Review of Effects of NaCl and Other Road Salts on Terrestrial Vegetation in Canada

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1. INTRODUCTION

This report was prepared for the technical review for Environment Canada's evaluation of Road Salt, targeted for environmental assessment in the publication of the Canadian Environmental Protection Act's second Priority Substances List (PS2). The authors of this report participated in the Vegetation Subgroup of the Environmental Resource Group for Road Salt.

An extensive literature review focused on the state of knowledge on effects of NaCl and $CaCl_2$ on terrestrial vegetation and the exposure of plants to road salts in the Canadian environment. The review was based on experimental evaluations and surveys of natural and landscape environments that provided insight into the effects of road salts on vegetation.

An environmental assessment of the effects of road salts on plants was completed following the procedures set out by Environment Canada (1977). A tiered approach to risk characterization has been used that incorporates an exposure and effects characterization, and a Tier I and Tier II quotient-based assessment. The methods used to derive the threshold values have been described in Section 3.4. and the methods used for the Tier I and II assessments have been described in Sections 4.2 and 4.3. A detailed risk characterization was completed, incorporating exposure data, threshold data, reports of reference sites that relate road salt application to plant effects and other relevant data.

1.1 Sources of Information

This review and assessment was developed using information and data from all applicable published articles in scientific journals and serials as well as technical reports dealing with any aspect of road salt impacts and the effects of Na, Cl, NaCl or $CaCl_2$ on plants. Additional references were incorporated as they became available during the preparation of this publication. For this reason, some of the data used for the Risk Characterization was not incorporated in the Tier I and Tier II assessments.

The exposure characterization quantified the levels of Na and Cl that plants are exposed to following known routes of exposure, in growing substrates (soil or water) or following aerial exposure. The exposure characterization required data that reported a Na or Cl concentration in soil or plant tissue at a recorded distance from a highway or road. All suitable references were used to develop the environmental effects value (EEV) for the Tier 1 assessment, while only references that reported levels in the Canadian environment were used for the Tier II assessment.

The development of threshold or critical toxicity values required studies that reported a series of environmental concentrations, plant tissues levels, or a series of treatments levels of road salt, Na, Cl, NaCl or $CaCl_2$, with a corresponding response evaluation. All suitable references available at the time were used for estimation of the threshold values. A summary of references that were unsuitable for estimation of thresholds has been included in Section 3.5.

2. EXPOSURE CHARACTERIZATION

2.1 Routes of Plant Exposure to NaCl and Road salts

De-icing salt impacts negatively on plants growing adjacent to road rights-of-way or other surfaces that are de-iced and areas used for storage and loading of de-icing chemicals. De-icing salt is applied directly to road surfaces as a crystal or solution. The salt remains on the pavement as a crystal, is crushed into finer particles by vehicular traffic or is dissolved into solution on the pavement. Melting ice or snow can also contain salt. The resulting salt solution may dry, leaving a salt precipitate on the road surface. Therefore de-icing salt can be present as a crystal, powder or liquid residue on the road; or in the snow and ice solution present on the road.

2.1.1 Substrate Exposure

Elevated levels of de-icing salts in roadside plant growing substrate (soil, soil water and runoff) occur due to movement of the crystals, powder or liquid residue off the road. This occurs due to direct splash of salty water, snow or slush by moving vehicles; clearing of snow and slush onto roadsides and medians by snow plows; run-off of salty water; and melting of snow banks. As well, salt spray, salt crystals and powder residues are deposited on roadside soils after being stirred up by moving vehicles and carried off the pavement in the wind. Elevated levels of de-icing salt in the soil generally occur within the first 20 m or less from the travelled portion of a four lane highway (Hofstra and Smith, 1984; Hutchinson and Olson 1967) or along drainage ditches where highway run-off and snow melt collects.

2.1.2 Aerial Exposure

Aerial movement of de-icing salt occurs when passing vehicles stir up salty water into a spray and stir up salt crystals or dried salt residues that are present on the pavement. The spray, crystals or powder is then blown off the road by vehicle turbulence or winds, and can be carried further by winds blowing across the highway. Injury extends much further in the windward direction from the road, for example. Visual plant injury due to salt spray or elevated de-icing salt levels in woody plant tissues fall off to background levels at from 40 m to 100 m from edge of pavement. The degree of injury or distance of effect depends on the sensitivity of the species, the topography of the site and the predominant wind direction at the site (Backman and Folkeson 1995, Hall *et al.*1972, Hofstra and Hall 1971, Northover 1987, Sucoff 1975).

2.1.3 Temporal Effects On Plants

Herbaceous plants and annual seeded crop plants are not normally exposed directly to salt spray or dust from de-icing operations. Most annual seeded crops in Canada are frost sensitive and complete their life cycle before winter. During the winter, the above ground growth from the previous growing season of over-wintering plants (winter annuals, biennials and perennials) dies down and the over-wintering parts of the plants, the roots and underground stems, are protected by the soil and any snow cover. The main exposure of herbaceous plants is uptake of salt via the soil once growth of over-wintering plants resumes in the spring or once seeds germinate. This generally occurs within the first 10 m from the edge of pavement, or where soil salt levels are elevated due to run-off, drainage patterns or soil water movement.

Perennial woody shrubs, vines and trees are exposed to salt via root uptake, in the same manner as herbaceous plants once growth resumes in the spring. The above ground plant parts are also exposed to aerial salt deposition whenever de-icing salts are applied to roads, throughout the late fall, winter and early spring.

Elevated soil levels of Na and Cl generally decrease over the growing season due to leaching of the ions by rainfall and run-off. Soil measurements in summer or fall indicate a decrease to background soil levels following elevated spring levels (Hutchinson and Olson 1967, Hofstra and Smith 1984).

2.1.4 Exposure Following Use of Dust Suppressants

Plants can be exposed to elevated soil levels of Ca and Cl from run-off or gravel throw following use of $CaCl_2$ as a dust suppressant for gravel roads (Emerson, personal communication; Strong 1944). Experimental evaluations indicated that leaf scorch and needle burn following use of dust suppressants was due to soil uptake of the salts, rather than foliar deposition in dust.

2.2 Exposure Values in Canadian Environment

2.2.1 Soil Concentrations and Gradients Found in the Canadian Environment

The following reports and accompanying figures provide site-specific records of soil concentration gradients of road salts measured as Cl or Na, sampled along various classes of highways in different parts of the country.

Loon Lake Road, Two-lane Highway, BC
Soil concentrations of Na and Cl were determined at various locations along a 2 km stretch of two-lane highway north of Cache Creek, BC. December soil concentrations of Cl were as high as 50.6 ppm at the 0-10 cm depth, 7 m from the highway, falling to 2.7 ppm at 10 m from the highway (Soilcon Laboratories Ltd. 1995). At the 40-50 cm depth, December soil concentrations of Cl were as high as 61.9 ppm, 6.5 m from the highway, falling to 3.5 ppm at 8.4 m from the highway.

By May, soil concentrations of Cl fell to 7.8 ppm at the 0-10 cm depth 6.5 m from the highway, reaching to a background level of 0.9 ppm at 11.3 m from the highway. At the 40-50 cm depth, May soil concentrations of Cl were as high as 30.3 ppm, 4.5 m from the highway, falling to 1.1 ppm at 10 m from the highway.

December soil concentrations of Na reached 24.5 ppm at the 0-10 cm depth 7 m from the highway, but fell to 4.1 ppm at 20 m from the highway. December soil concentrations of Na were as high as 21.5 ppm at the 40-50 cm depth, 4.5 m from the highway, falling to 4.1 ppm at 10 m from the highway.

By May, soil concentrations of Na fell to 13.6 ppm at the 0-10 cm depth 4.5 m from the highway falling to a background level of 0.3 ppm 10 m from the highway. May soil concentrations of Na were as high as 14.6 ppm at the 40-50 cm depth 4.5 m from the highway falling to 0.5 ppm 10 m from the highway.

The highest soil concentration of Cl was 61.9 ppm at the 40-50 cm depth, 6.5 m from the highway. The highest soil concentration of Na was 24.5 ppm at the 0-10 cm depth, 7 m from the highway.

London, ON, Two-lane Highway
The concentrations of Cl and Na were sampled in soil adjacent to the highway at six locations on Highways 2 and 22, both two lane highways near London, ON in 1975 (Foster and Maun 1978). Soil samples were taken at the 8 cm depth, at different sampling times from March until June, at 2 m intervals from 0 to 8 m from the edge of pavement.

The Na concentration in the soil was highest closer to the pavement and decreased with increasing distance from the road (Figure 2.1). The highest concentrations were found at the March and April sampling times, from 350 to 430 ppm, at 0 and 2 m from the edge of pavement. The concentration of Na fell to below 200 ppm at 4 and 8 m from the edge of pavement. By May and June, the concentration of Na ranged from 50 to 130 ppm within 4 m of the edge of pavement, and fell to 30 ppm at 8 m.

The Cl levels in the same zone, during the same sampling period had a less consistent pattern. At the March sampling, the highest levels of Cl, 380 and 410 ppm, occurred at 0 and 2 m respectively from the edge of pavement, falling off to 170 and 110 ppm at 4 and 8 m (Figure 2.2). With the April sampling period, Cl levels were highest at 0 and 8 m from the edge of pavement, 380 and 310 ppm respectively, falling to 210 and 170 ppm at 2 and 4 m.

At the later sampling periods, the lowest concentrations were present closest to the road, with the highest levels occurring at 2 m from the road in May, 340 ppm, and at 4 m from the road in June, 240 ppm. The increase in soil Cl levels, later in the season, was likely due to leaching of salt from below the paved road surfaces.

The highest soil concentration of Cl was 410 ppm and Na was 430 ppm, within 2 m of a two-lane highway.

Various Locations, BC, Two, Three and Four-lane Highways

Soil concentrations of Na and Cl were determined as part of a study of 17 roadside sites where forest tree decline had been observed in British Columbia (Davis *et al.* 1992). The soil samples were taken within 15 m of the highway on sites where tree injury was observed and compared to nearby control sites where the trees were healthy. Soil concentrations of Cl ranged from 0.6 to 12 ppm on control plots, compared to 0.9 to 230 ppm Cl on the plots with plant injury. On four of these plots, soil Cl exceeded 25 ppm.

Two of the sites that were adjacent to a 4-lane highway had soil Cl levels ranging from 3.0 to 198 ppm.

Soil concentrations of Na ranged from 0 to 10 ppm on control plots, compared to 0.02 to 50.2 ppm Na on the plots with plant injury. On four of these plots, soil Na exceeded 25 ppm. Two of the sites that were adjacent to a 4-lane highway had soil Na levels as high as 43 ppm.

The highest soil concentration of Cl was 230 ppm within 15 m of a two-lane highway and 198 ppm within 15 m of a four-lane highway. The highest soil concentration of Na was 50.2 ppm within 15 m of a two-lane highway and 43 ppm within 15 m of a four-lane highway.

Guelph, ON, Four-lane Highway

The concentrations of Cl and Na were sampled for 30 m on the north and south side and within the median of a four-lane highway near Guelph ON (Hofstra and Smith 1984). An additional transect was taken up to 200 m on the south side (leeward side) of the highway.

The concentrations of Cl and Na found in the 0-5 cm depth of soil are plotted in Figures 2.3 and 2.4. The highest concentrations, 720 ppm Na and 640 ppm Cl, were found in April, 10 m from the edge of pavement on the south side of the highway. The concentrations of Na and Cl fell with increasing distance from the pavement to a background levels of 250 ppm Cl and 15 ppm Na, 30 m from the edge of pavement on the south side. Soil concentrations of Cl and Na generally fell progressively by the August and November sampling periods. At the August sampling, the soil Cl concentration at 200 m was 110 ppm. However, the soil concentrations of Cl in the median remained above 300 ppm Cl and 270 ppm Na.

Soil samples were taken at different depths as part of this study. The concentrations found at the 6-10 cm soil depth are presented in Figures 2.5 and 2.6. The concentration gradients were similar to those found in the 0-10 cm soil layer. The highest soil concentrations were found in April within the median and 10 m from the edge of pavement on the south side of the highway, 570 ppm Cl and 890 ppm Na respectively.

Soil concentrations of both Cl and Na remained elevated within the median throughout the season. The soil concentrations in the median were 320 ppm Cl and 530 ppm Na in November. Background levels in August or November were less than 200 ppm Cl and 30 ppm Na at 30 m from the edge of pavement.

The highest soil concentration of Cl was 640 ppm and Na was 890 ppm, within 10 m of a four-lane highway.

Down Slope from a Four-lane Highway, BC

Soil concentrations of Na and Cl were evaluated in 1989 in Boitanio Park, located in Williams Lake, British Columbia (Van Barneveld and Louie 1990). The park was located west of a four-lane section of Highway 97 and the area of concern sloped toward the southwest with a grade of 5 to 15%. Two culverts were located along the highway above the park.

The highest soil concentration of Cl was 291 ppm, average of the 0-150 cm depth, 50 m from the highway. The highest soil concentration of Na was 151 ppm average of the 0-150 cm depth, about 75 m from the highway.

West of Kenora, ON, Patrol Yard Run-off
Surface soil concentrations of Na and Cl were determined in 1998, in an area behind a Highway patrol yard sand dome and salt storage sheds (Racette and Griffin 1989). Additional soil samples were taken along a drainage channel, across the highway from the patrol yard, that drains from the highway and the patrol yard.

The soil concentration of Na behind the sand dome and salt storage sheds sampled at the 0-5 cm depth, was 660 ppm and Cl concentration was 1200 ppm. Soil concentrations along a drainage channel that received drainage from the highway and patrol yard area had soil concentrations of Na ranging from 370 to 680 ppm and Cl concentrations from 780 to 1100 ppm. Samples taken from a control site, remote from the area, indicated that soil background levels were 91 ppm Na and 15 ppm Cl.

The highest soil concentration of Cl was 1200 ppm at the 0-5 cm depth, found behind a sand dome and salt storage buildings. The highest soil concentration of Na was 680 ppm at the 0-5 cm depth, along a drainage channel leading from the patrol yard and the highway.

2.2.2 Tissue concentrations found in the Canadian environment

Many studies have correlated elevated tissue levels of Na and Cl adjacent to highways as well as gradients of tissue levels with respect to the location of the highway and local weather conditions.

Guelph, ON, Four-lane Highway
Hofstra and Smith (1984) studied the levels of Cl and Na in unspecified vegetation adjacent to a four-lane controlled access highway south of Guelph, Ontario. The tissue concentrations of Cl and Na were sampled for 30 m on the north and south side and within the median of a four-lane highway near Guelph ON. An additional transect was taken up to 200 m on the south side (leeward side) of the highway.

Cl concentrations in the tissue of roadside and pasture vegetation sampled in August, were elevated within the median and 10 m from the roadside on the south side to just under 10,000 ppm, reflecting the peak observed in soil concentrations (Figure 2.7). Plant tissue levels were also elevated up to 80 m from the roadside on the south side to concentrations greater than 7,500 ppm. Plant tissue levels of Na were mainly elevated within the median to just under 2,000 ppm, roughly 10 times the background level found in the roadside sites (Figure 2.8). The vegetation levels reflected the soil levels of Na and Cl found on the site.

St. Catharines, ON, Four-lane Highway
Concentrations of Na and Cl were recorded in a peach orchard along the QEW, a busy, four-lane, controlled access highway near St. Catharines, Ontario (Northover 1987). This study is described in depth in Section 4.4. The Cl content of the peach twig tissue, from trees located 20 m from the highway, was greater than four times the levels found in trees 120 m from the highway; 9,000 ppm Cl at 20 m compared to 1,900 ppm Cl at 120 m (Figure 2.9). The Na content was elevated more than 7 times the levels detected 120 m from the highway, 6,900 ppm Na at 20 m compared to 900 ppm Na at 120 m (Figure 2.10). Na and Cl tissue content of shoot tissue decreased with increasing distance from the highway.

Grimsby, ON, Four-lane Highway
In a separate study, on a stretch of the same highway near Grimsby and Beamsville, ON, the Na and Cl concentration of twigs from peach and plum trees was sampled in May 1980 (McLaughlin and Pearson 1981). The Cl and Na content of the twigs was highest closest to the highway and generally decreased with increasing distance from the highway (Figures 2.11 and 2.12). Twig tissue Na concentration was 2,030 ppm at 45 m from the highway, compared to 1,100 ppm at 92 m from the highway. Cl Content was 2,300 ppm at 40 m from the highway compared to 1300 ppm at 82 m from the highway.

Loon Lake Road, Two-lane Highway, BC
A study of ponderosa pine and Douglas-fir foliar concentrations, found mean tissue levels of about 100 to 200 ppm Na and 1100 to 1300 ppm Cl on sites within 8.4 m of a two-lane highway north of Cache Creek, BC (Soilcon Laboratories Ltd. 1995) This compared to a mean of about 150 ppm Na and 110 ppm Cl found in trees located 10 to 20 from the highway.

Grimsby, ON, Four-lane Highway
A study along the QEW, a 4-lane controlled access highway in southern Ontario, using moss samplers, recorded the gradient of concentrations of Na and Cl with respect to the highway. The samplers were placed from 38 to 410 m from the highway near Grimsby and Beamsville, ON, during the winter of 1979 (McLaughlin and Pearson 1981). Sampler concentrations of Na and Cl were highest adjacent to the highway and fell with increasing distance from the highway. Cl concentrations collected on the south side of the highway between January 23 and February 21 were 31,000 ppm 38 m from the highway, falling to 1,000 ppm at 64 m from the highway. Na concentrations for the same period were 22,400 ppm 38 m from the highway, falling to 14000 ppm at 64 m from the highway. Although these values cannot be directly related to tissue concentrations, they demonstrate the pattern of aerial dispersal of Na and Cl from a highway source.

The vertical pattern of Na and Cl concentrations, from 1 to 9 m above the ground was evaluated using samplers placed on poles located 38 m from the highway. The range of concentrations collected for the period of January 23 to February 21 was 9,200 to 22,400 ppm Na and 10,500 to 31,000 ppm Cl on the south side of the highway. The highest concentration was at 2 m above the ground, falling with increasing height.

2.3 Estimated Exposure Values

Estimated exposure values for the toxicity assessments were calculated from reported levels of Na and Cl in the growing substrate and in plant tissue, following *in situ* exposure to de-icing salts. For the Tier I Assessment, the maximum levels reported along roadsides in American or Canadian environments were used. For the Tier II Assessment, the maximum levels reported along roadsides in the Canadian environment were used.

2.3.1 Substrate (Soil) Exposure Values

For estimation of substrate (soil) exposure values for the Tier I evaluation, data was reviewed from any references that provided measurements of substrate (soil, soil water or solutions) concentrations of Cl, Na or NaCl following road salting at specific distances from the road or highway. This data included samples taken at various soil depths, from the surface to 165 cm, and samples taken up to 200 m from the road or highway.

Ten references reporting studies done in Ontario, Maine, Vermont, New Mexico, England and Sweden were reviewed for soil concentrations of Cl (586 data points plotted in Figure 2.13). Twelve references reporting studies done in Ontario, Maine, Vermont, Michigan, Minnesota, England and Sweden were reviewed for soil concentrations of Na (984 data points plotted in Figure 2.14). One reference reported soil concentrations of NaCl in Connecticut (4 data points plotted in Figure 2.15).

The highest soil Cl concentration was 1564 ppm, reported directly adjacent to an interstate highway in Maine (Hutchinson 1968). The highest soil Na concentration was 8360 ppm, reported at 1 m from pavement edge, at the intersection of two interstate highways in Minnesota (Biesboer and Jacobson 1994). The highest soil NaCl concentration was 475 ppm, reported 1.5 m from a Connecticut highway (Prior 1968).

For a more precise estimation of Canadian environmental concentrations for the Tier II evaluation, data from the same group of references was restricted to Canadian sites. Three Ontario studies were reviewed for soil concentrations of Cl (99 data points plotted in Figure 2.16) and Na (99 data points plotted in Figure 2.17).

The highest soil Cl concentration was 1200 ppm in a sample taken behind a patrol yard along a highway in northwest Ontario (Racette and Griffin 1989). The highest soil Na concentration was 890 ppm in a sample taken 10 m from the highway, in a study along a four-lane highway in Ontario (Hofstra and Smith 1984).

Since the Canadian references did not report soil concentrations of NaCl, a value was estimated based on the highest concentration of Cl found in the soil behind a patrol yard along a highway, 1200 ppm, multiplied by a factor of 1.6485, resulting in 1978 ppm NaCl. A second value was estimated based on the highest concentration of Na found in the soil 10 m from the highway, 890 ppm, multiplied by a factor of 2.542, resulting in 2262 ppm NaCl. The average of these two values, 2120 ppm, was used in the Tier II assessment.

2.3.2 Plant Tissue Exposure Values

To estimate the aerial exposure of plants to NaCl, all references were reviewed that reported concentrations of Cl or Na in plant tissues at given distances from the road or highway. These values provided a method to directly link environmental aerial concentrations with plant effects.

Eight references reporting studies done in Ontario, Maine, Connecticut, Michigan, Illinois, California, Nevada and Sweden were reviewed for tissue concentrations of Cl (166 data points plotted in Figure 2.18) and 11 for Na (310 data points plotted in Figure 2.19). Data included samples from plants located up to1,018 m from the road or highway; the plant genera represented were *Pinus, Picea, Tsuga, Acer, Prunus* and unspecified vegetation, sampled for twig, needle or leaf tissue. The highest tissue Cl concentration was 14,000 ppm reported in *Acer saccharum*, sugar maple, growing 2.9 m from a Connecticut highway (Button and Peaslee 1966). The highest tissue Na concentration was 6900 ppm reported in peach, (*Prunus persica*) growing 20 m from a four-lane highway in southern Ontario (Northover 1987).

For a more precise estimation of Canadian environmental concentrations for the Tier II evaluation, data from the same group of references was limited to studies on Canadian sites. Three references with 65 data points were reviewed for tissue concentrations of Cl (plotted in Figure 2.20) and Na (plotted in Figure 2.21). These references reported studies from Ontario on *Prunus* and unspecified vegetation.

The highest tissue Cl concentration was 11,000 ppm, reported in unspecified vegetation growing 60 m from a four-lane highway in Ontario (Hofstra and Smith 1984). A second reference reported 9,000 ppm in peach growing 20 m from a four-lane highway in southern Ontario (Northover 1987). The highest tissue Na concentration was 6,900 ppm, reported in peach growing 20 m from a four-lane highway in southern Ontario (Northover 1987).

3. EFFECTS CHARACTERIZATION OF ROAD SALTS ON PLANTS

3.1 Canadian vegetation communities exposed to road salts

De-icing salt affects predominantly roadside woody species, including forest species, landscape species, fruit and nursery crop species and naturally occurring woody tree, shrub and vine species. Herbaceous plant injury is generally confined to landscape species and naturally occurring plants growing directly on roadsides rights-of-ways within the first 10 to 30 m from the edge-of-pavement.

For the purpose of this review, the literature on road salt effects on vegetation was evaluated according to the following categories:

Herbaceous species
Wetland species
Woody species
- Deciduous species
- Fruit crop species
- Coniferous species

3.1.1 Herbaceous Communities

Many types of natural, herbaceous communities are traversed by roads, across the country. These include understory plants in woody communities; old field vegetation communities on uncropped cleared land and disturbed sites; and native grasslands and prairie communities. These herbaceous communities include perennial, biennial and annual species that are both native and naturally occurring. Representative plant groups include broad-leaved plants, sedges, grasses, rushes, ferns, mosses, liverworts and lichens.

Roads impact many woody and herbaceous species growing in wetlands such as marshes, swamps, bogs, fens, lakes and rivers. Wetland plants include woody trees, shrubs and vine species; and herbaceous broad-leaved plants, sedges, grasses, rushes, ferns, mosses, liverworts, lichens and aquatic species.

3.1.2 Herbaceous Crops

Canadian crops represent grass species such as winter annual or annual grain crops, and perennial sod production and landscape turf. Other herbaceous crops include annual and biennial field and vegetable crops, vegetable and perennial fruit crops. Herbaceous crops usually are not exposed to salt spray since the above ground parts are dead during the winter and since elevated salt levels in soil are generally limited to the first 10 to 30 m from pavement, which is often within the road right-of-way. Re-growth of herbaceous perennials in the spring is from underground roots or stems, which are not exposed to aerial spray during the winter.

3.1.3 Woody Communities

Many of the areas of Canada that are predominantly forested are traversed by roads. Figures 3.1 to 3.3 shows the location of roads in relation to forested areas. Certain areas in the Maritimes, central to southern Ontario and Quebec, and central British Columbia have densely forested areas and are traversed by extensive road networks. Canadian forests have been classified into 8 forest regions across the country (Rowe 1972, Anonymous 1992), which are listed below with the principal tree species:

Boreal (predominantly forest)	*Abies balsamea* (balsam fir) *Betula papyrifera* (white birch) *Picea mariana* (black spruce) *Pinus banksiana* (jack pine) *Populus tremuloides* (trembling aspen) *Picea glauca* (white spruce)

Boreal (forest and barren)	*Larix laricina* (tamarack) *Picea glauca* (white spruce) *Picea mariana* (black spruce)
Boreal (forest and grass)	*Populus tremuloides* (trembling aspen) *Salix* sp. (willow)
Subapline	*Abies lasiocarpa* (alpine fir) *Pinus contorta* (lodgepole pine) *Picea engelmannii* (engelmann spruce)
Montane	*Pseudotsuga menziesii* (Douglas-fir) *Pinus contorta* (lodgepole pine) *Pinus ponderosa* (ponderosa pine) *Populus tremuloides* (trembling aspen)
Coast	*Picea sitchensis* (sitka spruce) *Pseudotsuga menziesii* (douglas-fir) *Thuja plicata* (western red cedar) *Tsuga heterophylla* (western hemlock)
Columbia	*Pseudotsuga menziesii* (Douglas-fir) *Thuja plicata* (western red cedar) *Tsuga heterophylla* (western hemlock)
Deciduous	*Acer* sp. (maple) *Carya* sp. (hickory) *Fagus* sp. (beech) *Juglans nigra* (black walnut) *Quercus* sp. (oak)
Great Lakes-St. Lawrence	*Acer* sp. (maple) *Betula alleghaniensis* (yellow birch) *Pinus resinosa* (red pine) *Pinus strobus* (eastern white pine) *Quercus* sp. (oak) *Tsuga canadensis* (eastern hemlock)
Acadian	*Picea rubens* (red spruce) *Abies balsamea* (balsam fir) *Acer* sp. (maple) *Betula alleghaniensis* (yellow birch)

Numerous other woody tree, shrub and vine species occur within these forest regions and in non-forest communities such as hedgerows, windbreaks, and parks.

3.1.4 Woody Landscape and Crop Plants

There are hundreds of woody tree, shrub and vine species grown in commercial nurseries and in landscape plantings along roads and city streets. Appendix Table 4 provides a list of a selected species in eastern Canada. This listing also provides a sample of commercial nursery species.

Other woody crops grown in Canada include:

Tree and vine fruit crops: nectarines, peaches, sweet and sour cherries, apples, apricots, pears, plums, grapes

Small fruit crops: raspberries, blueberries and cranberries

Christmas trees: white spruce, Colorado blue spruce, Scots pine, white pine, Douglas-fir, Fraser fir, balsam fir, grand fir, noble fir, concolor fir

Maple syrup: sugar maple, black maple

Nut orchards: Carpathian (English) walnuts, Chinese sweet chestnuts, hazelnuts (filberts), heartnuts (Japanese walnuts)

3.2 Toxicity of NaCl and other road salts

3.2.1 Plant Requirements

Chlorine is a micronutrient, required in small amounts for plant growth. An adequate plant tissue concentration is around 100 ppm. Calcium is a macronutrient, required in larger concentrations for plant growth; adequate plant tissue concentration is 5,000 ppm. While, sodium is not an essential element, it is commonly found in plants. It may improve the quality of certain vegetable crops.

Low amounts of these elements have a positive effect on plant growth, but when they are present in excessive amounts in soil or in plant tissues, they may be toxic.

3.2.2 Mechanisms of Road Salt Injury

Elevated levels of Na and/or Cl, in the substrate or soil and in tissues, have the following negative impacts on plants:

1) inhibition of water and nutrient absorption due to osmotic imbalances, resulting in reduced shoot and root growth and drought-like symptoms.
2) nutritional imbalances due to disruption of uptake of other nutrients.
3) long-term growth inhibition
4) phytotoxicity, manifested as leaf burn symptoms and tissue death.
5) deterioration of soil structure which negatively impacts seedling emergence and root growth.

Dobson (1991) reviewed the physiological effects of salt on plants. Salt stress in plants, results in abnormalities and damage at the cellular level, resulting in injury of root, leaf and shoot tissue. These effects are caused by toxic effects of Cl ions (Dirr 1975) and by disruptions due to differences in the osmotic potentials between plant cells and the water solution (in roots), or between plant cells and extracellular spaces in leaves and shoots (Dirr 1976). High concentrations of salt cause dehydration and collapse of plant tissues. Salt stress also results in reductions in water uptake and loss of photosynthetic capacity that reduce plant growth. These physiological effects may be the result of root death or loss of leaf area or they may be indirect effects due to cellular disruption in roots or leaves.

Excess soil salinity leads to deterioration of soil structure due to soil crusting and clogging of soil pores by entrapment of dispersed soil clay and silt particles (Morin *et al.* 2000). Soil crusting reduces shoot emergence of sub-surface seeds and root penetration of both surface and sub-surface seeds, resulting in reduced plant establishment. Clogging of soil pores reduces i) soil space available for air and water retention and ii) air and water penetration and permeation. Reduced soil aeration is a concern since reduced oxygen supply to plant roots affects root growth.

3.2.2 Characterization of Road Salt Injury

Laboratory and experimental field studies (done away from roadside locations) have demonstrated that soil and spray applications of NaCl and $CaCl_2$ severely injure woody plants. These studies have characterized the symptoms of NaCl and $CaCl_2$ injury in plants. Plants of English ivy, a broad-leaved evergreen, developed marginal necrosis (tissue death) that increased to almost total leaf necrosis within a few weeks, following spray applications of NaCl and $CaCl_2$ (Dirr 1975). Spray applications of NaCl de-icing salt resulted in foliar browning of white pine that worsened with increasing numbers of applications (Hall *et al.* 1972). Spray applications of NaCl de-icing salt on apple trees resulted in injury to flowers and shoots that increased in severity with the number of applications (Hofstra and Lumis 1975).

Soil applications of NaCl to 11 woody species resulted in a range of injury symptoms from wilting to leaf loss, stem necrosis and bud death (Dirr 1978, Headly and Bassuk 1991). Soil applications of $CaCl_2$ resulted in severe injury to four woody species (Paul *et al.*1984).

Dirr (1978) points out that the pattern of plant injury and elevated soil or tissue levels should be used to confirm that the cause of the damage is de-icing salts. The following injury patterns are associated with road salt injury to plants (Lumis *et al.* 1973, Dirr 1976):

- injury occurs in a linear pattern along roads or in areas where run-off from roads collects
- injury is more severe on the side of the plant facing the road
- injury decreases with the distance from the road
- injury is worse on the downwind side of the road
- parts of woody plants that are covered by snow, or were sheltered from spray, lack injury symptoms
- parts of trees that are above the salt spray zone are not injured or are injured less
- salt spray injury only extends a short distance into dense plants
- injury in coniferous trees becomes evident in late winter and continues into the growing season
- injury in decidous trees becomes evident in spring when growth resumes and continues into the growing season

3.2.2 Salt Injury Following Root Uptake

Plant symptoms in response to elevated soil levels of Na and Cl include general plant decline, reduction in leaf size and plant growth, leaf chlorosis, leaf burn and tissue death. Seed germination can be reduced or delayed, as well.

Elevated levels of de-icing salts in the soil resulted in injury to the root systems and crowns of turfgrasses. The injury was characterized by drought-like symptoms, decline in root proliferation and length, deterioration of turf quality, reduction in stand density and necrosis of grass foliage (Cordukes and Maclean 1973, Eggens 1980, Hannon and Bradshaw 1968). High levels of NaCl reduced germination, root growth and height of native prairie species (Harrington and Meikle 1992). High levels of $CaCl_2$ resulted in reduced root growth, reduced turf quality and a decrease in turf density of commonly planted turfgrass species (Cordukes and Maclean 1973).

When grown in soils treated with NaCl, woody plants developed foliar symptoms ranging from wilting, leaf coloration, leaf chlorosis (yellowing), and marginal necrosis (tissue death) which progressed to complete necrosis (plant death) (Dirr 1978). Symptoms progressed in an acropetal pattern (from the base to the tops of the plants) and the severity of the symptoms depended on species susceptibility.

Commercial tree or vine fruit crops are generally sensitive to elevated soil levels of salt. Shoot growth, and dry weight of grape vines decreased with increasing NaCl concentrations in the root zone (West and Taylor 1984) and growth of peach was reduced in saline soil (Bernstein and Hayward 1958).

Application of $CaCl_2$ as a dust suppressant in the summer (Davis *et al.* 1992; Emerson, personnel communication) or as a de-icier has injured woody plants. Symptoms in decidous woody species were similar to those caused by NaCl, including marginal leaf chlorosis, progressing to leaf scorch (marginal and interveinal leaf burn) and defoliation in decidous trees or needle burn in conifers (Paul *et al.* 1984, Strong 1944, Walton 1969).

As with NaCl, the relative sensitivity of plants to $CaCl_2$ depends on the species. Walton (1969) found that Norway maple was more sensitive to soil applied $CaCl_2$ than NaCl. Rich (1973) observed that NaCl was more toxic to roadside trees than $CaCl_2$. Strong (1944) found that elm and white pine were 5 to 10 times more sensitive to soil applications of NaCl than $CaCl_2$. Wilcox and Andrus (1987) found that sphagnum moss (*Sphagnum fimbriatum*) biomass production was twice as sensitive to $CaCl_2$ as NaCl.

3.2.3 Salt Injury by Aerial Deposits

Most woody plant injury on roadsides is due to aerial deposition of de-icing salt on dormant plants. Uptake of salt occurs in young shoots, buds and over-wintering needles (conifer leaves). Direct injury due to deposition on mature bark has not been observed, even in salt sensitive species. Injury due to salt spray is the result of tissue drought or desiccation and is related to the penetration of phytotoxic ions of Na and Cl through the stem, bud and leaf tissues (Barrick and Davidson 1980; Chong and Lumis 1990).

Studies indicate that use of salts as a dust suppressant does not result in plant injury due to aerial deposition on leaves, but rather through soil uptake by the plants (Strong 1944; Emerson, personal communication).

Death of stems and buds, usually on first year shoots, are the predominant symptoms on deciduous woody plants. The death of terminal buds or shoots results in new adventitious shoots being produced below the injury, resulting in a 'witches-broom' appearance. Resumption of growth in the spring may be delayed by as much as three weeks (Sucoff, 1975) and new growth may be reduced significantly compared to that of uninjured plants (Hofstra *et al.* 1979). Repeated injury, year after year, reduces the vigour and growth of trees and alters the size and shape of the crown. Crown shape is commercially important in nursery crops, which are sold on the basis of appearance; in landscape plants; and in fruit crops, where plants are pruned to optimize crop production and quality.

Conifers, which normally retain leaves for three years or more, exhibit premature leaf-drop and browning of needles as a result of salt-spray injury. This affects the photosynthetic (food producing) capacity and the vigour of conifers. Stem diameter growth, a measure of plant vigour, was reduced in sensitive white pine growing less than 40 m from a highway and exposed to greater salt spray, compared to plants growing more than 75 m away from a highway (Hall *et al.* 1972).

In woody fruit crops, salt spray injury results in partial to complete loss of leaf and flower bud viability, which affects plant growth and crop production (Northover 1987, Eaton *et al.* No date). In apple trees, injury worsened in the following progression with increasing number of salt spray applications:
1) a slight reduction in flower number,
2) a marked reduction in flowering,
3) death of flowering shoots (spurs) and tip of vegetative shoots,
4) arrested flower development, death of many flowering shoots (spurs) and marked dieback of vegetative shoots" (Hofstra and Lumis 1975).

Increasing salt content was associated with delayed leaf production in the spring and reduced the rate of leaf expansion. Bud break and the timing of flowering was delayed 1 to 2 weeks in severely injured trees, which would delay crop ripening.

Flower buds are more sensitive to salt injury than leaf buds, just as flower buds are more sensitive to cold injury. Trees exposed to salt spray may have no flowers on the highway side and shrubs may only have flowers below the snow line (Hofstra *et al.* 1979). As with other woody plants, the vigour and growth of sensitive woody fruit crops is reduced by repeated salt injury over a period of years.

Salt spray reduced fruit yield in a peach orchard at distances less than 80 m from a four-lane highway in southern Ontario (Northover 1987). Peach fruit number per shoot increased with increasing distance from the highway. Shoots in the tree canopy were 97% dead 20 m from the highway. Shoot death decreased to 8% at 80 m from the highway and decreased to a background level of less than 1% at 120 m from the highway. The percentage of shoots exhibiting die back and the Na and Cl tissue content of shoot tissue decreased with increasing distance from the highway.

Eaton *et al*. (No date) found that lowbush blueberry blossom number and yield was reduced within 35 m of a two-lane highway in western Nova Scotia and approached background levels beyond 50 m from the highway. Blossom number was reduced by 60% to 90% within 10 m of the highway and yield was reduced by 50% or more compared to samples taken at 50 m from the highway. Both blossom number and yield were negatively correlated with salt content of the blueberry stems taken in winter and early spring.

NaCl can reduce the cold hardiness of lilac and apple shoots resulting in increased winter injury (Sucoff and Hong 1976) and could be a factor in susceptibilities of peach cultivars with different winter hardiness ratings (Northover 1987).

Susceptibility of plants to salt spray injury also relates to the plant vigour. Ageing trees may be more susceptible to soil applications of salt due to decreasing plant vigour. For some species, younger plants are more sensitive to salt spray. With trees, this is often due to the fact that crowns of young trees are exposed to salt spray and splash, whereas the crowns of mature trees may be above the zone of salt spray and splash. For example, young white pine is very sensitive to salt spray, but mature white pine trees are not injured where the crown of the plant, the foliage and new shoots are above the zone of salt spray.

3.2.4 Comparative Sensitivity of Plant Species to De-Icing Salts

There are differences among plant species in salt sensitivity, both for NaCl and $CaCl_2$. A great deal of literature on salt injury to landscape and crop plants rates the relative sensitivity of species to elevated levels of salts. This provides information to producers and landscape specialists so that tolerant species can be used where salinity problems exist.

Different turf grass, crops, forage legumes and prairie (grass and herbaceous) species respond differently to elevated soil levels of salts (Biesboer and Jacobson 1994, Cordukes and Maclean 1973, Eggens 1980, Greub *et al.* 1985, Hannon and Bradshaw 1968, Harrington and Meikle 1992, Zelazny 1968). Kentucky 31 tall fescue (*Festuca arundinacea* cv. 'Kentucky 31') is more tolerant of NaCl than brome grass (*Bromus inermis*), creeping red fescue (*Festuca rubra*) or Kentucky bluegrass (*Poa pratensis*) (Hanes *et al*.1976). Perennial ryegrass (*Lolium perenne*) was more tolerant of $CaCl_2$ than creeping red fescue or Kentucky bluegrass. Turgeon (1999) rates the relative tolerance of different turfgrass species to soil salinity.

Lumis *et al.* (1983) listed 72 species of common Ontario roadside trees and shrubs, and selected fruit species for comparison (cherry, pear and apple) and rated them for resistance to air-borne highway de-icing salt spray (Appendix Table 1). Thirty percent of these species were rated as sensitive to road salt; 7% had severe injury symptoms that could result in plant death. A review of sensitivity ratings by Beckerson *et al.*(1980) found that 40% of 89 landscape species, commonly used in Canadian landscape plantings, had been rated as sensitive to road salt. There have been other extensive lists: Dirr (1976), over 110 species;

Dobson (1991), 332 species; Sucoff (1975), about 200 species; and Thuet (1977), over 450 trees and shrubs.

Appendix Table 2 compares the sensitivity of tree and vine fruit species to salt injury. The scientific and common names are listed as reported in the reference, as is the description of salt tolerance or sensitivity rating that was used. Entry pathway refers to whether soil or aerial (salt spray) was reported or whether no specific pathway was specified. A survey of the fruit trees, vines or shrubs listed in Appendix Table 2, indicated that 65% of 32 species, cultivars or varieties were considered sensitive to salt in at least once rating.

Commercial tree, vine and fruit crops are generally sensitive to salt spray injury. Nectarine and peach have been rated as extremely sensitive to aerial salt; sweet cherry, apple and apricot have been rated as very sensitive; pear and plum as sensitive and sour cherries and grapes as moderately sensitive (Appendix Table 2) (Slingerland, personnel communication). Apple, apricot, plum, peach and grape have been rated as sensitive or moderately sensitive to elevated levels of soil salinity (Appendix Table 2). There may also be differences in salt sensitivity of different cultivars with some species, for example with peach and grape cultivars.

Road salt injury to managed wild blueberry stands has been reported along highways in Nova Scotia (Eaton *et al.*). Ratings of ornamental woody fruit plants range from sensitive to tolerant depending on the species.

There are differences between species in their sensitivity to $CaCl_2$. Paul *et al.* (1984) found that London plane-tree (*Platanus acerifolia*) was less sensitive to $CaCl_2$ than mountain ash (*Sorbus aucuparia*), sycamore maple (*Acer pseudoplatanus*) or linden (*Tilia platyphyllos*). Strong (1944) observed the following relative sensitivity of 14 tree species. Balsam fir (*Abies balsamea*) and white spruce (*Picea glauca*) were the most sensitive. Red and white pine (*Pinus resinosa and P. strobus*), hemlock (*Tsuga canadensis*), black cherry (*Prunus serotina*), paper birch (*Betula papyrifera*), sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), trembling aspen (*Populus tremuloides*) and eastern cottonwood (*Populus deltoides*) were less sensitive. American elm (*Ulmus americana*) followed next; red and white oak (*Quercus borealis* and *Q. alba*) were the least sensitive to $CaCl_2$.

3.3 Methods Used for Assessment

3.3.1 Approach

A Tier I and Tier II, quotient-based assessment was done using the methods described in Environment Canada (1997). Assessment endpoints (plant effects) were chosen that had been reported in experimental or sampling evaluations of the response of plants to root or aerial exposure to road salt, NaCl, $CaCl_2$, Na or Cl. Thresholds were taken directly from reports or were estimated using the data reported in the studies. The methods used to derive the threshold values have been described in Section 3.4. and the methods used for the Tier I and II assessments have been described in Sections 4.2 and 4.3. A detailed risk characterization was completed, incorporating exposure data, threshold data, reports of reference sites that relate road salt application to plant effects and other relevant data.

3.3.2 Calculation of Threshold Values and Statistical Methods

The thresholds that were used for this assessment were Effects Concentrations (estimated at the 25% effect level) (EC_{25}), Critical Toxicity Values (CTV), No Observed Effect Level (NOEL) and Lowest Observed Effect Level (LOEL). A 25% effects level was chosen since it represented a level that would result in a recognizable plant effects. For example, 5% leaf necrosis could be considered a natural and possibly acceptable occurrence, but it was agreed that 25% necrosis of a plant would be detrimental.
In calculation of EC_{25} or CTV threshold values, data for each endpoint were extracted from the reports, and were plotted, either separately for each study, or pooled from studies of the same species. For each paper

and endpoint, data were plotted with dose on the x-axis and response on the y-axis (Appendices 7 and 8). Dose was exposure concentration expressed as either tissue Na or Cl concentration per tissue dry weight; soil Na, Cl, or NaCl concentration (expressed as dry weight of soil, or as the concentration in soil solution); or concentration of NaCl in a hydroponic solution. Linear regressions and 95 % confidence intervals were calculated and plotted with each data set. The EC_{25} or Critical Toxicity Value (CTV) was determined as the dose that resulted in a 25% reduction in the response parameter. For endpoints where there was no control value (for example, shoot growth *in situ*) a CTV was determined by using the 95% confidence interval of the regression equation. This provided the tissue Na or Cl concentration above which we were 95% confident that the reported tissue Na or Cl concentration result in a negative effect of the response being assessed.

For a number of endpoints, the No Observed Effect Level (NOEL) and Lowest Observed Effect Level (LOEL) were determined from data presented in the given research paper. The No Observed Effect Level (NOEL) was the highest concentration at which there was no observed response. The Lowest Observed Effect Level (LOEL) was the lowest concentration at which there was an observed effect.

3.3.3 Limitations of analysis

Many of the laboratory assay studies of plant response to NaCl were conducted using hydroponic growing systems. This method is reproducible and bioavailability of ions is predictable. However, similar soil-related studies introduce variability such as in composition, unless the soil is characterized, and it may be difficult to compare the bio-available NaCl in different soils, based on measurements of total NaCl concentrations.

Critical toxicity values (or EC_{25} values, or any other measure of adverse effect) developed from hydroponic laboratory assays usually cannot be related to field studies. If EC_{25} values from hydroponic studies are to be used in environmental regulation, then it make sense to compare these values to soil solution concentrations.

If the concentrations of Na used in many hydroponic studies were used in soils, they would adversely affect soil structure and plant growth causing effects that would be unlike Na or Cl phytotoxicity. For this reason, separate thresholds were established for hydroponic and soil studies.

Two additional issues need to be considered in hydroponic studies of plant responses to NaCl: salt shock and calcium. In some of the studies used to estimate thresholds, the NaCl concentrations were gradually increased after the plants were established in the hydroponic system, to avoid shock, while other studies did not address this issue. Some of the studies maintained a uniform Ca/Na ratio over the experimental range of NaCl concentrations, to avoid confounding of Na and Ca effects; other studies did not address this issue. It is uncertain what variability these two issues have introduced into the calculation of thresholds.

3.4 Types of Effects (Endpoints) Used for Assessment

The endpoints used for the effects characterization and the threshold estimations were plant effects or responses due to salt exposure or treatment evaluated in the literature. These studies evaluated plant response to deicing salts in the substrate or following aerial expose in terms of plant heath, productivity and reproduction.

The parameters or endpoints assessed for road salt injury to herbaceous species were chosen because they represent effects that reflect the productivity and overall health of the plants. All data were expressed as percentage change relative to a control (untreated treatment). The parameters were:

-shoot growth
-root growth
-seed germination
-relative growth rate

The parameters assessed for conifers and deciduous woody plants were chosen because they represent effects that reflect the status of tree health and salt injury symptoms. The parameters were:

- dry matter accumulation or increase
- height
- survival or mortality
- various injury ratings or damage rating indexes
- injury or foliar injury
- chlorosis and necrosis
- shoot death
- tree defoliation
- seed germination

The parameters assessed for fruit trees were chosen because they represent effects that would influence fruit tree health or yield, and reflect symptoms of salt injury. The parameters were:

- twig dieback
- dead buds
- crop yield

The doses reported for aerial exposure to woody plants were for tissue Na and Cl concentration, and were converted to ppm Na or Cl per tissue dry weight.

3.5 Effects Summary

The calculated threshold values (CTV, EC_{25}, NOEL and LOEL values) are presented in Appendix Tables 3-6, organized alphabetically by author. The figures used in the calculation of the EC_{25} values or CTV's have been organized alphabetically by author in Appendices 7 (herbaceous species) and 8 (woody species).

The following section discusses the source of data used to calculate the threshold values.

3.5.1 Herbaceous Species

Data Evaluation

The papers discussed in the following sections are all that were remotely useful in the evaluation of critical concentrations for adverse effects of NaCl on herbaceous species. An additional 31 papers were evaluated, and were rejected for one of the following reasons:

- Soil or solution salinity expressed in mmhos. which was not convertible to concentration units (ppm)
- Use of complex mixtures of NaCl with other salts which confounded the effects of individual salts
- Focused on elucidating physiological mechanisms of salt tolerance, or Na uptake and translocation
- Focused on ecotypes from marine environments

In Situ Studies

Hanes *et al*., 1976: The influence of NaCl on the yields of four grasses grown in the field was assessed by supplementing a sandy loam site with NaCl in the second year of grass establishment. The data could not be used in the determination of thresholds, because the exposure concentration was expressed as the application rates in lb/acre, which cannot be converted with confidence to ppm. However, the yields of all four grass species (brome grass, creeping red fescue, Kentucky bluegrass and Kentucky 31 tall fescue) declined as the application rate increased from control to 13,440 kg/ha. This provides evidence of the negative impact of NaCl on plants grown in soils.

Venables and Wilkins, 1978: Six species of plants were collected from a natural setting in which brine pumping over the previous 20 to 30 years had resulted in saline soils. These plants were then evaluated for salt tolerance (to NaCl) in solution culture. Individuals were then crossed, and the progeny of those parental lines evaluated for salt tolerance, using hydroponic culture. The species varied widely in their salt tolerance to NaCl in solution culture, and the degree of tolerance demonstrated was related to the salinity of the site from which the individual was collected. There was a positive correlation between plant tolerance to NaCl in solution culture, and the conductivity of the soil from which the plants were collected. The range of salt tolerance also varied greatly from species to species. The data from this study were not used in the determination of thresholds, because of the natural selection for salt tolerance within the plant population that had occurred.

Laboratory Assay – Hydroponic Exposure

Ahmad and Wainwright, 1977: Three ecotypes of bentgrass (*Agrostis stolonifera*) were collected from sites with differing levels of marine salt contamination (salt marsh, spray zone and inland locations). Runners of these plants from each of these locations were cultured in four different NaCl concentrations in hydroponic solution culture to test for salt tolerance. Salt tolerance was expressed as relative growth rate, by harvesting plants at intervals of 0, 2, 4 and 6 weeks and determining dry weights of roots and shoots. Plants from the salt marsh had the highest root plus shoot RGR's and inland plants had the lowest RGR's relative to control NaCl solutions (72.9% and 12.6%, respectively). This suggests that natural selection for salt tolerance does occur, and that results of studies using plant material collected from natural situations could be influenced by the salt exposure history of the collected plant material. All of these data were included in the calculation of thresholds.

Ashraf *et al*., 1986; Ashraf *et al*., 1987: Breeding studies for the selection of salt tolerance in crop species were assessed for usefulness in the determination of thresholds for NaCl effects on plants. These studies originated from the increasing salination of irrigated agronomic land, and the need to develop plant lines that can produce successfully under these conditions. Both of these studies evaluated plant performance under NaCl stress in hydroponic culture. Ashraf *et al*. (1986) used root length of progeny as an indicator of plant response to NaCl while Ashraf *et al.* (1987) used shoot length of seedlings. In both cases, the focus of the paper was on the progeny from crosses of individuals initially selected in a screening process. It did not seem that these data would make a useful contribution to the determination of thresholds, so there were not included in the data set.

Biesboer and Jacobson, 1994: A study of seed germination in response to NaCl concentration in solution was conducted on a similar cohort of prairie species. Three replicates of 400 seeds of each of six species (little blue-stem, *Schizachyrium scoparium;* buffalo grass, *Buchloe dactyloides;* grama grass, *Bouteloua gracilis* and*Bouteloua curtipendula;* prairie dropseed and sand-dropseed, *Sporobolus heterolepsis* and *Sporobolus cryptandrus*) were scored for germination in solutions of increasing NaCl concentration (0 to 40,000 ppm). *B. gracilis* and *B. dactyloides* appeared to be the most likely to germinate under saline conditions; *S. cryptandrus* was the least tolerant to NaCl. These data were used in the determination of thresholds.

Marcum and Murdoch, 1994: Five tropical grass species were assessed for relative shoot growth (as % of control) in response to NaCl in hydroponic culture, ranging from 5,850 to 23,400 ppm. Species specific regressions indicated that plant response ranged from near-total loss of growth at 11,700 ppm NaCl (centipede grass, *Eremochloa ophiuroides*) to stimulation of growth by 36% greater than control, at 11,700 ppm NaCl (Augustine grass, *Stenotaphrum secundatum*). At the highest NaCl concentration, there was growth reduction in all species tested. Despite the fact that these species are not native nor introduced to Canada, these data were included in the determination of thresholds, with caution regarding their role in shaping the regression line from which the threshold was determined.

Rozema *et al.*, 1978: Creeping red fescue (*Festuca rubra*) from inland, salt-marsh and sand-dune sites were grown in culture solution with added NaCl to assess relative salt tolerance of ecotypes from sites of contrasting salinity. As would be expected from previous studies of these kinds of ecotypes, the inland ecotype of fescue (*F. rubra*) was most sensitive to NaCl in solution culture, whereas the salt marsh ecotype was most tolerant. The data were not used in the determination of thresholds, because of the natural selection for tolerance that had already occurred, and the lack of relevance to most situations in Canada. As well, the data were not tabulated, and could not be determined from the tiny graphs with confidence.

Rozema and Visser, 1981: Four species of rush (*Juncus* sp.) were compared for salt tolerance to four concentrations of NaCl in root solution, by measuring root and shoot growth relative to plants in control solution, after six and twenty days of exposure. After six days, there was little reduction in the relative growth rate of any of the four rush species, except for jointleaf rush (*J. articulatus*) and northern green rush (*J. alpino-articulatus*ssp. *atricapillus*) at a concentration of 11,700 ppm. After twenty days, these two species were demonstrating reduced growth in response to 5850 ppm, and the growth of all four species was retarded by 11,700 ppm. The data for relative growth rate, as a function of both NaCl concentration in the rooting solution, and tissue Na concentration, were used in the determination of thresholds. This study also reported relative growth rates for creeping red fescue (*Festuca rubra*) from two locations – coastal and inland. These data were presented only in tiny graphs, with no tabulation. Extrapolation from the axes was not considered a reliable source of numbers for determination of thresholds.

Schwarz and Gale, 1984: A collection of species which embraced a range of salt tolerance were examined for shoot and root productivity, and relative growth rates, during 12 or 14 days of exposure, relative to control plants. Dry weight production of shoots and roots of kidney bean (*Phaseolus vulgaris)* grown in 2340 ppm NaCl (salt sensitive) was reduced by 29% and 13% relative to the control, respectively. In contrast, the shoot and root dry weight production of the halophyte grown in 9945 ppm NaCl sea orach (*Atriplex halimus*) were reduced by 4% and stimulated by 3% relative to the control, respectively. The shoot and root dry weight productions of the other two species -cocklebur (*Xanthium strumarium*), salt tolerant; and corn (*Zea mays*) salt sensitive - were more similar to the kidney bean than the sea orach . The relative growth rates of the four species were reduced by exposure to NaCl, although the rates are not directly comparable, as four different exposure concentrations were used. There were only four data points for each response endpoint, so the data were used for a pooled determination of thresholds.

Smith and McComb, 1981: Shoot fresh weight growth of four plant species was measured after three (kidney bean, *Phaseolus vulgaris* and beet, *Beta vulgaris*) or seven (orache, *Atriplex undulata*and sea blite, *Suaeda australis*) weeks in hydroponic solution of NaCl. Three of the four species demonstrated growth stimulation (percent change relative to growth in 0 ppm NaCl) in response to 3,660 ppm NaCl; kidney bean did not. As well, growth of the two halophytes, orache and sea blite, was stimulated by 7313 ppm and 14625 ppm NaCl. These data were included in the calculation of thresholds, without inclusion of the halophyte data.

Laboratory Assay - Soil Exposure

Greub *et al*., 1985: Multiple species of temperate grasses and legumes were screened for salt tolerance, in a study that added NaCl (2.65M) to potted soil-grown plants, to the equivalent of 4.48 mg/ha. These units of NaCl concentration prevented the data from being used in the determination of thresholds, but the data did demonstrate widespread decline of shoot yield and increased visible foliar injury in the salt-amended pots. It was clear that some of the species, all of which might be found in the roadsides of northern temperate regions of North America, were more salt-tolerant than others.

Hanes *et al*., 1976: Greenhouse research was carried out with three grass species, Kentucky 31 fescue, creeping re fescue and Kentucky bluegrass. Details of exposure and the culture substrate were not clear. The root and shoot yields of all three species generally declined as the concentration of the applied NaCl treatment solutions increased from control to 4000 ppm. No error terms were available in this data set, so it is unclear whether or not the slight growth stimulation observed in some of the species was different from no response at all, relative to control plants. One data set in this study, that related reduction in shoot growth to shoot concentrations of Na and Cl, was used in the determination of thresholds. The remaining data in this study were expressed in tons/acre of NaCl applied, so exposure concentration could not be calculated. These data were also not used in the determination of thresholds, as the soil concentration of NaCl could not be determined. However, the remaining data in this study confirm, for soil grown plants, that increasing NaCl concentrations inhibit growth of plants.

Harrington and Meikle, 1992: The germination and growth of eight prairie species, five warm grass species and three forb (broad-leaved) species, grown in soil amended with NaCl was assessed in a long-term greenhouse study. Four of the grass species and two of the forb species are important components of prairies in parts of the prairie provinces and Ontario (Morgan *et al.* 1995). A sterilized silt-loam mix was amended with NaCl resulting in Na concentrations ranging from 0 to 2000 ppm, or 0 to 400 ppm, for the measurement of seed germination responses to NaCl. For all species combined, there was a 44% germination rate at 0 ppm Na; this declined to between 9 and 0.3% at Na concentrations between 500 and 2000 ppm. When a range of 0 to 400 ppm was used, seed germination rates were between 42% and 29%, and suggested that a threshold for seed germination effects occurred between 300 and 500 ppm Na. The seed germination data were used in the determination of thresholds.

The study also measured root and shoot biomass responses of the five species to soil Na in an eight week study, and determined that the root growth of all of the species was reduced by Na in the soil, but that the degree to which reduction occurred was species specific. For example, wild rye (*Elymus canadensis*) was sensitive, with reductions of between 30% and 73% in soils with 100 to 400 ppm Na. Plant shoot growth was both stimulated and inhibited by NaCl in the soil: Grama grass (*Bouteloua curtipendula*) and buffalo grass (*Buchloe dactyloides*) had greater above-ground biomass at 100 (65%) and 200 (42%) ppm Na, than at 0 ppm Na, respectively. The shoot growth of all species was reduced at 400 ppm Na. The root and shoot growth data were used in the determination of thresholds.

3.5.2 Wet Area Herbaceous Species

In Situ Studies

Wilcox 1986a: The salt tolerance limits (NOEL) for survival of various wetland species was determined following sampling of a bog located adjacent to an uncovered salt storage pile. The salt storage pile had been in operation for 10 years on an embankment above the bog. The site was in northwestern Indiana, along the Indiana Toll Road, I-80/90. General gradients of water sodium and chloride were identified and related to plant survival (Table 3.1). The sodium and chloride water chemistry data should only be viewed as general ranges. The data for woody plants on this site are presented in Table 3.6 (Section 3.5.3). Wilcox (1986a) also tabulated salt tolerance limits (NOEL) reported in the literature for a number of the same species and other bog species (Table 3.2).

Table 3.1. Salt tolerance limits (NOEL) for selected herbaceous bog species (Wilcox 1986a).

Species	Salt tolerance limit (NOEL) (ppm NaCl)
marsh fern, *Drypoteris thelypteris*	1070
St.-John's wort, *Hypericum virginicum*	1070
wool-grass, *Scirpus cyperinus*	1070
beggar-ticks, *Bidens connata*	1030
sphagnum moss, *Sphagnum* sp.	770
panic grass, *Panicum implicatum*	760
goldenrod, *Solidago graminifolia*	760
sundew, *Drosera intermedia*	360
white beak-rush, *Rhynchospora alba*	360
three-fruited sedge, *Carex trisperma*	280

Table 3.2. Salt tolerance limits (NOEL) reported in the literature for selected herbaceous bog species (from Wilcox 1986a).

Species	Salt tolerance limit (NOEL)(ppm NaCl)	Reference
common duckweed (*Lemna minor*)	66,600	Haller *et al.* 1974
narrow-leaved cattail (*Typha angustifolia*)	20,000	McMillan 1959
narrow-leaved cattail (*Typha angustifolia*)	16,800	Penfound and Hathaway 1938
common cattail (*Typha latifolia*)	5,260-12,870	Kaushik 1963
common cattail (*Typha latifolia*)	11,300	Penfound and Hathaway 1938
common cattail (*Typha latifolia*)	10,000	McMillan 1959
arrow-head (*Sagittaria* sp.)	8,900	Penfound and Hathaway 1938
buttonbush (*Cephalanthus occidentalis*)	8,900	Penfound and Hathaway 1938
bladderwort (*Utricularia* sp.)	5,300	Penfound and Hathaway 1938

Laboratory Assay - Hydroponic Exposure

Schauffler, 1993: Cotton grass sedge, *Eriophorum vaginatum* var. *spissum*, growth and flowering response to NaCl was evaluated in hydroponic culture. Plants were grown for 7 weeks at NaCl concentrations from 400 to 6000 ppm NaCl. Biomass and tiller production was reduced at all concentrations although there were no visual symptoms at 400 ppm NaCl. The LOEL for biomass and tiller production was 400 ppm NaCl, compared to 1600 ppm NaCl for flower production.

Wilcox, 1984: The response of recurved sphagnum, *Sphagnum recurvum*, to increasing levels of NaCl, from 300 to 1500 ppm Cl and one level of $CaCl_2$ at 1500 ppm Cl was studied in hydroponic culture. Growth was reduced with increasing concentrations of NaCl and at all concentrations of both salts. The estimated LOEL for reduction in mean length growth was 300 ppm Cl (8.5 mM NaCl).

Wilcox and Andrus, 1987: studied the effect of increasing concentrations of NaCl, from 300 to 1500 ppm as Cl and $CaCl_2$ at 1500 ppm as Cl on the length and biomass increase and gametophore production of sphagnum moss, *Sphagnum fimbriatum.* Length growth was reduced at concentrations about 300 ppm Cl and halted at 3000 ppm Cl. Biomass growth was reduced at concentrations greater than 900 ppm Cl. Gametophore production was reduced by all concentrations of Cl. The Estimated LOEL values was 300 ppm Cl for gametophore production, 500 ppm Cl for length increase and 1500 ppm Cl for biomass increase. Application of $CaCl_2$ at 1500 ppm as Cl had a similar reduction in length increase as NaCl, but a more than double reduction in biomass increase.

3.5.3 Woody Species

Data Evaluation

Thirty papers were initially considered for determining the effect of road salts on coniferous tree species. Upon review, this list was narrowed down to 12 papers. These papers were focused on because the species studied were grown in Canada, the endpoints studied were relevant to concerns regarding the health of conifer trees and the papers contained a clear expression of dose (tissue or soil Na or Cl concentrations, rather than soil EC, for example).

Similarly, 46 papers were reviewed for the effect of road salts on deciduous woody species, but thresholds were only calculated from 10 papers. Thirteen papers were initially considered for determining the effect of road salts on fruit trees. Upon review, this list was narrowed down to five papers; these were chosen because the species studied were grown in Canada, the endpoints studied were relevant to concerns regarding fruit trees and contained a clear expression of dose (tissue Na or Cl, rather than soil EC, for example). Upon data analysis, a further two of these five papers were rejected. These two papers contained results demonstrating negative effects at extremely low tissue Na and Cl concentrations. These concentrations were greater than an order of magnitude below those reported in the other papers. Following discussions with one of the co-authors, there was reason to believe that the concentrations presented in the paper were erroneously reported.

Effects Summary

The following are brief synopses of the woody plant papers, organized alphabetically by author. These include observational studies, *in situ* studies and laboratory (experimental) assays.

Bedunah and Trlica, 1979: Twelve EC_{25} values were generated from two studies with relatively few data that examined the effect of winter-applied (either in the soil or as a spray) NaCl to two year old ponderosa pine (*Pinus ponderosa*) seedlings growing in pots in a lath house. In the first study, NaCl was applied, and the concentrations of Na and Cl in soil solution (not dry weight of soil) was related to foliar injury (proportion of brown tissue) and mortality. The second part of the first study related the concentrations of foliar tissue Na and Cl to these same two parameters. Regressions contained only 3 data points each, and thus have very large confidence intervals surrounding the regression line. The second study related concentrations of soil and tissue Na and Cl to foliar injury in the same manner, but NaCl was applied as a foliar spray. While there were more data available to carry out regressions and determine these EC_{25} values, the range of doses was below the EC_{25} value, and significant extrapolation was required to determine the EC_{25} values.

Bicknell and Smith, 1975: This study was on the effect of NaCl on seed germination. Soil was held at 20 % moisture content and % germination was related to the concentration of NaCl expressed as a % dry weight of soil. Pitch pine, (*Pinus rigida*) seed germination was delayed by NaCl in that the seeds germinated in 6 days as opposed to 3 days. Germination was unaffected by the NaCl concentrations used; thus, this EC_{25} represents a delay of germination and not an inhibition of germination; perhaps not a very serious effect. Yellow birch (*Betula alleghaniensis*) seed germination was inhibited up to 33 days after planting at the 0.10 % NaCl and higher. This EC_{25} represents germination at 6 days after planting. Similarly, southern catalpa (*Catalpa bignonioides*) seed germination was inhibited up to 33 days after planting at the 0.1 % NaCl and higher. This EC_{25} represents germination at 3 days after planting. As with the *Pinus rigida*, this may represent a delay in germination at later time periods. NaCl had a similar effect to different degrees on the other woody species evaluated in this study, but the data were not suitable for calculations of threshold.

Button and Peaslee, 1966: Twenty mature maple trees along a section of Connecticut highway that had been salted for several years with NaCl and $CaCl_2$, were sampled for foliar tissue analysis in August. The trees were located from 1.4 to3.8 m from the pavement and at various elevations from -0.5 to 1.4 m relative to the pavement. The trees were evaluated for leaf burn symptoms and degree of defoliation during the growing season. The degree of tree defoliation and the percentage of leaves with burn increased with increasing foliar Na content. The data was not normal, so EC_{25} values were not calculated from this data.

Chong,and Lumis. 1990: This was a study on the effectiveness of various film-forming spays in preventing salt spray injury in peach. Two cultivars (Garnet Beauty and Madison) of peach (*Prunus persica*) trees, located along the side of a major highway were sprayed with one of five film-forming products (plus two controls; unsprayed or burlap covered) in the fall. The following spring, damage to the trees was assessed. Tissue Na and Cl concentrations were measured in oven dried twigs (with no indication of whether they were washed or not) harvested on March 22 (when tissue concentrations were highest), and related to both the length of twig dieback and the percentage of dead flower buds.

Dirr, 1974: Honey-locust (*Gleditsia triacanthos* var. *inermis)* seedlings were cultured in increasing concentrations of NaCl. Shoot and root dry weight were evaluated as well as shoot and root Na and Cl content sampled 30 or 36 days after treatment. Shoot dry weight and mean root dry weight decreased with increasing concentration of NaCl. Root dry weight and tissue concentration samples were consolidated to provide sufficient tissue for Na and Cl analysis. Root EC_{25} values were not calculated since the data were not normally distributed.

Dirr, 1975: A solution of NaCl (200 ml of 14,630 ppm) was drenched daily to the rooting medium (1 soil:1 peat:1 perlite) of English ivy (*Hedera helix*) plants growing in clay pots for six weeks (Dirr, 1975). At the end of the experiment, the plants were harvested, divided into roots and shoots, and dry weights determined. Relative to control plants, the shoot dry weight of English ivy was 73% reduced by this treatment and root dry weight was reduced by 21%. These data were not included in the calculation of thresholds, as soil concentration of NaCl, Na or Cl was not reported.

Aerial exposure was evaluated in separate experiments. A solution of 25 ml of 0.25 N NaCl or $CaCl_2$ was sprayed daily onto the shoots of English ivy (*Hedera helix*) plants growing in clay pots for six weeks (Dirr, 1975). At the end of the experiment, the plants were harvested and divided into roots and shoots, and dry weights determined. Relative to control plants, the shoot dry weight of *H. helix* was reduced 71% by this treatment and the root dry weight was reduced by 25%. Following $CaCl_2$, shoot dry weight was reduced by 73% and root dry weight by 28%. The resulting tissue content was 27,720 ppm Cl following NaCl treatment or 31,900 ppm Cl following $CaCl_2$ treatment. These data were not included in the calculation of thresholds, as there was only one value reported per treatment.

Dirr, 1978: Two-year old seedling of seven woody species growing in controlled environments were treated with 0.25 N NaCl compared to an untreated control for 12 days except for nanking cherry (*Prunus tomentosa*) which was harvested after 7 days when most of the leaves had abscised. Five of the species had a reduced appearance index compared to the control. Both Russian olive (*Elaeagnus angustifolia*) and Turkestan rose (*Rosa rugosa*) were not affected by the salinity treatments. All species in this study were used to estimate EC_{25} values although sand cherry, (*Prunus besseyi*) is not native to Canada.

Foster and Maun, 1977: There were four studies assessed in this paper; the EC_{25} values determined from each study are labeled with a 1, 2, 3, or 4 in Appendix Table 6 to denote which study they came from. All studies dealt with effects of road salt on eastern white cedar (*Thuja occidentalis*), and were carried out in a greenhouse. In Study 1, NaCl was added to soil. The amount of Na and Cl in soil (on a dry weight basis) and in tissue (washed, on a dry weight basis) was related to the percentage of discolored foliage or the amount of damage observed in roots, reported as a Root Damage Rating Index. The Root Damage Rating Index ranged from 1 to 6, with the following symptoms: 1 (0-10% burnt root tips), 2 (11-50% burnt root tips), 3 (51-75% burnt root tips), 4 (76-95% burnt root tips), 5 (96-100% burnt root tips, red roots), and 6 (100% burnt root tips, black roots). Study 2 looked at the effect of adding NaCl to different soil types, and related the concentration of Na and Cl in roots and foliage and roots to Foliage and Root Damage Rating Indexes, respectively. The Root Damage Index was the same as outlines in Study 1, and the Foliage Damage Rating Index used was as follows: 1 (0% discolored foliage), 2 (1-20% discolored foliage), 3 (21-40% discolored foliage), 4 (41-60% discolored foliage), 5 (61-80% discolored foliage), and 6 (81-100% discolored foliage). In Study 3, NaCl was supplied as a foliar spray, and foliage and root Na and Cl concentrations were related to the same Foliage and Root Damage Rating Indexes described above. Roots were not affected in this study, so an EC_{25} value was not calculated for the effects of foliar applications of NaCl on root health. In Study 4, roots were exposed to solutions containing NaCl, and the concentration of NaCl in the exposure solutions and in the foliage and roots were related to Foliage and Root Damage Rating Indexes once again.

Foster and Maun, 1980: In this study, three year old white cedar plants (*Thuja occidentalis*) raised in a greenhouse were transferred to growth chambers and maintained under different humidity conditions and sprayed with NaCl solutions for 20 days. Tissue concentrations of Na and Cl (of washed, dried tissue) were related to damage, expressed as a damage rating index., ranging from 1 to 6, depending on the percentage of discolored foliage. 1 was 0%, 2 was 1 to 20%, 3 was 21 to 40%, 4 was 41 to 60%, 5 was 61 to 80% and 6 was 81 to 100%. The EC_{25} value was therefore a rating of 2.25.

Hanes *et al.* 1976: Leaf and twig samples were taken from mature silver maple (*Acer saccharinum*) trees growing in a highway environment, about 4.6 m from Highway US 7 in Vermont. The site contained about 250 trees, although it is not clear how many trees were sampled. Sampling occurred in April, June and September over a four year period and the trees were visually rated for symptoms on a scale of 1 (healthy) to 5 (severe defoliation, extreme limb deterioration or death). Many of the maples on this site were injured at the start of the sampling and declined from 1967 to 1969, particularly on the east side of the road. EC_{25}

values were estimated for the regression of symptoms on foliar Cl, foliar Na, and stem Cl. There was no significant linear relationship for stem Na on symptom rating.

A separate study in the report evaluated the response of 18 woody species to different rates of NaCl (1680 to 13,440 kg/ha) and $CaCl_2$ (3360 to 6720 kg/ha) applied in field experimental locations. Split applications were applied from late December through early March over three winters. It is not clear whether the total rate of application or repeated rates of application were reported. These data were not used to calculate EC_{25} values since the application rates are reported as lb/acre. The plants were rated for average salt-tolerance ratings in June or August of the two final years. The salt tolerance ratings of the different species to the salt treatments were reported. Of the deciduous tree species evaluated, sweet honey locust (*Gleditsia triacanthos* var *inermis*) () was tolerant to both NaCl and $CaCl_2$. Green ash (*Fraxinus pennsylvanica)* and tulip-tree (*Liriodendron tulipifera*) were injured by both NaCl and $CaCl_2$ at all application rates. Of the shrub species, amur privet (*Ligustrum amurense*) and tartarian honeysuckle (*Lonicera tatarica*) () were most tolerant of the NaCl and $CaCl_2$ treatments. Rose (*Rosa multiflora*) and spirea (*Spiraea Vanhouttei*) were sensitive to both NaCl and $CaCl_2$. Of the conifer species evaluated, pfitzer juniper (*Juniper chinensis Pfitzeriana*) () was most tolerant and Canadian hemlock (*Tsuga canadensis*) was the least tolerant.

Hofstra and Hall, 1971: This study evaluated white cedar and white pine growing adjacent to Highway 401, a 4-lane divided highway near Colborne and Newcastle, Ontario. One study evaluated white cedar growing on the north (windward) and south (leeward) sides of the highway. Injury was measured by separating tissue into green and brown portions and determining the ratio of brown by weight after drying. Tissue concentrations of Na and Cl were determined on a dry weight basis, but it is not indicated whether or not tissue was washed prior to drying. In another study in this paper, it is possible to estimate EC_{25} values from graphs presented (but raw data are not provided). EC_{25} values for three transects of white pine were approximately 3,000-5,000 ppm (tissue Cl, % injury). The EC_{25} value was 9,000 ppm (tissue Cl, % injury) in a transect of white cedar.

Lacasse and Rich, 1964: 550 maple trees growing along a 15 km stretch of New Hampshire highway were sampled for maple decline symptoms and occurrence of the symptoms relative to the road. The plants consisted of predominantly sugar maple (*Acer saccharum*) and 96 red maple (*Acer rubrum*) and less that a dozen each of silver maple *(Acer saccharinum*) and Norway maple (*Acer platanoides*). The degree of maple decline symptoms was inversely related to distance from the road. Na content of the leaf and twig tissue was significantly higher in trees less than 9 m from the road compared to those greater that 9 m from the road.

EC_{25} values were calculated from regressions of the maple decline symptoms of 150 sugar maples and red maples on Na content of the leaves or twigs presented in the paper. The correlation coefficients were 0.40 and 0.42 respectively. Greenhouse studies were also carried out on the effect of 18 applications 0 to 2000 ppm NaCl applied to the growing media on alternate days of seedlings of sugar maple, white birch (*Betula payrifera*), tulip-tree (*Liriodendron tulipifera*) () and white ash (*Fraxinus americana*). White birch and white ash were not injured by the treatments. Tulip-tree had injury ratings of 3.9/5.0 at the highest level of treatment. Sugar maple seedling had injury ratings of 3.6/5.0 with the 2000 ppm treatment and 2.8/5.0 with the 1000 ppm treatment. The authors noted that maple was more susceptible to NaCl than other tree species and that the maple decline symptoms were likely due to severe salt injury.

Lumis *et al.* 1976: Twig tissue samples (deciduous species) and conifer needle samples (conifers) were collected bi-weekly from January to early May from plants of 12 coniferous and deciduous species growing along Brock Road (formerly Highway 6, a 2-lane highway) and Highway 401, a 4-lane highway, south of Guelph, ON (Table 3.3). Samples were also taken from woody plants growing on the University of Guelph campus for comparison of background levels. Maximum tissue levels of Cl ranged from 5600 ppm to 21000 ppm. Maximum levels of Na were lower, ranging from 1300 ppm to 11,200 ppm. These values compared to less than 600 ppm in the background samples for both Cl and Na. Injury ratings were made of all the plants sampled on the highway. Except for beech, species that were severely injured by de-icing salt had high levels of Cl and Na in their tissues, while more resistant species had lower concentrations. Beech was sensitive to de-icing salt and had low tissue concentrations of Cl and Na. The tissue data from all species was used to calculate an EC_{25} value. The R^2 value was 0.28.

Table 3.3. Woody species sampled in Lumis *et al.* 1976

Manitoba maple (*Acer negundo*)
Norway maple (*Acer platanoides*)
sugar maple (*Acer saccharum*)
red-osier dogwood (*Cornus stolonifera*)
American beech (*Fagus grandifolia*)
amur privet (*Ligustrum amurense*)
crab apple (*Malus sylvestris*)
Austrian pine (*Pinus nigra)*
white pine (*Pinus strobus*)
white willow (*Salix alba*)
common lilac (*Syringa vulgaris*)
Eastern white cedar (*Thuja occidentalis*)

McLaughlin and Pearson. 1981: This study was on the effect of snow fence barriers on salt spray along the QEW, a 4-lane highway in southern Ontario. Peach and plum trees in orchards along the side of the highway, which were either behind or not behind snow fences, were sampled in April and May to determine the amount of Na and Cl in the twig tissues. For the purposes of this analysis, data from all trees, whether or not they were behind a fence, were combined. Twigs were oven dried and unwashed prior to analysis for tissue Na and Cl. Tissue Na and Cl concentrations were related to the length of twig dieback.

Northover 1987: This first part of the study was done on Loring peach trees (*Prunus persica*) located along a 4-lane highway near St. Catharines, Ontario. Tissue Na and Cl concentrations were determined from dead twigs in June, which were oven dried prior to analysis. Tissue Na and Cl concentrations were then related to yield per tree, determined in August of that year. The second part of the study was also done on Loring peach trees and involved dipping dormant peach shoots in NaCl solution, determining absorption of Na (per gram of oven dried tissue) and relating this to bud viability.

Sharpf and Srago, 1974: This study was carried out in the Lake Tahoe Basin. In this study, tissue concentrations of Na and Cl were determined for dried tissue of white fir (*Abies concolor*), but no indication was given as to whether or not tissue was washed prior to drying. Tissue concentrations were related to a damage rating of Control, No Damage ("No tip burn or needle browning. Chlorotic trees were included in this rating until further symptoms developed."), Light Damage ("Damage to one-third or less of the foliage, with only the very tips of the needles showing tip burn."), Moderate Damage ("One-third to two-thirds of the foliage damaged, and one-half or less of the length of the damaged needles on pines showing tip burn."), or Severe Damage ("Two-thirds or more of the foliage damaged, and on pines 50 % or more of the needle length showing tip burn. Trees completely brown and apparently dead were included in this category."). For the purposes of analysis, the categories were assigned values of 0 through 4, with the EC_{25} value being set at 1. For the determination of the Na EC_{25} value, the highest value was dropped, since it appeared to be an outlier; leaving it in doubled the EC_{25} value.

Simini and Leone, 1986: Dormant plants of sugar maple (*Acer saccharum*) and Norway maple (*Acer platanoides*) were treated with simulated salt spray containing 40,000 ppm NaCl for 13 days for a period of 6 hr/day. Following treatment, the plants were either placed outdoors in ambient conditions or placed outdoors with protection from precipitation. Leaf and stem dry weight, and shoot length were significantly reduced by the salt applications. Percentage buds opening were not affected in either species. Height increase was not affected in Norway maple while it was increased by the salt treatment where the plants were kept under cover. EC_{25} value was calculated from the regression of leaf dry weight on foliar Cl content. The r^2 value was 0.605.

Thompson and Rutter, 1986: Eleven shrub species were evaluated for their response to foliar spray applications of 4,000 to 32,000 ppm NaCl and 9 species were evaluated for their response to soil applications of 4,000 to 32,000 ppm of NaCl in England. The species discussed in this review will be limited to those found in Canadian landscapes or natural environments (Table 3.4).

Table 3.4. Woody species evaluated in Thompson and Rutter (1986)

hedge maple (*Acer campestre*)
red dogwood (*Cornus sanguinea*)
English hawthorn (*Crataegus monogyna*)
sea-buckthorn (*Hippophae rhamnoides*)
sweetbrier (*Rosa rubiginosa*)
basket willow (*Salix viminalis*)
wayfaring tree (*Viburnum lantana*)
European highbush cranberry (*Viburnum opulus*)

In the spray experiment, plants grown outdoors in containers were sprayed bi-weekly, seven times from early January to early April and eight times the following winter from early December to mid March with of 4000 to 32000 ppm NaCl. The salt spray treatment, resulted in a significant reduction in plant dry weight increase, up to 45% reduction for red dogwood and up to 24% reduction for European highbush cranberry. The salt spray treatments also resulted in a greater number of dead shoots with red dogwood, English hawthorn, sweetbrier, basket willow and the wayfaring tree , from 6.4 to 32 more dead shoots per plant. EC_{25} values were determined for the regression of the number of dead shoots in all species, except sweetbrier (*Rosa*) on NaCl treatment concentration. One value of the dogwood data (32000 ppm) was omitted from the regression analysis as an outlier. The r^2 value was 0.406.

In the soil experiment, plants grown in the same set-up as the salt spray experiment were treated at approximately the same times with soil treatments of 4000 to 32000 ppm NaCl. The 32000 ppm soil treatments resulted in 8 to 10 deaths per 10 plants with the hedge maple, English hawthorn and the basket willow. The English hawthorn was most sensitive to the NaCl soil treatment; the number of plant deaths increased from 1 to 10, with increasing rate of salt application. An EC_{25} value was determined for the regression of percentage of plant deaths on soil solution concentration. The r^2 value was 0.927. Soil applications of NaCl significantly reduced dry weight increase in red dogwood, sweetbrier, basket willow, wayfaring tree and European highbush cranberry. EC_{25} values were determined for the regression of plant dry weight increase on NaCl treatment concentration for red dogwood, sweetbrier and wayfaring tree. The r^2 values were between 0.80 and 0.97. The regressions were not significant for the basket willow and European highbush cranberry dry weight increase.

Townsend 1980: The effect of 0 to 7,000 ppm NaCl applied in water culture was evaluated over a 5 week period in six woody species (Table 3.5). Height growth was reduced in sycamore, *Platanus occidentalis*, at 4,500 and 7,000 ppm and in dogwood, *Cornus florida*, at 7,000 ppm. Height growth was not impacted in the other species, likely due to the short term of the experiment. An EC_{25} value was determined for height growth of dogwood, since there were only 3 data points for the sycamore.

Since the composite data for dry weight of all species were not normal, only the species that were significantly affected by salt treatment were analyzed. EC_{25} values were determined for height growth of dogwood. Stem, root and leaf dry weights were reduced by 21 to 50 % in white pine and by up to 84% in Japanese pagoda tree, *Sophora japonica.* Only leaf dry weight was significantly reduced in dogwood by 59 to 77 %. EC_{25} values were determined for leaf dry weight of dogwood and sycamore, for root dry weight of dogwood, sycamore and white pine, *Pinus strobus,* and stem plus root dry weight of sycamore and white pine. The data were not normal when other species were included in the analysis, therefore the analysis was completed using these species. The authors found that stem tissue concentration of Cl was better correlated with the species sensitivity to NaCl than stem tissue concentration of Na or leaf tissue concentration of Cl or Na.

Table 3.5. Woody species sampled in Townsend 1980

flowering dogwood (*Cornus florida*)
sweet honey locust (*Gleditsia triacanthos*)
Eastern sycamore *(Platanus occidentalis)*
white pine (*Pinus strobus*)
pin oak (*Quercus palustris*)
Japanese pagoda tree (*Sophora japonica*

Townsend 1983: This was a study on the effects of NaCl on six five-needled pine species. Plants were sprayed with NaCl solutions and the internal Cl concentration of needles was determined as were injury symptoms (compared with control plants) two weeks after spraying ended. Injury was recorded as the percentage of chlorosis and necrosis on treated plants minus the percent of chlorosis of the control plants. Different species accumulated different amounts of Cl and had greater injury than others, with Macedonian pine (*Pinus peuce)*, Eastern white pine (*P. strobus*), and bristle-cone pine (*P. aristada*) having the highest accumulation of Cl and greatest injury.

Townsend and Kwolek, 1987: In this study, thirteen pine species were sprayed for four weeks with NaCl solutions and evaluated for injury in a manner similar as described above (Townsend, A. M., 1983). Needle samples were taken and analysed for the internal Cl tissue concentration, four weeks after spraying ended; injury was assessed at the same time, and survival was determined 17 weeks after spraying ended.

Walton, 1969: The effect of winter and spring NaCl and $CaCl_2$ application was studied on Norway maple (*Acer platanoides*) trees planted in experimental sites in Connecticut. The study indicates that a total of 99 trees were treated over two winters, but there is no clear indication of replication or experimental design. There was no statistical analysis of the data, except for regression analysis of foliar symptom index on foliar chloride levels for plants treated in each winter of the study and plants treated in the spring. There was a significant linear relationship between foliar chloride levels and the symptom index from the trees treated with NaCl or $CaCl_2$ in the spring. The calculated EC_{25} value was 5000 ppm foliar Cl.

The tissue content of Cl and Na and a foliar symptom index was recorded following spring applications of NaCl or $CaCl_2$. Severity of the foliar symptoms increased with increasing rate of application.

Applications of NaCl or $CaCl_2$ to the soil during the winter apparently reduced dry weight with some treatments but not with others. Without statistical analysis, it is unclear if the observed means are due to treatment effects or plant variability. There was no linear relationship between foliar symptom index and foliar chloride levels following winter applications. EC_{25} values were not calculated because the treatments were reported as gm/m^2.

Werkhoven *et al.* 1966: In this study, the effect of adding NaCl, $CaCl_2$ and $MgSO_4$ to air-dried soil on dry matter, height and survival of Colorado blue spruce (*Picea pungens*) and Scots pine (*Pinus sylvestris*) grown at either 15% or 22% relative humidity. While the treatment was a mixture of salts, most of the salts added (about 60% by mass) was NaCl, so the mass of NaCl alone was used as the dose. In most cases, increasing the relative humidity conferred some protection to NaCl; the EC_{25} values tended to be similar, but slightly higher for plants grown at 22% relative humidity.

Wilcox 1986a: As discussed in Section 3.3.2, the salt tolerance limits (NOEL) was determined for survival of various woody wetland species following sampling of a bog located adjacent to an uncovered storage pile for 10 years (Table 3.6). The sodium and chloride water chemistry data should only be viewed as general ranges. Wilcox (1986a) also reported that salt tolerance limits were reported in the literature as moderate for pear (*Pyrus* sp.), and as low for holly (*Ilex* sp.), red maple (*Acer rubrum*), American larch (*Larix laricina*)and highbush blueberry (*Vaccinium corymbosum*).

Table 3.6 Salt tolerance limits (NOEL) for selected woody bog species (Wilcox 1986a).

Species	**Salt tolerance limits (NOEL) NaCl (ppm)**
holly (*Ilex* sp.)	1150
pear (*Pyrus* sp.)	1070
highbush blueberry (*Vaccinium corymbosum*)	580
red maple (*Acer rubrum*)	540
black highbush blueberry (*Vaccinium atrocuccum*)	400
common mountain holly (*Nemopanthus mucronata* [*mucronatus*])	280

3.6 Threshold value analysis

This section discusses the threshold values presented in Appendix Tables 3-6 on the basis of threshold type (EC_{25}, CTV, NOEL or LOEL), form of salt (Cl, Na or NaCl) and exposure route (substrate or aerial (tissue concentrations)).

3.6.1 Substrate Evaluations

Substrate evaluations include studies where plants were exposed to either soil or water applications of NaCl, Cl or Na. Some of these studies involve hydroponic (water) culture. It may be difficult to translate water culture concentration of NaCl, Cl or Na to soil concentration. Additionally, we know of no reliable method to convert concentrations of NaCl (as road salt might be regulated) to Na and Cl, or the reverse. The dissolution of NaCl in water will empirically result in equivalent molar concentrations of Na and Cl, but various binding processes with other substrate elements such as soil, post-dissolution, will remove some of the Na or Cl from the solution.

Table 3.7 summarizes the EC_{25} threshold values for plants exposed to NaCl via the growing substrate, where dosage was reported in concentrations of either Cl or Na. These values have been used in the threshold analysis as discussed below.

Table 3.7. EC_{25} threshold values, Na or Cl concentrations, for plant exposure via substrate (soil, soil solution or hydroponic (water) culture).

Threshold Values for Substrate EC_{25}		**Species**	**Endpoint**	**Study**
Na (ppm)	**Cl (ppm)**			
67.5	215	ponderosa pine (*Pinus ponderosa*)	foliar injury	Bedunah and Trlica, 1979
140	350	ponderosa pine	mortality	Bedunah and Trlica, 1979
160	350	ponderosa pine	foliar injury	Bedunah and Trlica, 1979
202		Temperate prairie species	root growth	Harrington and Meikle, 1992
232		Temperate prairie species	shoot growth	Harrington and Meikle, 1992
240	450	white cedar (*Thuja occidentalis)*	discolored foliage	Foster and Maun, 1977
270		Temperate prairie species	seed germination	Harrington and Meikle, 1992
300	500	White Cedar	root damage rating index	Foster and Maun, 1977

The first three EC_{25} threshold values are 67.5, 140 and 160 ppm for Na and 215, 350, and 350 for Cl. These threshold values are for foliar injury and mortality following soil application of a NaCl solution to ponderosa pine, a woody coniferous species. These threshold values are relevant to the regulation of road salt since this species grows in southern British Columbia, however the regression lines have very wide confidence intervals.

The second "group" of EC_{25} threshold values (202, 232 and 270 ppm Na) will be considered together, because of the similarity in the values. All values are from a study on prairie grasses and forbs (Harrington and Meikle 1992) but represent different endpoints (seed germination, shoot and root growth). This study has a high level of applicability to the regulation of road salt, since six of the plants are native to Canada and are important components of various prairie communities across the country (Morgan *et al.* 1995); and since the experiments were conducted in soil.

The final "group" of EC_{25} threshold values, 240 and 300 ppm Na paired with 450 and 500 ppm Cl are for root and foliage injury of white cedar, a species that is native to eastern Canada

For the Tier 1 and Tier 2 assessments, the study by Bedunah and Trlica (1979) reporting foliar injury of Ponderosa pine, had the lowest substrate EC_{25} threshold values, 215 ppm for Cl and 67.5 ppm for Na.

Table 3.8 summarizes the EC_{25} threshold values for plants exposed to NaCl via the growing substrate, where dosage was reported in concentrations of NaCl. These values have been used in the threshold analysis as discussed below and have been divided into four groups for the purpose of the discussion.

Table 3.8. EC_{25} threshold values, NaCl concentration, for plant exposure via substrate (soil, soil solution or hydroponic (water) culture).

Threshold Values for Substrate EC_{25}, CTV NaCl (ppm)	Species	Endpoint	Study	Group
600	*Picea pungens* (Colorado Blue Spruce)	survival	Werkhoven *et al.*, 1966	1
600	*Pinus sylvestris* (Scots Pine)	dry matter	Werkhoven *et al.*, 1966	
630	*Picea pungens* (Colorado Blue Spruce)	dry matter	Werkhoven *et al.*, 1966	
650	*Pinus sylvestris* (Scots Pine)	dry matter	Werkhoven *et al.*, 1966	
700	*Pinus sylvestris* (Scots Pine)	survival	Werkhoven *et al.*, 1966	
700	*Betula alleghaniensis*	germination	Bicknell and Smith 1975	
800	*Picea pungens* (Colorado Blue Spruce)	dry matter	Werkhoven *et al.*, 19666	
836	*Cornus florida, Platanus occidentalis*	leaf dry weight	Townsend 1980	
850	*Picea pungens* (Colorado Blue Spruce)	survival	Werkhoven *et al.*, 1966	
882	*Catalpa bignoides*	germination	Bicknell and Smith 1975	
950	*Pinus rigida*	germination	Bicknell and Smith, 1975	
1750	*Pinus sylvestris* (Scots Pine)	survival	Werkhoven *et al.*, 1966	2
2200	*Pinus sylvestris* (Scots Pine)	height	Werkhoven *et al.*, 1966	
2240	*Platanus occidentalis, Pinus strobus*	dry weight of stem plus root	Townsend 1980	

Table 3.8. Continued				
Threshold Values for Substrate EC_{25}, CTV NaCl (ppm)	**Species**	**Endpoint**	**Study**	**Group**
<2500	Temperate prairie species	germination	Biesboer and Jacobson, 1994	2
2700	*Cornus florida*	seedling height growth	Townsend 1980	
2935	*Pinus rigida*	germination	Bicknell and Smith 1975	
4250	*Cornus florida, Platanus occidentalis, Pinus strobus*	root dry weight	Townsend 1980	
5250	*Pinus sylvestris* (Scots Pine)	height	Werkhoven *et al.*, 1966	
5500	*Picea pungens* (Colorado Blue Spruce)	height	Werkhoven *et al.*, 1966	
5900	Bean, beet	shoot growth	Smith and McComb, 1981	3
6690	*Agrostis stolonifera*	relative growth rate	Ahmad and Wainwright, 1994	
8400	*Juncus* spp.	relative growth rate	Rozema and Visser, 1981	
10000	Tropical grasses	shoot growth	Marcum and Murdoch, 1994	
10800	*Crataegus monogyna*	plant death	Thompson and Rutter, 1986	4
13100	*Rosa rubiginosa*	dry weight increase per plant (% of control)	Thompson and Rutter, 1986	
18900	*Viburnum lantana*	dry weight increase per plant (% of control)	Thompson and Rutter, 1986	
25000 (CTV)	*Cornus sanguinea*	dry weight increase per plant (% of control)	Thompson and Rutter, 1986	

The first "group" of EC_{25} threshold values ranges from 600 to 950 ppm, contains eleven individual EC_{25} values. These are derived from four studies of woody plants including *Picea pungens* (Colorado Blue Spruce), *Pinus sylvestris* (Scots Pine), *Betula alleghaniensis* (yellow birch), *Cornus florida* (flowering dogwood), *Platanus occidentalis* (American sycamore or plane tree), *Catalpa bignoides* (southern Catalpa), and *Pinus rigida* (pitch pine). The Werkhoven *et al.* (1966) and Bicknell and Smith (1975) studies were conducted using soil as the delivery media for NaCl. The endpoints were germination, survival and dry matter accumulation of seedlings.

The Townsend (1980) study evaluated *Cornus* and *Platanus* plant response to NaCl in water culture. The endpoint for this EC_{25} value is leaf dry weight, which was reduced by increasing salt concentration. The species covered in Group 1 are commonly found in the vicinity of roadsides or in forest or ornamental sites in parts of Canada that receive road salt. Therefore, these EC_{25} threshold values are credible values for consideration in regulating road salts in the environment. Of the three studies that contributed EC_{25} threshold values to Group 1, the threshold values from the Werkhoven *et al.* (1966) study (600-850 ppm) seem more ecologically relevant. They would protect critical endpoints (survival, germination and dry matter accumulation) as well as the less critical endpoint (height).

The last EC_{25} value (950 ppm) in Group 1 is a study on germination of *Pinus rigida* (pitch pine) seeds. Pitch pine is native to Ontario and eastern Canada, so this EC_{25} value merits some examination. The study measured germination after 3 and 6 days; there was an effect at three days (the data that are the basis of the EC_{25} threshold value), but there was no effect on germination after 6 days. This suggests that the effect was transient, one of delay of germination rather than reduction. Further, there is little biological or ecological reason to suggest that a three day delay in germination is a negative effect since under some circumstances this delay might have positive impact on plant success.

The second group of EC_{25} threshold values range from 1,750 to 5,500 ppm. Four of these (1,750, 2,200, 5,250 and 5,500 ppm) are from the same study as the group of EC_{25} values ranging from 600 to 850 ppm (Werkhoven *et al*. 1966). The biological effects were evaluated at low and higher humidity, and the endpoints were height and survival. Height was a less sensitive endpoint than survival (1750 ppm) or dry matter accumulation (not in this group at all).

In the middle of this group is an EC_{25} value (<2,500) that is estimated from an $EC_{45.}$ It was the lowest concentration used in the study, of the effect of NaCl on germination of temperate prairie species, that resulted in an EC_{45}.

The four EC_{25} values from the Townsend (1980) study, were estimated from studies of *Cornus florida*, *Platanus occidentalis* and *Pinus strobus* done in water culture.. The endpoints were leaf dry weight (*Cornus*, *Platanus*); stem plus root dry weight (*Platanus*, *Pinus*); root dry weight (*Cornus*, *Platanus*, *Pinus*) and seedling height (*Cornus*). Leaf dry weight was the most sensitive endpoint (836 ppm), but would not critically affect plant survival unless a repeated event. The middle and highest EC25 values of this group (2,240 and 4,250) would be more biologically relevant, since they protect dry matter accumulation.

The next group of EC_{25} values range from 5,900 to 10,000 ppm. These have been grouped together, because they are herbaceous species. More importantly, they are all studies that were conducted in water culture, with root or shoot growth, or relative growth rate as the endpoint. Because we know of no reliable way that effective concentrations in water culture could be related to total soil concentrations (presumably the method by which road salts in soils will be monitored), we have little sense that these hydroponically derived EC_{25} values are useful in the regulation of road salts in the environment. It could, perhaps, be argued that hydroponic NaCl concentrations would be relevant to soil water concentrations of NaCl, if those were monitored, but that extrapolation would require some careful characterization of soil-solution chemistry. This may also be true for EC_{25} values determined from soil studies, as one might expect that soil-solution chemistry, which varies with soil type, may influence the availability of Na or Cl ions to plant roots.

The final group of EC_{25} and CTV values (10,800 to 18,900) are from the same study and use soil applied treatments of NaCl solution on *Craetagus monogyna*, *Rosa rubiginosa*, *Cornus sanguinea* and *Viburnum lantana*. The endpoints are plant death (10,800) and dry weight increase. The first two species are native woody shrub species and last two are landscape shrub species, which make these credible values for consideration.

For the Tier 1 and Tier 2 assessments, the study by Werkhoven *et al.* (1966), reporting survival of Colorado blue spruce, had the lowest substrate EC_{25} value having a significant effect, 600 ppm NaCl.

Table 3.9 summarizes the NOEL threshold values for plants exposed to NaCl via the growing substrate, where dosage was reported in concentrations of NaCl. These values have been used in the threshold analysis as discussed below and have been divided into two groups for the purpose of the discussion.

The first group of NOEL values, with respect to NaCl concentration for plants growing *in situ*, ranges from 280 to 1070 ppm NaCl, and is taken from a study of bog species. These values are imprecise, since they represent general ranges resulting from sampling of bog water. The endpoints were the existence of the individual species within the concentration zones, which was interpreted as salt tolerance.

The next group of NOEL values range from 5,300 to 66,600 ppm NaCl, and were assembled by Wilcox (1986a) from four literature reports for other bog species.

The NOEL values from these five studies are relevant to the regulation of road salts since all of these species are found in wet areas in Canada.

For the Tier 1 and Tier 2 assessments, the study by Wilcox (1986a), reporting the salt tolerance of *Carex trisperma* and *Nemopanthus mucronata* [*mucronatus*], had the lowest substrate NOEL having a significant effect, 280 ppm NaCl.

Table 3.9. NOEL threshold values, NaCl concentration, for plant exposure via substrate (soil, soil solution or hydroponic (water) culture).

Threshold Values for Substrate NOEL	Species	Endpoint	Study	Group
NaCl (ppm)				
280	*Nemopanthus mucronata [mucronatus]*	tolerance	Wilcox 1986a	1
280	*Carex trisperma*	tolerance	Wilcox 1986a	
360	*Rhynchospora alba*	tolerance	Wilcox 1986a	
360	*Drosera intermedia*	tolerance	Wilcox 1986a	
400	*Solidago graminifolia*	tolerance	Wilcox 1986a	
400	*Vaccinium atrocuccum*	tolerance	Wilcox 1986a	
540	*Acer rubrum*	tolerance	Wilcox 1986a	
580	*Vaccinium corymbosum*	tolerance	Wilcox 1986a	
760	*Panicum implicatum*	tolerance	Wilcox 1986a	
770	*Sphagnum* sp.	tolerance	Wilcox 1986a	
1030	*Bidens connata*	tolerance	Wilcox 1986a	
1070	*Scirpus cyperinus*	tolerance	Wilcox 1986a	
1070	*Hypericum virginicum*	tolerance	Wilcox 1986a	
1070	*Drypoteris thelypteris*	tolerance	Wilcox 1986a	
1070	*Pyrus* sp.	tolerance	Wilcox 1986a	
1150	*Ilex* sp.	tolerance	Wilcox 1986a	
5300	*Utricularia*	tolerance	Penfold and Hathaway 1938 (taken from Wilcox 1986a)	2
5260-12870	*Typha latifolia*	tolerance	Kaushik 1963 (taken from Wilcox 1986a)	
8900	*Cephalanthus occidentalis*	tolerance	Penfold and Hathaway 1938 (taken from Wilcox 1986a)	
8900	*Sagittaria*	tolerance	Penfold and Hathaway 1938 (taken from Wilcox 1986a)	
10000	*Typha latifolia*	tolerance	McMillan 1959 (taken from Wilcox 1986a)	
11300	*Typha latifolia*	tolerance	Penfold and Hathaway 1938 (taken from Wilcox 1986a)	
16800	*Typha angustifolia*	tolerance	Penfold and Hathaway 1938 (taken from Wilcox 1986a)	
20000	*Typha angustifolia*	tolerance	McMillan 1959 (taken from Wilcox 1986a)	
66600	*Lemna minor*	tolerance	Haller *et al.* 1974 (taken from Wilcox 1986a)	

Table 3.10 summarizes the LOEL threshold values for plants exposed to NaCl via the growing substrate, where dosage was reported in concentrations of Cl. These values have been used in the threshold analysis as discussed below.

These four LOEL threshold values are from two studies on sphagnum moss, *Sphagnum recurvum* and *S. fimbriatum*, which are native to wetlands in eastern Canada (Crum and Anderson 1981). The endpoints are gametophore production (measure of reproduction) (300 ppm), length increase and biomass production.

For the Tier 1 and Tier 2 assessments, the study by Wilcox (1984), reporting length increase of *Sphagnum recurvum*, had the lowest substrate LOEL threshold value having a significant effect, 300 ppm Cl.

Table 3.10. LOEL threshold values, Cl concentration, for plant exposure via substrate (soil, soil solution or hydroponic (water) culture).

Threshold Values for Substrate LOEL	**Species**	**Endpoint**	**Study**
Cl (ppm)			
300	*Sphagnum recurvum*	length increase	Wilcox 1984
300	*Sphagnum fimbriatum*	gametophore production	Wilcox and Andrus 1987
500	*Sphagnum fimbriatum*	length increase	Wilcox and Andrus 1987
1500	*Sphagnum fimbriatum*	biomass increase	Wilcox and Andrus 1987

Table 3.11 summarizes the LOEL threshold values for plants exposed to NaCl via the growing substrate, where dosage was reported in concentrations of NaCl. These values have been used in the threshold analysis as discussed below.

Table 3.11. LOEL threshold values, NaCl concentration, for plant exposure via substrate (soil, soil solution or hydroponic (water) culture).

Threshold Values for Substrate LOEL	**Species**	**Endpoint**	**Study**
NaCl (ppm)			
400	*Eriophorum vaginatum* var. *spissum*	biomass	Schauffler 1993
400	*Eriophorum vaginatum* var. *spissum*	tiller production	Schauffler 1993
1600	*Eriophorum vaginatum* var. *spissum*	flower production	Schauffler 1993

These LOEL threshold values are for *Eriophorum vaginatum* var. *spissum*, a sedge species that is found across Canada in bogs and conifer swamps. The end points are for biomass and tiller (shoot) production (400 ppm) and flower production (1600 ppm).

For the Tier 1 and Tier 2 assessments, the study by Schauffler (1993), reporting biomass increase and tiller production of *Eriophorum vaginatum* var. *spissum*, had the lowest substrate LOEL threshold value having a significant effect, 400 ppm NaCl.

3.6.2 Tissue Evaluations

Table 3.12 summarizes the EC_{25} threshold values for plants exposed to NaCl via aerial exposure, where dosage was reported in concentrations of Na. Table 3.13 summarizes the EC_{25} threshold values for plants exposed to NaCl via aerial exposure, where dosage was reported in concentrations of Cl. These values in these two tables have been used in the threshold analysis as discussion that follows.

For the most part, the EC_{25} values in the above two tables are paired from the same studies, and will be discussed together. All of the endpoints are for tissue injury or symptom rating (Hanes *et al.* 1976, Lacasse and Rich 1964).

The lowest Na EC_{25} threshold value (200 ppm) is not credible, because the value of it is driven entirely by the inclusion (or not) of an extreme outlier in the data set, with no information to discern whether or not the value should be included, or not, in the analysis. This is matched with the second lowest Cl EC_{25} value (2,000 ppm), the determination of which is credible. The species, white fir, *Abies concolor*, is planted as a landscape tree.

The next pair of Na EC_{25} values (575 and 631 ppm) are from an *in situ* study of 150 trees representing two maple species that are native to eastern Canada. The values represent decline symptoms, which would provide an indication of plant survival. These values are credible and relevant to the regulation of road salt.

The lowest Cl EC_{25} value (1,650); the next lowest Na EC_{25} value (1,750 ppm) (paired with a Cl EC_{25} of 4,000 ppm); and two pairs of Na/Cl EC_{25} values (2,100/1,650 and 2,750/7,000 ppm) are for foliar injury and mortality of *Pinus ponderosa.* Since this species is native to the southern part of British Columbia, these values should be considered. However, the data required significant extrapolation to determine the EC_{25} values.

Table 3.12. EC_{25} threshold values, expressed as Na concentration, for plant aerial exposure to NaCl.

Threshold Values for Tissue EC_{25}	**Species**	**Endpoint**	**Study**
Na (ppm)			
200	White Fir	injury rating	Scharf and Srago, 1974
575	*Acer saccharum* and *Acer rubrum*	decline symptoms	Lacasse and Rich 1964
631	*Acer saccharum* and *Acer rubrum*	decline symptoms	Lacasse and Rich 1964
1750	*Pinus ponderosa* (ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
1900	*Prunus persica* (peach cv Madison)	% dead buds	Chong and Lumis, 1990
2100	*Thuja occidentalis* (white cedar)	foliar injury	Hofstra and Hall, 1971
2100	*Pinus ponderosa* (ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
2380	*Acer saccharinum*	symptom rating	Hanes *et al.* 1976
2750	*Pinus ponderosa* (ponderosa pine)	mortality	Bedunah and Trlica, 1979
3300	*Prunus persica* (peach cv Loring)	% dead buds	Northover, 1987
4200	Woody species	injury class rating	Lumis, Hofstra and Hall 1976
4200	*Thuja occidentalis* (white cedar)	damage rating index	Foster and Maun, 1980
8000	*Pinus* spp. (multiple pine species)	survival	Townsend and Kwolek, 1987
10500	*Pinus* spp. (Multiple Pine species)	chlorosis and necrosis	Townsend and Kwolek, 1987
15700	*Gleditsia triacanthos var. inermis*	shoot dry weight	Dirr 1974
16100	Deciduous species	appearance index	Dirr 1978

Table 3.13. EC_{25} threshold values, expressed as Cl concentration, for plant aerial exposure to NaCl.

Threshold Values for Tissue EC_{25} Cl (ppm)	Species	Endpoint	Study
1650	*Pinus ponderosa* (ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
2000	White fir	injury rating	Scharf and Srago, 1974
4000	*Pinus ponderosa* (ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
4700	*Thuja occidentalis* (white cedar)	foliar injury	Hofstra and Hall, 1971
4950	Woody species	injury class rating	Lumis, Hofstra and Hall 1976
5000	*Acer platanoides*	foliar symptom index	Walton 1969
5005	*Pinus strobus*	injury rating	Hall, Hofstra and Lumis 1972
6950	*Acer saccharum* and *Acer platanoides*	leaf dry wt	Simini and Leone 1986
7000	*Pinus ponderosa* (ponderosa pine)	mortality	Bedunah and Trlica, 1979
7200	*Thuja occidentalis* (white cedar)	damage rating index	Foster and Maun, 1980
9000	*Prunus persica* (peach cv Madison)	percentage dead buds	Chong and Lumis, 1990
13000	*Pinus* spp. (multiple pine species)	survival	Townsend and Kwolek, 1987
14000	*Pinus* spp. (multiple pine species)	chlorosis and necrosis	Townsend, 1983
16000	*Pinus* spp. (multiple pine species)	chlorosis and necrosis	Townsend and Kwolek, 1987
22980	*Acer saccharinum*	symptom rating	Hanes *et al.* 1976
23100	*Acer saccharinum*	symptom rating	Hanes *et al.* 1976
35700	Deciduous species	appearance index	Dirr 1978
39400	*Gleditsia triacanthos* var. *inermis*	shoot dry weight	Dirr 1974
70700	*Acer saccharinum*	symptom rating	Hanes *et al.* 1976

The next lowest Na EC_{25} value (1,900 ppm) is for percent dead buds of peach, and is paired with the Cl EC_{25} value of 9000 ppm. Since these data were gathered from plants *in situ* in Ontario, these EC_{25} values are highly credible.

The next lowest Na EC_{25} value (2,100 ppm) is for injury of white cedar (*Thuja occidentalis*) and is paired with the Cl EC_{25} of 4700. Since these data were gathered *in situ*, and the species is native to Canada, these EC_{25} values for Na and Cl are highly credible.

The next lowest Na EC_{25} value (2,380 ppm) is for injury of silver maple (*Acer saccharinum*) and is paired with Cl EC_{25} values ranging from 22,980 to 70,700 ppm. This species is native to Canada.

The next Na EC_{25} (3,300 ppm) is for dead buds of peach. Since these data were gathered *in situ,* in Ontario, this EC_{25} is credible and relevant to the regulation of road salts.

The next Na EC_{25} value (4,200 ppm) is paired with a Cl EC_{25} value of 7,200 ppm, and is for *Thuja occidentalis*, and the endpoint was overall tree health. These data were not gathered *in situ*, rather in a laboratory spray solution. The species is native to Canada, so the EC_{25} value has some relevance to the regulation of road salts.

A second Na EC_{25} of 4,200 ppm is paired with a Cl EC_{25} value of 4,950 ppm. These are for injury data of 12 woody species that are native to Canada or planted as landscape plants.

The next unmatched Cl EC_{25} values are 5,000 and 5,005 ppm, for injury to Norway maple (*Acer platanoides*) and white pine (*Pinus strobus*), respectively. These species are both relevant to Canadian landscapes.

The next Na EC_{25} value (8,000 ppm) is paired with Cl EC_{25} value of 13000 ppm, and is derived from a study with multiple *Pinus* species, only some of which are native to Canada. The endpoint was survival of seedlings in the laboratory study using foliar spray. A superficial evaluation of the impact of the non-native species on the determination of Na EC_{25} value suggests that, in fact, their sensitivity may be largely driving the value of Na EC_{25}. The same comment can be made for the Cl EC_{25} value. It may be worth noting that *P. strobus* and *P. resinosa* are the two most sensitive species in the grouping, and both are native to Canada. For these reasons, it is recommended that neither of the EC_{25} values be accepted as is; if they turn out to be in the neighbourhood of the critical values for regulation of road salts, then the regression analysis should be re-examined.

The next Na EC_{25} value (10,500 ppm) and the matching Cl EC_{25} value (16,000 ppm) are for the study described in the preceding paragraph; the endpoint is the ratio of healthy/unhealthy tissue, where "unhealthy" was defined as necrotic/chlorotic. The same mix of native and non-native species has been examined, but with this endpoint *P. strobus* was the most sensitive. The same value would have been arrived at with or without the inclusion of the non-native species data.

The next EC_{25} value is an unmatched Cl EC_{25} value (14,000 ppm), using six pine species, five of which were non-native, and *P. strobus*; the endpoint was ratio of healthy/unhealthy tissue. The regression is driven largely by non-native species, so we recommend that this EC_{25} value not be looked at further or be re-examined.

The last group are Cl EC_{25} values, ranging from 35,700 to 70,700 ppm, for injury symptoms or dry weight of decidous, woody species found in Canadian landscapes.

For the Tier 1 and Tier 2 assessments, the study by Lacasse and Rich (1964), reporting decline symptoms of *Acer saccharum* and *Acer rubrum*, had the lowest tissue Na EC_{25} value having a significant effect, 575 ppm Na. the study by Bedunah and Trlica (1979), reporting foliar injury of *Pinus ponderosa*, had the lowest tissue Cl EC_{25} value having a significant effect, 1,650 ppm Cl.

Two EC_{25} values for plant tissue were determined for turfgrasses following root uptake. A Na EC_{25} value of <280 ppm was estimated for turfgrasses using data from a soil-pot study. This is paired with a Cl EC_{25} value of <4100 ppm. Since the turfgrass species chosen (tall fescue, red fescue, bromegrass and Kentucky bluegrass) are used for roadside and urban landscaping, these values could make a credible contribution to evaluating the environmental risk of road salts. However, the values are imprecise, because the regression passes through the origin at a value greater than 25% loss of shoot growth.

A Na EC_{25} value (17,800 ppm) was determined for shoot concentration of *Juncus* spp., a herbaceous wetland species, from a water culture study. Since this is a known salt tolerant genus, and the caryopses (seeds) for this study were collected from saline environments, it is recommended that this EC_{25} value not be considered further.

Table 3.14 summarizes the CTV threshold values for aerial exposure of plants NaCl, where dosage was reported in concentrations of either Cl or Na. These values have been used in the threshold analysis as discussed below.

CTV's were calculated in cases where EC25 values could not be determined. This was the case in studies where there was no control treatment, *per se*, because the data were determined from *in situ* observations. For example, twig dieback as an endpoint was generally not reported in the literature as a percent of the total twig length, but rather as number of centimeters, with no information about how long the twig was.

Table 3.14. CTV threshold values, Na , Cl or NaCl concentrations, for plant aerial exposure.

Threshold Values for Tissue CTV			**Species**	**Endpoint**	**Study**
NaCl (ppm)	**Na (ppm)**	**Cl (ppm)**			
	650	800	*Prunus persica* and *Prunus domestica* (Peach and Plum)	twig dieback	McLaughlin and Pearson, 1981
	1000	1700	*Prunus persica* (Peach cv Loring)	yield	Northover, 1987
	1100	4800	*Prunus persica* (Peach)	twig dieback	Chong and Lumis, 1990
	1600	5600	*Prunus persica* (Peach cv Garnet Beauty)	twig dieback	Chong and Lumis, 1990
	1700		*Prunus persica* (Peach cv Loring)	% dead buds	Northover, 1987
	1800	7800	P*runus persica* (Peach cv Madison)	twig dieback	Chong and Lumis, 1990
	1900	8000	*Prunus persica* (Peach cv Madison)	% dead buds	Chong and Lumis, 1990

This means that it is not possible to determine 25% of the maximum effect, as we would need to know the total twig length for that calculation. For the most part, the CTV's are paired from the same study, and will be discussed together. All of the endpoints in the table are for tissue injury. The CTV for NaCl foliar spray solution is 25000 ppm for the endpoint of number of dead shoots.

The first Na/Cl CTV's (650 ppm and 800 ppm) were for twig dieback of peach and plum, measured *in situ* in Ontario, so are highly credible and relevant to the regulation of road salts in Canada.

The second pair of CTV's (1000 ppm for Na; 1700 ppm for Cl) were for peach (cv. Loring) and the response was fruit yield; the data were gathered *in situ*, in Ontario, so are highly credible and relevant to the regulation of road salts in Canada.

The third pair of CTV's (1100 ppm for Na; 4800 ppm for Cl) were for twig dieback of peach (cvs. Garnet Beauty and Madison). The individual cultivars had similar CTV values (Garnet Beauty: 1600 ppm for Na and 5600 ppm for Cl; Madison: 1800 ppm for Na and 7800 ppm for Cl). The pooled CTV's are lower than the individual CTV's because CTV's are dependent on the confidence interval, which is in turn dependent on the number of data points. Analyzing the cultivars individually increases the uncertainty, and thus results in wider confidence bands.

For the Tier 1 and Tier 2 assessments, the study by McLaughlin and Pearson (1981), reporting twig dieback of peach and plum, had the lowest tissue Cl and Na CTV's having significant effects, 800 ppm Cl and 650 ppm Na.

4.0 TOXICITY ASSESSMENT

4.1. Approach

The toxicity assessment for road salts on plants has been done using quotient based Tier I and Tier II assessments and a Detailed Risk Characterization. The methods used for the Tier I and II assessments followed the guidelines provided by Environment Canada (1977).

The Tier I and II assessments have been done on all types of plants as a group. The assessments were done for the following:

- each type of threshold, EC_{25}, CTV, LOEL and NOEL
- each form of salt that was evaluated in the literature, NaCl, Cl and Na
- each mode of exposure, growing substrate exposure (soil, soil water or water) and aerial (direct tissue) exposure.

EC_{25} threshold values were identified for Cl, Na and NaCl in growing substrates and for Cl and Na in plant tissue. CTV threshold values were identified for Cl and Na in plant tissue. LOEL threshold values were identified for Cl and NaCl in growing substrate and a NOEL threshold value was identified for NaCl in growing substrate.

4.2 Tier I Assessment

4.2.1 Effects Threshold Values

For the Tier I assessment the values used for each type of threshold were the lowest concentrations that were identified in the threshold value analysis (Section 3.6):
- EC_{25} threshold values for Cl, Na and NaCl in growing substrates and for Cl and Na in plant tissue
- CTV threshold values for Cl and Na in plant tissue
- LOEL threshold values for Cl and NaCl in growing substrates
- NOEL threshold value for NaCl in growing substrates

These threshold values have been tabulated in Tables 4.1 and 4.2. The plant species represented include sphagnum moss; two sedge species; a deciduous shrub, mountain holly; coniferous tree species including pine, and spruce; and decidous trees including maple, peach and plum.

The threshold values were as follows:
- 215 to 300 ppm Cl in growing substrates (either applied soil solution or hydroponic (water) culture solution)
- 67.5 ppm Na in growing substrates (applied soil solution)
- 280 to 600 ppm NaCl in growing substrates (applied to soil or recorded as a general solution gradient in bog water)
- 800 to 1650 ppm Cl in tissue (foliage or twigs)
- 575 to 650 ppm Na in twig tissue

4.2.2 Application Factors

The threshold values were multiplied by an application factor to provide the estimated no effect values (ENEV). The application factors were determined by evaluating the individual studies. A higher application factor was used if the studies were performed in experimental or laboratory environments, for shorter exposure periods on a limited number of taxon and if there was a limited database.

In most instances, an application factor of 100 was used since the individual studies involved only one or two species and involved a limited database of less than 50 individuals (Table 4.1). About half of the studies were done in controlled environment (laboratory) settings and involved time frames that only covered a few weeks or months in the life of a perennial plant.

In the study of three-fruited sedge and mountain holly (Wilcox 1986a), the measurements of substrate concentrations were only general salt ranges taken from samples of a wetland environment which introduced an element of uncertainty about the precise threshold value. For this reason, an application factor of 100 was used for the NOEL of NaCl in substrate.

An application factor of 10 was applied for the Lacasse and Rich (1964) maple study. The trees that were sampled were mature trees in field settings that had been exposed to operational road salting for a number of winters. One hundred and fifty trees of two maple species were sampled during the evaluation.

4.2.3 Estimated Exposure Values

In order to estimate exposure values, literature was reviewed from applicable Canadian, American and European studies. Studies were selected that reported values of NaCl, Na or Cl concentrations for soil or vegetation samples and reported the sampling distance for each sample from the source of de-icing salt application (i.e., distance from a road or highway) (Section 2.2). The values used were substrate (soil or soil solution) concentrations and plant tissue concentrations following in situ exposure to de-icing salts.

4.2.4 Substrate (Soil, Soil Water or Aqueous Substrate) Exposure Values

For estimation of substrate (soil) exposure values for the Tier I evaluation, data was reviewed from references that provided measurements of substrate (soil, soil water or aqueous substrate) concentrations of Cl, Na or NaCl following road salting at given distances from the road or highway. This data included samples taken at various soil depths, from the surface to 165 cm, and samples taken up to 200 m from the road or highway and in median areas.

Ten references were reviewed for soil concentrations of Cl, from studies done in Ontario, Maine, Vermont, New Mexico, England and Sweden. Twelve references were reviewed for soil concentrations of Na, from studies done in Ontario, Maine, Vermont, Michigan, Minnesota, England and Sweden. Only 1 reference reported soil concentrations of NaCl along a highway in Connecticut.

The highest soil Cl concentration was 1564 ppm, reported directly adjacent to an interstate highway in Maine (Hutchinson 1968).

The highest soil Na concentration was 8360 ppm, reported at 1 m from edged of pavement, at the intersection of two interstate highways in Minnesota (Biesboer and Jacobson 1994).

The highest soil NaCl concentration was 475 ppm, reported 1.5 m from a Connecticut highway (Prior 1968).

4.2.5 Plant Tissue Exposure Values

In order to estimate the aerial exposure of plants to NaCl following road de-icing, references were reviewed that reported concentrations of Cl or Na in plant tissues at given distances from the road or highway, following exposure to road salt aerial dispersion. These values provided a method of directing linking the environmental aerial concentrations with plant effects.

Eight references were reviewed for tissue concentrations of Cl and 11 references were reviewed for tissue concentrations of Na from studies done in Ontario, Maine, Connecticut, Michigan, Illinois, California, Nevada and Sweden. This data included plant tissue samples taken from 1.4 to 1018 m from the road or highway. The plant genera represented were *Pinus, Picea, Tsuga, Acer, Prunus* and unspecified vegetation sampled for twigs, needle or leaf tissue.

The highest tissue Cl concentration was 14000 ppm, reported in *Acer saccharum*, sugar maple growing 2.9 m from a Connecticut highway (Button and Peaslee 1966).

The highest tissue Na concentration was 6900 ppm, reported in *Prunus persica*, peach growing 20 m from a four-lane highway in southern Ontario (Northover 1987).

4.2.6 Quotient Estimation

The quotients were calculated by dividing the EEV by the ENEV. Table 4.2 summarizes the values calculated for the Tier I assessment. All quotients were greater than 1, indicating that environmental exposure values exceeded the estimated no effects values.

The quotients for Cl present in the growing substrate ranged from 521 for sphagnum moss to 727 for Ponderosa pine, therefore a Tier II assessment is warranted.

The quotient for Na present in the growing substrate was 12,385 for Ponderosa pine, therefore a Tier II assessment is warranted.

The quotients for NaCl present in the growing substrate ranged from 119 for dense cottongrass sedge to 808 for three-fruited sedge and mountain holly, therefore a Tier II assessment is warranted.

The quotients for Cl present in the plant tissue ranged from 848 for Ponderosa pine to 1750 for peach and plum, therefore a Tier II assessment is warranted.

The quotients for Na present in the plant tissue ranged from 120 for maple to 1062 for peach and plum, therefore a Tier II assessment is warranted.

Table 4.1. Determination of application factors for the Tier I evaluations.

Plant Species, End Point	Source	Form	Threshold	Threshold Values	Controlled environment or field	Length of Exposure	Number of taxa	Limited database	Other Notes	Application Factor
Pinus ponderosa (Ponderosa pine), foliar injury	substrate (applied soil solution)	Cl	EC_{25}	215	CE	150 days	1	yes		100
Sphagnum recurvum (Sphagnum moss), length growth reduction	substrate (hydroponic solution)	Cl	LOEL	300	CE	45 days	1	no, 560 plant samples		100
Pinus ponderosa (Ponderosa pine), foliar injury	substrate (applied soil solution)	Na	EC_{25}	67.5	CE	150 days	1	yes		100
Picea pungens (Colorado blue spruce), seedling survival	substrate (applied to soil)	NaCl	EC_{25}	600	CE	up to 98 days	1	no, 300 seedlings		100
Carex trisperma (three-fruited sedge) and *Nemopanthus mucronata* [*mucronatus*] (mountain holly), salt tolerance limit	substrate (general gradient in bog water)	NaCl	NOEL	280	F	over 3 years	2	no, multiple sampling transects over 3 year period	Concentration questionable, represents general salt ranges in a wetland system	100
Eriophorum vaginatum var. *spissum* (dense cottongrass sedge), biomass and tiller reductions	substrate (hydroponic culture)	NaCl	LOEL	400	CE	49 days	1	no, 128 plants		100
Pinus ponderosa (Ponderosa pine), foliar injury	tissue (foliar)	Cl	EC_{25}	1650	CE	150 days	1	yes		100
Prunus persica (peach) and *Prunus* sp. (plum), twig [shoot] dieback	tissue (twig)	Cl	CTV	800	F	field samples of roadside trees	2	yes		100
Acer saccharum (sugar maple) and *Acer rubrum* (red maple), symptoms of plant decline	tissue (twig)	Na	EC_{25}	575	F	field samples of roadside trees	2	no, 150 trees		10
Prunus persica (peach) and *Prunus* sp. (plum), twig [shoot] dieback	tissue (twig)	Na	CTV	650	F	field samples of roadside trees	2	yes		100

Table 4.2. Determination of quotients for the Tier I evaluations.

Plant Species, End Point	Reference	Source	Form	Threshold	Threshold Values (TV)	Application Factor	ENEV TV/Appl. factor	EEV	Quotient EEV/ ENEV
Pinus ponderosa (Ponderosa pine), foliar injury	Bedunah and Trlica 1979	substrate (applied soil solution)	Cl	EC_{25}	215	100	2.15	1564	727
Sphagnum recurvum (Sphagnum moss), length growth reduction	Wilcox 1984	substrate (hydroponic solution)	Cl	LOEL	300	100	3.0	1564	521
Pinus ponderosa (Ponderosa pine), foliar injury	Bedunah and Trlica 1979	substrate (applied soil solution)	Na	EC_{25}	67.5	100	0.675	8360	12,385
Picea pungens (Colorado blue spruce), seedling survival	Werkhoven, Salisbury and Cram 1966	substrate (applied to soil)	NaCl	EC_{25}	600	100	6.0	475	377
Carex trisperma (three-fruited sedge) and *Nemopanthus mucronata* [*mucronatus*] (mountain holly), salt tolerance limit	Wilcox 1986a	substrate (general gradient in bog water)	NaCl	NOEL	280	100	2.8	475	808
Eriophorum vaginatum var. *spissum* (dense cottongrass sedge), biomass and tiller reductions	Schauffler 1993	substrate (hydroponic culture)	NaCl	LOEL	400	100	4.0	475	119
Pinus ponderosa (Ponderosa pine), foliar injury	Bedunah and Trlica 1979	tissue (foliar)	Cl	EC_{25}	1650	100	16.5	14,000	848
Prunus persica (peach) and *Prunus* sp. (plum), twig [shoot] dieback	McLaughlin and Pearson 1981	tissue (twig)	Cl	CTV	800	100	8.0	14,000	1750
Acer saccharum (sugar maple) and *Acer rubrum* (red maple), symptoms of plant decline	Lacasse and Rich 1964	tissue (twig)	Na	EC_{25}	575	10	57.5	6,900	120
Prunus persica (peach) and *Prunus* sp. (plum), twig [shoot] dieback	McLaughlin and Pearson 1981	tissue (twig)	Na	CTV	650	100	6.5	6,900	1062

4.3 Tier II Assessment

4.3.1 Effects Threshold Values

For the Tier II assessment the values used for each type of threshold were the lowest concentrations that were identified in the threshold value analysis (Section 3.6) for each type of threshold:
- EC_{25} threshold values for Cl, Na and NaCl in growing substrate and for Cl and Na in plant tissue
- CTV threshold values for Cl and Na in plant tissue
- LOEL threshold values for Cl and NaCl in growing substrate
- NOEL threshold value for NaCl in growing substrate.

These threshold values have been tabulated in Tables 4.3 and 4.4. The plant species represented include sphagnum moss; two sedge species; a deciduous shrub, mountain holly; coniferous tree species including pine, and spruce; and decidous trees including maple, peach and plum.

The threshold values were as follows:
- 215 to 300 ppm Cl in growing substrate (either applied soil solution or hydroponic (water) culture solution);
- 67.5 ppm Na in growing substrate (applied soil solution);
- 280 to 600 ppm NaCl in growing substrate (applied to soil or general solution gradient in bog water);
- 800 to 1650 ppm Cl in tissue (foliage or twigs); and
- 575 to 650 ppm Na in twig tissue.

4.3.2 Application Factors

The threshold values were multiplied by an application factor to provide the estimated no effect values (ENEV). The application factors were determined by evaluating the individual studies. A higher application factor was used if the studies were performed in controlled environments, for shorter exposure time on a limited number of taxon and if there was a limited database.

In most instances, an application factor of 100 was used since the individual studies involved only one or two species and involved a limited database of less than 50 individuals (Table 4.3). About half of the studies were done in controlled environment (laboratory) settings and involved timeframes that only covered a few weeks or months in the life of a perennial plant.

In the study of three-fruited sedge and mountain holly (Wilcox 1986a), the substrate concentration measurements were only general salt ranges taken from samples of a wetland environment which introduced an element of uncertainty about the precise threshold value. For this reason, an application factor of 100 was used for the NOEL of NaCl in substrate.

An application factor of 10 was applied for the Lacasse and Rich (1964) maple study. The trees that were sampled were mature trees in field settings that had been exposed for a number of winters to operational road salting. One hundred and fifty trees of two maple species were sampled during the evaluation.

4.3.3 Estimated Exposure Values

For a more precise estimation of Canadian environmental concentrations, the data used for estimating exposure values for the Tier II analysis, was limited to references dealing with Canadian sites. Studies were selected that reported values of NaCl, Na or Cl concentrations for soil or vegetation samples and reported the sampling distance for each sample from the source of de-icing salt application (i.e., distance from a road or highway) (Section 2.2). The values used were substrate (soil or soil solution) concentrations and plant tissue concentrations following in situ exposure to de-icing salts.

4.3.4 Substrate (Soil, Soil Water or Aqueous Substrate) Exposure Values

For estimation of substrate (soil) exposure values for the Tier II evaluation, data was reviewed from references that provided measurements of substrate (soil, soil water or aqueous substrate) concentrations of Cl, Na or NaCl following road salting at given distances from the road or highway in Canadian environments. Three references reporting Ontario studies were reviewed for soil concentrations of Cl and Na (Section 2.2). This data included samples taken at various soil depths, from the surface to 35 cm, and samples taken up to 200 m from the road or highway as well as in median areas.

The estimated exposure values (EEV) used in the Tier II assessment were the highest values extracted from the all the literature dealing with environmental concentrations in Canada of Cl or Na in growing substrate (soil or aqueous) in roadside conditions. The highest soil Cl concentration reported was 1050 ppm in a sample taken in the highway median, and the highest soil Na concentration was 890 ppm in a sample taken 10 m from the highway, both from a study along a four-lane highway in Ontario (Hofstra and Smith 1984).

No Canadian references reported soil concentrations of NaCl. A value of soil NaCl was estimated based on the highest concentration of Cl found in the soil in a highway median, 1050 ppm. which was multiplied by a factor of 1.6485, resulting in a value of 1731 ppm NaCl. A second value of soil NaCl was estimated based on the highest concentration of Na found in the soil 10 m from the highway, 890 ppm, which was multiplied by a factor of 2.542, resulting in a value of 2262 ppm NaCl. The average of these two values, 1997 ppm NaCl, was used in the Tier II evaluation.

4.3.5 Plant Tissue Exposure Values

In order to estimate the aerial exposure of plants to NaCl following road de-icing, references were reviewed that reported concentrations of Cl or Na in plant tissues at given distances from the road or highway, following exposure to road salt aerial dispersion. These values provided a method of directing linking the environmental aerial concentrations with plant effects. For a more precise estimation of Canadian environmental concentrations, data was limited to studies on Canadian sites (refer to Section 2.2).

Three references were reviewed for tissue concentrations of Cl and Na. This data included plant tissue samples taken from 10 to 200 m from the road or highway. These references reported studies from Ontario on *Prunus* (peach and plum) and unspecified vegetation.

The highest tissue Cl concentration was 11000 ppm, reported in unspecified vegetation growing 60 m from a four-lane highway in Ontario (Hofstra and Smith 1984). Northover (1987) reported 9000 ppm in *Prunus persica*, peach, growing 20 m from a four-lane highway in Ontario. It was decided to use the second value since the plant species was recorded. The highest tissue Na concentration was 6900 ppm, reported in twig tissue of *Prunus persica*, peach growing 20 m from a four-lane highway in southern Ontario (Northover 1987).

4.3.6 Quotient Estimation

The quotients were calculated by dividing the EEV by the ENEV. Table 4.4 summarizes the values calculated for the Tier II assessment. All quotients were greater than 1, indicating that environmental exposure values exceeded the estimated no effects values.

The quotients for Cl present in the growing substrate ranged from 350 for sphagnum moss to 488 for Ponderosa pine, therefore a Tier III assessment is warranted.

The quotient for Na present in the growing substrate was 1,319 for Ponderosa pine, therefore a Tier III assessment is warranted.

The quotients for NaCl present in the growing substrate ranged from 333 for Colorado blue spruce to 713 for three-fruited sedge and mountain holly, therefore a Tier III assessment is warranted.

The quotients for Cl present in the plant tissue ranged from 545 for Ponderosa pine to 1125 for peach and plum, therefore a Tier III assessment is warranted.

The quotients for Na present in the plant tissue ranged from 120 for maple to 1062 for peach and plum, therefore a Tier III assessment is warranted

Table 4.3. Determination of application factors for the Tier II evaluations.

Plant Species, End Point	Source	Form	Threshold	Threshold values	Controlled environment or field	Length of Exposure	Number of taxa	Limited database	Other Notes	Application Factor
Pinus ponderosa (Ponderosa pine), foliar injury	substrate (applied soil solution)	Cl	EC_{25}	215	CE	150 days	1	yes		100
Sphagnum recurvum (Sphagnum moss), length growth reduction	substrate (hydroponic solution)	Cl	LOEL	300	CE	45 days	1	no, 560 plant samples		100
Pinus ponderosa (Ponderosa pine), foliar injury	substrate (applied soil solution)	Na	EC_{25}	67.5	CE	150 days	1	yes		100
Picea pungens (Colorado blue spruce), seedling survival	substrate (applied to soil)	NaCl	EC_{25}	600	CE	up to 98 days	1	no, 300 seedlings		100
Carex trisperma (three-fruited sedge) and *Nemopanthus mucronata* [*mucronatus*] (mountain holly), salt tolerance limit	substrate (general gradient in bog water)	NaCl	NOEL	280	F	over 3 years	2	no, multiple sampling transects over 3 year period	Concentration questionable, represents general salt ranges in a wetland system	100
Eriophorum vaginatum var. *spissum* (dense cottongrass sedge), biomass and tiller reductions	substrate (hydroponic culture)	NaCl	LOEL	400	CE	49 days	1	no, 128 plants		100
Pinus ponderosa (Ponderosa pine), foliar injury	tissue (foliar)	Cl	EC_{25}	1650	CE	150 days	1	yes		100
Prunus persica (peach) and *Prunus* sp. (plum), twig [shoot] dieback	tissue (twig)	Cl	CTV	800	F	field samples of roadside trees	2	yes		100
Acer saccharum (sugar maple) and *Acer rubrum* (red maple), symptoms of plant decline	tissue (twig)	Na	EC_{25}	575	F	field samples of roadside trees	2	no, 150 trees		10
Prunus persica (peach) and *Prunus* sp. (plum), twig [shoot] dieback	tissue (twig)	Na	CTV	650	F	field samples of roadside trees	2	yes		100

Table 4.4. Determination of quotients for the Tier II evaluations.

Plant Species, End Point	Reference	Source	Form	Threshold	Threshold Values	Application Factor	ENEV Threshold value/Appl. factor	EEV	Quotient EEV/ENEV
Pinus ponderosa (Ponderosa pine), foliar injury	Bedunah and Trlica 1979	substrate (applied soil solution)	Cl	EC_{25}	215	100	2.15	1050	488
Sphagnum recurvum (Sphagnum moss), length growth reduction	Wilcox 1984	substrate (hydroponic solution)	Cl	LOEL	300	100	3.0	1050	350
Pinus ponderosa (Ponderosa pine), foliar injury	Bedunah and Trlica 1979	substrate (applied soil solution)	Na	EC_{25}	67.5	100	0.675	890	1319
Picea pungens (Colorado blue spruce), seedling survival	Werkhoven, Salisbury and Cram 1966	substrate (applied to soil)	NaCl	EC_{25}	600	100	6.0	1997	333
Carex trisperma (three-fruited sedge) and *Nemopanthus mucronata* [*mucronatus*] (mountain holly), salt tolerance limit	Wilcox 1986a	substrate (general gradient in bog water)	NaCl	NOEL	280	100	2.8	1997	713
Eriophorum vaginatum var. *spissum* (dense cottongrass sedge), biomass and tiller reductions	Schauffler 1993	substrate (hydroponic culture)	NaCl	LOEL	400	100	4.0	1997	499
Pinus ponderosa (Ponderosa pine), foliar injury	Bedunah and Trlica 1979	tissue (foliar)	Cl	EC_{25}	1650	100	16.5	9,000	545
Prunus persica (peach) and *Prunus* sp. (plum), twig [shoot] dieback	McLaughlin and Pearson 1981	tissue (twig)	Cl	CTV	800	100	8.0	9,000	1125
Acer saccharum (sugar maple) and *Acer rubrum* (red maple), symptoms of plant decline	Lacasse and Rich 1964	tissue (twig)	Na	EC_{25}	575	10	57.5	6,900	120
Prunus persica (peach) and *Prunus* sp. (plum), twig [shoot] dieback	McLaughlin and Pearson 1981	tissue (twig)	Na	CTV	650	100	6.5	6,900	1062

4.4 Detailed Risk Characterization

Since the precise data was not available for typical Tier III assessment that would evaluate the distribution of plant exposure and effects due to road salt, a detailed risk characterization has been completed. The risk characterization incorporated the exposure data, the threshold data and reports of reference sites that provide evidence of road salt application directly resulting in plant effects. This risk characterization reviews concentrations of Cl and Na in soils or tissue that produce biologically relevant effects on vegetation and relates these to concentrations found in the Canadian environment. The data presented represents primarily Canadian literature and incorporates threshold values that were estimated for the Tier I and Tier II analyses (Section 3.6, Appendices 3-6). Reference sites are presented that document injury of vegetation that can be traced to application of road salts.

4.4.1 Substrate (Soil) Exposure

Summary of Effects Levels and Threshold Values for Root Uptake
A number of experiments have reported plant response to road salts, in terms of Na, Cl or applied NaCl in the soil or in water culture. Table 4.5 summarize the range of threshold values that were calculated for different plant categories following root uptake, based on soil, solution culture concentrations (Section 3.6, Appendices 3-6).

Plotting the threshold values from Tables 3.7 to 3.9, created a series of curves that allows visual comparison of the sensitivity of endpoints related to acute, reproductive and chronic plant effects. The threshold values were plotted using a linear-log scale with 95% confidence intervals around each curve (Figures 4.24 to 4.25). The number of genera (or endpoints) affected was plotted on the y-axis and concentration of Na or NaCl was plotted on the x-axis.

For these figures, the threshold values for substrate exposure to NaCl were divided into acute effects (toxicity or tolerance), reproductive effects (seedling germination and growth), and chronic effects (remaining endpoints) on plants (Figure 4.24). The data for substrate exposure to Na was plotted together (Figure 4.25).

Table 4.5. Range of threshold values estimated for soil and water for various forms of plants.

Pathway	Form	Plant Form	Threshold Type	Threshold Range (ppm)
Soil	Na	Herbaceous	EC_{25}	202-270
Soil	Na	Woody	EC_{25}	67.5-300
Root uptake	Na	All species	EC_{25}	67.5-300
Water solution	Cl	Wetland	LOEL, EC_{25}	300-1,500
Soil	Cl	Woody	EC_{25}	215-500
Root uptake	Cl	All species	EC_{25}, LOEL	215-1,500
Soil	NaCl	Woody	EC_{25}	600-5,500
Solution culture	NaCl	Herbaceous	EC_{25}	<2,500 - 10,000
Solution culture	NaCl	Wetland	NOEL, LOEL	280-66,600
Solution culture	NaCl	Woody	EC_{25}, CTV, NOEL	836-25,000
Root uptake	NaCl	All species	EC_{25}, CTV, NOEL, LOEL	280-66,600

Response to Sodium in Soil

Seed germination of prairie grass and broad-leaved wildflower species; and seedling root and shoot growth were reduced by applications of NaCl (Harrington and Meikle 1992). When a range of 100 to 400 ppm NaCl was applied, seed germination rates were between 42% and 29% of the control. The results suggested that a threshold for seed germination effects occurred between 300 and 500 ppm Na.

Root growth of all of the prairie species was reduced by Na in the soil, but that the degree to which a reduction occurred was species specific. For example, *Elymus canadensis* was sensitive, with reductions of between 30% and 73% in soils with 100 to 400 ppm Na. In contrast, *Buchloe dactyloides* was least sensitive with a stimulation of root growth at 100 ppm Na and essentially no reduction in root growth with 200 to 400 ppm Na. Plant shoot growth was both stimulated and inhibited by NaCl in the soil: *Bouteloua curtipendula* and *Buchloe dactyloides* had greater above-ground biomass at 100 and 200 ppm Na, a 65% and 42% increase, respectively, compared to 0 ppm Na. The shoot growth of all species was reduced at 400 ppm Na. The EC_{25} threshold values that were estimated from this study for Na concentration in soil were 202 to 270 ppm.

Winter soil applications of 3000 to 9000 ppm NaCl on two-year old ponderosa pine (*Pinus ponderosa*) seedlings growing in pots in a lath house, resulted in significant foliar injury and mortality (Bedunah and Trlica 1979). The EC_{25} threshold values for pine seedling mortality was 140 ppm Na measured in the soil solution.

The range of threshold values for root applied NaCl, evaluated as Na, was 67.5 to 300 ppm (Table 4.5, Appendices 3-6).

Response to Chloride in Soil

Wilcox (1984) studied the response of sphagnum moss, *Sphagnum recurvum*, to increasing levels of NaCl applied in hydroponic culture, from 300 to 1500 ppm Cl; and to one level of $CaCl_2$ at 1500 ppm Cl. Growth was reduced with increasing concentrations of NaCl and at all concentrations of both salts. The estimated LOEL for reduction in mean length growth was 300 ppm Cl (8.5 mM NaCl).

In the ponderosa pine (*Pinus ponderosa*) study by Bedunah and Trlica (1979), discussed above for Na, the EC_{25} threshold values for pine seedling mortality was 350 ppm Cl in the soil solution.

The range of threshold values for root applied NaCl or Ca Cl_2 evaluated as Cl was 215 to 1,500 ppm (Table 4.5, Appendices 3-6).

Response to NaCl in Soil

A number of experiments have evaluated the response of plants to applications of NaCl as the salt. Germination of three woody species, *Betula alleghaniensis*, *Catalpa bignoides* and *Pinus rigida*, was delayed by increasing concentrations of NaCl (Bicknell and Smith 1975). The EC_{25} threshold values that were estimated from this study for NaCl concentration in soil were 700 to 950 ppm.

Nine woody, deciduous, shrub species were evaluated for their response to soil applications of NaCl in a container yard in England (Thompson and Rutter 1986). The results considered from this study have been limited to those species found in Canadian landscapes or natural environments. The container-grown plants were treated bi-weekly, seven times from early January to early April and eight times the following winter, from early December to mid March with soil treatments of 4000 to 32000 ppm NaCl. The 32,000 ppm soil treatments resulted in 8 to 10 deaths per 10 plants with hedge maple (*Acer campestre*), English hawthorn (*Crataegus monogyna*) and basket willow (*Salix viminalis*). Soil applications of NaCl significantly reduced dry weight increase in red dogwood (*Cornus sanguinea*), sweetbrier (*Rosa rubiginosa*), wayfaring tree (*Viburnum lantana*), European highbush cranberry (*Viburnum opulus*) and basket

willow. The EC_{25} threshold value for plant death of hawthorn was 10,800 ppm NaCl and for shoot dieback of all species was 7,140 ppm NaCl in soil solution.

The range of threshold values for root applied NaCl was 280 to 66,600 ppm, reflecting a range of plant sensitivity to NaCl (Appendices 3-6).

No Canadian references reported soil concentrations of NaCl, however, values have been estimated using reported concentrations of Na and Cl. A value of soil NaCl of 1978 ppm was estimated by multiplying the highest concentration of Cl found in the soil in a highway median, 1200 ppm, by a factor of 1.6485. A second value of soil NaCl of 2,262 ppm NaCl, was estimated by multiplying the highest concentration of Na found in the soil 10 m from the highway, 890 ppm by a factor of 2.542. The average of these two values, 2,120 ppm NaCl, was about ten times the lowest threshold value of 280 ppm.

Response to NaCl in Wetland Water Solution

Cotton grass sedge, *Eriophorum vaginatum* var. *spissum*, growth and flowering response to NaCl was evaluated in hydroponic culture (Schauffler 1993). Plants were grown for 7 weeks at NaCl concentrations from 400 to 6000 ppm NaCl. Biomass and tiller production was reduced at all concentrations although there were no visual symptoms at 400 ppm NaCl. The LOEL for biomass and tiller production was 400 ppm NaCl, compared to 1600 ppm NaCl for flower production.

The range of threshold values for root applied NaCl for wetland species was 280 to 66,600 ppm (Table 4.5, Appendices 3-6).

Relationship of Substrate Concentration Gradients to Effects Levels

Roadsides

The highest reported soil Na concentration was 890 ppm in a sample taken 10 m from a four-lane highway in Ontario (Hofstra and Smith 1984). This value exceeded the estimated threshold range of 67.5 to 300 ppm. Surveying the data from Canadian sites plotted in Figure 2.17, the zone of elevated Na levels occurred up to 20 m from the road.

The highest soil Cl concentration reported in a highway situation was 1050 ppm, in a sample taken at 11-15 cm depth in the highway median along a four-lane highway in Ontario (Hofstra and Smith 1984). A soil concentration of 1200 ppm Cl was found in the soil behind a patrol yard located along a highway in north-western Ontario (Racette and Griffin 1989). These values are well above the lowest threshold value of 215 ppm. Surveying the data from Canadian sites plotted in Figure 2.16, the zone of elevated Cl levels occurred up to 30 m from the road.

Soil concentrations of Na or Cl are greatest in median areas or immediately adjacent to roadsides, and fall to background levels with increasing distance. Elevated soil levels of Na or Cl have been recorded up to 30 m from four-lane highways (Hofstra and Smith 1984, Davis *et al.*1992), and up to 15 m from two-lane highways (Foster and Maun 1978, Soilcon Laboratories Ltd. 1995, Davis et al, 1992). The threshold range of 70 to 300 ppm Na and 215 to 450 ppm Cl in soil would be exceeded in a zone of up to 30 m from the road (Figures 2.16 and 2.17), depending on the class of road, application rates, local topography and climate.

Catling and McKay (1980) reported the occurrence of 20 salt-tolerant plant species along roadsides in Ontario, of which 4 plant species were reported for the first time in the province. The range of 4 additional species were extended significantly. These species were spreading naturally along highways in response to the use of de-icing salts and the decline of non-adapted vegetation. The sites studied had Na concentrations in the range of 1000 ppm and growing conditions that that ranged from aquatic, moist, periodically moist to dry. Hofstra and Smith (1984) found elevated Na levels up to 900 ppm in median areas and at 10 m from a four-lane highway in southern Ontario.

Wetlands

Wilcox and Andrus (1987) studied the effect of salt level and form on the length and biomass increase and gametophore production of sphagnum moss, *Sphagnum fimbriatum* growing in hydroponic culture. NaCl was applied from 300 to 1500 ppm as Cl; and $CaCl_2$ at 1500 ppm as Cl. Length growth was reduced at about 300 ppm Cl and halted at 3000 ppm Cl. Biomass growth was reduced at concentrations greater than 900 ppm Cl. Gametophore production was reduced by all concentrations of Cl. The Estimated LOEL values was 300 ppm Cl for gametophore production, 500 ppm Cl for length increase and 1500 ppm Cl for biomass increase. Application of $CaCl_2$ at 1500 ppm as Cl had a similar reduction in length increase as NaCl, but a more than double reduction in biomass increase.

Wilcox (1982, 1986a, 1986b) found that Na and Cl contamination of a bog in northwestern Indiana, that had been impacted by road salt run-off, resulted in plant community impacts. This study is discussed more thoroughly in Section 4.4.3 on Reference Sites. The salt contamination had resulted in a shift in vegetation species, in that nearly all naturally occurring (endemic) plant species had been replaced with non-bog species, dominated by narrow-leaved cattail (*Typha angustifolia*). The highly impacted area lacked most of the plant species that were dominant in unimpacted parts of the bog. The most severely impacted area had mean salt concentrations as high as 486 ppm Na and 1215 ppm Cl in the interstitial waters of the peat mat. The pattern of the zones of affected vegetation were correlated with elevated Na and Cl concentrations. The zone of elevated levels extended up to 120 m into the bog, with the highest concentrations at about 50 m.

These values exceeded the lowest threshold values for all media, 67.5 ppm Na, and 215 ppm Cl.

Snowmelt

Snowmelt is present along roadsides and snow storage areas in the spring and early summer, when seed germination occurs for many species. Elevated levels of Na and Cl in snowmelt, along with other major snowmelt contaminants (such as copper and zinc) have the potential to alter both the species composition and biomass of roadside and wetland vegetation communities. A laboratory study evaluated the effect of roadside snowmelt on five wetland species using seed collected in central (four of the species) and eastern Ontario (purple loosestrife) (Isabelle *et al.* 1987). The effect of snowmelt concentration was evaluated on seed germination; community biomass; and species diversity, evenness and richness, determined using a potted plant community.

Seeds of flat-topped white aster (*Aster umbellatus*), three-way sedge (*Dulichium arundinaceum*), purple loosestrife (*Lythrum salicaria*), woolgrass sedge (*Scirpus cyperinus*) and common cattail (*Typha latifolia*) were seeded in pots in February 1985 in a random grid pattern, keeping the location of the seeds identical among the pots. The pots were treated with concentrations of 0, 20 and 100% snowmelt, combined from three snow dump and roadside storage sites in Ottawa.

Increasing concentrations of snowmelt reduced the percent germination of all species. At 100% snowmelt, the aster and sedges had 0% germination, while the purple loosestrife had 30% germination and the cattail had 7.6% germination. Increasing concentration of snowmelt reduced species diversity. The 100% snowmelt reduced community biomass, species evenness and richness.

Snowmelt concentrations of Na and Cl were evaluated along three classes of highway in southern Ontario in 1992 during periods when snow melt produced run-off into highway ditches during January, February and March (Whiteley and Snodgrass 1994). Average concentrations on a busy, multi-lane section of Highway 401 within metropolitan Toronto were 920 ppm Cl. Average concentrations along a busy, four to six-lane section of Highway 401, between Toronto and Kitchener, were 1250 ppm Cl. Along a 2 to 4-lane section of Highway 6, between Burlington and Marden, the average concentration was 450 ppm. These concentrations exceeded the lowest threshold values of 215 ppm for woody species and 300 ppm for wetland species (Table 4.5).

4.4.2 Aerial Exposure

Summary of Effects Levels and Threshold Values for Aerial Exposure
Table 4.6 summarizes the range of threshold values that were calculated for different plant categories based on tissue concentrations (Section 3.6, Appendices 3-6).

Plotting the threshold values from Tables 3.12 to 3.14, created a series of curves that allows visual comparison of the sensitivity of endpoints related to various plant effects. The threshold values were plotted using a linear-log scale with 95% confidence intervals around each curve (Figures 4.26 to 4.27). The number of genera (or endpoints) affected was plotted on the y-axis and concentration of Na or Cl was plotted on the x-axis.

Response to Sodium

Lumis *et al.* (1976) found that twig or needle tissue content of Na was related to injury symptoms in 11 woody species sampled along two-lane and four-lane highways in southern Ontario. Maximum levels of Na ranged from 1,300 ppm to 11,200 ppm, compared to less than 600 ppm in the background samples (taken at an arboretum site away from a highway). An EC_{25} value of 4,200 ppm Na was calculated from the tissue concentration data for all species.

Table 4.6. Range of threshold values for woody tissue concentrations following aerial exposure.

Pathway	Form	Plant Form	Threshold Type	Threshold Range (ppm)
Vegetation conc.	Na	Woody	EC_{25}	200-16,100
Vegetation conc.	Cl	Woody	EC_{25}, CTV	800-70,700
Foliar spray conc.	NaCl	Woody	CTV	7,140

Hofstra and Lumis (1975) experimentally treated established orchard trees of *Malus sylvestris*, apple, with regular applications of a 2% (20,000 ppm) solution of NaCl de-icing salt. Tissue Na content of apple twigs increased from an untreated level of 200 ppm Na to 3,600 ppm Na following 24 applications over an 8 week period. The tissue content increased with increasing number of spray applications along with the degree of plant injury. Trees that had 6 applications showed a slight reduction in flowering. Injury increased to arrested flower development, death of many flower spurs and extensive twig dieback following 24 applications over and 8 week period.

The range of threshold values for Na measured in plant tissue content was 200 to 17,800 ppm, again reflecting a range of plant sensitivity to NaCl (Table 4.6, Appendices 3-6).

Response to Chloride

As discussed above, Lumis *et al.* (1976) found that twig or needle tissue content of Na and Cl, was related to injury symptoms in 11 woody species sampled along southern Ontario highways. Maximum levels of Cl ranged from 5600 ppm to 21000 ppm, compared to less than 600 ppm in the background samples (taken at an arboretum site away from a highway). An EC_{25} value of 4,950 ppm Cl was calculated from the tissue concentration data for all species.

Hall *et al.* (1972) found that foliar Cl concentrations of *Pinus strobus*, white pine, grown in controlled environments, increased with repeated experimental spray applications of highway de-icing salt and was correlated with observed foliar injury (leaf tissue death). The foliar Cl concentration was 5,000 ppm after five applications and increased to 16,000 ppm after 25 applications. The compared to a foliar Cl concentration of about 1000 ppm. Foliar injury was 25% after 10 applications and increased to 65% after 25 applications.

In the study by Hofstra and Lumis (1975) on *Malus sylvestris*, apple, tissue Cl content of apple twigs increased from an untreated level of 300 ppm Cl to 8,200 ppm Cl following the 24 applications of a 2% (20,000 ppm) solution of NaCl de-icing salt over an 8 week period. The tissue content increased with increasing number of spray applications along with the degree of plant injury. As indicated above, injury increased to arrested flower development, death of many flower spurs and extensive twig dieback following 24 applications.

The range of threshold values for Cl measured in plant tissue content was 800 to 70,700 ppm (Table 4.6), reflecting a range of plant sensitivity to NaCl (Table 4.6, Appendices 3-6).

Relationship of Environmental Tissue Concentration Gradients to Effects Levels

Roadsides

The highest reported tissue Na concentration was 6900 ppm, reported in peach, *Prunus persica*, growing 20 m from a four-lane highway in southern Ontario (Northover 1987). This value exceeded the lowest threshold value of 200 ppm Na, but was lower than the highest threshold value of 16,100 ppm Na, indicating that some species would be damaged by salt spray adjacent to highways. In the two studies by MacLaughlin and Pearson (1981) and Northover (1987) indicated that elevated tissue levels of Na occurred in a zone of up to 50 to 80 m from the highway (Figure 2.21).

The highest tissue Cl concentration was 11000 ppm, reported in unspecified vegetation growing 60 m from a four-lane highway in Ontario (Hofstra and Smith 1984). A second reference reported 9000 ppm in peach, *Prunus persica*, growing 20 m from a four-lane highway in southern Ontario (Northover 1987). These values exceeded the lowest threshold value of 800 ppm Cl, but was lower than the highest threshold value of 70,700 ppm Cl, again indicating that some species would be damaged by salt spray adjacent to highways. Surveying the data from Canadian sites plotted in Figure 2.20, elevated tissue levels of Cl occurred in a zone of up to 50 to 80 m from the highway.

In studies of salt injury due to salt spray, woody tissue concentrations of Na or Cl were greatest immediately adjacent to roadsides, and fell to background levels with increasing distance. Elevated tissue levels of Na or Cl, as compared to background levels on site, were recorded up to

80 m from four-lane highways (Hofstra and Smith 1984, McLaughlin and Pearson 1981, Northover 1987). The lowest threshold values of 200 ppm Na and 800 ppm Cl in plant tissue would be exceeded in a zone of up to at least 80 m from a 4-lane highway, depending on application rates, local topography and climate.

4.4.3 Reference Sites

A number of studies have evaluated environmental concentrations and plant effects in Canadian sites where de-icing salt has been applied. This discussion presents reference sites that relate road salting and environmental NaCl concentrations to observed plant effects. Other studies have been included in this section that report on situations not presented in the Canadian studies.

Woody Vegetation

Salt Spray from a Two-lane Highway on Blueberries in Western Nova Scotia

Eaton *et al*. (No date) evaluated the effects of road salt from a two-lane highway, Highway 104, in the Folly Mountain area, west of Truro, over the winters from 1993 to 1995. Salt application in this area was 33 and 40 tonnes of NaCl per km of highway during the winters of 1993-4 and 1994-5, respectively.

They found that lowbush blueberry blossom number and yield was reduced within 35 m of the highway and approached background levels beyond 50 m from the highway. Blossom number was reduced by 60% to 90% within 10 m of the highway and yield was reduced by 50% or more compared to samples taken at 50 m from the highway. Yield under protective structures of nursery film was 4224 kg/ha of fresh fruit in

1994 compared to less than 2000 kg/ha at 30 m and less than 200 kg/ha at 5 m from the highway. In 1995, yield under the protective structures was 8092 kg/ha compared to less than 3000 kg/ha at 35 m and less than 1500 kg/ha at 5 m from the highway.

Stem tissue salt levels taken under the protective structures were 0.53 and 0.3 g NaCl per 20 stems in 1993-4 and 1994-5, respectively. This compared to levels from 6 to over 10 g at 10 m from the road in spring 1994 and 3 to over 8 g in spring 1995. Tissue levels were elevated up to 45 or 50 m from the highway. Both blossom number and yield were negatively correlated with salt content of the blueberry stems taken in winter and early spring.

Salt Spray from a Four-lane Highway to Peach and Plum Orchards in Southern Ontario

The effect of salt spray was evaluated on Loring Peach trees (*Prunus persica*) during the 1973-1974 winter (Northover 1987). The trees were located on the south side of an east-west section of the QEW, a busy, four-lane, controlled access highway near St. Catharines, Ontario. During the winter, a total of 24,300 kg of road salt (almost pure NaCl) was applied per four-lane-km (12,150 kg/2-lane-km). Individual application rates were 320 kg of NaCl per four-lane-km (160 kg/2-lane-km) applied as road salt and 60 kg of NaCl per four-lane-km (30 kg.2-lane-km) highway applied as a sand-salt mixture (containing a minimum of 5% NaCl).

Meteorological records indicated that wind blew predominantly from the NW, N or NE at this location. The direction of wind passing over the highway during the six hours following each salt or sand-salt application was reported. Winds occurred from the NW, N or NE directions for 59.4% of the time compared to 23.2% from the SW, S or SE directions or 17.4% from the E or W directions.

The orchard was located at the same elevation as the highway. The Cl content of the peach twig tissue, from trees located 20 m from the highway, was greater than 4 times the levels found in trees 120 m from the highway, 9,000 ppm as compared to 1,900 ppm Cl (Figure 2.9). The Na content was elevated more than 7 times the levels detected 120 m from the highway, 6,900 ppm as compared to 900 ppm Na (Figure 2.10). Na and Cl tissue content of shoot tissue decreased with increasing distance from the highway, but remained elevated for up to 80 m from the highway.

Fruit yield was reduced at distances less than 80 m from the highway and peach fruit number per shoot increased with increasing distance from the highway. Shoots in the tree canopy were 97% dead 20 m from the highway. Shoot death decreased with increasing distance from the highway, falling to 8% at 80 m from the highway and decreasing to a background level of less than 1% at 120 m from the highway. The Na and Cl content of the shoots were positively correlated with the percentage of dead wood in the canopy of the trees.

The soil levels of Na and Cl were not elevated on this site, indicating that the elevated tissue levels and plants effects were primarily due to aerial salt spray from the highway.

In a similar study, the effect of distance on salt spray was studied in a number of peach and plum plantings along the QEW, a four-lane, controlled access highway in the Grimsby and Beamsville area of Ontario (McLaughlin and Pearson 1981). Peach and plum trees were evaluated for terminal twig dieback in April 1980 and 1981. The Na and Cl concentration of twigs from the same trees was sampled in May 1980.

The Cl and Na content of the twigs was highest closest to the highway and generally decreased with increasing distance from the highway (Figures 2.11 and 2.12). Twig tissue Na concentration was 2,030 ppm at 45 m from the highway and Na Content was 2,300 ppm at 40 m from the highway.

Twig dieback was greatest in the plants closest to the highway and decreased with increasing distance from the highway (Figure 4.1), however the degree of dieback differed between years and species. Injury was greater on the south side of the highway in April of 1981; peach twig dieback was 288 mm at 22 m from the highway, decreasing to 97 mm at 82 m from the highway. In April of 1980, peach twig dieback on the south side of the highway, fell from 91 mm at 36 m from the highway to 8 mm at 82 m from the highway.

Twig dieback was correlated with tissue concentrations of Na and Cl. Twig dieback increased with increasing concentrations of Na and Cl in the combined peach and plum data (Section 3.5 3, Appendix 8).

Soil Concentrations and Woody Plant Injury Adjacent to Highways in Interior BC

Davis *et al.* (1992) reported on field evaluations of the causes of observed roadside tree injury and decline on 17 forested sites in south central/eastern British Columbia (Figure 4.2). These evaluations included historical review of common stress factors involved in tree decline and sampling of soil and plant tissues.

The sites were located on 2, 3 or 4-lane highways. At 15 of the sites, NaCl was used for winter maintenance at 60-130 kg/lane km as conditions dictated. On two of the sites that had gravel roads, NaCl was not used for de-icing, although sand with 3-5% NaCl was applied in the winter and $CaCl_2$ or $MgCl_2$ was used in the summer for dust suppression.

At each site, three 20 by 20 m plots were selected within a 1.0 to 1.5 km section. Two plots were selected with severe visible tree injury and a third control plot was selected with no visible injury. All conifer trees within the plots were rated for injury symptoms. The species present on the plots included Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*) and hybrid white spruce (*Picea engelmannii* X *glauca*).

Injury symptoms were consistent with NaCl injury, including needle tip browning or discoloration and needle loss. In severely injured trees this progressed to severe needle loss, stem dieback and tree death. The pattern of injury was similar between all the sites. Injury decreased with increasing distance from the highway. In most of the sites, the injury occurred on a narrow strip, within 15 m down slope of the highway. On one site, injury was evident for 40 m into a stand that received road runoff from a culvert. On another site, minor injury was evident 50 m from the highway due to wind and salt spray from the road.

Soil Cl concentrations at 0-10 cm depth in the control plots ranged from <1 to 12 ppm. Soil concentrations of Cl on the plots with plant injury ranged from 0.9 to 230 ppm Cl and were greater than 25 ppm on six of the sites. Two of the sites that were adjacent to a 4-lane highway, had soil Cl levels ranging from 3.0 to 198 ppm.

Soil Na concentrations at 10-10 cm depth in the control plots ranged from <1 to 8.5 ppm. Soil concentrations of Na ranged from 0.02 to 50.2 ppm Na on the plots with plant injury.
At 13 sites, soil Na concentrations were greater than the control on one or both of the injury plots and were greater than 17 ppm on seven of the sites. Two of the sites that were adjacent to a 4-lane highway had soil Na levels as high as 43 ppm.

Foliar tissue Na and Cl was reported on a content basis (for 50 needles). The Cl content of the needles from the injury plots increased up to 3.4 times that found in the control needle samples. The Na content of needles from the injury plots increased up to 206 times that found in the control needles.

Na tissue levels were not elevated on the two sites where NaCl is not used for winter de-icing. At these two sites, tissue Cl levels were 2 to 2.4 times greater than the control plots on at least one of the injury plots. The likely cause was the use of either $CaCl_2$ or $MgCl_2$ for dust suppression as part of summer maintenance programs on these sites.

Based on plant injury symptoms, and Na and Cl concentrations in soil and vegetation, salt was strongly implicated as a major contributor to the observed roadside tree injury and decline on 16 of the sites.

Soil and Woody Foliar Concentration Adjacent to a Two-lane Highway

Soilcon Laboratories Ltd. (1995) evaluated levels of salt in soil and plant tissue with respect to plant injury levels along a 2 km section of Loon Lake Road, a two-lane highway northwest of Kamloops in British Columbia. The dominant forest species on the site were ponderosa pine and Douglas-fir. The study was carried out over the winter of 1993-1994.

The individual rock salt applications rates on this stretch of road were 22, 88 or 153 kg/2-lane km, depending on whether low, average or heavy applications were applied. The total salt loading over the winter was 1561 kg/2-lane km, consisting of 1031 kg applied as rock salt and 530 kg applied as sand with 5% salt. Salt or sand applications were made from November 15, 1993 to February 23, 1994.

Nine sites were evaluated within a 2 km section along Loon Lake Road, where trees displayed low, moderate or severe salt injury symptoms. Trees in the low injury class had less than 10% discoloration and dead branches with healthy crowns. Trees in the moderate injury class had 10-50% discoloration and defoliation; some dead branches with crowns alive. Trees in the severe injury class were dead or had greater than 50% foliar discoloration and crown dieback.

Trees that fell in the moderate and severe injury classes were located from 3 to 8.4 m from the road. In comparison, trees that fell in the low injury class were located from 10 to 20 m from the road.

Soil concentrations of Cl and Na were sampled on the 9 sites in December 1993 and April 1994 and compared to control values sampled in April 1991. On sites with moderate and severe tree injury, soil concentrations of Cl measured in the 0-10 cm layer were 31.3 ppm Cl (range of 84.5-4.1) in December. By April, the concentrations fell to 5.12 ppm Cl (range of 12.6 to 1.6). On sites with low tree injury, soil concentrations of Cl measured in the 0-10 cm layer were 7.2 ppm Cl (range of 23.5-1.4) in December. By April, the concentrations fell to 2.9 ppm Cl (range of 4.5 to 1.3). This compared to background levels of 3.8 ppm Cl (range 7.5 to 0.2).

On sites with moderate and severe tree injury, soil concentrations of Na measured in the 0-10 cm layer were 15.9 ppm Na (range of 28.2 to 1.9) in December. By April, the concentrations fell to 9.1 ppm Na (range of 30.7 to 1.0). On sites with low tree injury, soil concentrations of Na measured in the 0-10 cm layer were 4.7 ppm Na (range of 11.7 to 5.6) in December. By April, the concentrations fell to 1.2 ppm Na (range of 1.8 to 0.5). This compared to background levels of 2.3 ppm Na (range of 2.7 to2.0).

Soil concentrations of Cl and Na were higher on the sites with plants in the moderate and severe injury class, than on the sites with plant in the low injury class in both December and April. Soil concentrations were approaching background levels by the April sampling period. It was likely that Na and Cl had leached from the soil by April by rainfall since the last salt application was in February.

Foliar Na and Cl concentrations were sampled in December, March, April and May. Foliar Cl and Na concentrations sampled in May 1994 increased with increasing injury class (Figure 4.3). Over the December to May sampling period, foliar Cl concentrations ranged from 110 to 560 ppm in trees in the low injury class. Foliar Cl ranged from 110 to 3180 ppm in trees in the moderate injury class and from 870 to 5590 ppm in trees in the severe injury class.

During the same period, foliar Na concentrations ranged from 0.5 to 70 ppm in trees in the low injury class. Foliar Na ranged from 0.5 to 190 ppm in trees in the moderate injury class and from 30 to 920 ppm in trees in the severe injury class.

The elevated levels of Na and Cl in the soils; and the corresponding elevated levels in the plant tissues indicated that the injury symptoms observed in the ponderosa pine and Douglas fir were due to soil uptake of road salt.

Soil and Woody Plant Concentrations Down-slope from a Four-lane Highway, BC

A site investigation was conducted in 1989 to investigate the sources of tree injury and decline that was evident in Boitanio Park, located in Williams Lake, British Columbia (Van Barneveld and Louie 1990). Tree injury symptoms and concentrations of Na and Cl in soil and woody vegetation were surveyed as part of a multifaceted investigation.

Boitanio Park is located west of a four-lane section of Highway 97 and the area of concern slopes toward the southwest with a grade of 5 to 15%. Two culverts are located along the highway above the park. The dominant tree species in the park is rocky mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*).

Plant injury was evaluated along a grid pattern running away from the highway with sampling locations every 50 m along the grid. Tree injury was rated using the following scale: low, moderate or severe salt injury symptoms. Trees in the low injury class had less than 10% discoloration and dead branches with healthy leaders. Trees in the moderate injury class had 10-50% discoloration; defoliation and some dead branches with leaders alive. Trees in the severe injury class were dead or had greater than 50% foliar discoloration; defoliation and dead tops.

Detailed sampling locations were selected in order to have 5 replicates of each injury class. At these sites, soil samples were taken from the 0 to 150 cm depth in 25 cm increments. Foliage of two nearby trees were sampled, dividing the needles into current year's (0) to age 3 growth, and age 4 to 6.

In general, the sites with trees in the severe injury class were on the east side of the park, within 50 m of Highway 97. Tree injury decreased with increasing distance from the highway. The sites with trees in the low injury class were generally located from 75 to 100 m away from the road.

Soil concentrations of Na and Cl were elevated on sites with severe or moderate injury compared to those with low injury. The average soil concentration of Na was 108.7 ppm on the severe injury sites, 37.9 ppm on the moderate injury sites and 29.0 ppm on the low injury sites. The average soil concentration of Cl was 52.1 ppm on the severe injury sites, 50.0 ppm on the moderate injury sites and 20.3 ppm on the low injury sites. Severe injury sites had soil Na concentrations that were 3.7 times the concentration in low injury sites, further away from the highway. Similarly, severe injury sites had soil Cl concentrations that were 2.6 times the concentration in low injury sites.

Foliar concentrations of Na and Cl were higher in the plants with a severe or moderate injury rating compared to the plants with a low injury rating. The average concentration of Na in the 0-3 year needles was 113 ppm on the severe injury sites, 54.8 ppm on the moderate injury sites and 59.7 ppm on the low injury sites. This compared to average concentrations of Na in the 4-6 year needles of 208 ppm on the severe injury sites, 72.7 ppm on the moderate injury sites and 47.9 ppm on the low injury sites. The average concentration of Cl in the 0-3 year needles was 3560 ppm on the severe injury sites, 2630 ppm on the moderate injury sites and 572 ppm on the low injury sites. A similar pattern was observed in the average concentrations of Cl in the 4-6 year needles: 4180 ppm on the severe injury sites, 2667 ppm on the moderate injury sites and 1060 ppm on the low injury sites. Foliar concentrations of Na and Cl decreased with increasing distance from the highway.

Other factors such as recent drought, presence of other contaminants in the run-off, insects and recent brush removal may have aggravated the decline of the trees. However it was determined that these factors were not the primary cause of the decline in the park. The injury symptoms on the Douglas-fir in this site were consistent with salt injury and supported by the pattern of decreasing injury symptoms with increasing distance from the road. Elevated soil and tissue concentrations of Na and Cl were correlated with more severe injury symptoms in the trees. The topography of the park and the elevated soil concentrations of Na and Cl indicated that runoff from the road resulted in salt injury and overall decline of these trees.

Woody Foliar Concentrations Directly Adjacent to a Two-lane Highway

Button and Peaslee (1966) reported foliar concentrations of Cl and Na in sugar maple (*Acer saccharum*) leaves sampled from mature (about 70 year old) trees. The trees were growing close (from 1 to 4 m) to Route 17 between Middletown and Durham, a two lane highway in Connecticut. This paper provides a scenario with woody vegetation directly adjacent to a salted highway. The research is relevant to Canadian conditions since sugar maple is a native forest species, used for maple syrup production and planted as a landscape tree. This area of Connecticut has a similar hardiness zone to areas of southern Ontario, the Maritimes and British Columbia.

Although salt load is not provided in the paper, the authors indicate that 70,000 tons of rock salt and 2,500 tons of calcium were used annually on 4,487 miles of highway. This converts to an annual application of 9850 kg/km of rock salt and 350 kg/km of calcium.

The trees growing on the west side of the highway (positive distance values in Figure 4.4) had road surface drainage flowing directly towards the trees. The trees growing on the east side of the highway had drainage diverted by a curb that had been installed during the summer prior to the study.

Foliar concentrations of Cl at the different sampling periods averaged 5200 to 6700 ppm on the west side of the road (Figure 4.4). These were significantly higher than the concentrations found on the east side of the road, averaging 1600 to 5400 ppm. This compared to levels ranging from 200 to 1400 ppm Cl in control trees of the same species and age, located away from a road. Foliar Na levels ranged from an average of 1100 to 1600 ppm on the west side of the highway compared to non-detectable to 200 ppm on the east side of the highway, and 0 in the control trees (Figure 4.5).

The higher concentrations of Cl and Na found in the foliage of the trees on the west side of the highway were correlated with moderate to severe injury symptoms in the trees on the west side of the road. This compared to no or light injury symptoms in the trees on the east side of the road and no injury in the control plants. This research provides an example of injury to woody plants that receive run-off of salty water.

Soil and Woody Foliar Concentrations Adjacent to a Patrol Yard

Racette and Griffin (1989) reported on the investigation of the cause of severe woody plant injury in the vicinity of a highway maintenance patrol yard, east of Kenora, Ontario. The extent of the plant injury was evaluated and tissue and soil samples were taken in the affected areas.

Trees in the area behind the sand dome and salt storage sheds and along a drainage channel that received drainage from the highway and patrol yard area had severe injury symptoms. These included severe marginal necrosis (death) of leaves of trembling aspen, balsam poplar and speckled alder; and severe necrosis of 1-year-old black spruce needles. Other injury evident included severe marginal chlorosis (yellowing) of serviceberry foliage and severe interveinal chlorosis of white birch foliage.

In a nearby sand and gravel storage area, salt treated sand had been stored on at least one occasion. In this area, jack pine, spruce, balsam fir and poplar trees had died a number of years ago. Existing vegetation was damaged along a drainage course in this area. Grasses had been killed and trembling aspen had symptoms of severe marginal necrosis.

Plant tissue levels of Na and Cl were sampled in September 1988, in the areas where the injury was evident. Plants were sampled in the areas behind the sand dome and salt storage sheds, in the gravel/sand storage area and along a drainage channel that received drainage from the highway and patrol yard area. Foliar concentrations of Cl ranged from 1,800 ppm (serviceberry foliage) to 22,000 ppm Cl (white birch foliage). Foliar concentrations of Na ranged from 10 ppm (black spruce foliage) to 86 ppm Na (serviceberry foliage). Background foliar concentrations of Cl ranged from less than 20 ppm (serviceberry and white birch) to 1900 ppm Cl (trembling aspen). Background foliar concentrations of Na ranged from 7 ppm (black spruce) to 19 ppm Na (serviceberry).

Twig concentrations of Na and Cl were also elevated in these areas. Twig concentrations of Cl ranged from 900 ppm (trembling aspen) to 9100 ppm Cl (black spruce). Twig concentrations of Na ranged from 9 ppm (trembling aspen) to 78 ppm Na (black spruce). Background twig concentrations of Cl ranged from less than 20 ppm (trembling aspen) to 200 ppm Cl (black spruce). Background twig concentrations of Na ranged from 7 ppm to 17 ppm Na (both in black spruce).

Surface soil concentrations of Na and Cl at these two sites, taken at 0-5 cm depth, were elevated compared to a control site, remote from the area. The soil concentration of Cl ranged from 780 to 1200 ppm and the soil concentration of Na ranged from 370 to 680 ppm. Background concentrations were 15 ppm Cl and 91 ppm Na.

The injured plants contained elevated plant tissue levels of Na and Cl. This was correlated with elevated soil levels of Na and Cl due to run-off from the patrol yard operations and the highway.

Changes were initiated in the winter of 1988-1989 to reduce losses of salt from the patrol yard operations. The area and severity of the vegetation injury had decreased by August 1989. The concentrations of Na and Cl in the foliage also declined, although levels were still elevated in comparison to background levels (control).

Wetland Vegetation

Community Changes in a Road-salt Impacted Bog

The effects of Na and Cl contamination were studied in Pinhook bog, located in northwestern Indiana, southeast of Michigan City, that had been impacted by road salt run-off (Wilcox 1982, Wilcox 1986a, 1986b). This study is relevant to the regulation of road-salts in Canada since it provides evidence of plant community impacts by elevated salt levels. Many of the predominant plant species in this bog are native, wetland species that are found in Canada. This part of Indiana is part of the Great Lakes Basin and has the same climatic zone as parts of southern Ontario, the Maritimes and British Columbia.

An uncovered road-salt storage pile had been located on an embankment adjacent to the bog from 1963 to 1972. A protective dome was placed over the salt pile in 1972 to limit run-off and salt storage was discontinued on this site in mid 1981. The bog also received run-off from a one-km stretch of a 4-lane highway (Interstate 80/90). The objectives of the study were to determine the pattern of elevated salt concentrations within the bog and to quantify the vegetation community changes within the bog.

Chloride inputs into the bog were calculated for the ten-year period from 1963-1972 from road maintenance operations (Ten Ech Envir. Consultants 1975, as summarized in Wilcox 1982). Highway salting contributed 40,900 kg Cl per year through runoff and infiltration, and the salt storage pile contributed 233,770 kg Cl per year. The annual, road salt application for the adjacent highway was 11,300 kg per km (5,650 kg/2-lane km).

The most severely impacted area had mean salt concentrations as high as 486 ppm Na and 1215 ppm Cl in the interstitial waters of the peat mat. The pattern of elevated Na and Cl concentration in the bog was correlated with zones of affected vegetation. The salt concentrations in the root zone decreased each year from 1979 to 1981.

Vegetation evaluations were carried out on the unimpacted and impacted portions of the bog from 1980 to 1983. The dominant plants in the unimpacted areas of the bog were mosses of the genus *Sphagnum*. Other major herbaceous species included pitcher-plant (*Sarracenia purpurea*), three-fruited sedge (*Carex trisperma*) and white beakrush (*Rhynchospora alba*). The prevalent woody species were tamarack trees (*Larix laricina*) and the following shrub species: huckleberry (*Gaylussacia baccata*), purple chokeberry

(*Pyrus floribunda*), mountain holly (*Nemopanthus mucronata*), leatherleaf (*Chamaedaphne calyculata angustifolia*), small cranberry (*Vaccinium oxycoccos*), highbush blueberry (*Vaccinium corymbosum*) and black highbush blueberry (*Vaccinium atrococcum*).

The salt contamination had resulted in a shift in vegetation species in the impacted areas. Nearly all of the endemic plant species were absent from the portion of the bog with elevated salt levels. They had been replaced with non-bog species dominated by narrow-leaved cattail (*Typha angustifolia*). Some of the plant species present on the impacted area were present in the unimpacted area, while others were not common elsewhere in the bog. The highly impacted area lacked most of the plant species that were dominant in the unimpacted bog.

As salt levels declined by 50% over the 4-year study period, many endemic species returned to the impacted bog. Some of the species that had invaded during the high salt conditions declined, while others such as *Typha angustifolia* and *Pyrus floribunda* remained dominant in parts of the impacted bog. The result of the salt contamination of the bog was a change in the vegetative community of the impacted area.

These reference sites provide examples of elevated environmental concentrations of Na and Cl and plant impacts as a result of de-icing salt application to roads or run-off as a result of handling activities in highway maintenance patrol yards.

4.4.4 Population effects

Plant species differ widely in their sensitivity to salt, so the zone of impact depends on the species present on a site. There have been extensive compilations of ratings of sensitivity of woody plants from various observational and experimental studies, since woody plant injury is evident due to aerial salt spray. Comparative sensitivities for selected woody plant species have been provided in Appendix 1 and for woody fruit crop species in Appendix 2. More extensive woody plant summaries have been referenced in Section 3.2.4.

A survey of woody plant ratings (ornamental and forest species) indicated that from 29.6 to 50.8% of the plants listed in each report were deemed sensitive to salt, in at least one rating, due to foliar or aerial exposure (Beckerson *et al.* 1980; Dirr 1976; Dobson 1991; Lumis *et al.* 1973, 1983; Sucoff 1975; Thuet 1977). Each of these studies covered between 71 and 466 species, cultivars or varieties.

Lumis *et al.* (1983) and Beckerson *et al.* (1980) focussed on roadside plants and species commonly used in Canadian landscape plantings. Lumis *et al.* (1983) making field observations, rated 30% of 72 species as sensitive to road salt; 7% had severe injury symptoms that could result in plant death. A review of sensitivity ratings by Beckerson *et al.*(1980) found that 40% of 89 species had been rated as sensitive to road salt.

A survey of the salt tolerance ratings of 32 cultivars or varieties of fruit trees, vines or shrubs, representing commercial crop and landscape plants (Appendix 2), indicated that 65% were considered sensitive to salt in at least one rating.

Most of these evaluations cover species that grow along roadsides, are crop plants or make up landscape plantings. There are many wild species that have not been evaluated for sensitivity to de-icing salts. There are 15 principal genera of trees (over 25 species) within Canadian forested regions according to Rowe (1972) (see Section 3.1). Eleven of 15 (73%) of these genera of forest trees contain species that have been rated as sensitive to road salt (Beckerson *et al.* 1980, Dirr 1976, Dobson 1991, Lumis *et al.* 1983, Sucoff 1975, Thuet 1977). The following genera contain both species that have been rated as sensitive to road salt, and other species that have been rated as either tolerant or moderately tolerant: *Salix* sp., *Acer* sp., *Carya* sp., *Quercus* sp., *Pinus* sp. and *Picea* sp.

Looking at individual species listed by Rowe, eight of 15 species (53%) have been rated as sensitive to road salt in at least one rating (same references). There was no rating information available for the following species: *Abies lasiocarpa*, *Tsuga heterophylla*, *Picea mariana*, *Picea rubens*, *Picea sitchensis* and *Pinus contorta* var. *latifolia*.

The serious injury observed with very sensitive woody species includes severe leaf necrosis, severe shoot dieback, reduction in flower and fruit production and plant mortality or seedling mortality following seed production. Such impacts could result in population effects for sensitive species if they are growing in the zone of impact, up to 40 m of multi-lane highways or within 10 m of two-lane highways where de-icing salt is used. With less, sensitive species, the impact may be limited to reduced vigour and competitive ability of affected woody plants or impairment of reproductive capability, since flower buds are especially sensitive to aerial salt exposure.

As indicated in the review of literature for the Tier I and II assessments, only a limited number of herbaceous or wetland species have been evaluated in experimental or observational studies for salt tolerance. The literature provides evidence that sensitive, herbaceous species can be affected by reduced germination and seedling injury or mortality due to elevated salt levels in soil or surface water. It is difficult to estimate the number of species potentially impacted by elevated soil or surface water levels, in light of the many herbaceous species that grow naturally or under cultivation immediately adjacent to roadsides.

DiTommaso *et al.* (2000) found that ragweed (*Ambrosia artemisiifolia*) germinated at higher salinity levels than three grasses; alkaligrass, red fescue, perennial ryegrass; and three legumes; black medic, bird'-foot trefoil or white clover. Only ragweed germinated at 400mM NaCl. Peak germination of all species was delayed by increasing levels of salinity, from 200 to 400 mM. Species that germinated more readily at higher salt concentrations would have an advantage in roadside conditions. It was also observed that seeds from populations of ragweed from roadside sites in Quebec had higher germination totals and rates when compared to seed from Quebec agricultural populations (DiTommaso, personal communication). This indicates natural selection of roadside ragweed populations for salinity tolerance.

4.4.5 Community effects

A few studies provide evidence of de-icing salt impacts on natural communities. Research presented on the response of different plant species to de-icing salts, indicate that there are impacts on individual populations that would result in plant injury or death. In a natural or landscaped environment, the use of de-icing salt would reduce the number of or eliminate sensitive species within the zone of impact.

Wilcox (1982, 1986a) studied impacts of de-icing salt contamination in a bog (discussed as a Reference Site in Section 4.4.3). Elevated Na and Cl concentrations within the bog were correlated with vegetation community changes within the bog. A shift in species composition was observed in the impacted areas, in that nearly all of the endemic plant species were absent from the portion of the bog with elevated salt levels. They had been replaced with non-bog species, dominated by narrow-leaved cattail (*Typha angustifolia*). The highly impacted area lacked most of the plant species that were dominant in the unimpacted bog. The result of the salt contamination of the bog was a change in the vegetative community of the impacted area, that was not corrected by reductions in levels of Na and Cl.

The spread of halophytic species, characteristic of sea coasts and salt marshes, has been observed along roadsides in Ontario (Catling and McKay 1980, Reznicek 1976). Similar observations have been made in Michigan, which has a similar climate and flora to southern Ontario (Reznicek 1980). Catling and McKay (1980) observed that salt-tolerant plant species were spreading naturally along Ontario roadsides in response to the use of de-icing salts and the decline of non-adapted vegetation. Reznicek *et al.* (1976) reported the increase in distribution of *Carex praegracilis*, an alkali-tolerant, western species, since its' first observation in Ontario in 1973. This species was recorded in 28 highway locations in 14 Ontario counties.

Catling and McKay (1980) observed the occurrence along roadsides of species that were tolerant of soil Na levels of 500 to 1,000 ppm and were often associated with halophytic species. These included narrow-leaved cattail (*Typha angustifolia*), common reed-grass (*Phragmites australis*), and weedy species such as annual and perennial sow-thistle (*Sonchus oleraceus, Sonchus arvensis*, *Sonchus uliginosus*), common ragweed (*Ambrosia artemisiifolia*), wild carrot (*Daucus carota*) and kochia (*Kochia scoparia*).

These species grow commonly along roadsides in Ontario, invading sites roadside sites following construction or invading established roadsides. Extensive stands of common reed grass have developed in numerous locations along highways in Ontario and Quebec, replacing natural and planted roadside communities.

A study of plant species distribution and NaCl concentrations in the area around a salt pile was carried out in Beltsville, MD (Buzio *et al.*, 1977). The mean number of plants per site declined with increasing NaCl concentration. There appeared to be a threshold after the first class of NaCl soil concentrations (0-5000 ppm), where the number of plants per 66 m^2 declined from 200 to approximately 20. Between 5000 and 25000 ppm NaCl, the number of plants per 66 m^2 varied between 20 and 45, but not in a dose-response progression. The 0-5000 ppm site had twenty-nine different species, whereas the plots with greater salinity had few species. Only six species were present at the site with the highest NaCl concentration. While only some of the species in this study are relevant to Canada, this study provided evidence that elevated NaCl concentrations in soil cause changes in plant community structure.

These studies and reports provide evidence of the impact of de-icing salt on plant communities adjacent to roadsides. Changes have occurred in plant communities adjacent to roads, due to the decline of species that are sensitive to Na and Cl, and their replacement by plants that tolerate high levels of salt.

4.4.6 Risk Characterization Summary and Conclusions

There is an impact of road salts on susceptible plant species following operational application and as result of storage and handling procedures that result in salty run-off into adjacent areas. Elevated soil levels of sodium and chloride or aerial dispersion of sodium and chloride results in foliar, shoot and root injury; growth reductions; reductions in germination and seedling establishment; and severe reductions in flowering and fruiting of sensitive plant species. The species affected include native grass species; wetland species such as sphagnum moss and sedges; and woody species such as maple, pine, Douglas-fir, dogwood, peach and plum.

Plant species differ widely in their sensitivity to salt, so the zone of impact depends on the species present on a site. Comparative sensitivity of various plant species have been listed in Appendices 1 and 2 and more extensive woody plant summaries have been referenced at the end of Section 3.1.

The zone of impact is usually linear, along roads and highways or other areas where NaCl is applied for de-icing. Aerial dispersal of NaCl occurs along roads during the winter months when de-icing is required and impacts mainly woody plants. The impact of aerial dispersion of NaCl extends, in general, about 40 to 100 m from the edge of the road although this depends on local conditions. The degree and distance of dispersion depends on the salt load, traffic volume and velocity, local topography and prevailing winds.

Elevated soil levels of road salts normally occur within the first 20 m of the highway or along paths of overland flow or drainage where highway run-off and snow melt collects. These elevated soil levels impact all types of susceptible vegetation. Rain leaches the soil during the growing season, reducing the concentrations of Na and Cl, however levels may remain elevated in areas such as medians throughout the year. In certain conditions, salts used for dust suppression on gravel roads, are washed into the roadside environment during the growing season, resulting injury to roadside vegetation.

Changes of plant communities have been recorded in response to elevated levels of deicing salts in areas impacted by road salt run-off and aerial dispersion. Loss of non-salt tolerant communities have been recorded as well as the spread in occurrence of non-native halophytic species.

4.5 Exposure Maps for Canadian Vegetation and Crop Groups

In order to provide an indication of regions where specific vegetation was more likely to be exposed to higher salt loadings, exposure maps were developed using salt loading data that was developed by the members of the of the Environmental Resource Group for Road Salt (Morin and Perchanok 1998). This data was overlaid with crop and vegetation coverage maps provided by Agriculture Canada (Agriculture Canada, Canadian Soil Information System, http://res.agr.ca/cansis/, 1999), and analysed for the occurrence of high, medium or low salt loading with high, medium or low density of the crop or vegetation type.

4.5.1 Method of Analysis

The following crop types were selected, since they are perennial woody crops or vegetation types that would be exposed to salt spray during the winter months:

Berry crops
Grape vines
Fruit trees
Maple trees
Forest

These vegetation types are not limited to the areas identified in these maps. However, due to the density classes used to define vegetation density, not all the areas with these vegetation types were included in the analysis.

The following density divisions were chosen, based on an overview of the data in the database:

High density	>0.10 ha per ha of vegetation
Medium density	0.10 ha to 0.005 ha per ha of vegetation
Low density	0.005 ha to 0.0005 ha per ha of vegetation

Salt loading was categorized according to the following categories:

High loading	>10.0 g per m2
Medium loading	0.5 to 10.0 g per m2
Low loading	<0.5 g per m2

The resulting categories were:

HH	High density/high salt loading
HM	High density/medium salt loading
HL	High density/low salt loading
MH	Medium density/high salt loading
MM	Medium density/medium salt loading
ML	Medium density/low salt loading
LH	Low density/high salt loading
LM	Low density/medium salt loading
LL	Low density/low salt loading

The analysis was done using ArcView Version 3.1 GIS. The data were mapped using an Albers Equal-Area projection. The original vegetation data was provided as ha/Soil Landscapes of Canada (SLC) polygons and was converted to ha/ha of SLC polygon.

4.5.2 Results of Mapping Analysis

The results of the mapping analysis are presented in Figures 4.6 to 4.22, and are discussed below.

Berry Production
Figures 4.6 to 4.9 focus on berry production. Parts of southern British Columbia, southern Ontario, Quebec, New Brunswick, Nova Scotia, and PEI are categorized as having medium berry production and high or medium road salt loadings.

Grape Production
Figures 4.10 and 4.11 focus on grape production. Grape production density in southern Ontario ranges between low and high with high road salt loadings.

Fruit Trees
The relation between fruit tree density and road salt loadings is presented in Figures 4.12 to 4.15. Areas in southern Ontario and southern Quebec have the highest density of fruit trees with high road salt loadings.

Maple Trees
Figures 4.16 to 4.18 present the density of maple tree taps and road salt loadings. Though these maps clearly indicate there is a high density of maple tree taps in certain areas of Ontario, New Brunswick and Nova Scotia, the greatest overall density is in Quebec. In areas of Quebec and Ontario where there is a high density of maple trees, a large portion of the areas also have high road salt loadings.

Evergreen Cultivation
Figures 4.19 to 4.22 depict the relation between the density of evergreen cultivation and the intensity of road salt loadings. Areas with evergreen cultivation in central Ontario and southeastern Quebec have high density of evergreen cultivation and high road salt loadings.

Forested Areas
Figure 4.23 categorizes areas according to the percentage of areas that are forested and the intensity of road salt loadings. This map indicates that forested areas in southern Ontario and southern Quebec are subject to the highest road salt loadings. Furthermore, many of these areas (which are bright yellow and green on the map) appear to be small, isolated forest stands which may be more adversely affected by the application of road salts than larger forest stands.

4.5.3 Limitations of the Analysis

One of the shortcomings of this analysis is the way vegetation densities were estimated. Originally, hectares of crop production by type were provided by SLC polygon. Since the size of SLC polygons vary, a comparison based on hectares of crop was not a logical option; the larger the area of a polygon, the more likely it is to have a greater area of crop production. For this reason, crop density (ha of crop/ha of SLC polygon) was calculated to ensure a more reliable comparison. While this approach is logical, there are shortcomings. For example, there could be small areas with high vegetation densities located within a large SLC polygon. When averaged over the entire area of the polygon, however, the density is much lower.

These exposure maps show the relationship between the density of different vegetation types and road salt loadings. While these maps identify areas where different vegetation types may face adverse effects from the use of road salts, it should not be automatically assumed that vegetation is adversely affected. Furthermore, vegetation in areas that were not identified may be adversely affected by the use of road salts.

These maps should be viewed as a screening tool to help identify areas where salt sensitive crops are cultivated and where there are high road salt loadings. These maps can be further validated by comparing areas have been identified to areas where there has been a noted impact from the use of road salts.

5.0 SUMMARY AND CONCLUSIONS

The Priority Substances Assessment Program defines a substance as toxic according to the definition in Section 11 of the Canadian Environmental Protection Act (CEPA) "if it is entering or may enter the environment in a quantity or concentration or under conditions ....having or that may have an immediate or long-term harmful effect on the environment." (Anonymous 1997) This review evaluated the evidence to determine if road salts are toxic to plants under CEPA.

There are numerous studies of plant injury due to road salts and comparative evaluations and rankings of plant sensitivity. Road salt, primarily NaCl and $CaCl_2$, effects on plants have been characterized in experimental evaluations and linked to plant symptoms and elevated environmental concentrations along roadsides or in areas exposed to salty runoff.

Road salts have a harmful effect on plants growing along roads or in areas that have localized contamination due to runoff with elevated salt levels. Elevated soil levels, or aerial dispersion of sodium and chloride result in severe reductions in flowering and fruiting of sensitive plant species; severe foliar burn, shoot dieback and root injury; growth reductions; and reductions in germination and seedling establishment.

Symptoms of root exposure affect all plant forms, while aerial exposure is mainly evident on woody plants. Symptoms in roadside conditions typically occur in zones along salted roads and are generally most severe in late winter and spring. Symptoms of aerial injury are worst on the side of the plants that face the road, and the degree of injury decreases with increasing distance from the road. The species affected include native grass species; wetland species such as sphagnum moss and sedges; and woody species such as maple, pine, Douglas-fir, blueberry, dogwood, peach and plum.

Severe effects may result in plant mortality, while repeated (chronic) injury of perennial plants, year after year, results in reduced plant growth, shoot die-back and leaf burn. Repeated stress on plants reduces plant vigour and the ability to deal with insects, disease and abiotic stresses. These effects can lead to loss of plants within a community as well as impacts on other organisms that rely on plants for food and cover, due to reduced foliage and fruit production.

A quotient based risk characterization was performed using exposure values from literature dealing with road salt effects on plants. Exposure values for soil and tissue Na and Cl were determined using Canadian data. The highest reported soil concentrations of Na and Cl were 890 and 1200 ppm respectively. The highest reported tissue values of Na and Cl were 6900 and 11000 ppm respectively.

Threshold values were determined from estimates of effects concentrations providing a 25% effects level, NOEL or LOEL values and critical toxicity values estimated from experimental evaluations or field sampling following applications of NaCl or $CaCl_2$. Threshold values for root exposure to Na ranged from 215 to 300 ppm, and for Cl was 300 ppm. Threshold values for tissue exposure to Na ranged from 575 to 650 ppm, and for Cl ranged from 800 to 1650 ppm. The maximum exposure values reported in the Canadian environment exceeded the corresponding threshold values.

Changes in plant communities in terms of the occurrence and diversity of salt sensitive species, have been recorded along roadsides and in areas impacted by road salt run-off. In herbaceous plant communities, species that are sensitive to Na and Cl decline in zones where soil levels are elevated, and are replaced by plants that tolerate high levels of salt. Halophytic species, such as cattails and common reed grass, and other salt tolerant weedy species readily invade areas impacted by salt. Changes in wetland species composition and the invasion of salt tolerant species such as cattail have been documented in response to elevated Na and Cl levels.

The zone of impact of salt injury to plants is usually linear, along roads and highways where NaCl is applied for de-icing. Aerial dispersal of NaCl impacts mainly woody plants and extends, in general, about 40 to 100 m from the edge of the road, depending on local conditions. Woody plant communities adjacent to roads with high salt loadings have been affected up to 100 m from the highway, with severe impacts occurring in the first 30 to 40 m from the highway. The degree and distance of aerial dispersion depends on the salt load, class of road, traffic volume and velocity, local topography and prevailing winds.

Elevated soil levels of road salts normally occur within the first 10 to 20 m of the highway or along paths of overland flow or drainage where highway run-off and snow melt collects or adjacent to road salt storage and loading facilities. Symptoms are most evident in spring once plant growth resumes for the season. Rain leaches the soil during the growing season, reducing the concentrations of Na and Cl, however levels may remain elevated throughout the year in areas such as medians. In certain conditions, salts, such as $CaCl_2$ used for dust suppression on gravel roads, are washed into the roadside environment during the growing season, resulting injury to roadside vegetation due to elevated salt levels in the soil during the growing season.

Plant species differ widely in their sensitivity to road salts, so the zone of impact also depends on the species composition of naturally occurring and landscape plant communities adjacent to roads. Fifty-three percent of principal forest tree species in Canada have been rated as sensitive to road salt and 73% of the principal genera of forest trees contain species that have been rated as sensitive to road salt. Impacts of road salts on forest species adjacent to roadsides have been documented in central and southern British Columbia. In these areas, the zone of impact was up to the first 10 to 15 m from two-lane highways. Adjacent to a four-lane highway in British Columbia, the zone of severe injury of forest trees covered the first 50 m from the highway. Areas of high forest density in Canada, that experience medium to high salt loadings (based on average annual loadings, by maintenance district) include Vancouver Island, southwestern and central Alberta, central Ontario, parts of southern Ontario, southern and central Quebec and areas in New Brunswick and Nova Scotia.

Severe plant injury and reductions in fruit production have been reported in fruit crops in a zone up to 50 to 80 m from four-lane highways in southern Ontario and up to 35 m from a two-land highway in Nova Scotia. Sixty-five percent of 32 varieties of fruit trees, vines or shrubs have been rated as sensitive to salt. Areas of high fruit crop density in Canada, that experience medium to high salt loadings include southern Ontario and southern Quebec.

Sensitive landscape plantings and nursery crops suffer severe plant injury and plant death due to elevated soil levels of road salt and salt spray. From 30 to 40% of common landscape species used in Ontario have been rated as sensitive to road salt. Seven percent of these species had symptoms that were severe enough to result in plant death.

In conclusion, the use of road salts results in environmental levels of Na and Cl that are high enough to cause harmful impacts on plants and plant communities in the Canadian environment.

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Figure 2.1. Concentrations of Na in soil at 8 cm depth at increasing distance from the road on two-lane highways near London, ON. (data from Foster and Maun 1978). Each value represents three soil cores taken at each of six locations.

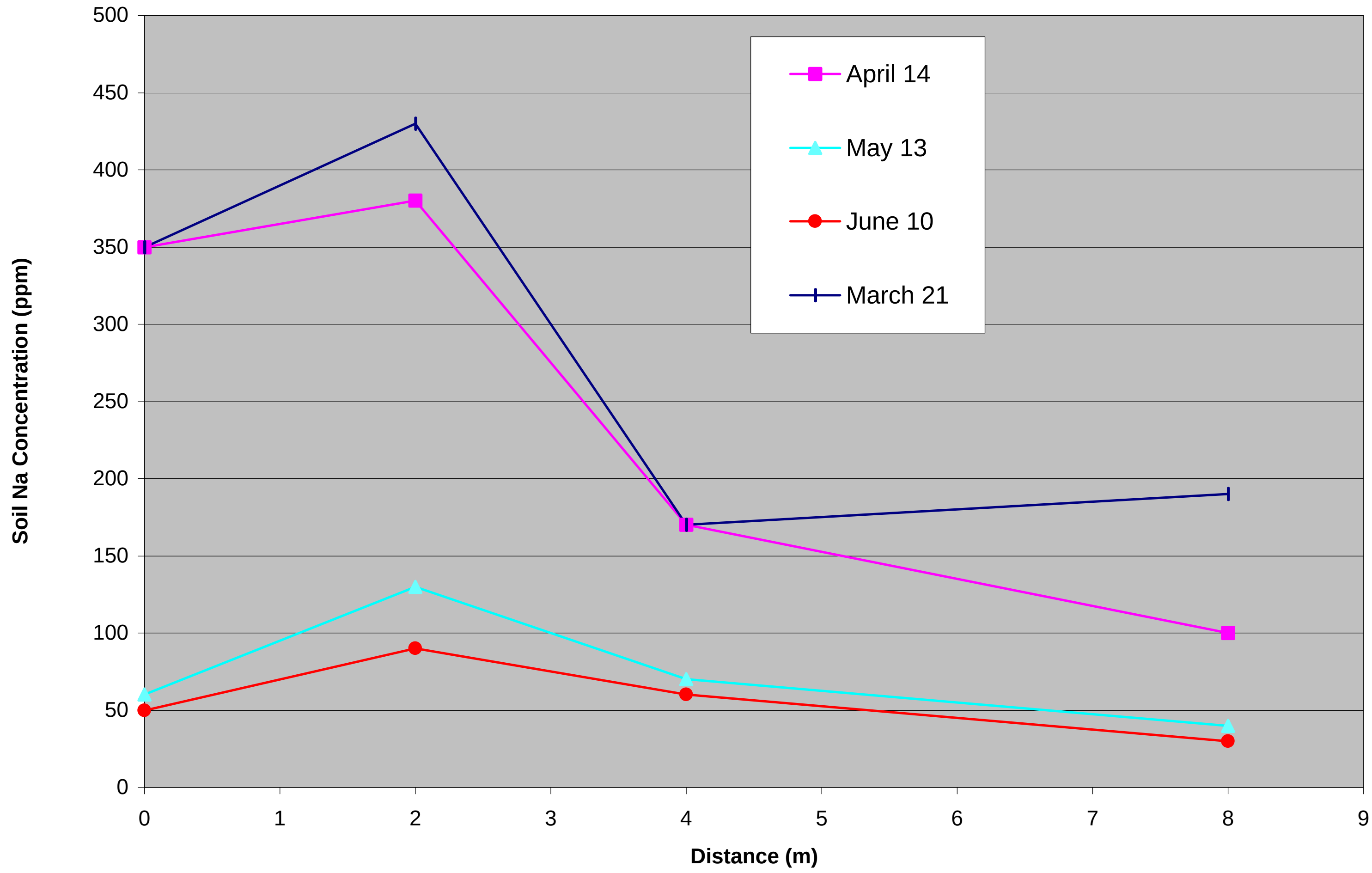


Figure 2.2. Concentrations of Cl in soil at 8 cm depth at increasing distance from the road on two-lane highways near London, ON. (data from Foster and Maun 1978). Each value represents three soil cores taken at each of six locations.

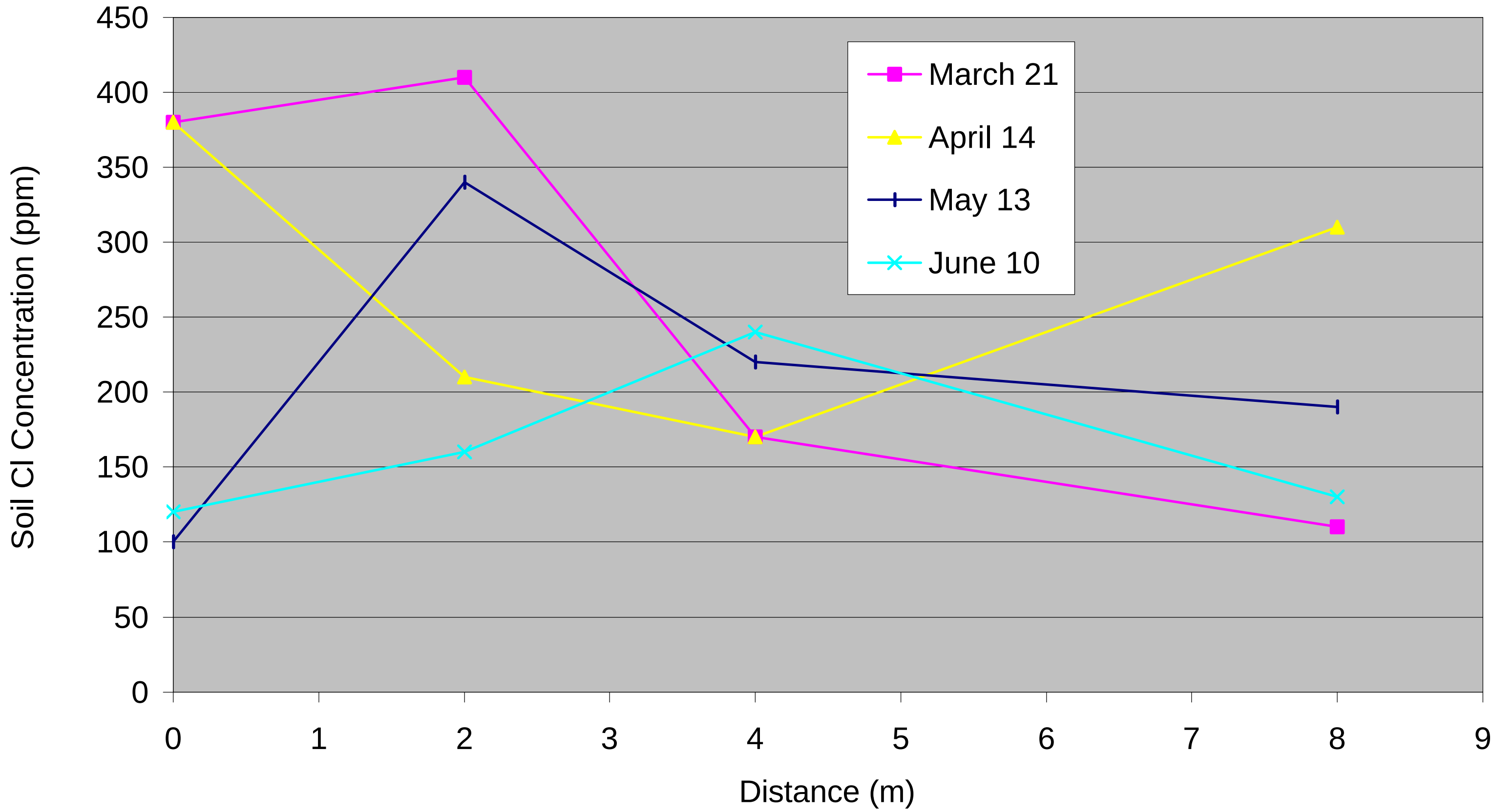


Figure 2.3. Concentrations of Cl in soil at 0-5 cm depth at increasing distance from the road on a four-lane highway near Guelph, ON (data from Hofstra and Smith 1984). Each value represents 24 (-30 to 30 m) or 12 (40 to 60 m) soil cores.

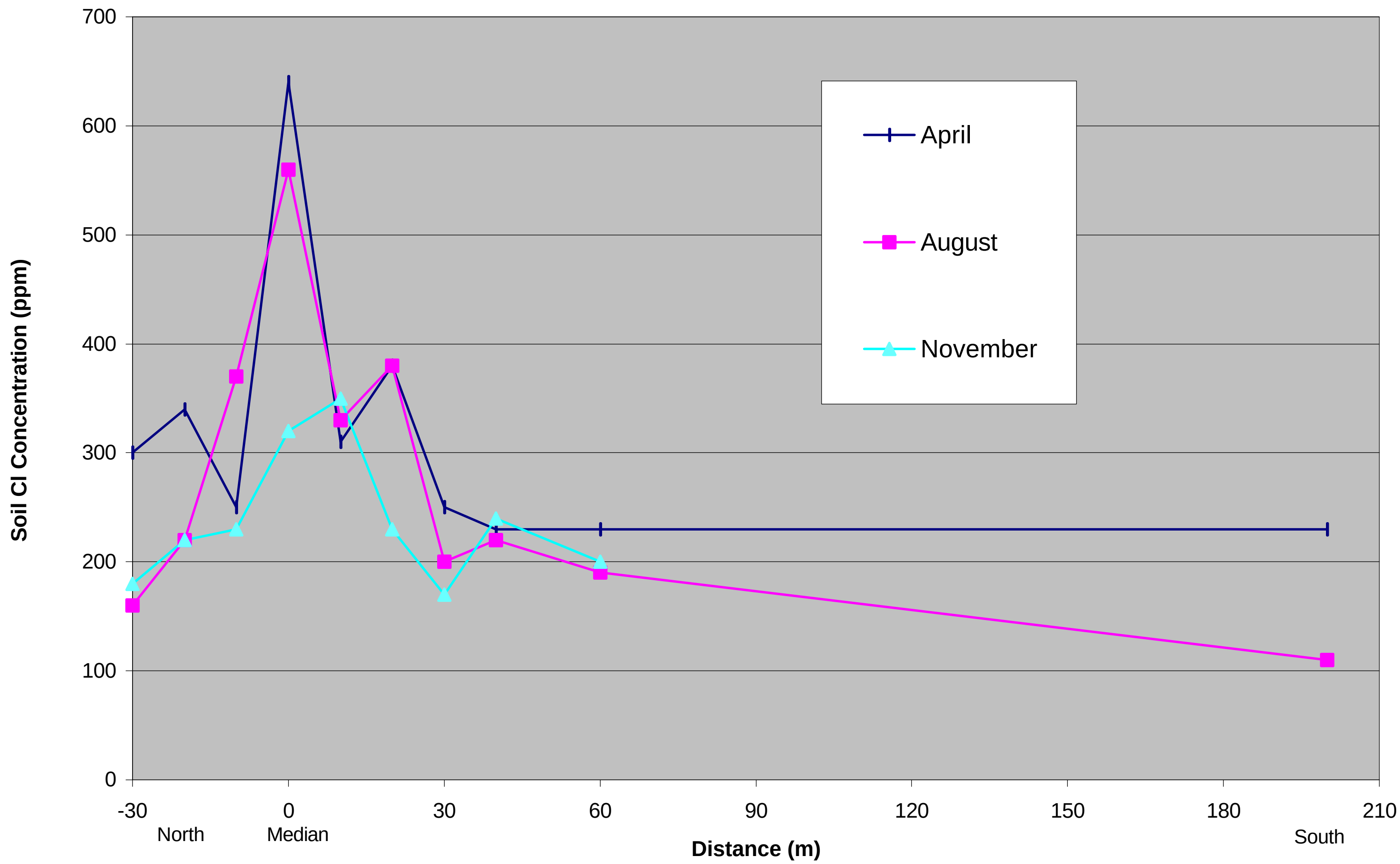


Figure 2.4. Concentrations of Na in soil at 0-5 cm depth at increasing distance from the road on a four-lane highway near Guelph, ON. (data from Hofstra and Smith 1984). Each value represents 24 (-30 to 30 m) or 12 (40 to 60 m) soil cores.

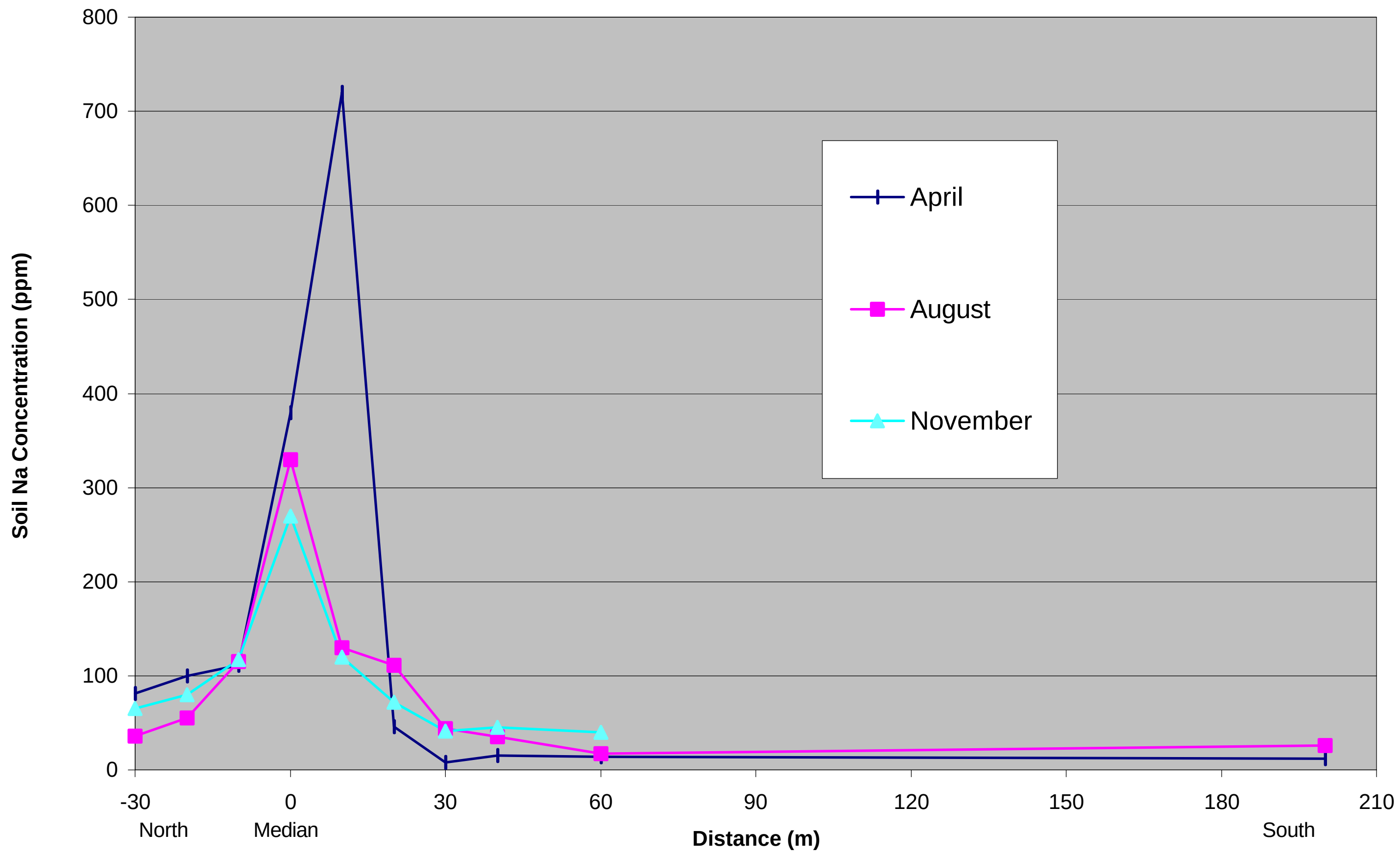


Figure 2.5. Concentrations of Cl in soil at 6-10 cm depth at increasing distance from the road on a four-lane highway near Guelph, ON. (data from Hofstra and Smith 1984). Each value represents 24 soil cores.

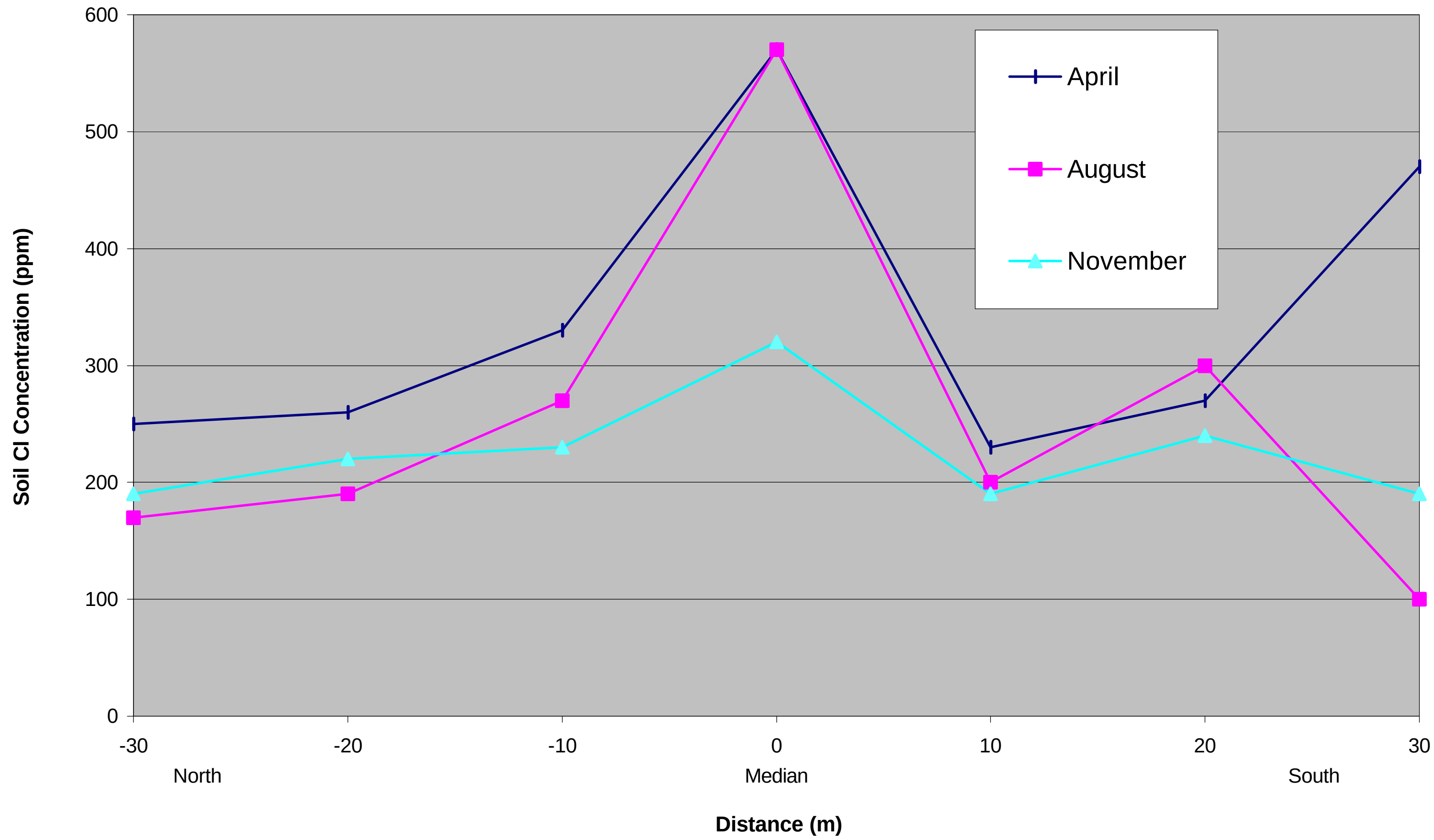


Figure 2.6. Concentrations of Na in soil at 6-10 cm depth at increasing distance from the road on a four-lane highway near Guelph, ON. (data from Hofstra and Smith 1984). Each value represents 24 soil cores.

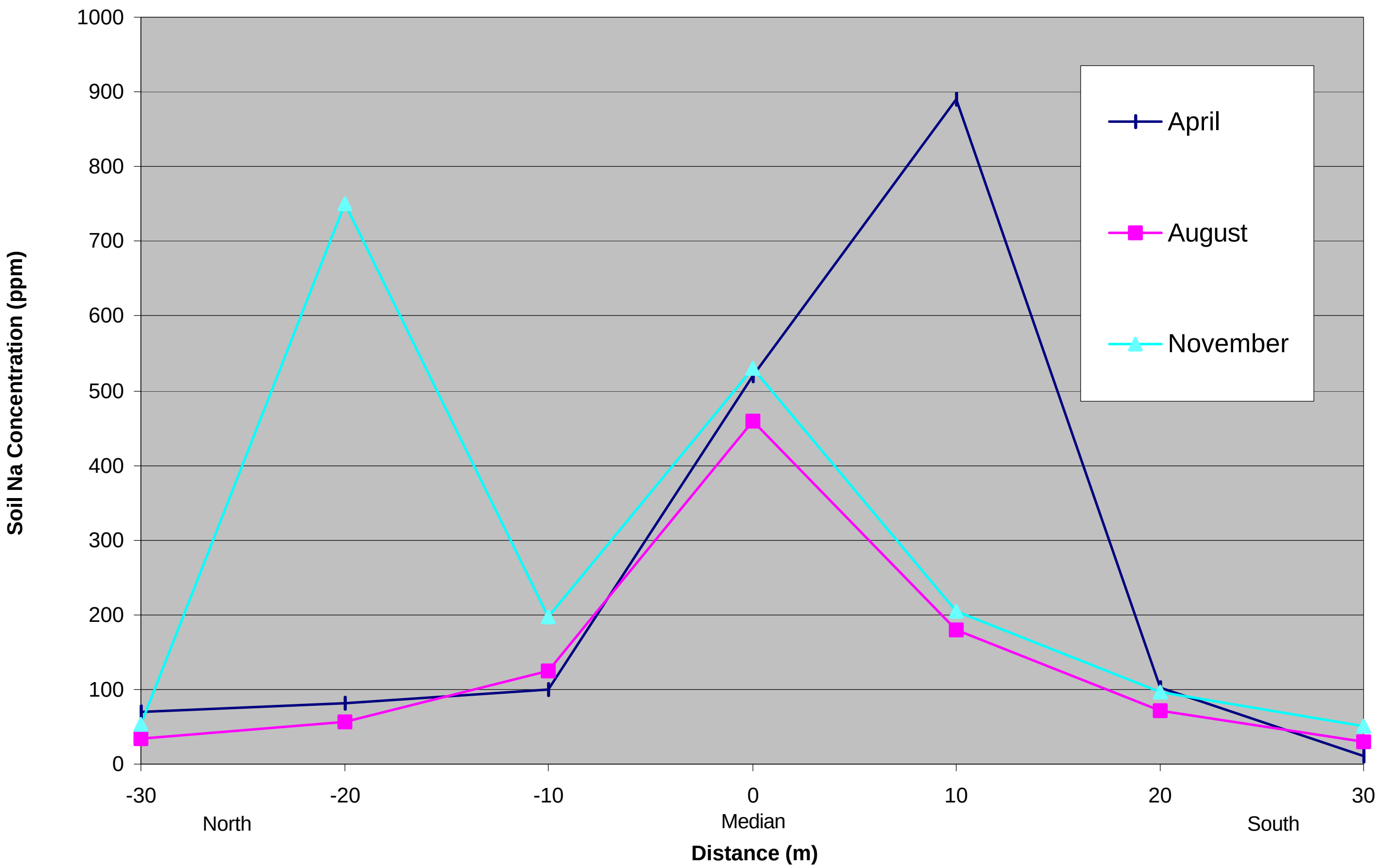


Figure 2.7. Concentration of Cl in tissue of roadside and pasture vegetation at increasing distance from the highway in August 1974 (data from Hofstra and Smith 1984). Each value represents 6 sub-samples.

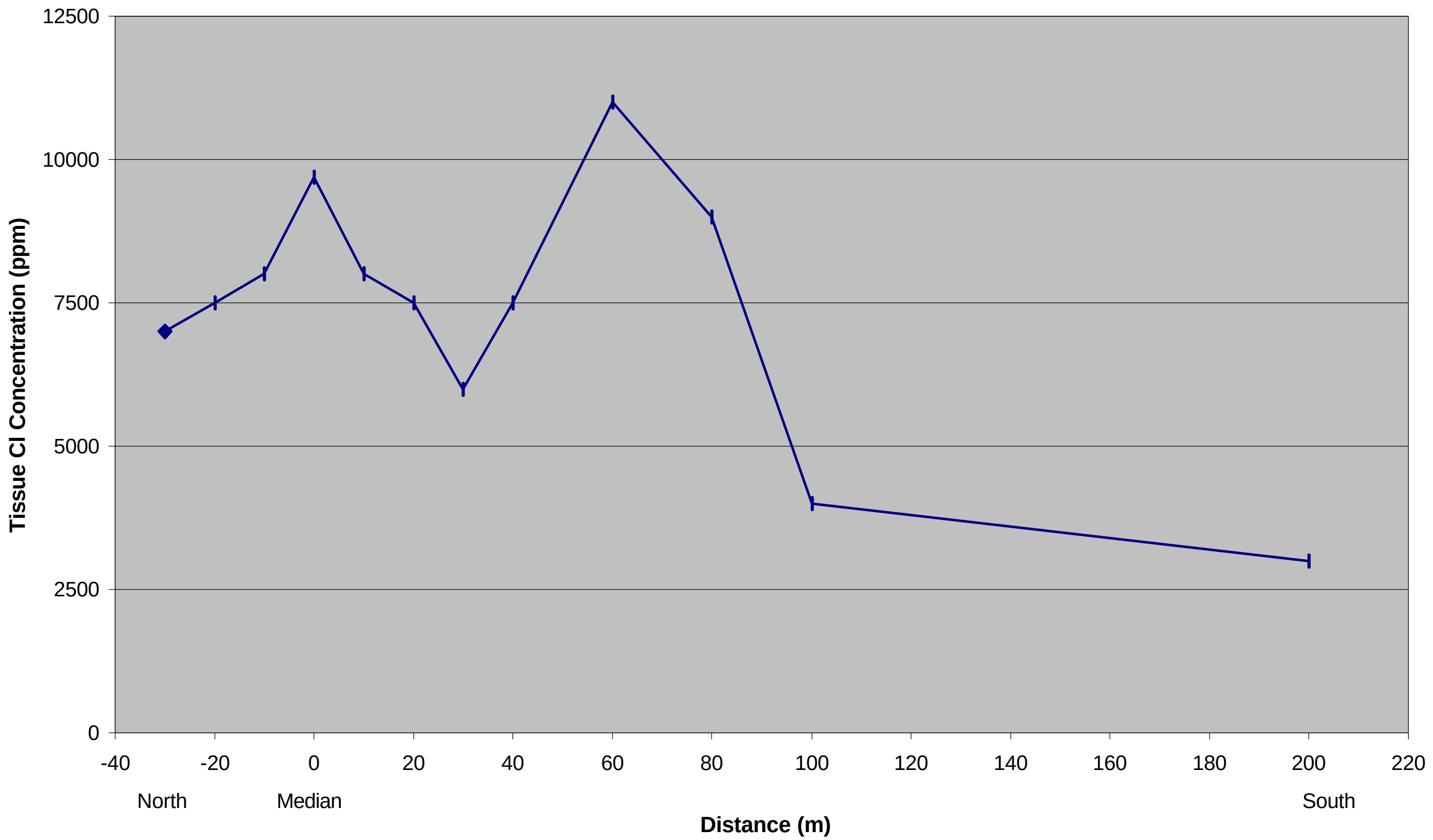


Figure 2.8. Concentration of Na in tissue of roadside and pasture vegetation at increasing distance from the road in June 1974 (data from Hofstra and Smith 1984). Each value represents 6 sub-samples.

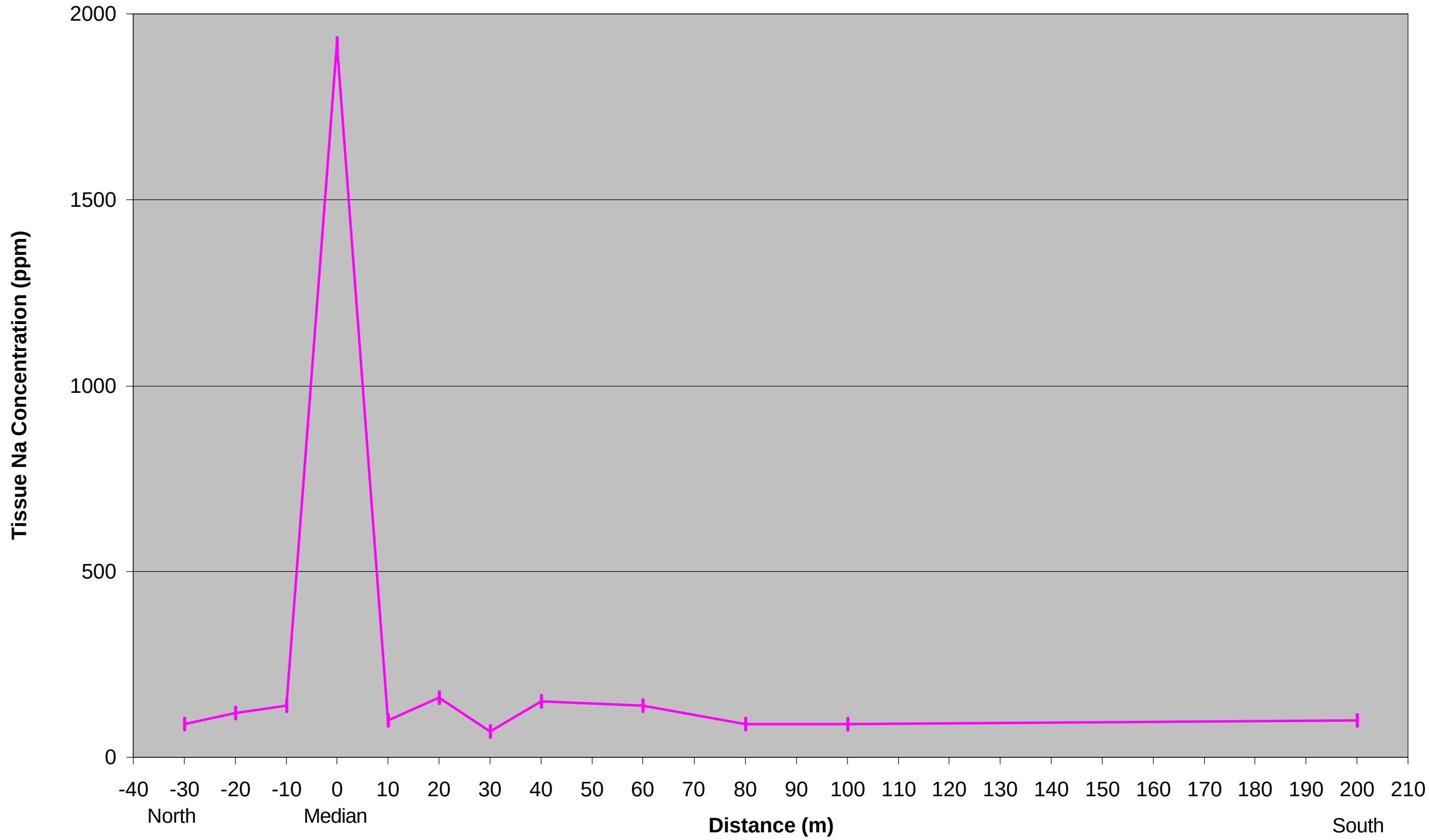


Figure 2.9. Concentration of Cl in dead peach twig tissue at increasing distance from the highway in June 1974 (data from Northover 1987). Each value represents a sample of 25 canopy shoots.

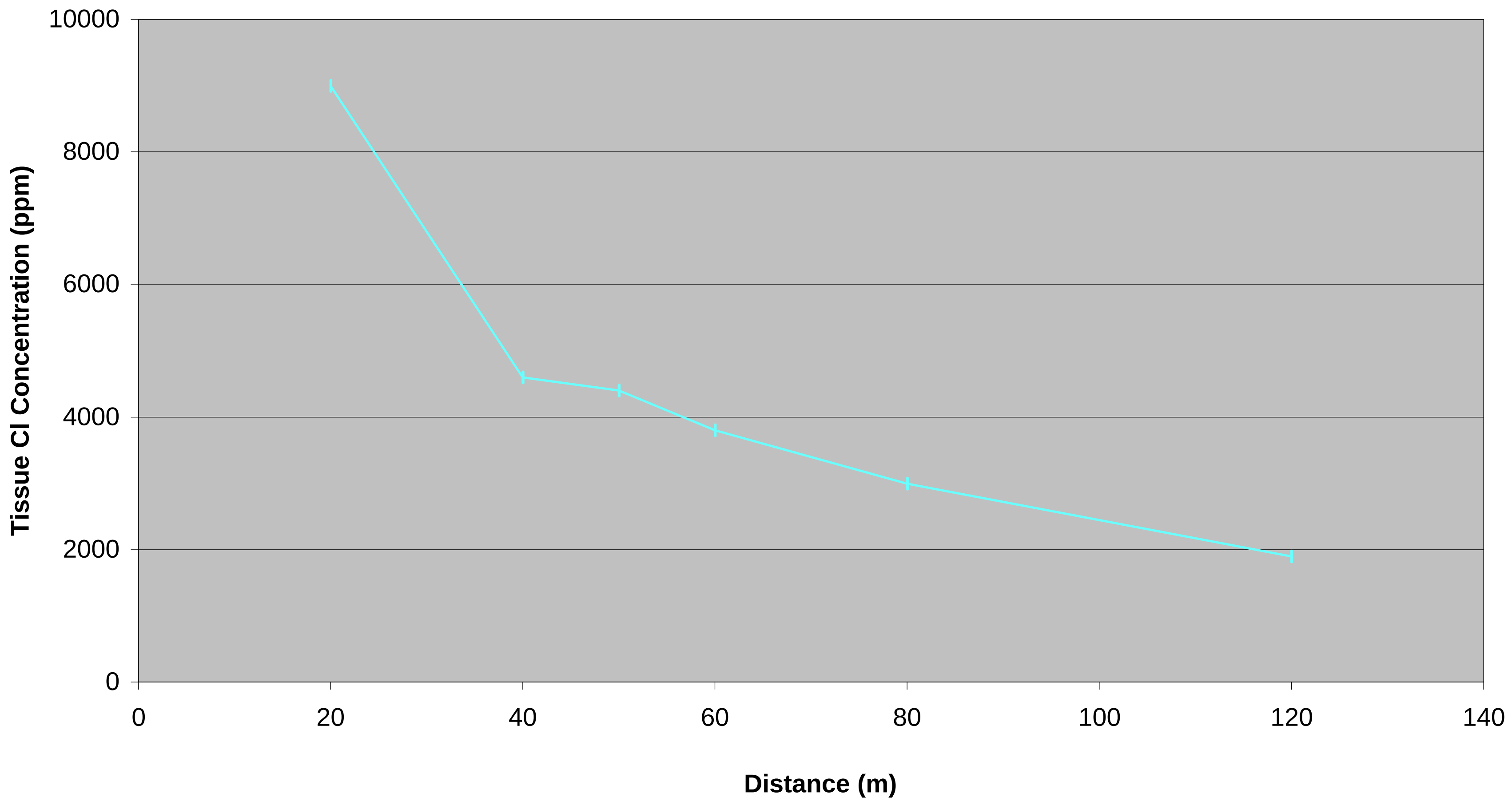


Figure 2.10. Concentration of Na in dead peach twig tissue at increasing distance from the highway in June 1974 (data from Northover 1987). Each value represents a sample of 25 canopy shoots.

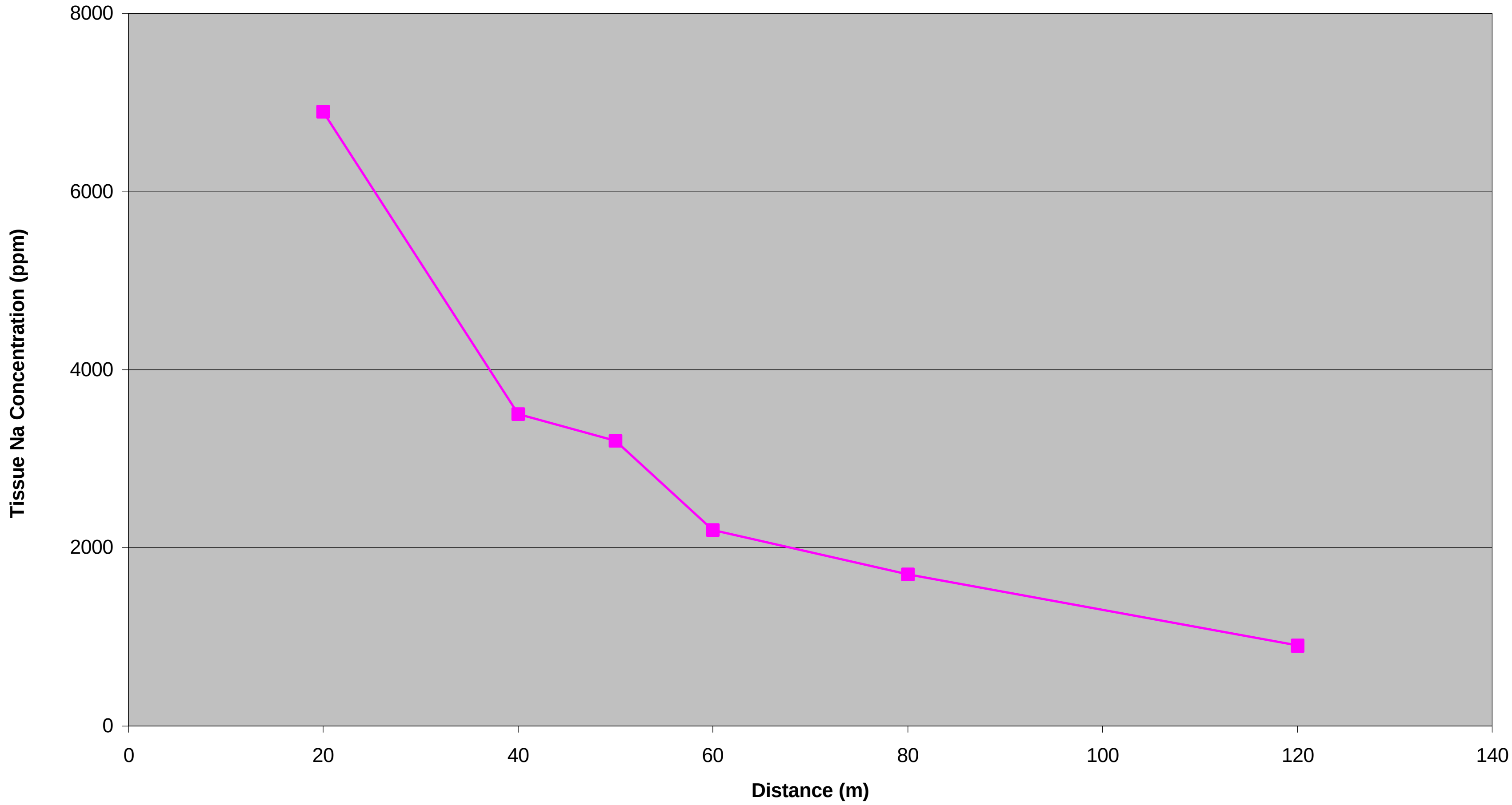


Figure 2.11 . Concentration of Na in peach and plum twig tissue at increasing distance from the highway in April1980 (McLaughlin and Pearson 1981).

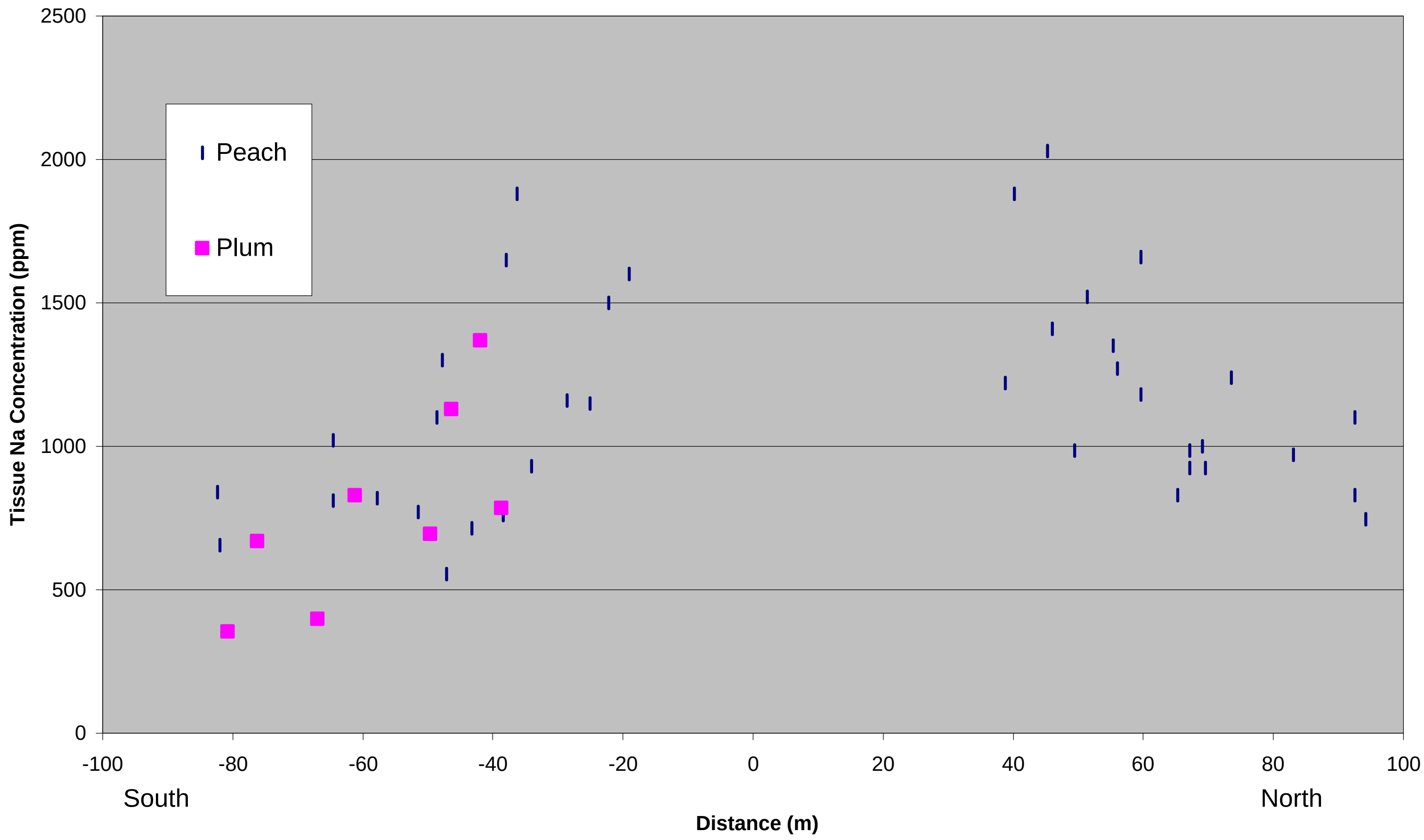


Figure 2.12. Concentration of Cl in peach and plum twig tissue at increasing distance from the highway in April1980 (McLaughlin and Pearson 1981).

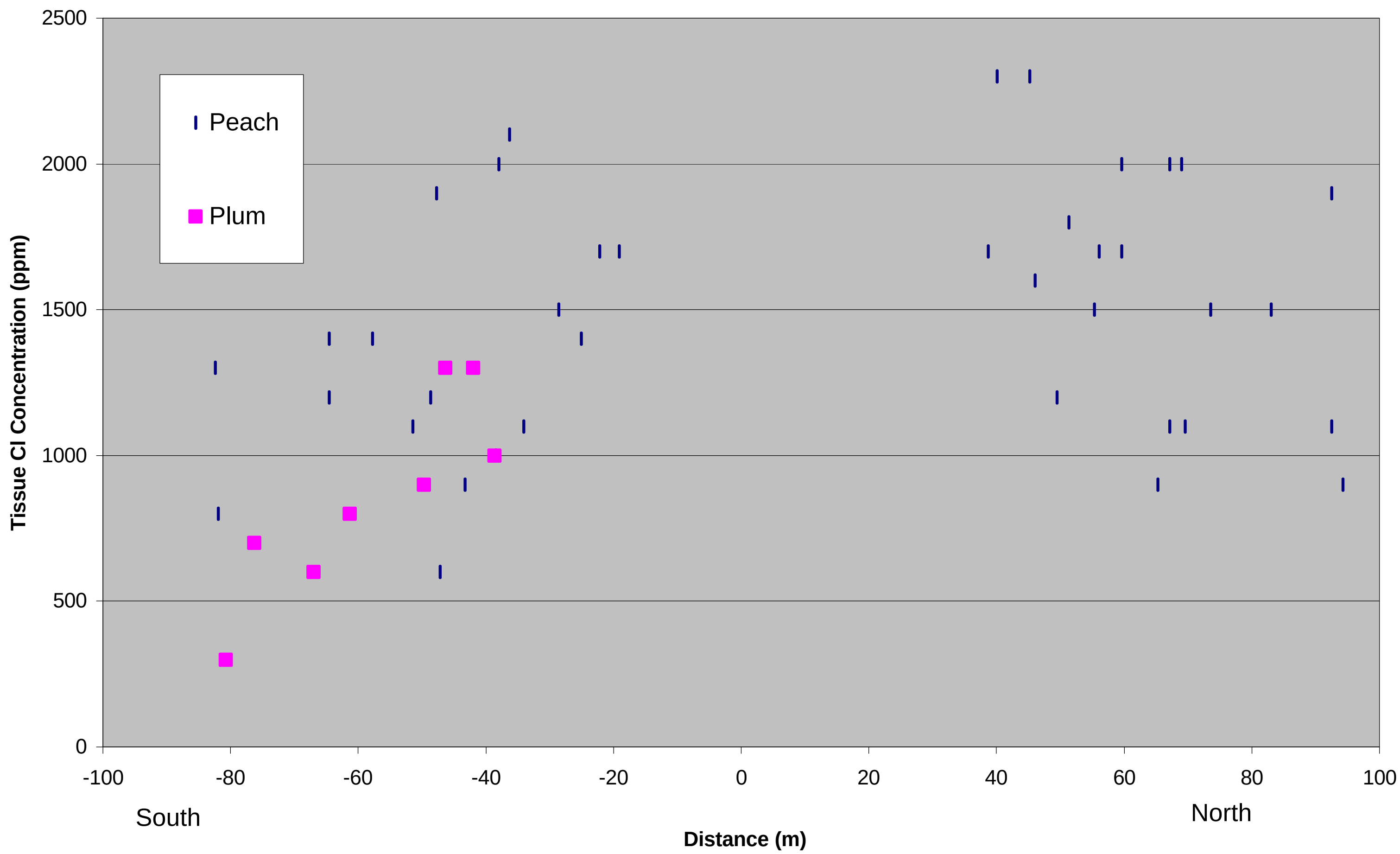


Figure 2.13. Concentration of Cl in soil at increasing distance from the road. All references**.**

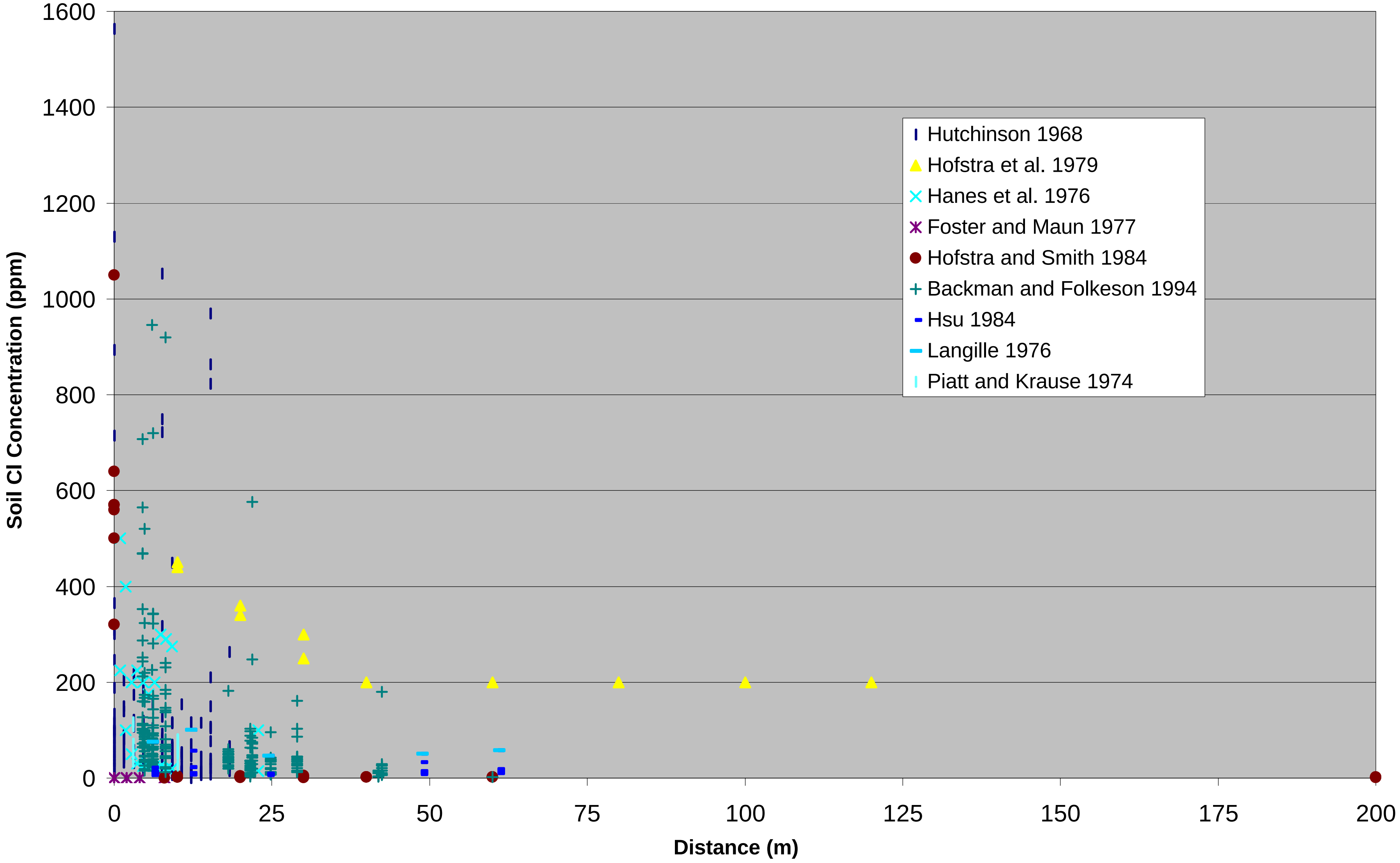


Figure 2.14. Concentration of Na in soil at increasing distance from the road. All references**.**

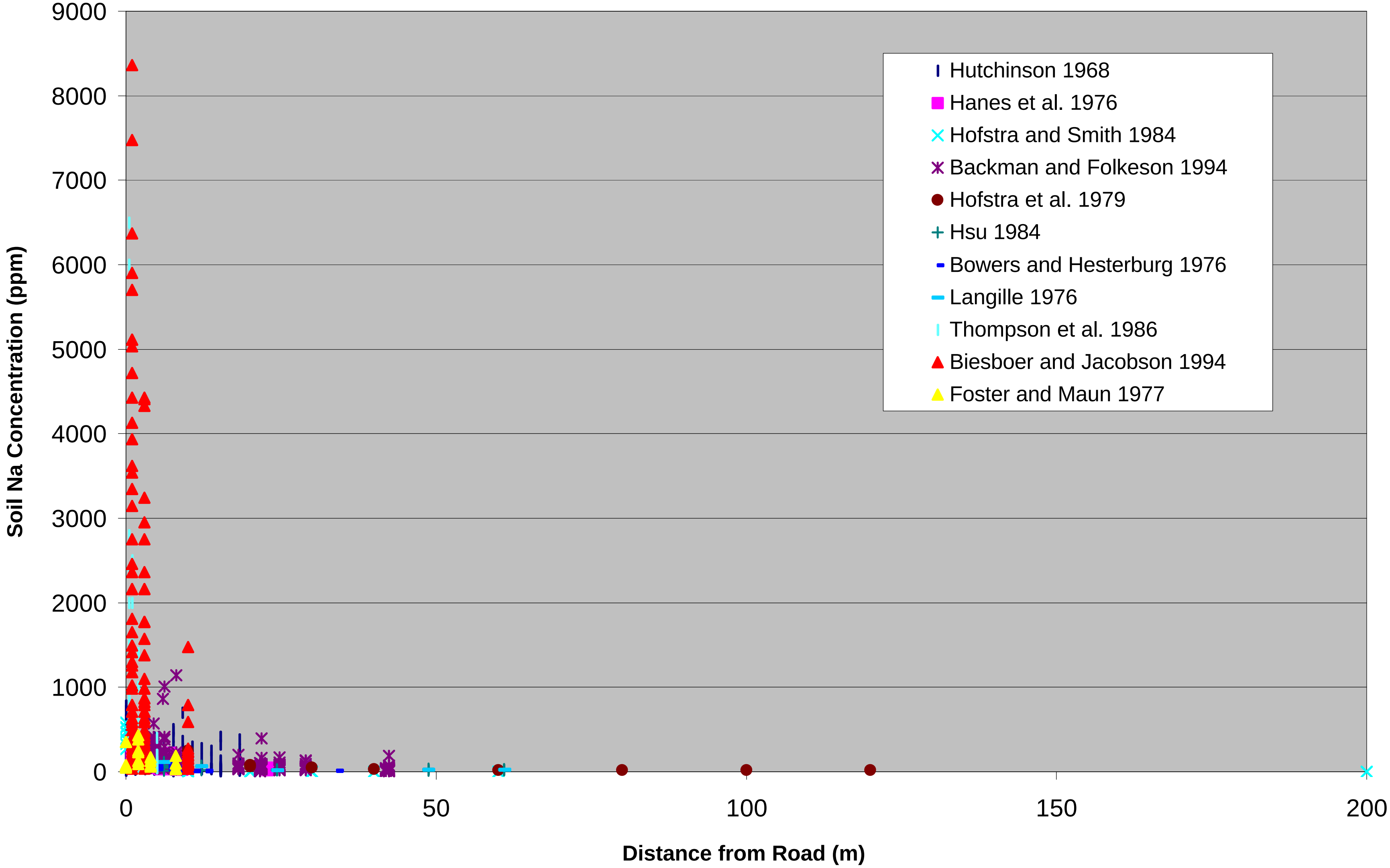


Figure 2.15. Concentration of NaCl in soil at increasing distance from the road, from Prior (1968).

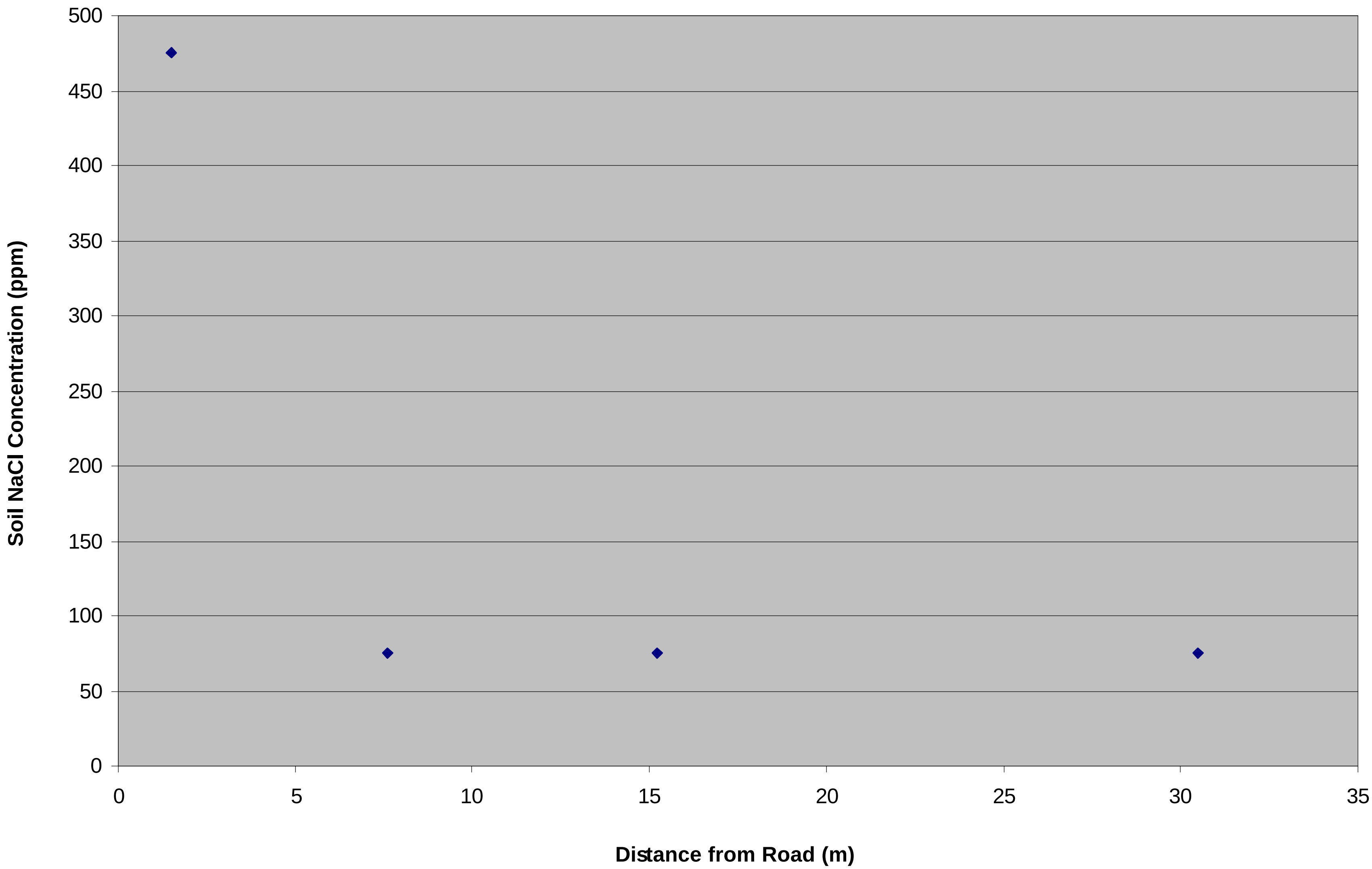


Figure 2.16. Concentration of Cl in soil at increasing distance from the road. Canadian references.

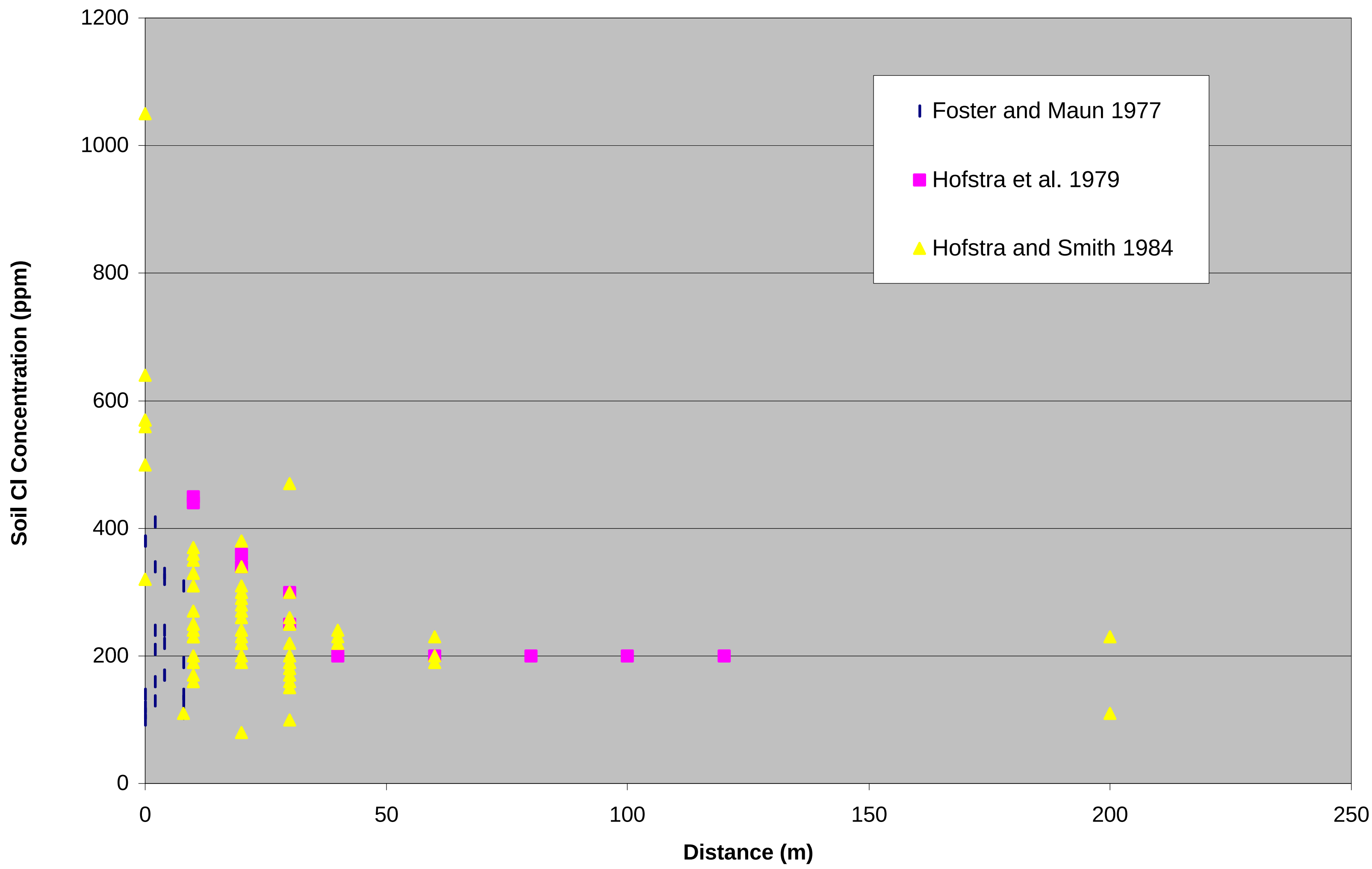


Figure 2.17. Concentration of Na in soil at increasing distance from the road. Canadian references.

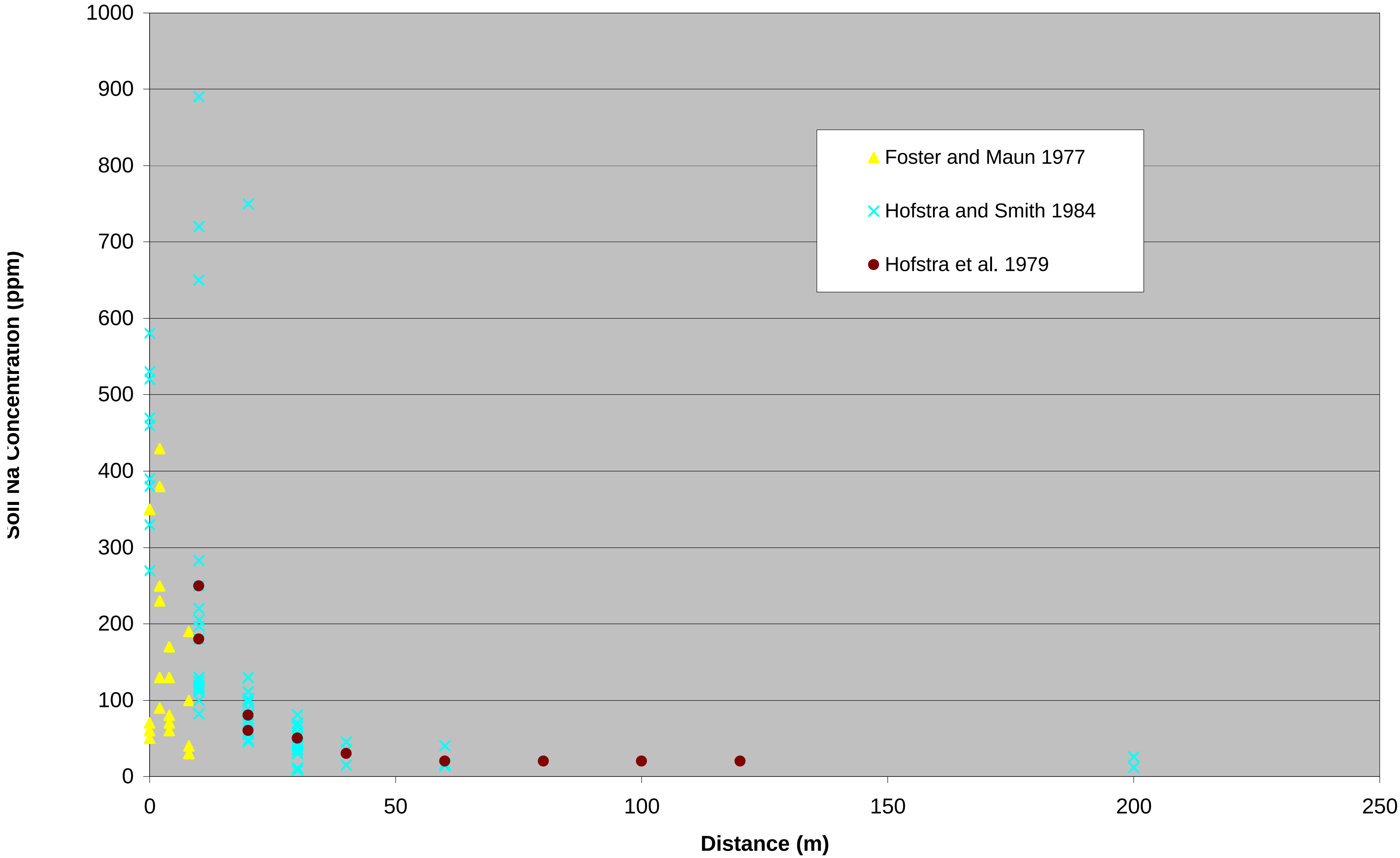


Figure 2.18. Concentration of Cl in plant tissue at increasing distance from the road. All references.

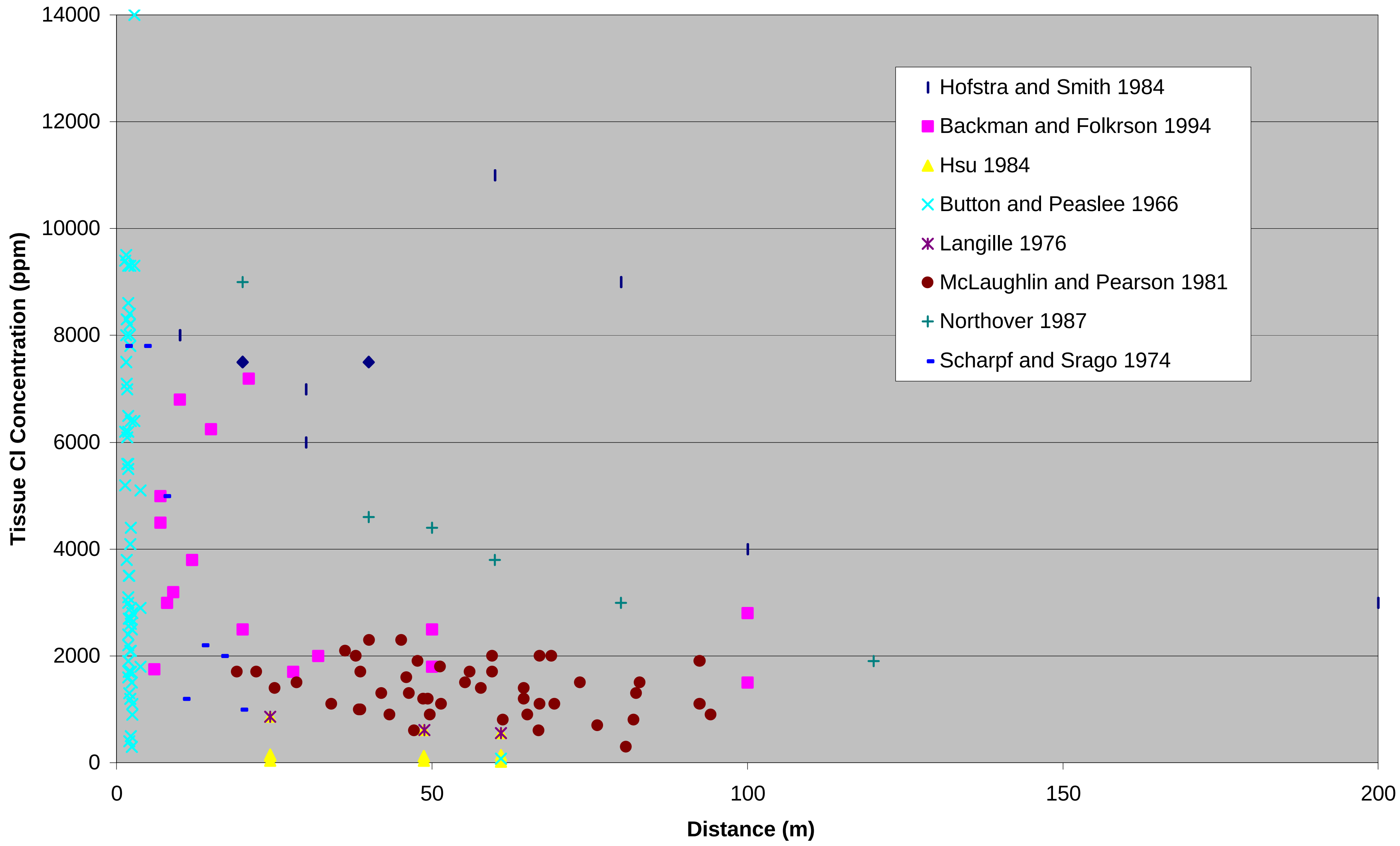


Figure 2.19. Concentration of Na in plant tissue at increasing distance from the road. All references.

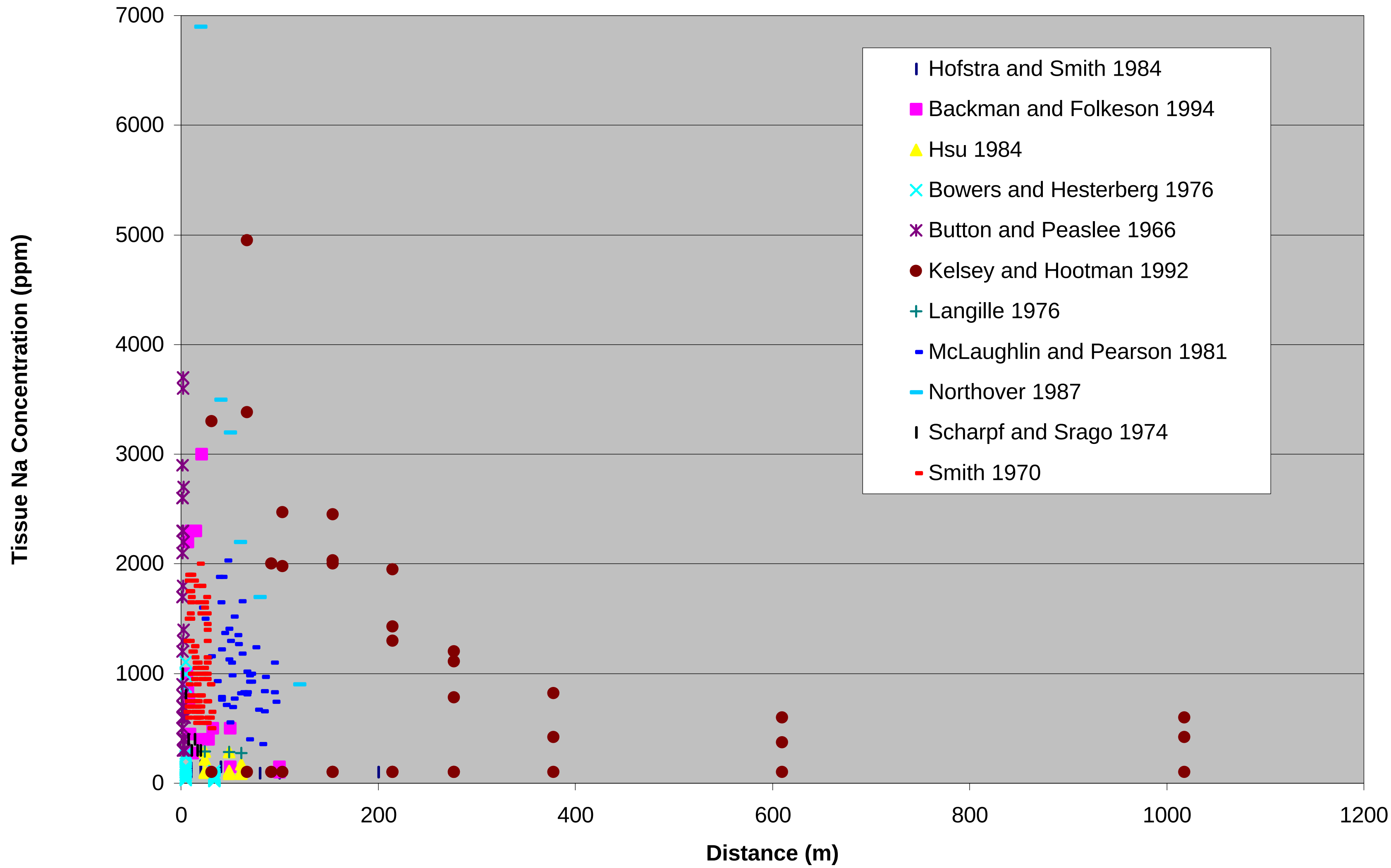


Figure 2.20. Concentration of Cl in plant tissue at increasing distance from the road. Canadian references.

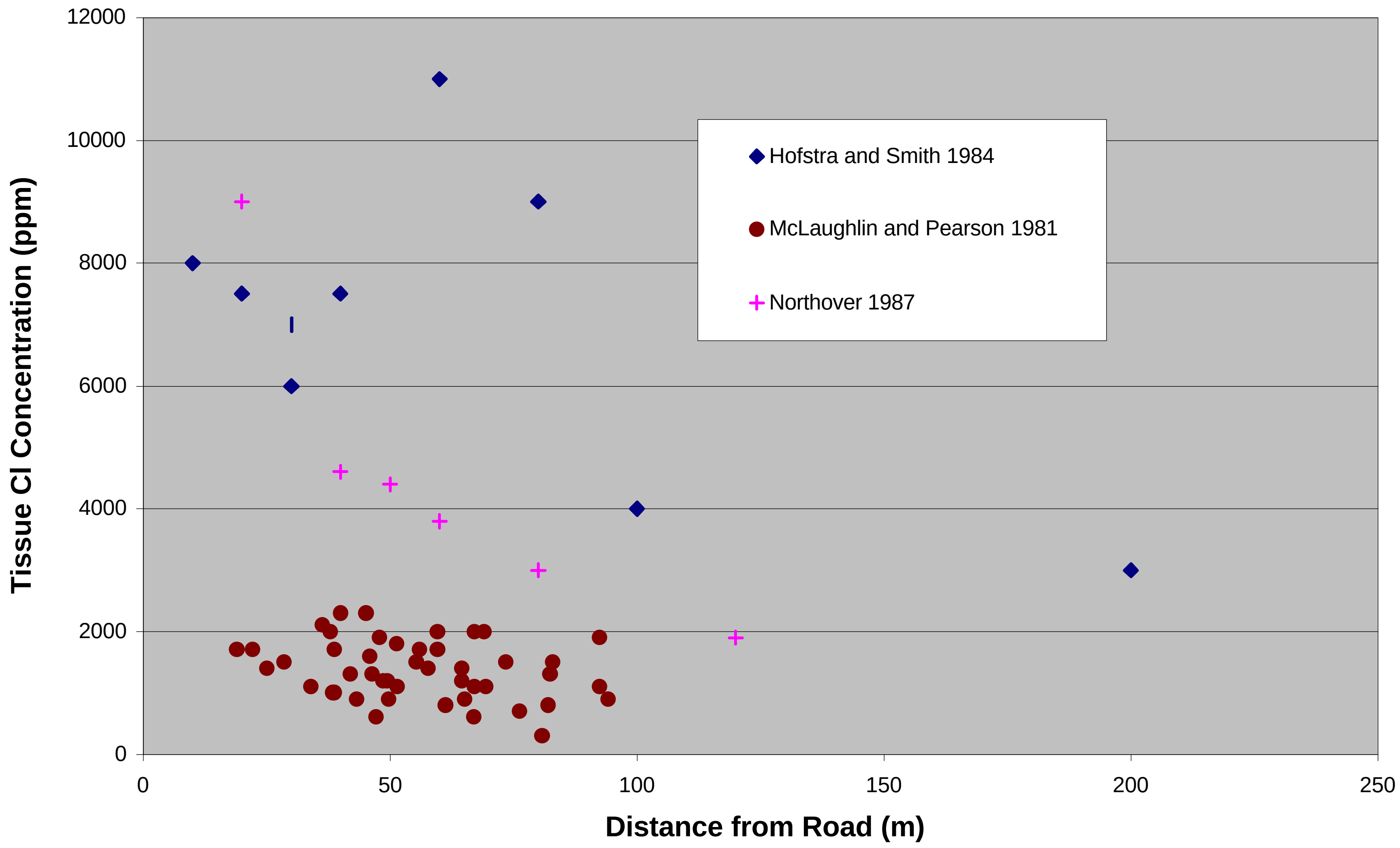


Figure 2.21. Concentration of Na in plant tissue at increasing distance from the road. Canadian references.

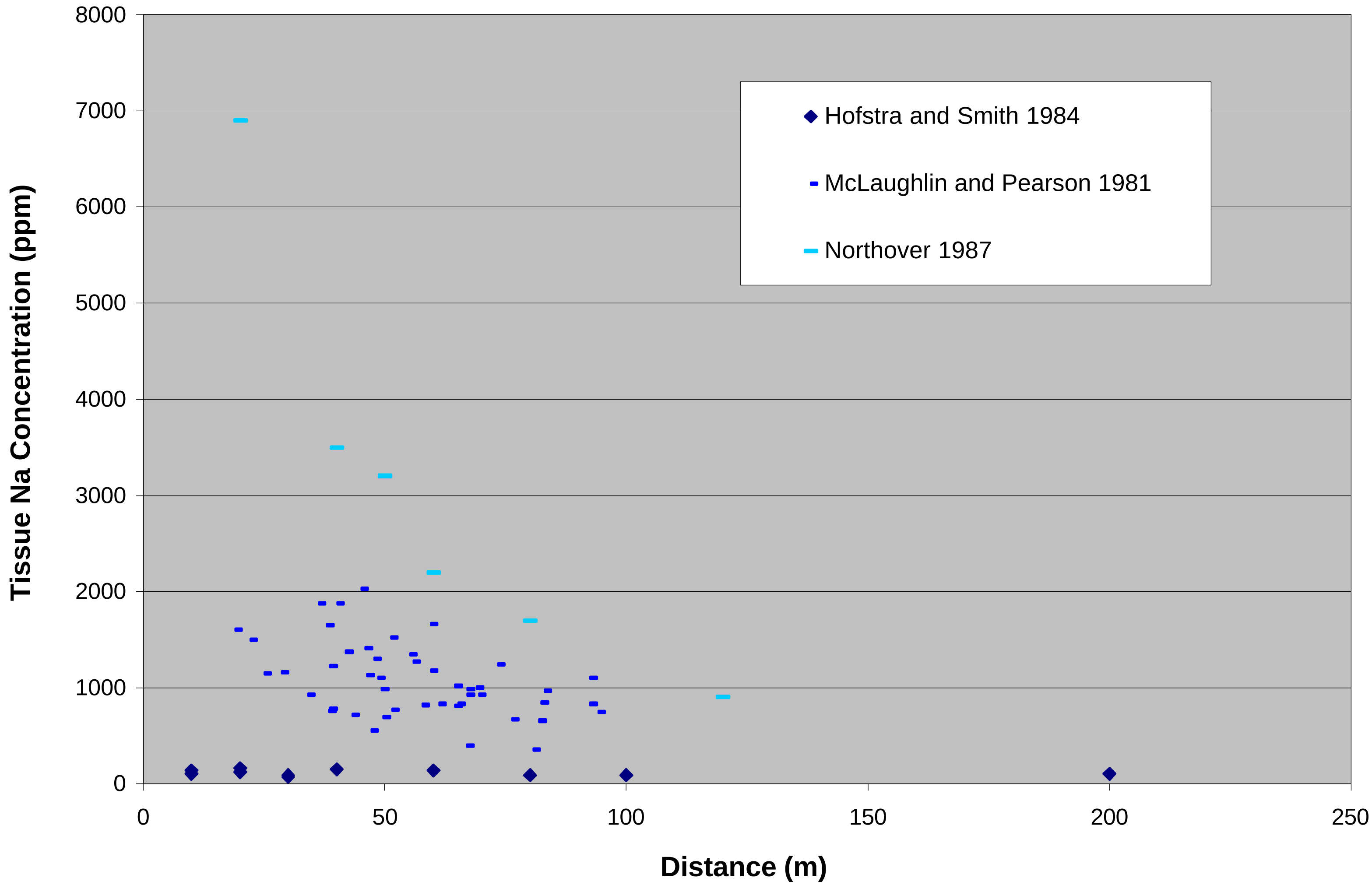


Figure 3.1 - Location of roads in Eastern Canada in relation to the percent of the land area that is forested.

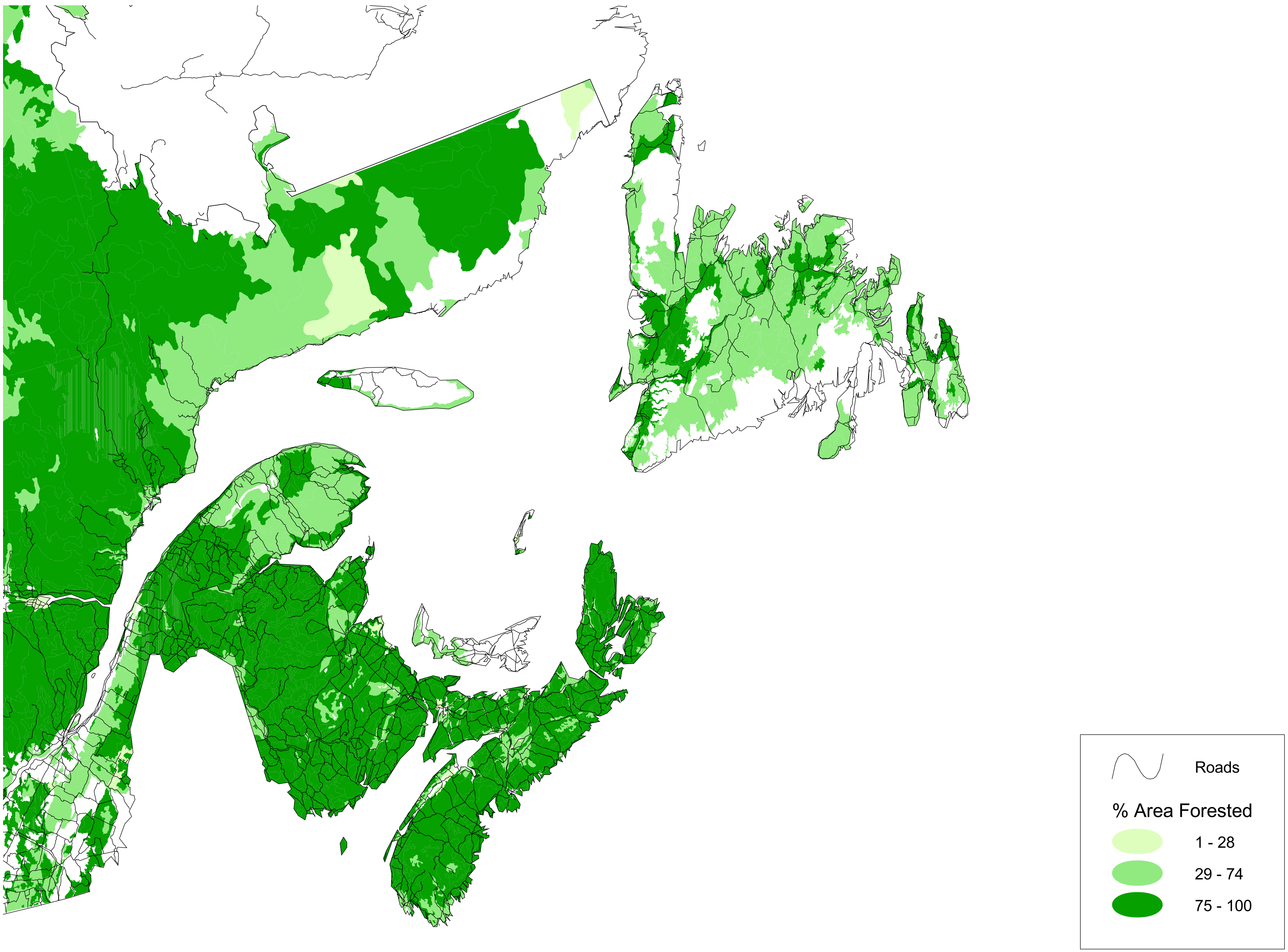


Figure 3.2 - Location of roads in Central Canada in relation to the percent of the land area that is forested.

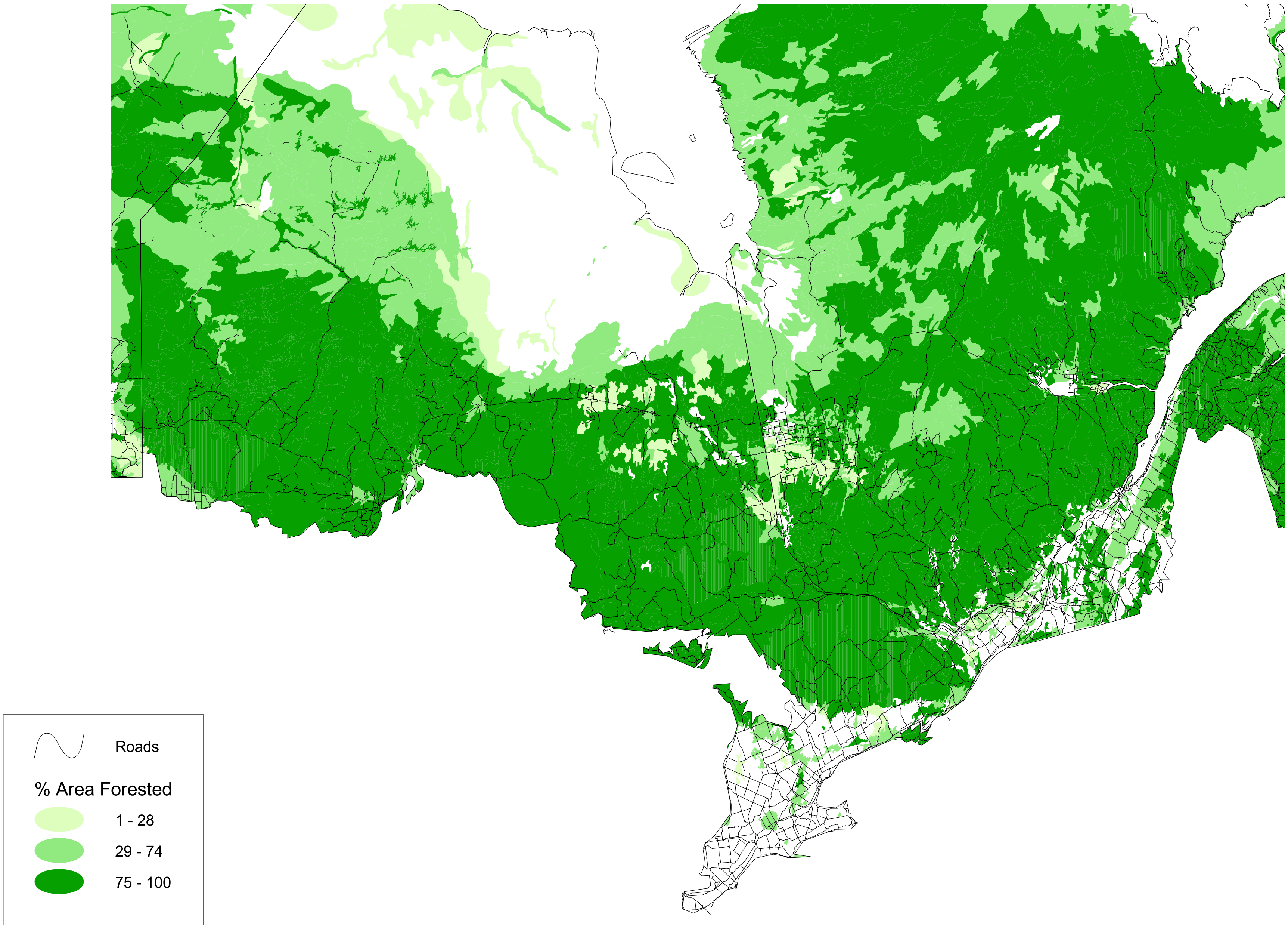


Figure 3.3 - Location of roads in Western Canada in relation to the percent of the land area that is forested.

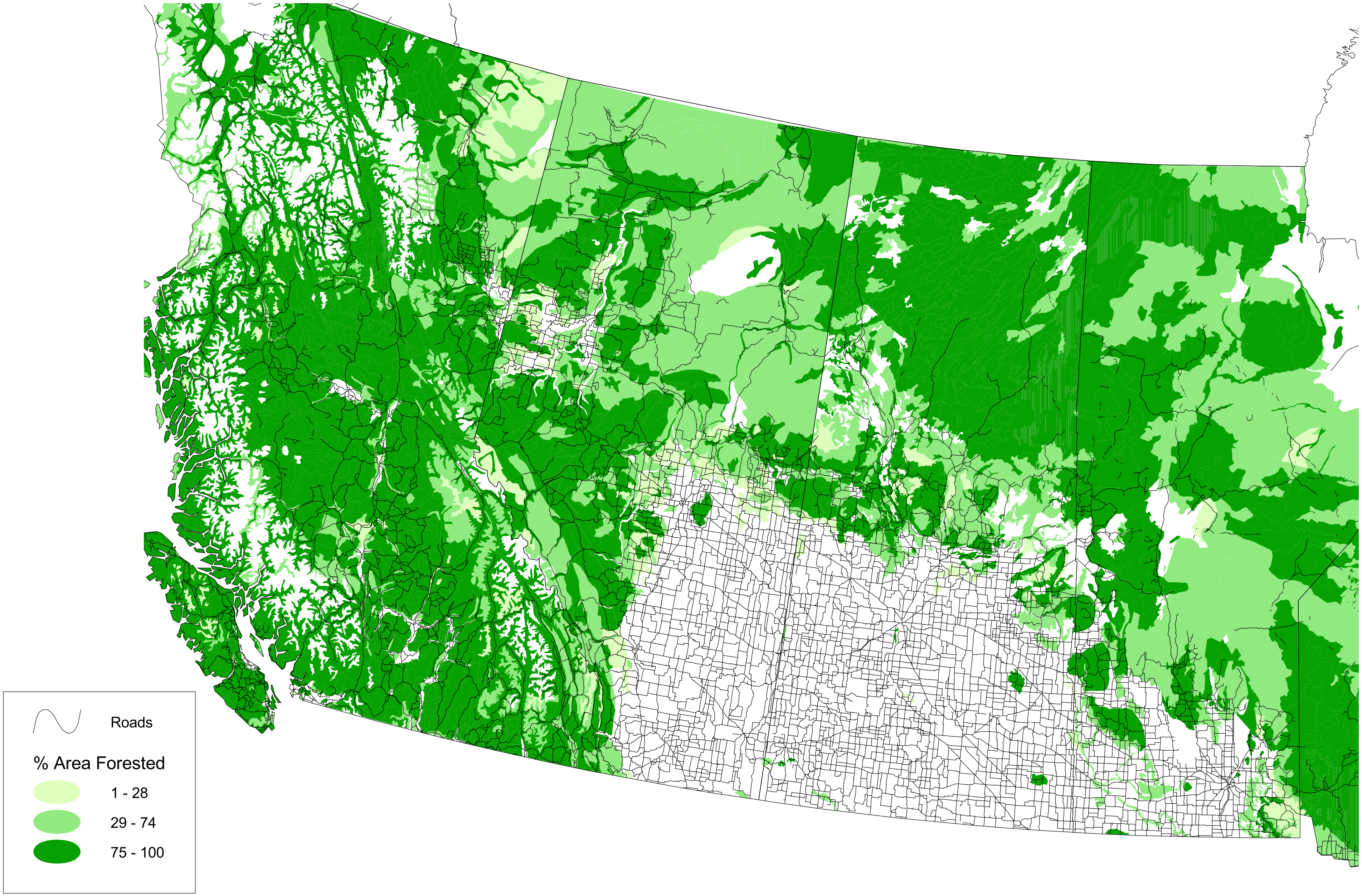


Figure 4.1. Peach and plum terminal twig dieback at increasing distance from the highway in April 1980 and 1981 (data from McLaughlin and Pearson 1981).

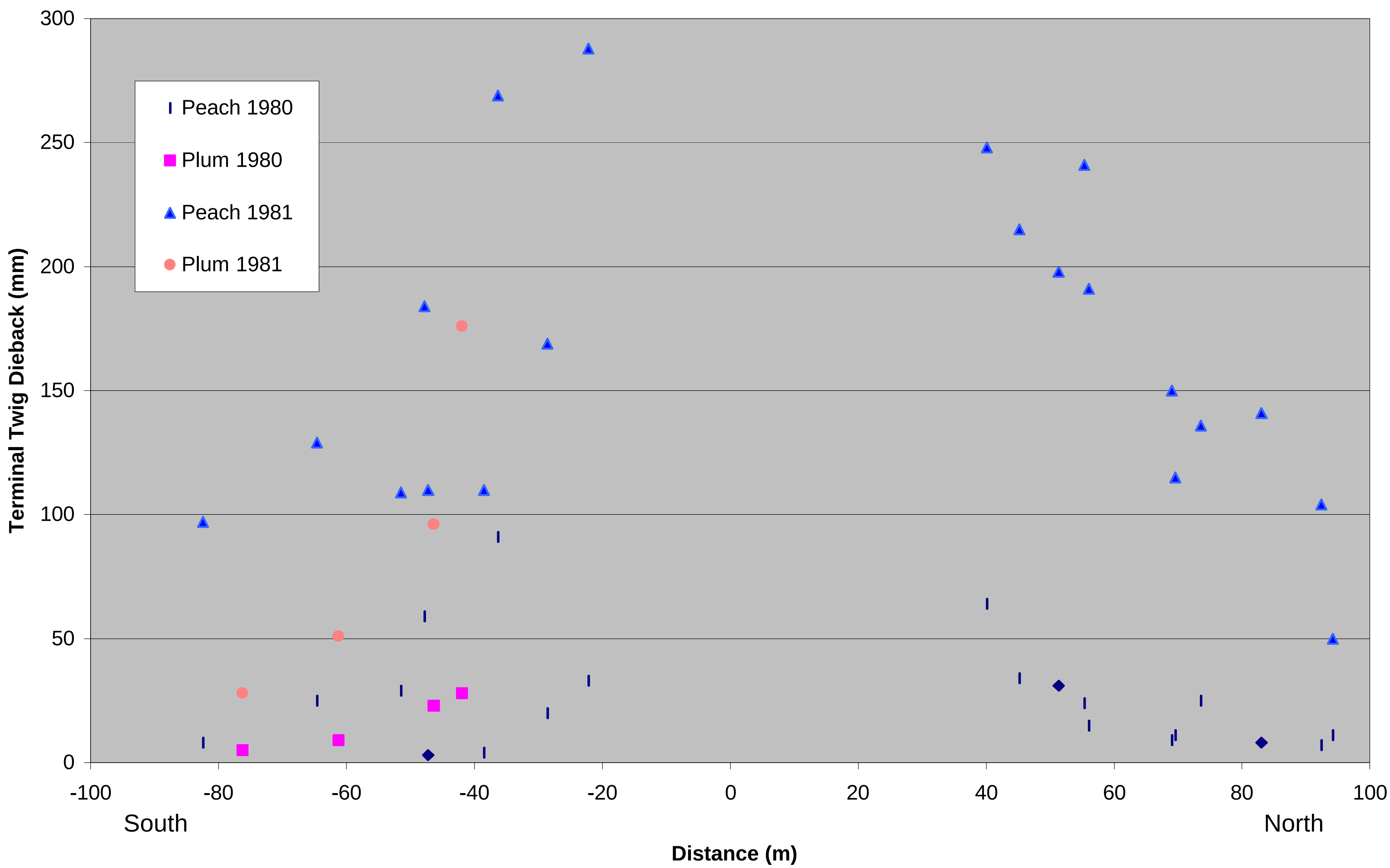


Figure 4.2. Locations of 17 forested sites adjacent to highways evaluated for tree injury and decline in south central/eastern British Columbia in 1991. The sites are indicated by the circled numbers. (From Davis *et al* 1992).

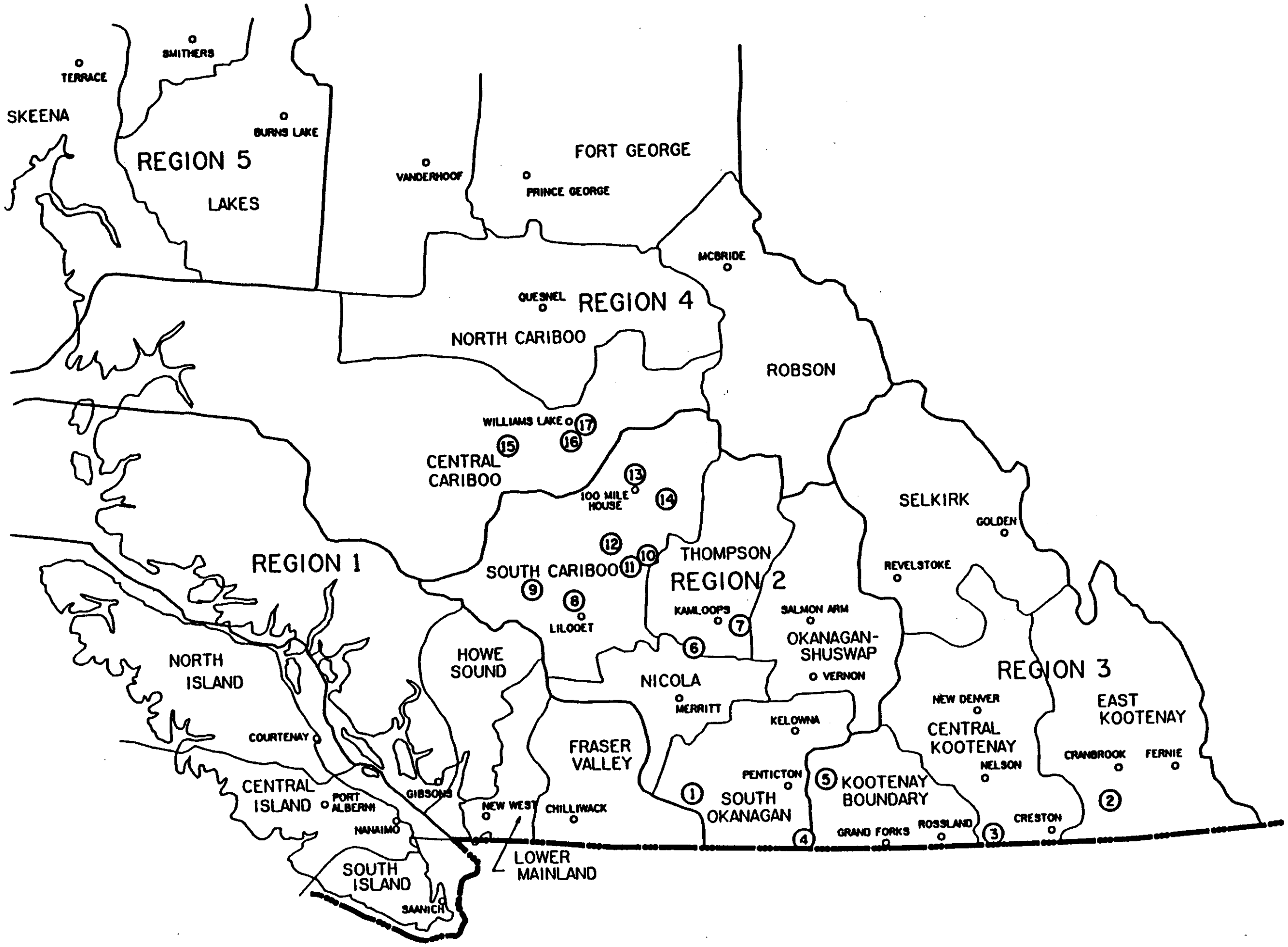


Figure 4.3. Foliar concentrations of Na and Cl by injury class following sampling of Douglas-fir and ponderosa pine needles on Loon Lake Road in B. C. in May 1994. The error bars indicate the range of values. (From Soilcon Laboratories Ltd. 1995)

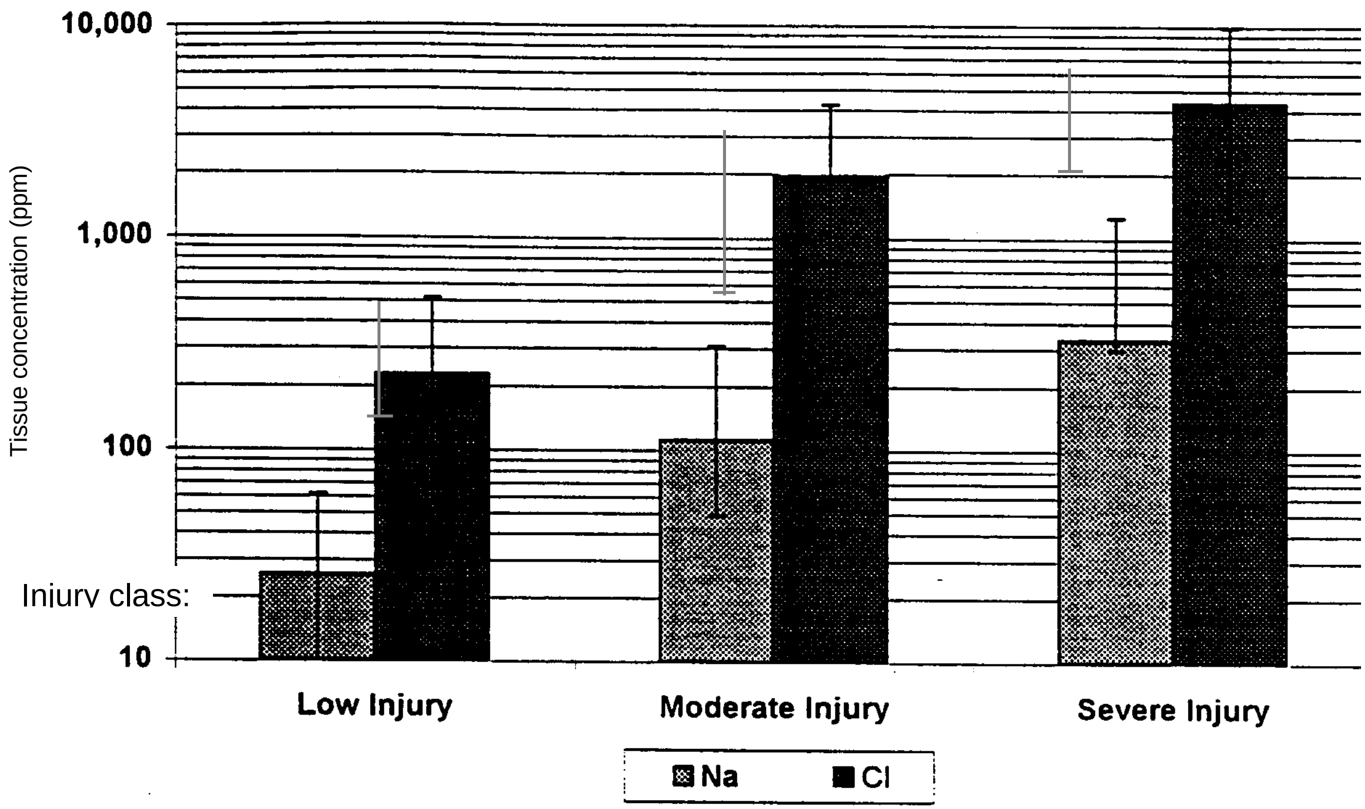


Figure 4.4. Concentration of Cl in sugar maple leaf tissue at increasing distance from the road at three time periods (data from Button and Peaslee 1966). Each value represents a sample of one tree.

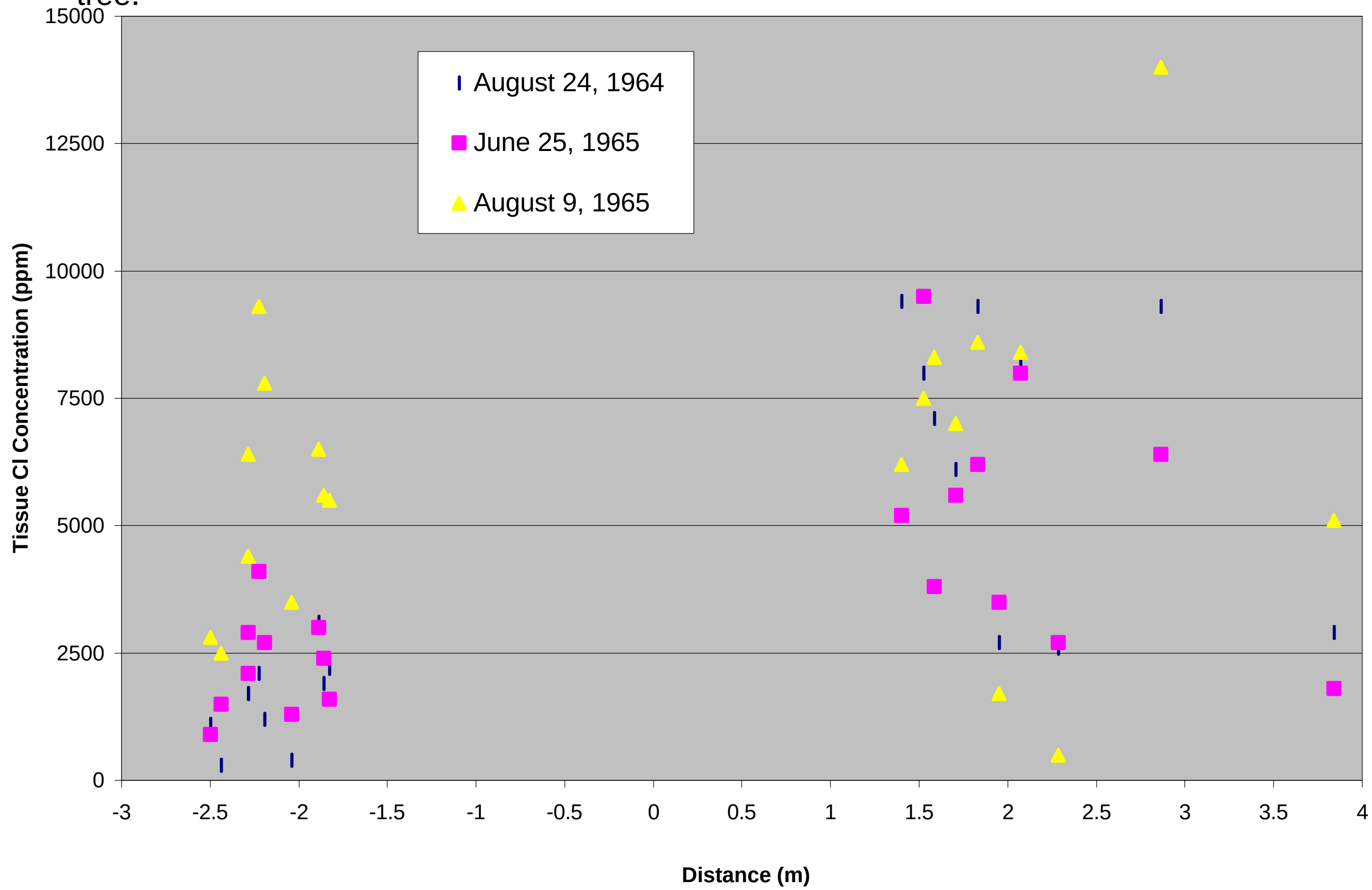


Figure 4.5. Concentration of Na in Sugar maple leaf tissue at increasing distance from the road at three time periods (data from Button and Peaslee 1966). Each value represents a sample of one tree

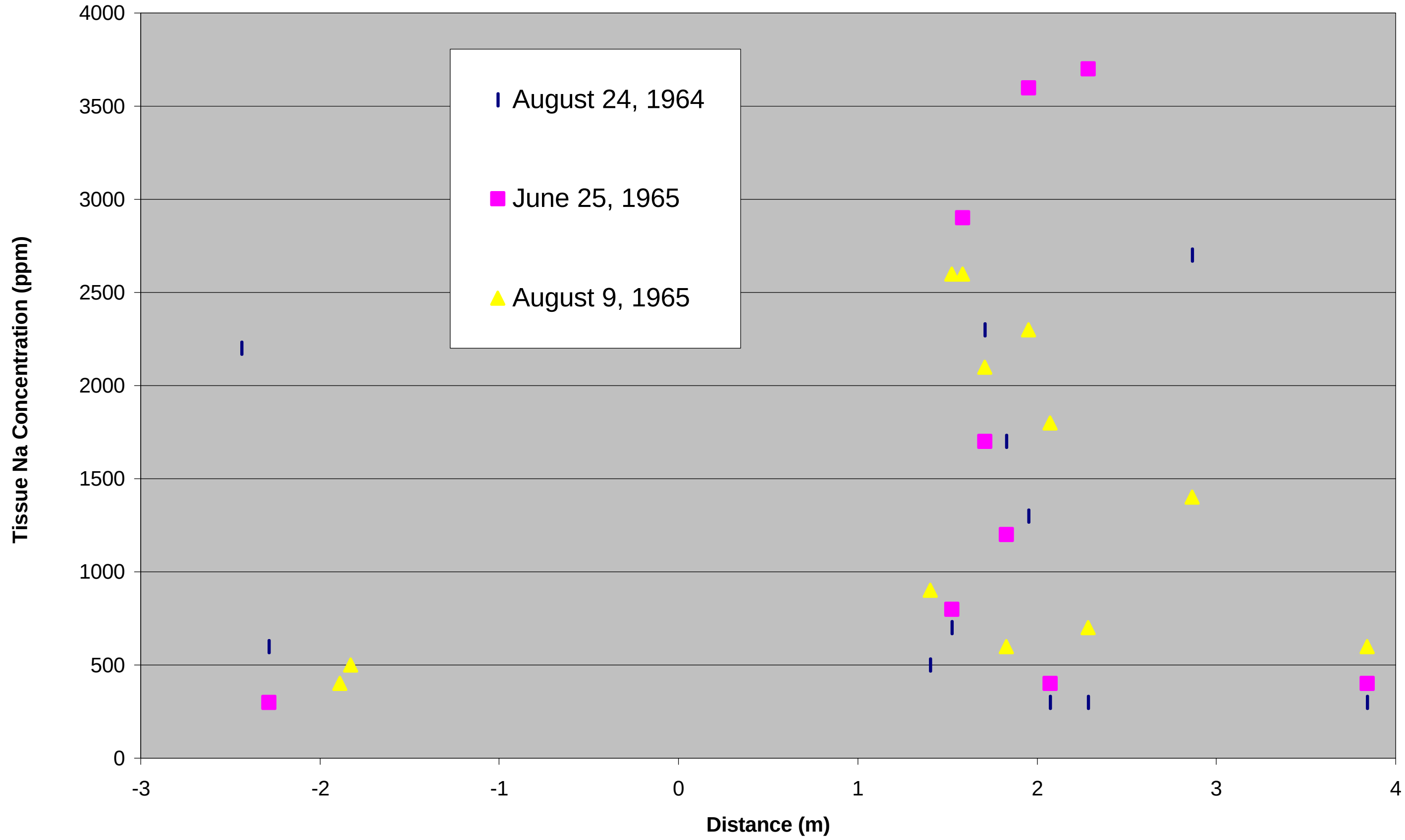


Figure 4.6. Relation between the density of berry production (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - British Columbia

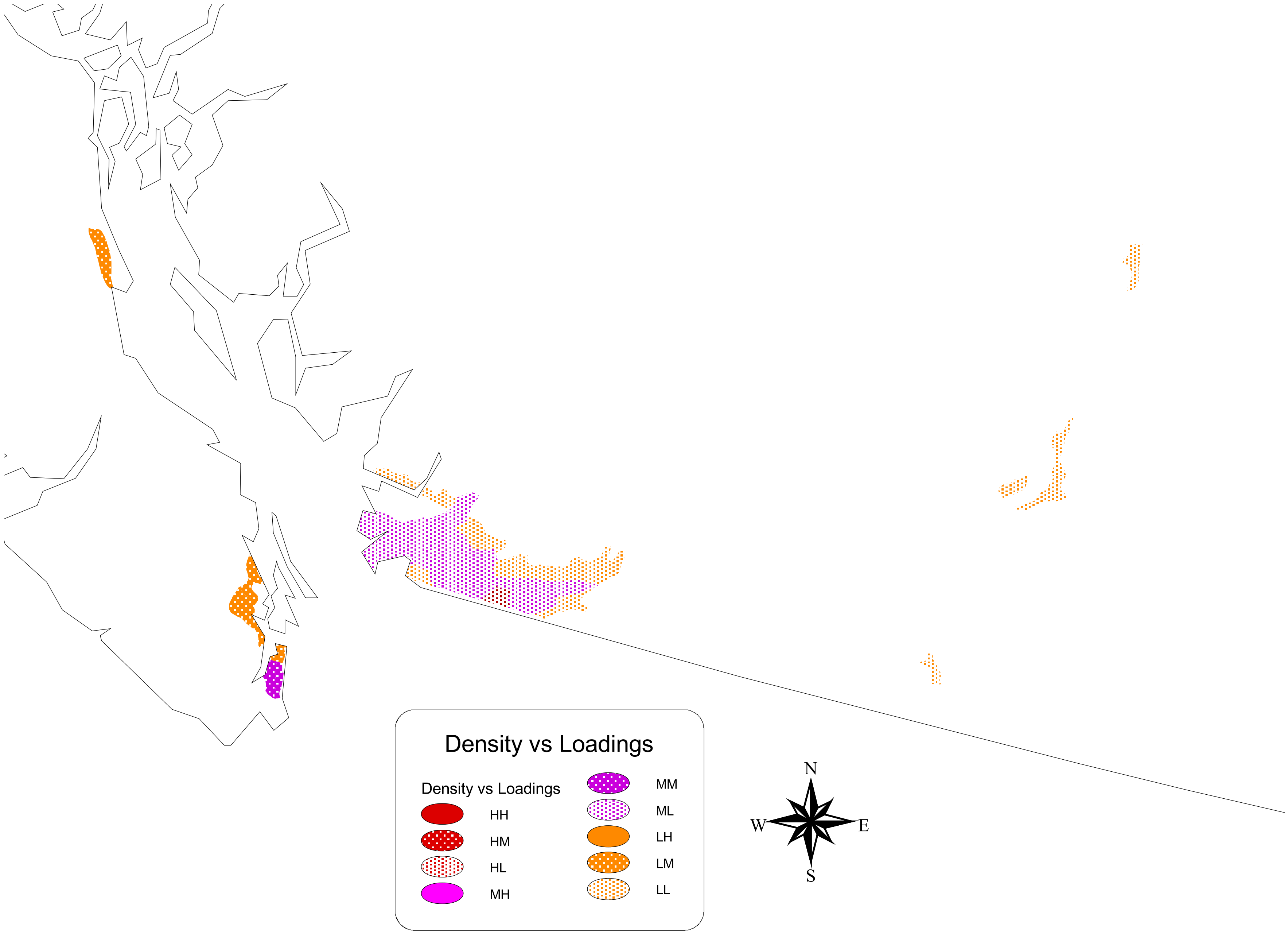


Figure 4.7. Relation between the density of berry production (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - Ontario

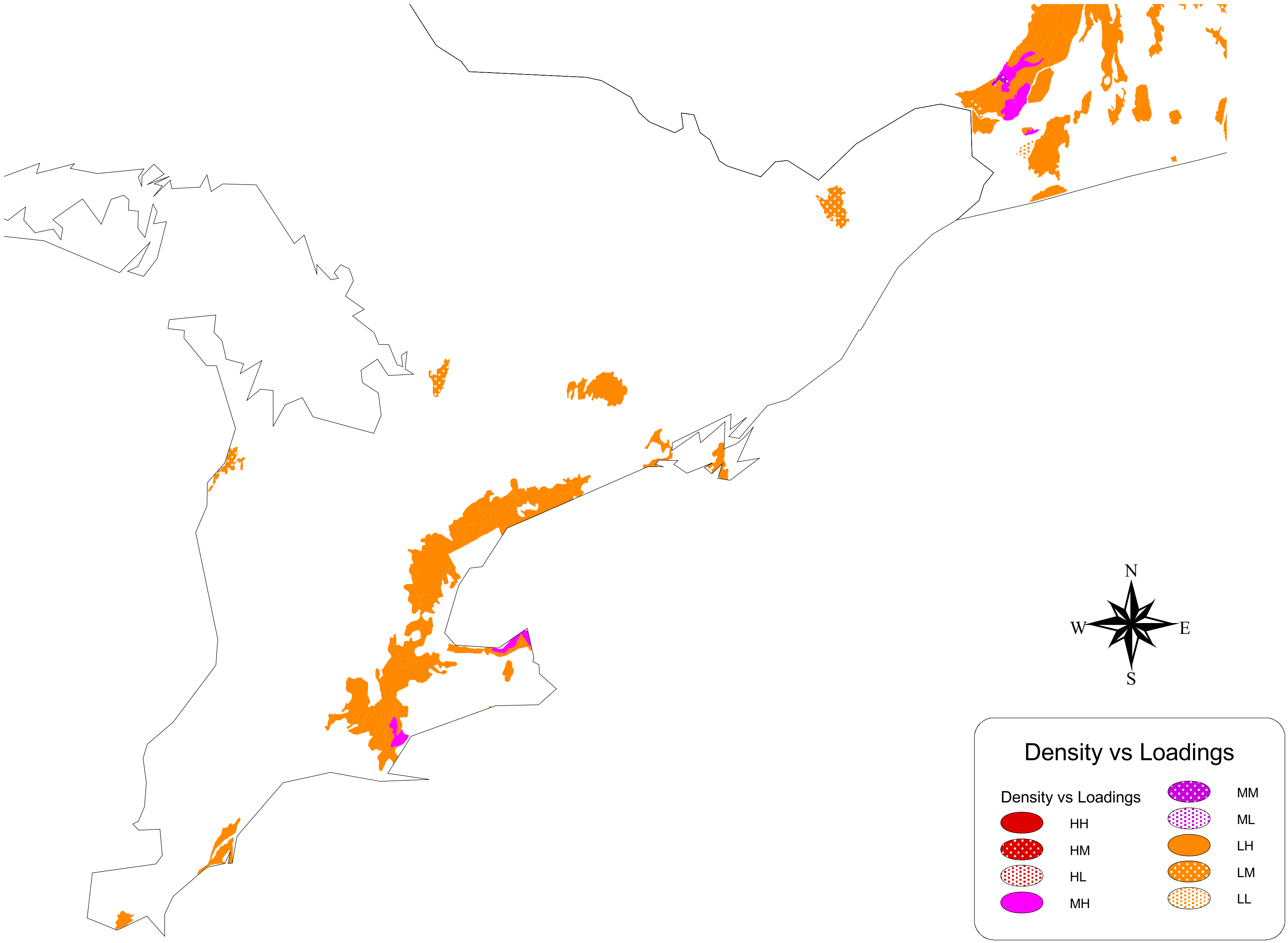


Figure 4.8. Relation between the density of berry production (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - Quebec

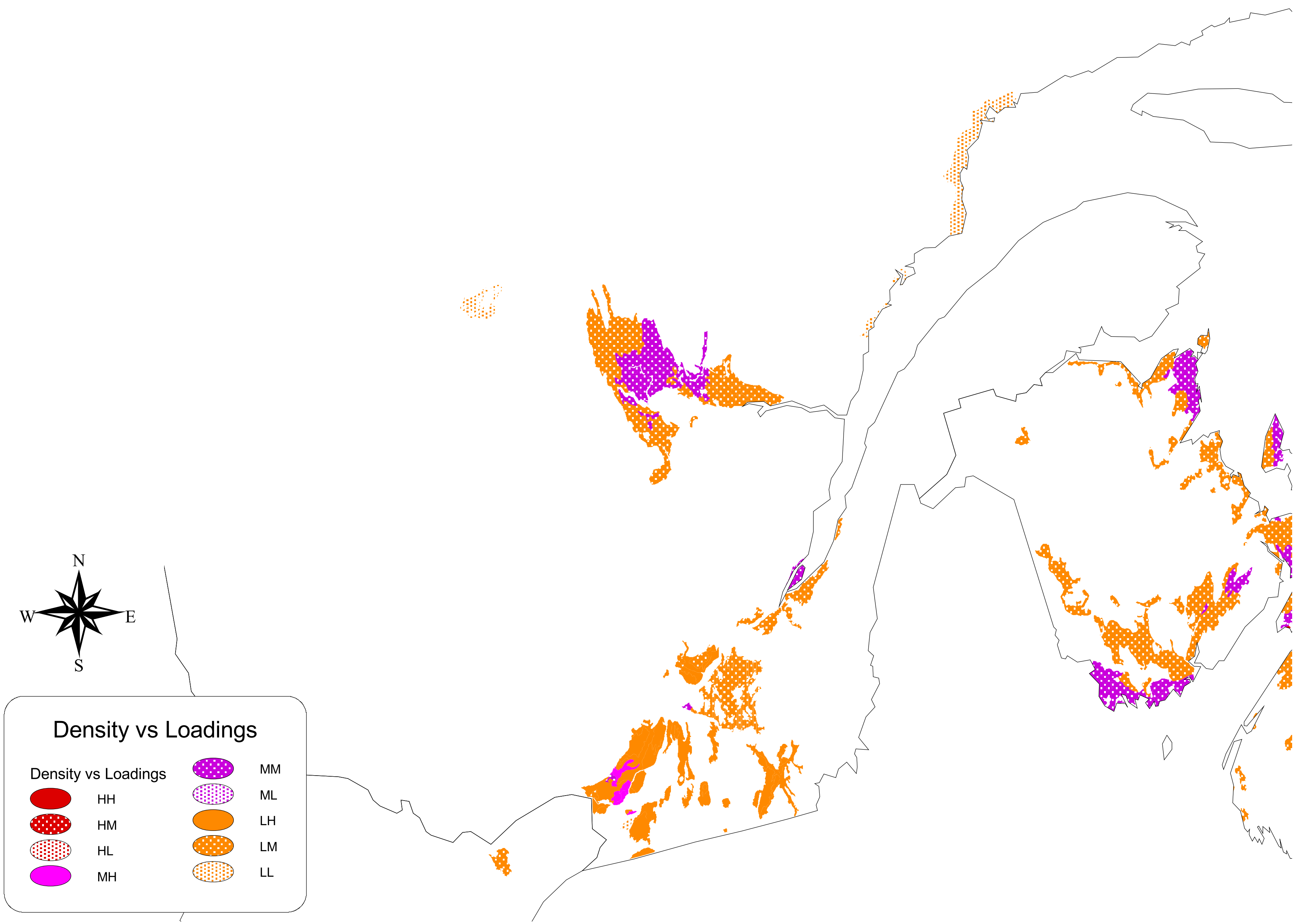


Figure 4.9. Relation between the density of berry production (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - Maritimes

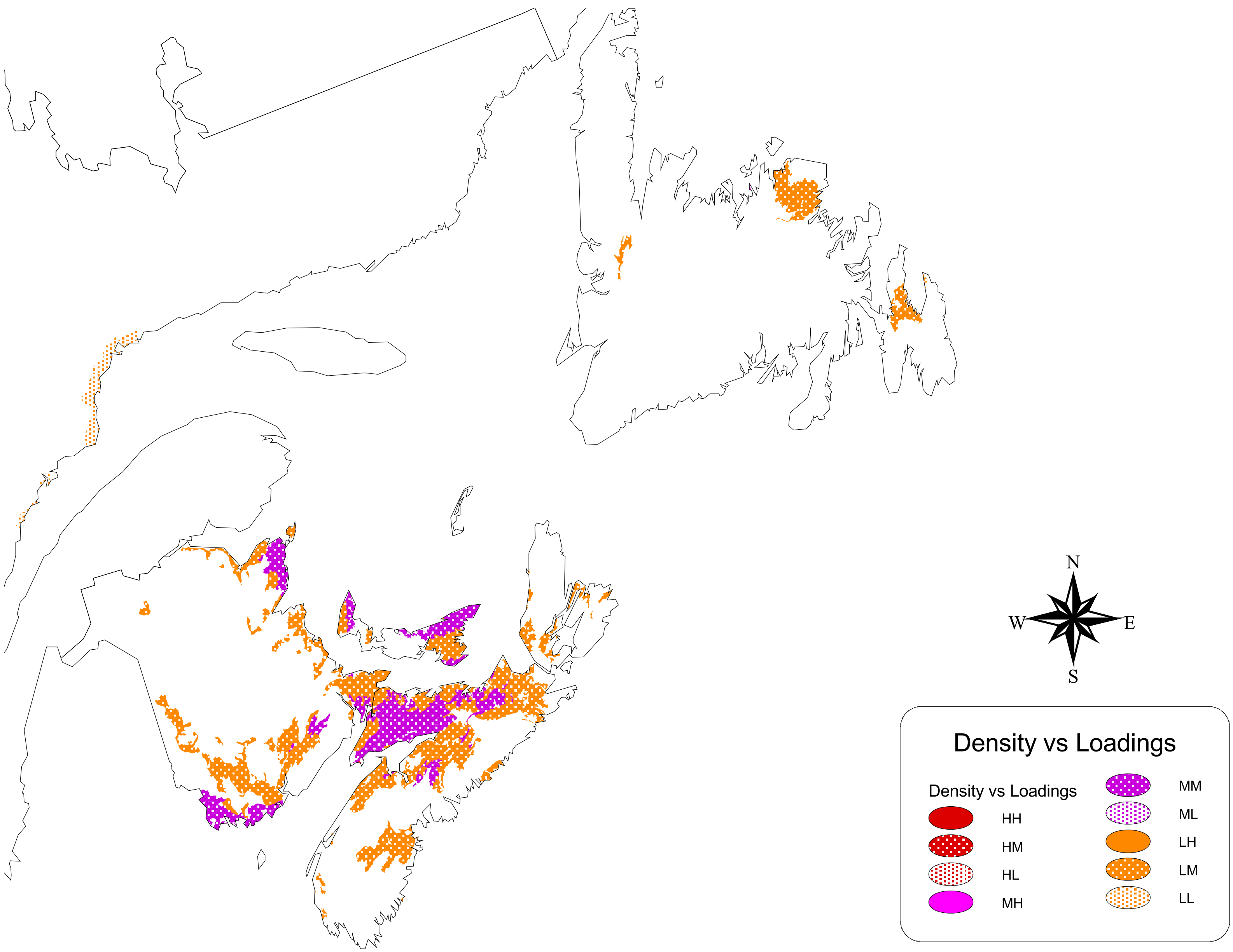


Figure 4.10. Relation between the density of grape production (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - British Columbia

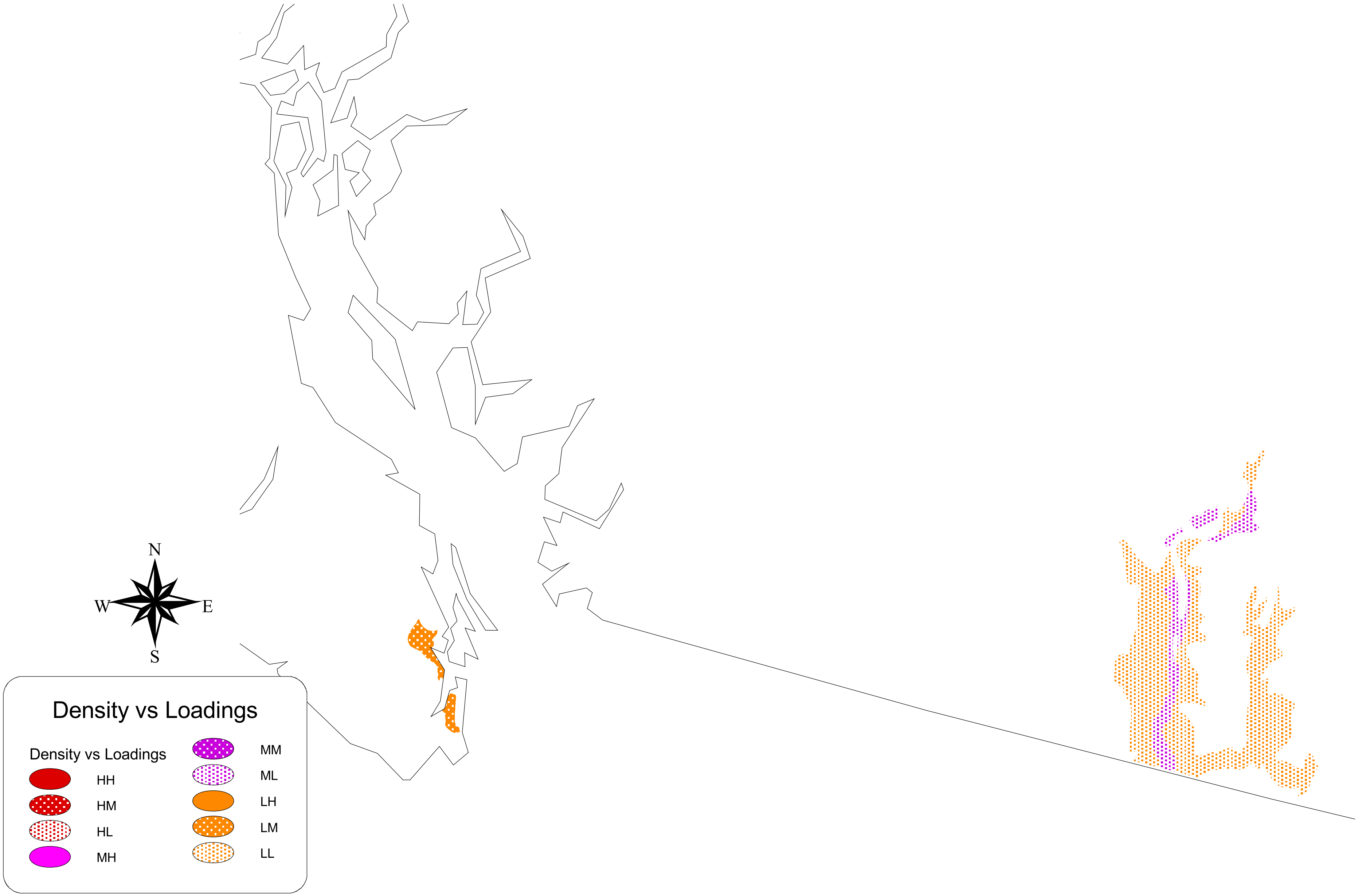


Figure 4.11. Relation between the density of grape production (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - Ontario

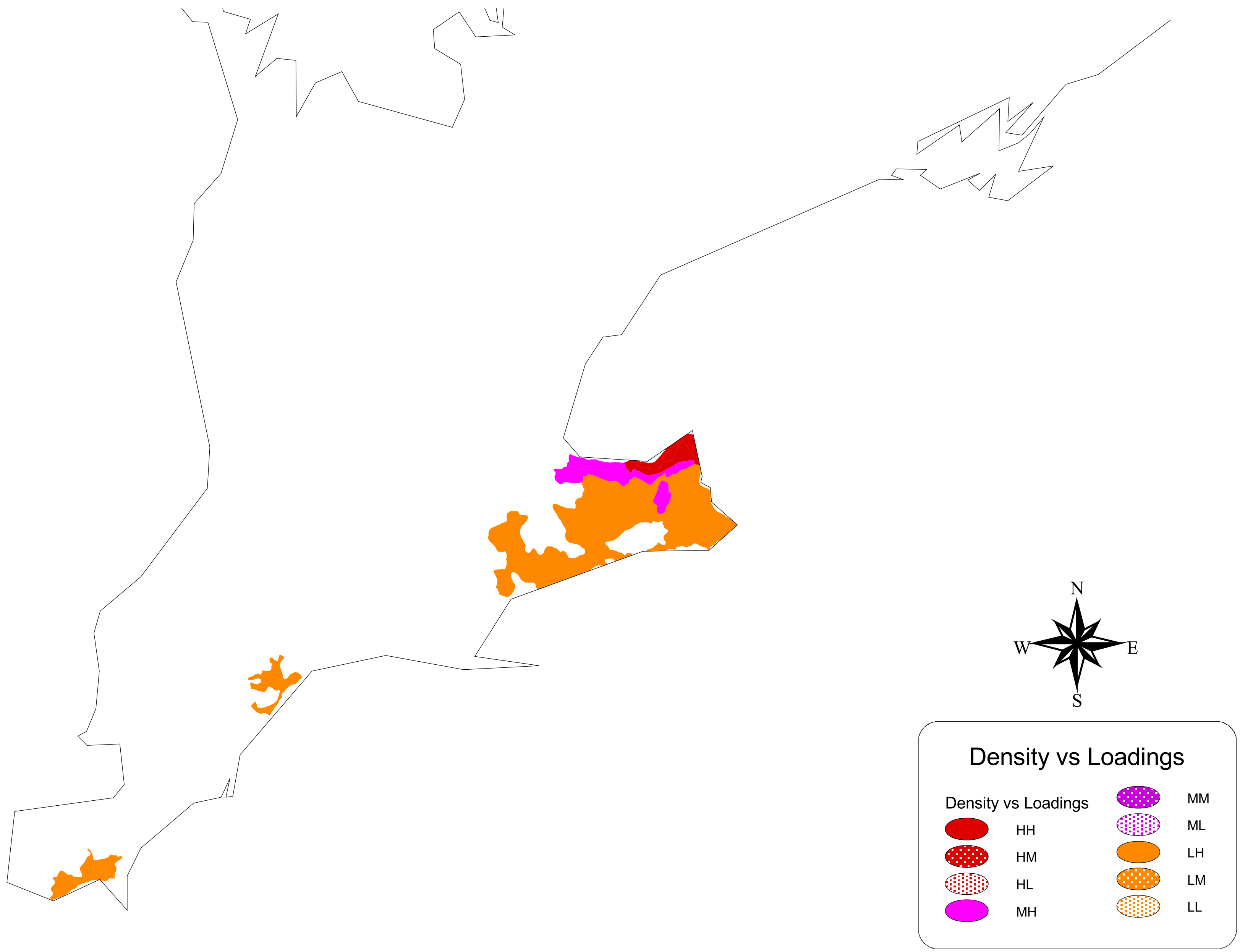


Figure 4.12. Relation between the density of production fruit trees (low,medium, high) and the level of average annual road salt loadings (low, medium, high) - British Columbia

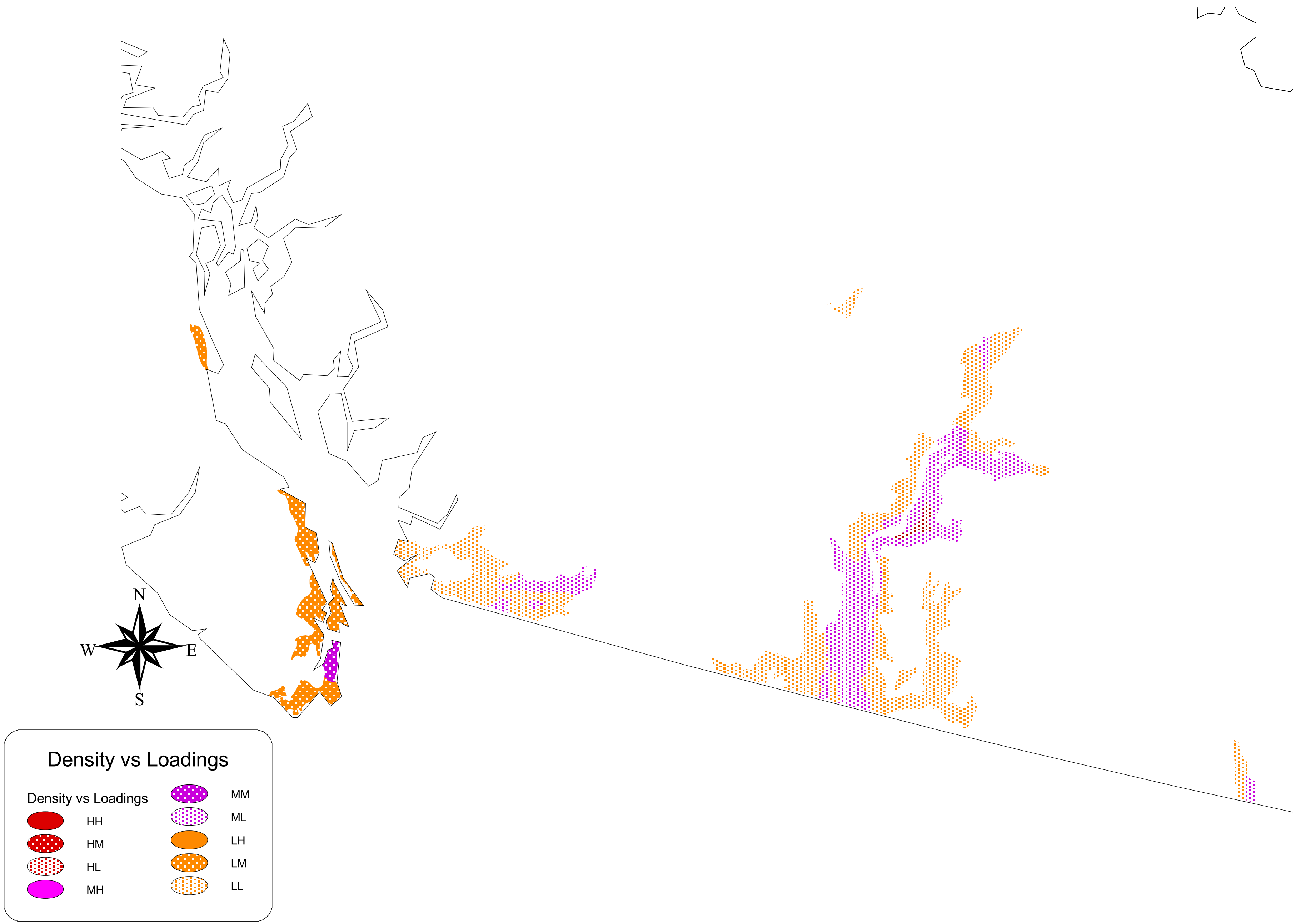


Figure 4.13. Relation between the density of production fruit trees (low,medium, high) and the level of average annual road salt loadings (low, medium, high) - Ontario

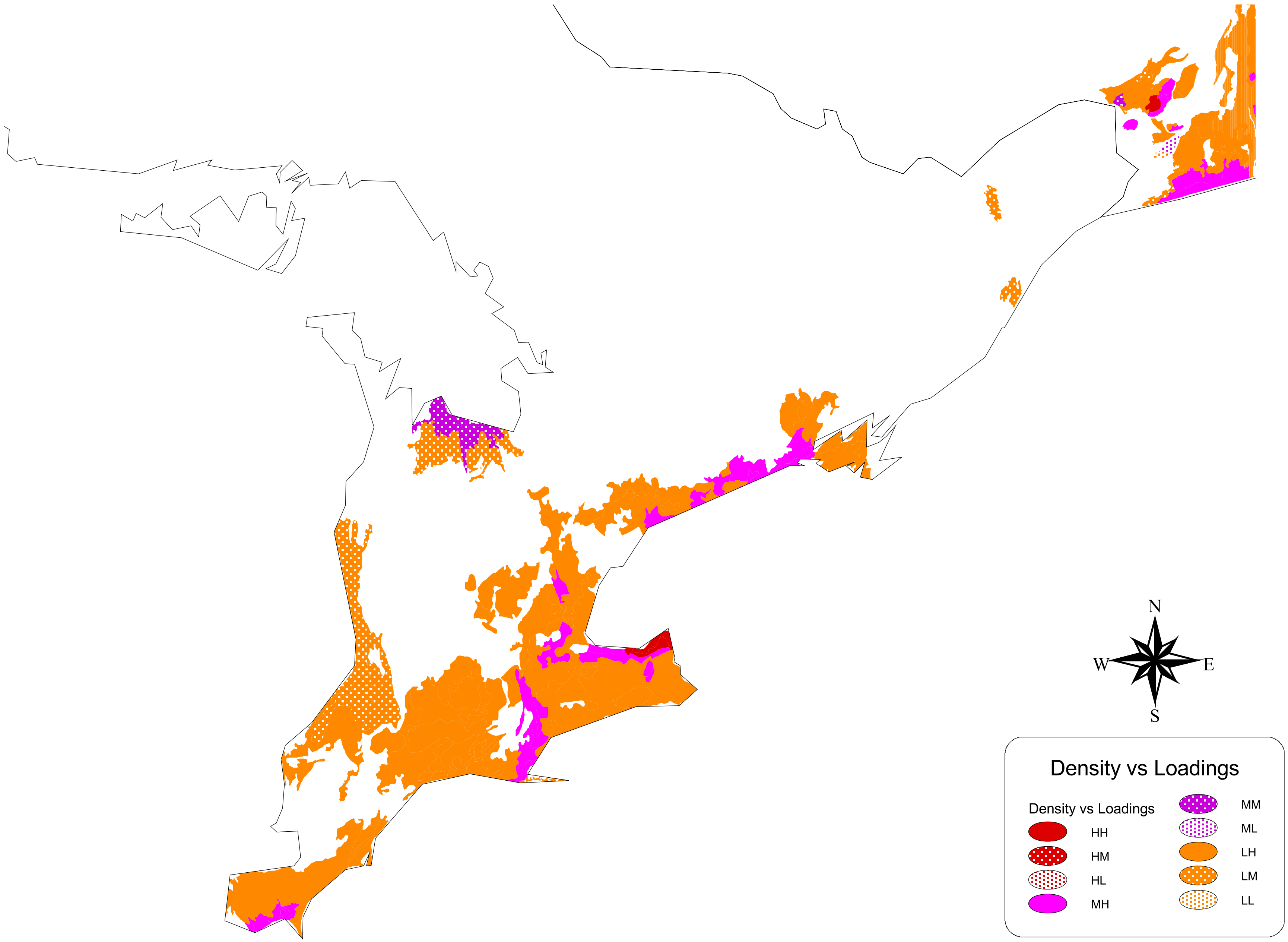


Figure 4.14. Relation between the density of production fruit trees (low,medium, high) and the level of average annual road salt loadings (low, medium, high) - Quebec

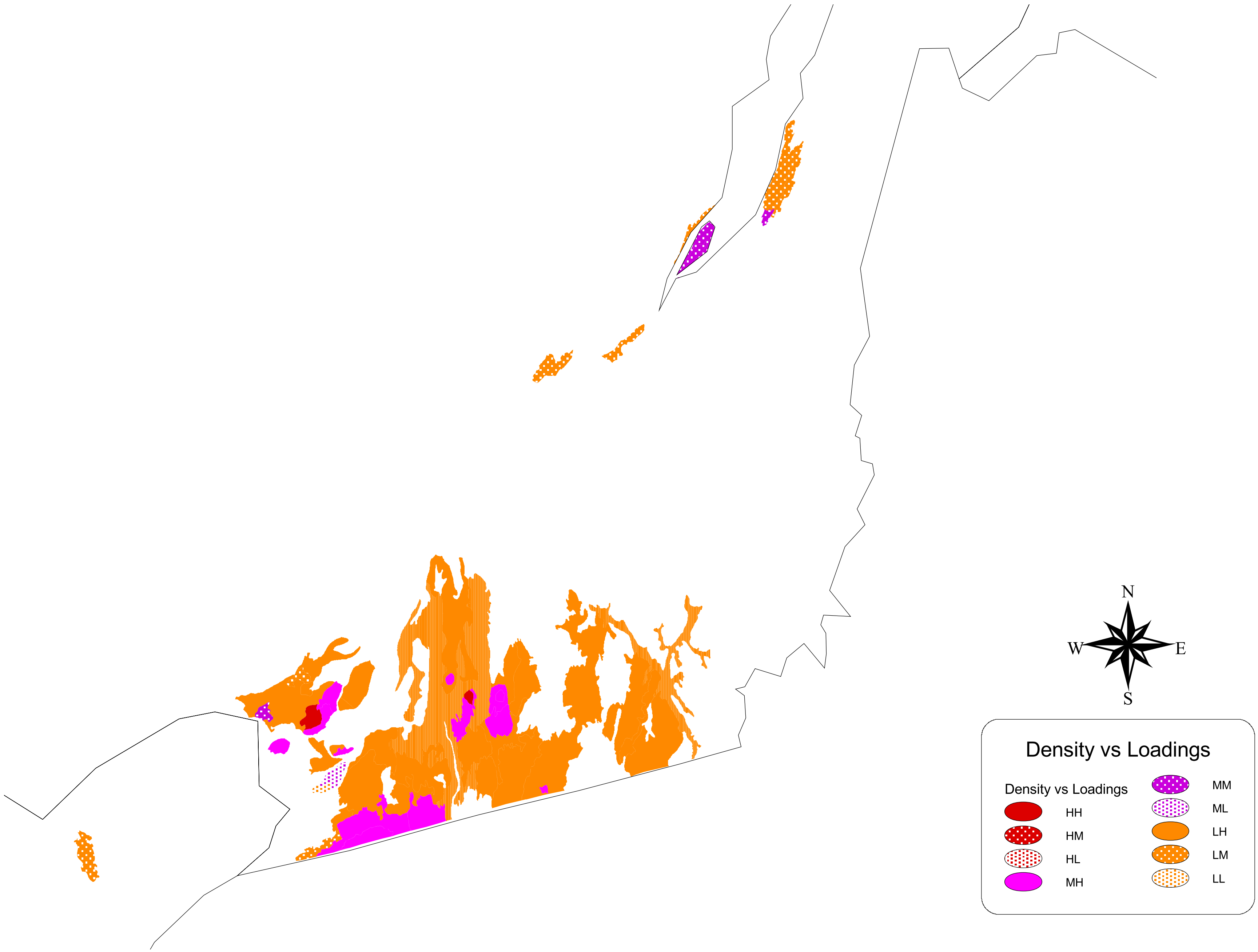


Figure 4.15. Relation between the density of production fruit trees (low,medium, high) and the level of average annual road salt loadings (low, medium, high) - Maritimes

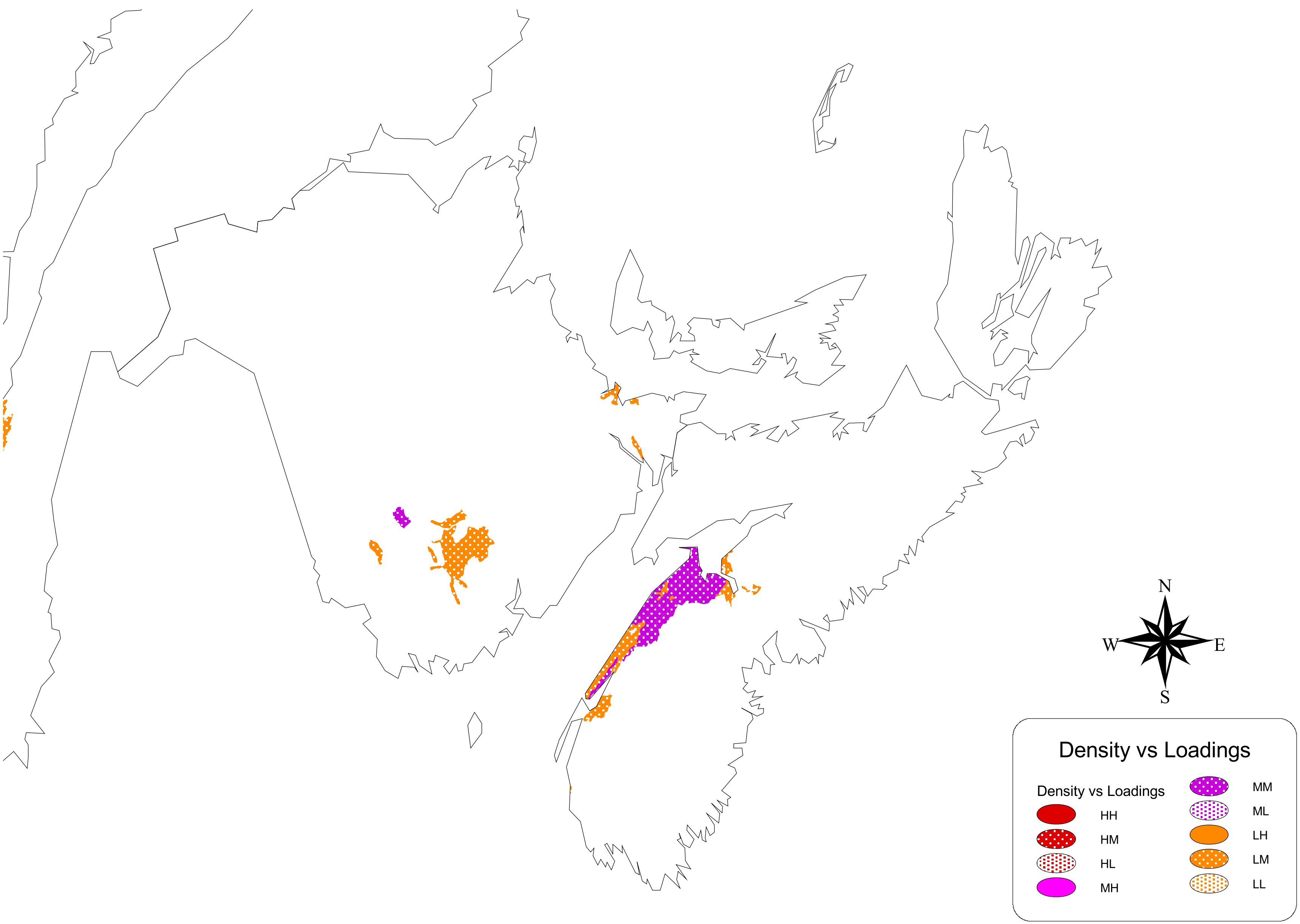


Figure 4.16. Relation between the density of maple tree taps (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - Ontario

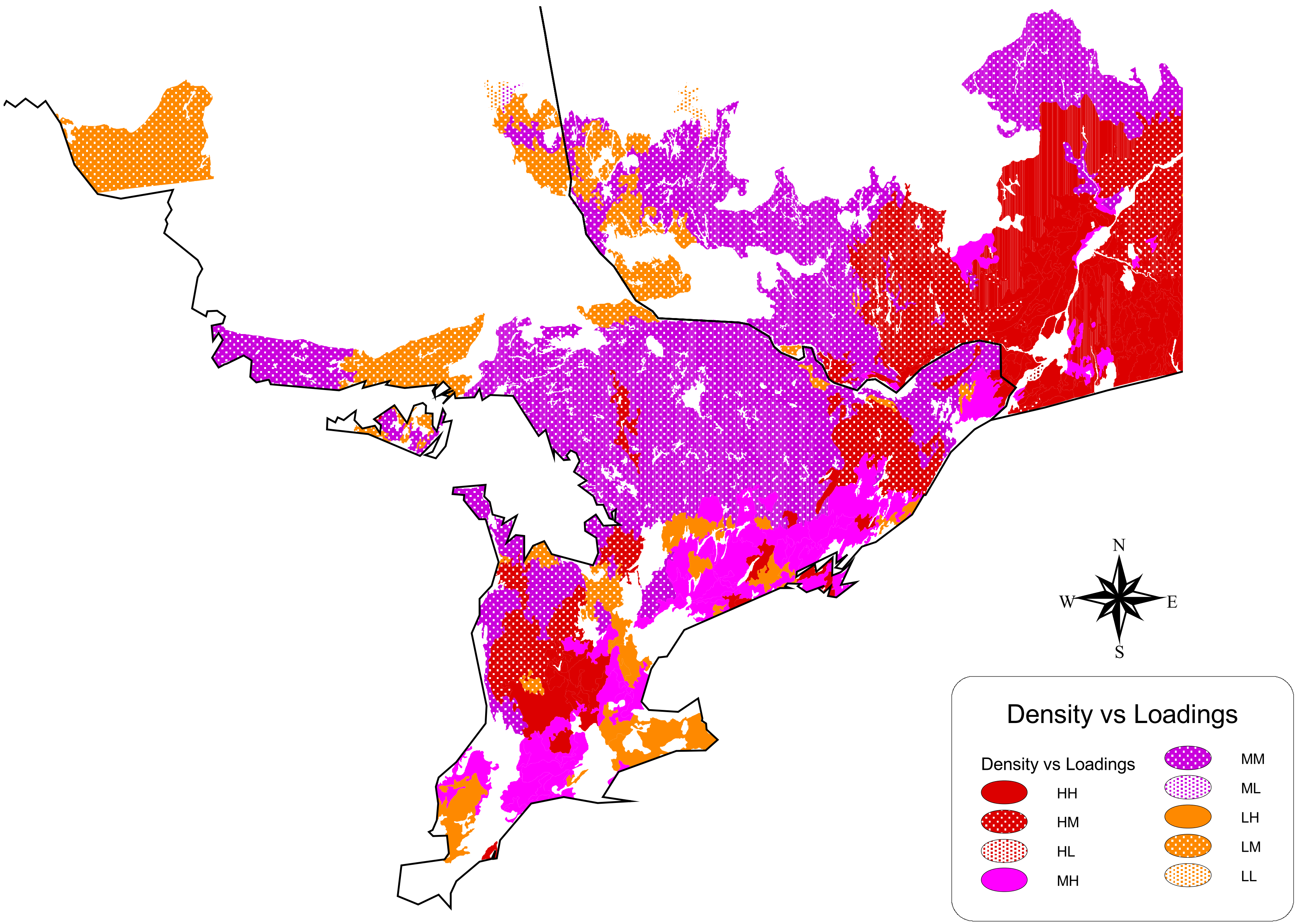


Figure 4.17. Relation between the density of maple tree taps (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - Quebec

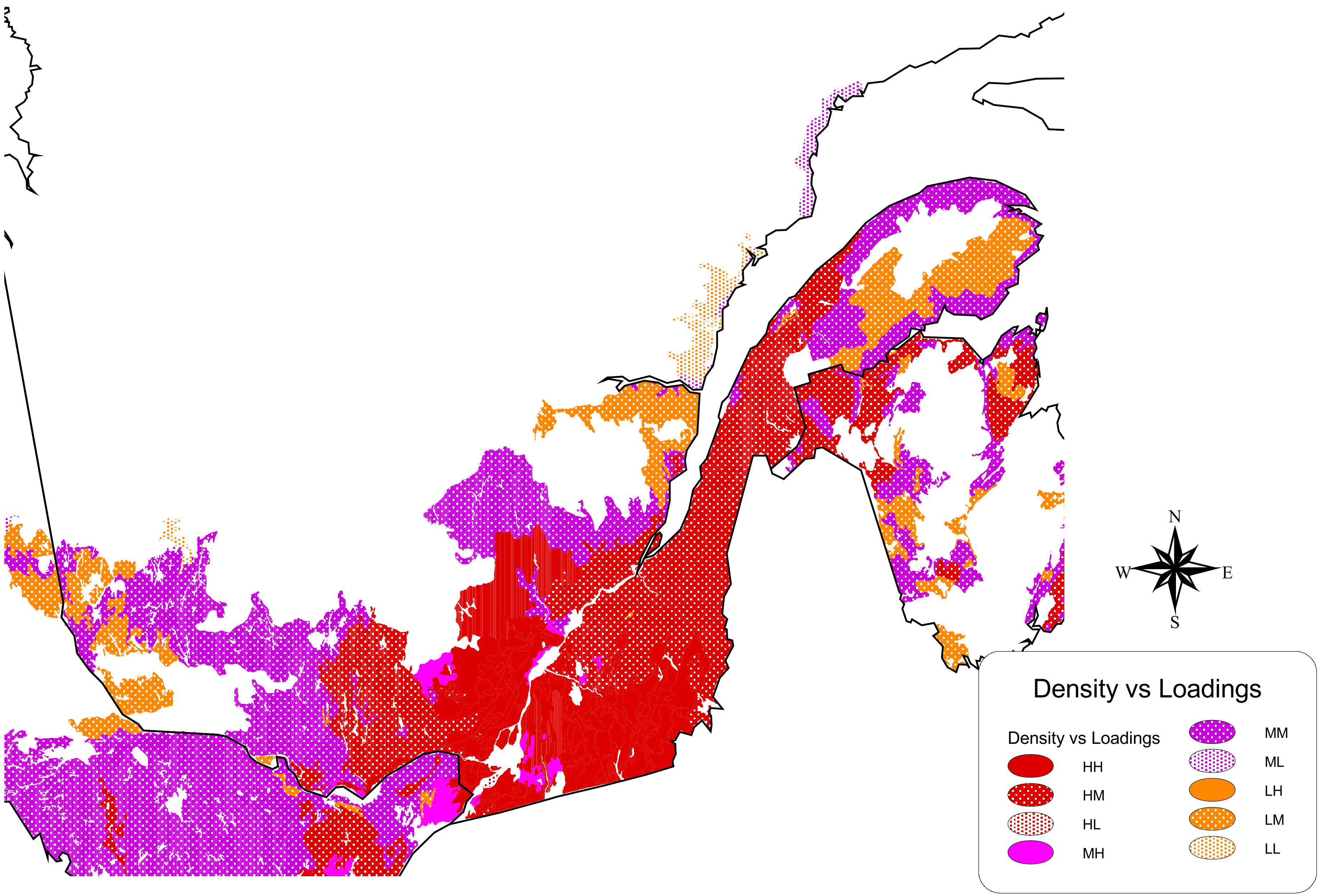


Figure 4.18. Relation between the density of maple tree taps (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - Maritimes

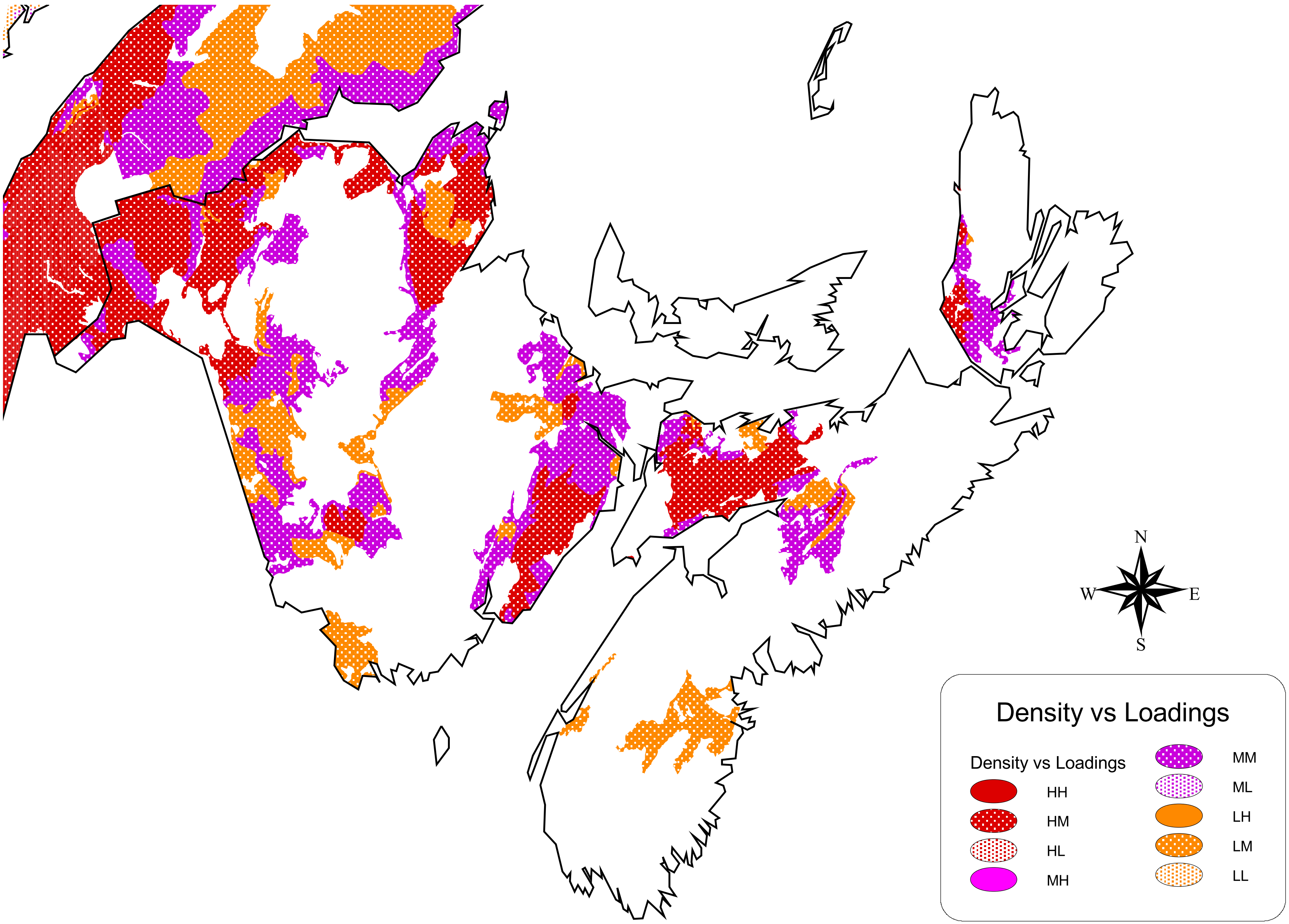


Figure 4.19. Relation between the density of evergreen cultivation (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - British Columbia

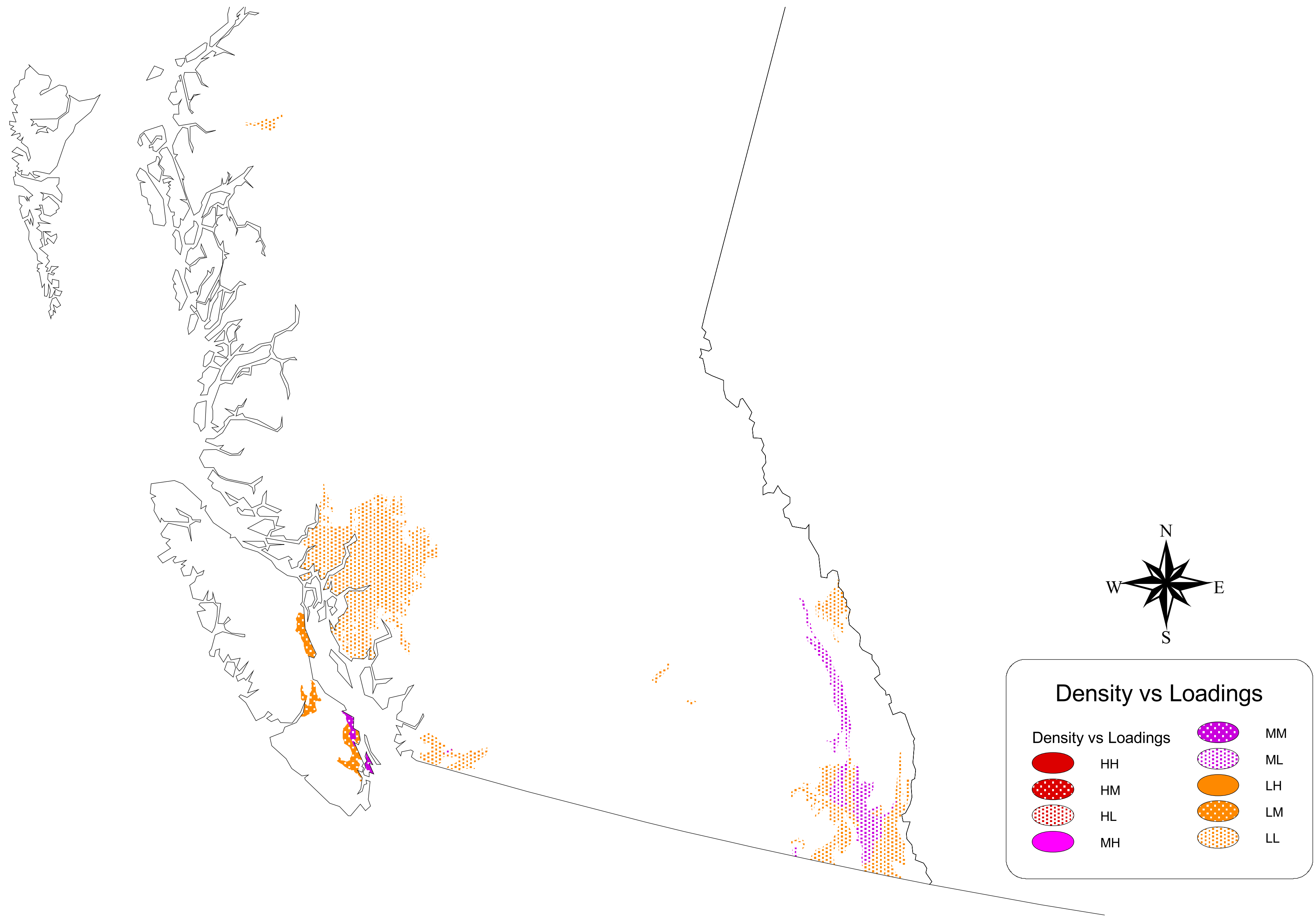


Figure 4.20. Relation between the density of evergreen cultivation (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - Ontario

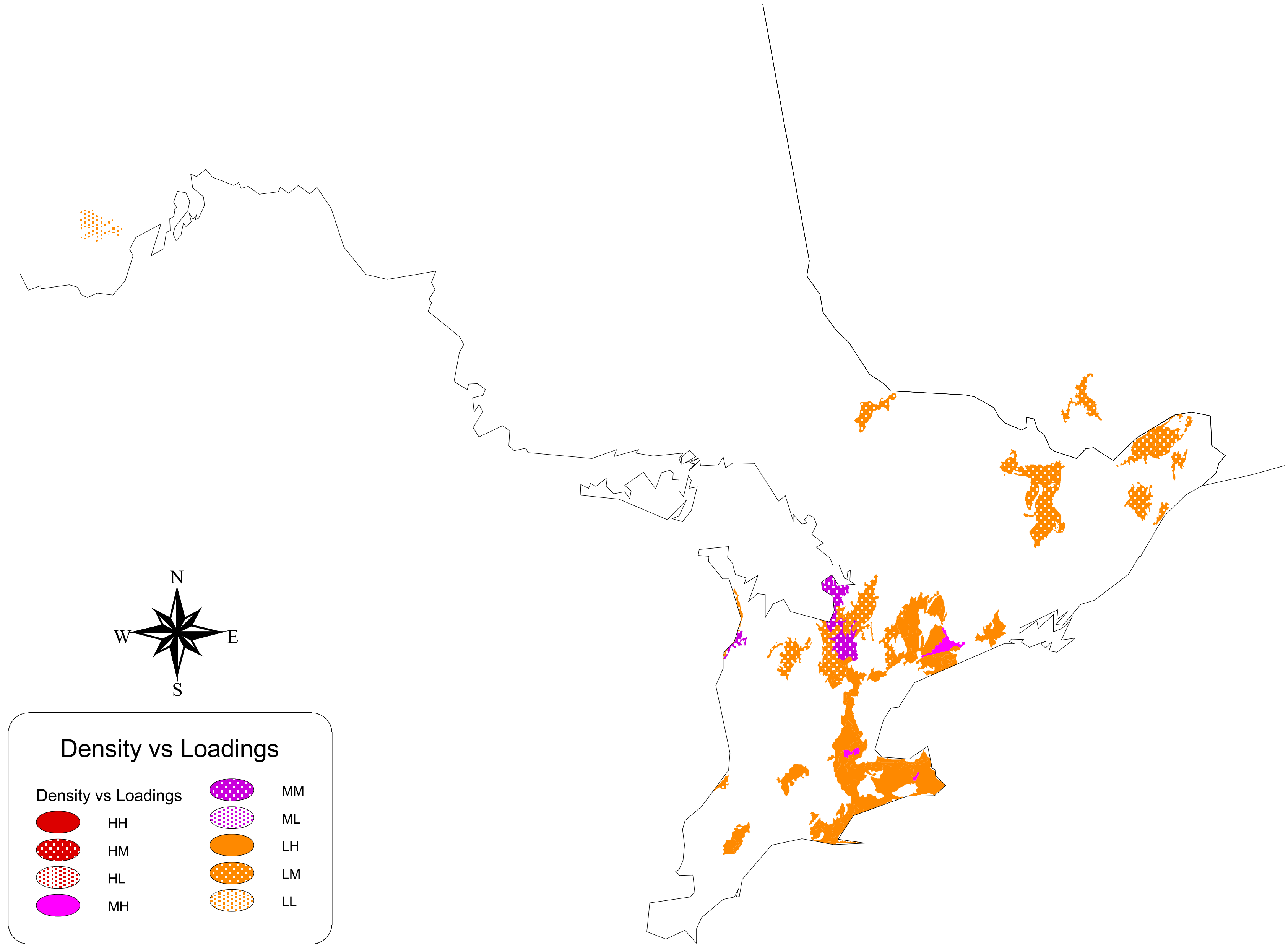


Figure 4.21. Relation between the density of evergreen cultivation (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - Quebec

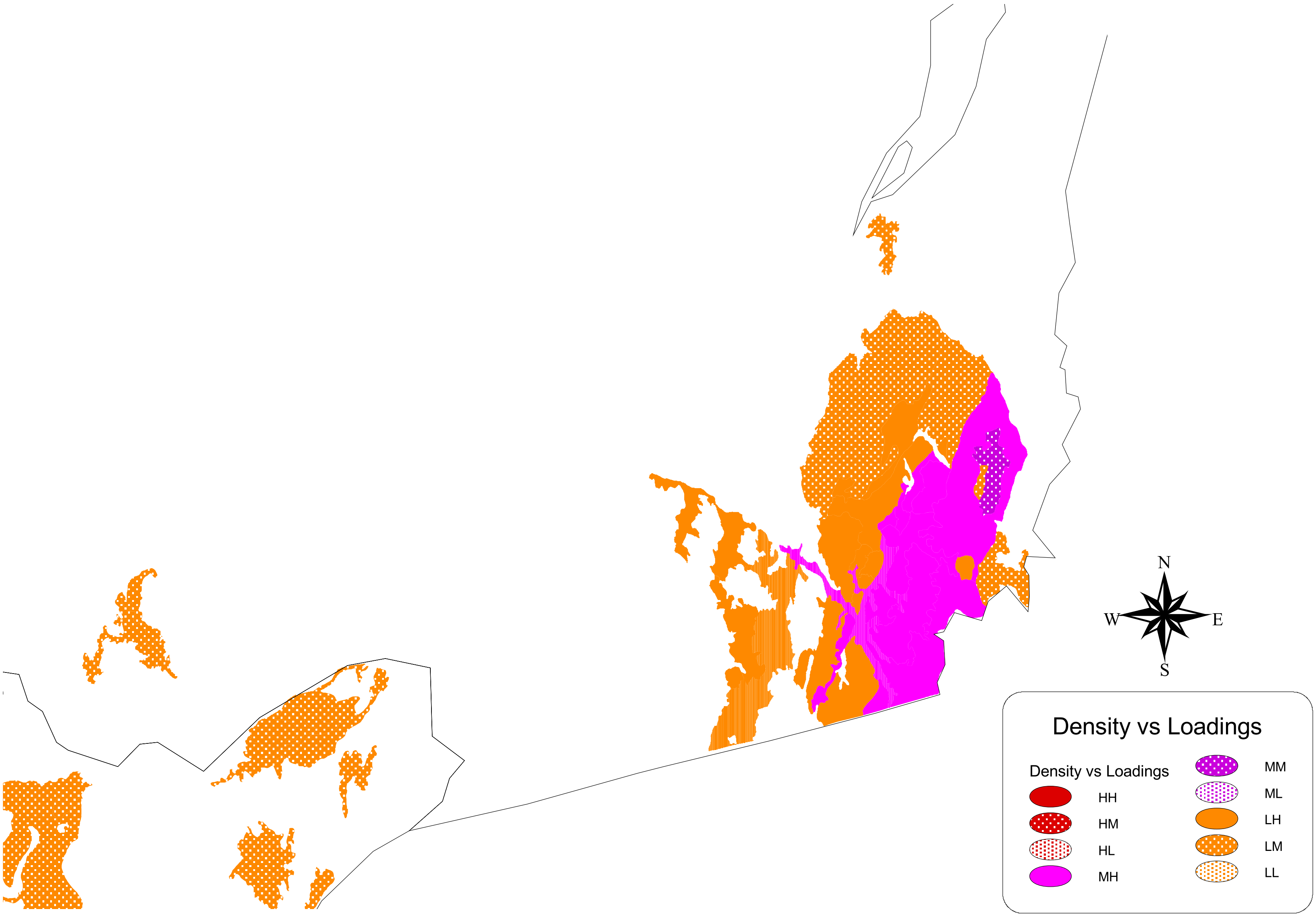
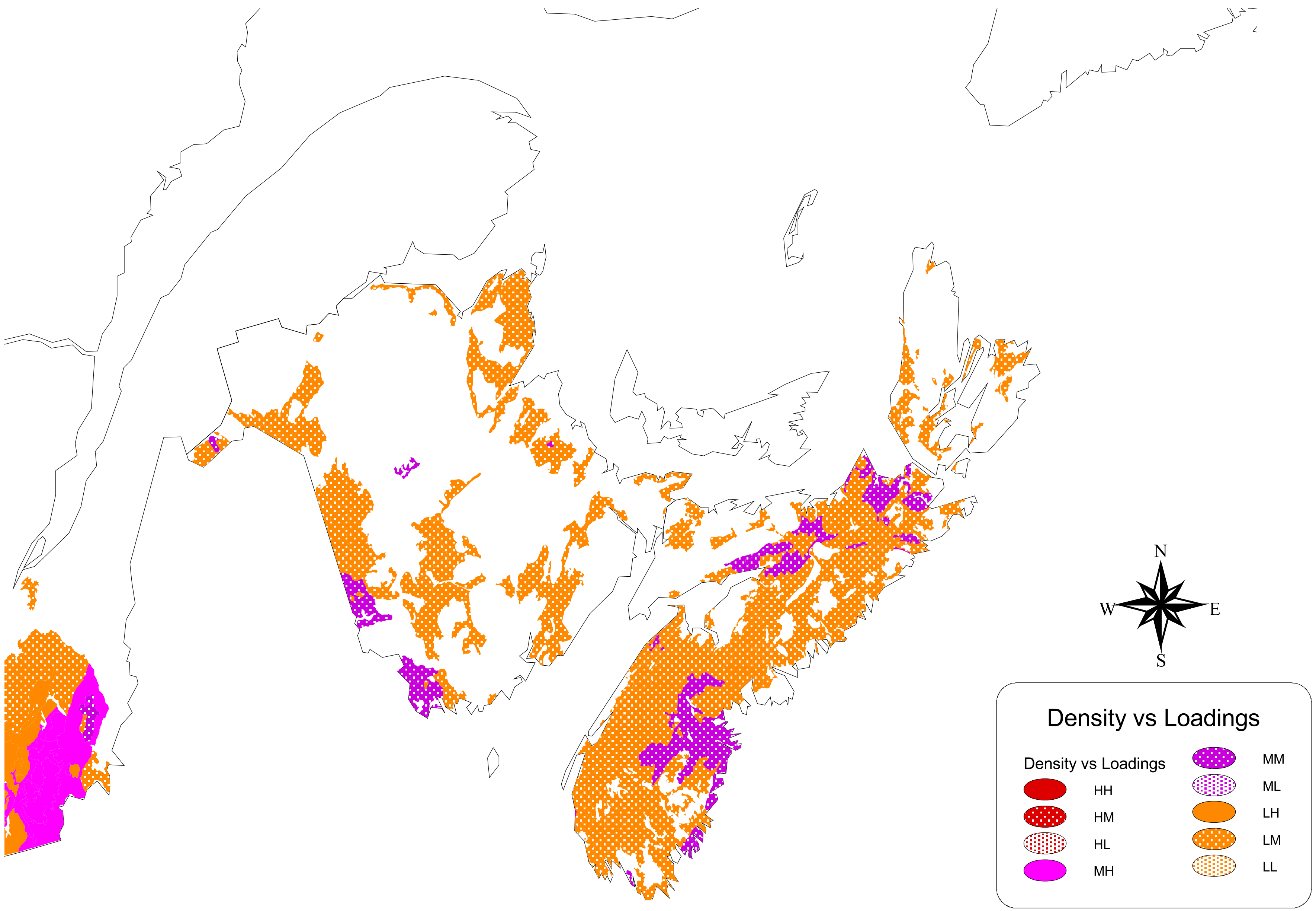


Figure 4.22. Relation between the density of evergreen cultivation (low, medium, high) and the level of average annual road salt loadings (low, medium, high) - Maritimes



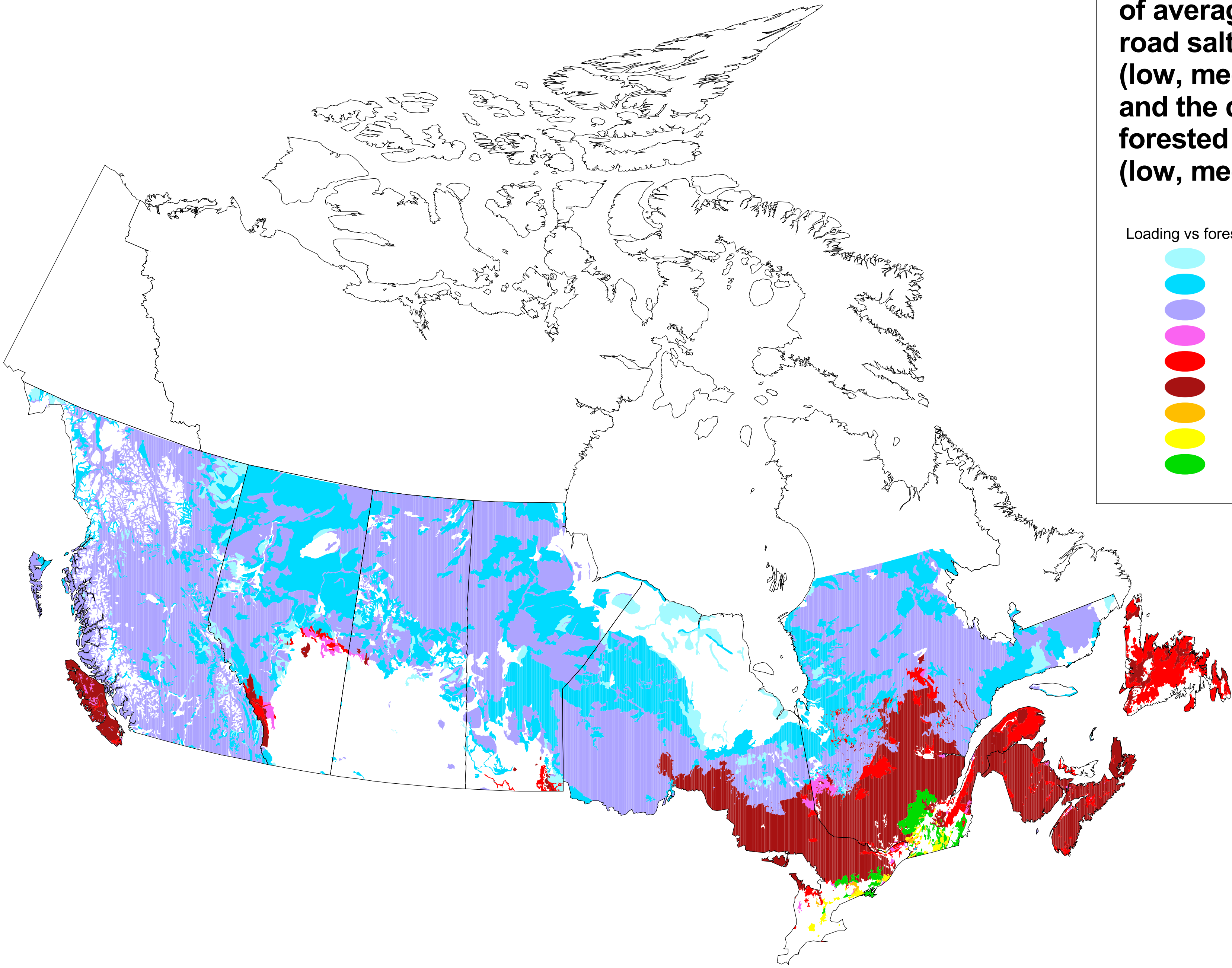


Figure 4.23. Relation between the level of average annual road salt loadings (low, medium, high), and the density of forested areas (low, medium, high)

Figure 4.24. The number of genera (or endpoints) with EC_{25} threshold values at given Na concentrations, for pine and prairie grass exposure via substrate. The threshold values were plotted using a linear-log scale with 95% confidence intervals around each curve. The data represent pine and prairie grass species. The endpoints include plant growth, injury, germination and mortality (Table 3.7).

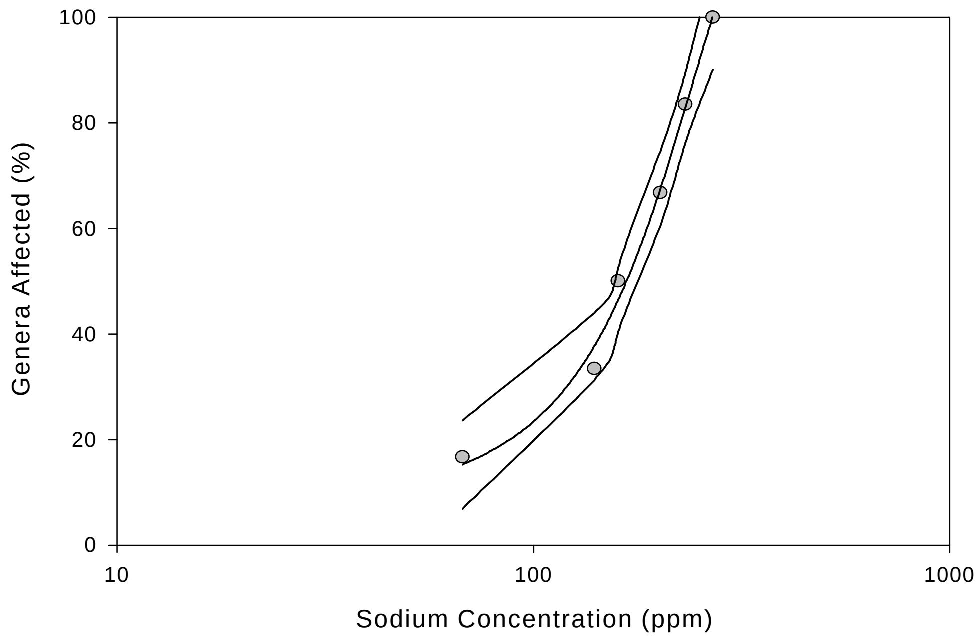
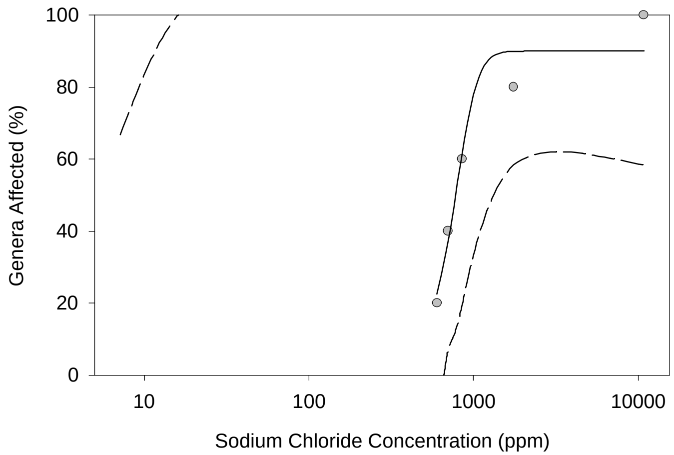
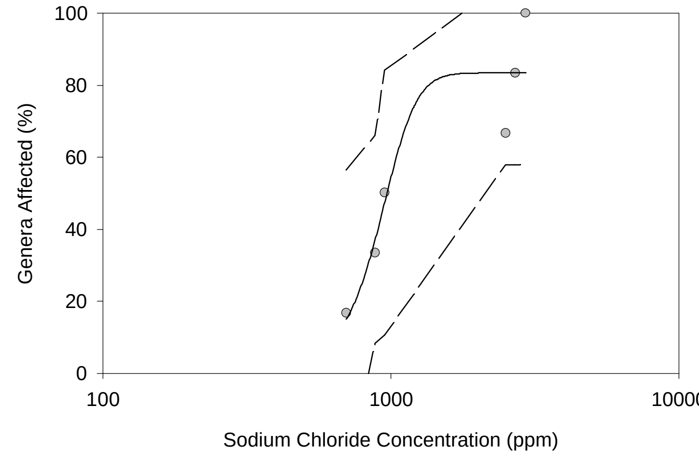
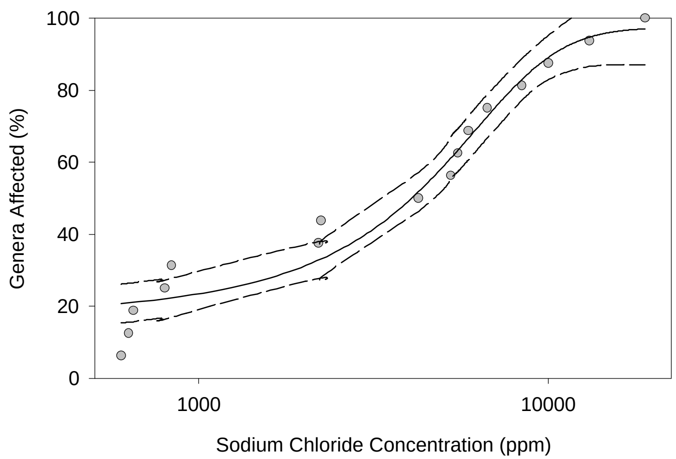


Figure 4.25. (next page) The number of genera (or endpoints) with EC_{25} threshold values at given NaCl concentrations, for woody, herbaceous and wetland plant exposure via substrate. The threshold values were plotted using a linear-log scale with 95% confidence intervals around each curve. (A) Endpoints represent toxic effects (plant survival; (B) Endpoints represent germination and seedling growth; (C) Endpoints represent chronic (plant growth and height) effects (Table 3.8). (D) Endpoints represent wetland plant tolerance (Table 3.9).


Genera Affected (%)
0
20
40
60
80
100
10
100
1000
10000
Sodium Chloride Concentration (ppm)


Genera Affected (%)
0
20
40
60
80
100
100
1000
10000
Sodium Chloride Concentration (ppm)


Genera Affected (%)
0
20
40
60
80
100
1000
10000
Sodium Chloride Concentration (ppm)

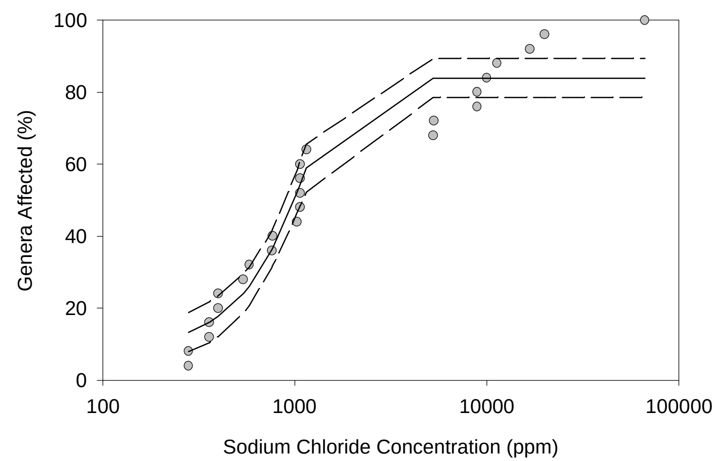

Genera Affected (%)
0
20
40
60
80
100
100
1000
10000
100000
Sodium Chloride Concentration (ppm)

Figure 4.26. The number of genera (or endpoints) with EC_{25} threshold values at given tissue Na (A) or Cl (B) concentrations, for woody plant aerial exposure. The threshold values were plotted using a linear-log scale with 95% confidence intervals around each curve. Endpoints include plant injury, growth and survival. Data from Tables 3.12 and 3.13.

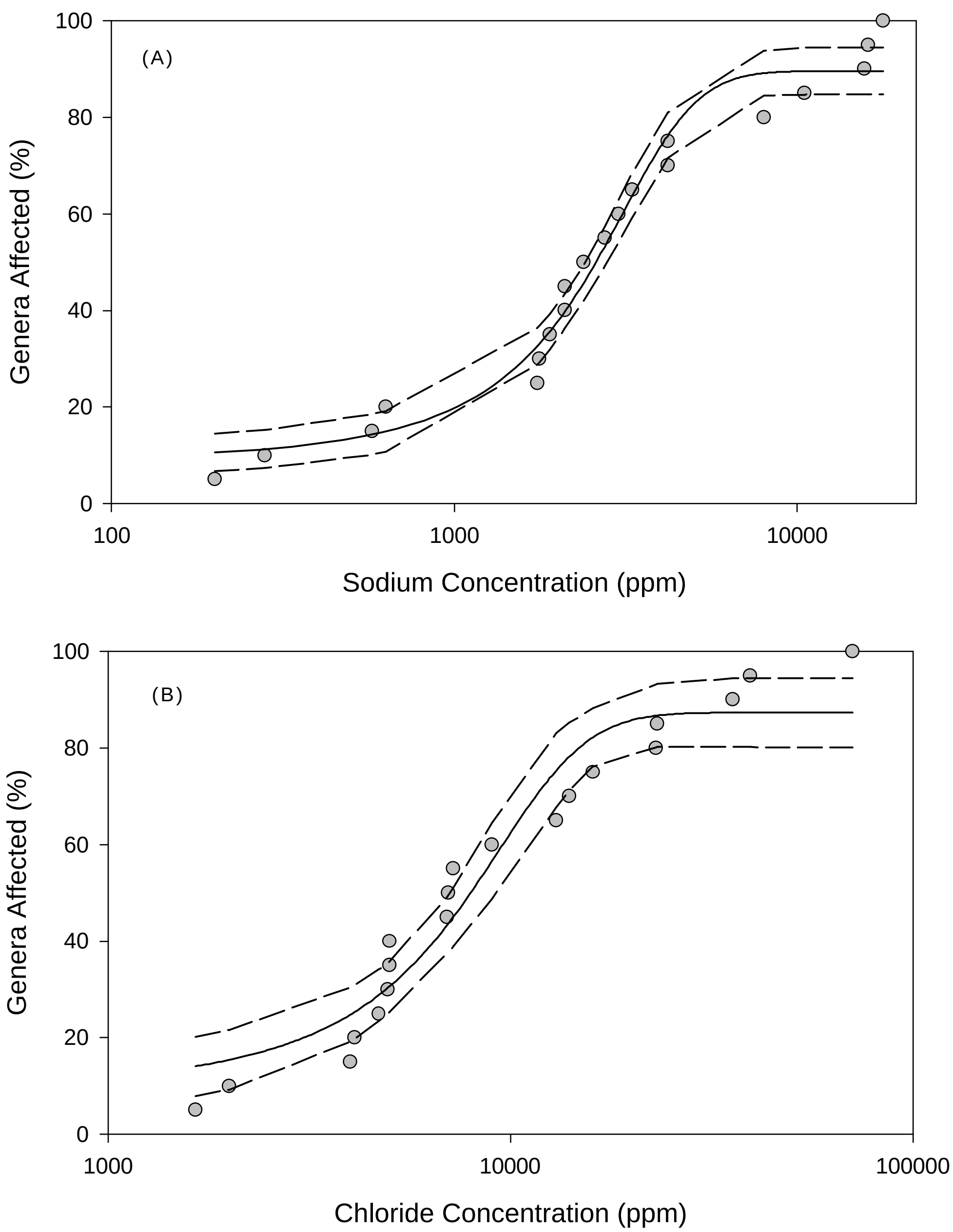
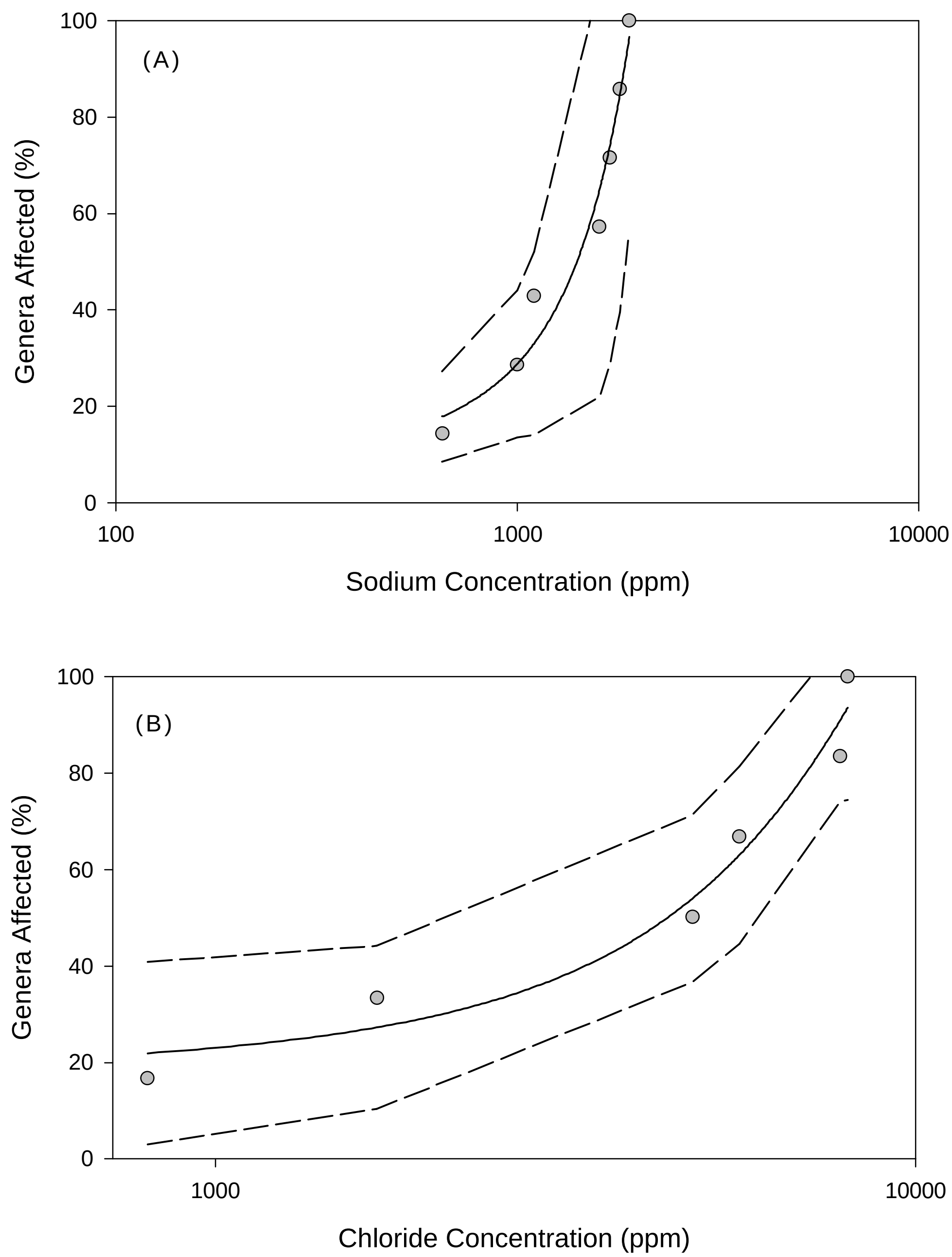


Figure 4.27. The number of genera (or endpoints) with CTV threshold values at given tissue Na (A) or Cl (B) concentrations, for peach and plum aerial exposure. The threshold values were plotted using a linear-log scale with 95% confidence intervals around each curve. Endpoints include yield and shoot and bud injury. Data from Table 3.14.



APPENDIX TABLE 1. Species list of roadside trees and shrubs rated for their resistance to air-borne highway salt spray

Deciduous Trees	Injury* Rating		Injury* Rating
Norway maple *Acer platanoides*	1	Weeping golden willow *Salix alba* 'Tristis'	4
Horse-chestnut *Aesculus hippocastanum*	1	American beech *Fagus grandifolia*	5
Tree of Heaven *Ailanthus altissima*	1		
Honeylocust *Gleditsia triacanthos inermis*	1	Deciduous Shrubs	
Cottonwood *Populus deltoides*	1	Siberian peashrub *Caragana arborescens* .	
Black locust *Robinia pseudoacacia*	1	Sea-buckhorn *Hippophae rhamnoides*	1
Shagbark hickory *Carya ovata*	2	Staghorn sumac *Rhus typhina*	1
Russian-olive *Elaeagnus angustifolia*	2	Burningbush *Euonymus alatus* .	1
White ash *Fraxinus americana*	2	Honeysuckle *Lonicera* spp.	2
Largetooth aspen *Populus grandidentata*	2	Japanese tree lilac *Syringa amurensis*	2
Lombardy poplar *Populus nigra* 'Italica'	2	*japonica*	2
Trembling aspen *Populus tremuloides*	2	Common lilac *Syringa* vulgaris	
Choke cherry *Prunus virginiana*	2	Speckled alder *Alnus rugosa*	2
Pear *Pyrus* sp.	2	Border forsythia *Forsythia x intermedia*	3
Red oak *Quercus rubra*	2	Privet *Ligustrum* spp.	3
Mountain-ash *Sorbus aucuparia*	2	Mockorange *Philadelphus* spp.	3
Amur maple *Acer ginnala*	3	Flowering-quince (Sweet) *Chaenomeles*	3
Red maple *Acer rubrum*	3	*speciosa*	4
Silver maple *Acer saccharum*	3	Beautybush *Kolkwitzia amabilis*	
Sugar maple *Acer saccharum*	3	Bumalda spirea Spiraea x bumalda	4
Paper birch *Betula papyrifera*	3	European cranberry-bush *Viburnum opulus*	4
Gray birch *Betula populifolia*	3	Gray dogwood *Cornus racemosa*	4
Northern catalpa *Catalpa speciosa*	3	Red-osier dogwood *Cornus stolonifera*	5
Quince *Cydonia oblonga*	3		5
Green ash *Fraxinus pennsylvanica*	3	Conifers	
lanceolata			
Black walnut *Juglans nigra*	3	Blue spruce Picea *pungens* Englem. *glauca*	
English walnut *Juglans regia* .	3	Jack pine *Pinus banksiana*	1
Black willow *Salix nigra*	3	Mugo pine *Pinus mugo*	1
Basswood *Tilia americana*	3	Austrian pine *Pinus nigra*	1
White elm *Ulmus americana*	3	Red cedar Juniperus virginiana	1
Siberian elm *Ulmus pumila*	3	Juniper *Juniperus* spp.	2
Manitoba maple *Acer negundo*	4	Norway spruce *Picea abies*	2
Allegheny serviceberry *Amelanchier*	4	Yew *Taxus* spp.	3
laevis .		White spruce *Picea glauca*	3
Hawthorn *Crataegus* spp.	4	Red pine *Pinus resinosa* .	4
Apple *Malus* sp.	4	Scots pine *Pinus sylvestris*	4
Crabapple *Malus* spp.	4	White cedar *Thuja occidentalis*	4
Mulberry *Morus* sp.	4	White pine *Pinus strobus*	4
Peach *Prunus persica*	4	Hemlock *Tsuga canadensis*.	5
			5

* A rating of 1 indicates no twig dieback or needle browning of conifers and no dieback, tufting, or inhibitions of flowering of deciduous trees and shrubs. Ratings of 5 represent complete branch dieback and needle browning of conifers, and complete dieback, evidence of previous tufting, and lack of flowering of deciduous trees and shrubs. Under severe conditions plants rated 5 will eventually die. Ratings of 2, 3, and 4 encompass slight, moderate and extensive gradations of the above injury symptoms.

Source: Lumis, G. P., G. Hofstra and R. Hall, "Salt Damage to Roadside Plants", Factsheet, Ontario Ministry of Agriculture and Food, May 1983.

APPENDIX TABLE 2: Comparative salt tolerance of fruit trees, shrubs and vines.

Commercially important:				
Scientific Name	**Common Name**	**Entry Pathway**	**Salt Tolerance***	**References**
Malus domestica*, *Malus sylvestris	apple	aerial aerial aerial soil soil not specified	very sensitive moderate injury tolerant tolerant sensitive sensitive	Slingerland 1996 Lumis *et al.*1976 Sucoff 1975 Thuet 1977 Downton 1984 Maas and Hoffman 1977 per Tinus 1984
Malus species and cultivars	apple	aerial aerial not specified not specified	extensive injury sensitive sensitive moderate, poor tolerance	Lumis et al. 1977 Thuet 1977 Thuet 1977 Per Dirr 1976
Prunus *sp.*	prune	not specified	sensitive	Thuet 1977
Prunus armeniaca	apricot	aerial aerial soil soil not specified not specified	very sensitive sensitive sensitive tolerant very tolerant good tolerance	Slingerland 1996 Thuet 1977 Downton 1984 Thuet 1977 Thuet 1977 Per Dirr 1976
Prunus avium	sweet cherry	aerial aerial not specified not specified not specified	very sensitive tolerant sensitive moderate tolerant	Slingerland 1996 Sauer 1967 per Dobson 1991 Leh 1973/75 per Dobson 1991 Per Dirr 1976 Toth 1972 per Dobson 1991
Prunus cerasus	sour (tart) cherry	aerial	moderately sensitive	Slingerland 1996

Scientific Name	Common Name	Entry Pathway	Salt Tolerance*	References
Prunus domestica	European plum, prune-type, cultivated plum	aerial not specified soil	moderately sensitive sensitive sensitive	Slingerland 1996 Richards 1954; Maas and Hoffman 1977 both per Tinus 1984 Downton 1984
Prunus persica	nectarine	aerial	extremely sensitive	Slingerland 1996
Prunus persica	peach	aerial aerial aerial aerial soil not specified	extremely sensitive susceptible extensive injury severe injury, differences in aerial susceptibility of 'Loring', 'Sunhaven' and 'Redhaven' cultivars sensitive sensitive	Slingerland 1996 Chong and Lumis 1990 Lumis *et al.* 1977 Northover 1987 Downton 1984 Thuet 1977
Pyrus species	pear	not specified	moderate tolerance	Per Dirr 1976
Pyrus calleryana	Asian pear, callery pear, limited commercial production	not specified	tolerant	Bassuk 1991
Pyrus communis	pear	aerial	moderately sensitive	Slingerland 1996
Vitis vinifera	grape	soil soil	moderate, cultivar differences moderately sensitive	West and Taylor 1984 Downton 1984
Vitis spp.	grape	aerial	moderately sensitive, *V. labrusca* generally more tolerant than *V. vinifera* or French hybrids	Slingerland 1996

Closely related species:				
Scientific Name	**Common Name**	**Entry Pathway**	**Salt Tolerance***	**References**
Malus baccata	crabapple Siberian crabapple	soil not specified not specified soil	sensitive moderate tolerance moderately tolerant moderately tolerant	Tinus 1984 Per Dirr 1976 Thuet 1977 Thuet 1977
Malus spp.	crabapple	aerial aerial aerial aerial not specified	low tolerance extensive injury moderately tolerant susceptible sensitive	Delahunt and Hasselkus 1996 Lumis *et al.* 1977 Thuet 1977 Sucoff 1975 Thuet 1977
Prunus americana	American plum	soil	sensitive	Tinus 1984
Prunus avium 'Mazzard'	mazzard cherry, rootstock	aerial not specified	moderately tolerant tolerant	Thuet 1977 Thuet 1977
Prunus besseyi	western sand cherry	soil aerial	intermediate low tolerance	Dirr 1978 Delahunt and Hasselkus 1996
Prunus caroliniana	cherry laurel	aerial	tolerant	Flint 1983
Prunus mahaleb	mahaleb cherry, rootstock	aerial soil	very sensitive sensitive	Thuet 1977 Glasau 1966 per Dobson 1991
Prunus maritima	beach-plum	aerial not specified	tolerant tolerant	Flint 1983 Thuet 1977
Prunus padus	European bird-cherry	aerial aerial soil not specified not specified	tolerant moderately tolerant tolerant good tolerance moderately tolerant to tolerant	Thuet 1977 Sucoff 1975 Sucoff 1975 Per Dirr 1976 Thuet 1977

Scientific Name	Common Name	Entry Pathway	Salt Tolerance*	References
Prunus serotina	wild cherry, black cherry	aerial aerial aerial aerial soil not specified not specified	low tolerance tolerant tolerant to susceptible susceptible tolerant sensitive to very sensitive good, poor tolerance	Delahunt and Hasselkus 1996 Flint 1983 Sucoff 1975 per Dobson 1991 per Dobson 1991 Thuet 1977 Per Dirr 1976
Prunus sargentii	sargent cherry	not specified	good tolerance	Bassuk 1991
Prunus spinosa	blackthorn	aerial not specified	sensitive tolerant	Thuet 1977 Thuet 1977
Prunus tomentosa	manchu cherry	soil	sensitive	Dirr 1978
Prunus virginiana	choke-cherry	aerial aerial aerial soil not specified	slight injury low tolerance tolerant tolerant moderately sensitive /insensitive	Lumis *et al.* 1977 Delahunt and Hasselkus 1996 Thuet 1977 Tinus 1984 Beckerson *et al.* 1980
Pyrus species	pear, ornamental	aerial not specified not specified	moderately tolerant moderate tolerance sensitive	Thuet 1977 Delahunt and Hasselkus 1996 Thuet 1977
Pyrus padus	European bird pear	not specified	moderately tolerant	Thuet 1977
Vitis spp.	grape rootstocks	soil	more tolerant than *V.* vinifera, differences in degree of salt-exclusion by different species of rootstocks	Downton 1984

*Salt tolerance rating as expressed in the publication cited.

References for Comparative Ratings of Fruit Species

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APPENDIX TABLE 3: Effective concentration causing a 25% reduction in response (EC_{25}) For effects of NaCl On herbaceous plant species. Organized alphabetically by author.

EC_{25} (ppm)	Form	Vegetation	Source	Endpoint	Study
6690	NaCl	*Agrostis stolonifera*	concentration in water culture	relative growth rate	Ahmad and Wainwright, 1977
<2500	NaCl	Temperate prairie grasses	concentration in water	seed germination	Biesboer and Jacobson, 1994
<280	Na	Turfgrasses	concentration in tissue, soil study	shoot growth	Hanes *et al*., 1976
<4100	Cl	Turfgrasses	concentration in tissue, soil study	shoot growth	Hanes *et al*., 1976
202	Na	Temperate prairie species	concentration in soil	root growth	Harrington and Meikle, 1992
232	Na	Temperate prairie species	concentration in soil	shoot growth	Harrington and Meikle, 1992
270	Na	Temperate prairie species	concentration in soil	seed germination	Harrington and Meikle, 1992
10,000	NaCl	Tropical grasses	concentration in water	shoot growth	Marcum and Murdoch, 1994
17,800	Na	*Juncus* spp.	tissue concentration, water culture study	relative growth rate	Rozema and Visser, 1981
8400	NaCl	*Juncus* spp.	concentration in water	relative growth rate	Rozema and Visser, 1981
5900	NaCl	Bean, beet	concentration in water	shoot growth	Smith and McComb, 1981
6200	NaCl	All species, hydroponic studies	concentration in water	shoot growth	All studies
7300	NaCl	All species, hydroponic studies	concentration in water	relative growth rate	All studies

APPENDIX TABLE 4: LOEL's For Effects of Road Salts on Wetland Plants. Organized Alphabetically by Author.

LOEL (ppm)	Form	Vegetation	Source	Endpoint	Study
400	NaCl	*Eriophorum vaginatum var. spissum*	hydroponic culture	biomass	Schauffler 1993
400	NaCl	*Eriophorum vaginatum var. spissum*	hydroponic culture	tiller production	Schauffler 1993
1600	NaCl	*Eriophorum vaginatum var. spissum*	hydroponic culture	flower production	Schauffler 1993
300	Cl	*Sphagnum recurvum*	concentration in water	length increase	Wilcox 1984
300	Cl	*Sphagnum fimbriatum*	concentration in water	gametophore production	Wilcox and Andrus 1987
500	Cl	*Sphagnum fimbriatum*	concentration in water	length increase	Wilcox and Andrus 1987
1500	Cl	*Sphagnum fimbriatum*	concentration in water	biomass increase	Wilcox and Andrus 1987

APPENDIX TABLE 5: NOEL's for effects of road salts on herbaceous wetland plants. Organized alphabetically by author.

NOEL (ppm)	Form	Vegetation	Source	Endpoint	Study
66600	NaCl	*Lemna minor*	media	tolerance	Haller *et al.* 1974 (taken from Wilcox 1986)
5260-12870	NaCl	*Typha latifolia*	media	tolerance	Kaushik 1963 (taken from Wilcox 1986)
10000	NaCl	*Typha latifolia*	media	tolerance	McMillan 1959 (taken from Wilcox 1986)
20000	NaCl	*Typha angustifolia*	media	tolerance	McMillan 1959 (taken from Wilcox 1986)
5300	NaCl	*Utricularia*	media	tolerance	Penfold and Hathaway 1938 (taken from Wilcox 1986)
8900	NaCl	*Sagittaria* sp.	media	tolerance	Penfold and Hathaway 1938 (taken from Wilcox 1986)
16800	NaCl	*Typha angustifolia*	media	tolerance	Penfold and Hathaway 1938 (taken from Wilcox 1986)
11300	NaCl	*Typha latifolia*	media	tolerance	Penfold and Hathaway 1938 (taken from Wilcox 1986)
400	NaCl	*Eriophorum vaginatum* var. *spissum*	media	biomass	Schauffler 1993
400	NaCl	*Eriophorum vaginatum* var. *spissum*	media	tiller production	Schauffler 1993
1600	NaCl	*Eriophorum vaginatum* var. *spissum*	media	flower production	Schauffler 1993
280	NaCl	*Carex trisperma*	bog water gradient	tolerance	Wilcox 1986
360	NaCl	*Rhynchospora alba*	bog water gradient	tolerance	Wilcox 1986
360	NaCl	*Drosera intermedia*	bog water gradient	tolerance	Wilcox 1986
400	NaCl	*Solidago graminifolia*	bog water gradient	tolerance	Wilcox 1986
760	NaCl	*Panicum implicatum*	bog water gradient	tolerance	Wilcox 1986
770	NaCl	*Sphagnum* sp.	bog water gradient	tolerance	Wilcox 1986
1030	NaCl	*Bidens connata*	bog water gradient	tolerance	Wilcox 1986
1070	NaCl	*Scirpus cyperinus*	bog water gradient	tolerance	Wilcox 1986
1070	NaCl	*Hypericum virginicum*	bog water gradient	tolerance	Wilcox 1986
1070	NaCl	*Drypoteris thelypteris*	bog water gradient	tolerance	Wilcox 1986

APPENDIX TABLE 6: Critical toxicity values (CTV) and effective concentration causing a 25% reduction in response (EC_{25}) for effects of road salts on fruit trees, deciduous woody species and conifers. Organized alphabetically by author.

Threshold	Form	Conc. (ppm)	Source	Vegetation	Endpoint	Study
Fruit Trees						
CTV	Na	1100	tissue concentration	*Prunus persica* (Peach)	twig dieback	Chong and Lumis, 1990
CTV	Cl	4800	tissue concentration	*Prunus persica* (Peach)	twig dieback	Chong and Lumis, 1990
CTV	Na	1600	tissue concentration	*Prunus persica* (Peach cv Garnet Beauty)	twig dieback	Chong and Lumis, 1990
CTV	Cl	5600	tissue concentration	*Prunus persica* (Peach cv Garnet Beauty)	twig dieback	Chong and Lumis, 1990
CTV	Na	1800	tissue concentration	*Prunus persica* (Peach cv Madison)	twig dieback	Chong and Lumis, 1990
CTV	Cl	7800	tissue concentration	*Prunus persica* (Peach cv Madison)	twig dieback	Chong and Lumis, 1990
CTV	Na	1900	tissue concentration	*Prunus persica* (Peach cv Madison)	% dead buds	Chong and Lumis, 1990
CTV	Cl	8000	tissue concentration	*Prunus persica* (Peach cv Madison)	% dead buds	Chong and Lumis, 1990
EC_{25}	Na	1900	tissue concentration	*Prunus persica* (Peach cv Madison)	% dead buds	Chong and Lumis, 1990
EC_{25}	Cl	9000	tissue concentration	*Prunus persica* (Peach cv Madison)	% dead buds	Chong and Lumis, 1990
CTV	Na	650	tissue concentration	*Prunus persica* & *Prunus domestica* (Peach and Plum)	twig dieback	McLaughlin and Pearson, 1981
CTV	Cl	800	tissue concentration	*Prunus persica* & *Prunus domestica* (Peach and Plum)	twig dieback	McLaughlin and Pearson, 1981
CTV	Na	1700	tissue concentration	*Prunus persica* (Peach cv Loring)	% dead buds	Northover, 1987
EC_{25}	Na	3300	tissue concentration	*Prunus persica* (Peach cv Loring)	% dead buds	Northover, 1987
CTV	Na	1000	tissue concentration	*Prunus persica* (Peach cv Loring)	yield	Northover, 1987
CTV	Cl	1700	tissue concentration	*Prunus persica* (Peach cv Loring)	yield	Northover, 1987

Threshold	Form	Conc. (ppm)	Source	Vegetation	Endpoint	Study
Multiple Tree Species						
EC_{25}	Na	4200	foliar tissue concentration	Woody species	injury class rating	Lumis, Hofstra and Hall 1976
EC_{25}	Cl	4950	foliar tissue concentration	Woody species	injury class rating	Lumis, Hofstra and Hall 1976
EC_{25}	NaCl	2240	hydroponic solution concentration	*Platanus occidentalis*, *Pinus strobus*	dry weight of stem plus root	Townsend 1980
EC_{25}	NaCl	4250	hydroponic solution concentration	*Cornus florida*, *Platanus occidentalis*, *Pinus strobus*	root dry weight	Townsend 1980
Deciduous woody species						
EC_{25}	NaCl	700	soil concentration	*Betula alleghaniensis*	germination	Bicknell and Smith 1975
EC_{25}	NaCl	882	soil concentration	*Catalpa bignoides*	germination	Bicknell and Smith 1975
EC_{25}	Na	15700	shoot concentration	*Gleditsia triacanthos var. inermis*	shoot dry weight	Dirr 1974
EC_{25}	Cl	39400	shoot concentration	*Gleditsia triacanthos var. inermis*	shoot dry weight	Dirr 1974
EC_{25}	Na	16100	foliar tissue concentration	Deciduous species	appearance index	Dirr 1978
EC_{25}	Cl	35700	foliar tissue concentration	Deciduous species	appearance index	Dirr 1978
EC_{25}	Na	631	foliar tissue concentration	*Acer saccharum* and *Acer rubrum*	decline symptoms	Lacasse and Rich 1964
EC_{25}	Na	575	twig tissue concentration	*Acer saccharum* and *Acer rubrum*	decline symptoms	Lacasse and Rich 1964
EC_{25}	Na	2380	foliar concentration	*Acer saccharinum*	symptom rating	Hanes *et al.* 1976
EC_{25}	Cl	70700	foliar concentration	*Acer saccharinum*	symptom rating	Hanes *et al.* 1976
EC_{25}	Cl	22980	stem concentration	*Acer saccharinum*	symptom rating	Hanes *et al.* 1976

Threshold	Form	Conc. (ppm)	Source	Vegetation	Endpoint	Study
NOEL	NaCl	8900	media	Cephalanthus occidentalis	tolerance	Penfold and Hathaway 1938 (taken from Wilcox 1986)
EC_{25}	Cl	6950	foliar concentration	*Acer saccharum* and *Acer platanoides*	leaf dry wt (g)	Simini and Leone 1986
CTV	NaCl	25000	soil solution concentration	*Cornus sanguinea*	dry weight increase per plant (% of control)	Thompson and Rutter 1986
EC_{25}	NaCl	10800	soil solution concentration	*Crataegus monogyna*	plant death	Thompson and Rutter 1986
EC_{25}	NaCl	13100	soil solution concentration	*Rosa rubiginosa*	dry weight increase per plant (% of control)	Thompson and Rutter 1986
EC_{25}	NaCl	18900	soil solution concentration	*Viburnum lantana*	dry weight increase per plant (% of control)	Thompson and Rutter 1986
EC_{25}	NaCl	2700	hydroponic solution concentration	*Cornus florida*	seedling height growth	Townsend 1980
EC_{25}	NaCl	836	hydroponic solution concentration	*Cornus florida*, *Platanus occidentalis*	leaf dry weight	Townsend 1980
NOEL	NaCl	280	bog water concentration	*Nemopanthus mucronata* [*mucronatus*]	tolerance	Wilcox 1986
NOEL	NaCl	400	bog water concentration	*Vaccinium atrocuccum*	tolerance	Wilcox 1986
NOEL	NaCl	540	bog water concentration	*Acer rubrum*	tolerance	Wilcox 1986
NOEL	NaCl	580	bog water concentration	*Vaccinium corymbosum*	tolerance	Wilcox 1986
NOEL	NaCl	1070	bog water concentration	*Pyrus* sp.	tolerance	Wilcox 1986
NOEL	NaCl	1150	bog water concentration	*Ilex* sp.	tolerance	Wilcox 1986
EC_{25}	Cl	5000	foliar tissue concentration following NaCl or $CaCl_2$ treatments, pooled data	*Acer platanoides*	foliar symptom index	Walton 1969

Threshold	Form	Conc. (ppm)	Source	Vegetation	Endpoint	Study
Coniferous Species						
EC_{25}	Na	160	soil solution concentration	*Pinus ponderosa* (Ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
EC_{25}	Cl	350	soil solution concentration	*Pinus ponderosa* (Ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
EC_{25}	Na	140	soil solution concentration	*Pinus ponderosa* (Ponderosa Pine)	mortality	Bedunah and Trlica, 1979
EC_{25}	Cl	350	soil solution concentration	*Pinus ponderosa* (Ponderosa Pine)	mortality	Bedunah and Trlica, 1979
EC_{25}	Na	1750	tissue concentration	*Pinus ponderosa* (Ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
EC_{25}	Cl	4000	tissue concentration	*Pinus ponderosa* (Ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
EC_{25}	Na	2750	tissue concentration	*Pinus ponderosa* (Ponderosa Pine)	mortality	Bedunah and Trlica, 1979
EC_{25}	Cl	7000	tissue concentration	*Pinus ponderosa* (Ponderosa Pine)	mortality	Bedunah and Trlica, 1979
EC_{25}	Na	67.5	soil concentration	*Pinus ponderosa* (Ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
EC_{25}	Cl	215	soil concentration	*Pinus ponderosa* (Ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
EC_{25}	Na	2100	tissue concentration	*Pinus ponderosa* (Ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
EC_{25}	Cl	1650	tissue concentration	*Pinus ponderosa* (Ponderosa Pine)	foliar injury	Bedunah and Trlica, 1979
EC_{25}	NaCl	950	soil concentration	*Pinus rigida*	germination	Bicknell and Smith, 1975
EC_{25}	NaCl	2935	soil concentration	*Pinus rigida*	germination	Bicknell and Smith, 1975
EC_{25} (1)	Na	240	soil concentration	*Thuja occidentalis* (White Cedar)	discolored foliage	Foster and Maun, 1977
EC_{25} (1)	Cl	450	soil concentration	*Thuja occidentalis* (White Cedar)	discolored foliage	Foster and Maun, 1977
EC_{25} (1)	Na	300	soil concentration	*Thuja occidentalis* (White Cedar)	root damage rating index	Foster and Maun, 1977
EC_{25} (1)	Cl	500	soil concentration	*Thuja occidentalis* (White Cedar)	root damage rating index	Foster and Maun, 1977

Threshold	Form	Conc. (ppm)	Source	Vegetation	Endpoint	Study
EC_{25} (1)	Na	2500	foliage concentration	*Thuja occidentalis* (White Cedar)	discolored foliage	Foster and Maun, 1977
EC_{25} (1)	Cl	7500	foliage concentration	*Thuja occidentalis* (White Cedar)	discolored foliage	Foster and Maun, 1977
EC_{25} (1)	Na	3250	root concentration	*Thuja occidentalis* (White Cedar)	root damage rating index	Foster and Maun, 1977
EC_{25} (1)	Cl	not sensitive	root concentration	*Thuja occidentalis* (White Cedar)	root damage rating index	Foster and Maun, 1977
EC_{25} (2)	Na	9000	foliage concentration	*Thuja occidentalis* (White Cedar)	foliage damage rating index	Foster and Maun, 1977
EC_{25} (2)	Cl	4000	foliage concentration	*Thuja occidentalis* (White Cedar)	foliage damage rating index	Foster and Maun, 1977
EC_{25} (2)	Na	950	root concentration	*Thuja occidentalis* (White Cedar)	root damage rating index	Foster and Maun, 1977
EC_{25} (2)	Cl	4750	root concentration	*Thuja occidentalis* (White Cedar)	root damage rating index	Foster and Maun, 1977
EC_{25} (3)	Na	1500	foliage concentration	*Thuja occidentalis* (White Cedar)	foliage damage rating index	Foster and Maun, 1977
EC_{25} (3)	Cl	9750	foliage concentration	*Thuja occidentalis* (White Cedar)	foliage damage rating index	Foster and Maun, 1977
EC_{25} (4)	Na	1750	foliage concentration	*Thuja occidentalis* (White Cedar)	foliage damage rating index	Foster and Maun, 1977
EC_{25} (4)	Cl	7000	foliage concentration	*Thuja occidentalis* (White Cedar)	foliage damage rating index	Foster and Maun, 1977
EC_{25} (4)	Na	2500	root concentration	*Thuja occidentalis* (White Cedar)	root damage rating index	Foster and Maun, 1977
EC_{25} (4)	Cl	1600	root concentration	*Thuja occidentalis* (White Cedar)	root damage rating index	Foster and Maun, 1977
EC_{25} (4)	NaCl	5850	hydroponic solution concentration	*Thuja occidentalis* (White Cedar)	foliage damage rating index	Foster and Maun, 1977
EC_{25} (4)	NaCl	8190	hydroponic solution concentration	*Thuja occidentalis* (White Cedar)	root damage rating index	Foster and Maun, 1977
EC_{25}	Na	4200	tissue concentration	*Thuja occidentalis* (White Cedar)	damage rating index	Foster and Maun, 1980
EC_{25}	Cl	7200	tissue concentration	*Thuja occidentalis* (White Cedar)	damage rating index	Foster and Maun, 1980

Threshold	Form	Conc. (ppm)	Source	Vegetation	Endpoint	Study
EC_{25}	Cl	5010	foliar tissue concentration	*Thuja occidentalis* (White Cedar)	damage rating index	Foster and Maun, 1980
EC_{25}	Cl	5005	soil concentration	*Pinus strobus*	foliar injury rating	Hall, Hofstra and Lumis, 1972
EC_{25}	Na	2100	tissue concentration	*Thuja occidentalis* (White Cedar)	foliar injury	Hofstra and Hall, 1971
EC_{25}	Cl	4700	tissue concentration	*Thuja occidentalis* (White Cedar)	foliar injury	Hofstra and Hall, 1971
EC_{25}	Na	200	tissue concentration	White Fir	injury rating	Scharpf and Srago, 1974
EC_{25}	Cl	2000	tissue concentration	White Fir	injury rating	Scharpf and Srago, 1974
EC_{25}	Cl	14000	tissue concentration	*Pinus* spp. (Multiple Pine species)	chlorosis and necrosis	Townsend, 1983
EC_{25}	Na	8000	tissue concentration	*Pinus* spp. (Multiple Pine species)	survival	Townsend and Kwolek, 1987
EC_{25}	Cl	13000	tissue concentration	*Pinus* spp. (Multiple Pine species)	survival	Townsend and Kwolek, 1987
EC_{25}	Na	10500	tissue concentration	*Pinus* spp. (Multiple Pine species)	chlorosis and necrosis	Townsend and Kwolek, 1987
EC_{25}	Cl	16000	tissue concentration	*Pinus* spp. (Multiple Pine species)	chlorosis and necrosis	Townsend and Kwolek, 1987
EC_{25}	NaCl	630	soil concentration	*Picea pungens* (Colorado Blue Spruce)	dry matter	Werkhoven, et al., 1966
EC_{25}	NaCl	800	soil concentration	*Picea pungens* (Colorado Blue Spruce)	dry matter	Werkhoven, et al., 1966
EC_{25}	NaCl	not sensitive	soil concentration	*Picea pungens* (Colorado Blue Spruce	height	Werkhoven, et al., 1966
EC_{25}	NaCl	5500	soil concentration	*Picea pungens* (Colorado Blue Spruce)	height	Werkhoven, et al., 1966
EC_{25}	NaCl	600	soil concentration	*Picea pungens* (Colorado Blue Spruce)	survival	Werkhoven, et al., 1966
EC_{25}	NaCl	850	soil concentration	*Picea pungens* (Colorado Blue Spruce)	survival	Werkhoven, et al., 1966
EC_{25}	NaCl	600	soil concentration	*Pinus sylvestris* (Scots Pine)	dry matter	Werkhoven, et al., 1966
EC_{25}	NaCl	650	soil concentration	*Pinus sylvestris* (Scots Pine)	dry matter	Werkhoven, et al., 1966
EC_{25}	NaCl	5250	soil concentration	*Pinus sylvestris* (Scots Pine)	height	Werkhoven, et al., 1966
EC_{25}	NaCl	2200	soil concentration	*Pinus sylvestris* (Scots Pine)	height	Werkhoven, et al., 1966
EC_{25}	NaCl	700	soil concentration	*Pinus sylvestris* (Scots Pine)	survival	Werkhoven, et al., 1966
EC_{25}	NaCl	1750	soil concentration	*Pinus sylvestris* (Scots Pine)	survival	Werkhoven, et al., 1966

APPENDIX 7. FIGURES USED FOR CALCULATION OF HERBACEOUS SPECIES THRESHOLD VALUES

Figure #	EC_{50}	Species	Endpoint	Study
Figure 1	232 ppm	Temperate prairie species (soil culture)	Shoot growth	Harrington and Meikle, 1992
Figure 2	202 ppm	Temperate prairie species (soil culture	Root growth	Harrington and Meikle, 1992
Figure 3	180 ppm	Temperate prairie species (water culture)	Seed germination	Harrington and Meikle, 1992; Biesboer and Jacobson, 1994
Figure 4	2780 ppm	Bluegrass, fescue (water culture)	Shoot growth	Hanes et al., 1976
Figure 5	No negative effect	Bluegrass, fescue (water culture)	Root growth	Hanes et al., 1976
Figure 6	8400 ppm	Juncus sp.	Relative growth rate	Rozema and Visser, 19??
Figure 7	5900 ppm	Bean, beet (water culture)	Shoot growth	Smith and McComb, 1981
Figure 8	6690 ppm	Agrostis stolonifera (water culture)	Relative growth rate	Ahmad and Wainwright, 1977
Figure 9	10,000 ppm	Warm climate grasses (water culture)	Shoot growth	Marcum and Murdoch, 1994
Figure 10	No negative effect	All species (water culture)	Root growth	
Figure 11	6200 ppm	All species (water culture)	Shoot growth	
Figure 12	7300 ppm	All species (water culture)	Relative growth rate	
Figure 13	17,800 ppm	Juncus sp.	Shoot Na concentration	Ahmad and Wainwright, 1977

Figure 1:
Shoot growth - temperate prairie species
(Harrington and Meikle, 1992)

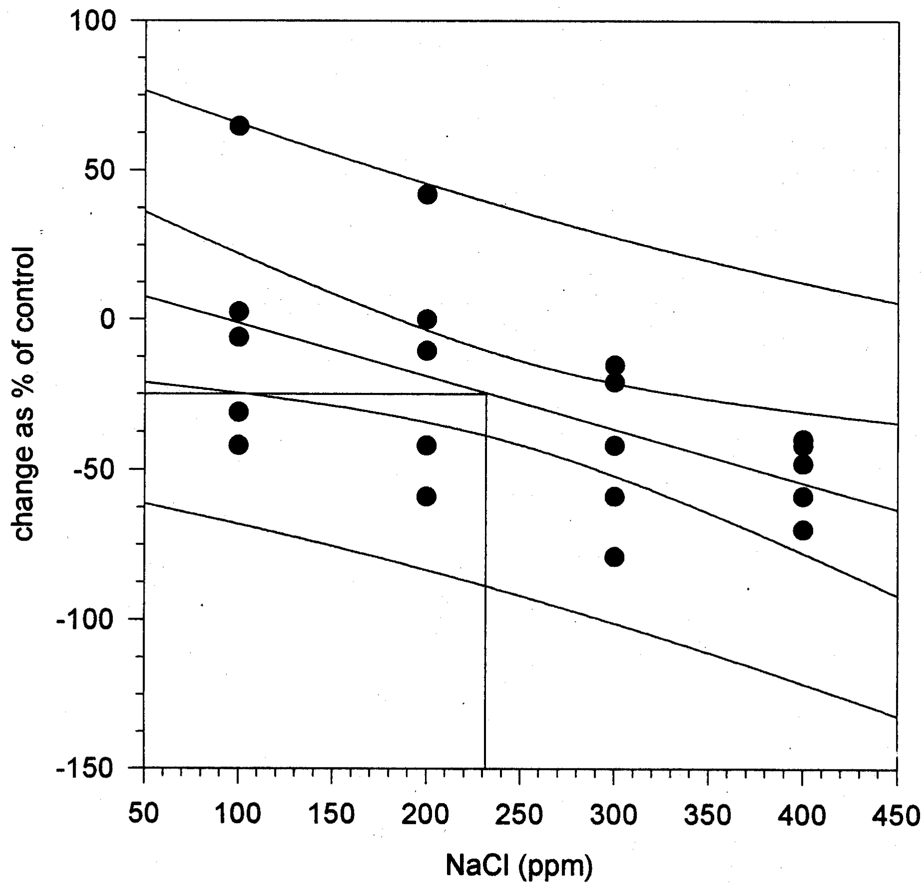


Figure 2:
Root growth - temperate prairie species
(Harrington and Meikle, 1992)

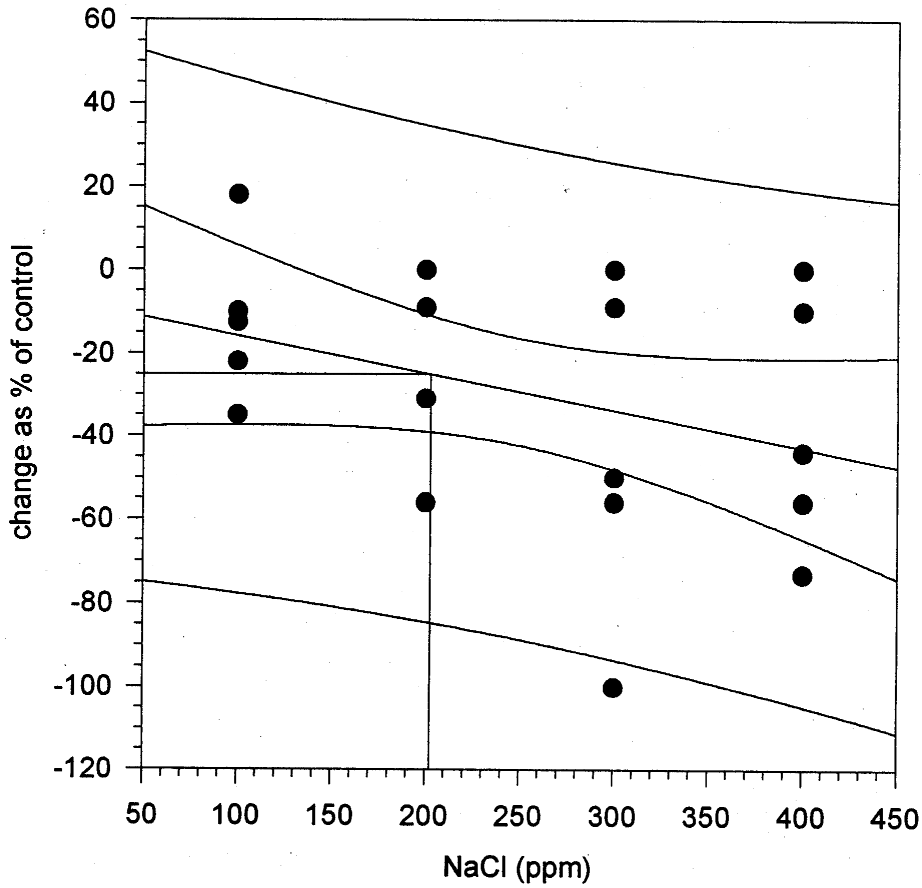


Figure 3:
Seed germination - Prairie species
(Harrington and Meikle, 1992;
Biesboer and Jacobson, 1994)

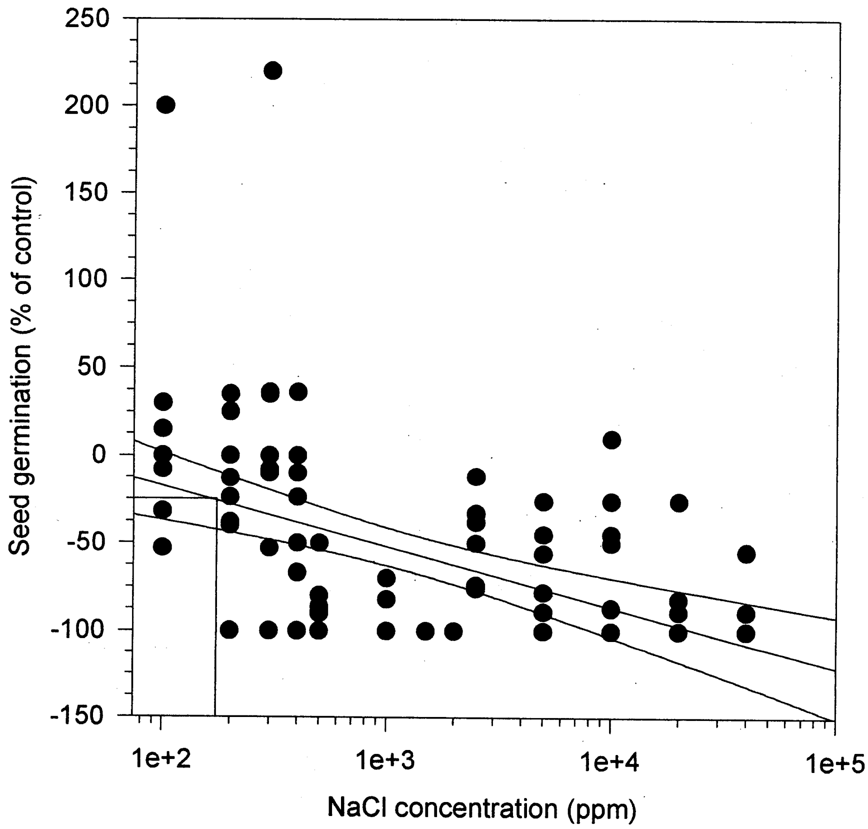


Figure 4:
Shoot growth - bluegrass, fescue
(Hanes et al., 1976)

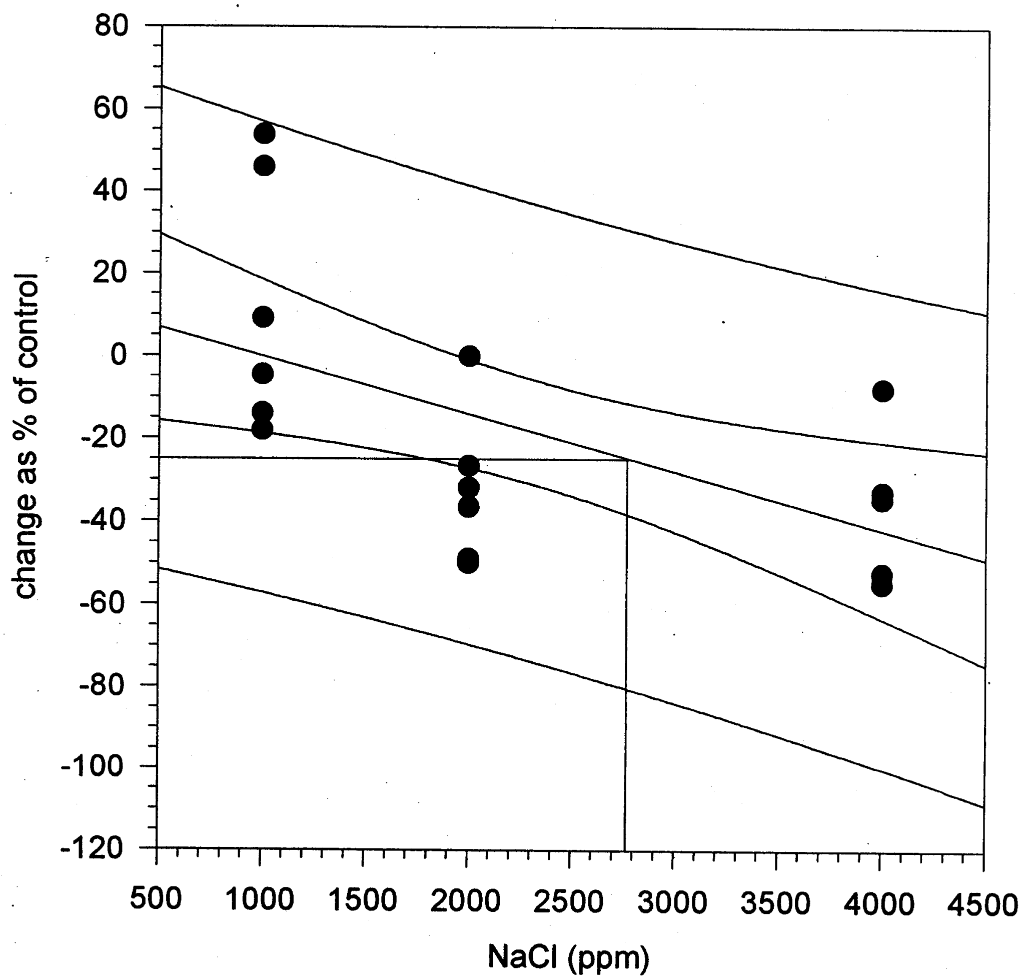


Figure 5:
Root growth - bluegrass, fescue
(Hanes et al., 1976)

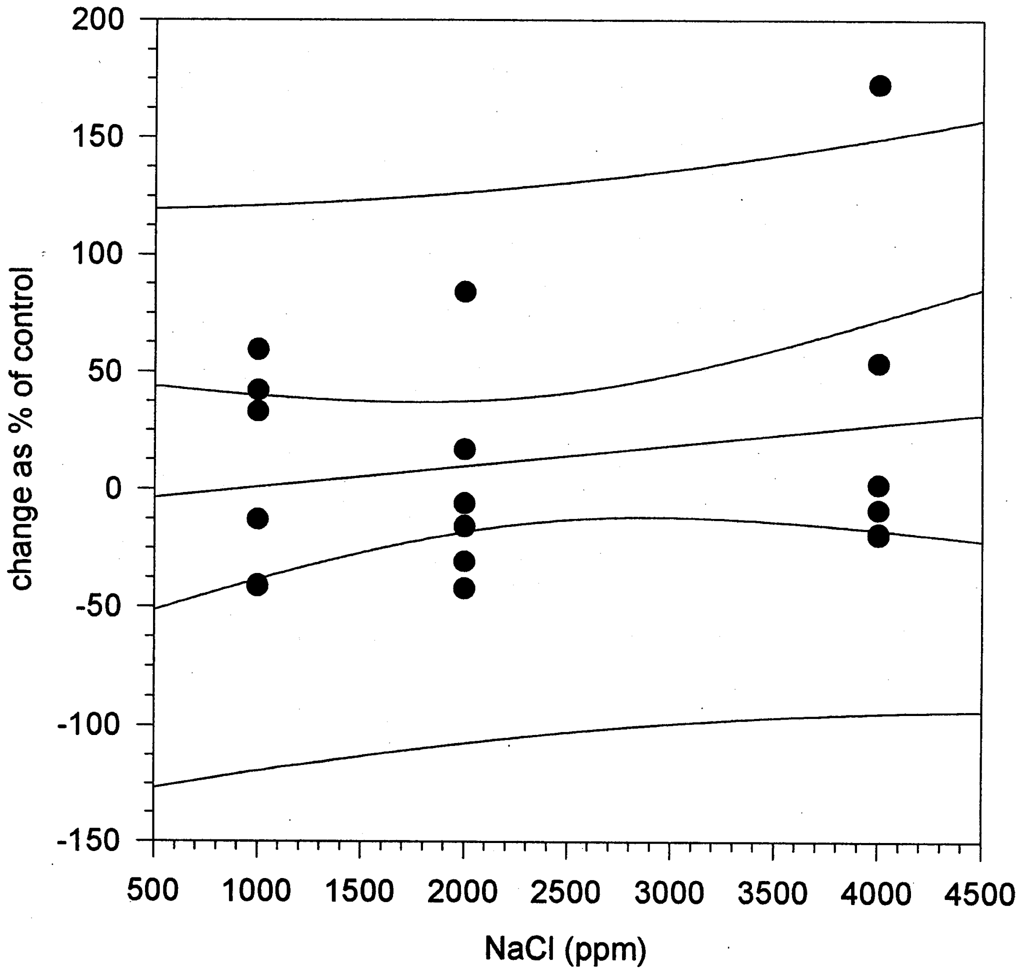


Figure 6:
Relative Growth Rate of *Juncus* sp.
(Rozema and Visser, 1981)

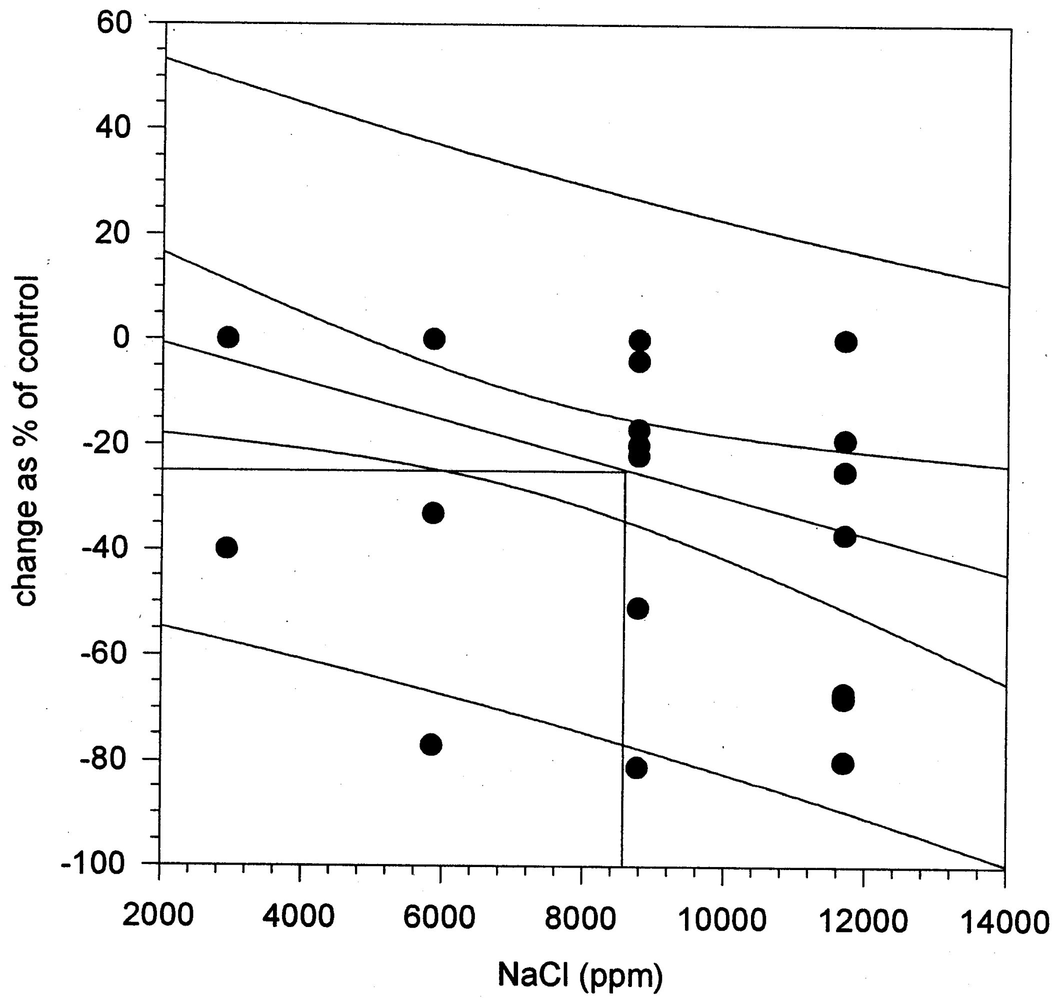


Figure 7:
Shoot growth - bean, beet
(Smith and McComb, 1981)

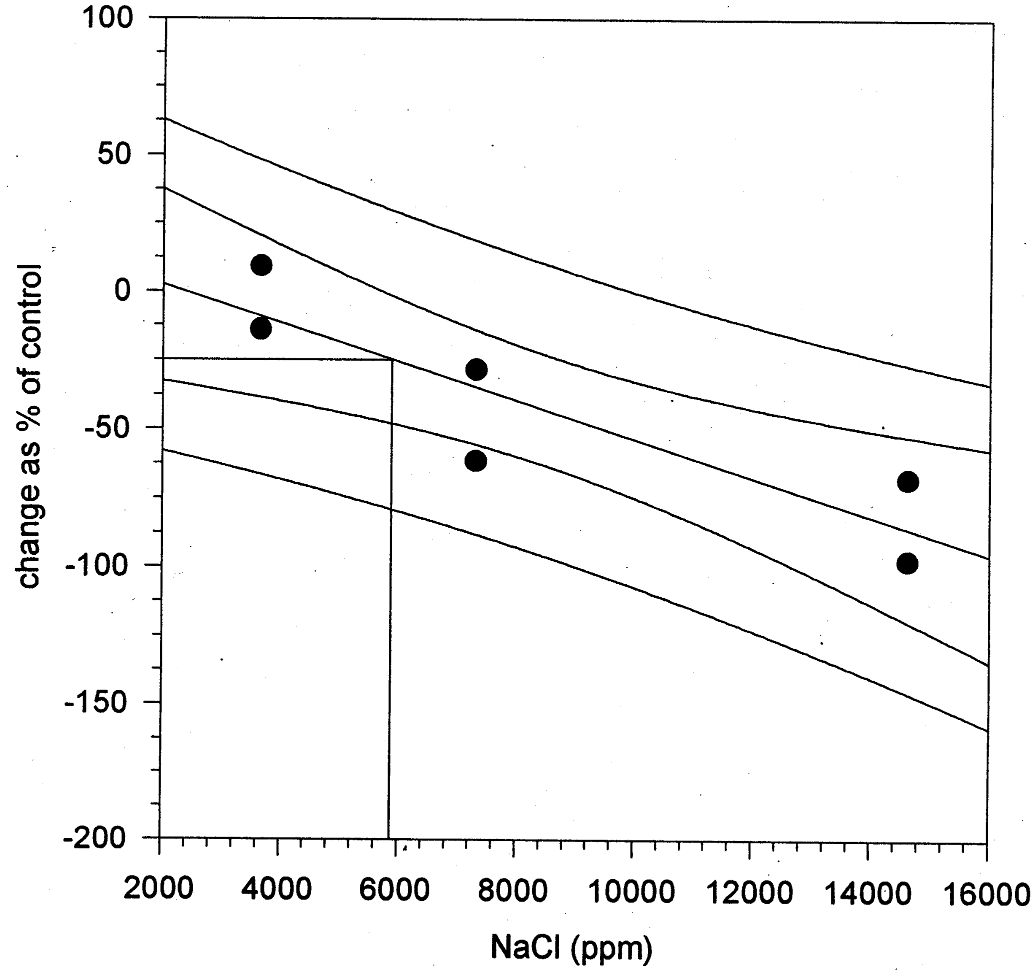


Figure 8:
RGR - Agrostis stolonifera
(Ahmad and Wainwright, 1977)

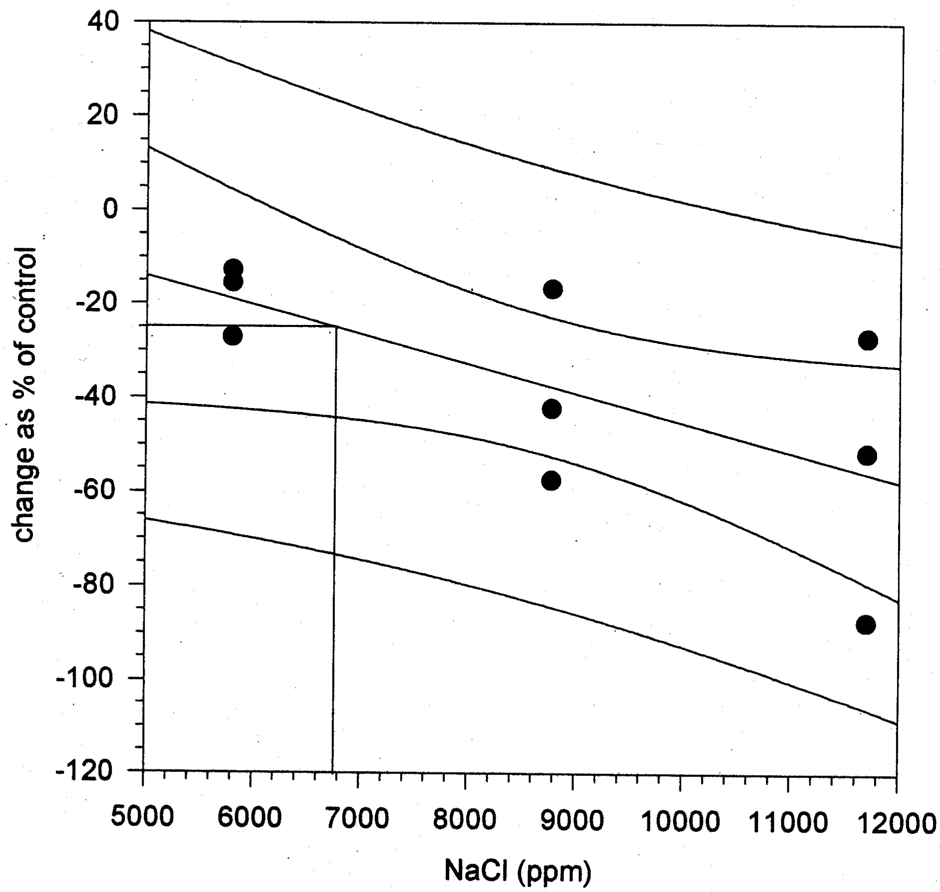


Figure 10:
Root growth - all water culture data

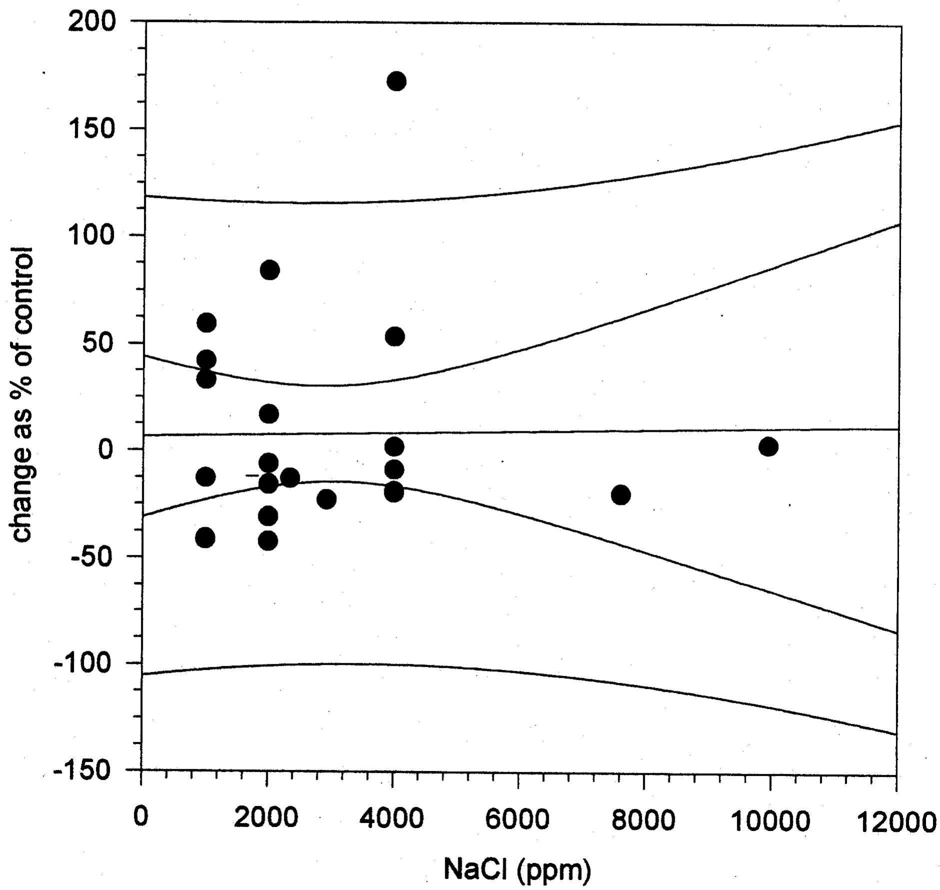


Figure 11:
Shoot growth - all water culture data

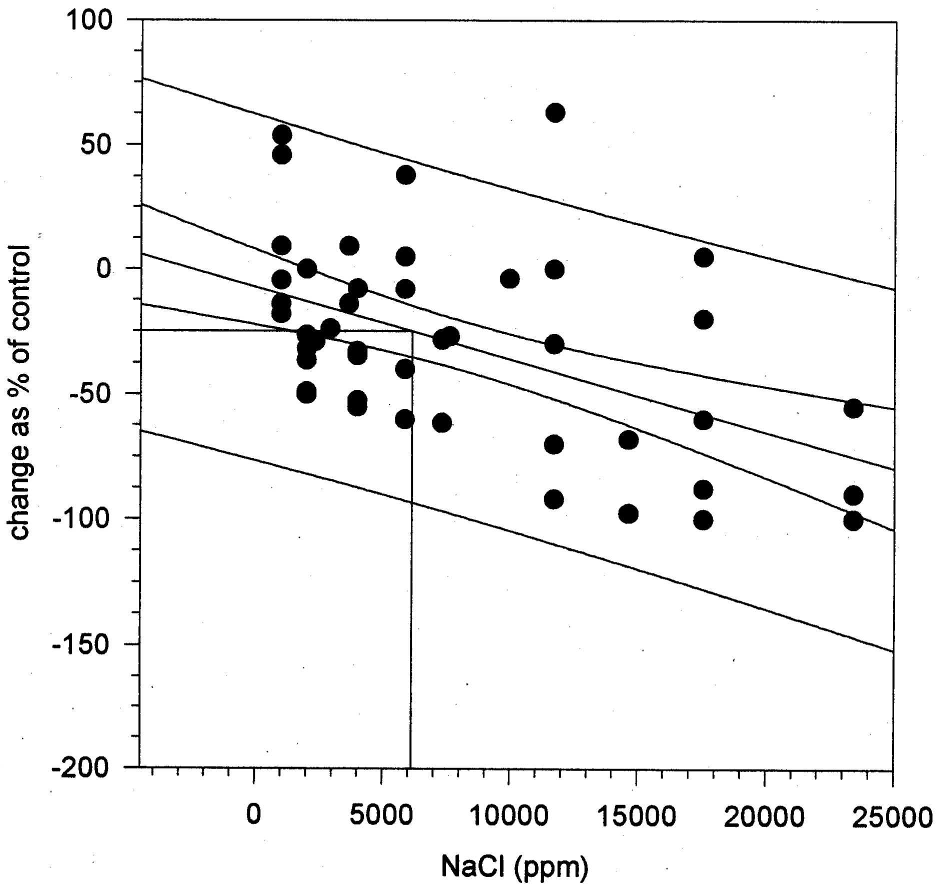


Figure 12:
Relative Growth Rate - all water culture studies

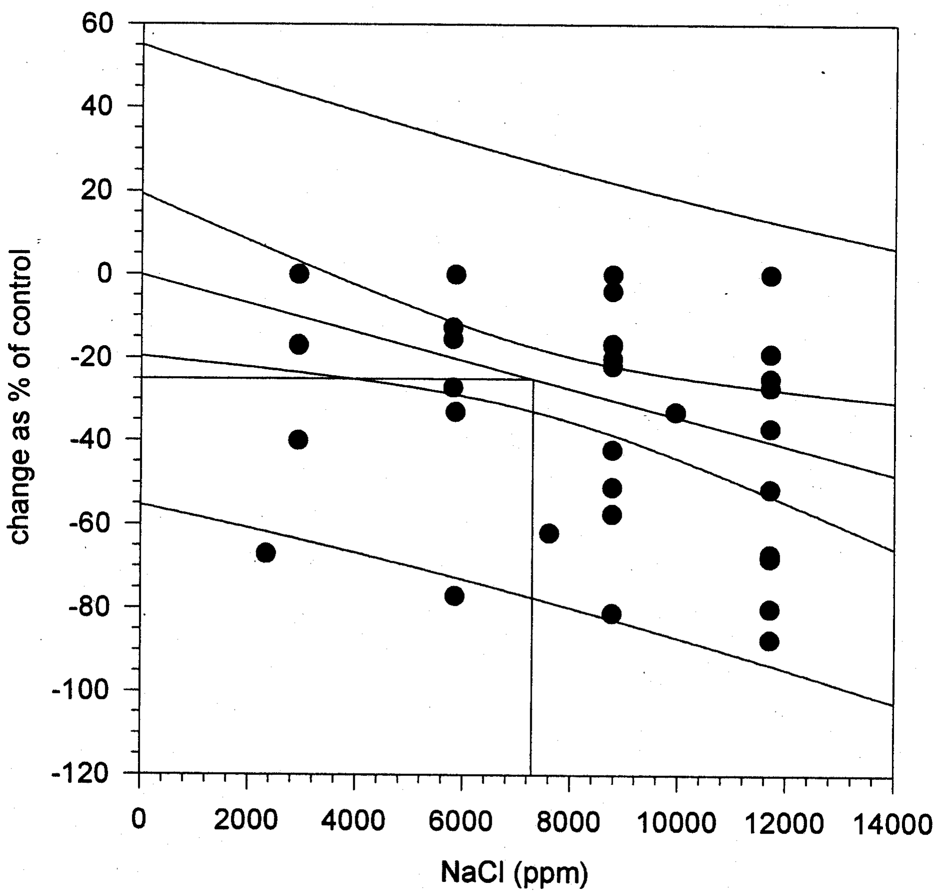
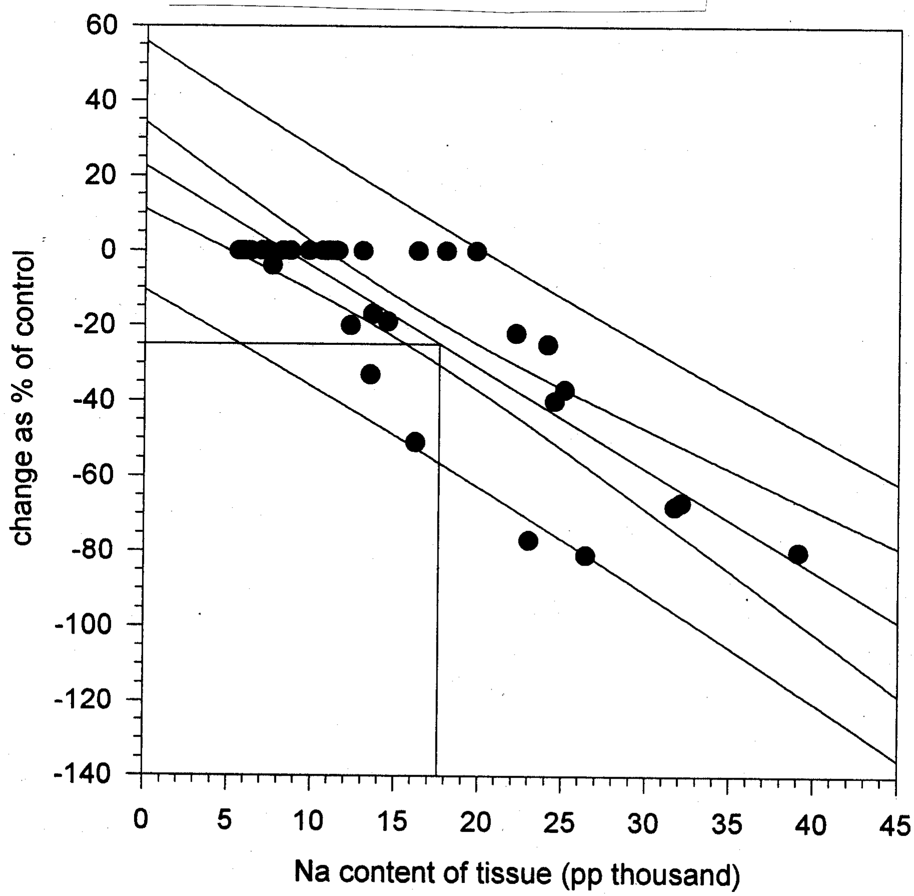


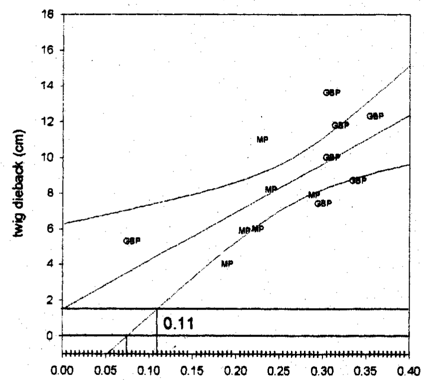
Figure 13:
Relative Growth Rate (Tissue Na Content)
***Juncus* sp.**
(Rozema and Visser, 1981)



APPENDIX 8. FIGURES USED FOR CALCULATION OF WOODY SPECIES THRESHOLD VALUES

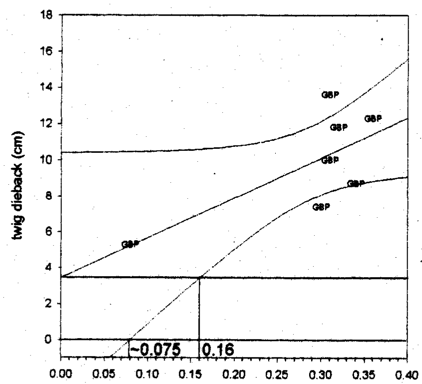
FRUIT CROPS

Twig Dieback- Peach; Chong and Lumis, 1990.



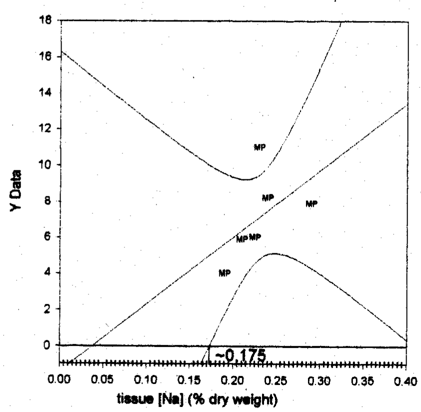
Plot 1
Order 1

All curves:
Coefficients:
b[0] 1.4969270202
b[1] 27.2070334032
r^2 0.4926454048



Plot 1
Order 1

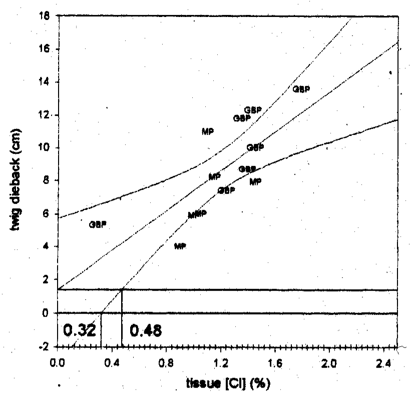
All curves:
Coefficients:
b[0] 3.4717962466
b[1] 22.1769436997
r^2 0.5048092413



Plot 1
Order 1

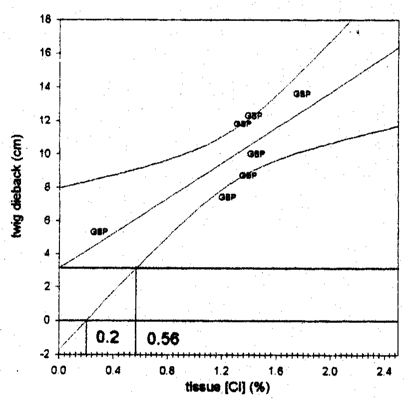
All curves:
Coefficients:
b[0]□-1.394173343
b[1]□37.0866715222
r^2□0.2686124991

Twig dieback- Peach; Chong and Lumis, 1990



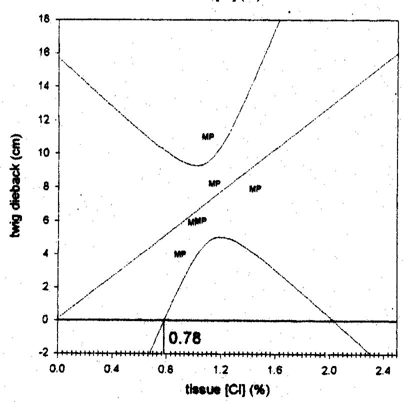
Plot 1
Order 1

All curves:
Coefficients:
b[0] 1.3939188926
b[1] 6.0281625655
r^2 0.5473847241



Plot 1
Order 1

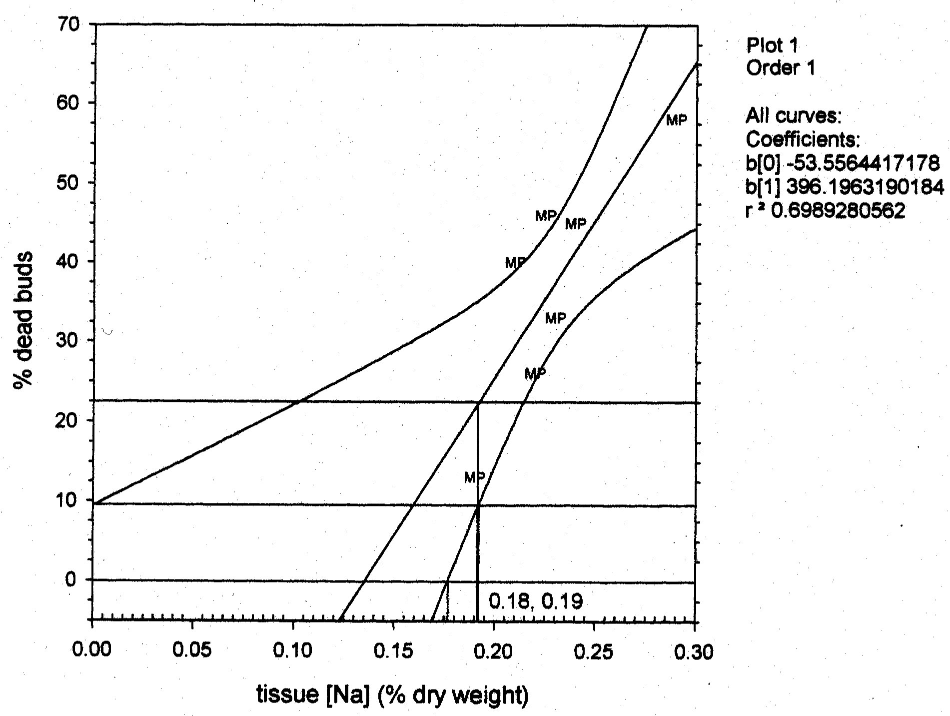
All curves:
Coefficients:
b[0] 3.1272620216
b[1] 5.2806673209
r^2 0.7037353816



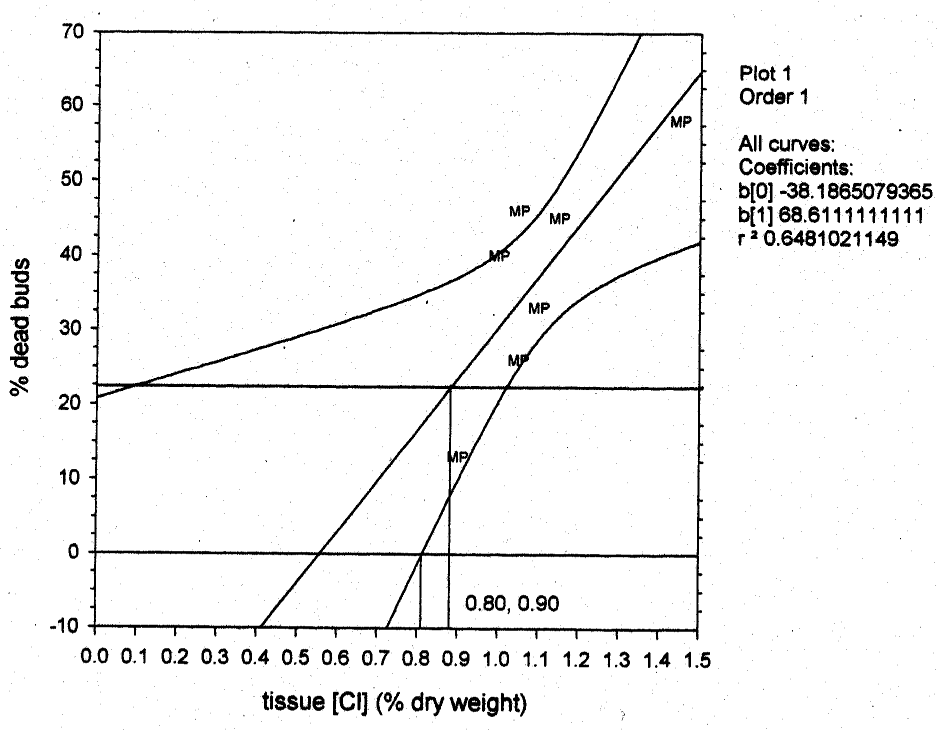
Plot 1
Order 1

All curves:
Coefficients:
b[0]□0.1150588235
b[1]□6.3623529412
r^2□0.2447058824

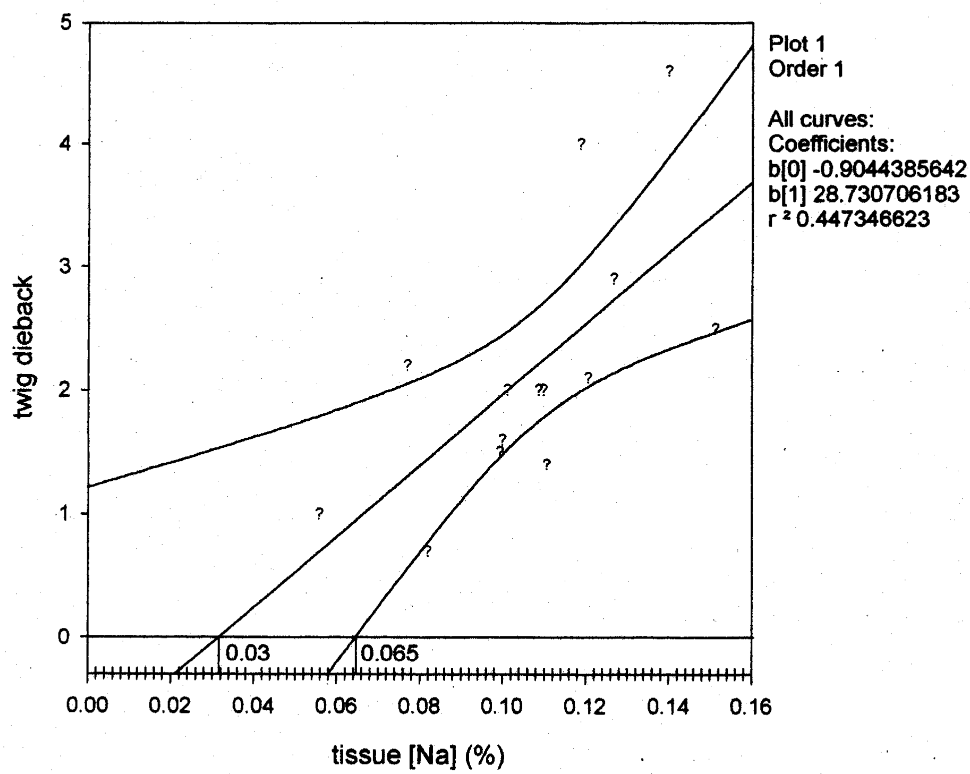
% dead buds- peach; Chong and Lumis, 1990.



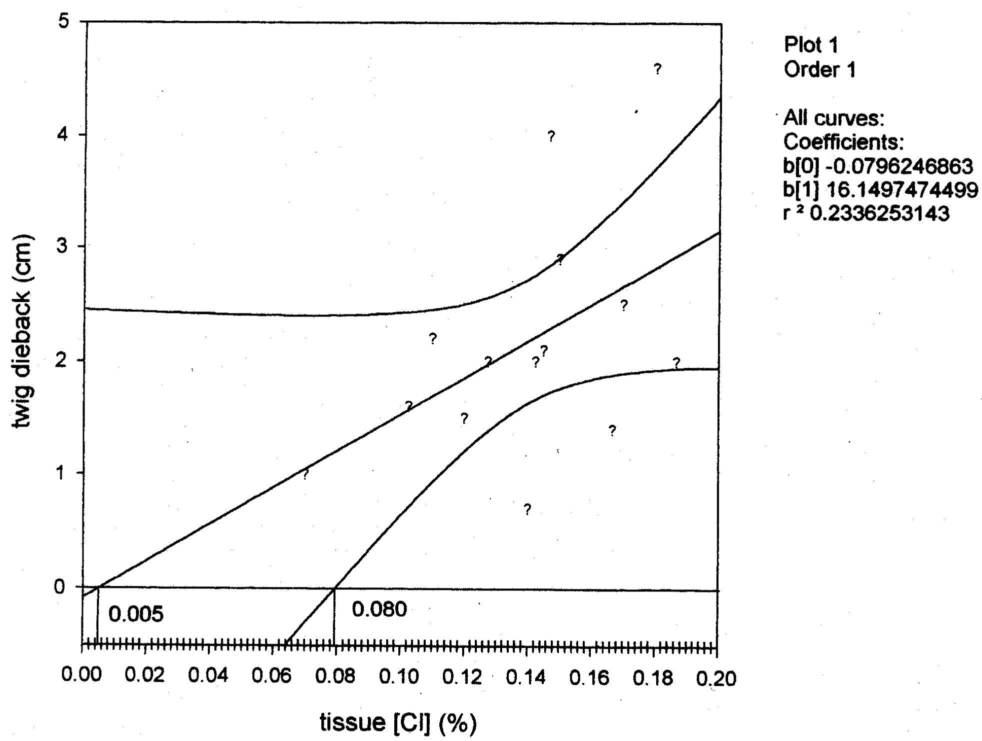
% dead buds- peach; Chong and Lumis, 1990.



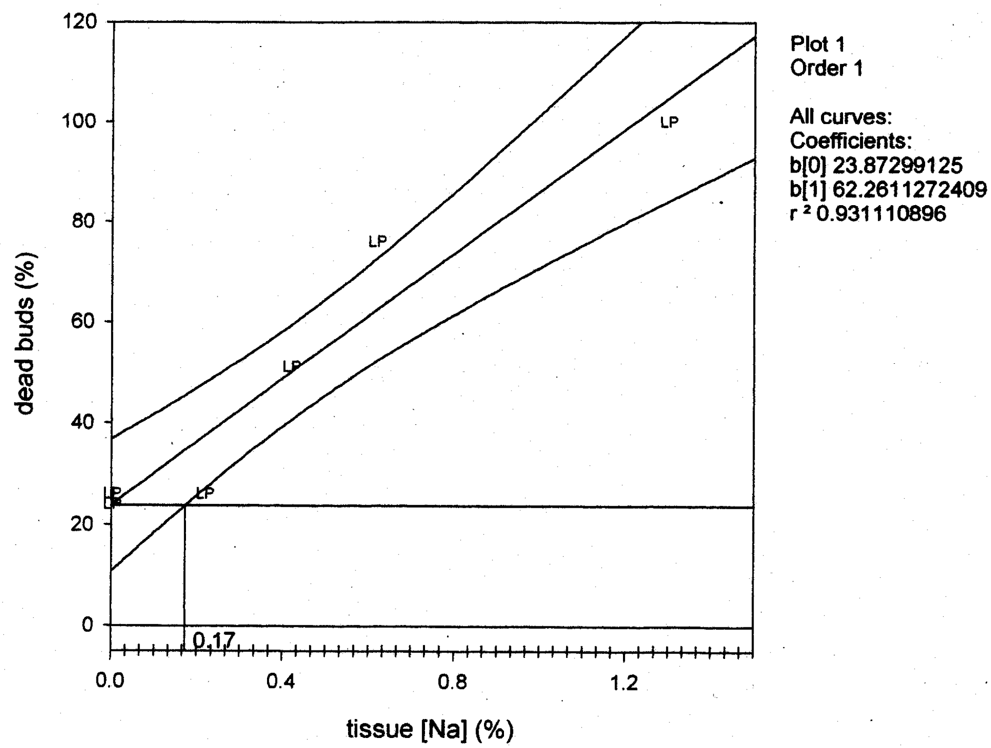
Twig dieback- (peach and plum); McLaughlin and Pearson, 1981



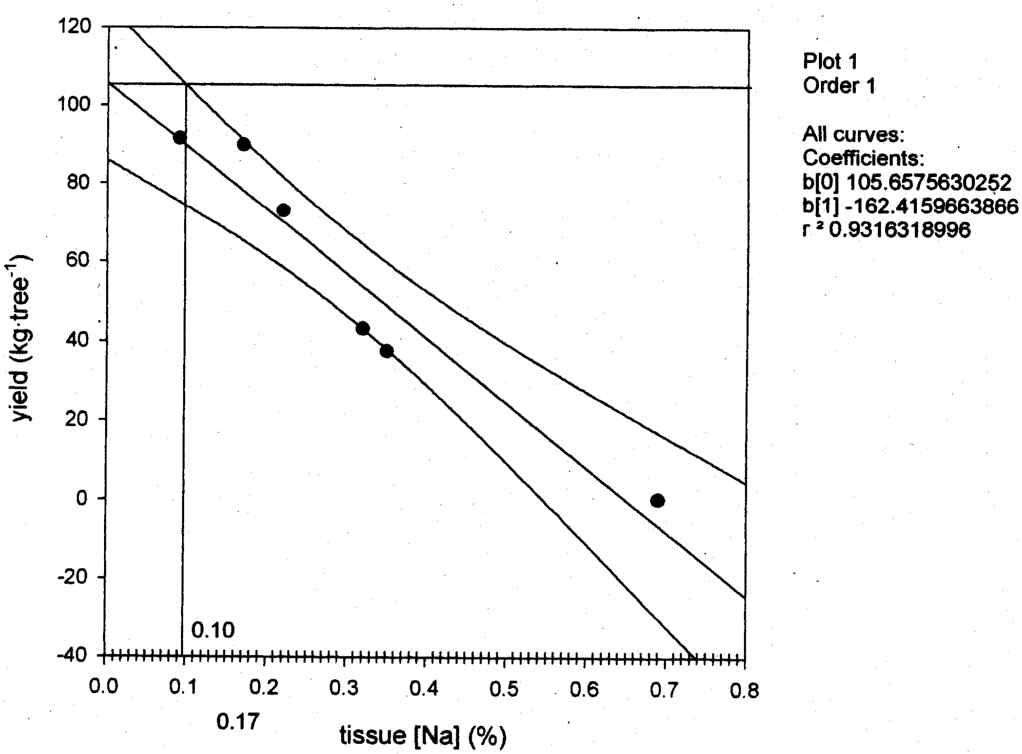
Twig dieback- (peach and plum); McLaughlin and Pearson, 1981.

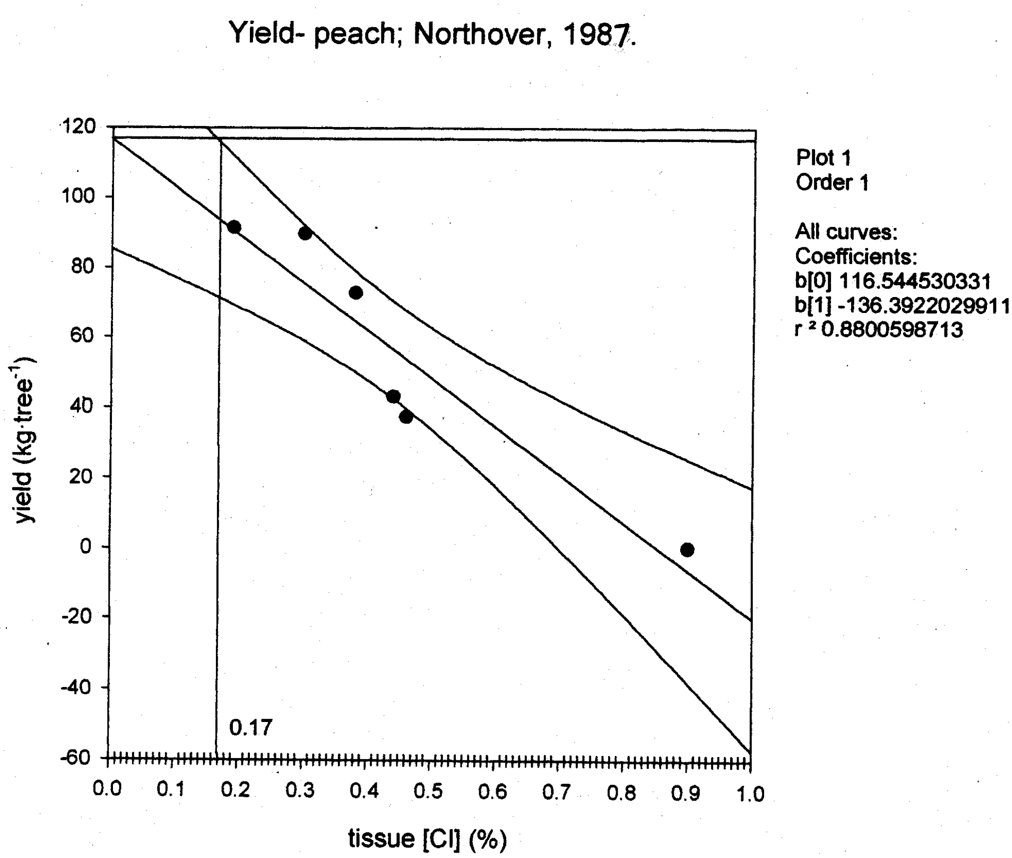


% dead buds- peach; Northover, 1987



Yield- peach; Northover, 1987.





Yield- peach; Northover, 1987.
120
100
80
60
40
20
0
-20
-40
-60
yield (kg·tree-1)
0.17
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
tissue [Cl] (%)
Plot 1
Order 1
All curves:
Coefficients:
b[0] 116.544530331
b[1] -136.3922029911
r ² 0.8800598713

MULTIPLE WOODY SPECIES, DECIDUOUS AND CONIFEROUS

Figure 1. Linear regression of tree injury rating on foliar Na concentration (ppm) for, 95% confidence intervals and data points (data from Lumis *et al.* 1976). EC_{25} value of 4200, calculated from 25% effects level of 2.43465.

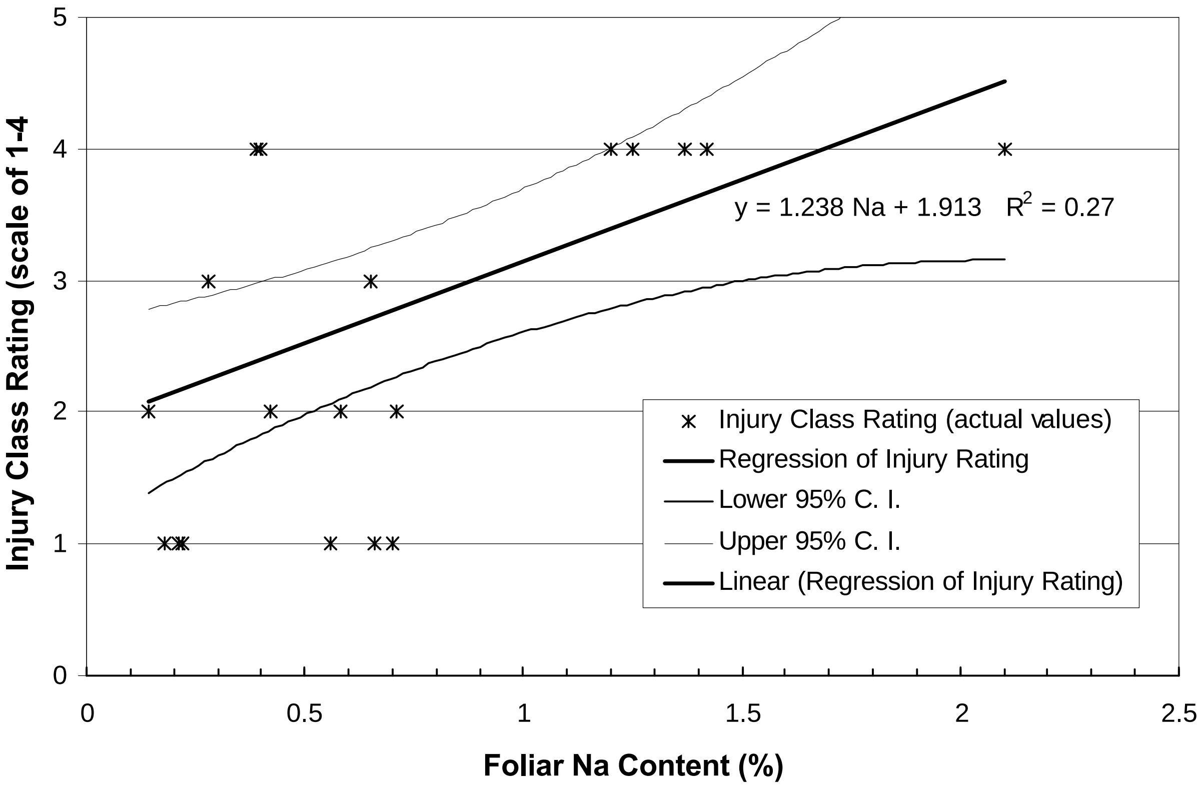


Figure 2. Linear regression of tree injury rating on foliar Na concentration (ppm) for, 95% confidence intervals and data points (data from Lumis *et al.* 1976). EC_{25} value of 4200, calculated from 25% effects level of 2.43465.

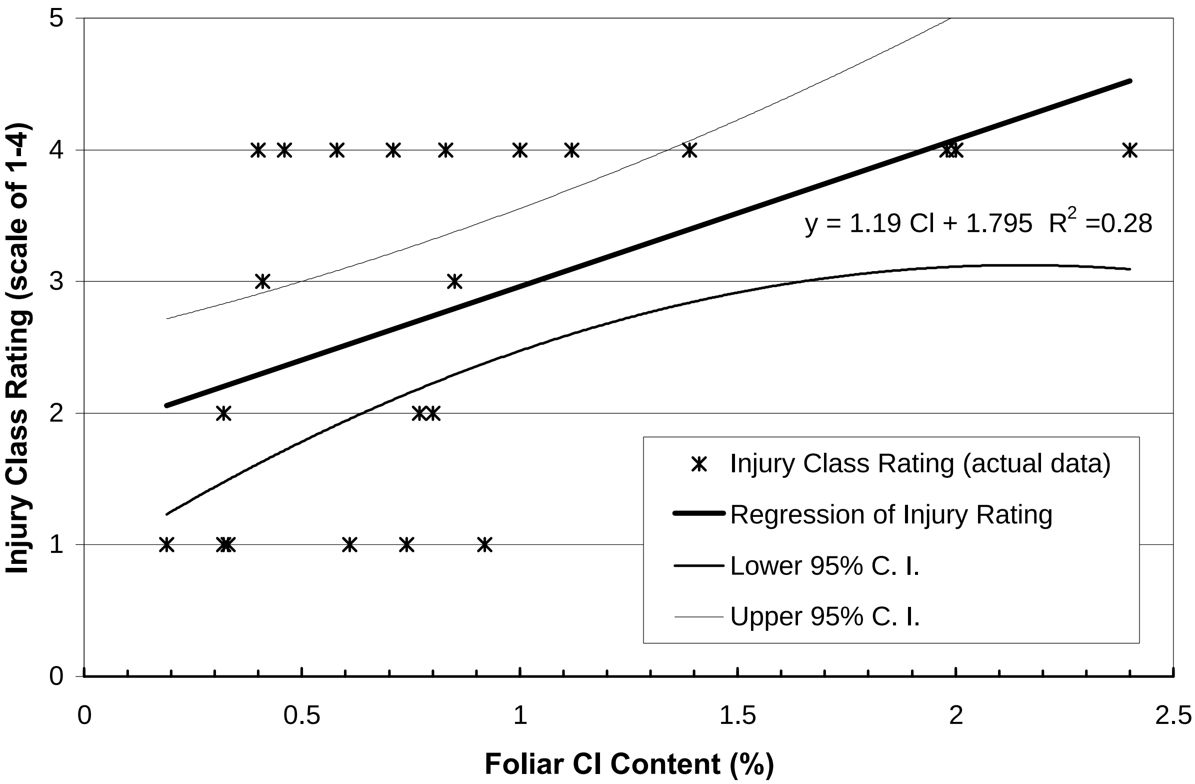
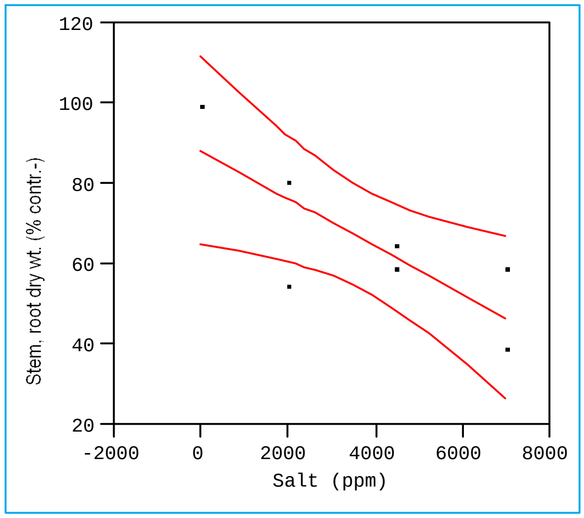


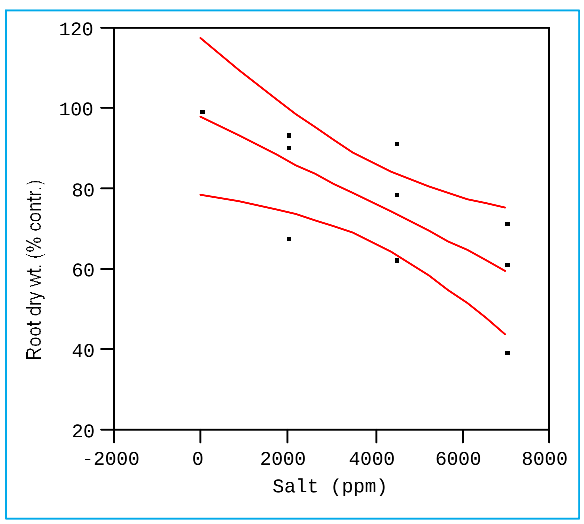
Figure 3. Linear regression of dry weight of stem plus root (% control) on NaCl concentration (ppm) for *Platanus occidentatis* and *Pinus strobus*, 95% confidence intervals and data points (data from Townsend 1980). EC_{25} value of 2240.



Stem, root dry wt. (% control) = 88.2462 – 0.00592 Salt (ppm)
R^2=0.637

75=88.2462-0.00592x x=2240 (3 sig. digits)

Figure 4. Linear regression of root dry wt. (% control) on NaCl concentration (ppm) for *Pinus strobus, Cornus florida* and *Platanus occidentalis*, 95% confidence intervals and data points (data from Townsend 1980). EC_{25} value of 4250.

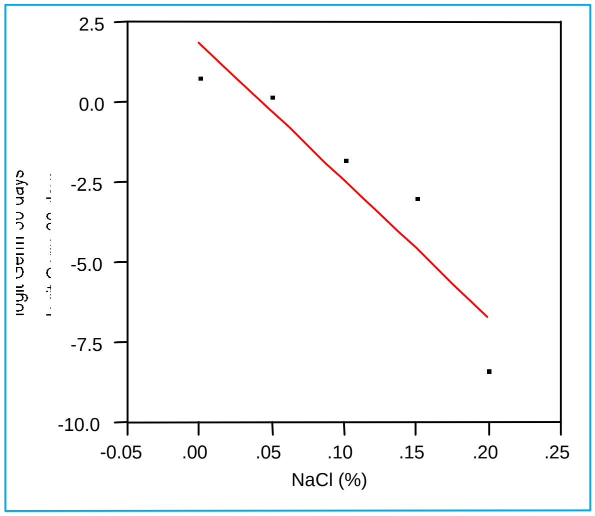


Root dry wt. (% contr.) = 98.2705 – 0.00547 Salt (ppm)
R^2=0.533

75=98.2705 – 0.00547x x=4250 (3 sig. digits)

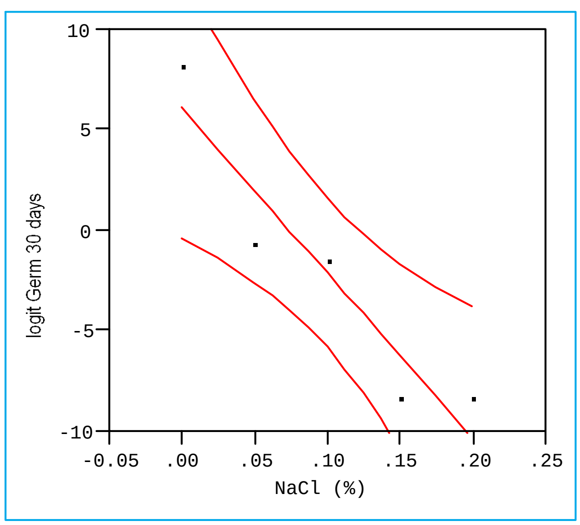
DECIDUOUS SPECIES

Figure 5. Linear regression of logit of germination (% control) at 30 days on NaCl soil concentration (ppm) for *Betula alleghaniensis* and data points (data from Bicknell and Smith 1975). EC_{25} value of 700.



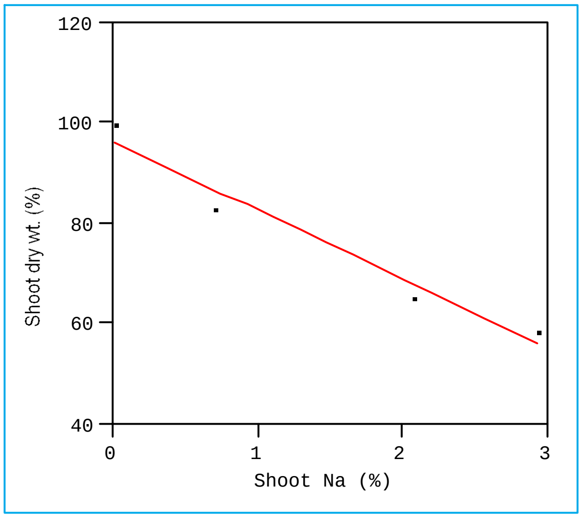
Logit of germination = 1.90054 – 42.8451 NaCl (%)
R^2=0.870

Figure 6. Linear regression of logit of germination (% control) at 30 days on NaCl soil concentration (ppm) for *Catalpa bignoides,* 95% confidence intervals and data points (data from Bicknell and Smith 1975). EC_{25} value of 882.



Logit of germination = 6.11088 – 81.7056 NaCl (%)
R^2=0.890

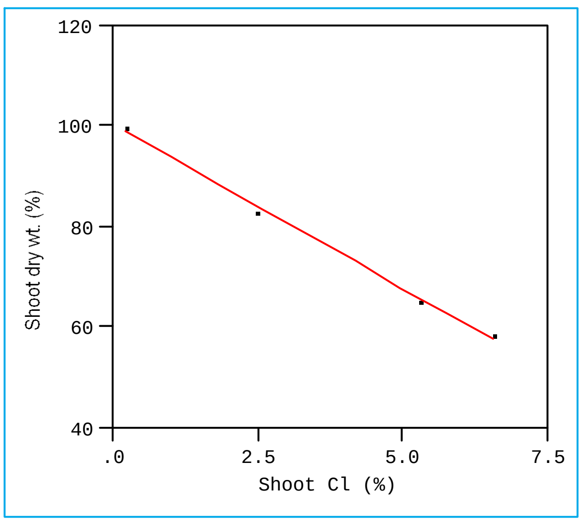
Figure 7. Linear regression of shoot dry weight (% control) on shoot Na concentration (ppm) for *Gledistsia triancanthos* var.*inermis* and data points (data from Dirr1974). EC_{25} value of 15,700 ppm.



Shoot dry wt. (% contr.) = 96.6978 – 13.821 Shoot Na (%)
R^2=0.960

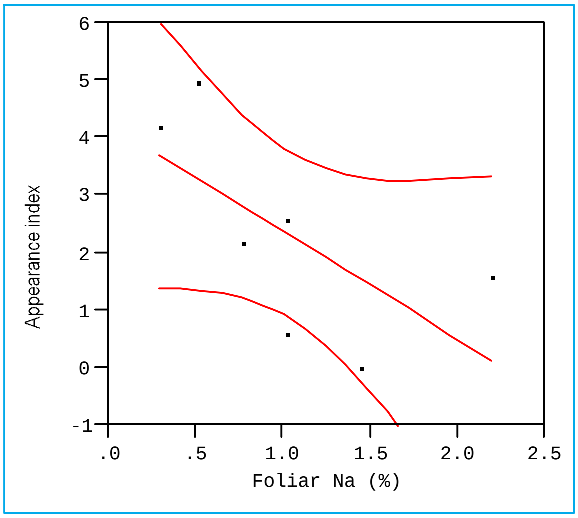
75=96.6978 – 13.821x x=15,700 ppm (3 sig. digits)

Figure 8. Linear regression of shoot dry weight (% control) on shoot Cl concentration (ppm) for *Gledistsia triancanthos* var.*inermis* and data points (data from Dirr 1974). EC_{25} value of 39,400 ppm.



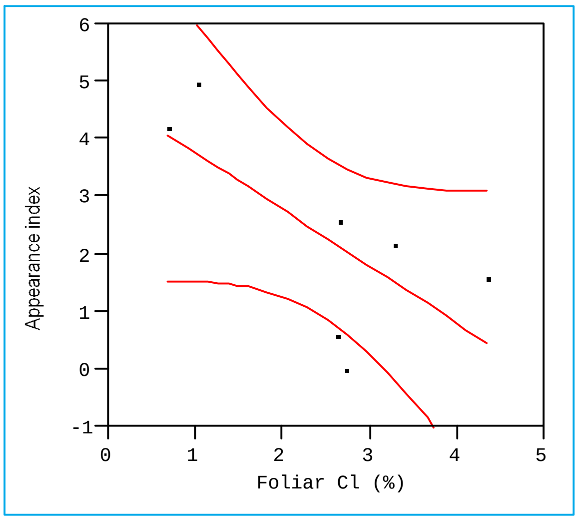
Shoot dry wt. (% contr.) = 100.717 – 6.52853 Shoot Cl (%)
R^2=0.996
75=100.717 – 6.52853x x=39,400 ppm (3 sig. digits)

Figure 9. Linear regression of appearance index on foliar Na concentration (ppm) for woody deciduous species, 95% confidence intervals and data points (data from Dirr1978). EC_{25} value of 16,100 ppm.



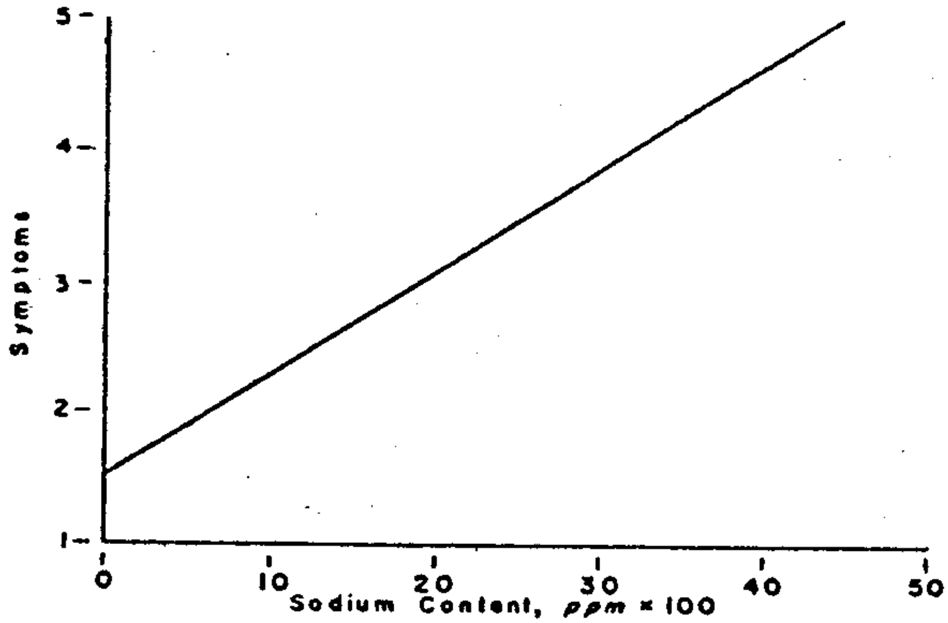
Appearance index = 4.27459 – 1.88232 Foliar Na (%)
R^2=0.433

Figure 10. Linear regression of appearance index on foliar Cl concentration (ppm) for woody deciduous species, 95% confidence intervals and data points (data from Dirr1978). EC_{25} value of 35,700 ppm.



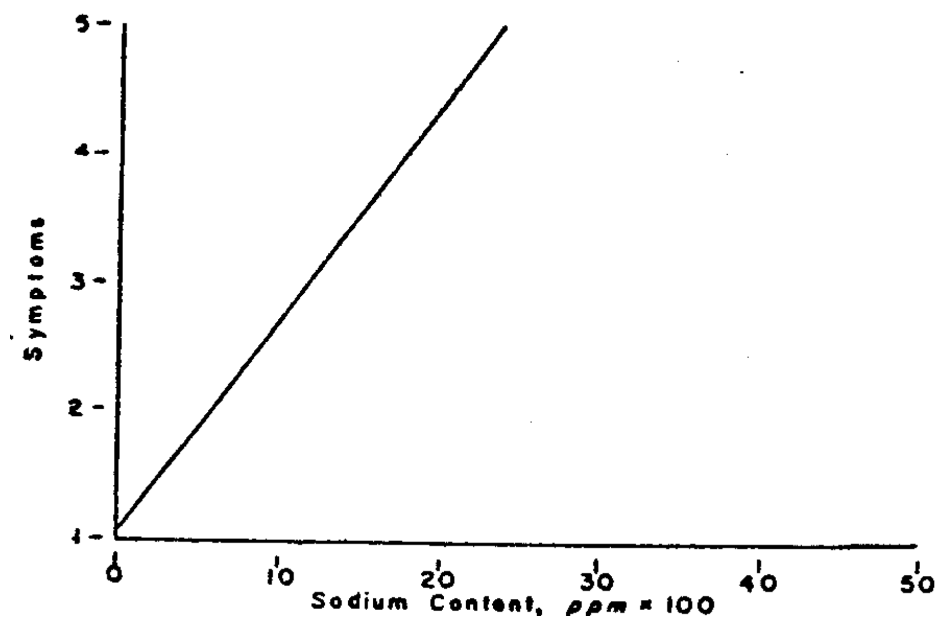
Appearance index = 4.77424 – 0.99078 Foliar Cl (%)
R^2=0.474

Figure 11. Linear regression of salt injury symptom rating on foliar Na concentration (ppm X 100) for woody deciduous species (figure from Lacasse and Rich 1964). EC_{25} value of 631 ppm.



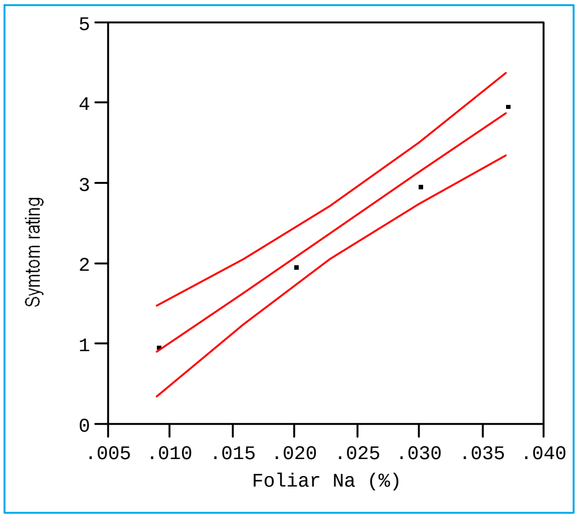
Injury symptom rating = 1.4950 + 0.0008 Foliar Na (ppm X 100)
R^2=0.4

Figure 12. Linear regression of salt injury symptom rating on twig Na concentration (ppm X 100) for woody deciduous species (figure from Lacasse and Rich 1964). EC_{25} value of 575 ppm.



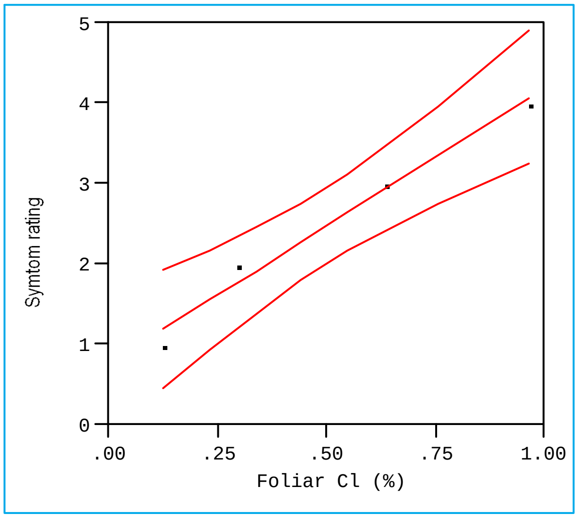
Injury symptom rating = 1.0227 + 0.0017 Twig Na (ppm X 100)
R^2=0.42

Figure 13. Linear regression of salt injury symptom rating on foliar Na concentration (%) for *Acer saccharinum*, 95% confidence intervals and data points (data from Hanes *et al.* 1976). EC_{25} value of 2,380 ppm.



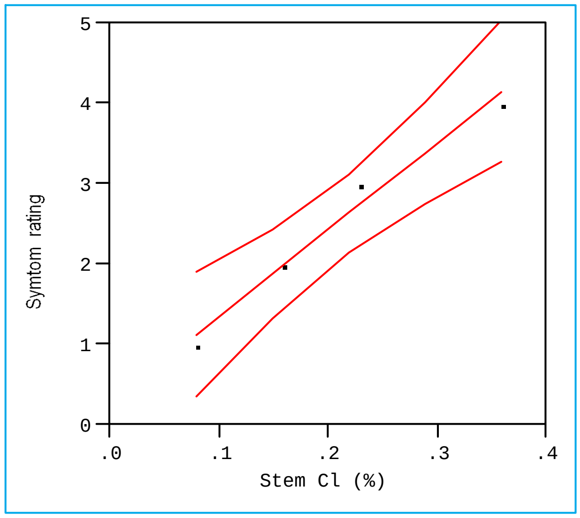
Injury symptom rating = -0.0291 + 105.381 Foliar Na (%)
R^2=0.991

Figure 14. Linear regression of salt injury symptom rating on foliar Cl concentration (%) for *Acer saccharinum*, 95% confidence intervals and data points (data from Hanes *et al.* 1976). EC_{25} value of 70,700 ppm.



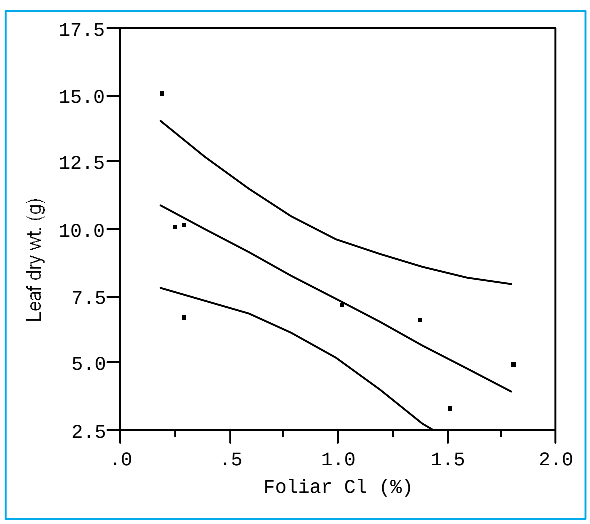
Injury symptom rating = 0.75108 + 3.42926 Foliar Cl (%)
R^2=0.981

Figure 15. Linear regression of salt injury symptom rating on stem Cl concentration (%) for *Acer saccharinum*, 95% confidence intervals and data points (data from Hanes *et al.* 1976). EC_{25} value of 22,980 ppm.



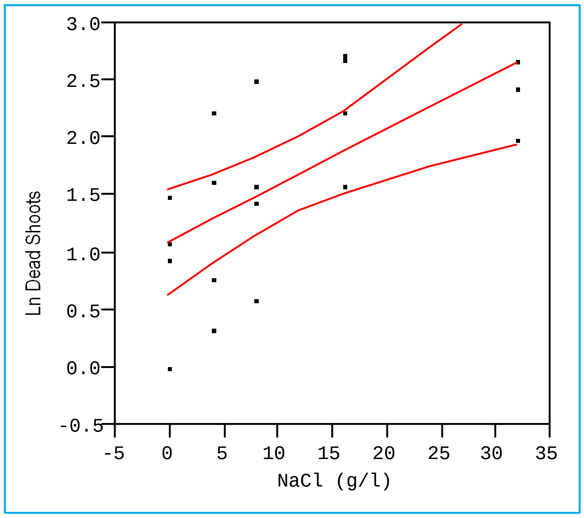
Injury symptom rating = 0.26671 + 10.7629 Stem Cl (%)
R^2=0.979

Figure 16. Linear regression of salt injury symptom rating on stem Cl concentration (%) for *Acer saccharinum* and *Acer platanoides*, 95% confidence intervals and data points (data from Simini and Leone 1986). EC_{25} value of 6,950 ppm.



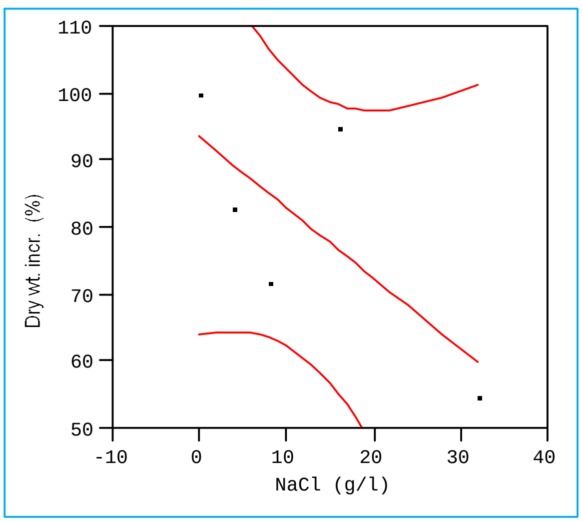
Leaf dry wt. (g) = 11.7633 – 4.33777 Foliar Cl (%)
R^2=0.605

Figure 17. Linear regression ln dead shoot number on NaCl soil solution concentration (g/l) for deciduous shrubs, 95% confidence intervals and data points (data from Thompson and Rutter 1986, including *Cornus sanguinea, Crataegus monogyna, Salix viminalis* and *Viburnum lantana*). Outlier of *Cornus,* 32 g/l not included. EC_{25} value of 7,140 ppm.



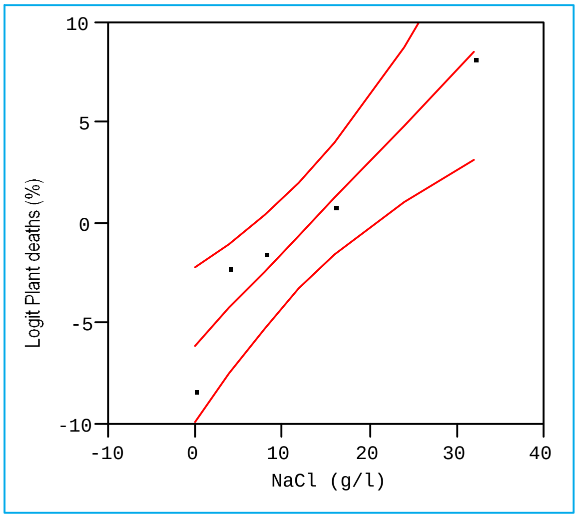
Ln Dead Shoots = 1.09703 + 0.04902 NaCl (g/l)
R^2=0.406

Figure 18. Linear regression of dry weight increase on NaCl soil solution concentration (g/l) for *Cornus sanguinea*, 95% confidence intervals and data points (data from Thompson and Rutter 1986). EC_{25} value of 25,000 ppm.



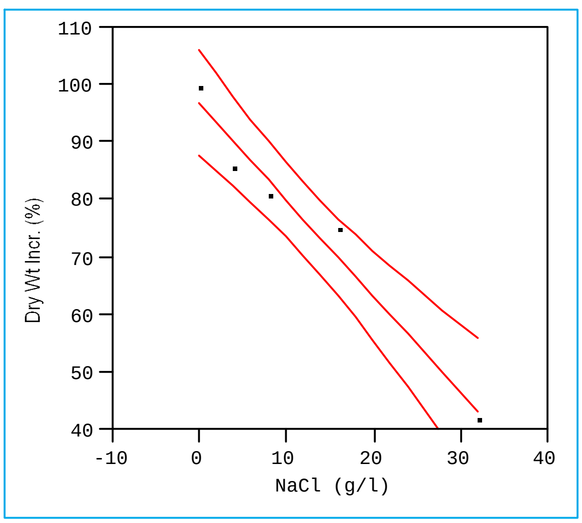
Dry wt. increase (%) = 93.6 – 1.05 NaCl (g/l)
R^2=0.535

Figure 19. Linear regression of logit of plant death (%) on NaCl soil solution concentration (g/l) for *Crataegus monogyna*, 95% confidence intervals and data points (data from Thompson and Rutter 1986). EC_{25} value of 10,800 ppm.



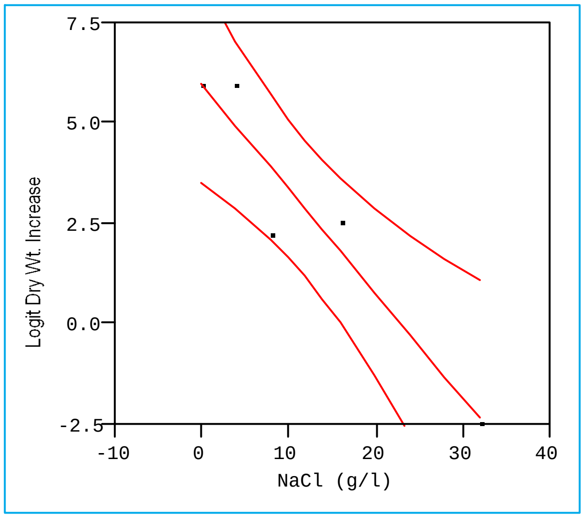
Logit plant deaths (%) = -6.02 + 0.4561 NaCl (g/l)
R^2=0.927

Figure 20. Linear regression of dry weight increase (% of control) on NaCl soil solution concentration (g/l) for *Rosa rubiginosa*, 95% confidence intervals and data points (data from Thompson and Rutter 1986). EC_{25} value of 13,100 ppm.



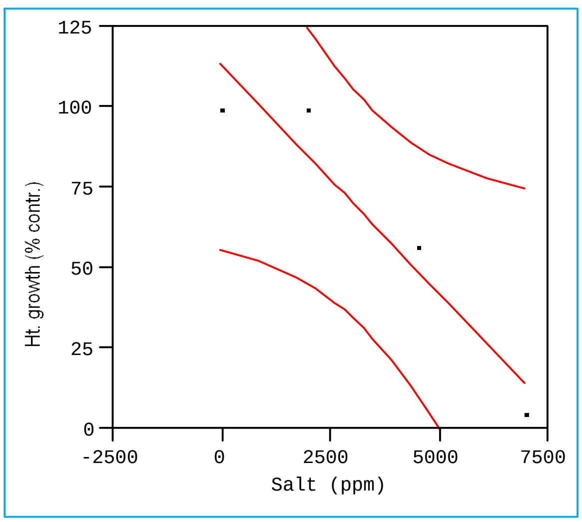
Dry Wt Incr. (%) = 96.9 – 1.675 NaCl (g/l)
R^2=0.968

Figure 21. Linear regression of dry weight increase (% of control) on NaCl soil solution concentration (g/l) for *Viburnum lantana*, 95% confidence intervals and data points (data from Thompson and Rutter 1986). EC_{25} value of 18,900 ppm.



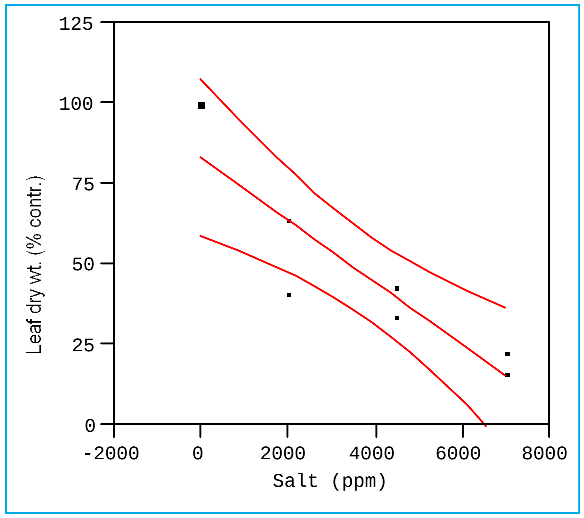
Logit dry weight increase = 6.01658 – 0.2611 NaCl (g/l)
R^2=0.911

Figure 22. Linear regression of seedling height growth (% of control) on NaCl growth solution concentration (g/l) for *Cornus florida*, 95% confidence intervals and data points (data from Townsend 1980). EC_{25} value of 2,700 ppm.



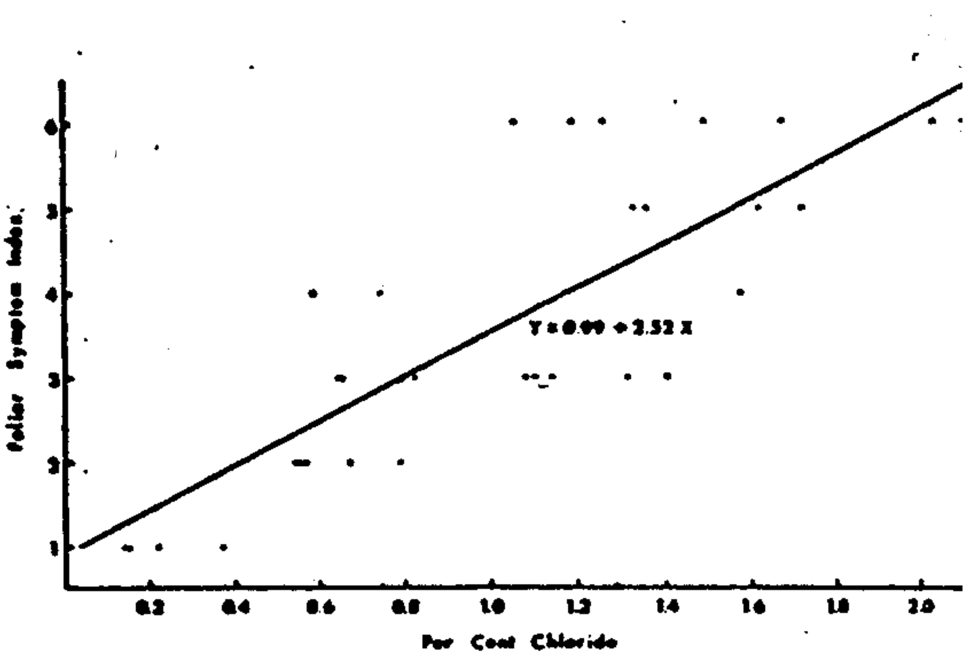
Height growth (% control) = 113.375 – 0.01419 Salt (ppm)
R^2=0.911

Figure 23. Linear regression of leaf dry weight (% of control) on NaCl growth solution concentration (g/l) for *Cornus florida* and *Platanus occidentalis*, 95% confidence intervals and data points (data from Townsend 1980). EC_{25} value of 836 ppm.



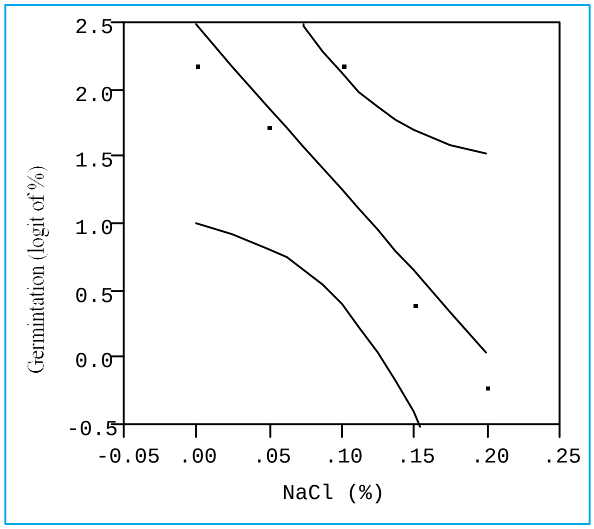
Leaf dry wt. (% contr.) = 83.0691 – 0.00965 Salt (ppm)
R^2=0.813

Figure 24. Linear regression of foliar symptom index on foliar Cl concentration (%) for *Acer platanoides* and data points following spring application of NaCl or $CaCl_2$ (figure from Walton 1969). EC_{25} value of 5000 ppm.



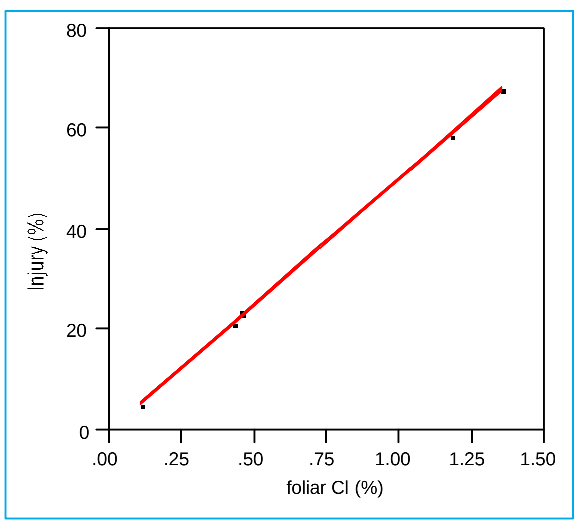
Foliar symptom index = 0.99 + 2.52 Cl conc. (%)

Figure 25. Linear regression of logit of germination (% control) at 3 days on NaCl soil concentration (ppm) for *Pinus rigida* and data points (data from Bicknell and Smith 1975). EC_{25} value of 2935 ppm.



Logit of germination = 2.49173 - 12.2497 NaCl (%)
$R^2 = 0.774$

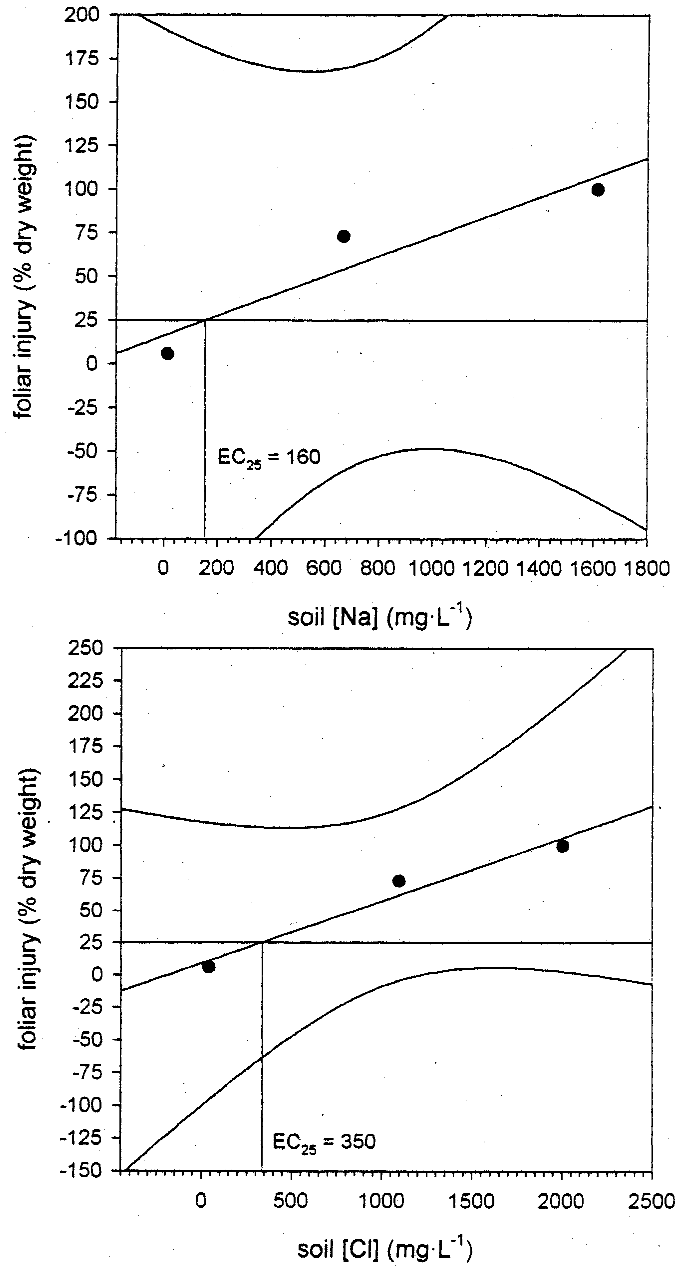
Figure 26. Linear regression of foliar injury on Cl concentration (%) for *Pinus strobus*, 95% confidence intervals and data points (data from Hall et al., 1972). EC_{25} value of 5005 ppm.



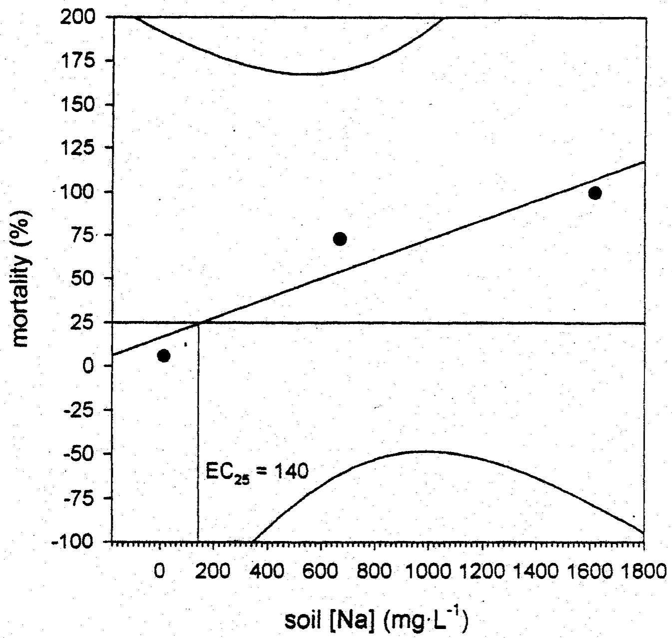
Logit of germination = 0.00603 + 49.935 Cl (%)
$R^2 = 0.99998$

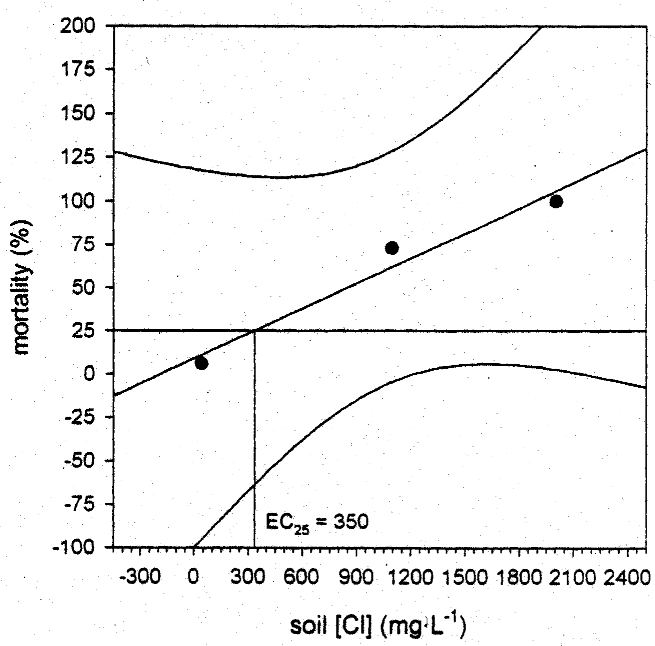
CONIFEROUS SPECIES

foliar injury- Ponderosa Pine
Bedunah and Trlica, 1979

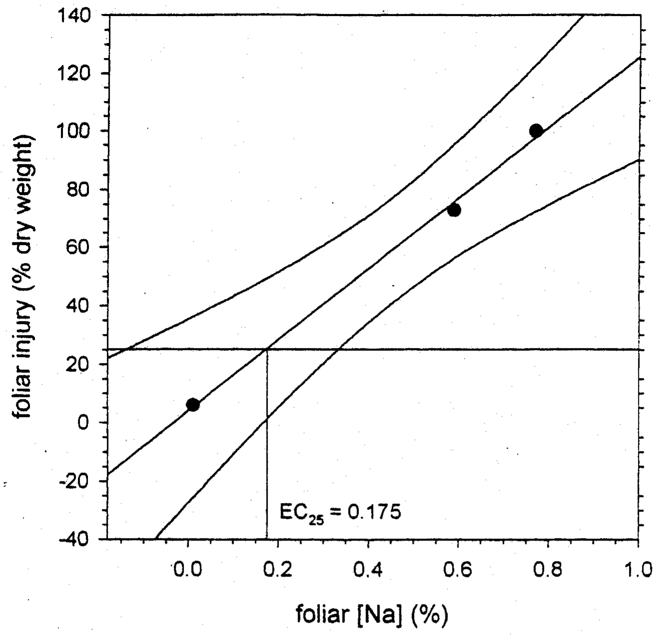


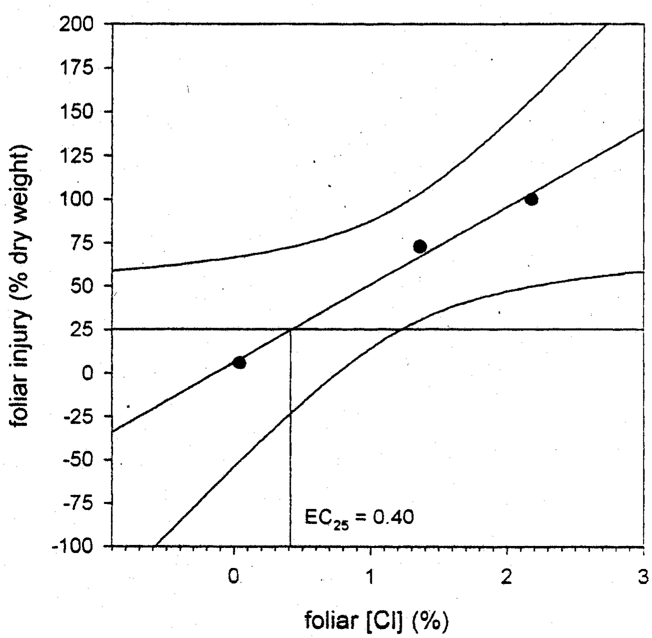
mortality - Ponderosa Pine
Bedunah and Trlica, 1979



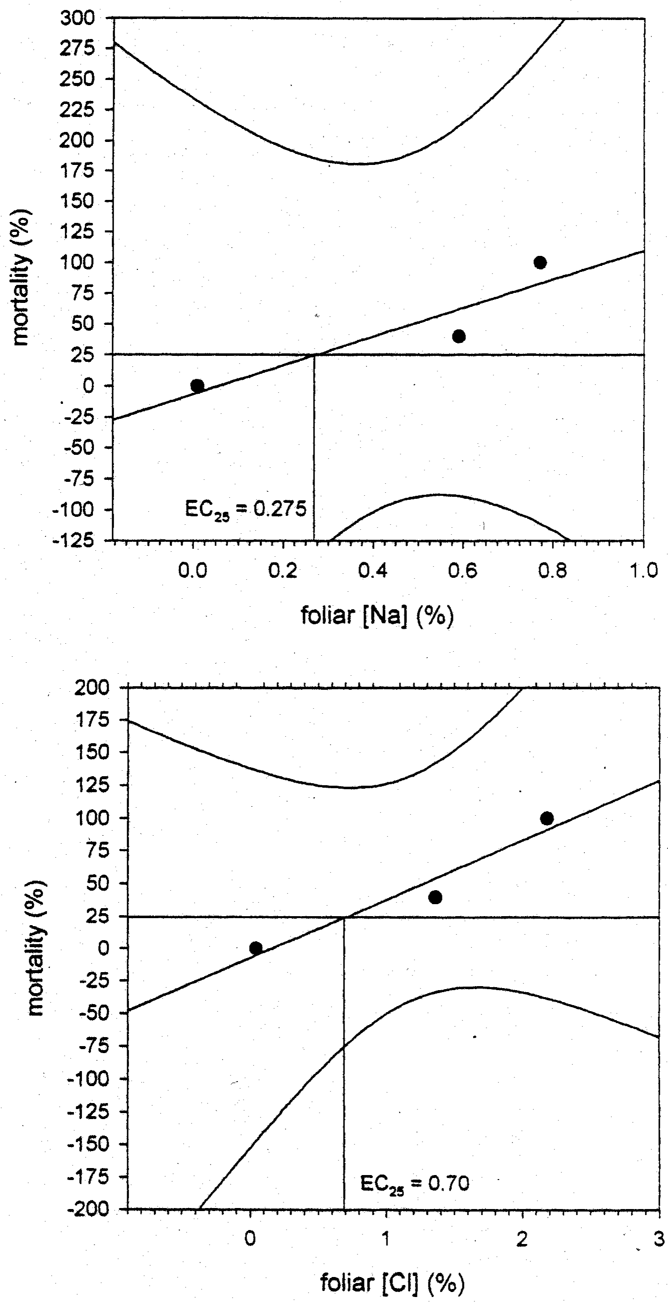


foliar injury- Ponderosa Pine
Bedunah and Trlica, 1979

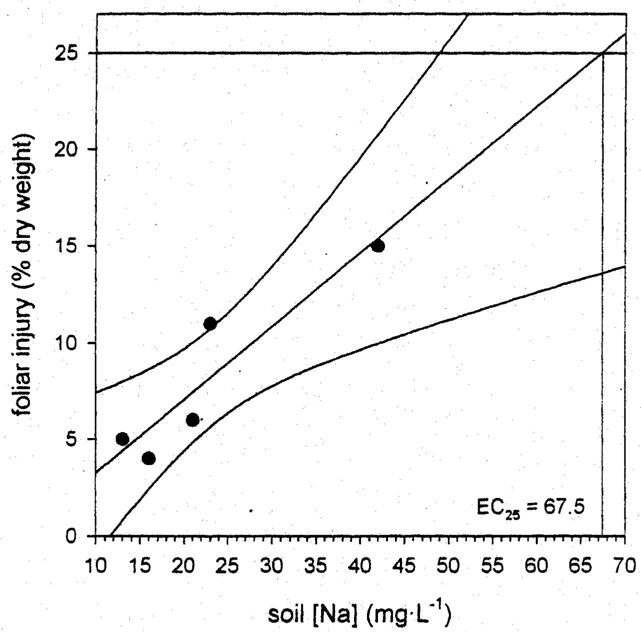


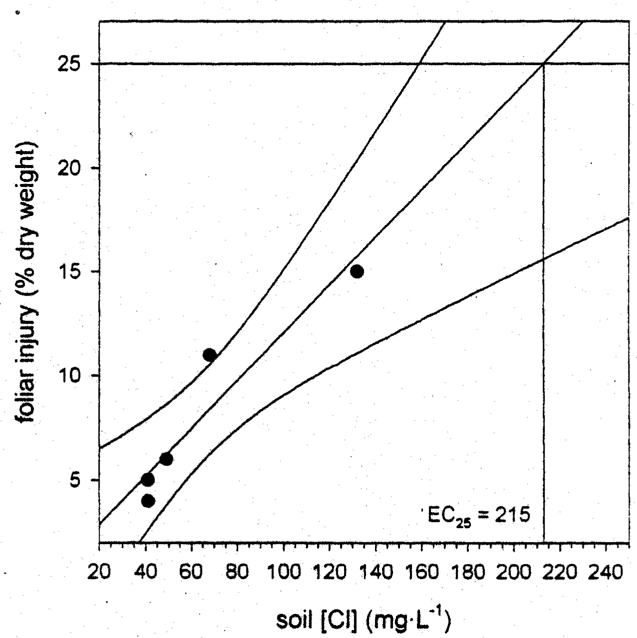


mortality- Ponderosa Pine
Bedunah and Trlica, 1979

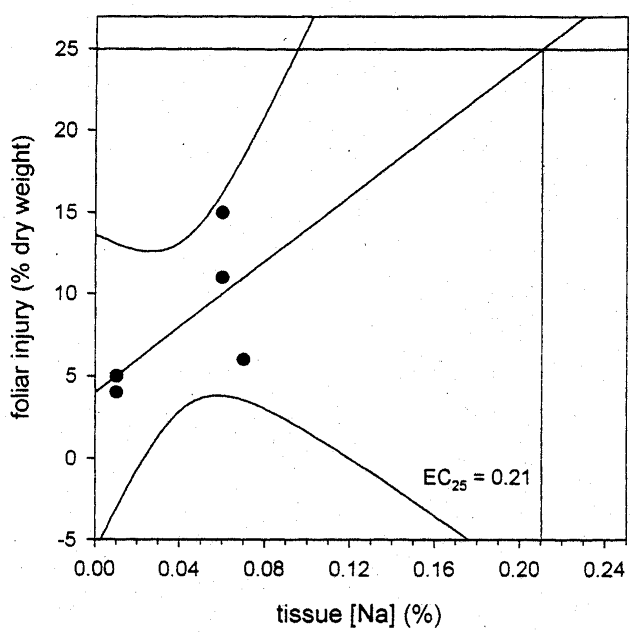


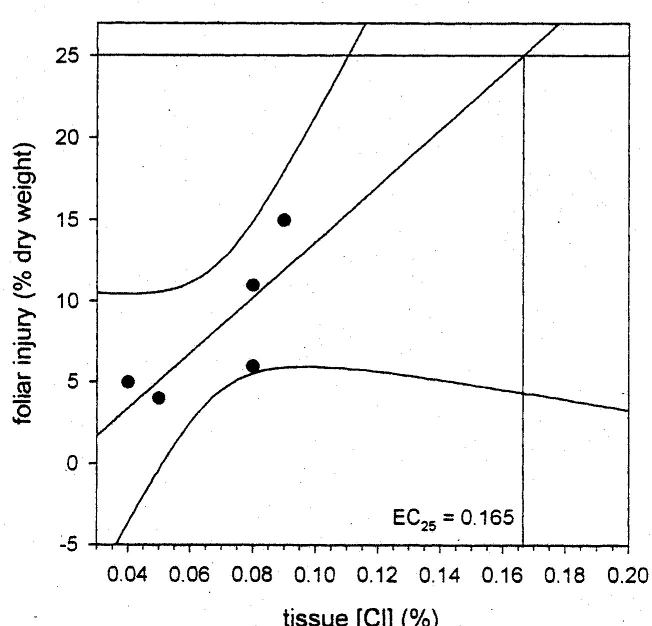
foliar injury- Ponderosa Pine
Bedunah and Trlica, 1979



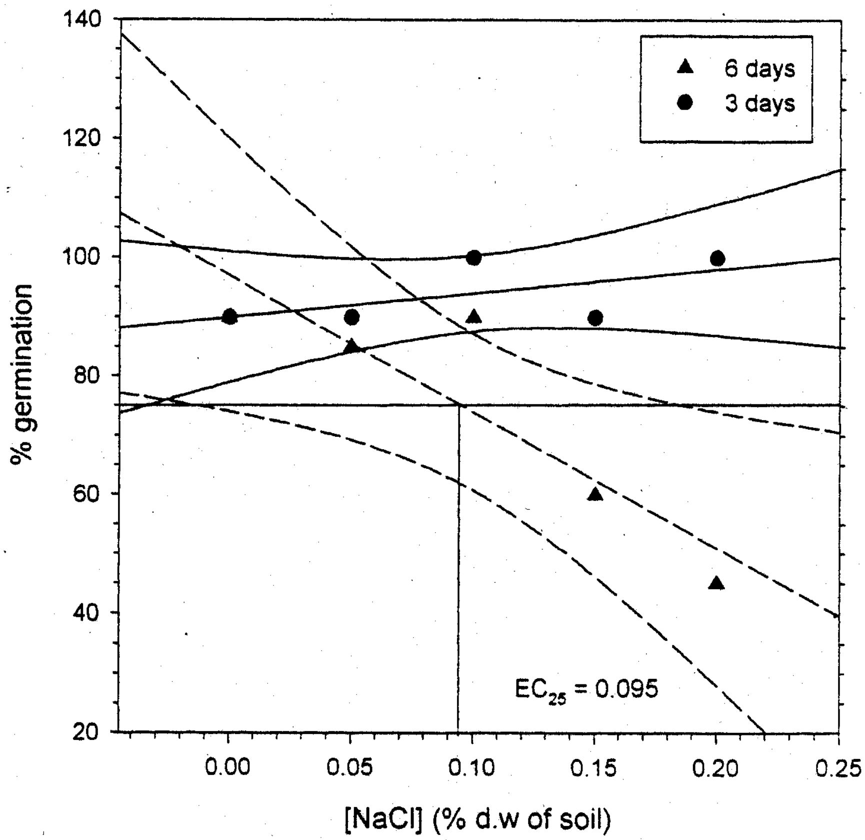


foliar injury - Ponderosa Pine
Bedunah and Trlica, 1979

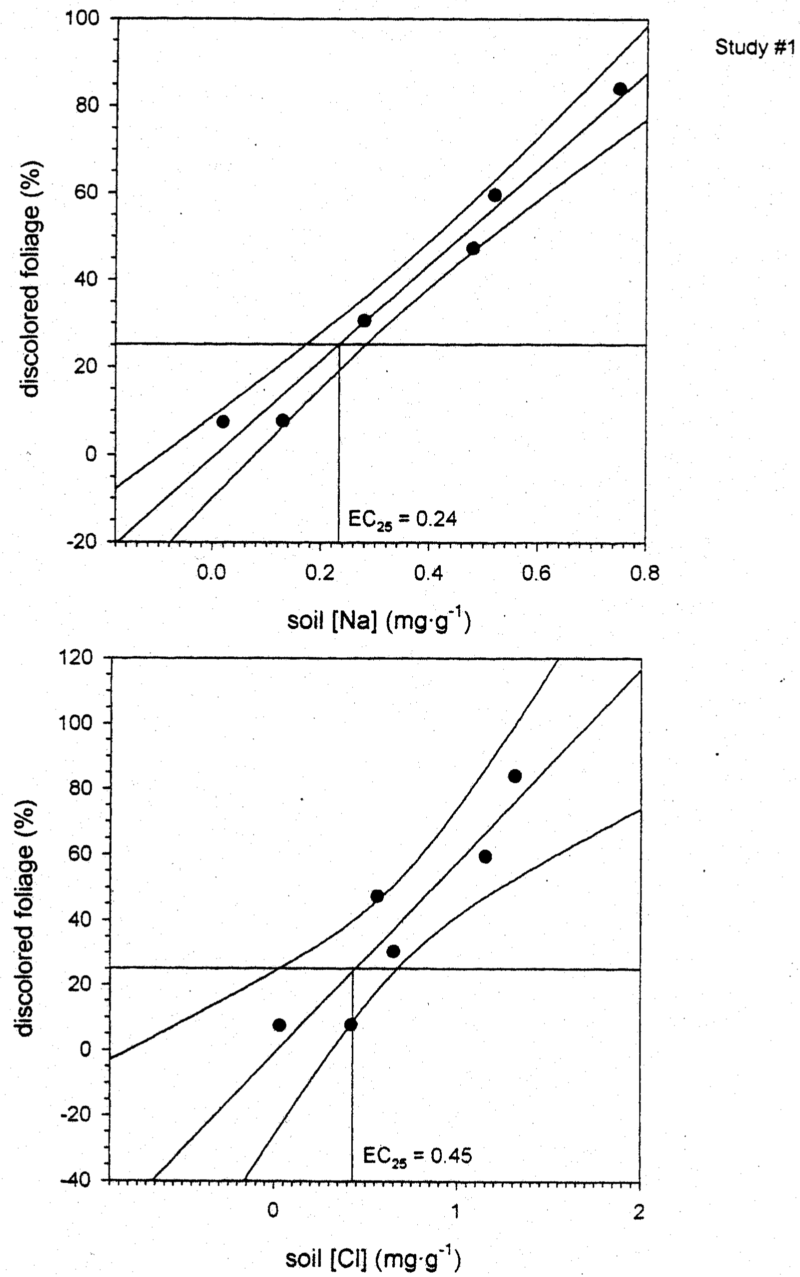




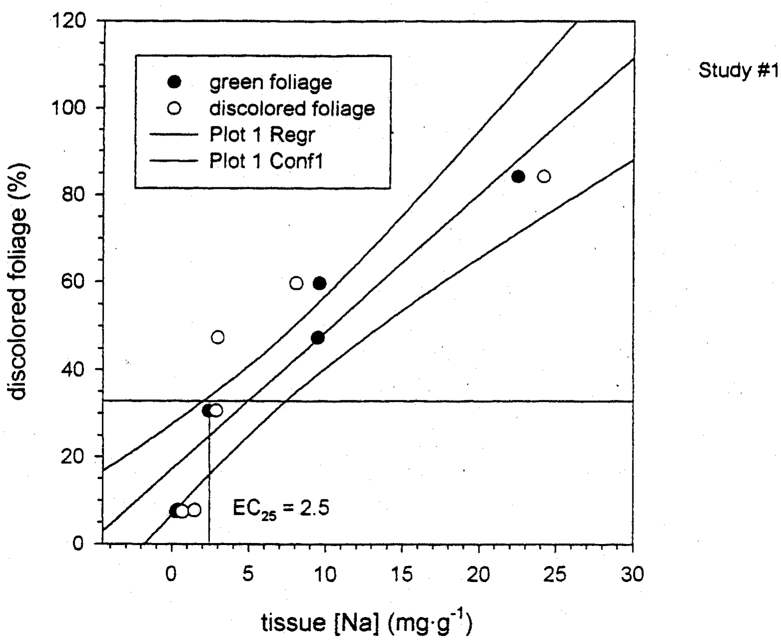
germination- *Pinus rigida*
Bicknell and Smith, 1975

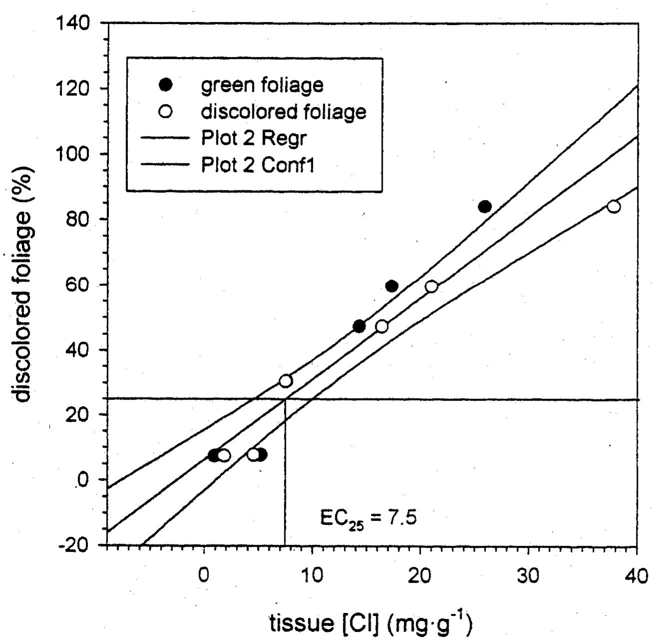


discolored foliage- *Thuja occidentalis* (Estern White Cedar)
Foster and Maun, 1977

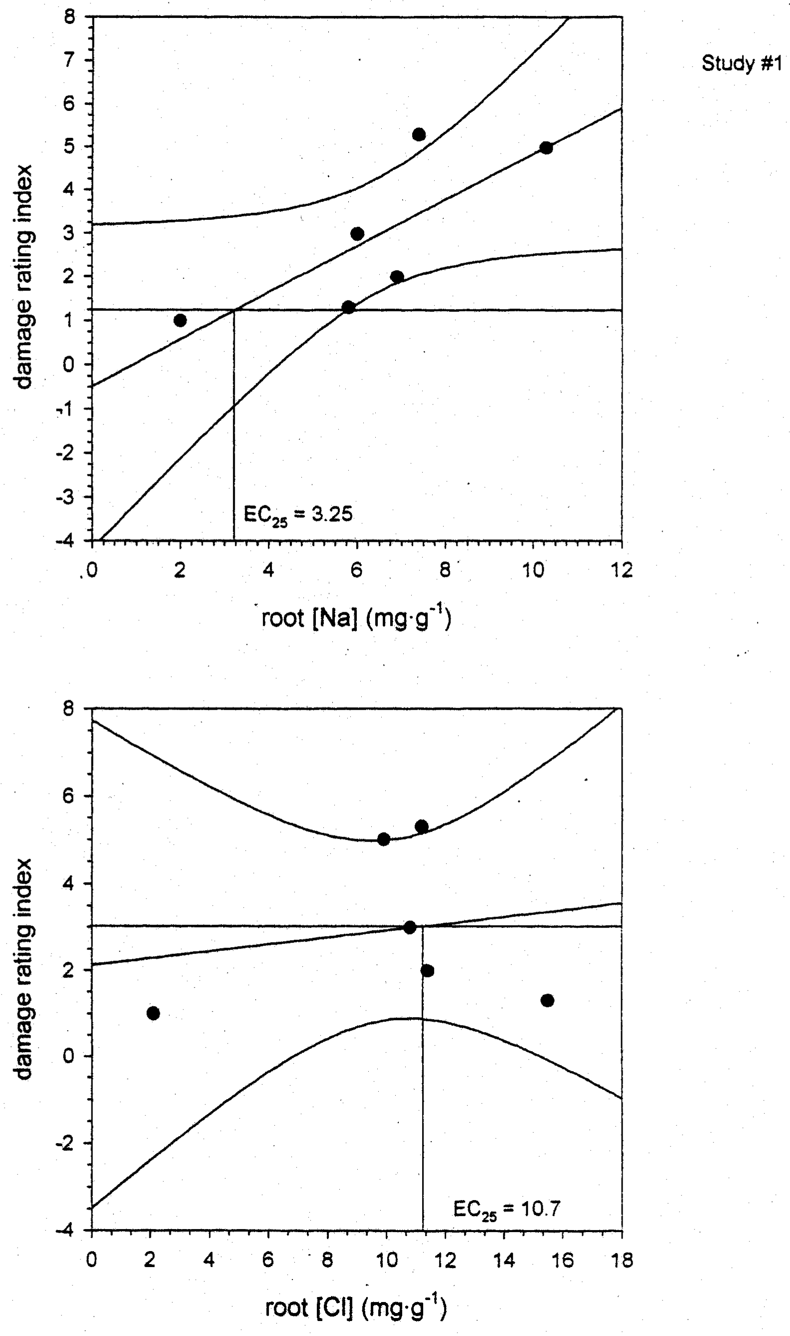


discolored foliage - *Thuja occidentalis* (Esatern White Cedar)
Foster and Maun, 1977

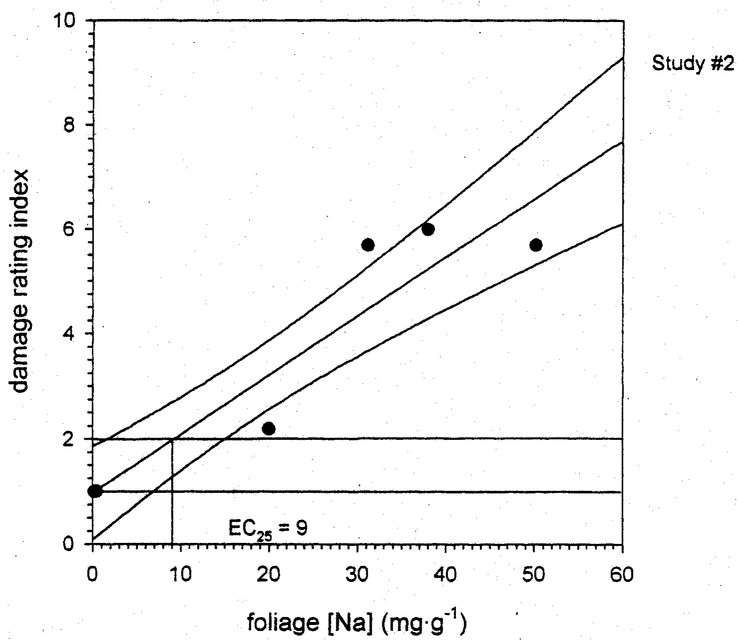


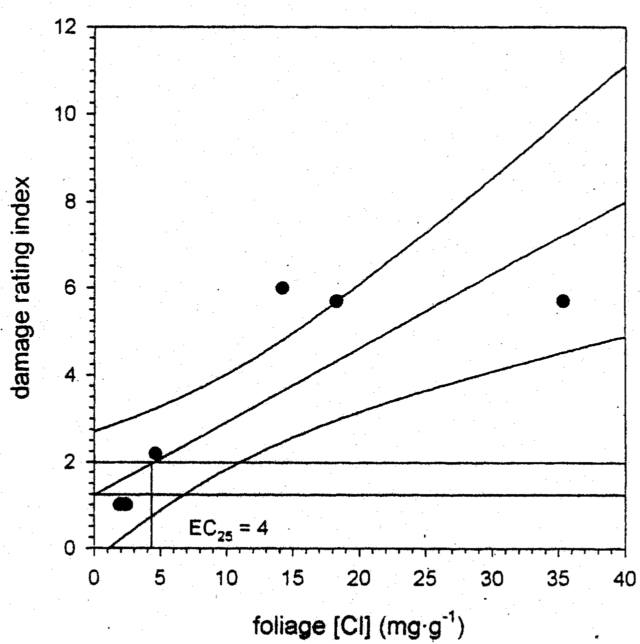


root damage rating index - *Thuja occidentalis* (Eastern White Cedar)
Foster and Maun, 1977

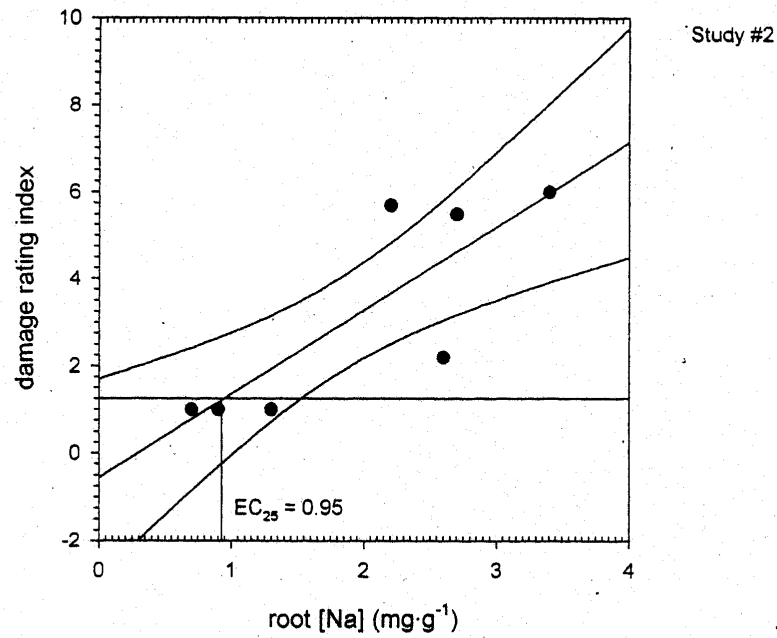


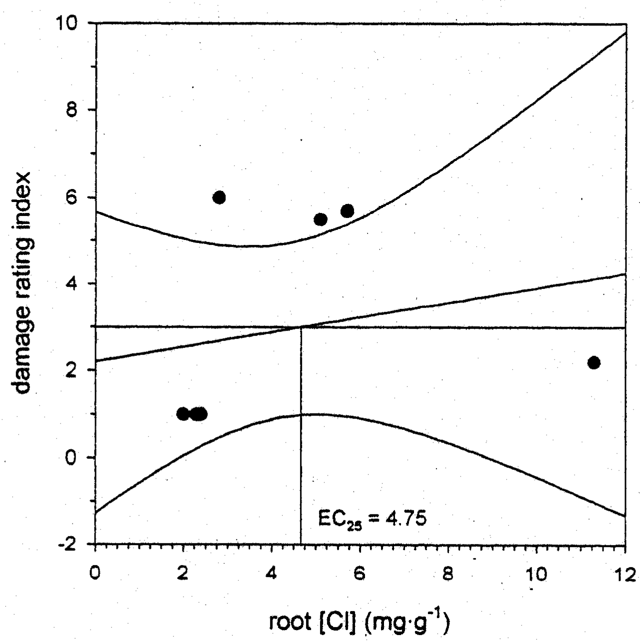
foliage damage rating index - *Thuja occidentalis* (Eastern White Cedar)
Foster and Maun, 1977





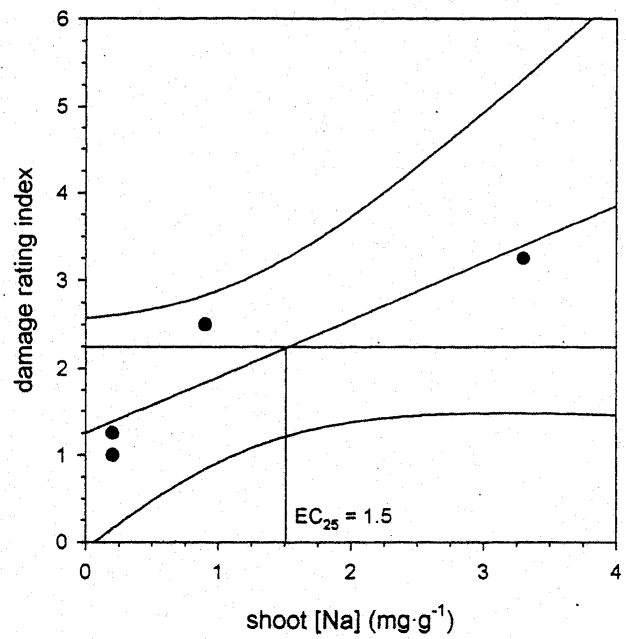
root damage rating index- *Thuja occidentalis* (Eastern White Cedar)
Foster and Maun, 1977

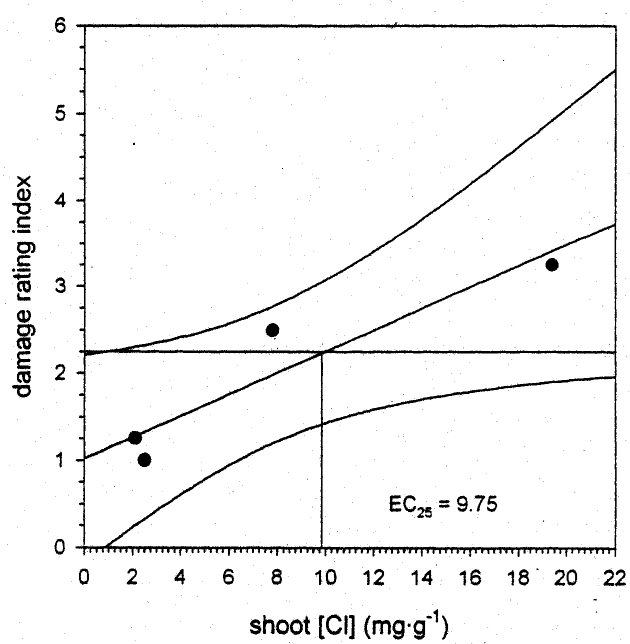




shoot damage rating index - *Thuja occidentalis* (Eastern white Cedar)
Foster and Maun, 1977

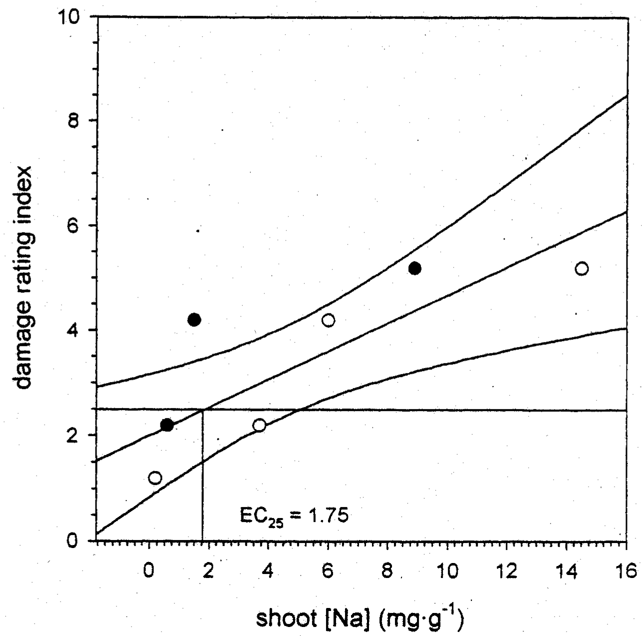
Study #3

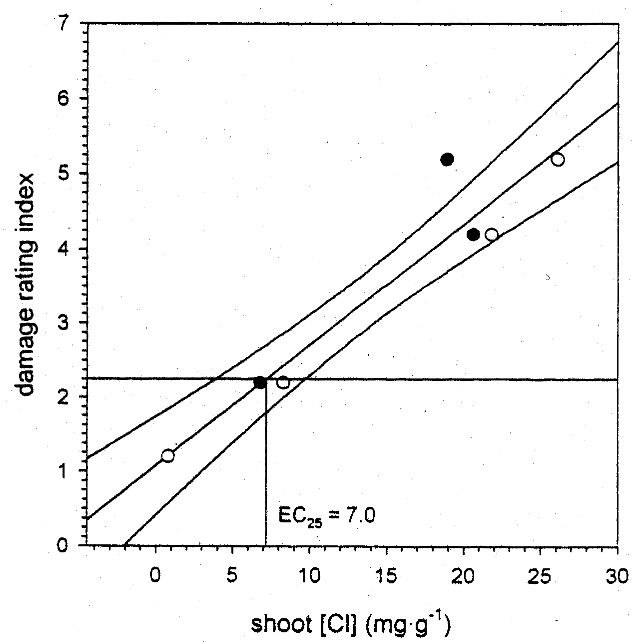




shoot damage rating index - *Thuja occidentalis* (Eastern White Cedar)
Foster and Maun, 1977

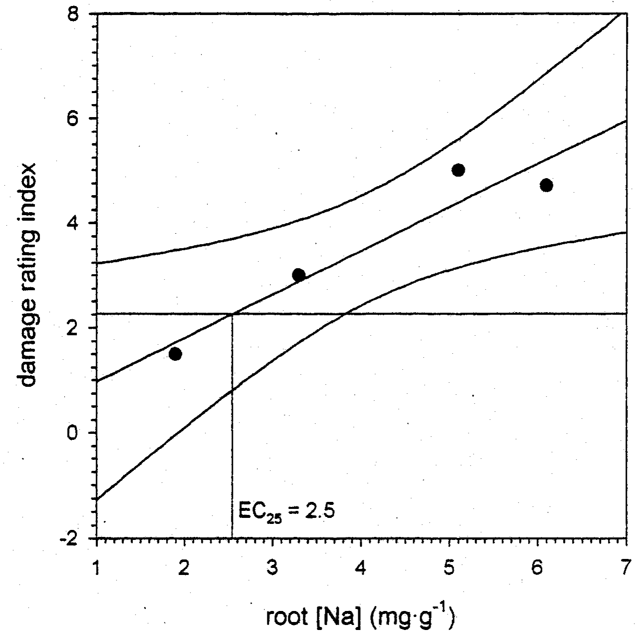
Study #4

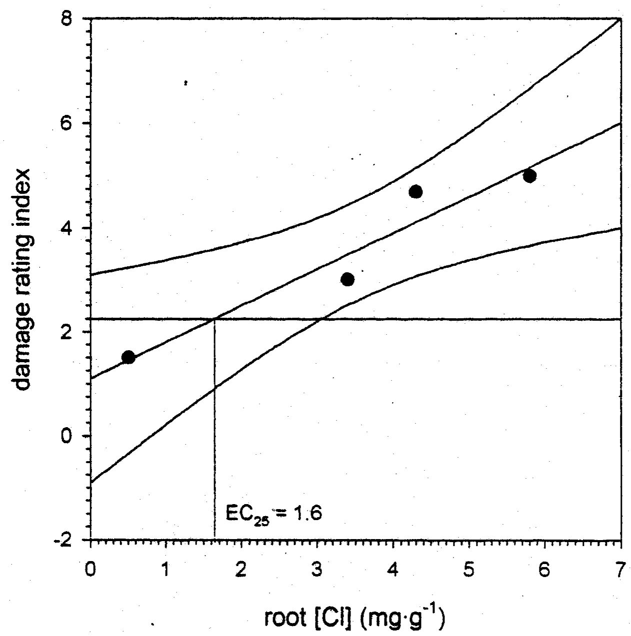




root damage rating index - *Thuja occidentalis* (Eastern White Cedar)
Foster and Maun, 1977

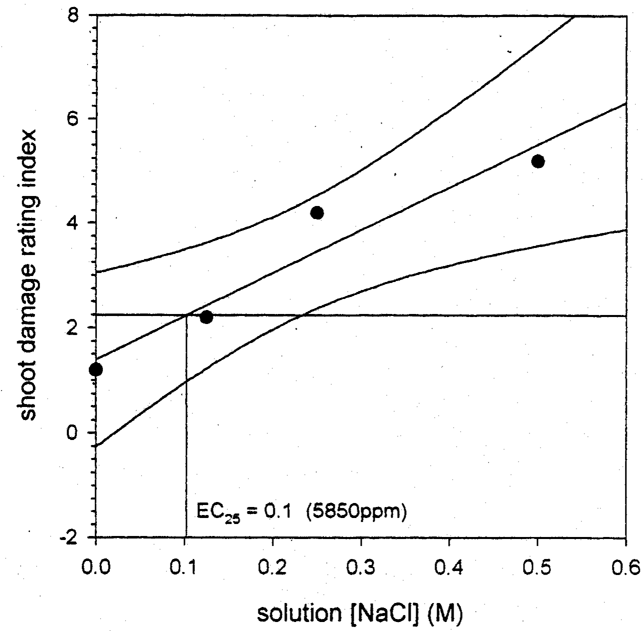
Study #4

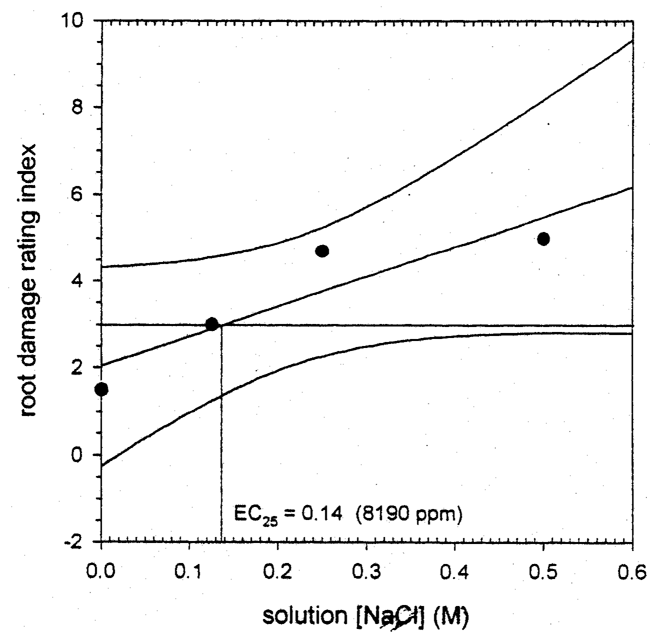




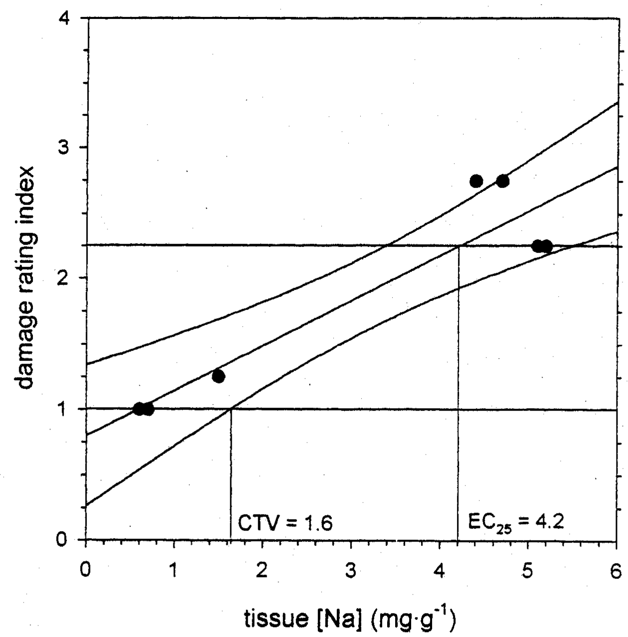
damage rating index - *Thuja occidentalis* (Eastern White Cedar)
Foster and Maun, 1977

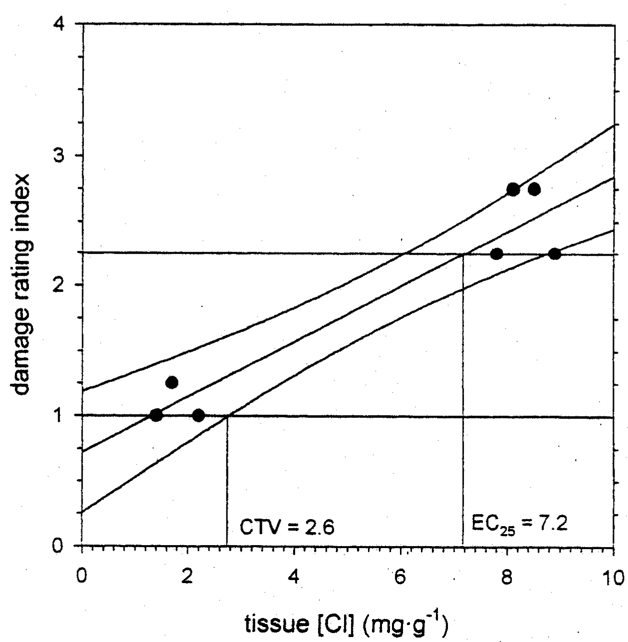
Study #4



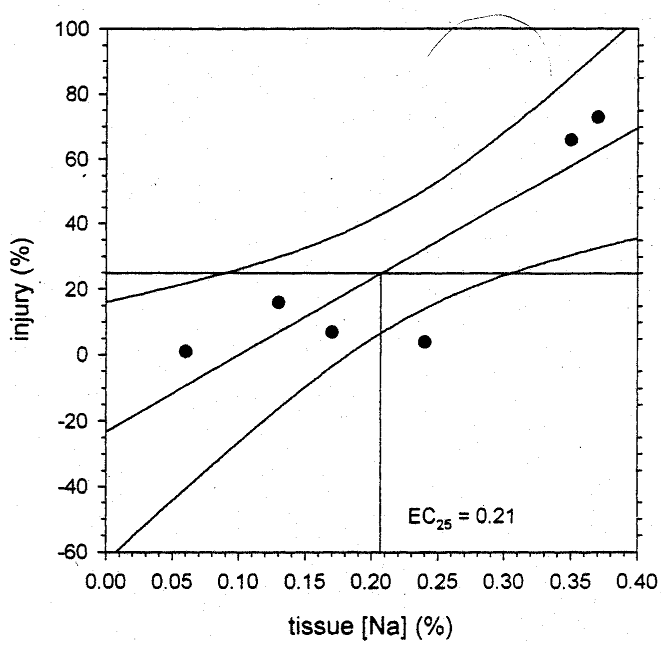


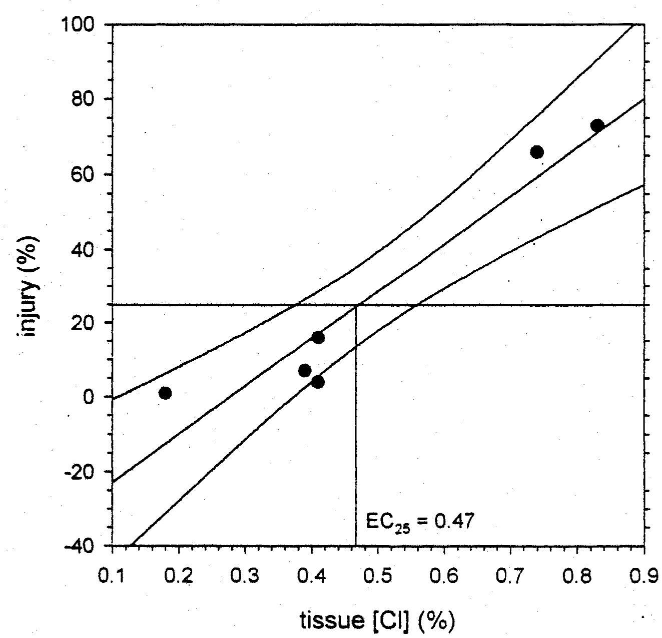
damage rating index- *Thuja occidentalis* (White Cedar)
Foster and Maun, 1980



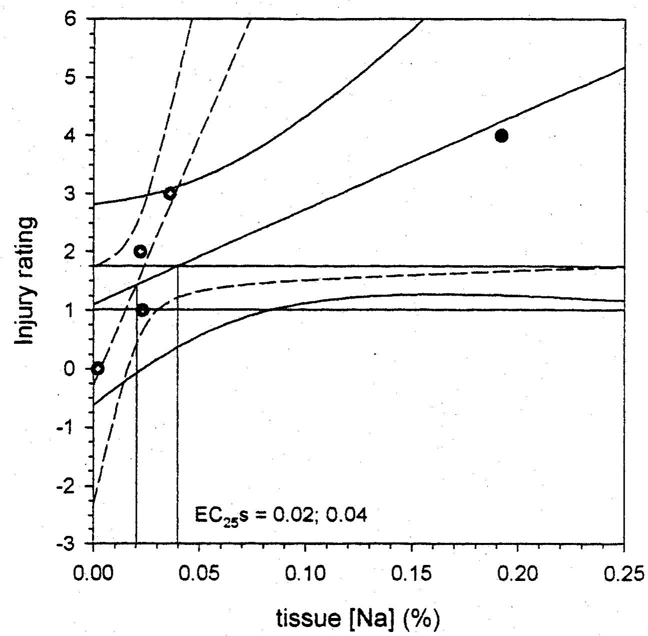


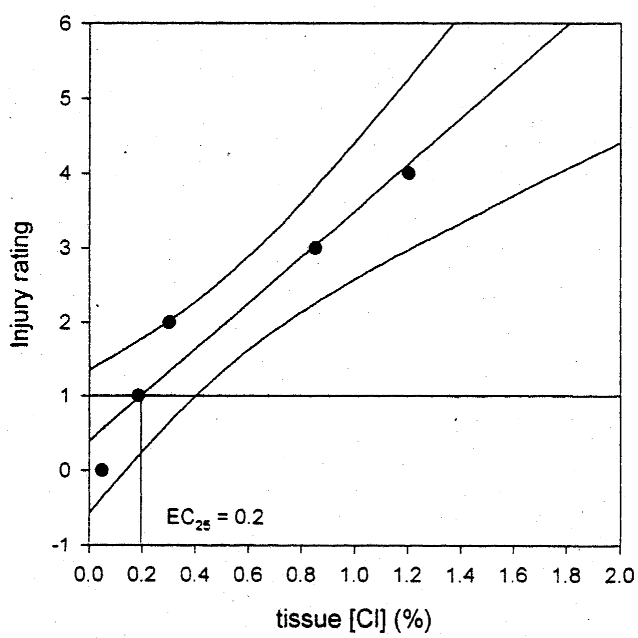
% injury - *Thuja occidentalis* (White Cedar)
Hofstra and Hall, 1971



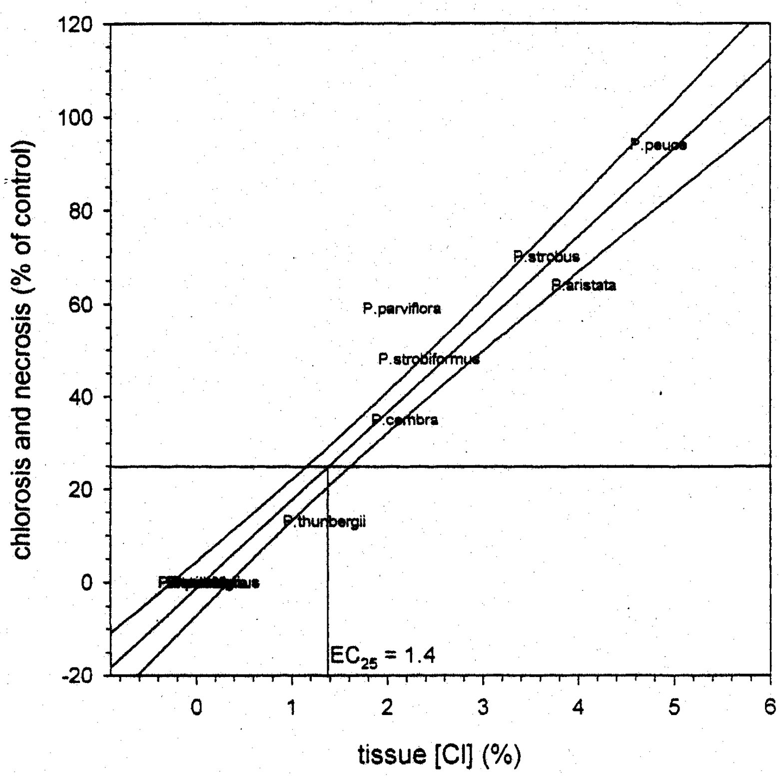


Injury rating- White Fir
Scharpf and Srago, 1974

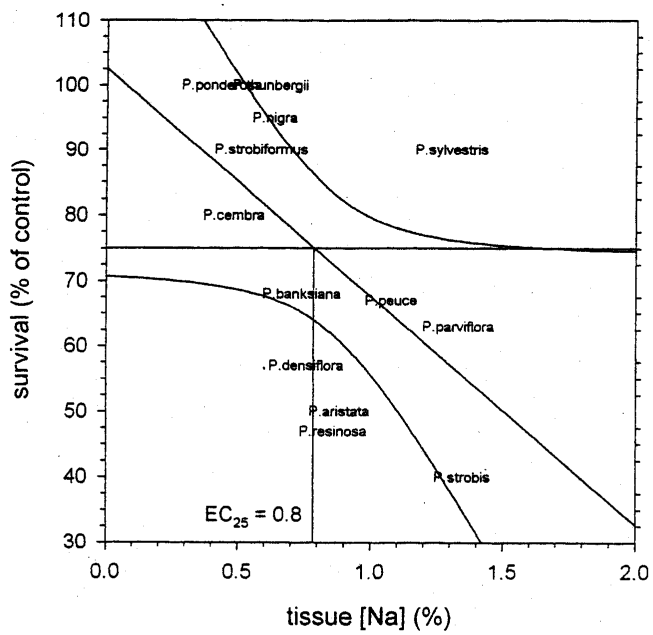


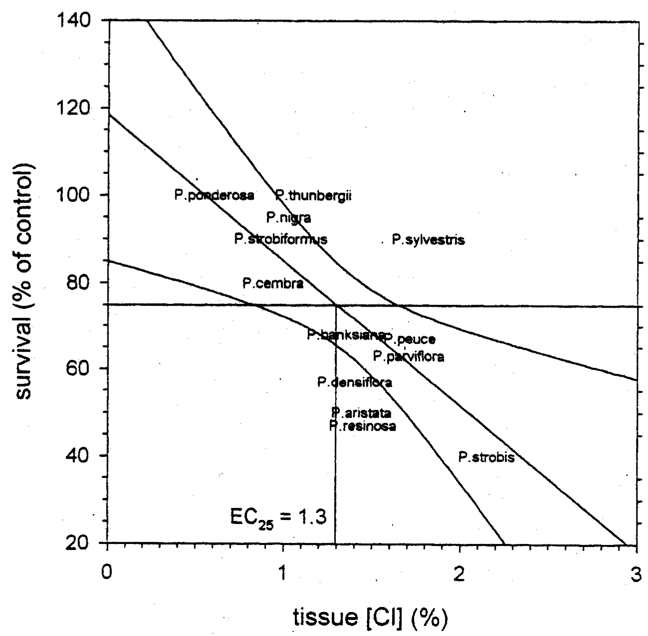


chlorosis and necrosis- *Pinus spp*. (multiple Pine species)
Townsend, 1983

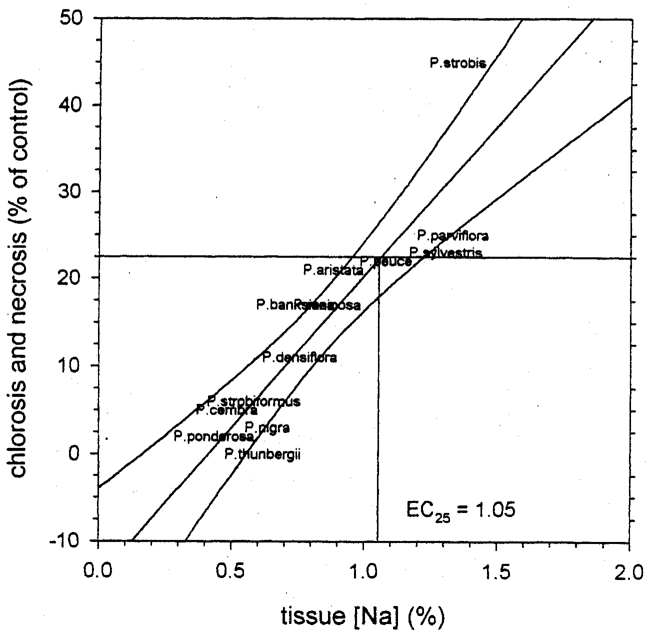


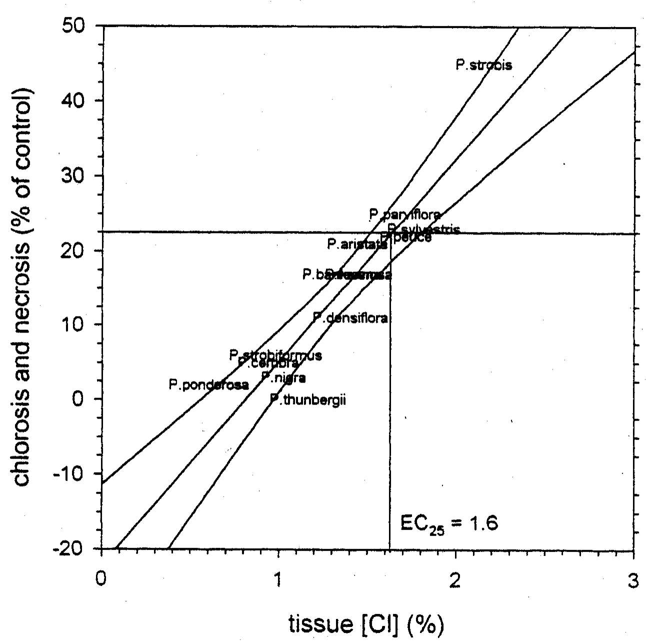
survival- *Pinus spp.* (multiple pine species)
Townsend and Kwolek, 1987



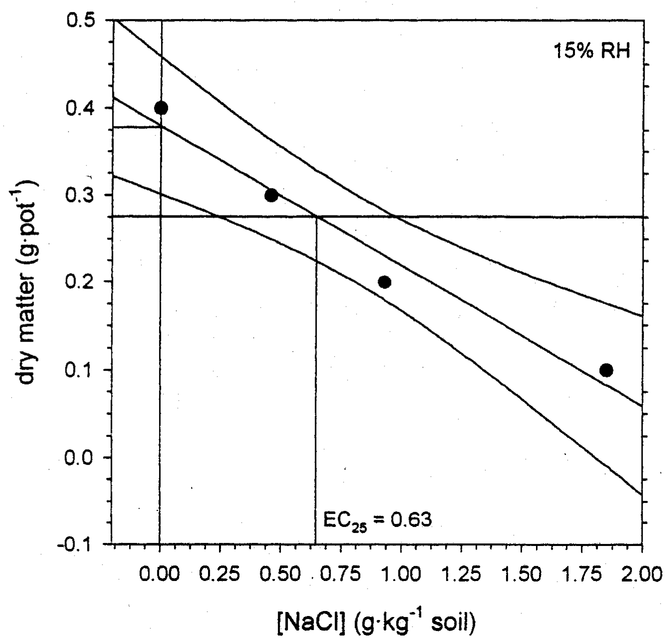


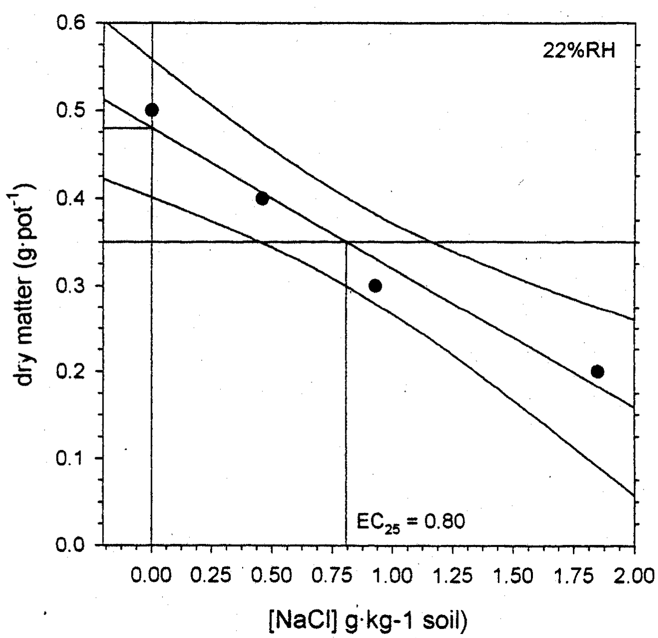
chlorosis and necrosis- *Pinus spp.* (multiple pine species)
Townsend and Kwolek, 1987



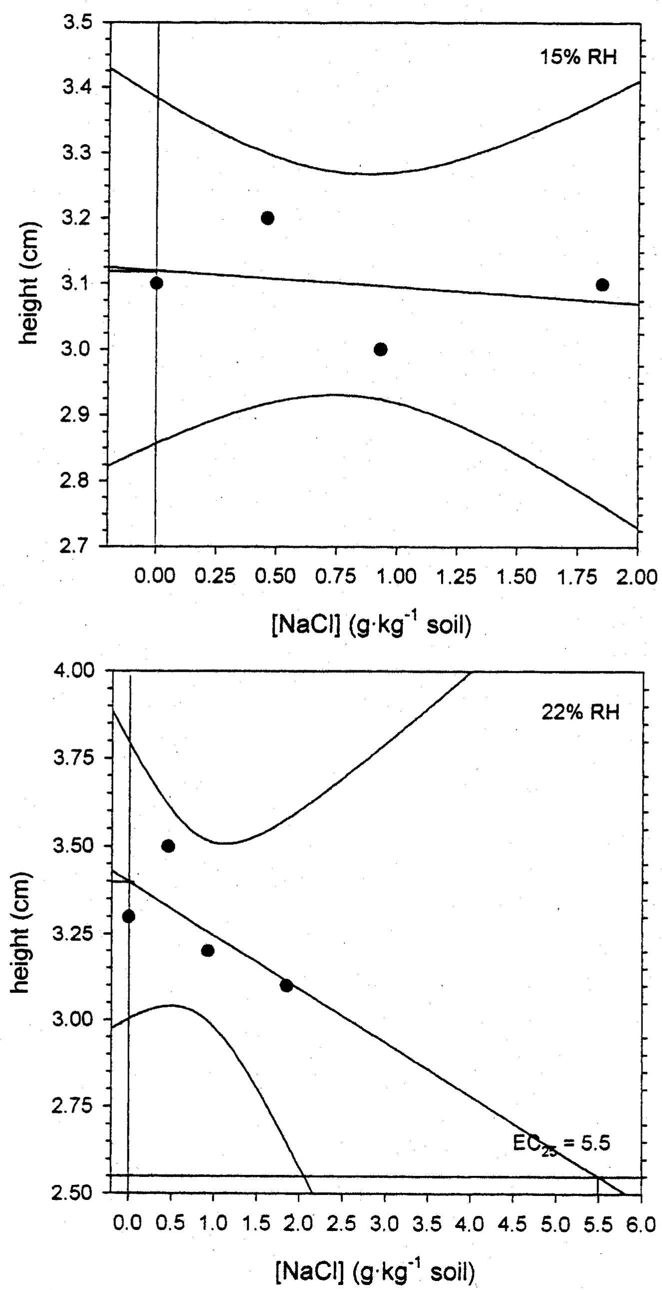


dry matter after 98 days- *Picea pungens* (Colorado Blue spruce)
Werkhoven *et al.*, 1990

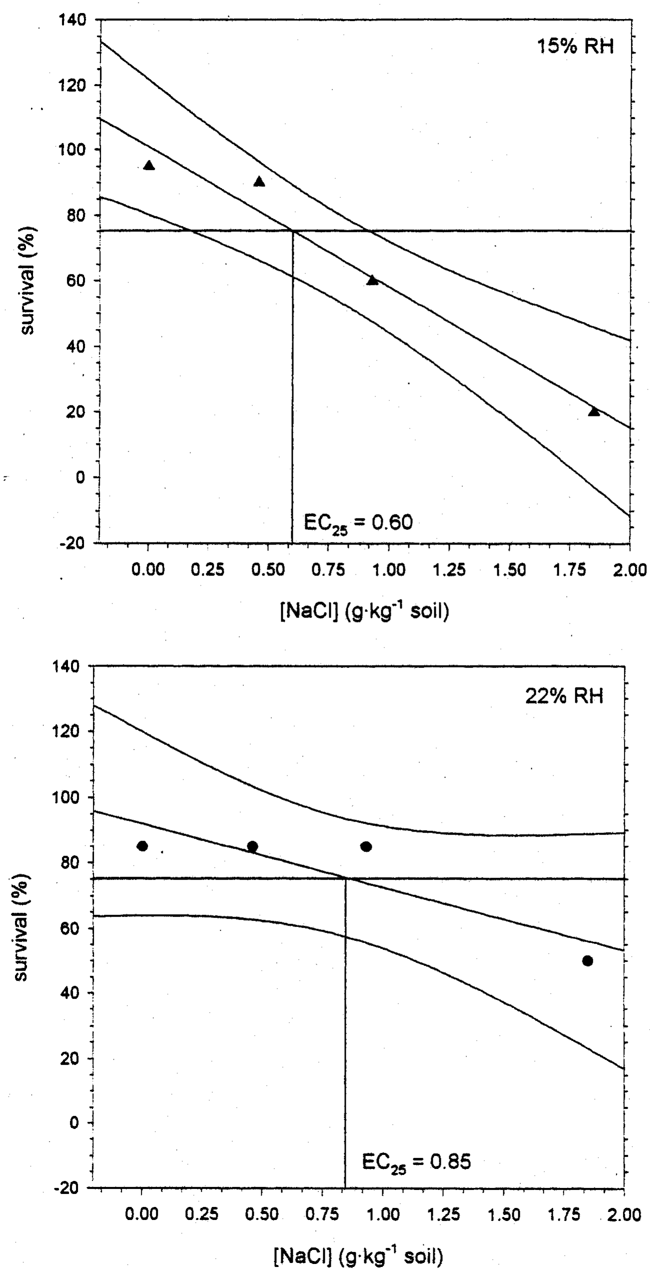




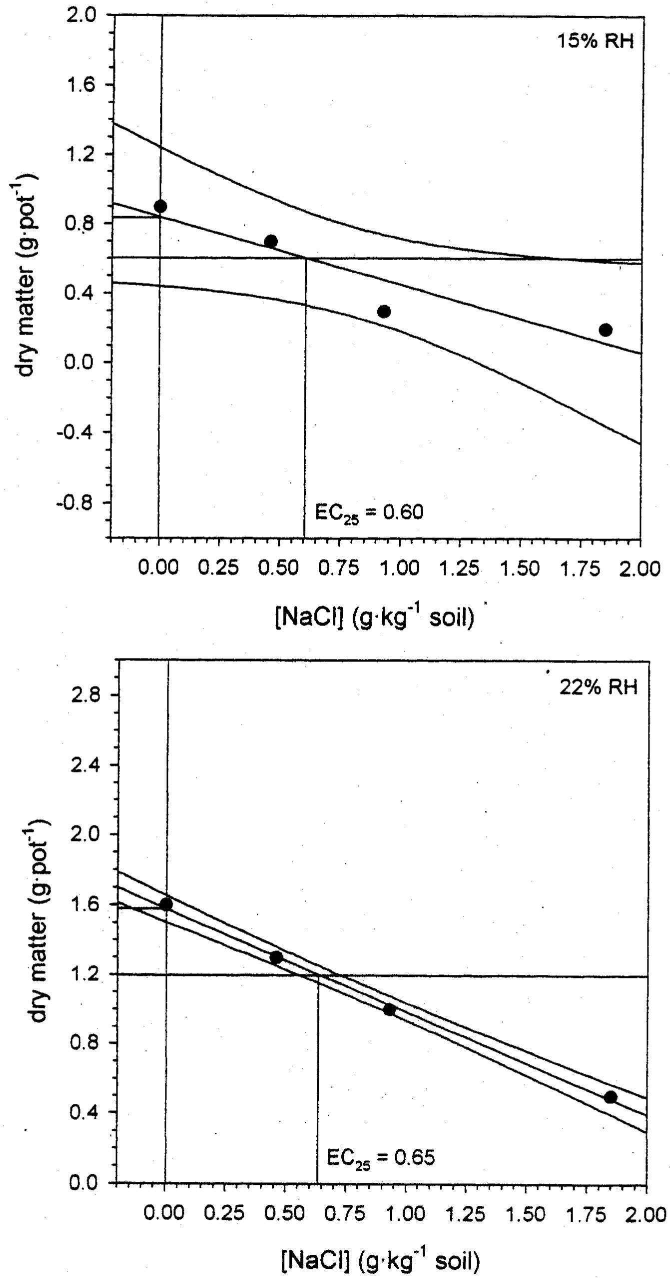
height after 98 days- *Picea pungens* (Colorado Blue Spruce)
Werkoven *et al.*, 1990



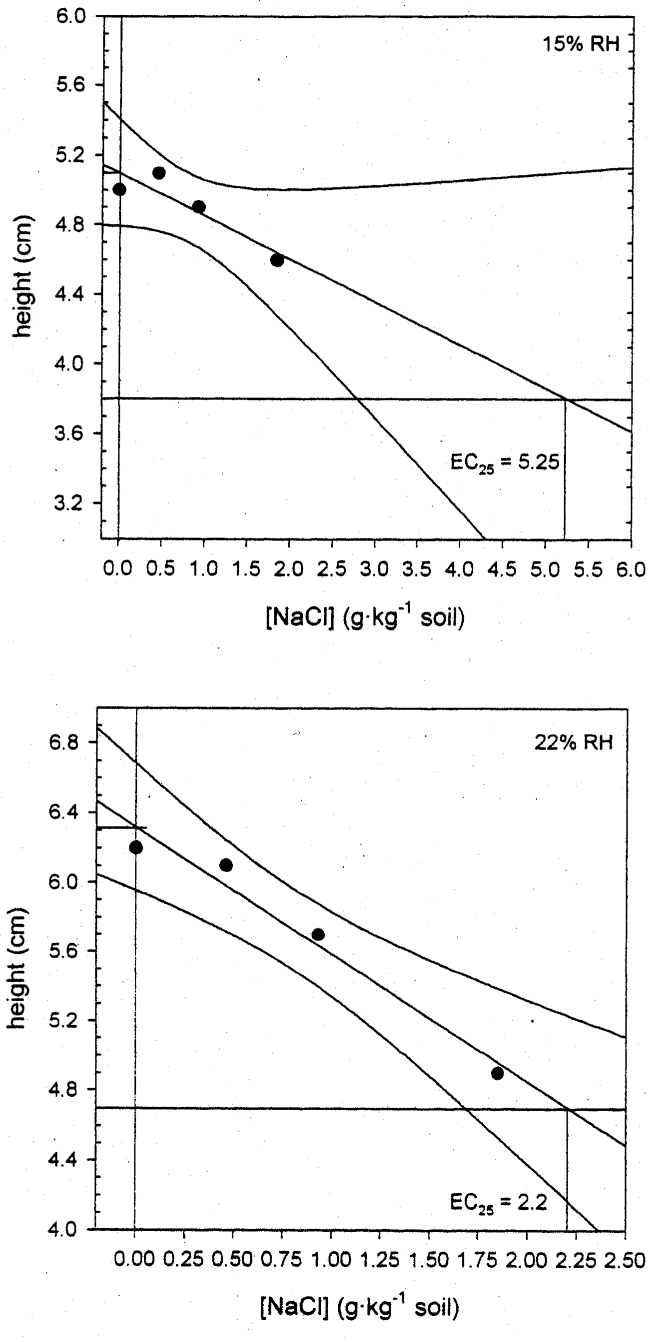
% survival- *Picea pungens* (Colorado Blue Spruce)
Werkhoven, *et al.*, 1990



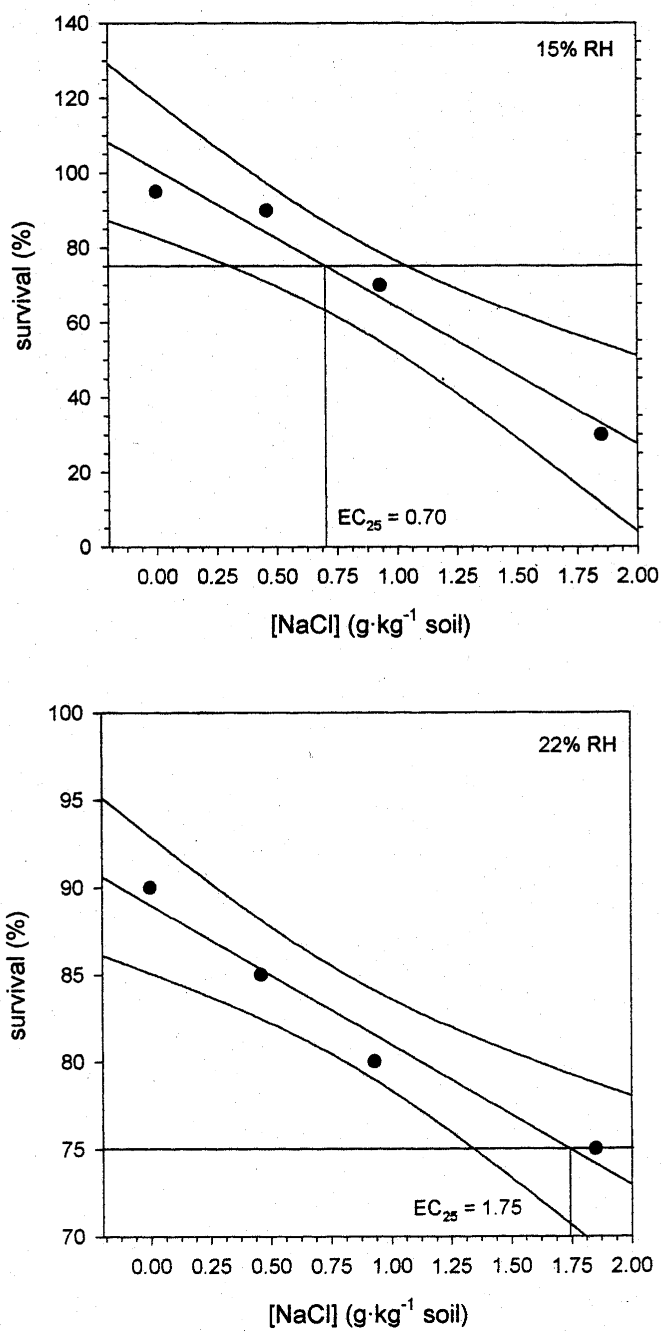
dry matter after 98 days- *Pinus sylvestris* (Scots Pine)
Werkoven *et al.*, 1990



height after 98 days *Pinus sylvestris* (Scots Pine)
Werkhoven, *et al.*, 1990



% survival- *Pinus sylvestris* (Scots pine)
Werkhoven *et al.*, 1990



Appendix 9 List of common and scientific names for plants referred to in this report.

Part A. Organized alphabetically by common name.

Common Name	Latin name
alder, speckled	*Alnus incana* ssp. *rugosa*
amur privet	*Ligustrum amurense*
apple	*Malus* sp.
apple	*Malus domestica*
apple, crab	*Malus sylvestris*
apple, Siberian crab	*Malus baccata*
apricot	*Prunus armeniaca*
arrow-head	*Sagittaria sp.*
ash, green	*Fraxinus pennsylvanica*
ash, mountain	*Sorbus aucuparia*
ash, white	*Fraxinus americana*
aspen, largetooth	*Populus grandidentata*
aspen, trembling	*Populus tremuloides*
aster, flat-topped white	*Aster umbellatus*
augustine grass	*Stenotaphrum secundatum*
basswood	*Tilia americana*
bean	*Phaseolus* sp.
beautybush	*Kolkwitzia amabilis*
beech	*Fagus* sp.
beech, American	*Fagus grandifolia*
beet	*Beta vulgaris*
beggar-ticks	*Bidens connata*
bent-grass	*Agrostis stolonifera*
birch, gray	*Betula populifolia*
birch, paper	*Betula papyrifera*
birch, white	*Betula papyrifera*
birch, yellow	*Betula alleghaniensis*
blackthorn	*Prunus spinosa*
bladderwort	*Utricularia* sp.
blue-stem (broom beard grass)	*Schizachyrium scoparium*
blueberry, black highbush	*Vaccinium atrocuccum*
blueberry, highbush	*Vaccinium corymbosum*
blueberry, lowbush	*Vaccinium angustifolium*
bluegrass, Kentucky (turfgrass)	*Poa pratensis*
brome grass (turfgrass)	*Bromus inermis*
buffalo grass	*Buchloe dactyloides*
burningbush	*Euonymus alatus*

Common Name	**Latin name**
butternut	*Juglans cinerea*
buttonbush	*Cephalanthus occidentalis*
carrot, wild	*Daucus carota*
catalpa, northern	*Catalpa speciosa*
catalpa, southern	*Catalpa bignonioides*
cattail, common	*Typha latifolia*
cattail, narrow-leaved	*Typha angustifolia*
cedar, eastern white	*Thuja occidentalis*
cedar, red	*Juniperus virginiana*
cedar, western red	*Thuja plicata*
centipede grass	*Eremochloa ophiuroides*
cherry, choke	*Prunus virginian*
cherry, European bird-	*Prunus padus*
cherry, laurel	*Prunus caroliniana*
cherry, mahaleb	*Prunus mahaleb*
cherry, nanking (or manchu)	*Prunus tomentosa*
cherry, sargent	*Prunus sargentii*
cherry, western sand	*Prunus besseyi*
cherry, sour (tart)	*Prunus cerasus*
cherry, sweet	*Prunus avium*
cherry, wild (or black cherry)	*Prunus serotina*
chokeberry, purple	*Pyrus floribunda*
cocklebur	*Xanthium strumarium*
corn	*Zea mays*
cottonwood, eastern	*Populus deltoides*
cranberry, European highbush	*Viburnum opulus*
cranberry, small	*Vaccinium oxycoccos*
dogwood, gray	*Cornus racemosa*
dogwood, flowering	*Cornus florida*
dogwood, red	*Cornus sanguinea*
dogwood, red-osier	*Cornus stolonifera*
dropseed, prairie	*Sporobolus heterolepsis*
dropseed, sand	*Sporobolus cryptandrus*
duckweed, common	*Lemna minor*
eglantine	*Rosa rubiginosa*
elm, American	*Ulmus americana*
elm, Siberian	*Ulmus pumila*
fescue, creeping red (turfgrass)	*Festuca rubra*
fescue, Kentucky 31 tall (turfgrass)	*Festuca arundinacea or F. elatior*
fir, alpine	*Abies lasiocarpa*
fir, balsam	*Abies balsamea*
fir, Douglas	*Pseudotsuga menziesii*
fir, rocky mountain Douglas	*Pseudotsuga menziesii* var. *glauca*
fir, white	*Abies concolor*

Common Name	Latin name
forsythia, border	*Forsythia x intermedia*
goldenrod	*Solidago graminifolia*
grama grass, side-oats	*Bouteloua curtipendula*
grama grass, blue	*Bouteloua gracilis*
grape	*Vitis spp.*
grape	*Vitis vinifera*
hawthorn, English	*Crataegus monogyna*
hemlock, eastern (or Canadian)	*Tsuga canadensis*
hemlock, western	*Tsuga heterophylla*
hickory	*Carya* sp.
hickory, shagbark	*Carya ova*
holly	*Ilex* sp.
holly, common mountain	*Nemopanthus mucronata [mucronatus]*
honey locust, sweet (thornless)	*Gleditsia triacanthos* var. *inermis*
honeysuckle, tartarian	*Lonicera tatarica*
horse-chestnut	*Aesculus hippocastanum*
huckleberry	*Gaylussacia baccata*
ivy, English	*Hedera helix*
Japanese pagoda tree	*Sophora japonica*
juniper	*Juniperus* spp.
juniper, pfitzer	*Juniper chinensis Pfitzeriana*
kidney bean	*Phaseolus vulgaris*
kochia	*Kochia scoparia*
larch, American	*Larix laricina*
leatherleaf	*Chamaedaphne calyculata angustifolia*
lilac, common	*Syringa vulgaris*
lilac, Japanese tree	*Syringa amurensis japonica*
linden	*Tilia platyphyllos*
locust, black	*Robinia pseudoacacia*
London plane-tree	*Platanus acerifolia*
maple, amur	*Acer ginnala*
maple, hedge	*Acer campestre*
maple, Manitoba	*Acer negundo*
maple, Norway	*Acer platanoides*
maple, red	*Acer rubrum*
maple, silver	*Acer saccharinum*
maple, sugar	*Acer saccharum*
maple, sycamore	*Acer pseudoplatanus*
marsh fern	*Drypoteris thelypteris (Thelypteris palustris)*
mockorange	*Philadelphus spp.*
mulberry	*Morus* sp.
nectarine	*Prunus persica*
oak, pin	*Quercus palustruis*

Common Name	Latin name
oak, red	*Quercus rubra* or *Q. borealis*
oak, white	*Quercus alba*
olive, Russian	*Elaeagnus angustifolia*
orach	*Atriplex undulata*
orach, sea	*Atriplex halimus*
panic-grass	*Panicum implicatum*
peach, cv Loring, Madison or Garnet Beauty	*Prunus persica*
peashrub, Siberian	*Caragana arborescens*
pear	*Pyrus communis*
pear, Asian or callery pear	*Pyrus calleryana*
pear, European bird	*Pyrus padus*
perennial ryegrass	*Lolium perenne*
pine, bristle-cone	*Pinus aristada*
pine, Austrian	*Pinus nigra*
pine, eastern white	*Pinus strobus*
pine, jack	*Pinus banksiana*
pine, lodgepole	*Pinus contorta var. latifolia*
pine, Macedonian	*Pinus Peuce*
pine, mugo	*Pinus mugo*
pine, pitch	*Pinus rigida*
pine, ponderosa	*Pinus ponderosa*
pine, red	*Pinus resinosa*
pine, Scots	*Pinus sylvestris*
pine, white	*Pinus strobus*
pitcher-plant	*Sarracenia purpurea*
plum, American	*Prunus americana*
plum, beach	*Prunus maritima*
plum, cultivated, European plum, prune-type	*Prunus domestica*
poplar, balsam	*Populus balsamifera*
poplar, Lombardy	*Populus nigra 'Italica'*
privet	*Ligustrum spp.*
prune	*Prunus* sp
purple loosestrife	*Lythrum salicaria*
quince	*Cydonia oblonga*
quince, flowering (sweet)	*Chaenomeles speciosa*
ragweed, common	*Ambrosia artemisiifolia*
red fescue	*Festuca rubra*
reed-grass, common	*Phragmites australis*
rose	*Rosa multiflora*
rose, turkestan	*Rosa rugosa*
rush, jointleaf	*Juncus articulatus*
rush, northern green	*Juncus alpino-articulatus*
rush, white beak-	*Rhynchospora alba*
rye, wild	*Elymus canadensis*

Common Name	**Latin name**
sea-buckthorn	*Hippophae rhamnoides*
sea blite	*Suaeda australis*
sedge, clustered field	*Carex praegracilis* W. Boott
sedge, dense cotton grass	*Eriophorum vaginatum* var. *spissum*
sedge, freeway-	*Carex praegracilis*
sedge, three-fruited	*Carex trisperma*
sedge, three-way	*Dulichium arundinaceum*
sedge, woolgrass	*Scirpus cyperinus*
serviceberry	*Amelanchier* sp.
serviceberry, smooth	*Amelanchier laevis*
sow-thistle, common (annual)	*Sonchus oleraceus*
sow-thistle, field (perennial)	*Sonchus arvensis*
sow-thistle, moist (perennial)	*Sonchus arvensis L.* ssp. *uliginosus*
sphagnum moss (peat-moss)	*Sphagnum fimbriatum*
sphagnum, recurved	*Sphagnum recurvum*
spirea	*Spiraea Vanhouttei*
spirea, bumalda	*Spiraea* x *bumalda*
spruce, black	*Picea mariana*
spruce, blue	*Picea pungens* Englem. *glauca*
spruce, Colorado blue	*Picea pungens*
spruce, engelmann	*Picea engelmannii*
spruce, hybrid white	*Picea engelmannii X glauca*
spruce, Norway	*Picea abies*
spruce, red	*Picea rubens*
spruce, sitka	*Picea sitchensis*
spruce, white	*Picea glauca*
St.-John's wort	*Hypericum virginicum*
sumac, staghorn	*Rhus typhina*
sundew	*Drosera intermedia*
sweetbrier or eglantine	*Rosa rubiginosa*
sycamore, eastern (American sycamore or plane tree)	*Platanus occidentalis*
tamarack (American larch)	*Larix laricina*
tree of heaven	*Ailanthus altissima*
tulip-tree	*Liriodendron tulipifera*
walnut, black	*Juglans nigra*
walnut, English	*Juglans regia*
wayfaring tree	*Viburnum lantana*
willow	*Salix* sp.
willow, basket	*Salix viminalis*
willow, black	*Salix nigra*
willow, weeping golden	*Salix alba* 'Tristis'
willow, white	*Salix alba*
yew	*Taxus* spp.

Part B. Organized alphabetically by scientific name.

Latin name	Common Name
Abies balsamea	fir, balsam
Abies concolor	fir, white
Abies lasiocarpa	fir, alpine
Acer campestre	maple, hedge
Acer ginnala	maple, amur
Acer negundo	maple, Manitoba
Acer platanoides	maple, Norway
Acer pseudoplatanus	maple, sycamore
Acer rubrum	maple, red
Acer saccharinum	maple, silver
Acer saccharum	maple, sugar
Aesculus hippocastanum	horse-chestnut
Agrostis stolonifera	bent-grass
Ailanthus altissima	tree of heaven
Alnus incana ssp. *rugosa*	alder, speckled
Ambrosia artemisiifolia	ragweed, common
Amelanchier laevis	serviceberry, smooth
Amelanchier sp.	serviceberry
Aster umbellatus	aster, flat-topped white
Atriplex halimus	orach, sea
Atriplex undulata	orach
Beta vulgaris	beet
Betula alleghaniensis	birch, yellow
Betula papyrifera	birch, paper
Betula papyrifera	birch, white
Betula populifolia	birch, gray
Bidens connata	beggar-ticks
Bouteloua curtipendula	grama grass, side-oats
Bouteloua gracilis	grama grass, blue
Bromus inermis	brome grass (turfgrass)
Buchloe dactyloides	buffalo grass
Caragana arborescens	peashrub, Siberian
Carex praegracilis	sedge, freeway-
Carex praegracilis W. Boott	sedge, clustered field
Carex trisperma	sedge, three-fruited
Carya ova	hickory, shagbark
Carya sp.	hickory
Catalpa bignonioides	catalpa, southern
Catalpa speciosa	catalpa, northern
Cephalanthus occidentalis	buttonbush

Latin name	Common Name
Chaenomeles speciosa	quince, flowering (sweet)
Chamaedaphne calyculata angustifolia	leatherleaf
Cornus florida	dogwood, flowering
Cornus racemosa	dogwood, gray
Cornus sanguinea	dogwood, red
Cornus stolonifera	dogwood, red-osier
Crataegus monogyna	hawthorn, English
Cydonia oblonga	quince
Daucus carota	carrot, wild
Drosera intermedia	sundew
Drypoteris thelypteris (Thelypteris palustris)	marsh fern
Dulichium arundinaceum	sedge, three-way
Elaeagnus angustifolia	olive, Russian
Elymus canadensis	rye, wild
Eremochloa ophiuroides	centipede grass
Eriophorum vaginatum var. *spissum*	sedge, dense cotton grass
Euonymus alatus	burningbush
Fagus grandifolia	beech, American
Fagus sp.	beech
Festuca arundinacea or F. elatior	fescue, Kentucky 31 tall (turfgrass)
Festuca rubra	fescue, creeping red (turfgrass)
Forsythia x intermedia	forsythia, border
Fraxinus americana	ash, white
Fraxinus pennsylvanica	ash, green
Gaylussacia baccata	huckleberry
Gleditsia triacanthos var. *inermis*	honey locust, sweet (thornless)
Hedera helix	ivy, English
Hippophae rhamnoides	sea-buckthorn
Hypericum virginicum	St.-John's wort
Ilex sp.	holly
Juglans cinerea	butternut
Juglans nigra	walnut, black
Juglans regia	walnut, English
Juncus alpino-articulatus	rush, northern green
Juncus articulatus	rush, jointleaf
Juniper chinensis Pfitzeriana	juniper, pfitzer
Juniperus spp.	juniper
Juniperus virginiana	cedar, red
Kochia scoparia	kochia
Kolkwitzia amabilis	beautybush
Larix laricina	tamarack (American larch)
Lemna minor	duckweed, common
Ligustrum amurense	amur privet
Ligustrum spp.	privet

Latin name	Common Name
Liriodendron tulipifera	tulip-tree
Lolium perenne	perennial ryegrass
Lonicera tatarica	honeysuckle, tartarian
Lythrum salicaria	purple loosestrife
Malus domestica	apple
Malus baccata	apple, Siberian crab
Malus sp.	apple
Malus sylvestris	apple, crab
Morus sp.	mulberry
Nemopanthus mucronata [mucronatus]	holly, common mountain
Panicum implicatum	panic-grass
Phaseolus sp.	bean
Phaseolus vulgaris	kidney bean
Philadelphus spp.	mockorange
Phragmites australis	reed-grass, common
Picea abies	spruce, Norway
Picea engelmannii	spruce, engelmann
Picea engelmannii X glauca	spruce, hybrid white
Picea glauca	spruce, white
Picea mariana	spruce, black
Picea pungens	spruce, Colorado blue
Picea pungens Englem. *glauca*	spruce, blue
Picea rubens	spruce, red
Picea sitchensis	spruce, sitka
Pinus aristada	pine, bristle-cone
Pinus banksiana	pine, jack
Pinus contorta var. latifolia	pine, lodgepole
Pinus mugo	pine, mugo
Pinus nigra	pine, Austrian
Pinus Peuce	pine, Macedonian
Pinus ponderosa	pine, ponderosa
Pinus resinosa	pine, red
Pinus rigida	pine, pitch
Pinus strobus	pine, eastern white
Pinus strobus	pine, white
Pinus sylvestris	pine, Scots
Platanus acerifolia	London plane-tree
Platanus occidentalis	sycamore, eastern (American sycamore or plane tree)
Poa pratensis	bluegrass, Kentucky (turfgrass)
Populus balsamifera	poplar, balsam
Populus deltoides	cottonwood, eastern
Populus grandidentata	aspen, largetooth
Populus nigra 'Italica'	poplar, Lombardy

Latin name	**Common Name**
Populus tremuloides	aspen, trembling
Prunus americana	plum, American
Prunus armeniaca	apricot
Prunus avium	cherry, sweet
Prunus besseyi	cherry, western sand
Prunus caroliniana	cherry, laurel
Prunus cerasus	cherry, sour (tart)
Prunus domestica	plum, cultivated, European plum, prune-type
Prunus mahaleb	cherry, mahaleb
Prunus maritima	plum, beach
Prunus padus	cherry, European bird-
Prunus persica	nectarine
Prunus persica	peach, cv Loring, Madison or Garnet Beauty
Prunus sargentii	cherry, sargent
Prunus serotina	cherry, wild (or black cherry)
Prunus sp	prune
Prunus spinosa	blackthorn
Prunus tomentosa	cherry, nanking (or manchu)
Prunus virginian	cherry, choke
Pseudotsuga menziesii	fir, Douglas
Pseudotsuga menziesii var. *glauca*	fir, rocky mountain Douglas
Pyrus calleryana	pear, Asian or callery pear
Pyrus communis	pear
Pyrus floribunda	chokeberry, purple
Pyrus padus	pear, European bird
Quercus alba	oak, white
Quercus palustruis	oak, pin
Quercus rubra or *Q. borealis*	oak, red
Rhus typhina	sumac, staghorn
Rhynchospora alba	rush, white beak-
Robinia pseudoacacia	locust, black
Rosa multiflora	rose
Rosa rubiginosa	eglantine
Rosa rubiginosa	sweetbrier or eglantine
Rosa rugosa	rose, turkestan
Sagittaria sp.	arrow-head
Salix alba	willow, white
Salix alba 'Tristis'	willow, weeping golden
Salix nigra	willow, black
Salix sp.	willow
Salix viminalis	willow, basket
Sarracenia purpurea	pitcher-plant
Schizachyrium scoparium	blue-stem (broom beard grass)
Scirpus cyperinus	sedge, woolgrass

Latin name	Common Name
Solidago graminifolia	goldenrod
Sonchus arvensis	sow-thistle, field (perennial)
Sonchus arvensis L. ssp. *uliginosus*	sow-thistle, moist (perennial)
Sonchus oleraceus	sow-thistle, common (annual)
Sophora japonica	Japanese pagoda tree
Sorbus aucuparia	ash, mountain
Sphagnum fimbriatum	sphagnum moss (peat-moss)
Sphagnum recurvum	sphagnum, recurved
Spiraea Vanhouttei	spirea
Spiraea x *bumalda*	spirea, bumalda
Sporobolus cryptandrus	dropseed, sand
Sporobolus heterolepsis	dropseed, prairie
Stenotaphrum secundatum	augustine grass
Suaeda australis	sea blite
Syringa amurensis japonica	lilac, Japanese tree
Syringa vulgaris	lilac, common
Taxus spp.	yew
Thuja occidentalis	cedar, eastern white
Thuja plicata	cedar, western red
Tilia americana	basswood
Tilia platyphyllos	linden
Tsuga canadensis	hemlock, eastern (or Canadian)
Tsuga heterophylla	hemlock, western
Typha angustifolia	cattail, narrow-leaved
Typha latifolia	cattail, common
Ulmus americana	elm, American
Ulmus pumila	elm, Siberian
Utricularia sp.	bladderwort
Vaccinium angustifolium	blueberry, lowbush
Vaccinium atrocuccum	blueberry, black highbush
Vaccinium corymbosum	blueberry, highbush
Vaccinium oxycoccos	cranberry, small
Viburnum lantana	wayfaring tree
Viburnum opulus	cranberry, European highbush
Vitis spp.	grape
Vitis vinifera	grape
Xanthium strumarium	cocklebur
Zea mays	corn