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Effects of Deicer Compounds on *Hackelia*

DETERMINATION OF THE EFFECTS OF ANTI-ICER COMPOUNDS UPON THE RARE PLANT *HACKELIA VENUSTA*

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16. ABSTRACT

The objective of the study was to determine whether Washington State Department of Transportation's winter use of road anti-icer compounds on Highway 2 in Chelan County, Washington, is having an impact on the federally endangered plant species *Hackelia venusta*. A controlled study was performed in the outdoor facilities at the Center for Urban Horticulture-University of Washington. This study evaluated two road anti-icer formulae available to WSDOT in the 2000-2002 winter seasons by testing the effects of different anti-icer dilutions on plant and soil parameters. Since it was not feasible to use *H. venusta* in a controlled study during the time of implementation, two other species were used. One species, *Mertensia platyphylla*, is a phylogenetic relative and the other, *Eriophyllym lanatum*, is a non-related ecosystem associate. From the analysis, we were able to conclude that both road anti-icers begin to have detrimental effects by causing a decrease in aboveground biomass and survival on the two plant species examined when the concentrations reached 1 part anti-icer: 100 parts solution. Given the information obtained from our study's results, more work is needed in order to better understand the implications of these results on the effects road anti-icer formulae have on *H. venusta*.

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DETERMINATION OF THE EFFECTS OF ANTI-ICER COMPOUNDS UPON THE RARE PLANT *HACKELIA VENUSTA*

Introduction. This technical summary describes the key findings of a Washington State Department of Transportation (WSDOT) project that is documented more fully in the research and technical reports titled "Determination of the Effects of Anti-icer Compounds upon the Rare Plant *Hackelia venusta*." The objective of the study was to determine the impacts WSDOT's winter use of road anti-icer compounds on Highway 2 in Chelan County, Washington, may be having on the federally endangered plant species *H. venusta*.

Research Approach. A controlled study was performed in the outdoor facilities at the Center for Urban Horticulture-University of Washington. This study evaluated two road anti-icer formulae available to WSDOT in the 2000-2002 winter seasons by testing the effects of different anti-icer dilutions on plant growth and soil parameters. Since it was feasibly impossible to use *H. venusta* in a controlled study during the time of implementation, two other species were used. One species, *Mertensia platyphylla*, was a close, phylogenetic relative and the other, *Eriophyllym lanatum*, was a non-related ecosystem associate.

Conclusions and Recommendations. From the analysis, we were able to conclude that both road anti-icers began to have detrimental effects on the two plant species examined when the concentrations reached 1 part anti-icer: 100 parts solution. While we do not have concrete field evidence, we believe that concentrations this high or greater would only occur in rare, extreme instances and may not be the concentrations experienced on the site of the *H. venusta* population.

Given the information obtained from our study's results, we recommend the following in order to reach a definitive conclusion: (1) Complete the research on the life history and growth requirements of *H. venusta;* (2) Determine the actual soil and snowmelt conditions on the Highway 2 road right-of-way on or adjacent to the current *H. venusta* population; (3) Monitor the road right-of-way where *H. venusta* occurs to prevent large concentrations of road anti-icers from accumulating; (4) Perform a controlled study with *H. venusta* or *Hackelia diffusa* var. *arida.*

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report documents a research study that continues WSDOT's commitment towards the conservation of the federally endangered plant species *Hackelia venusta* by evaluating WSDOT's current winter maintenance practices in Tumwater Canyon. The objective of the study was to determine the impacts WSDOT's winter use of road anti-icer compounds on Highway 2 in Chelan County, Washington, may be having on *H. venusta*.

A controlled study was performed in the outdoor facilities at the Center for Urban Horticulture-University of Washington. This study evaluated the road anti-icer formulae CalBan distributed by America West and NC-3000 distributed by Minnesota Corn Processors, both of which were available to WSDOT in the 2000-2002 winter seasons. The effects of different anti-icer dilutions were determined by comparing plant growth and soil parameters of each dilution to a control group. Since it was feasibly impossible to use *H. venusta* in a controlled study during the time of implementation, two other species were used. One species, *Mertensia platyphylla*, was a close, phylogenetic relative and the other, *Eriophyllym lanatum*, was a non-related ecosystem associate.

From the findings documented in this report, we were able to conclude that both road anti-icers began to have detrimental effects on the two plant species examined when the concentrations reached 1 part anti-icer: 100 parts water. While we do not have concrete field evidence, we believe that concentrations this high or greater would only occur in rare, extreme instances and may not be the concentrations experienced on the site of the *H. venusta* population. Neither of the two anti-icer formulae examined in this study is currently in use on Highway 2 where *H. venusta* occurs. The results from this study are still applicable, though, due to the fact that the current anti-icer formula is composed of ingredients similar to CalBan.

Within this report are recommendations for continued research in order to fully meet the goals of the objective of the research study. The tasks we recommend are to:

(1) Complete the research on the life history and growth requirements of *H. venusta*. The U.S.D.A. Forest Service has already begun working on these topics of interest but funding is scarce and the research is proceeding slowly.

(2) Determine the actual soil and snowmelt conditions on the Highway 2 road right-of-way on or adjacent to the current *H. venusta* population. Implementation of a soils and/or snowmelt-monitoring project near the current *H. venusta* population would aide the interpretation of this research study's results.

(3) Maintain low concentrations of road anti-icers within the road right-of-way where *H. venusta* occurs. In the unlikely case of an accident, WSDOT should maintain its awareness of the population's location and perform a swift clean-up of the road and snowbanks within the road right-of-way.

(4) Perform a controlled study with *H. venusta* or *Hackelia diffusa* var. *arida* similar to the one described in the research report. While *H. venusta* would be the ideal subject of a repeat study, it may not be possible. *H. diffusa* var. *arida* would be the best choice for a surrogate species should *H. venusta* not be available.

INTRODUCTION

THE PROBLEM

The past decade has seen a change in Washington State Department of Transportation's (WSDOT's) methods in managing its eastern highways and interstates during the winter months. Previously, WSDOT applied sand to its roads to increase traction and decrease potentially hazardous conditions. Over the last few years, WSDOT has developed and implemented a different method of winter safety: the application of anti-icer formulae prior to a storm event (Paul Wagner WSDOT unpublished personal communication January 2001; Rick Wood WSDOT unpublished personal communication February 2001). Of particular concern in the State of Washington and to several government agencies, including WSDOT, U. S. Fish and Wildlife Service (USFWS) and the U. S. D. A. Forest Service (USFS), is the effect of these anti-icer formulae on the federally endangered plant *Hackelia venusta* (showy stickseed) (Piper) St. John (Boraginaceae) which occurs in the road right-of-way for Highway 2 in Chelan County, Washington. The research project described below continues WSDOT's commitment towards the conservation of *H. venusta* by evaluating WSDOT's current winter maintenance practices in Tumwater Canyon and their impact to the population.

RESEARCH OBJECTIVES

The major objective of this study is to aid WSDOT in determining if road anti-icer formulae are having any negative effects on the rare plant *H. venusta*. To achieve this objective, we designed a controlled experiment to examine two specific anti-icer formulae that are available to WSDOT: CalBan, distributed by America West; and NC-

3000, produced and distributed by Minnesota Corn Processors. Due to the unavailability of propagation material for *H. venusta*, the study was designed to use two surrogate plant species to gauge the effects of the road anti-icer formulae in a manner that could be extrapolated to the wild *H. venusta* population.

The objectives of this study were to:

1) Determine whether different concentrations of the road anti-icer compounds examined have an adverse effect on the overall health and survival of plants selected to serve as surrogates for *H. venusta* in a polyhouse experiment;
2) Determine whether road anti-icer compounds alter the soil environment and whether the soil environment recuperates over time through the measurement of two soil parameters;
3) Relate the study's results to the *H. venusta* population and the conditions on the site where the population occurs.

The goal of the polyhouse study was to model the conditions under which *H. venusta* is exposed to the anti-icer compounds. *H. venusta* is believed to be exposed to anti-icer compounds during winter when it is dormant and during snow melt in the spring. The aboveground portion of *H. venusta* dies back into the roots in its dormant stage, leaving the roots as the organs most susceptible to exposure. The soils on the site are composed of granitic scree, a mixture of broken rock and sand, and are not expected to hold the compounds but, rather, to allow these compounds to leach out of the soils.

BACKGROUND

Hackelia venusta (Piper) St. John (Boraginaceae), also known as the showy stickseed, is a rare, endemic herbaceous perennial recently listed as endangered under the Federal Endangered Species Act on February 6, 2002. Currently, *H. venusta* occurs only in one extant population found in Chelan County, Washington, along a major highway. The population is located in the Tumwater Canyon Botanical Area of the Wenatchee National Forest with several individuals also occurring in the WSDOT road right-of-way. While the population numbers may fluctuate from year to year, the general trend has been a steady decrease in the number of individuals present and the area occupied (Gamon 1988; Harrod et al.1999; USFWS 2000). The reason or reasons perpetuating the decline is unknown. However, many potential factors have been discussed and it is believed that several factors proposed may be occurring simultaneously. These factors include decreased population vigor, human collection and trampling, alterations of the habitat, and random environmental events such as slope failures or genetic drift (Gamon 1988; USFWS 2000).

Maintenance and management practices of the road right-of-way have been of increasing concern and do pose a potential threat to individuals of *H. venusta* that occur in the right-of-way (USFWS 2000). There is some concern that WSDOT's winter maintenance practices are having a detrimental effect on the individuals of *H. venusta* occurring in the road right-of-way. Several years ago, WSDOT adopted the application of anti-icer compounds to many of the roads in the state (Paul Wagner unpublished personal communication January 2001; Rick Wood unpublished personal communication February 2001). Anti-icer compounds react with frozen roadways the same way as deicing salts but are sprayed upon the pavement prior to a storm event to prevent snow from sticking to the ground or ice from forming on the pavement. Over time, these compounds do dissolve into solution with melted water and drain to the sides of the roads in a diluted form (Chollar 1996; WSDOT 1998; Rick Woods unpublished personal communication February 2001).

The product used by WSDOT in the Tumwater Canyon Botanical Area during the years 2000-2002 was CalBan. CalBan is distributed by America West and generally contains 36% calcium chloride, 58% water, and 6% Ice Ban, a product of Natural Solutions derived from the wastewater of corn fermentation (Rick Wood WSDOT unpublished personal communication November 2001). It is comprised of a variety of organic compounds, mostly carbohydrates, and can vary widely in its contents (Roosevelt and Fitch 2000). The CalBan collected from WSDOT for the research project was analyzed by Accurate Testing Labs, LLC, of Coeur d'Alene, ID, on 05/23/2003, and was found to contain approximately 12.9% by volume calcium (Appendix A).

Another product available to WSDOT for the same purposes was NC-3000, produced and distributed by Minnesota Corn Processors, LLC. NC-3000 usually consists of 25% potassium acetate, 30% corn syrup, and 45% water (Bill Ricks Glacial Technologies unpublished personal communication November 2001). The NC-3000 collected from Minnesota Corn Processors for the research project was also analyzed by Accurate Testing Labs, LLC, of Coeur d'Alene, ID, on 5/20/2003, and was found to contain approximately 12.6% by volume potassium (Appendix A).

While these two anti-icer products contain diluted amounts of non-sodium salts, the salt constituents of these products are still the main concern for *H.venusta*. There may be different stressors acting on a plant due to the presence of external solutes, different solutes may also produce different effects, possibly due to different mechanisms being involved (ASCE 1990). The majority of cases of salt stress involve sodium chloride but a salt can be any ionic solid that disassociates completely in water (Harris 1995). The ions that may be evaluated in plant and soil studies include Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-, and NO_3^- (ASCE 1990; Hopkins 1995). Thus, salinity stress may refer to an excess of any of the ions listed above.

The two salts under consideration in this study are calcium chloride and potassium acetate. While calcium chloride in large concentrations is believed to have some adverse effects on plants (Richards 1954; Levitt 1980; Harris et al. 1999), its effects have not been as heavily studied as sodium chloride. A plant's response to abnormally high levels of ions in the soil water solution depends on the nutrient requirements of the plant for that specific ion (Richards 1954). Calcium is considered to be an essential macronutrient in order for plants to complete a normal life cycle with requirements ranging between 0.1% - 5.0% of a plant's dry weight (Marschner 1995). However, several reviewers have concluded that high calcium concentrations may have toxic effects in plants (Richards 1954; Lee 1999). In his review on plants adapted to calcareous soils, Lee (1999) states that plants generally adapted to low calcium soil concentrations have evolved methods to maximize calcium uptake that could lead to calcium toxicity if the plants were exposed to high levels of calcium. There is also the possibility that less-than-toxic concentrations of calcium can induce secondary stress rather than primary stress and that the anion accompanying calcium is of greater importance (Levitt 1980). Awada et al. (1995) concluded in their study that the ion associated with calcium influences the effectiveness of calcium to negate salinity stress caused by sodium salts.

According to Hopkins (1995), chloride is an essential micronutrient that is rarely deficient in nature and is typically taken up in plants in far greater concentrations than needed. In general, plants will develop a critical deficiency at chloride concentrations less than 6mM in the external solution while toxicity will develop in sensitive plants at external solution concentrations above 20mM of chloride (Marschner 1995). In agricultural settings, chlorides tend to negatively affect woody plants such as fruit trees and vines the most (Richards 1954; White and Broadley 2001) but may also have a detrimental effect on non-woody crops, depending on the species (Maas 1986; White and Broadley 2001). Several reviewers have also pointed out that chlorides have been known to decrease the availability of nutrients that are absorbed in the form of anions, such as phosphates (Levitt 1980) and nitrates (ASCE 1990).

Potassium acetate, the second salt to be considered in this study, is considered to be relatively benign to plants. As with calcium, potassium is a macronutrient that is needed by plants in very large quantities ranging from 2% to 5% of a plant's dry weight (Marschner 1995). Any effects seen with this salt will likely be due to secondary stresses that develop, such as nutrient deficiencies in iron, calcium, and magnesium (Richards 1954). There may also be more indirect impacts to the survival of a macronutrient to the soil environment as one study performed in Austria found that potassium carbonate used as a deicer had beneficial effects on vegetation near roadsides but caused a change in the graminoid species composition of roadside areas, allowing more aggressive species to flourish (Erhart and Hartl 2000).

Some research on acetate's effects on plants and soils has been performed due to the use of calcium magnesium acetate as a potential alternative deicer to sodium chloride. Acetate is readily degraded in the soil environment during optimal temperatures (Horner and Brenner 1992; Ostendorf et al. 1993). Acetate was found to degrade most quickly in the upper horizons of soils in a soil microcosm study, indicating that slower infiltration rates may aid the biodegradation of acetate (Ostendorf et al. 1993). During high runoff periods and in well-draining soils, however, calcium magnesium acetate may leach out of the soils and enter aqueous environments where it may increase the microbial activity and lead to a decrease in available dissolved oxygen (Horner and Brenner 1992). There is also the possibility that, when coupled with a macronutrient, it could indirectly impact native vegetation by increasing the competitive advantage of invasive and undesirable species.

Salinity may affect a soil by altering the soils' physical structure and chemistry, inducing a secondary stress on plants growing in the soil. Salts other than sodium chloride do not generally alter a soil's physical structure since most salts tend to prevent the soil colloids from dispersing (Brady and Weil 1999). In fact, ionic solutions may be utilized in sodic soil reclamation in an attempt to replace the sodium ions in the soil solution (Brady and Weil 1999). However, different salts have different effects on a soil's chemistry. When working with a salt-affected soil, it is important to determine the soil's pH, and electrical conductivity (ASCE 1990). The pH of the soil solution is also important as it can affect soil chemical reactions and alter which ions are less available, causing a deficiency, or more available, causing a toxicity (Levitt 1980; Brady and Weil 1999). Electrical conductivity is an indirect measure of the salts' content in a water solution. When a water solution's charged solute concentration increases, the water is better able to conduct electricity (Brady and Weil 1999). The higher the solute concentration, the higher the electrical conductivity will become.

Salinity-affected soils that recover quickly and easily will be soils with good drainage and large soil particle sizes, such as sandy soils (Hoffman 1986). Reclamation of salty soils requires a great deal of leaching of the soils with water that does not have an excess of salts to remove the excess ions. (Brady and Weil 1999). The ability of a soil to recover will depend on soil properties such as the permeability of the soil (ASCE 1990) along with the soil type, the nature of the salts present in the soils, the water available for leaching, and topography (Hoffman 1986).

PROCEDURES

PLANT MATERIALS

In the polyhouse study, we used adult individuals of two surrogate species, a close phylogenetic relative of *H. venusta, Mertensia platyphylla* Heller (Boraginaceae), and a non-related ecosystem associate, *Eriophyllum lanatum* (Pursh) Forbes (Asteraceae), in order to avoid the use of large numbers of a rare plant that is difficult to propagate. The phylogenetic relative, *M. platyphylla,* is an herbaceous perennial that grows from a rhizomatous root and typically grows along stream banks and in moist woodlands in the low elevations of the Cascade Mountain Range (Hitchcock et al. 1959). *Mertensia platyphylla* was purchased from Pacific Natives and Ornamentals in Bothell, WA, on Feb. 6th, 2001. The ecosystem associate we chose for the study was *E. lanatum.* *Eriophyllum lanatum* is a ubiquitous herbaceous perennial that grows in dry, open places from lowlands to mid elevations throughout the Cascade Mountain Range and northern Rocky Mountains (Hitchcock et al. 1959), including the site where *H. venusta* grows. *Eriophyllum lanatum* was purchased from Bosky Dell Natives in West Linn, OR, on May 13th, 2001.

SOIL MATERIALS AND COLLECTION

To account for soil conditions consistent with the *H. venusta* site, all of the plants were potted in soils collected from Tumwater Canyon near Leavenworth, WA, on September 14, 2002, with the exception of the individuals of *M. platyphylla* assigned to the Control 2 treatment group. We originally sifted the soils to remove larger rocks, using a chicken wire sifting frame, and then homogenized September 20th-21st, 2002, using a cement mixer, prior to potting the plants in the soil. The soils from Tumwater

Canyon are generally described as well-draining granitic scree. The soil series for the *H. venusta* site is classified as an Icicle-Chumstick-Rock Outcrop Association composed of very bouldery sandy loam (Beieler 1975). *M. platyphylla* is known to occur in more clayey soils along stream and river banks, so several individuals of *M. platyphylla* were assigned to a Control 2 group and potted in a sandy clay loam soil obtained from Red-E Topsoil in Redmond, WA.

EXPERIMENTAL DESIGN

Due to different light requirements and growth habits of the two species, the study was designed to consider the two species separately. A total of 117 individuals of *E. lanatum* and 110 individuals of *M. platyphylla* were used in the polyhouse experiment. The plants were separated into five sections in the polyhouse according to species, randomly assigned to treatment groups, and arranged in a randomized block design perpendicular to the direction of the environmental gradients as depicted in *Figure* 1. The pots were 8 inches in diameter and each pot was isolated from the ground and the surrounding pots by a 9-inch drainage bin.

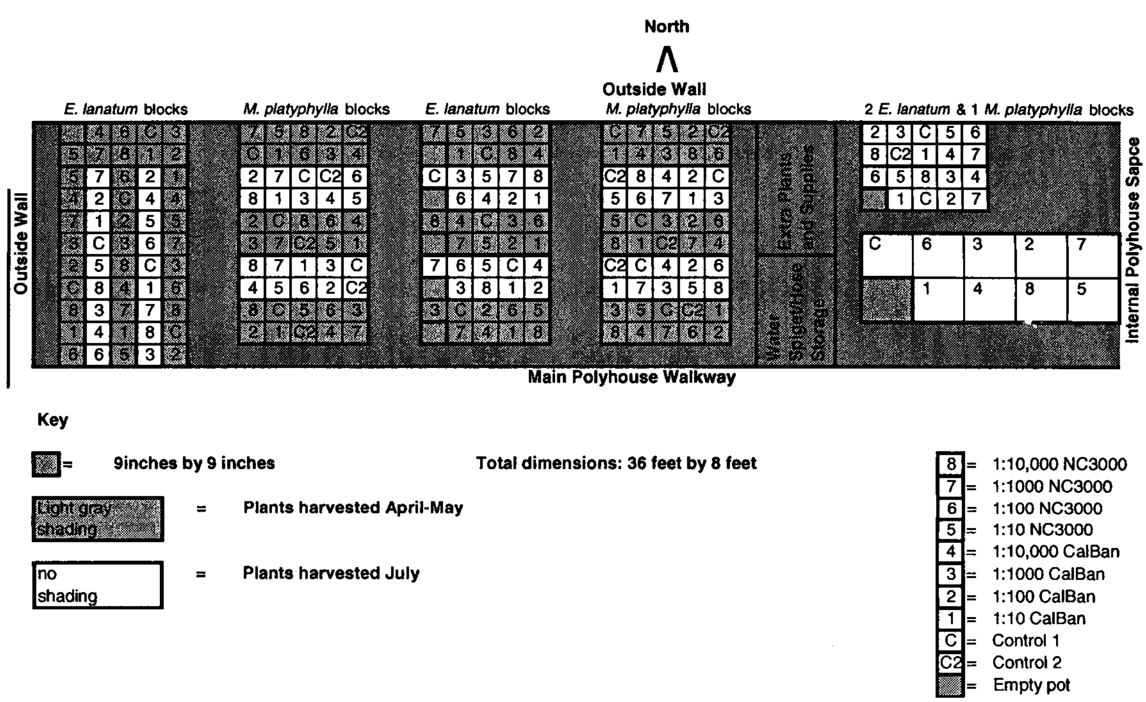
The temperatures in the polyhouse were approximately the same as the outdoor temperatures at the Center for Urban Horticulture during 2002. I obtained weather data from the weather station located at the Center for Urban Horticulture's Union Bay Natural Area that is operated by Stephen Burges of Civil and Environmental Engineering at the University of Washington. The monthly averages of daily low and high temperatures were recorded in degrees Fahrenheit and are:

January	low 3.4 °C	high 8.4 °C;
February	low 2.2 °C	high 10.4 °C;
March	low 2.8 °C	high 9.8 °C;

April	low 5.4 °C	high 14.2 °C;
May	low 7.7 °C	high 17.1 °C;
June	low 11.3 °C	high 22.4 °C;
July 1-10	low 11.4 °C	high 23.1 °C.

We procured both of the anti-icers through WSDOT and their contacts. CalBan was collected in three 5-gallon buckets from the WSDOT Steven's Pass Maintenance Facility near Leavenworth, WA. NC-3000 was collected in three 5-gallon buckets from the Minnesota Corn Processors LLC's Puyallup, WA, Bulk Terminal. Approximately every 5 days, 20 liters of each anti-icer dilution was mixed in 5-gallon buckets that had

Figure 1. Layout for treatment phase of *Hackelia venusta*/Anti-icer project in polyhouse at the Center for Urban Horticulture



been cleaned and rinsed several times with deionized water to prevent the formation of mold in the solutions.

The plants were watered daily throughout the period of dormancy beginning December 31, 2001, and ending April 8, 2002, shortly after *M. platyphylla* began to break dormancy. All plants were hand-watered with 150 ml of the treatment assigned to each plant except for Control 2, which was watered once a week due to the poorer draining capacity and greater water-holding capacity of the sandy clay loam soils. After all of the plants had been watered and the treatment solutions given enough time to percolate through the soils, the watering trays were emptied and the excess treatment solutions were discarded. The presence of any greenhouse pests was monitored and noted on a daily basis and actions were taken immediately to minimize the harm done to the research plants.

The treatment groups were as follows:

- Control 1: Individuals of both species were potted in soil from the *H. venusta* site and watered daily with 150 ml of deionized water only.
- Control 2: Individuals of *M. platyphylla* only were potted in a sandy clay loam soil and watered once a week with 150 ml of deionized water only.
- Treatment 1: Individuals of both species were potted in soil from the *H. venusta* site and watered daily with 150 ml of 1:10 Cal Ban: water solution.
- Treatment 2: Individuals of both species were potted in soil from the *H. venusta* site and watered daily with 150 ml of 1:100 Cal Ban: water solution.
- Treatment 3: Individuals of both species were potted in soil from the *H. venusta* site and watered daily with 150 ml of 1:1, 000 Cal Ban: water solution.

- Treatment 4: Individuals of both species were potted in soil from the *H. venusta* site and watered daily with 150 ml of 1:10, 000 Cal Ban: water solution.
- Treatment 5: Individuals of both species were potted in soil from the *H. venusta* site and watered daily with 150 ml of 1:10 NC-3000: water solution.
- Treatment 6: Individuals of both species were potted in soil from the *H. venusta* site and watered daily with 150 ml of 1:100 NC-3000: water solution.
- Treatment 7: Individuals of both species were potted in soil from the *H. venusta* site and watered daily with 150 ml of 1:1, 000 NC-3000: water solution.
- Treatment 8: Individuals of both species were potted in soil from the *H. venusta* site and watered daily with 150 ml of 1:10, 000 NC-3000: water solution.

PLANT SAMPLING AND MEASUREMENTS

On April 8, 2002, all of the plants were watered with their assigned treatments for the last time. Soil samples were collected April 10-11, 2002, and again July 2-9, 2002, from each of the pots in the manner described below. Harvesting for the first set of aboveground biomass data began April 19, 2002, and continued through May 16, 2002. Seven *E. lanatum* blocks and six *M. platyphylla* blocks occurring along similar environmental gradients were selected to be sampled for aboveground biomass (See Figure 1) for a total of 63 *E. lanatum* individuals and 60 *M. platyphylla* individuals (123 total). The second set of biomass sampling occurred from July 2-9, 2002, and consisted of the remaining six *E. lanatum* and five *M. platyphylla* blocks for a total of 54 *E. lanatum* individuals and 45 *M. platyphylla* individuals.

The aboveground biomass was removed with scissors and weighed to obtain a fresh weight. The aboveground structures were then placed in clearly labeled brown paper bags, placed in a Hotpack (Philadelphia, PA) Model 212061 High Performance Oven set at 70 °C for an average of 72 hours. They were then removed from the oven, allowed to cool for 15-20 minutes, and reweighed to determine the dry weight.

SOIL SAMPLING AND MEASUREMENTS

Every pot was sampled from a specific quadrat position to maintain consistency in the sample of the soils in the pots. Soil samples were collected using a one-inch soil corer placed directly over the quadrat and pushed down into the soil of the pot to a depth of 11.5 cm and then placing the core in a clearly labeled Ziploc bag. Once all soils had been collected, the samples were air dried on blotter paper for five days and then rebagged. The rebagged samples from the first sampling were stored in a laboratory drawer for several weeks before they were placed in cold storage at 2 °C in a Kysor Kalt cold storage unit. They were removed from cold storage in April 2003 for analysis. The samples from the second sampling were placed in cold storage in clearly labeled Ziploc bags on July 16th, 2002, at 2 °C, immediately following air-drying, and removed from cold storage when the soils parameters were to be measured.

Air-dried samples were sieved through a 2 mm soil sifter, weighed and mixed with deionized water to form a 1:2 soil weight: water volume soil solution. The pH for each soil sample was determined using a Digi-Sense Model 3938-10 pH meter distributed by Cole-Parmer Instrument Co., Vernon Hills, IL, with an Orion pH combination electrode. The electrical conductivity was measured with YSI Model 85 Dissolved Oxygen and Conductivity Meter distributed by YSI Inc., of Yellow Springs, OH, and recorded in units deciSiemens/meter (dS/m).

DATA ANALYSIS

We compared the means of treatment groups to the control in SAS 8.02 for Windows (SAS Institute Inc.) for the aboveground biomass, soil pH, and soil electrical conductivity data. We performed a repeated measures ANOVA with the aboveground biomass data and a three-factor ANOVA with unequal replication with the two soil parameters (Zar 1999). An experiment-wide significance value was set at 0.05. we performed a logarithmic transformation on the aboveground biomass data by using the equation $X' = \log(X+1)$ as described in Zar (1999) to include observational values of zero. A logarithmic transformation was also performed on the soil electrical conductivity data by using the equation $X' = \log(X)$.

We used a Dunnett's t-test with a Bonferroni correction to compare the means for the treatment effects against the control for significant differences. A Bonferroni correction of the alpha value for individual comparisons allows for a more conservative estimate of significant differences between treatment groups and the control. Bonferroni corrections are recommended when one is performing many comparisons. The alpha value for the Dunnett's t-test under the Bonferroni correction was ($0.05 / 5 = 0.01$) for the aboveground biomass of *E. lanatum*, ($0.05 / 6 = 0.0071$) for the aboveground biomass of *M. platyphylla*, and ($0.05 / 8 = 0.00625$) for both species for both soil parameters.

For the computational outputs of the analyses, please refer to Appendix B.

FINDINGS AND DISCUSSION

DRY-WEIGHT ABOVEGROUND BIOMASS

The second *M platyphylla* control group planted in a sandy clay loam soil experienced no difference in aboveground biomass accumulation or observed stress symptoms when compared to the *M. platyphylla* control group planted in soils native to the *H. venusta* site. Since the soil utilized in the study did not appear to benefit or harm individuals of *M. platyphylla*, we concluded the soils used in the rest of the study were acceptable growing medium and removed this second control group from the rest of the analysis.

The 1: 10 CalBan and 1: 10 NC-3000 treatment groups for both surrogate species experienced 100% mortality and were removed from the statistical analysis (Figures 2 and 3). For *E. lanatum*, the 1:100 NC-3000 also experienced 100% mortality. All of the plants in these groups had no aboveground biomass present to measure (Tables 1 and 2) and were obviously different from the control groups. Among the remaining treatment groups for *E. lanatum*, the 1: 100 CalBan treatment group was also different from the control groups (Figure 2). From observations recorded throughout the study, biomass accumulation in the 1: 100 CalBan group was affected by reduced growth as well as reduced survival of the plants with only 2 out of 6 plants surviving by the end of the study. In essence, the 1: 10 and 1: 100 dilutions for both anti-icers head a detrimental impact on the plants with the plants responding to the conditions created by high concentrations with a decrease in growth and survival.

Among the remaining treatment groups for *M. platyphylla*, the 1: 100 NC-3000 treatment group also experienced a reduction in biomass when compared to the control group (Figure 3). From observations recorded during the study, the plants in this treatment group did not experience a dramatic decrease in survival. However, stem necrosis was present throughout the growing period, causing stems to continuously die back before full development, thus causing a decrease in the accumulation of biomass. With this information we concluded 1: 10 dilutions of both anti-icers and the 1: 100 dilution of NC-3000 markedly reduced M. *platyphylla*'s ability to survive and grow.

Given that both species responded somewhat similarly to both anti-icers with negative impacts on biomass accumulation beginning at 1: 100, it is likely that the effects are a function of solute concentrations in general and not specific ionic toxicities. While these results may lead one to conclude that road anti-icers negatively impacting roadside vegetation, one must recollect that these dilution ranges may not be within the normally expected concentration ranges that individuals of *H. venusta* experience within the road right-of-way for Highway 2. The actual concentrations within the road right-of-way remain to be determined, as will be discussed in 'Recommendations.'

Figure 2. Treatment effects of CalBan and NC-3000 on log-transformed aboveground dry-weight biomass of *Eriophyllum lanatum*. Treatment groups marked with '*'are significantly different from the control (P < 0.01). Treatment groups marked with '^' were not included in the statistical analysis due to their lack of variance and obvious differences from the other treatment groups.

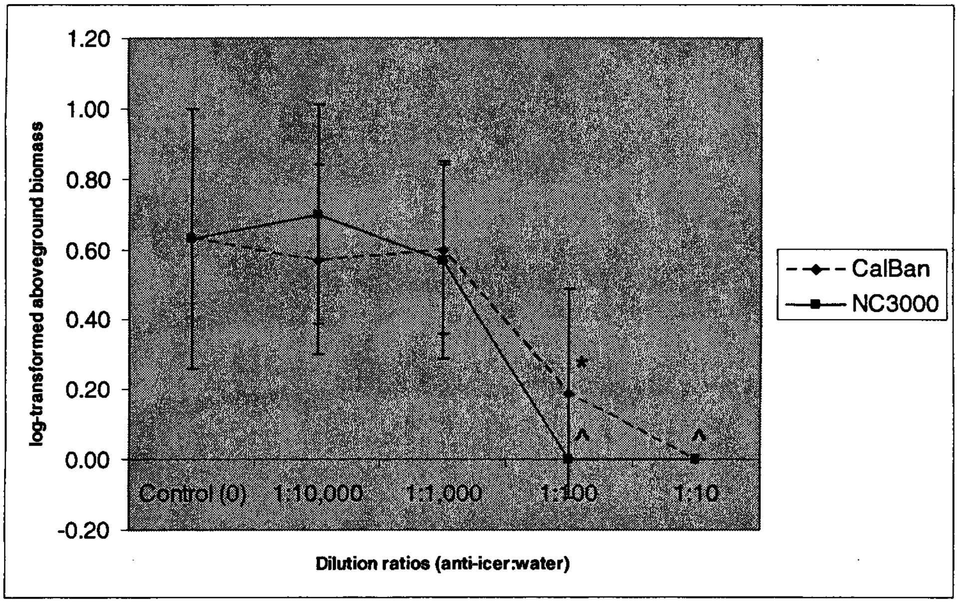


Figure 3. Treatment effects of CalBan and NC-3000 on log-transformed aboveground dry-weight biomass of *Mertensia platyphylla*. Treatment groups marked with '*'are significantly different from the control (P < 0.0071). Treatment groups marked with '^' were not included in the statistical analysis due to their lack of variance and obvious differences from the control.

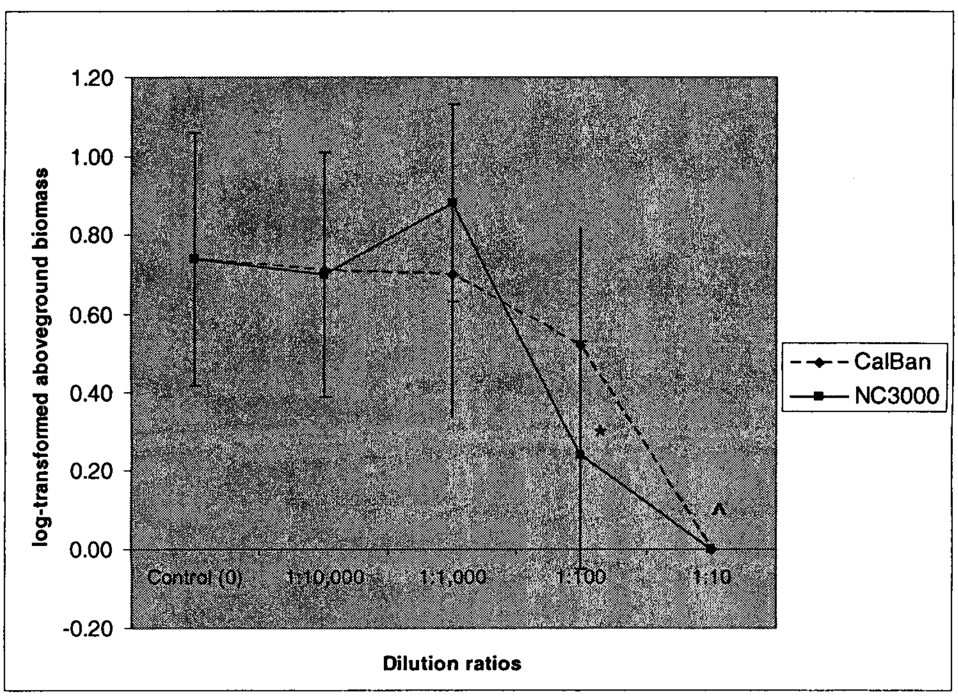


Table 1. Total number of individuals with shoots present for treatment groups of *Eriophyllum lanatum* from April 30th – July 9th, 2002 (n=6 for all treatment groups).

Treatment	4/30	5/14	5/21	5/28	6/4	6/12	6/18	6/25	7/9
Control	6	6	6	6	6	6	6	6	6
1:10,000 CalBan	6	6	6	5	5	5	5	5	5
1:1,000 CalBan	6	6	6	6	6	6	6	6	6
1:100 CalBan	5	5	2	2	2	2	2	2	2
1:10 CalBan	0	0	0	0	0	0	0	0	0
1:10,000 NC3000	5	5	5	5	5	5	5	5	5
1:1,000 NC3000	5	5	5	5	4	4	4	4	4
1:100 NC3000	0	0	0	0	0	0	0	0	0
1:10 NC3000	0	0	0	0	0	0	0	0	0

Table 2. Total number of individuals with shoots present for treatment groups of *Mertensia platyphylla* from April 30th – July 9th, 2002 (n=5 for all treatment groups).

Treatment	4/30	5/14	5/21	5/28	6/4	6/12	6/18	6/25	7/9
Control	5	5	5	5	5	5	5	5	5
Control2(sandy clay loam)	5	5	5	5	5	5	5	5	5
1:10,000 CalBan	5	5	5	5	5	5	5	5	5
1:1,000 CalBan	5	5	5	5	5	5	5	5	5
1:100 CalBan	5	5	5	5	5	5	5	5	5
1:10 CalBan	0	0	0	0	0	0	0	0	0
1:10,000 NC3000	5	5	5	5	5	5	4	4	4
1:1,000 NC3000	5	5	5	5	5	5	5	5	5
1:100 NC3000	5	5	5	5	4	5	4	5	4
1:10 NC3000	0	0	0	0	0	0	0	0	0

SOIL PH

For both surrogate species, the treatment groups 1: 10 NC-3000 and 1: 100 NC-3000 experienced a dramatic increase in the alkalinity of the soils when compared to the control groups (Figures 4 and 5). The soil pH range deemed healthy for plant species varies, depending on the soil habitat to which the species is adapted. Some species prefer more alkaline soils such as plants adapted to calcareous soils and other species prefer more acidic soils such as species adapted to bog ecosystems. For the surrogate species, the 1: 10 and 1: 100 dilution ratios of NC-3000 significantly increased the alkalinity of the potted soils to > pH 8 and >pH 7, respectively, and pH levels did not significantly change over three months. Given the overall health of the plants at pH levels around 5 and 6, one may conclude that the species in question are adapted to slightly acidic soils and the increase in alkalinity in the NC-3000 treatment groups may have been detrimental to the health of the plants. As discussed in 'Background,' a pH change of this magnitude may affect the availability of certain nutrients such as iron, manganese, and zinc (Brady and Weil 1999).

For *M. platyphylla*, the post-hoc test also indicated that the 1: 10 CalBan and 1: 10, 000 NC-3000 treatment groups were different from the control group (Figure 5). However, upon closer examination of these two groups, both groups remained below a pH of seven. When compared to the other treatment groups that experienced optimal plant growth, pH levels from 5.5 to 6.5 do not appear to be biologically detrimental. Therefore, the pH for these two groups was deemed biologically insignificant.

Figure 4. Treatment effects of CalBan and NC-3000 on potting soil pH for *Eriophyllum lanatum*. Treatment groups marked with '*'are significantly different from the control (P < 0.00625).

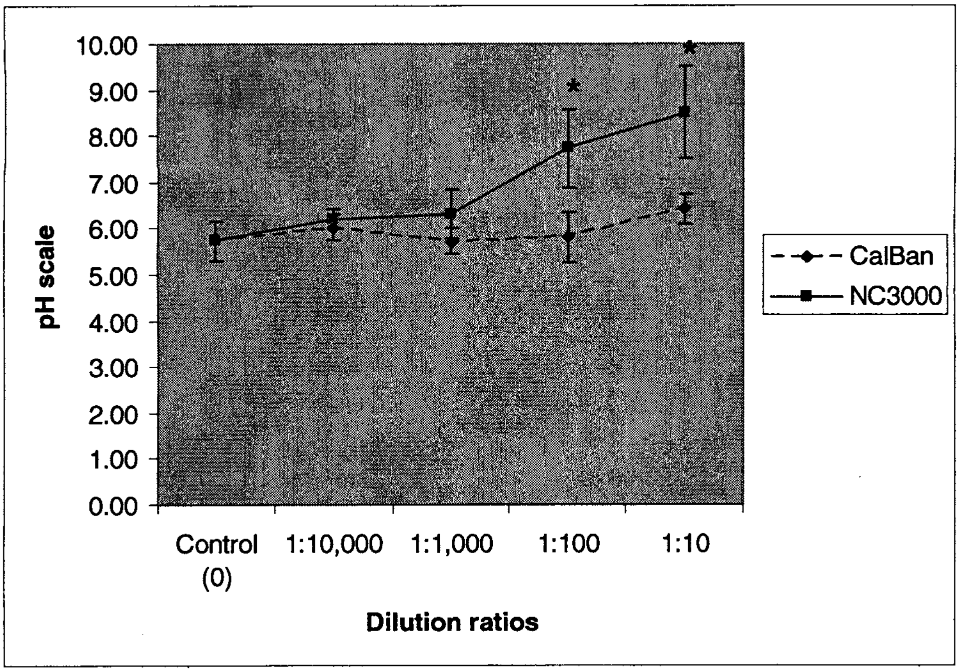
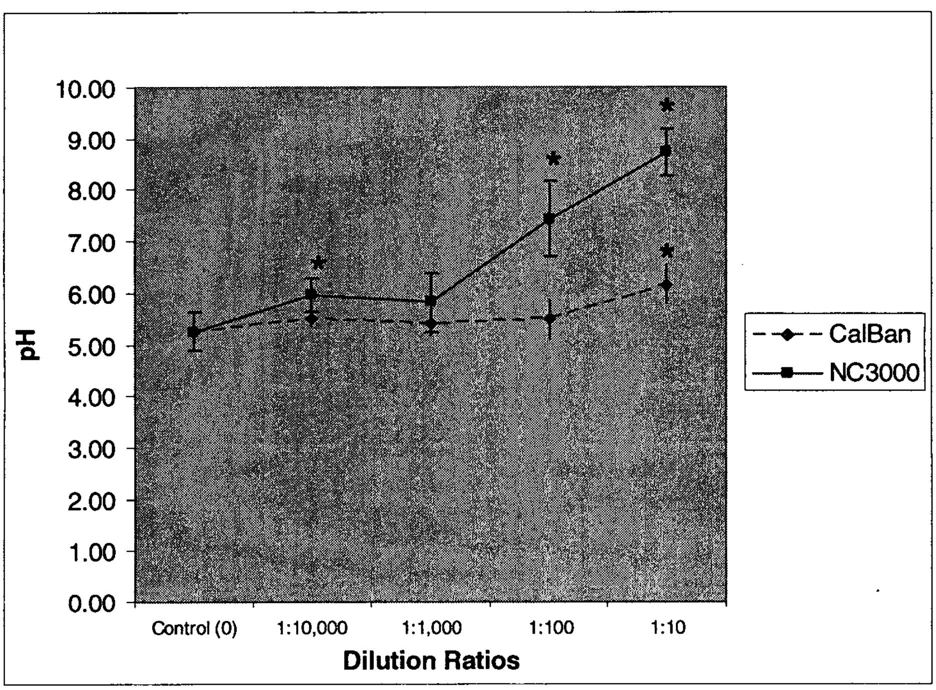


Figure 5. Treatment effects of CalBan and NC-3000 on potting soil pH for *Mertensia platyphylla*. Treatment groups marked with '*'are significantly different from the control (P < 0.00625).



SOIL ELECTRICAL CONDUCTIVITY

For both species, the treatment groups 1: 10 CalBan, 1: 10 NC-3000 and 1: 100 CalBan increased the soil electrical conductivity far above that of the control (Figures 6 and 7). Electrical conductivity is generally measured as the resistance of a solution towards the flow of an electrical current with higher concentrations of solutes within a solution creating greater resistance. Electrical conductivity is typically expressed in deciSiemens/ meter (dS/m) where deciSiemens is the reciprocal of resistivity (ASCE 1990; Harris 1995). For agricultural plants, the general consensus deems the electrical conductivity of a soil to become detrimental to sensitive agricultural plants at levels below 2 deciSiemens/ meter (dS/m) while more tolerant plants remain healthier until a higher soil electrical conductivity is attained (Richards 1954).

For our polyhouse study, the electrical conductivity of the potted soils remained well below 1 dS/m except for the 1: 10 dilutions of both anti-icer formulae. For CalBan, the mean electrical conductivity of the soils before log-transformation was 3.71 dS/m for *E. lanatum* and 3.74 dS/m for *M. platyphylla* while the mean electrical conductivity of the soils for NC-3000 before log-transformation was 1.15 dS/m for *E. lanatum* and 0.95 dS/m for *M. platyphylla*. One may conclude that, since both *E. lanatum* and *M. platyphylla* were detrimentally harmed beginning around the 1: 100 dilutions for both anti-icers, then both of these plants may be highly sensitive to the solute concentrations of the soils. Also, given *H. venusta*'s growth habits, one may conclude that *H. venusta* would also be highly sensitive to the salt contents of the soils.

In addition to differences between the treatment groups, there was a pronounced decrease in the electrical conductivity for both species after cessation of anti-icer exposure (Figure 8). While we were unable to further analyze this decrease statistically, we did notice a trend where the soil electrical conductivity decreased sharply in three months within the treatment groups with highly elevated solute levels, such as both 1: 10 dilutions, while treatment groups with soil electrical conductivity similar to the control did not exhibit a decrease in the same three month time period. In terms of soil recovery, this enforces the idea that well-draining soils will allow excess solutes to leach out of the soil solution. According to Hoffman (1986), sandy loams will require less water to leach slats from the root zone due to low water-holding capacity, leading to a high leaching efficiency. Given that the soils on the *H. venusta* site are a coarse, sandy loam with good drainage, one may conclude that the soils are capable of recovering from an influx of salts if water with low solute contents is present to leach the soils.

Figure 6. Treatment effects of CalBan and NC-3000 on log-transformed potting soil electrical conductivity for *Eriophyllum lanatum.* Treatment groups marked with '*'are significantly different from the control (P < 0.00625).

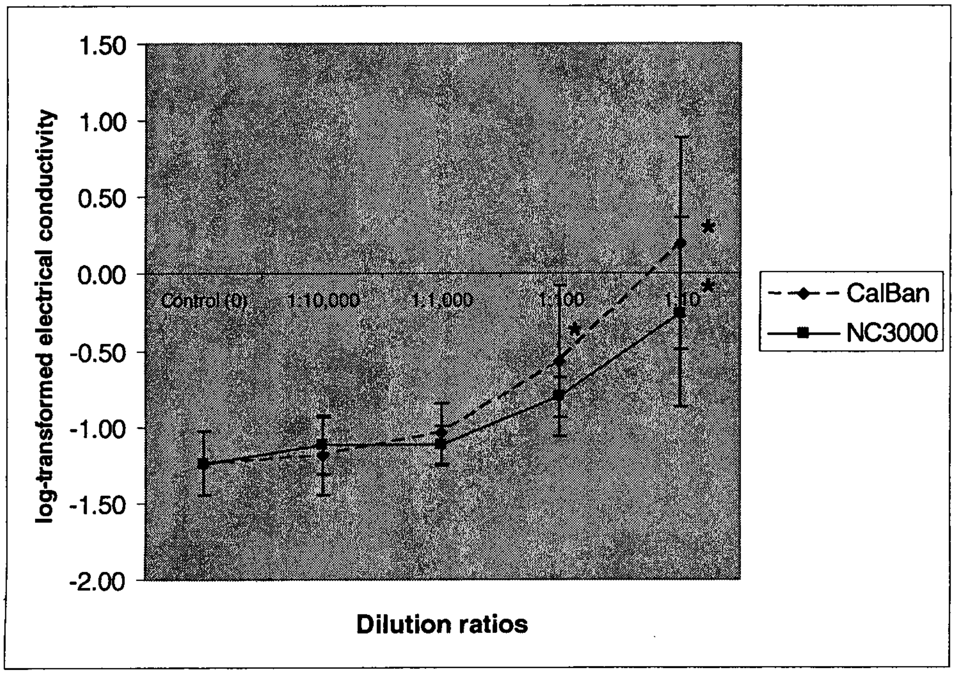


Figure 7. Treatment effects of CalBan and NC-3000 on log-transformed potting soil electrical conductivity for *Mertensia platyphylla.* Treatment groups marked with '*'are significantly different from the control (P < 0.00625).

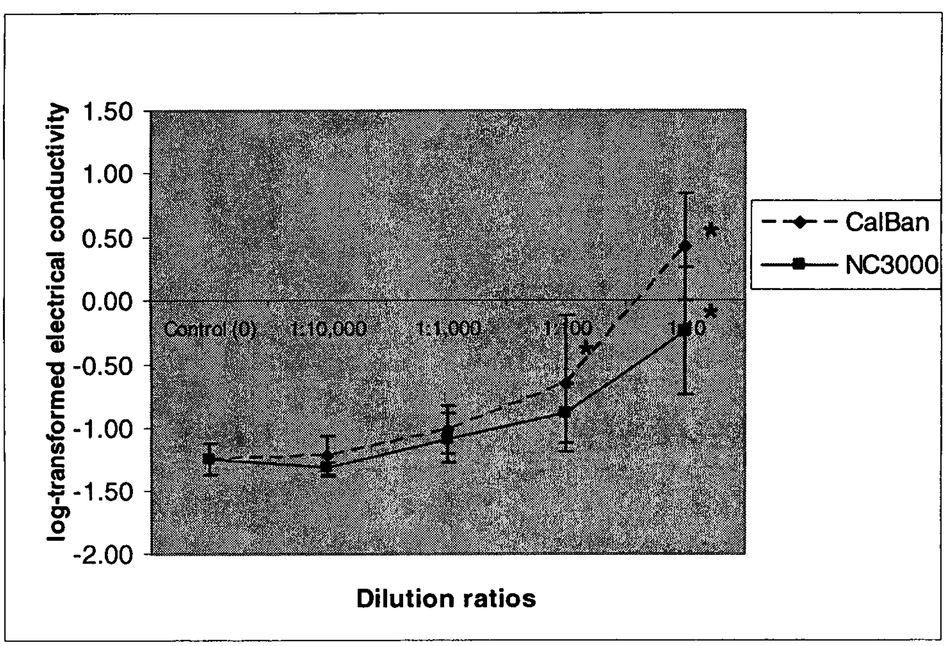
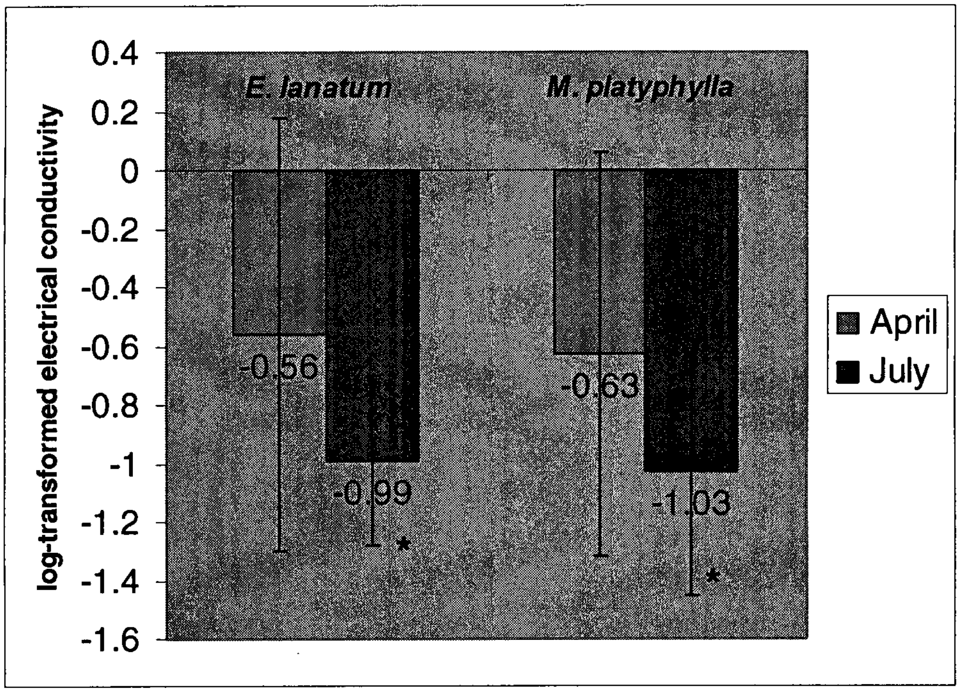


Figure 8. Combined harvest means for log-transformed potting soil electrical conductivity of *Eriophyllum lanatum* and *Mertensia platyphylla*. July harvest periods marked with '*' are significantly different from the April-May harvest periods for that species (P < 0.05).



CONCLUSIONS

Overall, a significant increase in the concentration of road anti-icers caused a decline in the aboveground biomass of both plant species, possibly due to the solute concentrations rather than specific ion toxicities. An increase in the concentration of both anti-icers also increased the solute content of the soil solution, with CalBan having a greater effect than NC-3000. Over time, though, the higher solute concentrations in the soils decreased when treatments ceased and the soils were flushed with tap water but not until after biological damage had occurred. The soil pH was also altered by an increase in the concentration of NC-3000. However, the concentrations at which all of these effects occurred may not be concentrations that occur naturally on the *H. venusta* site. In order to determine this, the conditions on the site need to be established.

One real concern regarding harmful levels of anti-icers entering the soil environment would be if an incident similar to the anti-icer spill near Tumwater Canyon on February 18, 2003, (WSDOT 2003) occurred on the *H. venusta* population site. The responses from the higher concentration groups in this study indicate that a quick and expeditious clean up of the roadway and adjacent snow banks would help minimize harm to *H. venusta* during such an incident.

The frequency of exposure as modeled in the experimental design also may not be wholly realistic. We chose the frequency as described in 'Procedures' to account for cumulative exposure from the release of road anti-icers from the snow banks through snowmelt. However, in research performed by Buttle and Labadia (1999) on snowmelt release of sodium chloride, modeling of snowmelt release needs to closely mimic on-site conditions such as the frequency of snowstorm events when deicers would be applied or temperature fluctuations that would affect freeze-thaw events. A weather station does exist on Tumwater Mountain and past weather data should be available. Unfortunately, we were unable to determine the managing agency of the weather station at the time I needed the information.

In addition to the concerns of how the study relates to the site's real conditions, one will need to keep in mind the relevant level of threat posed to the *H. venusta* population by road anti-icing practices. Road deicers typically do not travel on land further than 10-13 meters from the road (McBean and Al-Nassri 1987; Viskari and Karenlampi 2000), depending on the speed limit of the road (McBean and Al-Nassri 1987), the slope of the adjacent land, and wind direction (Buttle and Labadia 1999). Given the steepness of the slope on which *H. venusta* occurs, salts are unlikely to travel upwards unless carried by aerial spray. Relatively few individuals of the population exist within the 10-13 meter distance and would be directly impacted by the application of road anti-icer formulae. While these few individuals are important to the long-term health and survival of the population, other threats discussed in the proposal for federal listing do exist that directly threaten the entire population (USFWS 2000).

Despite these concerns, road anti-icing practices should continue to be considered a potential threat to individuals within the *H. venusta* population. Given the rapid development and changes within this new trend in road winter maintenance, new road anti-icer formulae should still be tested to determine if they would cause an undesirable impact on *H. venusta*. Some recommendations regarding future studies are discussed in the 'Recommendations' that will help determine the actual impact of anti-icers on *H. venusta*.

RECOMMENDATIONS

The results of this research provide a better understanding of the potential effects road anti-icers may have on *H. venusta*. While the research results indicate that road anti-icers begin to have an effect on the two surrogates in the 1: 100 dilution ratio, several questions are still left unanswered. To make a fully informed decision regarding the potential effects to *H. venusta*, the following tasks are recommended:

1. **Complete the research on the life history and growth requirements of *H. venusta*.**

As discussed in the 'Introduction: Background,' a great deal is still unknown with regards to the ecology and habitat requirements for *H. venusta*. While the experimental design incorporated many educated guesses regarding the plant's habits, a better design could be developed with more concrete information. Also, current conservation efforts for *H. venusta* require solving problems regarding the propagation and establishment of individuals on new sites. More in-depth knowledge of the plant's pollination biology, germination and growth requirements could increase the success of species recovery. For example, I am currently unaware of any soils analyses having been performed on the soils present on the site of the population. It is highly possible an uncommonly high concentration of a metal or nutrient exists on the site or a specific nutrient may be deficient in the soils. Until soil analyses are performed, whether *H. venusta* requires unique growing conditions will remain unknown.

2. **Determine the actual soil and snowmelt conditions on the Highway 2 road right-of-way on or adjacent to the current *H. venusta* population**

While the research project was able to determine roughly the concentrations at which road anti-icers become detrimental to plant health and survival, it is still difficult to apply this knowledge to the *H. venusta* population. One possible way to determine how this research's conclusions apply would be to implement a soils and/or snowmelt-monitoring project near the current *H. venusta* population, perhaps utilizing one of the existing turnoffs to direct attention away from the population. By determining the concentration of anti-icing formulae in the soils and snow banks on or adjacent to the population, one would be able to better interpret our results.

3. **Maintain low concentrations of road anti-icers within the road right-of-way where *H. venusta* occurs.**

As discussed in 'Conclusions,' it is unlikely that the concentrations that began to harm the surrogate plants would occur naturally on the *H. venusta* site. However, the plants in the study are sensitive to increases in solutes in the soil solution and it is highly likely that *H. venusta* is also sensitive. WSDOT should continue its vigilance along the *H. venusta* population and conduct a swift clean-up of the road and the snow along the road right-of-way should any accidents occur in order to prevent an accumulation of anti-icers within the snowbank.

4. **Perform a controlled study with *H. venusta* or *Hackelia diffusa* var. *arida* to determine the effects of road anti-icers on the actual plant of interest**

While one may predict the responses *H. venusta* will have when exposed to road anti-icers in a controlled setting with the use of surrogates, it is still ideal to be able to test the current formulae on the species of interest. However, given the difficulties experienced in the past with propagating and transplanting *H. venusta*, it may not be possible to use it at the time a controlled study is being designed. A better surrogate for such an experiment would be *Hackelia diffusa* var. *arida* (Piper) RL Carr (Boraginaceae), a closely related species of the same genus that also occurs in the same canyon and habitat as *H. venusta*. *Hackelia diffusa* var. *arida* is not currently available from the nursery industry. However, several populations exist within close proximity to the *H. venusta* population to serve as viable seed sources to propagate *H. diffusa* var. *arida* for experimental purposes. Collection of seeds would need to be in the spring, most likely in May, and should be coordinated with the U. S. Forest Service botanist at the Leavenworth Ranger Station. From seed obtained during a personal collection visit to a *H. diffusa* var. *arida* population in 2002, I found that the seed of *H. diffusa* var. *arida* would need a minimum of two months of cold stratification for optimal germination to occur. The plants will then need to develop for at least one growing season before they are ready for a controlled study.

ACKNOWLEDGEMENTS

This project would not have been possible without the help of countless individuals. The authors would like to express their appreciation to Paul Wagner and Bill Null with the Washington State Department of Transportation, Lauri Malmquist with the U.S.D.A. Forest Service, Ted Thomas with the U. S. Fish and Wildlife Service, Dr. Sarah Reichard, Dr. Sally Brown, Rachel Price and Morea Christenson with the University of Washington, as well as the entire faculty, staff and student body of the Center for Urban Horticulture for volunteering assistance, information, and emotional support throughout the duration of this research project.

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APPENDIX A: ACCURATE TESTING LABS, LLC ANTI-ICER ANALYSIS RESULTS

ATL Accurate Testing Labs, LLC

7950 Meadowlark Way Coeur d'Alene, ID 83815 Phone (208) 762 8378 Fax (208) 762 9082 Web site: www.accuratetesting.com E-mail: info@accuratetesting.com

Order No.: 2003050160
Description: Anti-Icer Effects
Date Received: 05/19/2003

Jennifer Brickey
U of W Center for Urban Horticulture
Box 354115
Seattle, WA 98195-4115

Certificate of Analysis

Sample No.: 1
Location: Cal-Ban
Collected By: Jennifer Brickey
D/T Collected: 05/08/2003
Matrix: Liquid
Sample Type: Other

Analyte	Result	Unit	PQL	Method	Analysis Date	Analyst
Calcium	12.9	%	0.06	SM 3120	05/23/2003	WM

Sample No.: 2
Location: NC-3000
Collected By: Jennifer Brickey
D/T Collected: 05/08/2003
Matrix: Other
Sample Type: Liquid

Analyte	Result	Unit	PQL	Method	Analysis Date	Analyst
Potassium	12.6	%	0.01	SM 3120	05/20/2003	WM

Laboratory Supervisor 05/23/2003
Walter Mueller
ND: Not Detected PQL: Practical Quantitation Limit
Page 1 of 1

APPENDIX B: COMPUTATIONAL RESULTS OF DATA ANALYSIS

DRY-WEIGHT ABOVEGROUND BIOMASS

Table 3. Summary statistics for the aboveground dry-weight biomass of *Eriophyllum lanatum*

Treatment Group	Mean of non-transformed data	Standard Deviation	Mean of log-transformed data	Standard Deviation
Control (0)	4.62	3.95	0.63	0.37
1: 10,000 CalBan	3.38	2.28	0.57	0.27
1: 1,000 CalBan	3.42	1.84	0.60	0.24
1: 100 CalBan	1.05	2.14	0.19	0.30
1: 10 CalBan	0.00	0.00	0.00	0.00
1: 10,000 NC-3000	3.18	2.39	0.54	0.29
1: 1,000 NC-3000	3.36	2.16	0.57	0.28
1: 100 NC-3000	0.00	0.00	0.00	0.00
1: 10 NC-3000	0.00	0.00	0.00	0.00

Table 4. Repeated-measures Table for the analysis of the log-transformed aboveground dry-weight biomass of *Eriophyllum lanatum*

Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Model	22	3.31714638	0.15077938	1.79	0.0423
Corrected Total	77	7.96015737			
Treatment	5	1.81042001	0.36208400	4.29	0.0023
Harvest	1	0.15844136	0.15844136	1.88	0.1763
Block (harvest)	11	0.89591653	0.08144696	0.96	0.4885
Treatment*Harvest	5	0.50090586	0.10018117	1.19	0.3276
Error	55	4.64301099	0.08441838		

Figure 9. Residuals vs. fitted values for log-transformed dry-weight biomass of *Eriophyllum lanatum* shoots prior to removal of treatment groups 1:10 CalBan, 1:10 NC-3000, and 1:100 NC-3000.

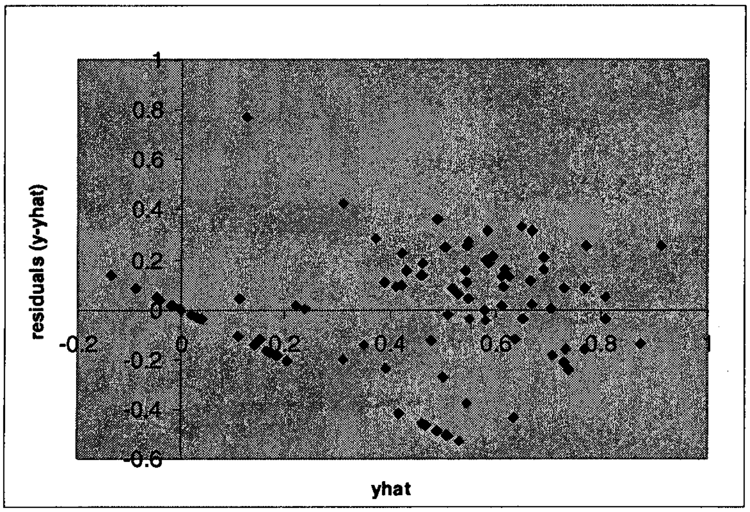


Figure 10. Residuals vs. fitted values for log-transformed dry-weight biomass of *Eriophyllum lanatum* shoots after removal of treatment groups 1:10 CalBan, 1:100 CalBan, and 1:10 NC-3000.

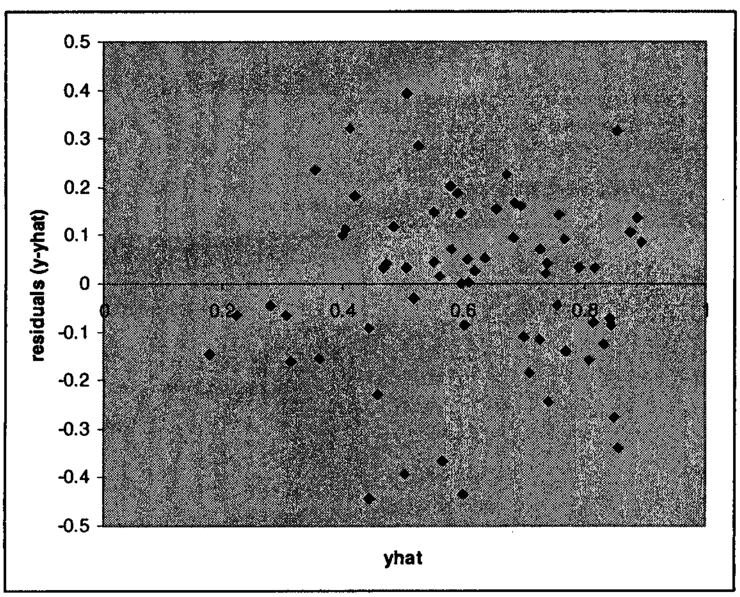


Table 5. Summary statistics of aboveground dry-weight biomass of *Mertensia platyphylla*

Treatment Group	Mean of non-transformed data	Standard Deviation	Mean of log-transformed data	Standard Deviation
Control (0)	5.90	4.90	0.74	0.32
Control (0 with sandy clay loam)	5.88	3.81	0.78	0.23
1: 10,000 CalBan	5.32	4.13	0.71	0.30
1: 1,000 CalBan	5.78	5.50	0.70	0.36
1: 100 CalBan	3.05	2.69	0.52	0.30
1: 10 CalBan	0.00	0.00	0.00	0.00
1: 10,000 NC-3000	5.00	3.07	0.70	0.31
1: 1,000 NC-3000	7.71	4.84	0.88	0.25
1: 100 NC-3000	1.25	2.17	0.24	0.29
1: 10 NC-3000	0.00	0.00	0.00	0.00

Table 6. Repeated-measures Table for the analysis of the log-transformed aboveground dry-weight biomass of *Mertensia platyphylla*

Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Model	22	5.39086768	0.24503944	3.44	0.0001
Corrected Total	76	9.24173052			
Treatment	6	3.01162380	0.50193730	7.04	< 0.0001
Harvest	1	0.30645815	0.30645815	4.30	0.0430
Block (harvest)	9	0.64714755	0.07190528	1.01	0.4450
Treatment*Harvest	6	1.68142662	0.28023777	3.93	0.0025
Error	54	3.85086284	0.07131227		

Figure 11. Residuals vs. fitted values for log-transformed dry-weight biomass of *Mertensia platyphylla* shoots prior to removal of 1:10 CalBan and 1:10 NC-3000.

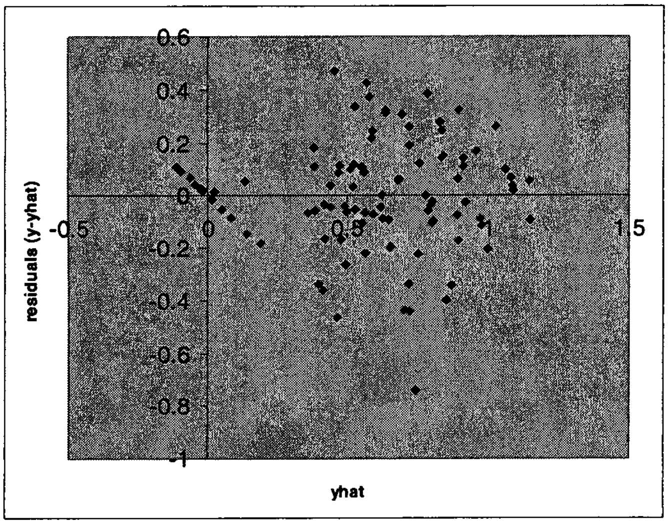
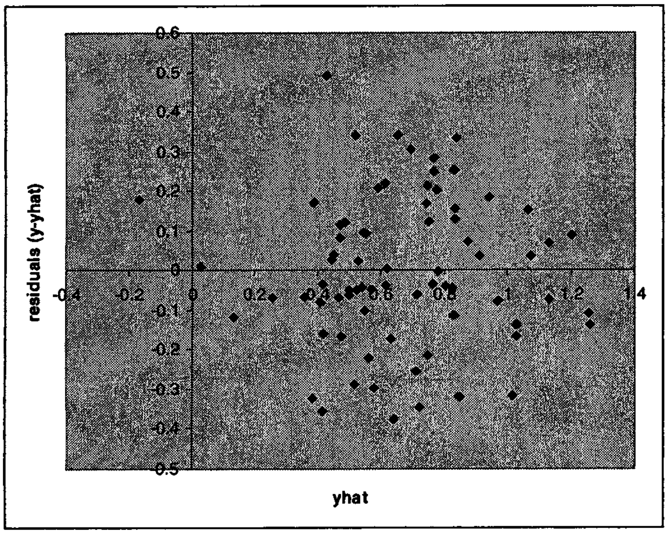


Figure 12. Residuals vs. fitted values for log-transformed dry-weight biomass of *Mertensia platyphylla* shoots after removal of 1:10 CalBan and 1:10 NC-3000.



SOIL PH

Table 7. Summary statistics for the potted soil pH of *Eriophyllum lanatum*

Treatment Group	Mean	Standard Deviation
Control (0)	5.74	0.44
1: 10,000 CalBan	6.02	0.28
1: 1,000 CalBan	5.72	0.28
1: 100 CalBan	5.82	0.55
1: 10 CalBan	6.41	0.32
1: 10,000 NC-3000	6.22	0.22
1: 1,000 NC-3000	6.32	0.52
1: 100 NC-3000	7.73	0.86
1: 10 NC-3000	8.51	1.00

Table 8. General linear model table for the potted soil pH of *Eriophyllum lanatum*

Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Model	67	117.8663806	1.7591997	20.16	< 0.0001
Corrected Total	106	121.2700976			
Treatment	8	90.89191526	11.36148941	130.18	< 0.0001
Block	5	0.64012408	0.12802482	1.47	0.2227
Harvest	1	1.66787483	1.66787483	19.11	< 0.0001
Treatment*Harvest	8	19.05864099	2.38233012	27.30	< 0.0001
Treatment*Block	40	5.38008930	0.13450223	1.54	0.0897
Block*Harvest	5	0.81150074	0.16230015	1.86	0.1239
Error	39	3.4037170	0.0872748		

Figure 13. Residuals vs. fitted values for pH of soils potted with *Eriophyllum lanatum*

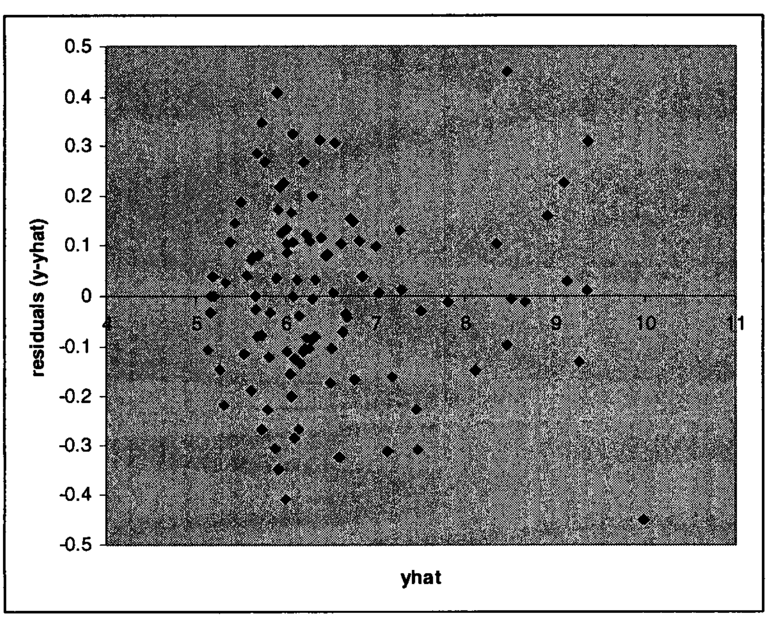


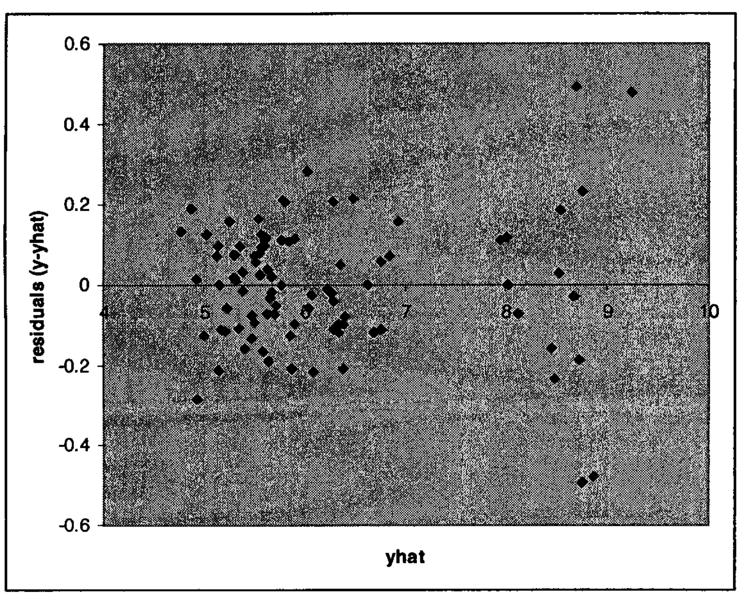
Table 9. Summary statistics for the potted soil pH of *Mertensia platyphylla*

Treatment Group	Mean	Standard Deviation
Control (0)	5.26	0.38
1: 10,000 CalBan	5.51	0.15
1: 1,000 CalBan	5.40	0.22
1: 100 CalBan	5.49	0.38
1: 10 CalBan	6.17	0.37
1: 10,000 NC-3000	5.96	0.33
1: 1,000 NC-3000	5.82	0.56
1: 100 NC-3000	7.44	0.72
1: 10 NC-3000	8.73	0.46

Table 10. General linear model table for the potted soil pH of *Mertensia platyphylla*

Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Model	57	118.2681388	2.0748796	28.03	< 0.0001
Corrected Total	88	120.5627121			
Treatment	8	104.8131108	13.1016388	177.00	< 0.0001
Block	4	0.1237164	0.0309291	0.42	0.7945
Harvest	1	0.0627429	0.0627429	0.85	0.3643
Treatment*Harvest	8	10.6323544	1.3290443	17.96	< 0.0001
Treatment*Block	32	1.2692111	0.0396628	0.54	0.9580
Block*Harvest	4	0.2689139	0.0672285	0.91	0.4713
Error	31	2.2945733	0.0740185		

Figure 14. Residuals vs. fitted values for pH of soils potted with *Mertensia platyphylla*



SOIL ELECTRICAL CONDUCTIVITY

Table 11. Summary statistics for the potted soil electrical conductivity of *Eriophyllum lanatum*

Treatment Group	Mean of non-transformed data	Standard Deviation	Mean of log-transformed data	Standard Deviation
Control (0)	0.07	0.04	-1.24	0.21
1: 10,000 CalBan	0.08	0.07	-1.18	0.26
1: 1,000 CalBan	0.10	0.05	-1.04	0.20
1: 100 CalBan	0.44	0.39	-0.57	0.49
1: 10 CalBan	3.71	3.51	0.20	0.69
1: 10,000 NC-3000	0.08	0.04	-1.12	0.19
1: 1,000 NC-3000	0.08	0.03	-1.12	0.13
1: 100 NC-3000	0.17	0.05	-0.80	0.13
1: 10 NC-3000	1.15	1.03	-0.25	0.62

Table 12. General linear model table for the log-transformed potted soil electrical conductivity of *Eriophyllum lanatum*

Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Model	67	36.42617689	2.87842328	118.35	< 0.0001
Corrected Total	105	37.35041903			
Treatment	8	22.77230602	2.84653825	117.03	< 0.0001
Block	5	0.14592607	0.02918521	1.20	0.3277
Harvest	1	4.11397426	4.11397426	36.24	< 0.0001
Treatment*Harvest	8	7.05174366	0.88146796	36.24	< 0.0001
Treatment*Block	40	1.56067570	0.03901689	1.60	0.0730
Block*Harvest	5	0.08378232	0.01675646	0.69	0.6348
Error	38	0.92424213	0.02432216		

Figure 15. Residuals vs. fitted values for log-transformed electrical conductivity of soils potted with *Eriophyllum lanatum*

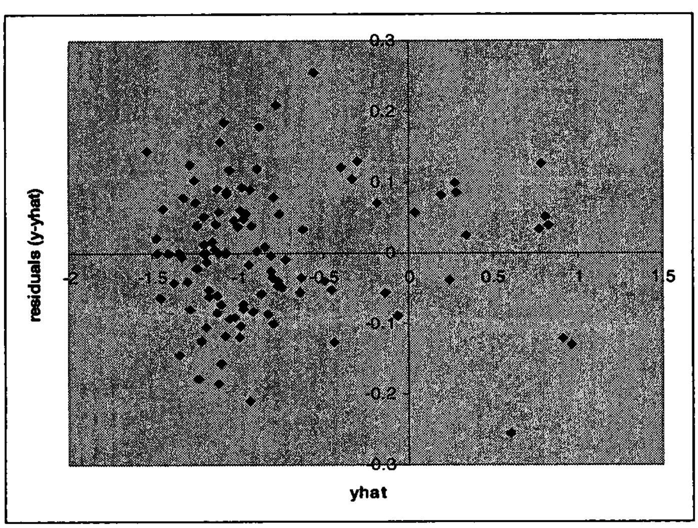


Table 13. Summary statistics for the potted soil electrical conductivity of *Mertensia platyphylla*

Treatment Group	Mean of non-transformed data	Standard Deviation	Mean of log-transformed data	Standard Deviation
Control (0)	0.06	0.02	-1.24	0.13
1: 10,000 CalBan	0.07	0.02	-1.22	0.17
1: 1,000 CalBan	0.10	0.04	-1.01	0.19
1: 100 CalBan	0.37	0.29	-0.65	0.54
1: 10 CalBan	3.74	2.69	0.42	0.42
1: 10,000 NC-3000	0.05	0.01	-1.32	0.05
1: 1,000 NC-3000	0.09	0.05	-1.08	0.20
1: 100 NC-3000	0.15	0.06	-0.88	0.23
1: 10 NC-3000	0.95	0.88	-0.24	0.50

Table 14. General linear model table for the log-transformed potted soil electrical conductivity of *Mertensia platyphylla*

Source	Degrees of Freedom	Type III Sum of Squares	Mean Square	F Value	Pr > F
Model	57	30.86339750	0.54146311	26.81	< 0.0001
Corrected Total	86	31.44914305			
Treatment	8	21.24423579	2.65552947	131.47	< 0.0001
Block	4	0.10169885	0.02542471	1.26	0.3087
Harvest	1	3.29046201	3.29046201	162.91	< 0.0001
Treatment*Harvest	8	2.49970410	0.31246301	15.47	< 0.0001
Treatment*Block	32	0.67210995	0.02100344	1.04	0.4598
Block*Harvest	4	0.14025593	0.03506398	1.74	0.1691
Error	29	0.58574555	0.02019812		

Figure 16. Residuals vs. fitted values for log-transformed electrical conductivity of soils potted with *Mertensia platyphylla*