH, inches	Beetle holes /ft ^{2}	Green tissue % DW Na	Green tissue % DW Cl	Brown tissue % DW Na	Brown tissue % DW Cl	Soils 0-12" EC_e	Soils 0-12" meq l^{-1} Na	Soils 0-12" meq l^{-1} Cl	Soils 12-24" EC_e	Soils 12-24" meq l^{-1} Na	Soils 12-24" meq l^{-1} Cl
						GROUP I								
197	20	2	27	14.2	.115	.129	-	-	-	-	-	-	-	-
202	30	12	27	10.7	.253	.253	.230	.140	-	-	-	-	-	-
210	20	2	12	12.0	.414	.270	.402	.293	1.11	10.80	1.93	-	-	-
177	15	4	12	2.0	.230	.340	.276	.321	-	-	-	-	-	-
180	15	6	10	0.0	.253	.236	-	-	0.63	4.40	4.49	0.74	5.16	5.25
189	40	7	11	4.4	.402	.232	.414	.257	0.63	4.40	4.99	0.76	5.10	5.25
193	40	7	10	0.0	.264	.481	.437	.501	0.50	6.85	2.97	0.33	3.28	1.68
207	50	5	12	34.0	.287	.416	.299	.436	-	-	-	-	-	-
214	25	4	15	16.0	.276	.160	.161	.235	-	-	-	0.19	1.64	0.71
						GROUP II								
222	10	1	23	31.3	.115	.035	.128	.038	-	-	-	-	-	-
230	10	1	19	19.0	.025	.024	.023	.005	-	-	-	-	-	-
181	1	1	10	4.8	.040	.019	.035	.018	0.08	0.40	0.42	0.11	0.64	0.40
183	1	4	15	4.8	.052	.017	-	-	-	-	-	0.08	0.76	0.47
218	15	3	15	19.2	.032	.035	.025	.027	-	-	-	-	-	-
226	20	1	27	16.0	.023	.021	.023	.008	-	-	-	0.10	0.76	0.45
234	35	2	20	28.8	.024	.073	.027	.057	-	-	-	-	-	-
238	20	1	16	16.5	.027	.063	.036	.036	-	-	-	0.08	0.50	0.33
						GROUP III								
242	20	2	16	24.0	.025	.012	.040	.015	-	-	-	-	-	-
250	35	2	21	32.0	.027	.039	.034	.025	-	-	-	-	-	-
185	7	1	30	4.0	.023	.017	.027	.006	0.11	1.44	1.72	0.15	0.36	0.64
187	2	3	9	5.3	.032	.015	-	-	0.11	1.44	1.72	0.15	0.36	0.64
246	40	1	29	26.5	.017	.105	.025	.082	-	-	-	-	-	-
254	2	1	6	0.0	.023	.011	.023	.008	-	-	-	-	-	-
258	20	1	13	18.5	.020	.021	.032	.019	-	-	-	-	-	-
262	8	2	9	5.3	.023	.051	.025	.040	-	-	-	-	-	-

Appendix II

Table 2A. Intensive Survey 1976. White fir data by sites and groups. Site 9.

Tree no.	Damage, %	Fill, inches	CBH, inches	Beetle holes /ft^2	Green tissue % DW Na	Green tissue % DW Cl	Brown tissue % DW Na	Brown tissue % DW Cl	Soils 0-12" EC_e	Soils 0-12" meq l^{-1} Na	Soils 0-12" meq l^{-1} Cl	Soils 12-24" EC_e	Soils 12-24" meq l^{-1} Na	Soils 12-24" meq l^{-1} Cl
Group I														
73	5	2	24	5.0	.041	.048	-	-	-	-	-	-	-	-
76	20	9	37	15.6	.029	.324	-	-	0.28	1.26	0.81	-	-	-
20	5	14	19	4.2	.042	.311	-	-	0.33	4.00	1.28	0.72	2.84	3.55
24	0	10	20	3.6	.035	.034	-	-	0.25	1.00	0.83	0.20	0.80	0.73
46	0	2	22	1.1	.036	.013	-	-	0.68	9.40	1.93	0.17	1.76	0.96
70	0	2	12	0.0	.035	.054	-	-	0.11	0.64	0.51	0.08	0.60	0.30
Group II														
61	50	2	34	3.5	.034	.038	-	-	0.09	0.36	0.34	0.06	0.24	0.09
79	0	4	31	1.6	.039	.074	-	-	0.06	0.24	0.38	0.06	0.24	0.44
23	0	4	12	0.0	.034	.048	-	-	0.23	2.40	0.98	0.21	2.20	0.79
28	0	2	17	4.2	.035	.024	-	-	0.11	0.70	0.56	-	-	-
54	0	4	34	0.0	.034	.024	-	-	0.12	1.00	0.38	0.15	0.80	0.39
88	0	2	26	2.8	.039	.032	-	-	-	-	-	0.20	0.80	0.51
Group III														
41	0	4	24	7.0	.035	.010	-	-	0.16	0.40	0.47	0.10	0.36	0.43
64	0	1	24	2.0	.029	.027	-	-	0.07	0.36	0.27	0.08	0.14	0.30
33	2	2	22	4.4	.029	.014	-	-	0.09	0.16	0.42	0.05	0.36	0.43
40	0	3	20	6.0	.032	.014	-	-	0.10	0.90	0.55	0.11	0.40	0.42
56	0	2	20	1.2	.034	.040	-	-	0.11	0.20	0.34	0.08	0.50	0.43
58	0	4	24	0.0	.035	.048	-	-	0.11	0.20	0.34	0.08	0.50	0.43

Appendix II

Table 2B. Intensive Survey, 1976. White fir data by sites and groups. Site 4.

Tree no.	Damage %	Fill, inches	CBH, inches	Beetle holes /ft^2	Green tissue % DW Na	Green tissue % DW Cl	Brown tissue % DW Na	Brown tissue % DW Cl	Soils 0-12" EC_e	Soils 0-12" meq l^{-1} Na	Soils 0-12" meq l^{-1} Cl	Soils 12-24" EC_e	Soils 12-24" meq l^{-1} Na	Soils 12-24" meq l^{-1} Cl
Group I														
131	3	2	3	0	.108	.068	-	-	0.70	6.40	4.33	0.80	6.80	5.08
132	5	1	5	0	.055	.068	-	-	0.40	3.60	2.34	0.44	4.00	2.81
116	0	2	1	0	.055	.079	-	-	0.55	4.70	3.13	0.97	9.80	5.61
123	0	2	8	0	.202	.142	-	-	0.71	7.00	4.38	0.83	7.20	5.15
125	0	2	4	0	.055	.043	-	-	0.58	5.20	3.96	0.69	6.40	4.99
128	10	3	4	0	.050	.107	.087	.049	0.56	4.20	3.58	0.50	3.52	3.30
129	3	3	5	0	.057	.103	-	-	0.56	4.20	3.58	0.50	3.52	3.30
130	10	2	3	0	.057	.347	-	-	0.56	4.20	3.58	0.50	3.52	3.30
Group II														
146	0	1	18	0	.051	.069	-	-	0.88	0.24	0.19	-	-	-
148	3	3	11	0	.034	.160	.036	.259	0.22	1.76	1.04	-	-	-
107	0	1	20	0	.055	.057	-	-	-	-	-	-	-	-
133	0	6	5	0	.050	.023	-	-	-	-	-	-	-	-
137	2	1	9	0	.059	.034	-	-	-	-	-	-	-	-
144	0	2	10	0	.040	.089	-	-	-	-	-	-	-	-
Group III														
151	11	1	11	0	.032	.062	.032	.103	-	-	-	0.08	0.64	0.32
171	0	1	10	0	.034	.045	-	-	0.10	0.16	0.20	0.09	0.16	0.42
155	3	1	36	4	.055	.133	.035	.128	0.14	0.64	0.64	0.10	0.96	0.32
159	1	1	12	0	.028	.112	.035	.171	0.20	0.24	0.33	-	-	-
163	4	1	7	0	.028	.042	.034	.038	-	-	-	0.10	0.24	0.47
167	0	1	9	0	.025	.024	-	-	0.10	0.86	0.58	0.05	0.24	0.11

Appendix II

Table 2C. Intensive Survey 1976. White fir data by site and groups. Site 14

Tree no.	Damage %	Fill, inches	CBH, inches	Beetle holes /ft²	Green Tissue, % D.W. Na	Green Tissue, % D.W. Cl	Brown Tissue, % D.W. Na	Brown Tissue, % D.W. Cl	Soils 0-12" EC_e	Soils 0-12" meq l⁻¹ Na	Soils 0-12" meq l⁻¹ Cl	Soils 12-24" EC_e	Soils 12-24" meq l⁻¹ Na	Soils 12-24" meq l⁻¹ Cl
						Group I								
211	8	1	9	2.7	.096	.122	.197	.284	-	-	-	-	-	-
198	3	3	11	0.0	.046	.085	-	-	-	-	-	-	-	-
190	1	2	12	0.0	.073	.155	-	-	0.50	6.85	2.97	0.33	3.28	1.68
194	5	3	31	1.6	.119	.233	.133	.225	-	-	-	-	-	-
201	30	4	8	0.0	.147	.085	.379	.269	-	-	-	-	-	-
208	10	10	26	1.9	.073	.550	.147	.619	-	-		0.19	1.64	0.71
215	10	6	10	0.0	.064	.597	.174	.462	-	-	-	-	-	-
						Group II								
223	5	2	14	0.0	.014	.059	.027	.104	-	-	-	-	-	-
231	4	1	14	5.1	.020	.016	.017	.020	-	-	-	-	-	-
203	3	6	14	3.4	.023	.079	.025	.117	-	-	-	-	-	-
219	5	1	6	0.0	.017	.186	.020	.212	-	-	-	-	-	-
227	8	1	18	0.0	.020	.033	.023	.014	-	-	-	0.10	0.76	0.45
235	5	1	19	2.5	.023	.023	.036	.032	-	-	-	-	-	-
239	5	1	14	1.7	.023	.087	.041	.083	-	-	-	0.08	0.50	0.33
						Group III								
243	2	1	7	0.0	.023	.044	.034	.086	-	-	-	-	-	-
251	3	2	9	0.0	.017	.049	.035	.082	.015	0.70	.066	0.10	0.80	0.64
204	10	3	18	5.3	.027	.108	.024	.153	-	-	-	-	-	-
247	1	1	13	0.0	.020	.031	.020	.038	-	-	-	-	-	-
255	2	1	8	0.0	.017	.038	.024	.041	-	-	-	-	-	-
259	1	1	26	0.0	.017	.051	.023	.068	-	-	-	-	-	-
263	3	1	15	4.8	.014	.055	.026	.066	-	-	-	-	-	-

Appendix II

Table 3A. Intensive Survey 1976. Incense cedar data by Site and Groups. Site 9.

Tree no.	Damage %	Fill inches	CBH, inches	Beetle holes /ft²	Green tissue % DW Na	Green tissue % DW Cl	Brown tissue % DW Na	Brown tissue % DW Cl	Soils 0-12" EC_e	Soils 0-12" meq l⁻¹ Na	Soils 0-12" meq l⁻¹ Cl	Soils 12-24" EC_e	Soils 12-24" meq l⁻¹ Na	Soils 12-24" meq l⁻¹ Cl
							GROUP I							
103	5	3	18	5.3	.046	.154	.065	.117	0.14	0.50	0.27	0.16	0.90	1.01
91	2	5	?	0.0	.036	.194	.046	.286	0.14	0.50	0.27	0.16	0.90	1.01
92	0	7	9	0.0	.055	.413	.066	.195	-	-	-	-	-	-
93	25	6	14	10.3	.052	.168	-	-	-	-	-	-	-	-
94	20	10	11	43.6	.042	.545	-	-	-	-	-	-	-	-
							GROUP II							
104	3	3	24	4.0	.034	.095	.034	.084	-	-	-	0.25	0.40	0.87
95	15	4	22	3.3	.035	.080	.055	.098	-	-	-	-	-	-
96	10	4	12	6.0	.032	.071	-	-	-	-	-	-	-	-
97	20	2	24	9.0	.034	.092	-	-	-	-	-	-	-	-
98	40	1	26	142.0	.039	.048	.029	.098	-	-	-	-	-	-
							GROUP III							
105	2	3	30	6.4	.021	.031	.023	.042	0.15	0.36	0.44	-	-	-
99	5	1	14	58.3	.020	.008	-	-	0.15	0.36	0.44	-	-	-
100	8	2	16	31.5	.025	.020	.026	.022	-	-	-	-	-	-
101	4	1	18	22.7	.025	.077	-	-	-	-	-	-	-	-
102	8	1	18	14.7	.025	.049	.032	.037	-	-	-	-	-	-

Appendix II

Table 3B. Intensive Survey, 1976. Incense cedar by Sites and Groups. Site 4.

Tree no.	Damage %	Fill, inches	CBH, inches	Beetle holes /ft²	Green tissue % DW Na	Green tissue % DW Cl	Brown tissue % DW Na	Brown tissue % DW Cl	Soils 0-12" EC_e	Soils 0-12" meq l^{-1} Na	Soils 0-12" meq l^{-1} Cl	Soils 12-24" EC_e	Soils 12-24" meq l^{-1} Na	Soils 12-24" meq l^{-1} Cl
						Group I								
109	0	1	5	0.0	.179	.439	-	-	-	-	-	0.42	3.20	2.68
13	20	4	15	24.0	.073	.087	.115	.152	0.43	1.00	5.20	0.50	0.80	0.63
121	15	1	7	0.0	.098	.616	.225	.896	0.42	3.60	2.97	0.29	2.76	2.49
174	10	3	10	7.2	.059	.471	-	-	-	-	-	-	-	-
17	3	3	3	0.0	.096	.354	-	-	2.04	21.60	19.88	1.54	12.20	10.95
114	10	2	12	0.0	.126	.616	.117	.560	0.56	4.70	3.13	0.97	9.80	5.61
119	60	6	5	0.0	.080	.756	.184	.491	0.50	4.00	3.03	0.70	6.40	3.96
127	5	1	8	0.0	.130	.532	-	-	0.58	5.20	3.96	0.67	6.40	6.99
						Group II								
142	5	2	29	0.0	.040	.090	.066	.077	-	-	-	-	-	-
149	15	1	9	0.0	.043	.278	.043	.248	0.22	1.76	1.04	-	-	-
175	1	3	11	8.7	.035	.038	-	-	-	-	-	-	-	-
2	3	4	13	0.0	.041	.172	.098	.128	0.23	1.60	1.11	0.18	1.40	1.01
4	10	34	38	7.6	.029	.272	.088	.395	0.33	3.16	1.40	0.41	4.10	1.66
6	5	14	29	0.8	.027	.383	.062	.366	0.98	9.80	6.79	0.89	7.40	6.01
7	4	5	22	1.1	.036	.143	.086	.181	0.25	1.10	1.91	0.37	1.60	1.89
138	0	2	12	0.0	.042	.067	-	-	0.11	0.50	0.16	-	-	-
						Group III								
152	3	1	15	0.0	.029	.113	.040	.130	-	-	-	0.08	0.64	0.32
172	3	2	7	0.0	.046	.045	-	-	0.10	0.16	0.20	0.09	0.16	0.42
176	1	3	11	0.0	.039	.013	-	-	-	-	-	-	-	-
156	6	1	17	5.7	.041	.093	.066	.198	0.14	0.64	0.64	0.10	0.96	0.32
160	3	1	12	2.0	.026	.094	.035	.069	0.20	0.24	0.33	-	-	-
164	2	1	16	0.0	.041	.021	.040	.018	-	-	-	0.10	0.24	0.47
168	1	1	6	0.0	.027	.027	-	-	0.10	0.86	0.58	0.05	0.24	0.11

Appendix II

Table 3C. Intensive survey, 1976. Incense cedar data by site and groups. Site 14.

Tree no.	Damage, %	Fill, inches	CBH, inches	Beetle holes/ ft^2	Green tissue % DW		Brown tissue % DW		Soils 0-12"			Soils 12-24"		
					Na	Cl	Na	Cl	EC_e	meq l^{-1} Na	meq l^{-1} Cl	EC_e	meq l^{-1} Na	meq l^{-1} Cl
Group I														
212	15	2	9	0.0	.126	.311	.216	.330	.028	2.20	1.64	0.14	1.50	0.55
199	25	1	9	2.7	.115	.426	-	-	-	-	-	-	-	-
191	9	4	12	0.0	.050	.391	.156	.521	0.53	6.85	2.97	0.33	3.28	1.68
195	3	2	27	3.6	.073	.338	.133	.675	-	-	-	-	-	-
209	50	6	13	0.0	.119	.704	.147	.421	-	-	-	-	-	-
216	50	5	9	0.0	.161	.612	.345	.357	-	-	-	-	-	-
Group II														
232	3	1	9	0.0	.027	.044	.057	.067	-	-	-	-	-	-
224	5	1	7	6.9	.032	.093	.048	.117	-	-	-	-	-	-
220	8	1	16	0.0	.014	.137	.020	.395	-	-	-	-	-	-
228	5	1	15	0.0	.034	.059	.025	.076	-	-	-	0.10	0.76	0.45
236	5	1	15	0.0	.017	.151	.046	.188	-	-	-	-	-	-
240	5	1	14	0.0	.023	.058	.032	.081	-	-	-	0.08	0.50	0.33
Group III														
244	2	1	7	0.0	.017	.039	.032	.037	-	-	-	-	-	-
252	3	2	13	0.0	.023	.054	.043	.082	-	-	-	-	-	-
248	2	2	18	0.0	.020	.014	.040	.003	-	-	-	-	-	-
256	1	1	15	1.6	.032	.143	.036	.139	-	-	-	-	-	-
260	1	1	10	0.0	.020	.058	.034	.045	-	-	-	-	-	-
264	1	1	7	3.4	.032	.050	.023	.225	-	-	-	-	-	-

Appendix II

Table 4. Soil Salt Application Study. Individual tree data for Jeffrey pine with six salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates.

Treatment	Repli-	May 1977			June 1977			July 1977			Aug. 1977			Sept. 1977		Oct. 1977		
		% DW		Dam-	% DW		Dam-	% DW		Dam-	% DW		Dam-	% DW		% DW		Dam-
T/A-year	cation	Na	Cl	age	Na	Cl	age	Na	Cl	age	Na	Cl	age	Na	Cl	Na	Cl	age
0. -1977	1	0.015	0.019	0	0.010	0.007	0	0.015	0.004	0	0.017	0.018	0	0.023	0.009	0.020	0.009	0
0. -1978	2	0.015	0.017	0	0.010	0.004	0	0.012	0.016	0	0.017	0.018	0	0.016	0.009	0.020	0.006	0
	3	0.012	0.015	0	0.010	0.004	0	0.021	0.005	0	0.027	0.018	0	0.017	0.009	0.017	0.009	0
	4	0.015	0.007	0	0.006	0.004	0	0.010	0.004	0	0.023	0.018	0	0.023	0.009	0.014	0.009	0
	5	0.010	0.007	0	0.006	0.004	0	0.010	0.005	0	0.027	0.018	0	0.017	0.007	0.011	0.009	0
	6	0.010	0.004	0	0.010	0.004	0	0.010	0.007	0	0.018	0.017	0	0.017	0.018	0.014	0.009	0
0.33-1977	1	0.021	0.021	0	0.010	0.007	0	0.012	0.005	0	0.017	0.018	0	0.024	0.009	0.020	0.009	0
0.5 -1978	2	0.021	0.016	0	0.010	0.005	0	0.012	0.009	0	0.023	0.018	0	0.014	0.015	0.011	0.009	0
	3	0.012	0.023	0	0.010	0.007	0	0.012	0.027	0	0.023	0.035	0	0.017	0.009	0.017	0.009	0
	4	0.015	0.043	0	0.006	0.049	0	0.010	0.069	0	0.023	0.018	0	0.014	0.053	0.014	0.044	0
	5	0.012	0.044	0	0.006	0.040	0	0.010	0.064	0	0.024	0.018	0	0.011	0.009	0.011	0.027	0
	6	0.021	0.031	0	0.010	0.005	0	0.010	0.013	0	0.017	0.018	0	0.017	0.027	0.017	0.018	0
0.67-1977	1	0.021	0.066	0	0.010	0.045	0	0.015	0.049	0	0.027	0.078	0	0.025	0.088	0.017	0.071	0
1.0 -1978	2	0.015	0.008	0	0.010	0.011	0	0.012	0.020	0	0.027	0.018	0	0.023	0.029	0.011	0.009	0
	3	0.015	0.016	0	0.010	0.013	0	0.012	0.016	0	0.027	0.018	0	0.023	0.009	0.017	0.009	0
	4	0.021	0.047	0	0.006	0.038	0	0.010	0.033	0	0.023	0.018	0	0.017	0.009	0.014	0.006	0
	5	0.012	0.016	0	0.006	0.029	0	0.006	0.016	0	0.024	0.035	0	0.014	0.062	0.030	0.195	0
	6	0.010	0.083	0	0.010	0.095	0	0.012	0.118	0	0.027	0.107	0	0.011	0.062	0.014	0.069	0

(Continued)

Table 4. Soil Salt Application Study. Individual tree data for Jeffrey pine with six salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates. (Continued)

Treatment T/A-year	Replication	Jan. 1978 % DW Na	Jan. 1978 % DW Cl	Jan. 1978 Damage	May 1978 % DW Na	May 1978 % DW Cl	May 1978 Damage	June 1978 % DW Na	June 1978 % DW Cl	June 1978 Damage	Sept. 1978 Damage
0. -1977	1	0.017	0.009	0	0.032	0.015	0	0.033	0.009	0	0
0. -1978	2	0.011	0.009	0	0.033	0.018	0	0.033	0.009	0	0
	3	0.017	0.006	0	0.033	0.018	0	0.033	0.009	0	0
	4	0.011	0.009	0	0.033	0.036	0	0.030	0.053	0	0
	5	0.011	0.009	0	0.017	0.036	0	0.027	0.009	0	0
	6	0.011	0.009	0	0.036	0.036	0	0.027	0.018	0	0
0.33-1977	1	0.023	0.009	0	0.042	0.053	0	0.047	0.044	0	0
0.5 -1978	2	0.017	0.009	0	0.036	0.072	0	0.045	0.009	0	0
	3	0.023	0.062	0	0.036	0.062	0	0.036	0.036	0	0
	4	0.011	0.062	0	0.023	0.151	0	0.033	0.124	0	0
	5	0.011	0.019	0	0.047	0.072	0	0.036	0.045	0	0
	6	0.011	0.009	0	0.023	0.053	0	0.027	0.027	0	0
0.67-1977	1	0.023	0.062	0	0.055	0.164	0	0.077	0.133	0	0
1. -1978	2	0.017	0.018	0	0.060	0.124	0	0.053	0.098	0	0
	3	0.023	0.009	0	0.042	0.063	0	0.160	0.240	0	0
	4	0.017	0.018	0	0.027	0.098	0	0.033	0.098	0	0
	5	0.011	0.107	0	0.027	0.133	0	0.027	0.160	0	0
	6	0.011	0.071	0	0.023	0.115	0	0.023	0.088	0	0

(Continued)

Appendix II

Table 4. Soil Salt Application Study. Individual tree data for Jeffrey pine with six salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates. (Continued)

Treatment T/A-year	Repli-cation	May 1977 % DW Na	May 1977 % DW Cl	May 1977 Dam-age	June 1977 % DW Na	June 1977 % DW Cl	June 1977 Dam-age	July 1977 % DW Na	July 1977 % DW Cl	July 1977 Dam-age	Aug. 1977 % DW Na	Aug. 1977 % DW Cl	Aug. 1977 Dam-age	Sept. 1977 % DW Na	Sept. 1977 % DW Cl	Oct. 1977 % DW Na	Oct. 1977 % DW Cl	Oct. 1977 Dam-age
1.33-1977	1	0.023	0.069	0	0.012	0.042	0	0.021	0.042	0	0.027	0.018	0	0.027	0.009	0.017	0.009	0
2. -1978	2	0.012	0 073	0	0.010	0.011	0	0.012	0.031	0	0.027	0.053	0	0.014	0.107	0.011	0.142	0
	3	0.015	0.064	0	0.012	0.058	0	0.010	0.069	0	0.027	0.018	0	0.036	0.044	0.017	0.071	0
	4	0.021	0.032	0	0.023	0.155	0	0.010	0.146	0	0.017	0.024	0	0.017	0.133	0.023	0.098	0
	5	0.010	0.077	0	0.010	0.044	0	0.010	0.057	0	0.024	0.018	0	0.017	0.009	0.011	0.027	0
	6	0.012	0.068	0	0.015	0.047	0	0.010	0.047	0	0.023	0.018	0	0.011	0.018	0.020	0.013	0
2.67-1977	1	0.024	0.021	0	0.010	0.007	0	0.012	0.018	0	0.023	0.018	0	0.024	0.009	0.017	0.009	0
4. -1978	2	0.024	0.116	0	0.029	0.129	0	0.023	0.142	0	0.042	0.231	0	0.017	0.009	0.036	0.497	0
	3	0.030	0.154	0	0.078	0.184	0	0.098	0.171	0	0.108	0.107	0	0.062	0.186	0.150	0.124	0
	4	0.020	0.053	0	0.021	0.116	0	0.012	0.128	0	0.027	0.053	0	0.017	0.133	0.023	0.346	0
	5	0.020	0.127	0	0.058	0.222	0	0.021	0.202	0	0.058	0.124	0	0.077	0.193	0.070	0.302	0
	6	0.030	0.204	0	0.044	0.175	0	0.029	0.157	0	0.047	0.107	0	0.077	0.169	0.080	0.213	0
5.33-1977	1	0.058	0.228	0	0.147	0.338	0	0.230	0.439	1	0.150	0.213	1	0.236	0.337	0.342	0.506	1
8. -1978	2	0.030	0.093	0	0.035	0.142	0	0.124	0.217	1	0.077	0.178	1	0.066	0.115	0.108	0.338	1
	3	0.168	0.533	1	0.230	0.474	2	0.138	0.403	3	0.201	0.195	3	0.042	0.355	0.191	0.391	3
	4	0.058	0.262	0	0.216	0.462	1	0.178	0.523	1	0.377	0.479	0	0.387	0.533	0.480	0.710	0
	5	0.133	0.471	0	0.403	0.856	1	0.322	1.192	1	0.538	0.941	2	0.584	1.218	0.604	1.287	3
	6	0.156	0.470	0	0.460	0.698	1	0.242	0.696	1	0.511	0.621	2	0.025	0.701	1.213	1.613	3

(Continued)

Appendix II

Table 4. Soil Salt Application Study. Individual tree data for Jeffrey pine with six salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates. (Concluded)

Treatment T/A-year	Repli-cation	Jan. 1978 % DW Na	Jan. 1978 % DW Cl	Jan. 1978 Dam-age	May 1978 % DW Na	May 1978 % DW Cl	May 1978 Dam-age	June 1978 % DW Na	June 1978 % DW Cl	June 1978 Dam-age	Sept. 1978 Dam-age
1.33-1977	1	0.042	0.071	0	0.055	0.115	0	0.058	0.071	0	0
2. -1978	2	0.023	0.151	0	0.095	0.355	0	0.049	0.311	0	0
	3	0.027	0.115	0	0.156	0.266	0	0.101	0.249	0	0
	4	0.023	0.124	0	0.033	0.231	0	0.033	0.284	0	1
	5	0.011	0.018	0	0.092	0.470	0	0.027	0.036	0	0
	6	0.017	0.018	0	0.042	0.080	0	0.033	0.045	0	0
2.67-1977	1	0.027	0.053	0	0.053	0.098	0	0.053	0.053	0	0
4. -1978	2	0.111	0.444	0	0.173	0.595	1	0.181	0.426	1	1
	3	0.150	0.169	0	0.191	0.293	1	0.236	0.355	2	2
	4	0.023	0.293	0	0.027	0.559	1	0.047	0.808	2	2
	5	0.077	0.293	0	0.070	0.302	0	0.060	0.311	0	0
	6	0.095	0.284	0	0.070	0.293	0	0.066	0.240	0	0
5.33-1977	1	0.181	0.213	1	0.195	0.250	1	0.209	0.320	1	1
8. -1978	2	0.083	0.160	1	0.085	0.378	1	0.164	0.302	1	1
	3	0.095	0.186	3	0.298	0.550	4	0.236	0.754	4	4
	4	0.377	0.657	0	0.377	0.808	2	0.352	0.817	2	3
	5	0.555	1.030	3	0.684	1.704	4	0.863	1.340	4	4
	6	0.604	1.553	3	0.475	1.385	4	0.920	1.908	4	4

[1]Damage ratings: 0 = no damage, 1 - 1st symptoms to 25%, 2 = 26-50%, 3 = 51-75%, and 4 = 76-100% browning and defoliation.

Appendix II

Table 5. Soil Salt Application Study. Individual tree data for white fir with six salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates.

Treatment T/A-year	Repli- cation	May 1977 % DW Na	May 1977 % DW Cl	May 1977 Dam- age	June 1977 % DW Na	June 1977 % DW Cl	June 1977 Dam- age	July 1977 % DW Na	July 1977 % DW Cl	July 1977 Dam- age	Aug. 1977 % DW Na	Aug. 1977 % DW Cl	Aug. 1977 Dam- age	Sept. 1977 % DW Na	Sept. 1977 % DW Cl	Oct. 1977 % DW Na	Oct. 1977 % DW Cl	Oct. 1977 Dam- age
0. -1977	1	0.010	0.036	0	0.010	0.062	0	0.027	0.084	0	0.023	0.036	0	0.014	0.071	0.011	0.027	0
0. -1978	2	0.012	0.035	0	0.012	0.025	0	0.021	0.038	0	0.023	0.036	0	0.011	0.036	0.023	0.018	0
	3	0.012	0.037	0	0.010	0.038	0	0.012	0.024	0	0.023	0.018	0	0.027	0.044	0.017	0.009	0
	4	0.012	0.039	0	0.006	0.029	0	0.010	0.042	0	0.023	0.018	0	0.017	0.036	0.020	0.071	0
	5	0.021	0.075	0	0.006	0.066	0	0.012	0.064	0	0.017	0.018	0	0.017	0.088	0.007	0.018	0
0.33-1977	1	0.006	0.039	0	0.006	0.016	0	0.012	0.087	0	0.023	0.071	0	0.014	0.080	0.011	0.071	0
0.5 -1978	2	0.010	0.134	0	0.012	0.162	0	0.015	0.293	0	0.027	0.249	0	0.023	0.266	0.011	0.284	0
	3	0.021	0.084	0	0.010	0.092	0	0.025	0.020	0	0.023	0.035	0	0.025	0.355	0.017	0.133	0
	4	0.010	0.101	0	0.006	0.124	0	0.010	0.215	0	0.017	0.213	0	0.020	0.124	0.023	0.222	0
	5	0.021	0.036	0	0.006	0.036	0	0.015	0.058	0	0.017	0.018	0	0.020	0.062	0.011	0.027	0
0.67-1977	1	0.010	0.053	0	0.006	0.060	0	0.010	0.082	0	0.014	0.098	0	0.020	0.062	0.014	0.098	0
1. -1978	2	0.012	0.146	0	0.012	0.189	0	0.015	0.303	0	0.021	0.242	0	0.027	0.302	0.036	0.346	0
	3	0.030	0.116	0	0.010	0.151	0	0.015	0.069	0	0.036	0.249	0	0.017	0.249	0.027	0.293	0
	4	0.012	0.166	0	0.010	0.242	0	0.010	0.292	0	0.036	0.337	0	0.025	0.328	0.045	0.515	0
	5	0.021	0.116	0	0.006	0.151	0	0.015	0.164	0	0.042	0.142	0	0.025	0.257	0.014	0.169	0

(Continued)

Appendix II

Table 5. Soil Salt Application Study. Individual tree data for white fir with six salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates. (Continued)

Treatment	Repli-	Jan. 1978			May 1978			June 1978			Sept. 1978
		% DW		Dam-	% DW		Dam-	% DW		Dam-	Dam-
T/A-year	cation	Na	Cl	age	Na	Cl	age	Na	Cl	age	age
0. -1977	1	0.011	0.044	0	0.015	0.050	0	0.017	0.062	0	0
0. -1978	2	0.021	0.015	0	0.024	0.051	0	0.027	0.062	0	0
	3	0.011	0.036	0	0.017	0.062	0	0.023	0.018	0	0
	4	0.027	0.044	0	0.017	0.045	0	0.017	0.045	0	0
	5	0.011	0.027	0	0.027	0.044	0	0.017	0.038	0	0
0.33-1977	1	0.023	0.080	0	0.024	0.096	0	0.020	0.115	0	0
0.5 1978	2	0.017	0.337	0	0.028	0.392	0	0.027	0.444	0	0
	3	0.011	0.151	0	0.042	0.204	0	0.023	0.257	0	0
	4	0.025	0.291	0	0.039	0.311	0	0.047	0.417	0	0
	5	0.011	0.053	0	0.042	0.063	0	0.017	0.053	0	0
0.67-1977	1	0.017	0.240	0	0.033	0.186	0	0.020	0.257	0	0
1. -1978	2	0.017	0.373	0	0.033	0.701	1	0.027	0.568	1	1
	3	0.017	0.302	0	0.053	0.426	0	0.067	0.482	0	0
	4	0.011	0.426	0	0.115	0.587	1	0.135	0.657	1	1
	5	0.017	0.240	0	0.036	0.311	0	0.017	0.284	0	0

(Continued)

Appendix II

Table 5. Soil Salt Application Study. Individual tree data for white fir with six salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates. (Continued)

Treatment T/A-year	Repli-cation	May 1977 % DW Na	May 1977 % DW Cl	May 1977 Dam-age	June 1977 % DW Na	June 1977 % DW Cl	June 1977 Dam-age	July 1977 % DW Na	July 1977 % DW Cl	July 1977 Dam-age	Aug. 1977 % DW Na	Aug. 1977 % DW Cl	Aug. 1977 Dam-age	Sept. 1977 % DW Na	Sept. 1977 % DW Cl	Oct. 1977 % DW Na	Oct. 1977 % DW Cl	Oct. 1977 Dam-age
1.33-1977	1	0.010	0.154	0	0.015	0.207	0	0.012	0.237	0	0.033	0.355	0	0.017	0.284	0.023	0.311	0
2. 1978	2	0.010	0.116	0	0.010	0.111	0	0.021	0.171	0	0.027	0.142	0	0.023	0.195	0.023	0.222	0
	3	0.012	0.099	0	0.010	0.176	0	0.021	0.182	0	0.011	0.160	0	0.423	0.284	0.036	0.293	0
	4	0.098	0.494	1	0.207	0.664	2	0.460	0.844	3	1.064	1.047	4	1.064	1.686	0.891	1.473	4
	5	0.012	0.113	0	0.010	0.167	0	0.015	0.179	0	0.028	0.170	0	0.025	0.195	0.017	0.213	0
2.67-1977	1	0.024	0.288	0	0.155	0.518	2	0.124	0.532	3	0.670	1.358	3	0.293	0.719	0.377	0.754	4
4. -1978	2	0.030	0.170	0	0.010	0.262	0	0.021	0.381	0	0.047	0.426	0	0.066	0.509	0.087	0.479	0
	3	0.024	0.179	0	0.044	0.351	0	0.058	0.315	0	0.066	0.337	0	0.056	0.595	0.062	0.524	1
	4	0.030	0.222	0	0.044	0.356	0	0.072	0.383	0	0.062	0.337	0	0.108	0.666	0.112	0.692	1
	5	0.024	0.120	0	0.010	0.216	0	0.015	0.244	0	0.132	0.249	0	0.023	0.355	0.014	0.373	0
5.33-1977	1	0.064	0.450	1	0.178	0.684	2	0.138	0.919	2	0.511	1.429	3	0.279	1.065	0.704	1.811	4
8. -1978	2	0.225	0.769	1	0.276	0.854	1	0.385	0.937	2	0.805	1.473	3	0.891	2.043	0.834	1.713	4
	3	0.042	0.167	0	0.015	0.238	0	0.018	0.214	0	0.046	0.320	0	0.027	0.337	0.047	0.391	0
	4	0.184	0.303	0	0.023	0.262	0	0.032	0.346	0	0.062	0.426	0	0.095	0.657	0.066	0.530	0
	5	0.207	0.609	2	0.216	0.707	4	0.575	1.310	4	1.438	1.722	4	1.265	2.272	1.104	2.281	4

(Continued)

Appendix II

Table 5. Soil Salt Application Study. Individual tree data for white fir with six salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates. (Concluded)

Treatment T/A-year	Repli-cation	Jan. 1978 % DW Na	Jan. 1978 % DW Cl	Jan. 1978 Dam-age	May 1978 % DW Na	May 1978 % DW Cl	May 1978 Dam-age	June 1978 % DW Na	June 1978 % DW Cl	June 1978 Dam-age	Sept. 1978 Dam-age
1.33-1977	1	0.023	0.541	1	0.055	0.533	2	0.023	0.426	2	2
2. -1978	2	0.011	0.311	0	0.042	0.302	0	0.027	0.328	0	0
	3	0.011	0.293	0	0.036	0.453	0	0.023	0.408	0	0
	4	0.920	1.562	4	-	-	4	-	-	4	4
	5	0.023	0.213	0	0.047	0.400	0	0.173	0.328	1	1
2.67-1977	1	0.101	0.985	4	0.415	1.101	4	0.250	1.065	4	4
4. -1978	2	0.220	0.790	1	0.270	1.172	1	0.027	0.417	1	1
	3	0.036	0.417	0	0.062	0.657	1	0.036	0.648	1	1
	4	0.226	0.373	1	0.397	1.704	3	0.108	1.038	4	4
	5	0.027	0.657	1	0.053	0.683	2	0.027	0.675	2	2
5.33-1977	1	0.415	1.464	4	-	-	4	-	-	4	4
8. -1978	2	0.642	1.566	4	-	-	4	-	-	4	4
	3	0.027	0.595	1	0.066	0.621	1	0.095	0.737	2	3
	4	0.352	1.500	1	0.173	1.243	2	0.449	1.358	3	3
	5	0.726	1.402	4	-	-	4	-	-	4	4

[1]Damage ratings: 0 = 1st symptoms to 25%, 2 = 26-50%, 3 = 51-75%, and 4 = 76-100% browning and defoliation.
[2]Deleted from means for the treatment because of abnormal damage.

Appendix II

Table 6. Soil Salt Application Study. Individual tree data for incense cedar with five salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates.

Treatment T/A-year	Replication	May 1977 % DW Na	May 1977 % DW Cl	May 1977 Damage	June 1977 % DW Na	June 1977 % DW Cl	June 1977 Damage	July 1977 % DW Na	July 1977 % DW Cl	July 1977 Damage	Aug. 1977 % DW Na	Aug. 1977 % DW Cl	Aug. 1977 Damage	Sept. 1977 % DW Na	Sept. 1977 % DW Cl	Oct. 1977 % DW Na	Oct. 1977 % DW Cl	Oct. 1977 Damage
0-1977 0-1978	1	0.012	0.020	0	0.021	0.007	0	0.015	0.024	0	0.013	0.018	0	0.010	0.009	0.017	0.009	0
	2	0.010	0.070	0	0.012	0.036	0	0.012	0.026	0	0.017	0.018	0	0.011	0.036	0.012	0.047	0
	3	0.012	0.067	0	0.023	0.007	0	0.021	0.020	0	0.014	0.027	0	0.017	0.018	0.017	0.009	0
	4	0.012	0.040	0	0.006	0.007	0	0.010	0.020	0	0.014	0.036	0	0.020	0.027	0.024	0.018	0
0.33-1977 0.5 -1978	1	0.035	0.092	0	0.021	0.069	0	0.010	0.104	0	0.017	0.151	0	0.020	0.142	0.017	0.160	0
	2	0.012	0.086	0	0.015	0.091	0	0.021	0.160	0	0.017	0.042	0	0.014	0.186	0.025	0.195	0
	3	0.023	0.076	0	0.023	0.029	0	0.021	0.044	0	0.017	0.089	0	0.014	0.062	0.022	0.098	0
	4	0.044	0.116	0	0.021	0.073	0	0.012	0.097	0	0.017	0.142	0	0.023	0.098	0.018	0.142	0
0.67-1977 1 -1978	1	0.011	0.124	0	0.044	0.131	0	0.012	0.199	0	0.023	0.355	0	0.017	0.382	0.017	0.382	0
	2	0.010	0.083	0	0.012	0.087	0	0.015	0.171	0	0.020	0.169	0	0.017	0.293	0.026	0.382	0
	3	0.044	0.096	0	0.021	0.058	0	0.021	0.067	0	0.023	0.107	0	0.025	0.178	0.026	0.178	0
	4	0.012	0.115	0	0.012	0.091	0	0.010	0.087	0	0.017	0.115	0	0.027	0.160	0.030	0.204	0
1.33-1977 2 -1978	1	0.010	0.074	0	0.023	0.153	0	0.012	0.255	0	0.015	0.320	0	0.020	0.604	0.028	0.825	0
	2	0.021	0.122	0	0.029	0.120	0	0.015	0.098	0	0.017	0.098	0	0.014	0.195	0.042	0.208	0
	3	0.032	0.123	0	0.021	0.124	0	0.023	0.252	0	0.014	0.355	0	0.014	0.391	0.019	0.417	0
	4	0.015	0.144	0	0.046	0.113	0	0.023	0.195	0	0.023	0.222	0	0.023	0.270	0.036	0.249	0
2.67-1977 4 -1978	1	0.072	0.420	0	0.207	0.880	1	0.216	0.798	2	0.112	0.896	2	0.042	0.681	0.066	1.340	3
	2	0.046	0.242	0	0.032	0.269	1	0.015	0.339	1	0.011	0.408	1	0.020	0.408	0.062	0.453	1
	3	0.023	0.163	0	0.015	0.127	0	0.010	0.221	0	0.014	0.337	0	0.020	0.364	0.020	0.515	0
	4	0.044	0.186	0	0.058	0.313	0	0.046	0.275	1	0.011	0.479	0	0.020	0.648	0.083	0.834	1

(Continued)

Appendix II

Table 6. Soil Salt Application Study. Individual tree data for incense cedar with five salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates. (Concluded)

Treatment T/A-year	Repli-cation	Jan. 1978 % DW Na	Jan. 1978 % DW Cl	Jan. 1978 Damage	May 1978 % DW Na	May 1978 % DW Cl	May 1978 Damage	June 1978 % DW Na	June 1978 % DW Cl	June 1978 Damage	Sept. 1978 Damage
0 -1977 0 -1978	1	0.011	0.036	0	0.007	0.063	0	0.011	0.045	0	0
	2	0.015	0.052	0	0.017	0.098	0	0.017	0.088	0	0
	3	0.017	0.062	0	0.008	0.124	0	0.017	0.053	0	0
	4	0.023	0.036	0	0.025	0.133	0	0.020	0.036	0	0
0.33-1977 0.5 -1978	1	0.027	0.222	0	0.020	0.195	0	0.020	0.205	0	0
	2	0.023	0.284	0	0.023	0.302	0	0.033	0.293	0	0
	3	0.023	0.115	0	0.023	0.151	0	0.042	0.160	0	0
	4	0.017	0.124	0	0.023	0.178	0	0.027	0.115	0	0
0.67-1977 1 -1978	1	0.020	0.364	0	0.026	0.388	0	0.030	0.396	0	0
	2	0.027	0.541	0	0.066	0.595	0	0.033	0.462	0	0
	3	0.027	0.062	0	0.017	0.320	0	0.023	0.249	0	0
	4	0.036	0.222	0	0.033	0.245	0	0.027	0.169	0	0
1.33-1977 2 -1978	1	0.037	1.349	1	0.036	1.598	3	0.047	0.870	3	3
	2	0.027	0.222	0	0.027	0.311	0	0.036	0.438	0	1
	3	0.017	0.633	0	0.029	0.767	1	0.025	0.666	1	1
	4	0.036	0.462	0	0.036	0.790	1	0.036	0.639	1	1
2.67-1977 4 -1978	1	0.053	0.985	3	0.124	1.198	4	0.042	0.967	4	4
	2	0.027	0.746	1	0.023	0.586	1	0.083	1.074	1	1
	3	0.027	0.559	1	0.023	0.604	1	0.020	0.524	1	1
	4	0.133	1.101	2	0.285	1.615	3	0.309	1.609	4	4

[1]Damage ratings: 0 = no damage, 1 = 1st symptoms to 25%, 2 = 26-50%, 3 = 51-75%, and 4 = 76-100% browning and defoliation.

Appendix II

Table 7. Soil Salt Application Study. Individual tree data for lodgepole pine with five salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates.

Treatment T/A-year	Repli-cation	May 1977 % DW Na	May 1977 % DW Cl	May 1977 Dam-age	June 1977 % DW Na	June 1977 % DW Cl	June 1977 Dam-age	July 1977 % DW Na	July 1977 % DW Cl	July 1977 Dam-age	Aug. 1977 % DW Na	Aug. 1977 % DW Cl	Aug. 1977 Dam-age	Sept. 1977 % DW Na	Sept. 1977 % DW Cl	Oct. 1977 % DW Na	Oct. 1977 % DW Cl	Oct. 1977 Dam-age
0-1977	1	0.012	0.005	0	0.006	0.002	0	0.011	0.013	0	0.017	0.018	0	0.027	0.007	0.017	0.009	0
0-1978	2	0.012	0.003	0	0.012	0.004	0	0.015	0.015	0	0.017	0.018	0	0.027	0.005	0.017	0.009	0
	3	0.010	0.011	0	0.010	0.004	0	0.012	0.007	0	0.027	0.009	0	0.020	0.009	0.011	0.018	0
	4	0.010	0.007	0	0.006	0.007	0	0.015	0.007	0	0.023	0.009	0	0.023	0.009	0.017	0.009	0
0.33-1977	1	0.015	0.041	0	0.006	0.042	0	0.006	0.036	0	0.017	0.018	0	0.023	0.009	0.017	0.009	0
0.5-1978	2	0.012	0.031	0	0.006	0.007	0	0.015	0.011	0	0.017	0.018	0	0.020	0.007	0.023	0.009	0
	3	0.012	0.015	0	0.010	0.004	0	0.012	0.009	0	0.047	0.018	0	0.027	0.009	0.011	0.027	0
	4	0.010	0.022	0	0.010	0.015	0	0.015	0.022	0	0.035	0.009	0	0.027	0.009	0.023	0.009	0
0.67-1977	1	0.015	0.060	0	0.012	0.027	0	0.015	0.049	0	0.027	0.018	0	0.027	0.009	0.017	0.009	0
1 -1978	2	0.010	0.045	0	0.010	0.047	0	0.021	0.051	0	0.017	0.036	0	0.025	0.098	0.027	0.062	0
	3	0.010	0.029	0	0.012	0.033	0	0.029	0.071	0	0.036	0.053	0	0.036	0.009	0.017	0.018	0
	4	0.012	0.040	0	0.006	0.011	0	0.015	0.049	0	0.050	0.053	0	0.026	0.036	0.017	0.018	0
1.33-1977	1	0.015	0.150	0	0.015	0.115	0	0.015	0.200	0	0.027	0.018	0	0.033	0.169	0.027	0.133	0
2 -1978	2	0.012	0.064	0	0.006	0.022	0	0.015	0.102	0	0.023	0.151	0	0.047	0.195	0.033	0.195	0
	3	0.010	0.068	0	0.029	0.062	0	0.021	0.098	0	0.033	0.115	0	0.033	0.080	0.027	0.186	0
	4	0.010	0.064	0	0.006	0.018	0	0.023	0.038	0	0.069	0.123	0	0.047	0.115	0.027	0.009	0
2.67-1977	1	0.030	0.178	0	0.035	0.175	0	0.046	0.210	0	0.062	0.249	0	0.066	0.328	0.062	0.346	0
4 -1978	2	0.012	0.063	0	0.012	0.015	0	0.012	0.027	0	0.017	0.027	0	0.017	0.018	0.150	0.142	0
	3	0.029	0.199	0	0.138	0.276	1	0.132	0.213	0	0.150	0.249	1	0.181	0.222	0.077	0.142	1
	4	0.012	0.072	0	0.058	0.065	0	0.046	0.098	0	0.132	0.142	0	0.181	0.133	0.164	0.169	0

(Continued)

Appendix II

Table 7. Soil Salt Application Study. Individual tree data for lodgepole pine with five salt treatments. Leaf sodium and chloride concentrations (% dry wt.) and damage ratings[1] are given on nine sampling dates. (Concluded)

Treatment	Repli-	Jan. 1978			May 1978			June 1978			Sept. 1978
		% DW			% DW			% DW			
T/A-year	cation	Na	Cl	Damage	Na	Cl	Damage	Na	Cl	Damage	Damage
0-1977	1	0.017	0.027	0	0.033	0.027	0	0.023	0.008	0	0
0-1978	2	0.017	0.009	0	0.017	0.027	0	0.017	0.008	0	0
	3	0.017	0.009	0	0.015	0.006	0	0.023	0.007	0	0
	4	0.023	0.009	0			0	0.027	0.007	0	0
0.33-1977	1	0.023	0.044	0	0.042	0.080	0	0.036	0.053	0	0
0.5 -1978	2	0.017	0.009	0	0.036	0.072	0	0.045	0.035	0	0
	3	0.023	0.009	0	0.036	0.045	0	0.047	0.007	0	0
	4	0.023	0.009	0	0.047	0.044	0	0.042	0.018	0	0
0.67-1977	1	0.033	0.036	0	0.068	0.151	0	0.089	0.151	0	0
1 -1978	2	0.053	0.044	0	0.062	0.142	0	0.035	0.089	0	0
	3	0.042	0.036	0	0.055	0.080	0	0.047	0.062	0	0
	4	0.023	0.027	0	0.053	0.071	0	0.047	0.045	0	0
1.33-1977	1	0.164	0.408	0	0.181	0.550	1	0.124	0.337	1	1
2 -1978	2	0.077	0.373	0	0.156	0.391	0	0.181	0.426	0	0
	3	0.030	0.180	0	0.036	0.151	0	0.033	0.133	0	0
	4	0.033	0.071	0	0.068	0.151	0	0.101	0.186	0	0
2.67-1977	1	0.141	0.524	0	0.226	0.559	1	0.164	0.630	1	1
4 -1978	2	0.042	0.044	0	0.066	0.108	0	0.033	0.062	0	0
	3	0.191	0.204	1	0.145	0.231	1	0.095	0.178	1	1
	4	0.213	0.213	0	0.283	0.333	0	0.250	0.249	0	0

[1]Damage ratings: 0 = no damage, 1 = 1st symptoms to 25%, 2 = 26-50%, 3 = 51-75%, and 4 = 76-100% browning or defoliation.

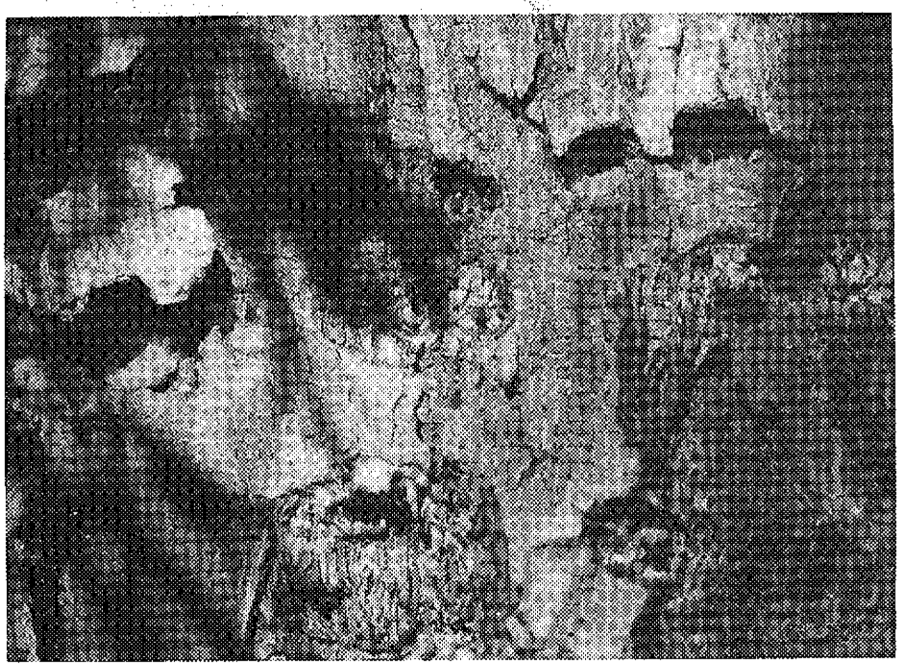

Photo 1. Beetle Damage. Holes in bark of Jeffrey pine. Pitch exudate is sometimes visible.

September 1975

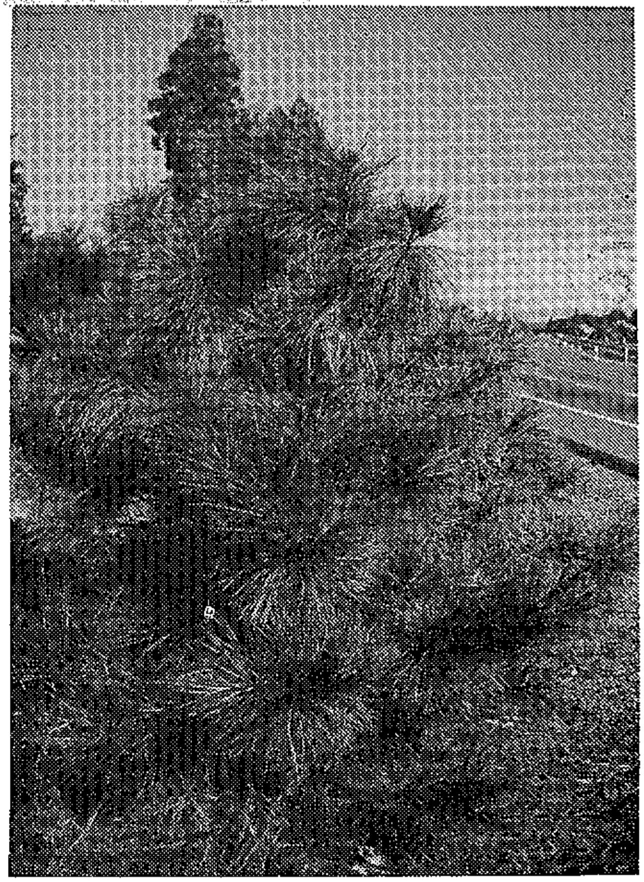

Photo 2. Beetle Damage. Symptoms in young Jeffrey pine, spreading basipetally (top to bottom) in tree. The tips and top branches are affected first.

October 1977

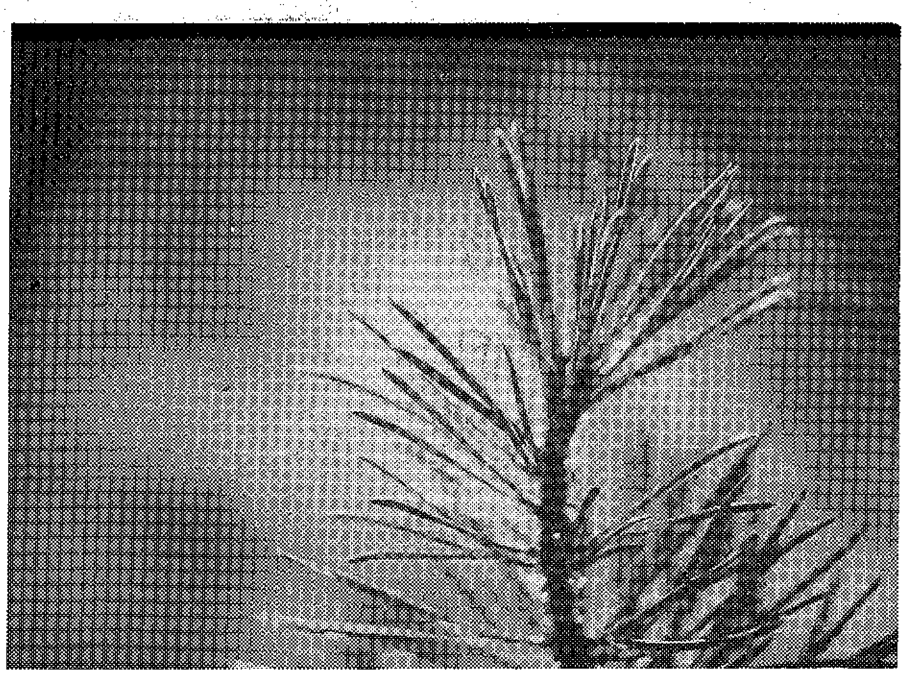

Photo 3. Beetle Damage. Symptoms in needles of Lodgepole pine develop acropetally (base to tip) in needles but basipetally in branches and tree.

October 1977

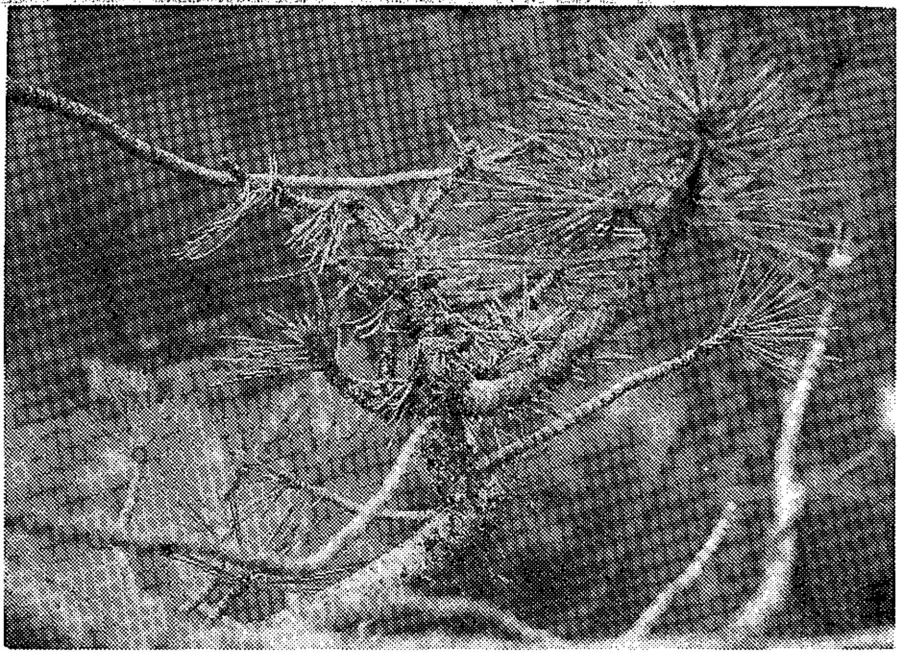

Photo 4. Mistletoe. Severe damage on Jeffrey pine caused by dwarf mistletoe; defoliation of older needles, dwarfing of younger needles, and swelling of branches.

May 1976

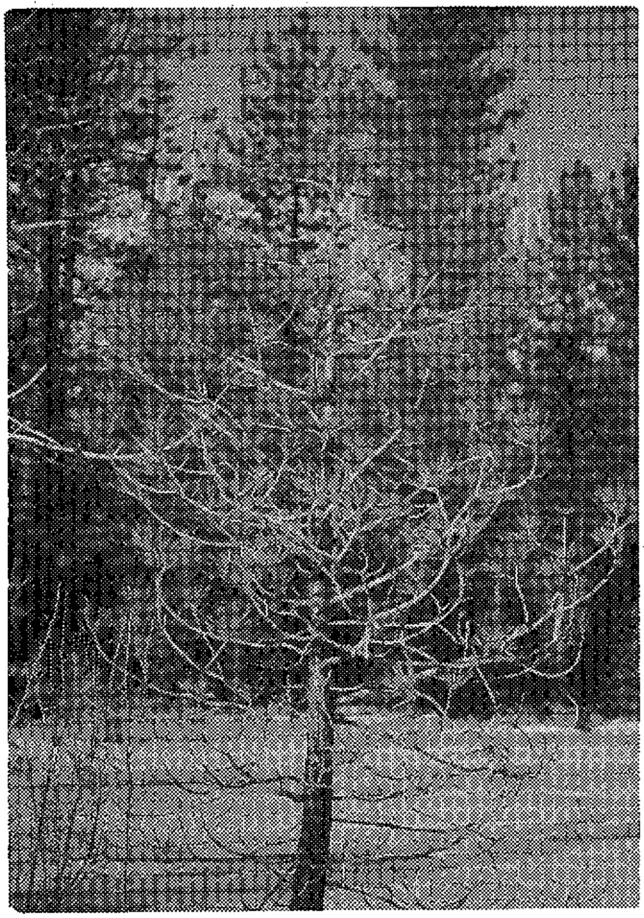

Photo 5. Salt Damage. Jeffrey pine treated with 5.33 T/A NaCl in 1977, photographed in January 1978. Damage is spreading acropetally (base to top) in the tree.

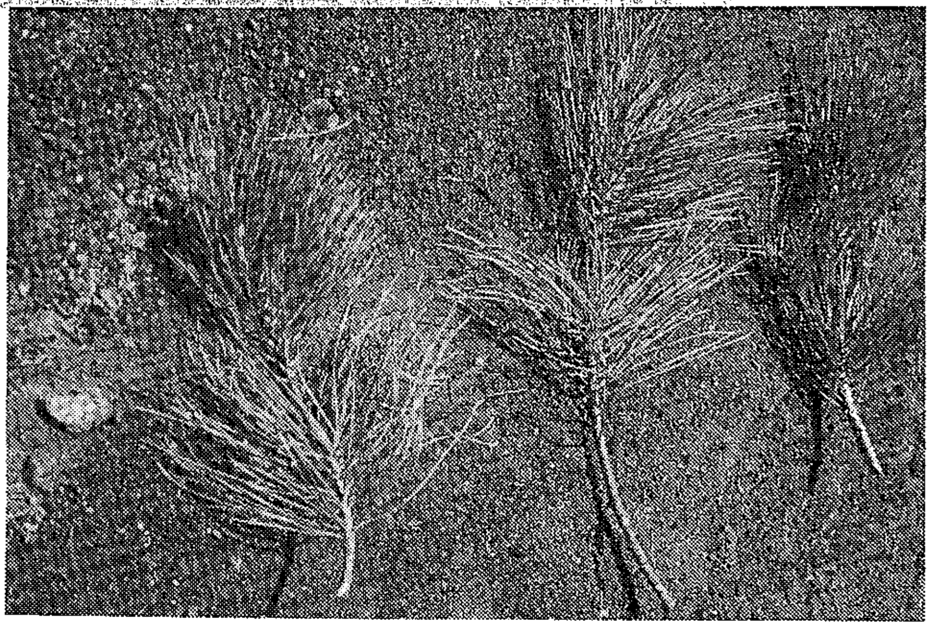

Photo 6. Salt Damage. Jeffrey pine needle damage spreads basipetally (tip to base) in needles. Left to right: 50, 25, and 0% damage (damage ratings of 2, 1, and 0).

May 1976

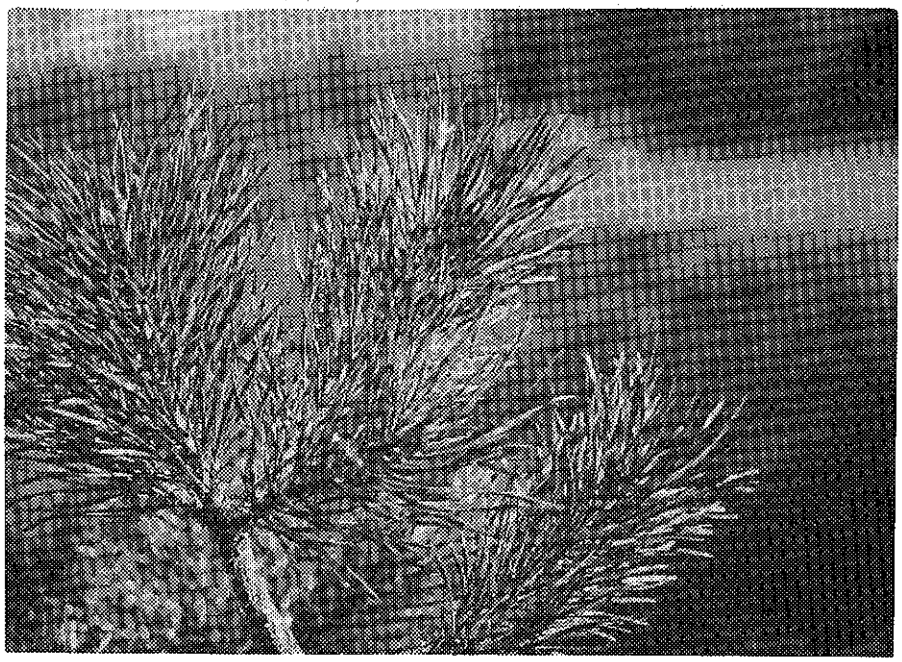

Photo 7. Salt Damage. Lodgepole pine treated with 2.67 T/A NaCl in 1977, photographed October 1977. Damage spreads basipetally (tip to base) in needles.

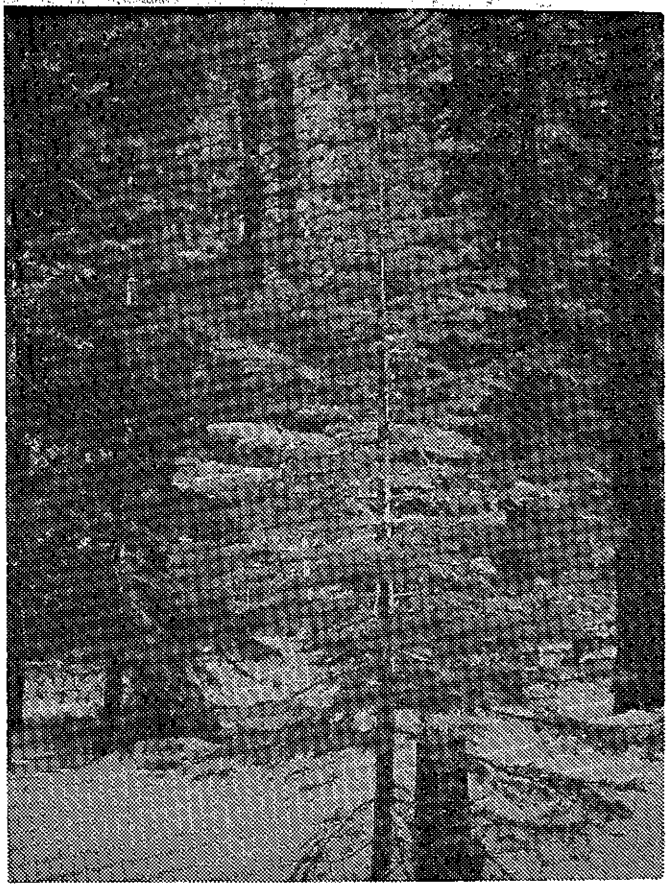

Photo 8. Salt Damage. White fir treated with 2.67 T/A NaCl in 1977, photographed January 1978. Damage spreads acropetally (base to top) in tree. The spiral pattern of damage sometimes seen, is developing in this tree.

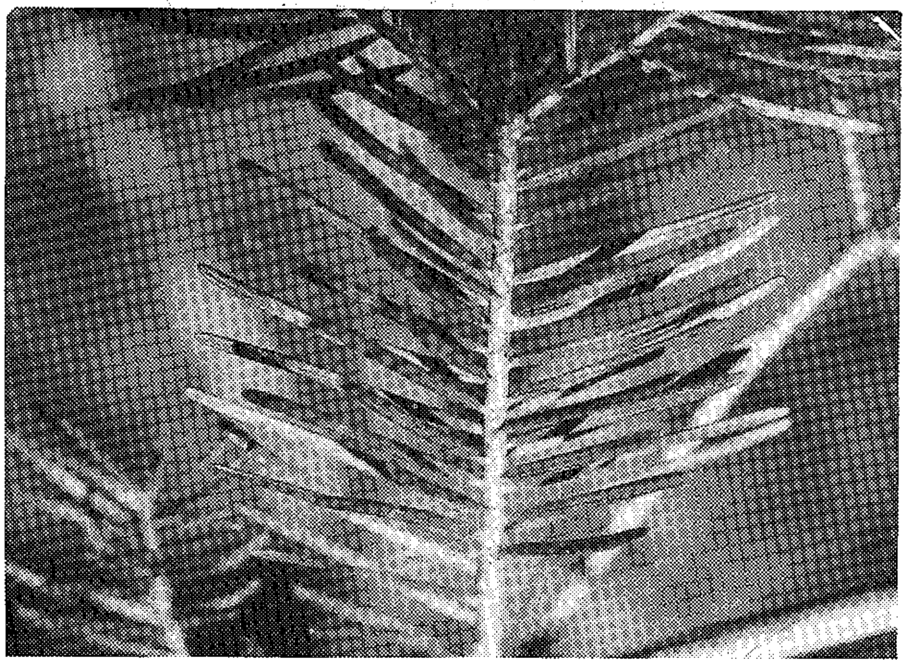

Photo 9. Salt Damage. White fir treated with 5.33 T/A NaCl in 1977, photographed in May 1977. Individual needle damage spreads basipetally (tip to base). These needles are about 75% brown.

Photo 10. Salt Damage. White fir treated with 5.33 T/A NaCl in 1977, photographed in September 1977. This tree is virtually dead. The last remaining needles are those formed in the summer of 1977.

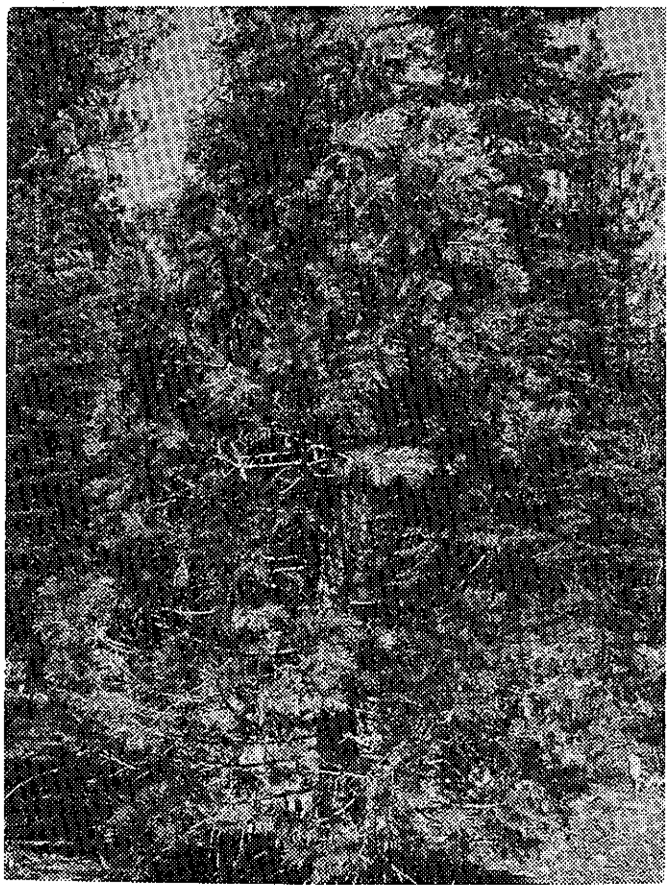

Photo 11. Salt Damage. Incense cedar treated with 2.67 T/A NaCl in 1977, photographed August 1977. The acropetal (bottom to top) development of symptoms in the tree, although present, is not as obvious as in pine or fir. Because of the scale-like leaves the browning must be observed in branchlet systems.

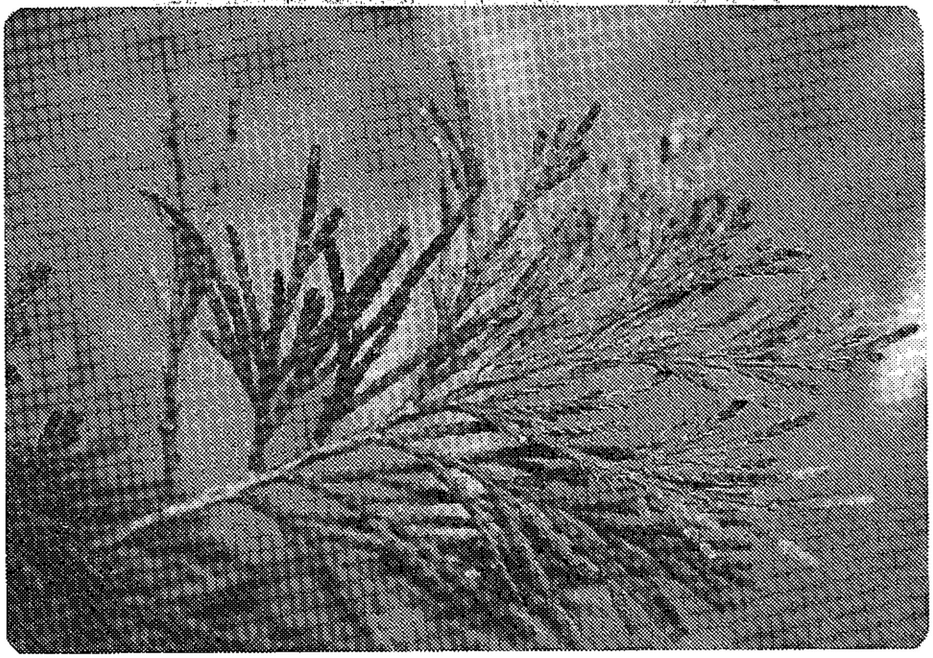

Photo 12. Salt Damage. Incense cedar treated with 1.33 T/A NaCl in 1977 and 2 T/A NaCl in 1978, photographed July 1978. Damage symptoms develop basipetally (tip to base) in the branchlets.