# EFFECTS OF VARIABLE RATE AERIAL APPLICATION OF VISION® ON MOOSE *(Alces alces)* WINTER BROWSING AND HARDWOOD VEGETATION

by

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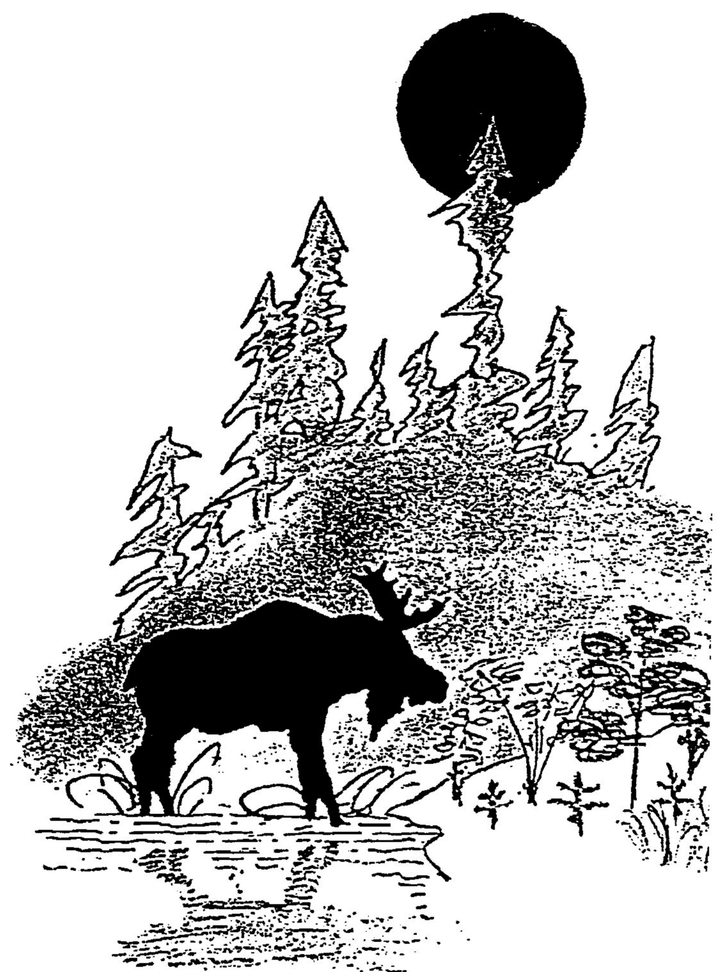

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# EFFECTS OF VARIABLE RATE AERIAL APPLICATION OF VISION®
# on
# MOOSE *(Alces alces)* WINTER BROWSING AND HARDWOOD VEGETATION

by

**Colin Patrick Kelly** ©

A Graduate Thesis Submitted
In Partial Fulfillment of the Requirements
for the Degree of Master of Science in Forestry

School of Forestry
Lakehead University
Thunder Bay, Ontario
Canada
November, 1993

# A CAUTION TO THE READER

This M.Sc.F. thesis has been through a formal process of review and comment by the supervisor, thesis committee, faculty members and an external examiner.

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# ABSTRACT

Kelly, C.P. 1993. Effects of variable rate aerial application of Vision® on moose (Alces alces) winter browsing and hardwood vegetation. 72pp. M.Sc.F. Thesis Lakehead University, Thunder Bay, Ontario, Canada. Supervisor: Dr. H.G. Cumming.

Key Words: Alces alces, competition, conifer regeneration, glyphosate, hardwood browse biomass, hardwood browsing intensity, hardwood cover, hardwood stem density, herbaceous cover, moose, soils, winter track, Vision®.

Experimental aerial treatment of 7 mixedwood areas in late summer for conifer release with Vision® at 0.80, 1.06, and 1.60 kg a.e./ha, decreased living hardwood stem densities after ten months by 42, 61 and 42% respectively on treated plots, while controls increased by 13%. Twenty two months after treatment stem densities were reduced (from pre-spray levels) by 48, 65 and 61%; controls increased 19%. Greatest numbers of stems occurred on moderately deep, fresh soils. After treatment, winter browsing rates decreased in both six and 18 months post spray on all plots and were consistently higher on controls when compared with treated sub-blocks. Decline was progressive over two years after treatment on sprayed areas but recovered in the second year on controls. The two highest application rates had the lowest browsing levels. Conversely, winter track data showed no differences in moose use between sprayed areas and controls, nor any difference among treatments. This suggested moose still traveled through sprayed areas, but did not stop to browse. In addition to stem density counts, cover (%) for both herbs and hardwoods were estimated to evaluate the effectiveness of Vision® as a conifer release. Hardwood cover was reduced significantly by all application rates; differences among treatments were not significant. Herbaceous ground cover was reduced approximately 20% on all treated areas one season after spray but by next year these sprayed areas had recovered to equivalent levels as controls. Neither crop tree diameter nor height growth was affected by Vision® application at this early stage of the experiment. Moose densities within these study areas appear to be low enough that food is not a limiting factor. The small amount of spraying in Ontario (relative to the productive forest land base) is not expected to affect moose populations. However, in areas with high concentrations of sprayed cutovers there should be concern. Results of this short term study suggest that 0.80 kg a.e./ha controlled hardwood and herbaceous competition as well as 1.06 & 1.60 kg a.e./ha. However, the lowest application rate showed signs of increased moose use two years post spray compared with the two higher rates. Consequently, when spray programs are concentrated in one management unit, the 0.80 kg a.e./ha rate is recommended.

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# INTRODUCTION

## 1. GLYPHOSATE /VISION®

Glyphosate was developed in the 1960's. Roundup®, the formulated product for application, was registered in Canada for agricultural, industrial and domestic use in 1984. Vision®, technically the same product as Roundup®, was registered specifically for forestry use in 1987. Roundup® no longer retains forestry uses in Canada (Canadian Pulp and Paper Association (CPPA) and Forestry Canada 1993), but is used under this name in the United States of America. Vision® is manufactured in Canada by Monsanto Canada Inc. It is a relatively non-selective herbicide (although conifers are resistant) that is effective on grasses, herbs, deep rooted perennials, as well as broadleaf brush and trees. Recommended application rates on the product label vary between 1.07 and 2.14 kg a.e./ha, depending on the species. Recommended rates for herbs and grasses are between 1.07-1.42 kg a.e./ha, increased to 1.78-2.14 kg a.e./ha for brush and trees. These rates are consistent for both site preparation and conifer release (CPPA and Forestry Canada 1993, 1992). The product label includes the following partial list of brush and tree species controlled: Birch (Betula spp.), Cherry (Prunus spp.), Maple (Acer spp.), Poplar (Populus spp.), Willow (Salix spp.), Alder (Alnus spp.), Raspberry (Rubus spp.), and Western Snowberry (Symphoricarpos occidentalis). Application rates of 2.14 kg a.e./ha are reserved for Maple, Alder, Raspberry and hard to control perennial weed species. Appendices C (animals, trees and shrubs) and D (herbaceous species) provide common and scientific names for species discussed in this paper.

In spray applications typical of conifer release, Vision® (and its active ingredient glyphosate) is absorbed through the leaves or young bark (Atkinson 1985). It translocates rapidly throughout the plant with very little damage to the translocating material at the recommended rates. Material in the phloem will go directly to the roots where the plant is killed. High concentrations can impede translocation by damaging plant tissue and therefore reducing weed control properties (Sutton 1978). Weed control is proportionate to translocation rates; effects will be greater if the herbicide is applied later in the growing season when higher rates of translocation from the crown to the roots occurs (CPPA and Forestry Canada 1993).

Vision® consists of 356 g/l of the active ingredient, glyphosate free acid, formulated as its isopropylamine salt (480 g/l/). Only 41% (by volume) of Vision® is active ingredient, the remaining 59% is comprised of water(44%) and surfactant (15%) (Monsanto Canada Inc. no date).

In forestry, vegetation management is used to direct site resources to favour the survival, growth and development of desired plants, generally conifers (Bell et al. 1992). In Ontario, vegetation management is usually used to improve conditions for conifers and includes both site preparation and release operations. Site preparation attempts to: reduce or manipulate debris, reduce vegetative competition and/or the organic layer, expose mineral soil, control crop tree spacing, and modify of micro-site conditions. Release is used in stands which are not "free-to-grow" to: 1) increase survival and reduce the time required to reach free-to-grow status; and 2) improve growth and yield (Bell et al. 1992).

## 2. MOOSE WINTER BROWSE

Moose (Alces alces) consume food all year round. Winter browse consists of parts of various tree or shrub species consumed after leaf fall but before leaf flush in the spring. This food source (i.e. dormant buds and twig tips) is referred to as "woody browse". Although Balsam Fir (Abies balsamea (L.) Mill.) sometimes plays an important role in the winter diet of moose (Cumming 1987), most often hardwood species are consumed which are nutritionally superior to softwoods. Species consumed vary with location. Cumming (1987) presented province-wide data from Ontario. Beaked Hazel (Corylus cornuta Marsh.) and Mountain Maple (Acer spicatum Lam.) were principal food species, while Mountain Ash (Sorbus americana Marsh.), Red Osier Dogwood (Cornus stolonifera Michx.) and Juneberry (Amelanchier bartramiana (Tausch) Roem.) were preferred. Principal foods of an animal are those it eats in greatest quantities. These may or may not be preferred. Preferred foods are those which are proportionately more frequent in the diet than in the available environment (Petrides 1975). Specifically for northwestern Ontario, Mastenbrook (1991) listed White Birch (Betula papyrifera Marsh.), Trembling Aspen (Populus tremuloides Michx.), Pin Cherry (Prunus pensylvanica L. fil) and Willow (Salix spp.) as principal foods, with Mountain Ash (Sorbus americana Marsh.), White Birch, and Trembling Aspen having the highest preference. Todesco (1988) reported similar results as White Birch, Trembling Aspen, Pin Cherry, and Mountain Ash were browsed most often. He confirmed that browse species varied as you moved to different habitats (for example, 100% of winter browse in swampy areas was Willow). Appendices C&D contain keys to scientific and common names of plant species.

## 3. EFFECTS OF GLYPHOSATE

### 3.1 Toxic Effects

Glyphosate is relatively non-toxic to both terrestrial and aquatic animals (Newton et al. 1984, Atkinson 1985, Sullivan 1985, 1990). The formulated product, Vision® is also considered practically non-toxic to mammals, but due to presence of surfactant, slightly to moderately toxic to aquatic invertebrates and fish (Hildebrand et al. 1980, Sullivan et al. 1981, Mitchell et al. 1987, Scrivener and Carruthers 1989). Although direct effects on moose (Alces alces) associated with the use of this herbicide seem unlikely, indirect effects (reduction of food and cover) concern biologists, primarily because the competing hardwood species most often killed constitute a major source of winter food for moose. If all sprayed areas became less desirable for moose, available winter habitat for the animals might be substantially reduced. Additionally, very little is known about the effects of glyphosate on long term vegetation structure. If conifer release programs become entrenched in forestry practices, how will this policy alter plant and associated animal communities?

## 3.2 Palatability

Does glyphosate render food unpalatable to moose (can they taste the compound), or would they avoid sprayed areas only simply because of reduced biomass? Legris and Coutue (1991) presented results that show moose do not avoid plants recently sprayed with Vision®. Other closely related species show similar results. Campbell et. al. (1981) showed that deer would readily consume browse treated with 2,4-D, but rejected some foliage treated with excessive (greater than label recommendations) rates of glyphosate. Sullivan and Sullivan (1979) stated that deer given a choice of control or glyphosate treated browse demonstrated no preference or ate more of the treated foliage. Sheep showed absolutely no rejection to hay treated with glyphosate and consumed it in equal proportions to the untreated hay (Jones and Forbes 1984).

## 3.3 Individual Plant Species Response To Treatment

Individual plant species respond differently to a glyphosate treatment. In British Columbia, Balfour (1989) found great variance among species. She stated that particularly sensitive species included Aspen (Populus spp.), Serviceberry (Amelanchier spp.) and Cherry (Prunus spp.). Lloyd (1989) would add Maple (Acer spp.) and Birch (Betula spp.) as sensitive species. Plants which seem to tolerate spraying better than most include Willow (Salix spp.) and Red-Osier Dogwood (Cornus stolonifera Michx.) (Lloyd 1989). Because glyphosate is absorbed through the foliage, seasonal timing of spraying and weather conditions before, during, and after treatment may also influence the effectiveness of Vision®. Balfour (1989) found substantial variation in plant response to glyphosate (measured in terms of severity of damage) even within species. Pojar (1990) took the ultimate skeptical position by claiming that the response of browse plants to glyphosate application is impossible to predict. Monsanto Canada Inc. (1989) suggests that for best results application should be in the early fall when the plant is still actively growing. Root and shoot growth potential should be high and the plant should not be under any stress, especially drought, as this results in a waxy coating on the leaf and inhibits absorption. Vision® works well from -4° C (as long as there is not a killing frost) up to 36° C. Higher temperatures promote efficiency due to higher plant activity. Greater humidity maximizes weed control since the cuticle becomes hydrated and readily absorbs the herbicide. With proper planning rain is not a problem since at maximum six hours are required for proper absorption of the chemical.

Vision® and Roundup® applications have changed both species composition and relative abundance. One to two years after application vigorous herbaceous growth is often reported (Lloyd 1990a, Nova Scotia Department of Lands and Forests 1989, Kennedy and Jordan 1985). Plant species diversity is either maintained (Timmermann et al. 1986, McMillan et al. 1990 a) or increased (Lautenschlager and McCormack 1989).

### 3.4 Short Term Effects On Winter Browse Availability And Browsing

Most recent studies demonstrate that browse availability on treated areas decreases significantly in the first growing season after glyphosate application. Kennedy and Jordan (1985) found that 1 growing season after treatment glyphosate treated areas contained about 1/2 the available browse biomass of areas treated with 2,4-D and 1/4 the browse present on areas not yet sprayed. Cumming (1989) showed that 1 growing season after applications of 1.07 kg a.e./ha (conifer release) and 2.7 kg a.e./ha (site preparation) moose browse availability decreased from 5-41% and 63-92% respectively. Connor and McMillan (1990) found that glyphosate reduced available browse on treated areas to 25% of controls 21 months after treatment. Twelve months later (33 months post spray) treated areas had recovered to 33% of controls. They also found that immediately post spray moose showed no preference for control areas (determined by winter track counts). However, 2 and 3 years after treatment, moose seemed to avoid sprayed areas. In British Columbia, Lloyd (1990 b) stated that in one study area moose winter use (determined from track counts) was 8 times higher in control than in treated areas. Hjeljord and Gronvold (1988) reported that glyphosate treated areas had less than 1% of the browse production before treatment and that moose use was significantly lower 3 years after application.

**3.5 Long Term Ecosystem Effects**

The long term effects of conifer release with herbicides, including Vision®, on ungulate populations are unclear. Lautenschlager (1986) states, "in treated areas, hardwood brush is reduced and therefore the habitat value and forage quality is lowered for several years following treatment. Of all the species examined, successful conifer release will likely reduce moose populations the most. However, any moose population decrease related to herbicide conifer release is unlikely to last long because some of the treated brush quickly sprouts, and some brush is missed during application. Therefore, the habitat value for moose in treated areas is expected to increase again." In support of this statement, Newton et al. (1989) found that intensive forest management (including glyphosate use) to release crop trees improved browse availability 8 years after treatment. Lautenschlager (1991) using data from Newton et al. (1989) developed a model for browse availability after a release operation. He stated browse reduction immediately after a herbicide application is likely offset by increased browse availability on these sprayed areas several years post treatment.

## 4. JUSTIFICATION OF STUDY

Label rates for conifer release with Vision® range from 1.07 to 2.14 kg a.e./ha. Some of these plant species targeted for control are of high value for moose winter browse (Cumming 1987). Nova Scotia researchers (Nova Scotia Department of Lands and Forests, 1989) demonstrated that competing vegetation could be controlled with lower than recommended rates of glyphosate. Red Maple (Acer rubrum L.) was effectively controlled (competition index reduced by as much as ten times compared to controls) at 0.83 kg a.e./ha, whereas the recommended rate for Red Maple control is approximately 1.7 kg a.e./ha in Nova Scotia. Therefore, a lower than standard application rate might be found that would still successfully release conifer crop trees but leave more browse for moose than label rates. Benefits associated with reduced rates could include: (1) increased production of browse on treated areas without compromising crop tree growth, (2) reduced constraints on where Vision® is applied, (3) increased knowledge about the environmental effects of this chemical, and (4) potential to increase revenue from the forest (maximize earnings from fibre and wildlife).

Hughes and Fahey (1991) concluded that, when compared with the natural process of regeneration (i.e. stand decay), clear-cutting results in significantly larger, heavier twigs and more nutritious browse (higher levels of protein and soluble carbohydrates) than that found in uncut stands. It would be a waste of this high quality browse to spray these areas at unnecessarily high concentrations of Vision®. As mentioned above several recent studies have shown that current conifer release treatments greatly reduce the availability of these moose foods (Kennedy and Jordan 1985, Hjeljord and Gronvold 1988, Cumming 1989, Newton et al. 1989, Lloyd 1989, 1990a, b, and Connor and McMillan 1990) during the first few years after treatment. Continued use of herbicides by forest managers may lead to significant losses of potential moose browse.

Integrated Resource Management (IRM), a priority among many environmental and forestry groups, was high on both the provincial and federal agendas in Ontario at least as early as 1978. Fifteen years ago, rather than referring to IRM, government agents of the Canada-Ontario Forest Management Subsidiary Agreement described a program to improve the viability of the forest products industry in Ontario by facilitating multi-use benefits from the forest (MMC Economic Consulting 1984). Public demand has consistently increased for integrated resource management since 1978. Currently IRM is a priority of the sustainable forestry initiatives of Canada and Ontario (Canadian Council of Forest Ministers 1992, OMNR 1992, 1991). Jordan et al. (1988) suggest that IRM can be used in forest management to meet the needs of both fibre and wildlife.

Concomitant with today's increased knowledge regarding the complexity of ecosystems, people are understandably wary of herbicides. The public, together with government and industry, is realizing the benefits of integrated resource management. Today, most would agree that there is much more to a forest environment than trees, and much more to forest products than simply pulp and timber. Use of herbicides is not only an environmental question, it is also an economic one. Herbicides are the cheapest option available to foresters; an integrated approach to forest management could help offset the probable increased cost of alternative vegetation management techniques. Wildlife represents a promising area for increasing revenue from the forest [Table 1].

Table 1. Revenue from forest products- fibre and wildlife (From Filion et al. 1990).

| | CANADA ($ billion) | ONTARIO ($ billion) |
|---|---|---|
| **Wood Products** | | |
| Lumber | 6.26 | 0.67 |
| Pulp | 8.19 | 2.35 |
| **Wildlife** | | |
| net economic value | 1.00 | 0.37 |
| actual expenditures | 5.10 | 1.62 |
| which generates: | | |
| gross business production | 10.70 | 3.85 |
| **+gross domestic product (GDP)** | **6.50** | **2.23** |
| taxes | 2.50 | 0.36 |
| personal income | 3.70 | 1.38 |
| jobs created (000's) | 160 | 62 |

+Total Canadian GDP (1987)=**$550 billion.**

A contribution of $6.5 billion to the GDP out of a possible $550 billion may not seem a significant fraction, but consider that the above statistics do not include fish. Filion et al. (1990) suggest that these values would be doubled if activities related to fishing were included. Greater than 80% of the Canadian public has experienced an outdoor-related activity and expressed interest in wildlife, yet only 2.5% of the population accounted for over 70% of expenditures. This suggests that the income from wildlife and related activities is vastly under-developed; via education the 80% of Canadians that expressed interest in outdoor-related activities would likely increase their expenditures. Wildlife constitutes a small but potentially significant portion to the Canadian economy. The total gross value of hunting moose in Ontario alone in 1982 was estimated at $180 million (Bisset 1987). This value includes license revenue, direct and indirect expenditures for moose hunting, meat, and moose-related activities other than hunting.

Dollar values of wildlife may never approach the economic values derived from wood products. However, any deviation from an optimum integration of wildlife management and timber/pulpwood management will result in lost revenue from one industry or the other. Detailed knowledge of the interactions between forest requirements for moose and wood products are essential for an integrated management approach. Tending forest plantations will become substantially more expensive if, through lack of knowledge about impacts, the use of chemicals for tending crop trees should be forbidden.

Production of moose to sustain, and perhaps increase, these economic values depends on food of sufficient quantity and quality. Yet silvicultural practices may be taking out of production each year many hectares of the best food available - that growing 5-20 years after burning or harvesting. More precise information about the extent of these losses, gathered by studies such as this, will allow better predictions about the effects of conifer release on moose populations and, therefore, this specific economic resource.

## PURPOSE OF STUDY

Suspecting that herbicide use will be reduced, foresters want to know what effects modified use of herbicides will have on crop trees and if this modified use will lessen possible adverse effects on wildlife. This study examined the response of vegetation and moose to Vision® applied at three different rates. Objectives were to discover if hardwood weed species could be controlled with lower than recommended rates, and if lower rates reduced the effect of chemical conifer release on moose.

# STUDY AREA

Study areas, all located within 150 km of Thunder Bay, ON, were chosen in consultation with silviculturalists from Canadian Pacific Forest Products (CPFP) and the Ontario Ministry of Natural Resources (OMNR) [figure 1]. All study areas were mechanically site prepared, planted with Black Spruce (Picea mariana (Mill.) B.S.P.) or Jack Pine (Pinus banksiana Lamb.) between 1980 and 1989, and released with a single aerial (helicopter) application of glyphosate (as Vision®) during August 30 - Sept. 4, 1990. Temperature during spray ranged from 10 - 26°C, relative humidity from 48 - 94%. The seven chosen clearcuts ranged in size from 44 to 95 ha (mean= 71 ha), with total area slightly exceeding 500 ha.

Soils on these upland sites were generally dry, shallow glacial tills over granite bedrock (the Canadian Shield), although sphagnum (Sphagnum spp.)/feathermoss (Hylocomium spendens, Pleurozium schreberi, Ptilium crista-castrensis) bogs were common in the lower areas at the edges of clearcuts. Soil on these sites were classified using the Forest Ecosystem Classification for Northwestern Ontario (Sims et. al. 1989) and Baldwin et. al. (1990). Approximately 40% of browse survey plots were characterized by very shallow mineral soils (soil types SS1, SS2 and SS4), 25% were shallow to moderately deep mineral (SS5, SS6 and SS7), 25% were deep mineral soils (S1, S2, S3 and S9), and 10% were organic (S12S and S12F). Topography was rolling. Temperature was cold; mean daily temperatures for January and July were -18.5°C and +16.1°C, respectively. Precipitation averaged 50.5mm in January and 77.5mm in July (Environment Canada 1992). Table 2 provides a summary of soils, clearcut size, site preparation, sampling intensity, harvest dates and planting dates. These sites were chosen for Vision® application by CPFP because competition was beginning to over-top the planted conifers. Residual dead White Birch (Betula papyrifera Marsh.) and Trembling Aspen (Populus tremuloides Michx.) over-topped the cut areas during spraying.

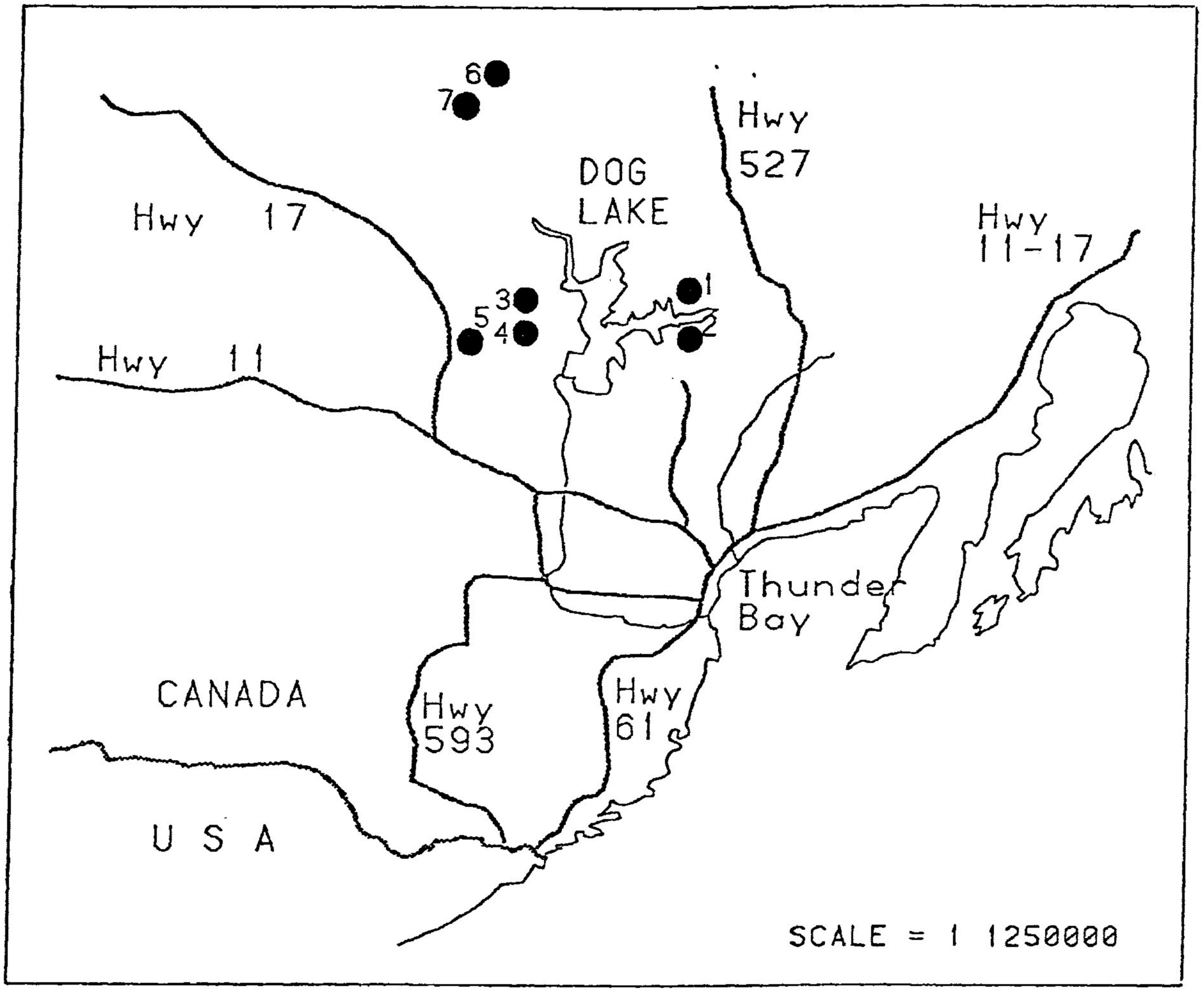


Figure 1. Locations of 7 cutovers near Thunder Bay, Ontario where effects of conifer release (using three concentrations of Vision® herbicide) on moose browse and crop trees were studied.

Appendices C (animal, tree and shrub species) and D (herbaceous species) contain a key to common and scientific names.

Table 2. Descriptions of blocks on which Vision® was applied in late summer 1990 to evaluate the effects of different application rates on moose browse and crop trees.

| Block | Soil | Total Area(ha) | Year Cut | Year Site Prep | Year Plant | Number of Sample Plots/ha Browse | Number of Sample Plots/ha Crop |
|---|---|---|---|---|---|---|---|
| 1 | coarse silty loam | 85 | 1985 | 1988 | 1989 barrel& chain | 2.9 | 1.5 |
| 2 | coarse silty loam | 50 | 1978 | 1980 | 1980-82 bracke | 4.8 | 1.4 |
| 3 | fine loam | 83 | 1986 | 1987 | 1988 barrel& chain | 1.9 | 1.0 |
| 4 | fine loam | 95 | 1986 | 1987 | 1988 barrel& chain | 2.3 | 1.0 |
| 5 | fine silt | 60 | 1987 | 1989 | 1989 barrel& chain | 2.6 | 1.3 |
| 6 | coarse loam | 80 | 1982 | 1985 | 1986 angle blade | 2.1 | 0.9 |
| 7 | coarse loam | 44 | 1982 | 1985 | 1986 power head | 4.4 | 0 |

# METHODS

## 1. SPRAYING

A baseline was established, and marked with posts, that approximately bisected each clearcut (block). From this baseline three transect lines were surveyed that subdivided each block into four sub-blocks. These divisions were made without the aid of the Global Positioning System (GPS) described later, and consequently were not entirely equal in area. Sub-blocks were randomly chosen for spraying by helicopter (Bell 206 Jet Ranger) in late August, 1990, such that each application rate (0.8, 1.06, and 1.60 kg a.e./ha) was applied to a block once, with 1 sub-block remaining as a control (0 kg a.e./ha). Boom length was 9.75 m, with 26 nozzles spaced 0.31 m apart along the centre 7.93 m of the boom. Nozzles were tilted back (from direction of flight) 45°. Swirl plates (D-6) had a 46° swirl. Spraying was at a pressure of 20-22 PSI with a 20 m swath width.

These application levels were determined from previous work (Bell 1989) and from discussions with foresters from CPFP, OMNR, and Monsanto Canada, Inc. Marking and spraying followed the OMNR Aerial Spraying for Forest Management Operational Manual (Carrow et al. 1981).

## 2. EFFECTS OF VISION® ON MOOSE BROWSING

### 2.1 Hardwood Winter Browsing Intensity

Browse surveys were completed between early May and early July in 1990 (pre-spray), 1991 (first year post spray) and 1992 (second year post spray). Each of the sub-blocks within each block was surveyed independently. Browse survey transect lines were run at right angles to the spray path and were similar to those described by Cumming (1987). Using a random start from the baseline, 1x20 m (1/500 ha) sample plots were examined every 20-40 m, depending on sub-block size, along transect lines. Depending on the variability of an area a minimum of 32 and a maximum of 64 sample plots were surveyed from each of the four sub-blocks in each block. On each sample plot, hardwood stems were counted by species and height class: B (0.5-0.99m), C (1-1.99 m), and D

(2m+). Height class A (0.01-0.49m) was not tallied as these small stems would not be available in the winter due to snow cover. All stems were classified as alive, alive browsed, dead or dead browsed.

## 2.2 Winter Aerial Track And Track Aggregate Data

During winter each of the seven clearcuts was surveyed from the air using helicopter and fixed wing aircraft. Aerial tracking commenced when there was sufficient snow cover (mid-December) and ceased in late winter (mid-March), when moose are known to avoid cutovers because of deep snow and crusting (Jackson et al. 1991). Seven flights were completed during the winter of 1989-90, and six flights each for the winters of 1990-91 and 1991-92. Although the number of flights was higher in the first winter observations were spread evenly throughout the whole winter for each year. All clearcuts were circled with the aircraft until tracks had been transcribed onto an aerial photograph of the cut. Land forms (ponds, swamps, clearcut edges) were used to ensure proper placement of the tracks on the photograph. Two to three days after a significant snowfall (to enable good identification of tracks) each clearcut was surveyed again using the same method. Winter track aggregates (a collection of tracks too complicated to represent as a single line) were recorded for the winter of 1991-1992 (one season only). Thus there was no pre-spray data for comparison. These aggregates were represented by delimiting the outside edges of the track aggregates and defining the resultant polygon as a track aggregate. The aerial photos and the winter moose tracks were digitized into Geographic Information System (GIS) (ARC/INFO) coverages (one coverage for each clearcut and year).

During the fall months of 1992, each clearcut was mapped with a Global Positioning System (Software and Hardware supplied by Trimble Navigation). Using this technology, it was possible to locate spray boundaries (i.e. the edge of the clearcut was not necessarily the spray edge) and treatment (i.e. experimental unit) boundaries within the sprayed areas to within 5m (Hurn 1989). Note that for control areas the clearcut edge had to be considered the edge of the experimental unit. Map information was then converted to GIS (ARC/INFO) coverages (one per clearcut) and superimposed onto the corresponding aerial photo coverage using known points. This enabled calculation of amount of track (m/ha) and track aggregate area ($m^2$/ha) within each treatment unit. Information from outside experimental units (and therefore invalid) that may have been included without the use of the GPS system, was eliminated. Erroneously, control areas for block #3 were excluded from observation from aircraft. Thus, there were only six replications for controls versus seven for treated areas.

# 3. VISION® CONTROL OF HARDWOOD COMPETITION

## 3.1 Hardwood Stem Density

Using information gained from the browse survey lines listed above (2.1), stem density on all sprayed areas and controls were calculated.

## 3.2 Available Hardwood Browse Biomass Calculations

Samples of each twig diameter class were cut by undergraduate assistants for all major browse species on a control area central to all blocks.. Major browse species were defined by ranking plant species as a % of diet and in descending order recording those species which contributed 90% of hardwood browse (Beaked Hazel (Corylus cornuta Marsh.), Trembling Aspen, White Birch, Mountain Maple (Acer spicatum Lam.), Willow (Salix spp.), Mountain Ash (Sorbus americana Marsh.), and Pin Cherry (Prunus pensylvanica L. fil)). Samples were also collected for Green Alder (Alnus crispa (Ait.) Pursh). Clipped portions were dried to a constant weight. Regression curves of weight on twig diameter were fitted for calculating biomass of available browse. Jensen and Urness (1981) demonstrated that, for Bitterbrush (Purshia tridentata) and Cliffrose (Cowania stansburiana) shrubs, diameter measurements provide accurate estimates of biomass. For a detailed methodology of calculation of regression curves see Smith (1992). Earlier work (Stronks 1985), completed in an adjacent area, was used for Mountain Ash and Red Osier Dogwood (Cornus stolonifera Michx.). Some regression curves were used for multiple species: Green Alder's curve was used for Speckled Alder (Alnus rugosa (Du roi) Spreng.), and Pin Cherry's curve was used for Service Berry (Amelanchier spp.) and Choke Cherry (Prunus virginiana L.).

On every 8th stem count plot (Every 6th if sampling intensity was low), the number and diameter of browsed and unbrowsed hardwood twigs were recorded, for the first 10 stems encountered per species. Thus each stem was classified by species, height, and twig diameter (mm) class (0<2, 2-4, and >4-6). A twig was defined as a portion of a stem or branch with no sub-branch larger than 6mm. Moose rarely consume twigs or branches larger than this, except when feeding on Mountain Ash (Belovsky 1981). For each treatment unit (sub-block) an average stem biomass, per species and height class was calculated. Diameters were entered into their respective species' regression curve equation to obtain a weight per twig. This number, multiplied by the number of twigs gave available biomass for the tree. These values were averaged within species and height classes for each sub-block. The average biomass for species x, height y, sub-block z, was multiplied by the corresponding # of stems/ha for species x, height y, sub-block z. All species and height classes were added together to obtain total available browse biomass/ha per treatment replication.

## 3.3 Conifer Regeneration Surveys

To evaluate effects of application rates on crop tree growth, circular sample plots (diameter = 2.2m) were located along new transect lines. The crop tree (planted or volunteer) nearest the line at predetermined points served as the plot center. On each crop tree the following was recorded for each year: internode lengths for the current and two previous years, total height, and diameter at 1/3 total height (for 1992 only). Additionally, each year an index of competition from non-crop trees and herbs was visually estimated using cover percentage charts (Ontario Institute of Pedology 1985) for non-crop species. Plants were identified with the aid of Baldwin and Sims (1989). Herbs (including graminoids and raspberry) and hardwood shrubs were assigned percent cover value as separate groups. Dead stems or herbs were not counted as competition. When crop trees were found dead, the plot was dropped from analysis.

**4. SOIL SURVEY:** For methodology and discussion please see appendix A.

**5. DATA ANALYSIS**

The experiment was analyzed as a randomized complete block design using repeated measures analysis of covariance (see appendix F for an ANCOVA table example). Pre-spray data were used as covariates to account for differences that may have existed prior to the experiment. Because this experiment measured the same variables over three successive years it was analyzed as a repeated measures model. Since the first year was used as a covariate, there were two repeated measures for each variable. Because of the nature of count data, all stem density, browsing intensity and biomass data were square root transformed. This enabled the assumptions of normality and homogeneity to be met (Box et al. 1976). For these study areas numbers of dead stems were simply the opposite of live stems. Consequently, only live stems were analyzed. Data for winter track aggregates were also transformed. Lack of fit was more severe, therefore aggregate area was taken to the fourth root. Track length was normally distributed and had homogenous variance. Most regeneration data did not need to be transformed, however crop tree diameter (1992), hardwood shrub cover (1992) and the number of herb species (1992) did not fit the proper residual pattern (i.e. when plotted residuals produced a cone shape, not an even band). In the interests of parsimony and consistency these data were not transformed. Thus, to be conservative, post hoc tests on the three variables listed above were performed using the Games-Howell test ($\alpha = 0.05$). This post hoc test is fairly robust for data that violate assumptions regarding normality and homogeneity (Gagnon et al. 1989). Without exception treatment means for all other dependent variables were compared using Fisher's protected LSD ($\alpha = 0.05$). Data analysis was performed on a Macintosh LCII computer, using the SuperANOVA software package (Abacus Concepts 1989).

# RESULTS

## 1. EFFECTS OF VISION® ON MOOSE BROWSING

### 1.1 Hardwood Winter Browsing Intensity

Treatment had a strong effect on browsing intensity [Table 4]. Little statistical difference in browsing could be detected between successive (i.e. 0 & 0.80, 0.80 & 1.06, 1.06 & 1.60) application rates. Generally, browsing differences were significant only when comparisons involved amounts of applied herbicide that were greater than amounts between successive rates used in this study (i.e. 0 & 1.06, 0 & 1.60, 0.80 & 1.60). To simplify presentation, species that responded similarly to Vision® application were grouped together (groups "A" "B" and "C").

A general pattern suggested by total browsing is followed by all three height classes and group "A" species (Beaked Hazel, Mountain Ash, & Salix) [Table 4, figure 2]. Browsing was lower on plots which received the two highest application rates. Browsing on plots which received the lowest application rate was not statistically different from controls, although browsing rates were still generally lower. Group "B" species (Pin Cherry, White Birch & Trembling Aspen) showed similar results to group "A" but more severe [figure 3]. Browsing on 0.80 kg a.e./ha plots was significantly less than controls [table 4]. Although Aspen responded similarly to Pin Cherry and White Birch, a remarkable browsing decrease also occurred on controls, unlike any other species (figure 3a), thus differences between treatments were not significant. Conversely, browsing on group "C" (Mountain Maple) was not reduced until application rates reached 1.60 kg a.e./ha [table 4]. Group "C" seemed to show a browsing rebound in 1992 at the two lower application rates [figure 4]. Differences among treatments were more subtle than differences between controls and treated areas (*P* values comparing controls with treatments were smaller than p values among sprayed plots). Tables 3a and 3b show actual treatment means (rounded numbers) for different height classes and species.

Generally, browsing on a species was a function of it's occurrence in the environment since browsing was proportionate to availability. Notable exceptions include Mountain Ash (Sorbus americana Marsh.) which was selected for (used in greater proportions in moose diet than in the available environment), and Speckled Alder (Alnus rugosa (Du Roi) Spreng.) and Mountain Maple (Acer spicatum Lam.) which comprised a lower proportion of moose diet than their relative availability. For a more complete presentation of stem availability (i.e. by year) see appendix E.

Table 3a. Intensity of moose browsing: by herbicide application rate, height class, and year (rounded numbers).

*Northwestern Ontario, Canada* — *Number of stems browsed per hectare*

| HEIGHT CLASS year | VISION® application rate (kg a.e. • $ha^{-1}$) 0.00 | 0.80 | 1.06 | 1.60 | ANNUAL TOTAL |
|---|---|---|---|---|---|
| B(0.50-0.99m) | | | | | |
| 1990 | 670 | 740 | 700 | 620 | 2 700 |
| 1991 | 430 | 290 | 260 | 330 | 1 300 |
| 1992 | 620 | 530 | 340 | 150 | 1 600 |
| C(1.00-1.99m) | | | | | |
| 1990 | 2 900 | 3 300 | 3 100 | 2 800 | 12 100 |
| 1991 | 1 700 | 1 500 | 1 000 | 1 200 | 5 400 |
| 1992 | 2 000 | 1 400 | 700 | 320 | 4 400 |
| D(2.00m+) | | | | | |
| 1990 | 160 | 450 | 380 | 300 | 1 300 |
| 1991 | 130 | 120 | 160 | 100 | 510 |
| 1992 | 230 | 90 | 90 | 50 | 460 |
| TOTALS (all heights.) | | | | | |
| 1990 | 3 700 | 4 500 | 4 200 | 3 700 | 16 100 |
| 1991 | 2 300 | 1 900 | 1 400 | 1 600 | 7 200 |
| 1992 | 2 900 | 2 000 | 1 100 | 520 | 6 500 |
| GRAND TOTALS | 8 800 | 8 400 | 6 700 | 5 900 | 29 800 |

Table 3b. Intensity of moose browsing: by herbicide application rate, hardwood species and year (rounded numbers).

| *Northwestern Ontario, Canada* | | | | *Number of stems browsed per hectare* | |
|---|---|---|---|---|---|
| | VISION® application rate (kg a.e. • ha$^{-1}$) | | | | |
| SPECIES year | 0.00 | 0.80 | 1.06 | 1.60 | ANNUAL TOTAL |
| Beaked Hazel | | | | | |
| 1990 | 1 200 | 1 300 | 1 600 | 1 100 | 5 200 |
| 1991 | 900 | 720 | 310 | 570 | 2 500 |
| 1992 | 1 400 | 1 100 | 630 | 110 | 3 200 |
| Mountain Ash | | | | | |
| 1990 | 300 | 150 | 280 | 410 | 1 100 |
| 1991 | 180 | 170 | 190 | 210 | 750 |
| 1992 | 180 | 70 | 10 | 70 | 330 |
| Mountain Maple | | | | | |
| 1990 | 270 | 650 | 400 | 240 | 1 600 |
| 1991 | 200 | 190 | 100 | 160 | 650 |
| 1992 | 250 | 340 | 220 | 40 | 850 |
| Pin Cherry | | | | | |
| 1990 | 210 | 180 | 220 | 290 | 900 |
| 1991 | 230 | 100 | 130 | 150 | 610 |
| 1992 | 240 | 40 | 30 | 40 | 350 |
| Salix spp. | | | | | |
| 1990 | 250 | 200 | 370 | 470 | 1300 |
| 1991 | 180 | 140 | 270 | 250 | 840 |
| 1992 | 110 | 90 | 40 | 180 | 420 |
| Trembling Aspen | | | | | |
| 1990 | 1 100 | 1 200 | 1 100 | 850 | 4300 |
| 1991 | 200 | 280 | 160 | 250 | 890 |
| 1992 | 200 | 150 | 140 | 40 | 530 |
| White Birch | | | | | |
| 1990 | 330 | 400 | 260 | 340 | 1 300 |
| 1991 | 420 | 320 | 260 | 230 | 1 200 |
| 1992 | 510 | 110 | 70 | 30 | 720 |
| TOTALS (all spp.) | | | | | |
| 1990 | 3 700 | 4 500 | 4 200 | 3 700 | 16 100 |
| 1991 | 2 300 | 1 900 | 1 400 | 1 600 | 7 200 |
| 1992 | 2 900 | 2 000 | 1 100 | 520 | 6 500 |
| GRAND TOTALS | 8 800 | 8 400 | 6 700 | 5 900 | 29 800 |

Table 4. Treatment pairwise comparison (browsing intensity) of *P* values[1]

| | APPLICATION RATE (kg a.e./ha) COMPARISON | | | | | |
|---|---|---|---|---|---|---|
| | controls Vs treated | | | among treatments | | |
| | 0.00 0.80 | 0.00 1.06 | 0.00 1.60 | 0.80 1.06 | 0.80 1.60 | 1.06 1.60 |
| Total Browsed Stems/ha | no | .0050 | .0018 | no | .0424 | no |
| Height Class | | | | | | |
| B 0.50-0.99m | no | .0193 | .0024 | no | .0494 | no |
| C 1.00-1.99m | no | .0064 | .0036 | no | .0490 | no |
| D 2.00m+ | no | .0270 | .0033 | no | no | no |
| Species | | | | | | |
| Beaked Hazel | no | .0170 | .0021 | no | .0127 | no |
| Mountain Ash | no | .0482 | no | no | no | no |
| Mountain Maple | no | no | .0408 | no | .0108 | no |
| Pin Cherry | .0002 | .0001 | .0015 | no | no | no |
| Salix spp. | no | no | no | no | no | no |
| Trembling Aspen | no | no | no | no | no | no |
| White Birch | .0250 | .0078 | .0019 | no | no | no |

[1] non significant *P* values not included.

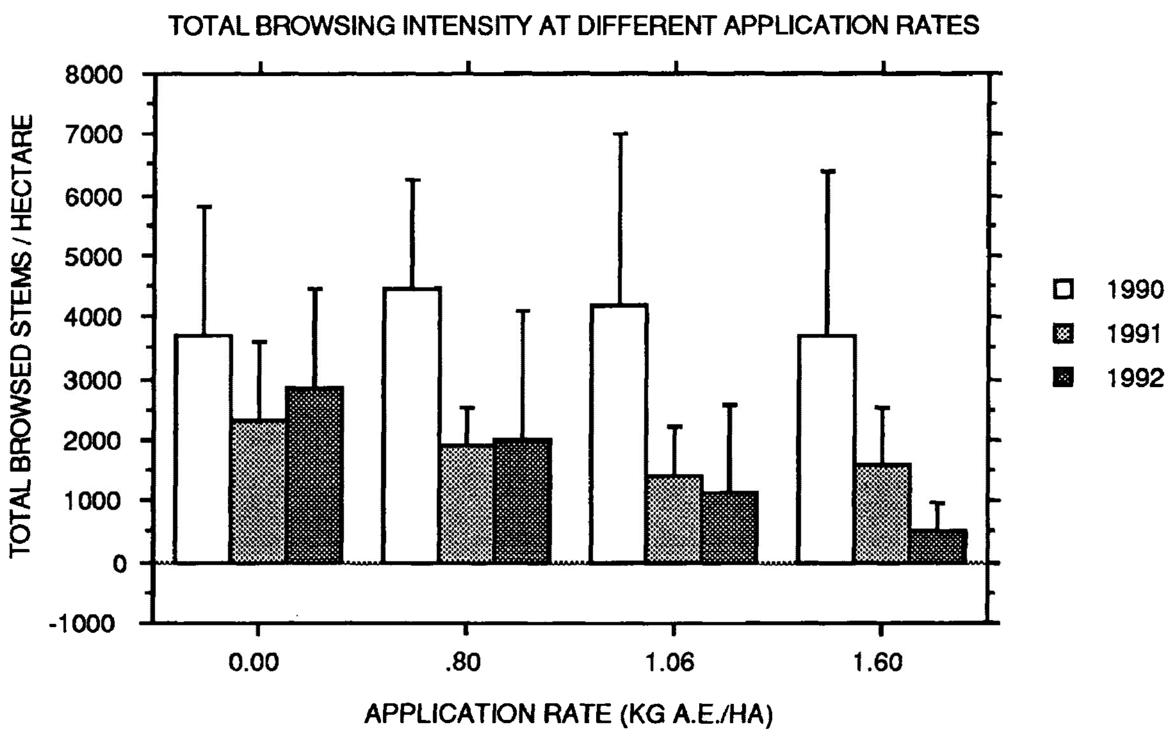


Figure 2 Browsing intensity group "A" (Beaked Hazel, Mountain Ash, Salix spp.), represented by total browsing intensity with 95% confidence error bars at three application rates of Vision® herbicide and a control.

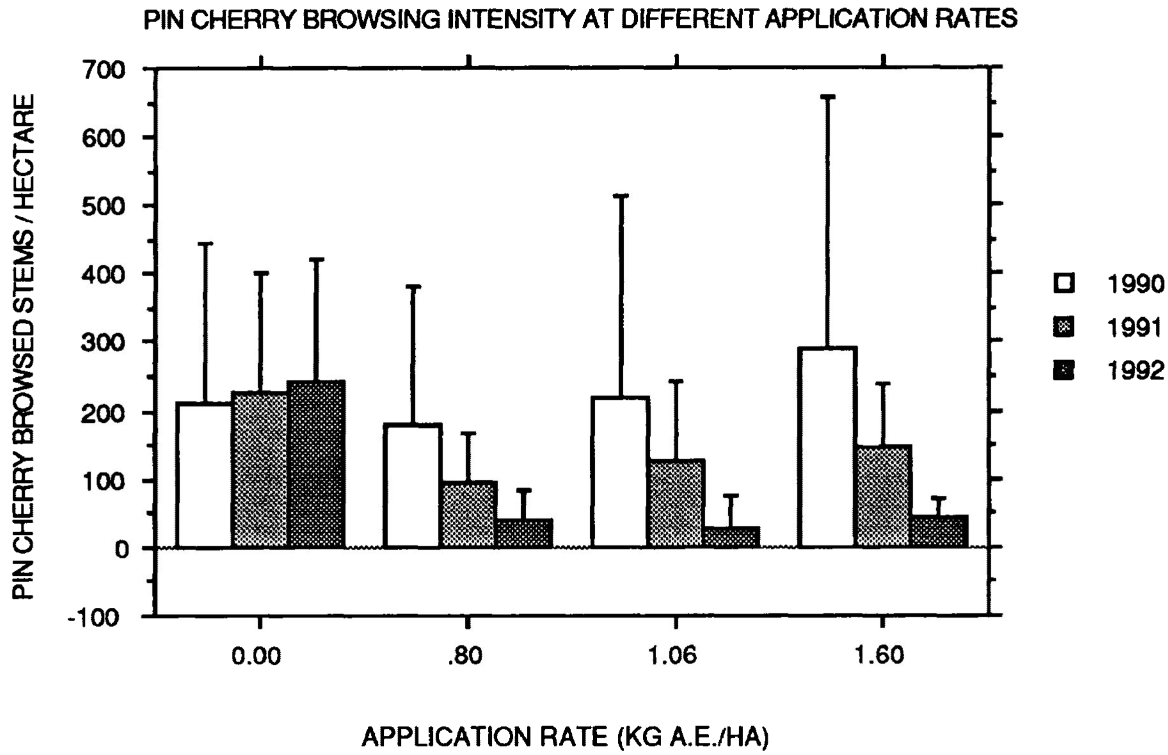


Figure 3 a. Browsing intensity group "B" (Pin Cherry, Trembling Aspen & White Birch) represented by Pin Cherry with 95% confidence error bars at three application rates of Vision® herbicide and a control.

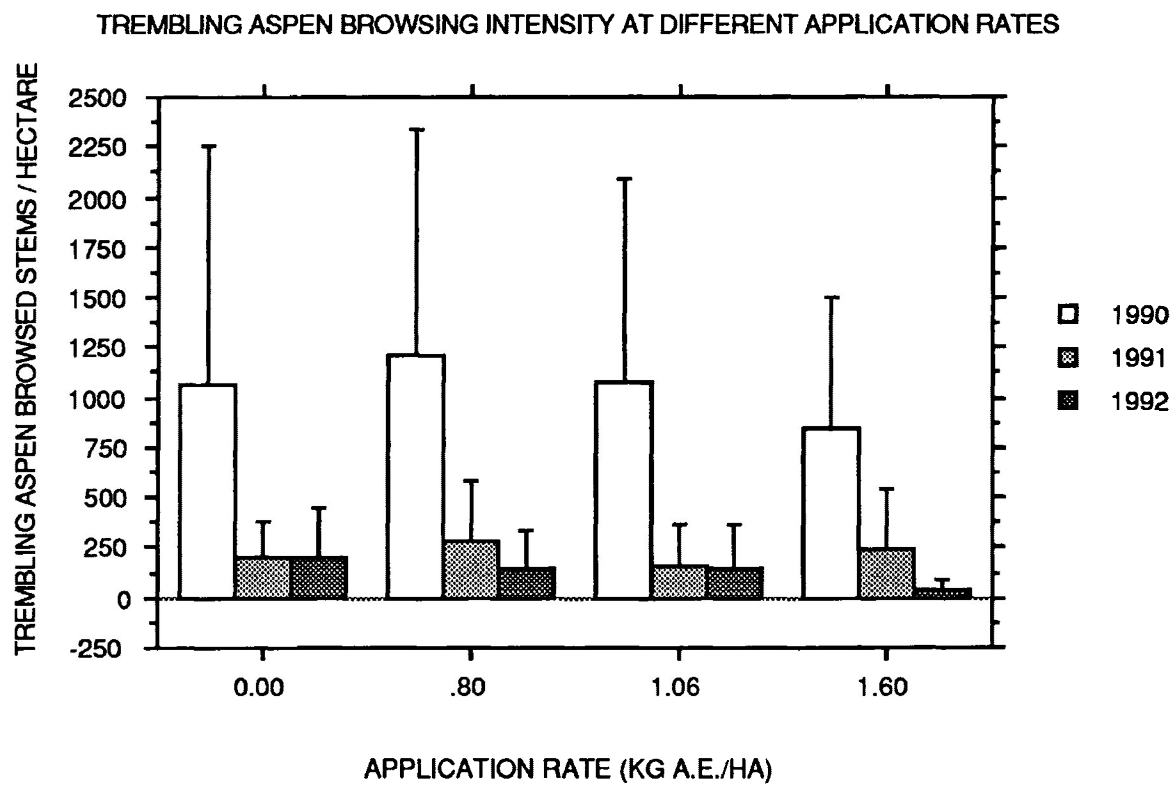


Figure 3 b. Total browsing intensity trembling aspen with 95% confidence error bars at three application rates of Vision® herbicide and a control.

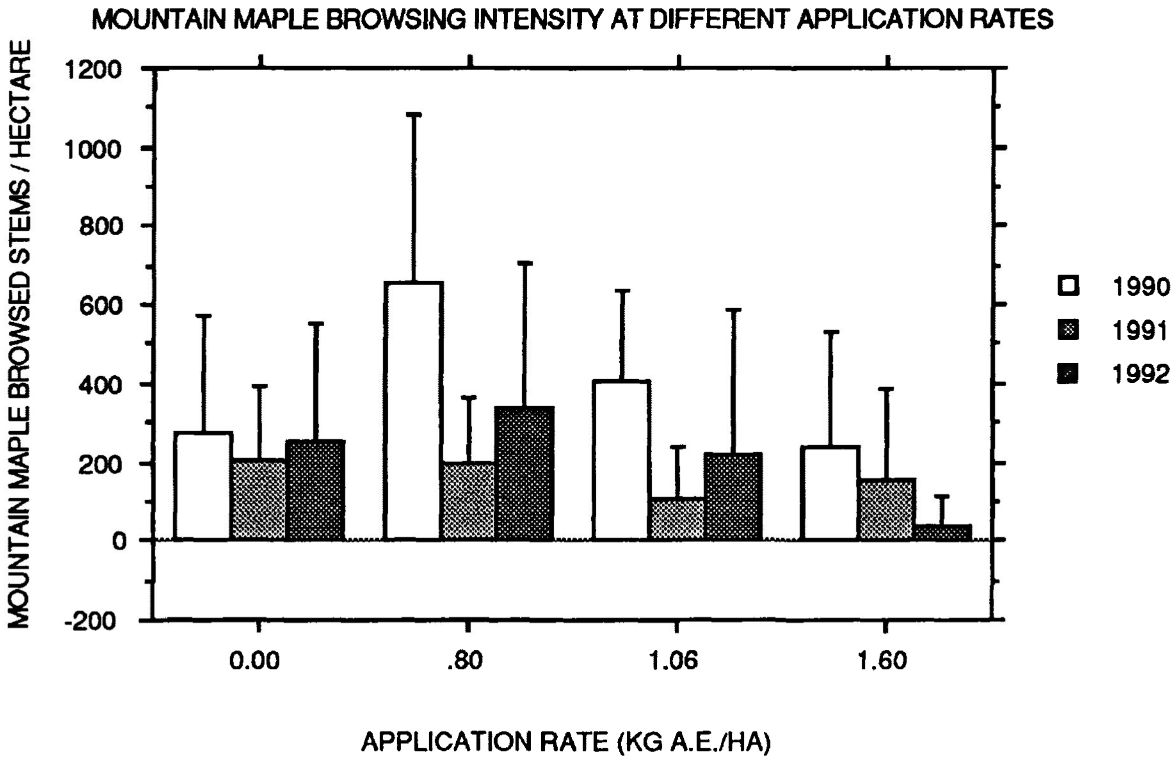


Figure 4 Browsing intensity group "C" (Mountain Maple) with 95% error bars at three application rates of Vision® herbicide and a control.

## 1.2 Winter Track and Track Aggregates

Pre-spray data (winter 1989-1990) could not explain any variance in the data ($P$= 0.55). The different application rates did not effect track length ($P$= .34). However, there were significant differences in track lengths in different clearcuts ($P$= 0.01) [figure 5]. Figures 20 a-g in appendix b show tracks (three winters) and aggregates (recorded in the third winter only) for each individual clearcut.

Similar track length in all treatments demonstrate that moose are not deterred from entering sprayed areas. Immediately post spray, track length was consistently greater (although not statistically) than pre-spray track at all application rates, and approximately equal two winters after treatment. When data were analyzed on a per year basis (i.e. all treatments summed together) significantly more tracks were recorded in

1990-1991 than pre-spray (1989-1990) or two seasons post spray (1991-1992) (*P*= 0.0001).

No significant differences occurred for either blocks or treatment for track aggregates. However, aggregate area was considerably lower in 1.06 kg a.e./ha sub-blocks (approximately half) than in other treatments. Interestingly, this application rate also resulted in the greatest control of hardwood browse species (i.e. the lowest live stem density). However, when aggregate area was regressed on percent live stems (data from spring 1991 as aggregates were recorded in the winter of 1991-1992), no relationship was observed (R squared = 0.00003).

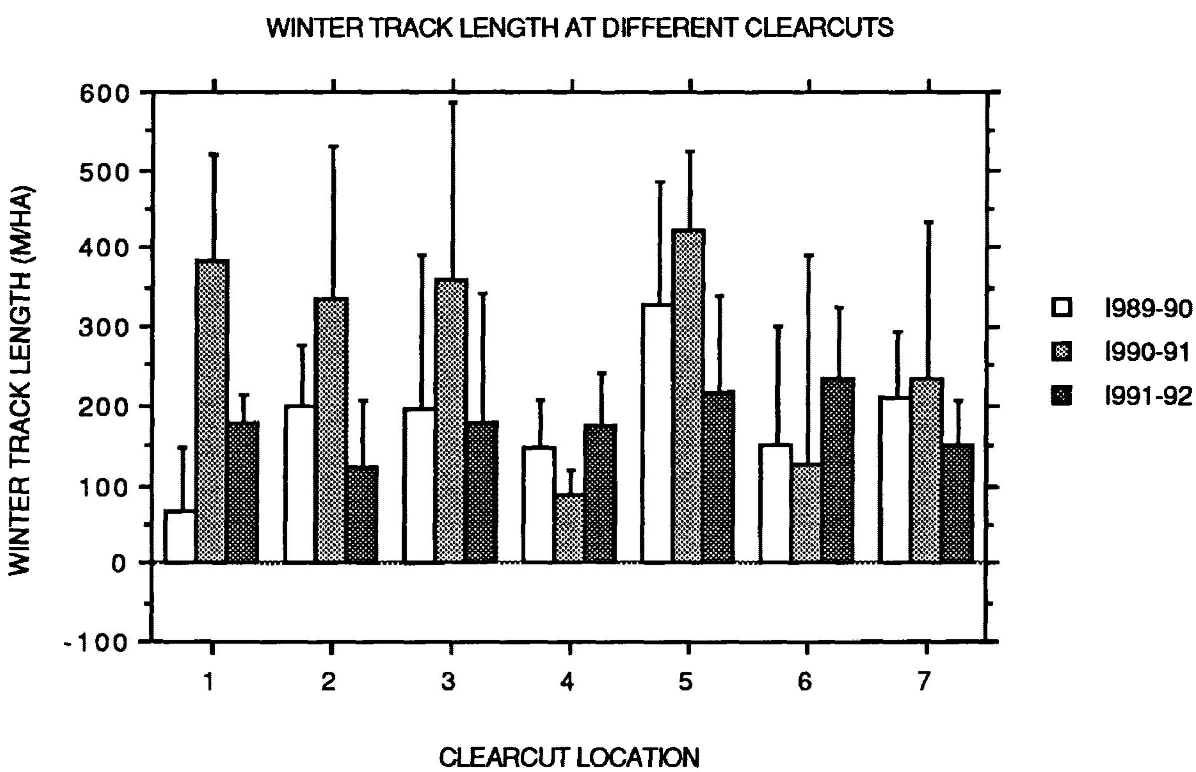


Figure 5. Length of winter tracks with 95% confidence error bars at seven different study areas.

# 2. VISION® CONTROL OF HARDWOOD COMPETITION

## 2.1 Hardwood Stem Density

Treatment consistently reduced live stem density [Table 6]. When total stem density was analyzed, all sprayed areas had lower living stem density than controls. Differences among treatments were more subtle, the only significant difference was between 0.80 kg a.e./ha and 1.06 kg a.e./ha [Table 6, figure 6]. To simplify presentation, species that responded similarly to Vision® application were grouped together (groups "A" "B" and "C").

When stem density was broken down by species and height class a pattern similar to browsing intensity emerged. In most cases all treatments had lower live stem densities than controls, but there was little difference among treatments [Table 6]. Group "A" species (Mountain Maple, Green Alder, Trembling Aspen, Pin Cherry, Salix & White Birch) are representative of this [figure 6]. Notable exceptions to this include height class C, where the lower application rate did not control hardwoods as well as the two higher rates. Group "B" (Beaked Hazel, Mountain Ash, Service Berry & Speckled Alder) demonstrated either resistance or resprouting proficiency as density figures increased in 1992 on the two highest application rates [figure 7]. The only application rate that lowered Mountain Ash density significantly was 1.06 kg a.e./ha. Speckled Alder density was reduced only at the lower two application rates. Group "C" (Choke Cherry & Red Osier Dogwood) [figure 8] severely deviated from the general pattern . No differences between treatments were observed for the latter and the only pair of treatments that differed statistically for Choke Cherry were 1.06 kg a.e./ha and 1.60 kg a.e./ha, with the lower rate resulting in more kill. Actual treatment means (rounded numbers) for height classes and species are presented in Tables 5a and 5b.

Table 5a. Live hardwood stem density: by herbicide application rate, height class, and year (rounded numbers).

*Northwestern Ontario, Canada* — *Number of stems browsed per hectare*

| HEIGHT year | VISION® application rate (kg a.e. • $ha^{-1}$) 0.00 | 0.80 | 1.06 | 1.60 | ANNUAL TOTAL |
|---|---|---|---|---|---|
| B (0.50-0.99m) | | | | | |
| 1990 | 6 000 | 5 700 | 4 300 | 4 700 | 20 700 |
| 1991 | 7 300 | 3 500 | 2 000 | 2 600 | 15 400 |
| 1992 | 7 800 | 4 200 | 2 500 | 2 400 | 16 900 |
| C(1.00-1.99m) | | | | | |
| 1990 | 13 600 | 17 500 | 15 100 | 12400 | 58 600 |
| 1991 | 17 400 | 11 400 | 5 500 | 5 800 | 40 100 |
| 1992 | 14 500 | 8 500 | 4 700 | 4 000 | 31 700 |
| D(2.00+m) | | | | | |
| 1990 | 1 700 | 3 500 | 2 100 | 1 700 | 9 000 |
| 1991 | 2 400 | 1 300 | 1 200 | 720 | 5 600 |
| 1992 | 3 400 | 2 000 | 1 300 | 960 | 7 700 |
| TOTALS (all heights) | | | | | |
| 1990 | 21 300 | 26 800 | 21 500 | 18 800 | 88 400 |
| 1991 | 27 100 | 16 300 | 8 600 | 9 000 | 61 100 |
| 1992 | 26 000 | 14 600 | 8 600 | 7 400 | 56 500 |
| GRAND TOTALS | 74 400 | 57 600 | 38 800 | 35 200 | 206 100 |

Table 5b. Live hardwood stem density: by herbicide application rate, species and year (rounded numbers).

*Northwestern Ontario, Canada* — *Number of stems browsed per hectare*

| SPECIES year | VISION® application rate (kg a.e. • $ha^{-1}$) 0.00 | 0.80 | 1.06 | 1.60 | ANNUAL TOTAL |
|---|---|---|---|---|---|
| Beaked Hazel | | | | | |
| 1990 | 8 600 | 7 100 | 7 500 | 5 700 | 28 900 |
| 1991 | 11 400 | 5 100 | 1 900 | 1 200 | 19 600 |
| 1992 | 10 800 | 4 000 | 3 200 | 1 900 | 19 900 |
| Choke Cherry | | | | | |
| 1990 | 290 | 640 | 300 | 560 | 1 800 |
| 1991 | 80 | 50 | 30 | 160 | 320 |
| 1992 | 30 | 60 | 70 | 180 | 340 |
| Green Alder | | | | | |
| 1990 | 410 | 810 | 710 | 640 | 2 600 |
| 1991 | 570 | 590 | 450 | 660 | 2 300 |
| 1992 | 680 | 570 | 250 | 520 | 2 000 |
| Mountain Ash | | | | | |
| 1990 | 510 | 540 | 520 | 680 | 2 300 |
| 1991 | 510 | 310 | 290 | 350 | 1 500 |
| 1992 | 590 | 360 | 250 | 460 | 1 700 |

| | | | | | |
|---|---|---|---|---|---|
| Mountain Maple | | | | | |
| 1990 | 3 000 | 6 700 | 4 100 | 2 600 | 16 400 |
| 1991 | 5 100 | 5 800 | 2 800 | 2 500 | 16 200 |
| 1992 | 4 400 | 5 100 | 2 300 | 1 000 | 12 800 |
| Pin Cherry | | | | | |
| 1990 | 910 | 670 | 860 | 1 100 | 3 500 |
| 1991 | 1 200 | 360 | 490 | 710 | 2 800 |
| 1992 | 1 400 | 290 | 310 | 320 | 2 300 |
| Red Osier Dogwood | | | | | |
| 1990 | 420 | 170 | 310 | 520 | 1 400 |
| 1991 | 700 | 120 | 140 | 70 | 1 000 |
| 1992 | 100 | 170 | 110 | 90 | 470 |
| Salix spp. | | | | | |
| 1990 | 740 | 720 | 870 | 1 100 | 3 400 |
| 1991 | 980 | 420 | 400 | 650 | 2 500 |
| 1992 | 1 000 | 470 | 340 | 600 | 2 400 |
| Service Berry | | | | | |
| 1990 | 380 | 450 | 420 | 500 | 1 800 |
| 1991 | 710 | 270 | 200 | 320 | 1 500 |
| 1992 | 780 | 310 | 200 | 360 | 1 700 |
| Speckled Alder | | | | | |
| 1990 | 980 | 450 | 1 000 | 1 300 | 3 700 |
| 1991 | 760 | 150 | 140 | 590 | 1 600 |
| 1992 | 1 100 | 360 | 290 | 820 | 2 600 |
| Trembling Aspen | | | | | |
| 1990 | 4 000 | 5 900 | 3 900 | 2 900 | 16 700 |
| 1991 | 3 500 | 2 400 | 1 200 | 1 000 | 8 100 |
| 1992 | 3 100 | 2 000 | 850 | 640 | 6 600 |
| White Birch | | | | | |
| 1990 | 1 100 | 2 600 | 1 000 | 1 200 | 5 900 |
| 1991 | 1 600 | 750 | 600 | 830 | 3 800 |
| 1992 | 2 000 | 860 | 490 | 480 | 3 800 |
| Total Stems | | | | | |
| 1990 | 21 300 | 26 800 | 21 500 | 18 800 | 88 400 |
| 1991 | 27 100 | 16 300 | 8 600 | 9 000 | 61 100 |
| 1992 | 26 000 | 14 600 | 8 700 | 7 400 | 56 500 |
| GRAND TOTALS | 74 400 | 57 600 | 38 800 | 35 200 | 206 100 |

Table 6. Treatment pairwise comparison (live stem density) of *P* values[1]

| | APPLICATION RATE (kg a.e./ha) COMPARISON | | | | | |
|---|---|---|---|---|---|---|
| | controls Vs treated | | | among treatments | | |
| | 0.00 / 0.80 | 0.00 / 1.06 | 0.00 / 1.60 | 0.80 / 1.06 | 0.80 / 1.60 | 1.06 / 1.60 |
| Total Live Stems/ha | .0087 | .0001 | .0002 | .0453 | no | no |
| Height B 0.50-0.99m | .0017 | .0001 | .0001 | no | no | no |
| C 1.00-1.99m | .0270 | .0002 | .0002 | .0408 | .0384 | no |
| D 2.00m+ | .0250 | .0032 | .0012 | no | no | no |
| Species Beaked Hazel | .0094 | .0004 | .0001 | no | .0289 | no |
| Choke Cherry | no | no | no | no | no | .0206 |
| Green Alder | no | no | no | no | no | no |
| Mountain Ash | no | .0355 | no | no | no | no |
| Mountain Maple | no | no | .0259 | .0488 | .0087 | no |
| Pin Cherry | .0006 | .0006 | .0035 | no | no | no |
| Red Osier Dogwood | no | no | no | no | no | no |
| *Salix* spp. | .0069 | .0020 | .0243 | no | no | no |
| Service Berry | .0040 | .0013 | .0122 | no | no | no |
| Speckled Alder | .0466 | .0311 | no | no | no | no |
| Trembling Aspen | no | .0029 | .0029 | no | no | no |
| White Birch | .0190 | .0014 | .0057 | no | no | no |

1 non significant *P* values not included.
underlining denotes low application rate with heavier kill

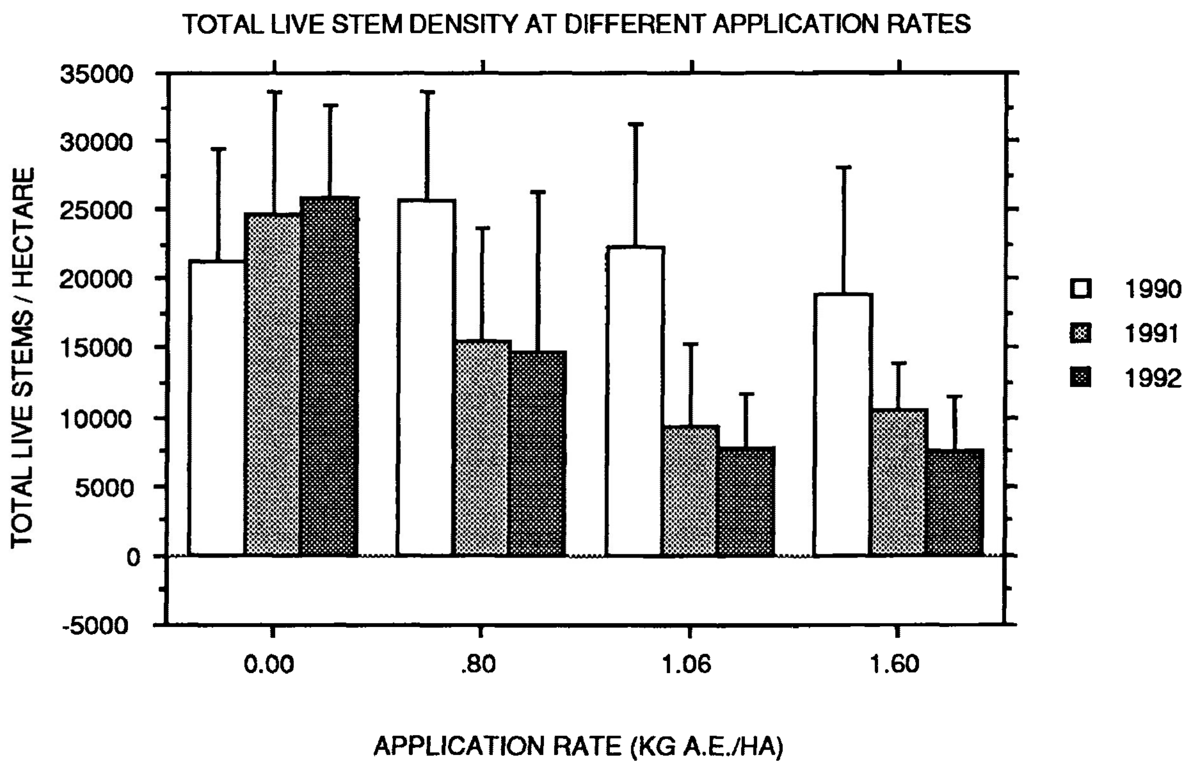


Figure 6. Live stem density group "A" (Mountain Maple, Green Alder, Trembling Aspen, Pin Cherry, *Salix* spp. & White Birch) represented by total live stem density with 95% confidence error bars at three application rates of Vision® herbicide and a Control

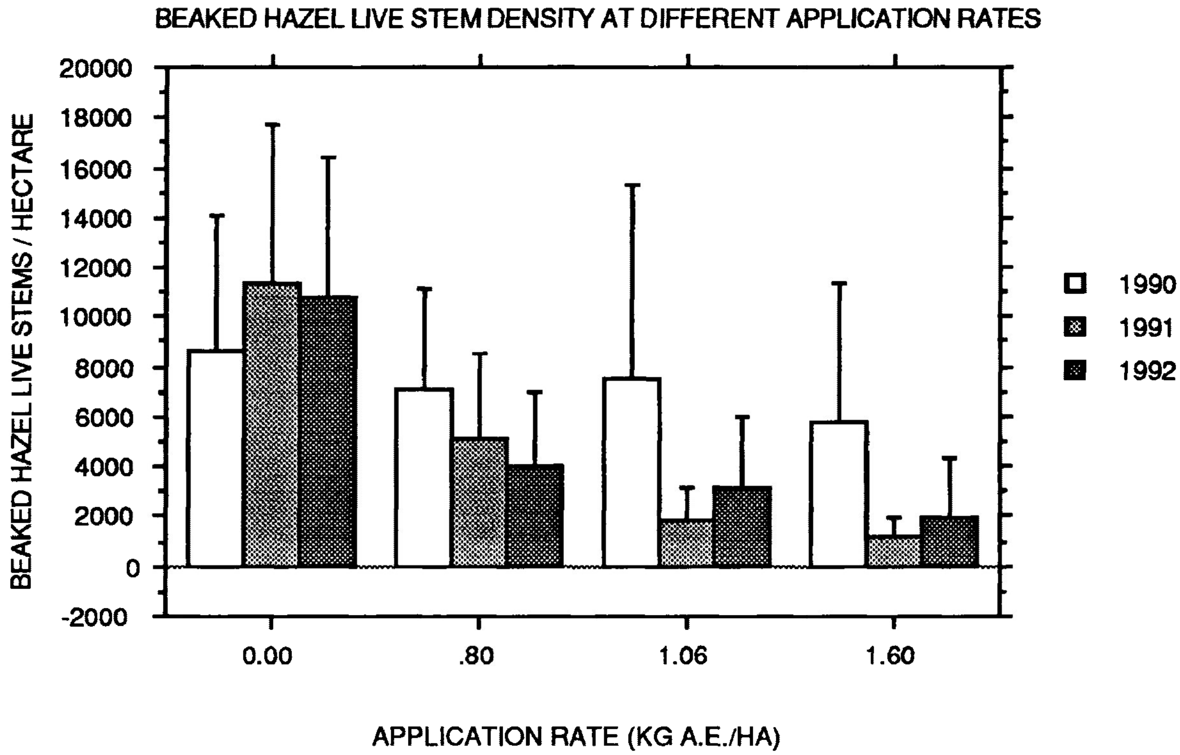


Figure 7. Live stem density group "B" (Beaked Hazel, Mountain Ash, Service Berry & Speckled Alder), represented by Beaked Hazel with 95% error bars at three application rates of Vision® herbicide and a control

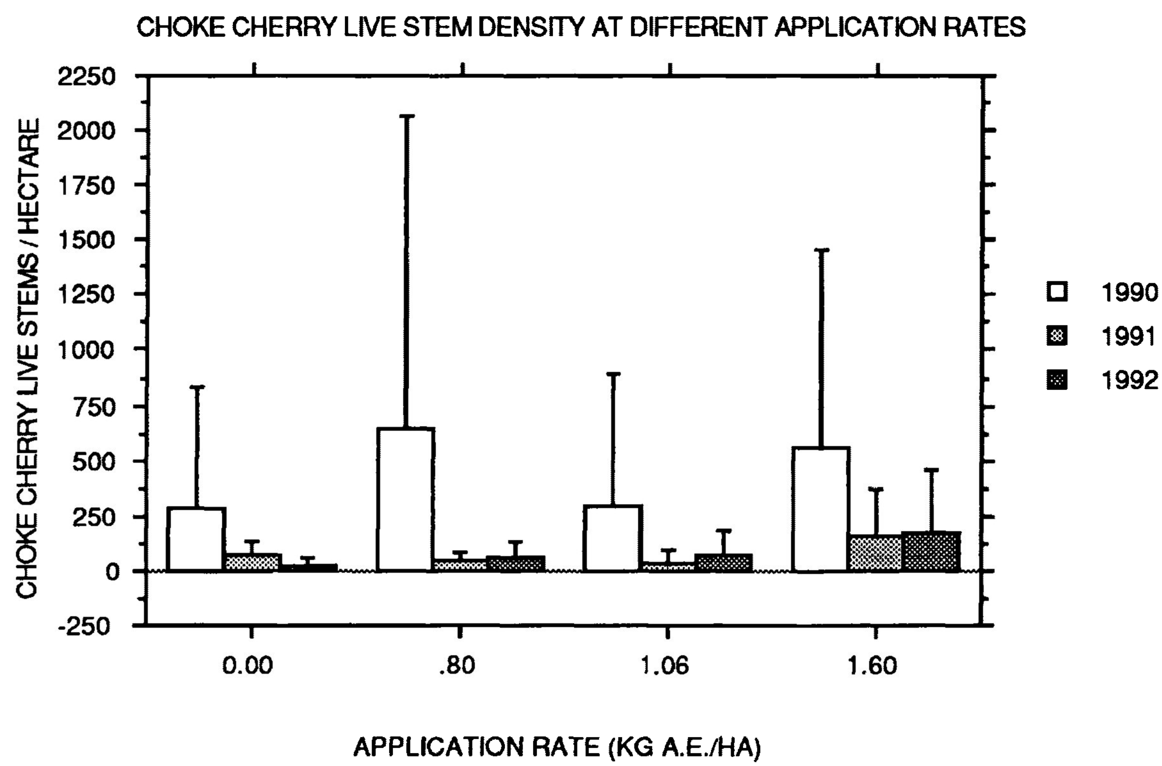


Figure 8 Live stem density group "C" (Red Osier Dogwood & Choke Cherry), represented by Choke Cherry with 95 % confidence error bars.

## 2.2 Available Hardwood Browse Biomass

All treatments reduced browse biomass (*P*=.0012). As application rate increased, biomass on treated plots decreased. Although the difference among application rates was not statistically significant, these trends suggest a more linear response to herbicide concentration than stem density. Tables 7 and 8 give treatment means and *P* values for different application rates. Figure 9 provides a graphic representation of the data.

Table 7. Treatment means of available browse biomass (kg/ha)

| | APPLICATION RATE (kg a.e./ha) | | | |
|---|---|---|---|---|
| | 0.00 | 0.80 | 1.06 | 1.60 |
| browse biomass (kg/ha) | | | | |
| 1990 | 1200 | 1800 | 1350 | 1130 |
| 1991 | 2750 | 1230 | 820 | 580 |
| 1992 | 2720 | 1310 | 610 | 430 |

Table 8. Treatment pairwise comparison (available browse biomass) of *P* values[1]

| | APPLICATION RATE (kg a.e./ha) COMPARISON | | | | | |
|---|---|---|---|---|---|---|
| | controls Vs treated | | | among treatments | | |
| | 0.00 | 0.00 | 0.00 | 0.80 | 0.80 | 1.06 |
| | 0.80 | 1.06 | 1.60 | 1.06 | 1.60 | 1.60 |
| browse biomass (kg/ha) | .0193 | .0010 | .0002 | no | no | no |

[1] non significant *P* values not included.

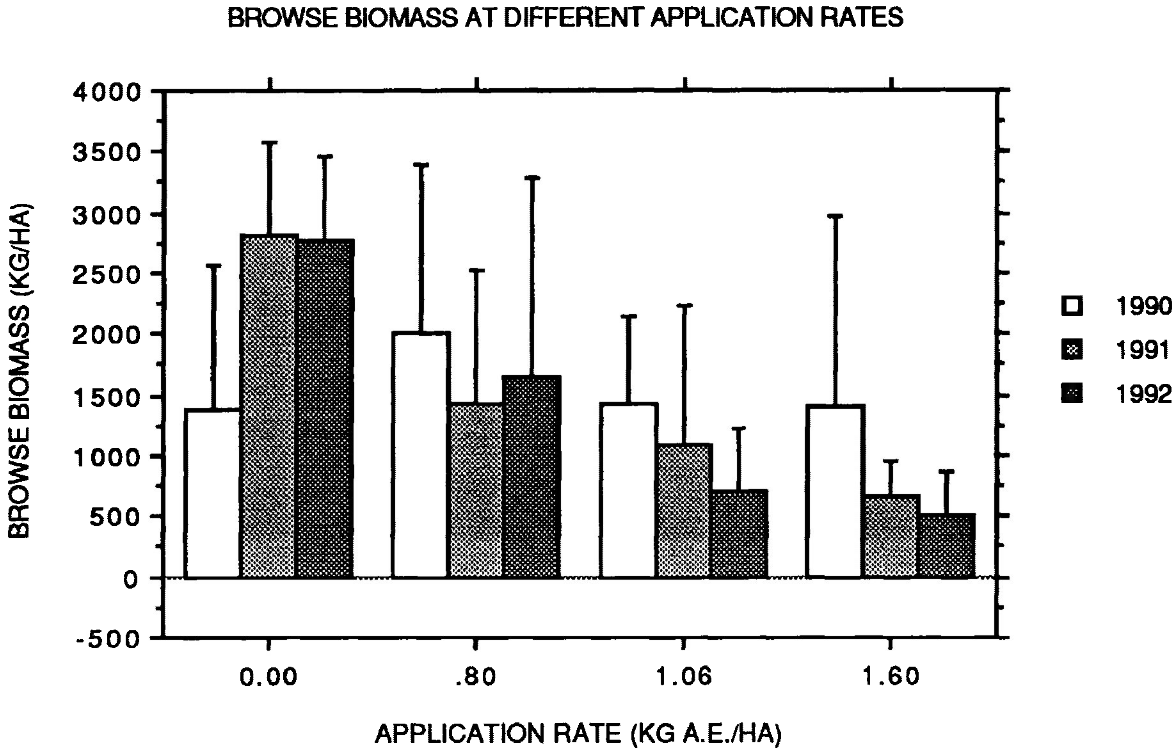


Figure 9. Browse biomass with 95% confidence error bars at three application rates of Vision® herbicide and a control.

## 2.3 Conifer Regeneration Surveys

Treatment in late August 1990 had no direct measurable positive effect on conifer crop trees. Neither height growth nor diameter (measured in 1992 only) was significantly increased by application of Vision® herbicide. However, although not significantly different than other application rates, diameter was highest at the intermediate application rate of 1.06 kg a.e./ha, suggesting that a future difference might develop. More striking was the fact that height growth increased on controls each year but decreased on treated plots one year post spray [figure 10]. Perhaps the conifers underwent a shock stress.

Hardwood shrub cover was reduced (p=.0001) [Table 10, Figure 11] by application of Vision®. All treatments had lower hardwood cover than controls. The intermediate rate controlled hardwood brush better than the lower rate. Interestingly the highest rate was no different from the lowest rate, even though no significant difference was found between 1.06 kg a.e./ha and 1.60 kg a.e./ha [Table 10]. Herbaceous cover and # herb species were not significantly affected by application of Vision® [Table 10]. There was a considerable reduction in herbaceous cover one year post spray, however any reduction was temporary as herbaceous cover rebounded within two years. Herbaceous cover was almost identical in 1992 on all controls and treated areas [Table 9, Figure 12]. Although there was a steady increase in the number of herbaceous species, this occurred on both treated areas and controls, thus it was probably not a result of the spray.

Application of Vision® did not increase recruitment of crop trees [Table 11, Figure 13]. In fact, areas sprayed with 1.06 (P=0.0019) kg a.e./ha and 1.60 (P=0.0396) a.e./ha experienced more mortality than controls. (For purposes of this study lost trees were assumed to be dead. The most plausible reason for not finding the seedlings was complete overtopping by competing herbaceous vegetation). Table 11 presents a detailed account of dead and lost trees.

Table 9. Treatment means of regeneration data

| | APPLICATION RATE (kg a.e./ha) | | | |
|---|---|---|---|---|
| | 0.00 | 0.80 | 1.06 | 1.60 |
| CROP TREES | | | | |
| diameter(cm) | | | | |
| 1992 | 1.126 | 1.260 | 1.418 | 1.347 |
| height growth(cm) | | | | |
| 1990 | 13.45 | 16.34 | 17.38 | 17.45 |
| 1991 | 15.86 | 15.04 | 14.62 | 16.58 |
| 1992 | 17.44 | 20.76 | 20.17 | 19.01 |
| COMPETITION | | | | |
| hardwood shrub cover(%) | | | | |
| 1990 | 33.0 | 37.7 | 29.1 | 30.5 |
| 1991 | 37.2 | 17.7 | 8.1 | 17.2 |
| 1992 | 31.9 | 17.6 | 11.8 | 15.7 |
| herbaceous cover(%) | | | | |
| 1990 | 76.1 | 70.7 | 75.3 | 73.1 |
| 1991 | 66.6 | 48.3 | 43.9 | 46.8 |
| 1992 | 59.3 | 59.3 | 59.9 | 57.8 |
| #herb species/plot | | | | |
| 1990 | 5.6 | 5.6 | 5.8 | 5.9 |
| 1991 | 7.6 | 7.4 | 7.4 | 6.7 |
| 1992 | 8.2 | 9.3 | 9.1 | 11.0 |

Table 10. Treatment pairwise comparison (regeneration surveys) of p values[1]

| | APPLICATION RATE (kg a.e./ha) COMPARISON | | | | | |
|---|---|---|---|---|---|---|
| | control Vs treated | | | among treatments | | |
| | 0.00 0.80 | 0.00 1.06 | 0.00 1.60 | 0.80 1.06 | 0.80 1.60 | 1.06 1.60 |
| CROP TREES | | | | | | |
| diameter (1992 only) | no | no | no | no | no | no |
| height growth | no | no | no | no | no | no |
| COMPETITION | | | | | | |
| hardwood shrub cover | .0001 | .0001 | .0001 | .0345 | no | no |
| herbaceous cover | no | no | no | no | no | no |
| # herb species | no | no | no | no | no | no |

1 non significant p values not included.

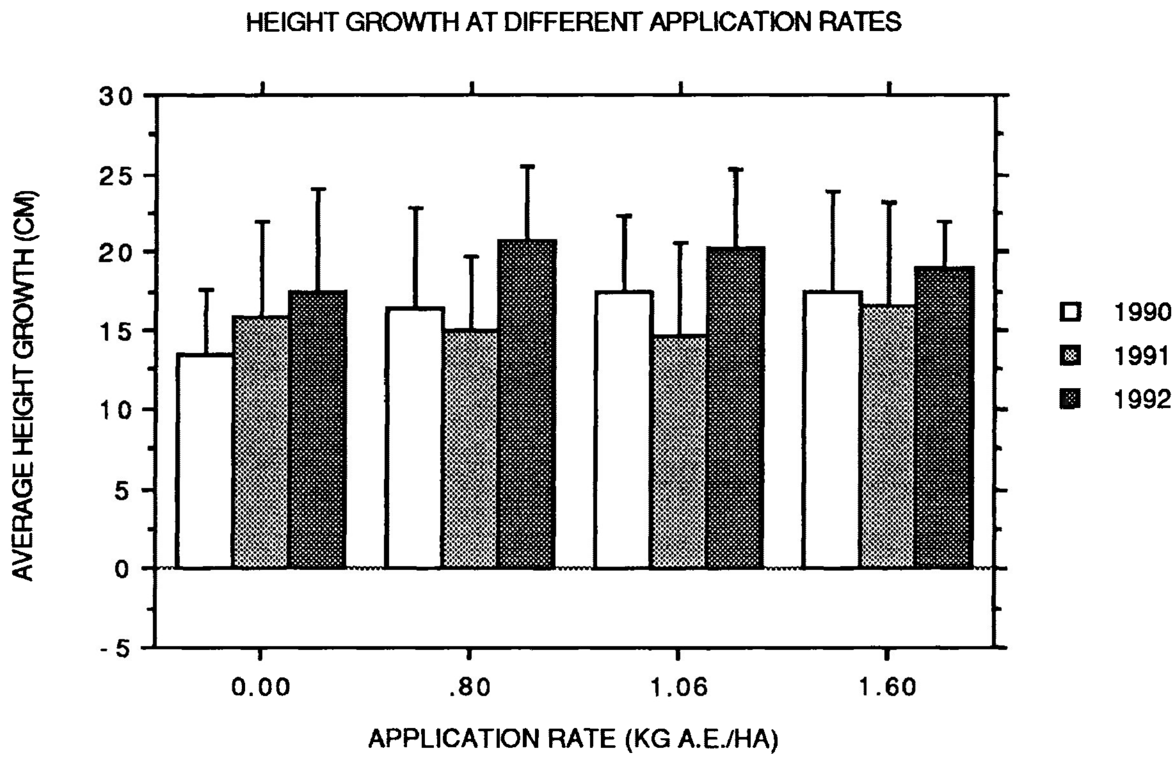


Figure 10. Height growth of crop trees with 95% confidence error bars at three application rates of Vision® herbicide and a control.

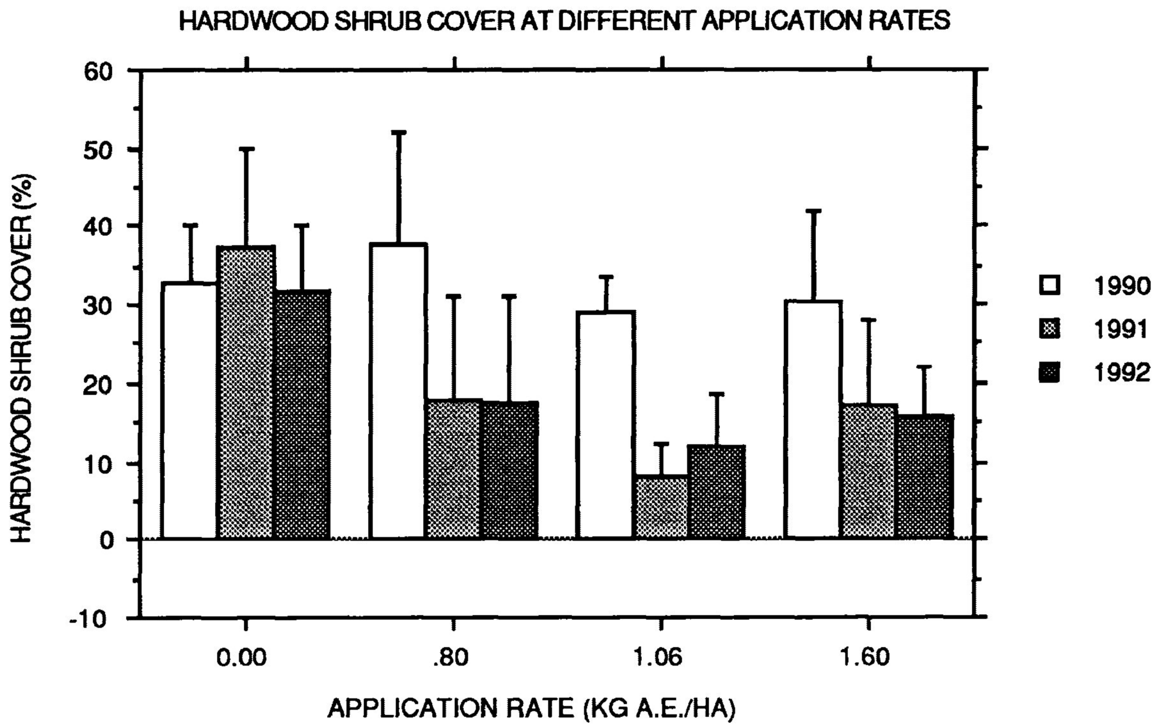


Figure 11. Hardwood shrub cover with 95% confidence error bars at three application rates of Vision® herbicide and a control.

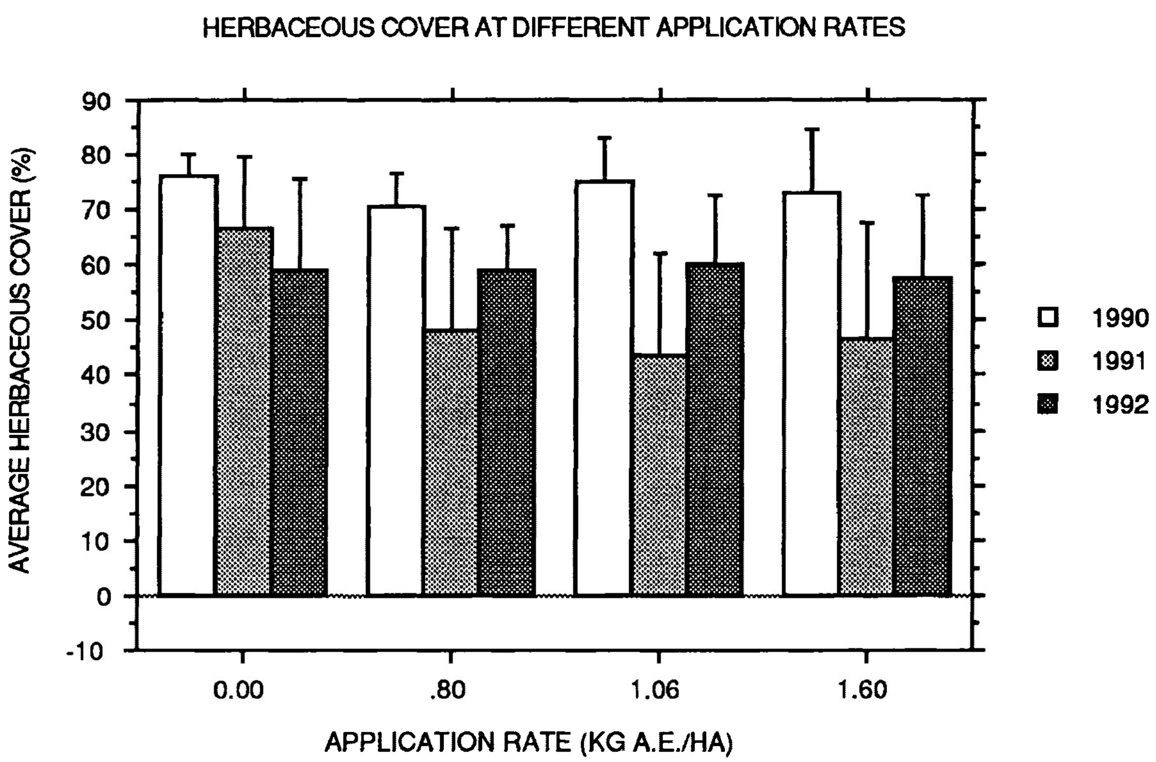


Figure 12. Herbaceous cover with 95% confidence error bars at three application rates of Vision® herbicide and a control.

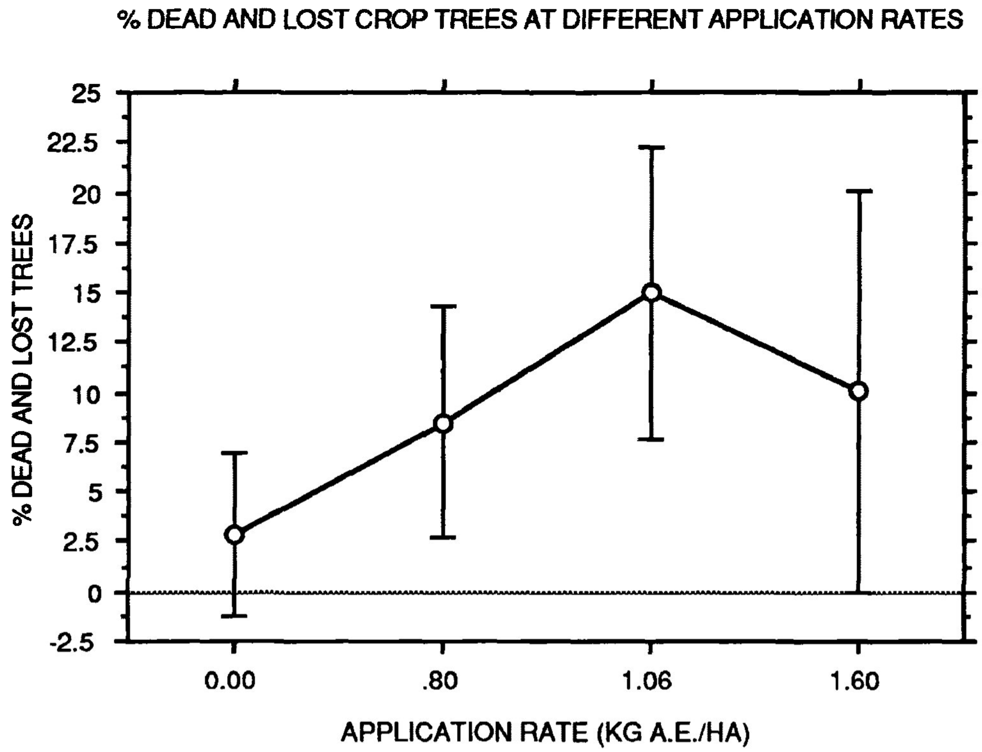


Figure 13. Treatment means (%) of combined dead and lost conifer crop trees with 95% confidence error bars at three application rates of Vision® herbicide and a control.

Table 11. Percentage of dead and lost conifer crop trees at different clearcuts and application rates of Vision® herbicide.

| Block | Treatment (Kg a.e./ha) | # Crop Trees surveyed | % Dead | % Lost | % Dead and Lost |
|---|---|---|---|---|---|
| 1 | 0.00 | 32 | 0.00 | 3.13 | 3.13 |
| 2 | 0.00 | 20 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 20 | 10.00 | 0.00 | 10.00 |
| 4 | 0.00 | 24 | 4.17 | 0.00 | 4.17 |
| 5 | 0.00 | 20 | 0.00 | 0.00 | 0.00 |
| 6 | 0.00 | 10 | 0.00 | 0.00 | 0.00 |
| | | avg. | 2.36 | 0.52 | 2.88 |
| 1 | 0.80 | 32 | 9.38 | 0.00 | 9.38 |
| 2 | 0.80 | 20 | 0.00 | 0.00 | 0.00 |
| 3 | 0.80 | 10 | 0.00 | 10.00 | 10.00 |
| 4 | 0.80 | 24 | 16.67 | 0.00 | 16.67 |
| 5 | 0.80 | 20 | 0.00 | 10.00 | 10.00 |
| 6 | 0.80 | 20 | 5.00 | 0.00 | 5.00 |
| | | avg. | 5.17 | 3.33 | 8.51 |
| 1 | 1.06 | 32 | 0.00 | 6.25 | 6.25 |
| 2 | 1.06 | 20 | 10.00 | 15.00 | 25.00 |
| 3 | 1.06 | 20 | 20.00 | 0.00 | 20.00 |
| 4 | 1.06 | 24 | 16.67 | 0.00 | 16.67 |
| 5 | 1.06 | 17 | 0.00 | 11.76 | 11.76 |
| 6 | 1.06 | 20 | 10.00 | 0.00 | 10.00 |
| | | avg. | 9.44 | 5.50 | 14.95 |
| 1 | 1.60 | 32 | 18.75 | 0.00 | 18.75 |
| 2 | 1.60 | 18 | 0.00 | 5.56 | 5.56 |
| 3 | 1.60 | 17 | 5.88 | 0.00 | 5.88 |
| 4 | 1.60 | 20 | 20.00 | 5.00 | 25.00 |
| 5 | 1.60 | 20 | 5.00 | 0.00 | 5.00 |
| 6 | 1.60 | 10 | 0.00 | 0.00 | 0.00 |
| | | avg. | 8.27 | 1.76 | 10.03 |

## 3. SOILS

Soil surveys showed depths from 0 - 100 cm and moisture regimes from 0 - 9 (appendix A). Highest stem densities grew on soils of medium depth and moisture regime. Deeper soils were most often very wet (moisture regime 8 - 9) and thus had restricted plant growth. Surprisingly, the shallow bedrock knob (BED KNOB) toposequence had approximately equal stem density to the deep sandy ablation till (DSAT) toposequence (appendix A).

# DISCUSSION

## 1. EFFECTS OF VISION® ON MOOSE BROWSING

### 1.1 Hardwood Winter Browsing Intensity

Reductions in moose browsing on all treatment and control plots may have been related to: 1) A shift in the moose population unrelated to the spraying , or 2) a loss of interest by moose in large areas where browse availability was reduced. Blocks 3, 4, and 5 were within a wildlife study area that has had a history of intensive aerial surveys to estimate moose populations. Data from 1985-86 to 1992-1993 suggest that the population is stable and may be increasing (Gollat 1993). Lowest densities of moose occurred in 1985-86 and 1986-87 (approximately 0.60 moose/km$^2$), while densities increased in subsequent years post spray to approximately 1.0 moose/km$^2$. Thus, decreased browsing is not due to a shift in moose population, at least in blocks 3,4, and 5.

Belovsky (1978) suggested that moose forage optimally. It may be that spraying reduced browse availability enough that treated and nearby non-treated areas provided insufficient winter browse and moose fed on better range. Furthermore, when compared with controls, treatment sub-blocks were browsed less, suggesting that moose might have been browsing least where energy gained/energy expended was least. However, because browse was not limiting moose populations (percentage of browsed stems rarely exceeded 10% on any experimental unit) we can't know the value (to moose) of the sprayed patches. Optimal foraging theory states that moose should forage in the highest quality patches first, and use lower quality patches as prey items decrease in the best sites. Therefore, moose may be ignoring sprayed areas, even though they contain valuable browse items. In other words, moose density may be low enough that only the highest quality patches are used.

Figure 14 illustrates a striking pattern, common to all species and heights. Browsing (browsed stems/ha) decreased on all application rates and controls one year post spray (1991). However, two years after treatment (1992) browsing began to increase

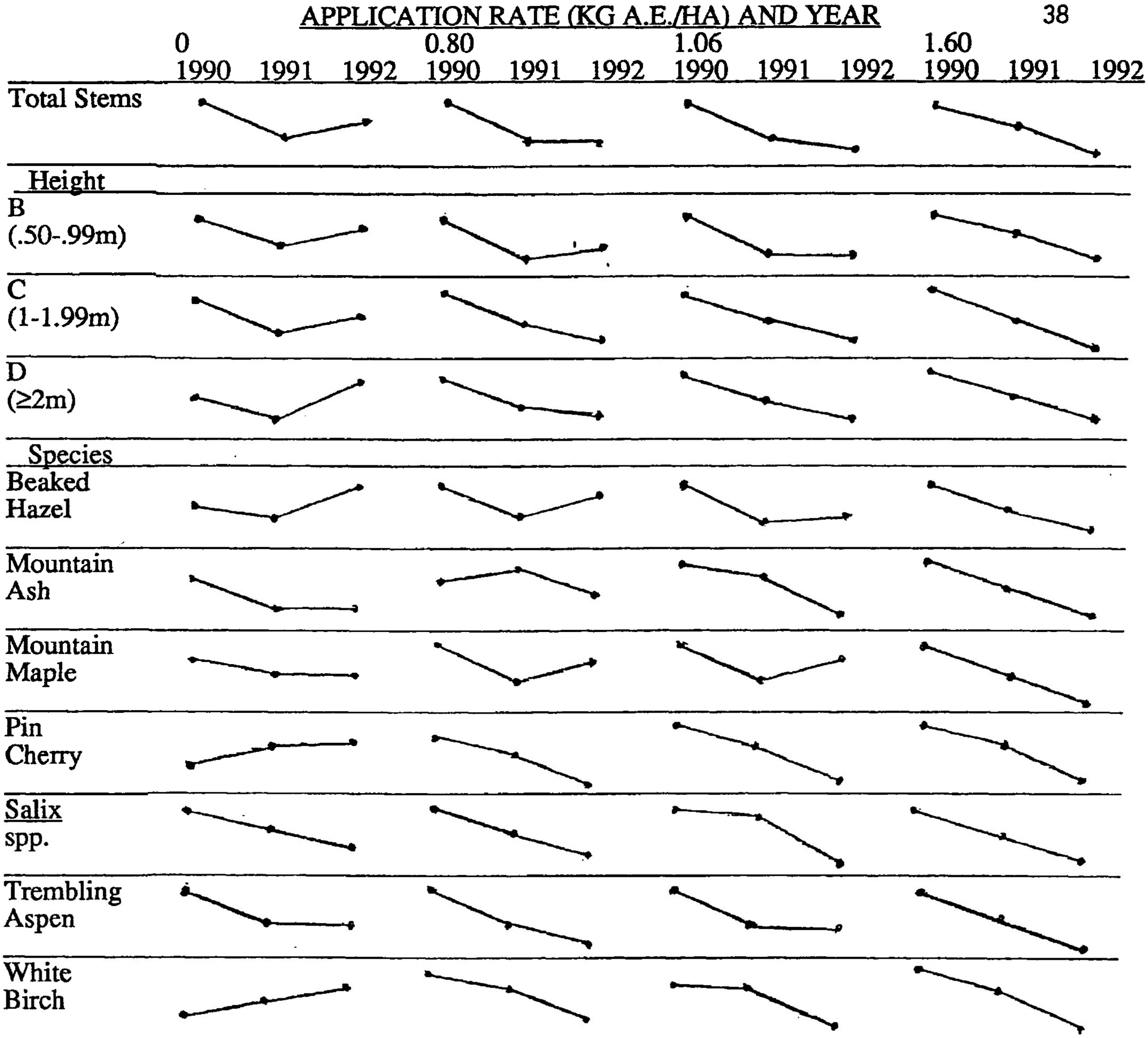


Figure 14. "Trend sketch" (not to scale) to demonstrate browsing intensity at three application rate of Vision® herbicide and a control (1990 = pre spray data).

to pre-spray levels and higher on controls, while continuing to decline on sprayed areas. In 1992 the lowest application rate (0.80 kg a.e./ha), while still declining overall, showed signs of rebounding before other rates; as there was some increase in browsing on Mountain Maple and Beaked Hazel as these species are fairly resistant to Vision®. At the two heaviest rates, and especially at 1.60 kg a.e./ha, browsing continued to drop sharply in 1992.

Although winter browsing did decrease on sprayed areas, browsing rates pre-spray (1990) rarely exceeded 10% of available stems. This suggests that there is an excess of food for moose and that any reduction in browse on sprayed areas is compensated for by food elsewhere. Ontario has 383 000 $km^2$ of productive forest land (Forestry Canada 1988), and in 1991, reached a maximum annual sprayed area of 1000 $km^2$ (Paquette and Bousquet 1991). Thus, at worst, spraying affects 0.26% of productive land each year (even less of the total forested area). It is interesting to consider the potential changes in habitat of sprayed areas to moose as succession proceeds. Lautenschlager (1991) presents a model that suggests sprayed areas have higher value for moose several years in the future than unsprayed areas, primarily because height growth of browse is delayed and browse remains in reach of moose for a longer period of time. Thus sprayed area cannot be said to be cumulative in the long term. His model demonstrates that 5 years post spray browse availability on treated areas recovers and begin to exceed levels on controls. In Ontario (applying maximum spray levels reached in 1991) over a five year period, the maximum cumulative effect would apply to only 1.3% of the productive forest land base (less than one per cent of Ontario's total forested area).

Additionally, patches of sprayed areas should have a higher component of conifers than controls. In Ontario, the results of the Ontario Independent Forest Audit (Ontario Independent Forest Audit Committee 1992) suggest that forest management techniques in our province are resulting in an increased component of hardwoods (Aspen and Birch), which will have higher browse values than the virgin forest. In the future sprayed areas should have higher conifer components than unsprayed. These patches of conifers within dense hardwood cover resulting from extensive forest management will preserve late winter habitat for moose that could be disappearing as a result of current management practices.

Although winter tracks and track aggregates showed no statistical reduction in moose use of sprayed areas (unlike Connor and McMillan (1990) who reported more track on controls 19, 31 and 43 months post spray) , browsing intensity demonstrated that moose do avoid sprayed areas in the short term after treatment. This is consistent with other studies that reported less moose use of sprayed areas (Connor and McMillan 1990, Hjeljord and GrØnvold 1988).

### 1.2 Winter Track and Track Aggregates

There was greater difference in track length among clearcuts (blocks) [Figure 5] than among treatments. This suggests that moose may not be able to distinguish between the relatively small sprayed areas, or that site differences are more important to moose than differences within one clearcut due to spraying. Simple linear tracks are not strong evidence of feeding behaviour, so some would argue that track length is not a good measure of moose browsing. Tracks left may simply be a result of movement from area to another. Complex, dense groupings of track ("aggregates") would be more indicative of feeding behaviour. Track aggregate information hints that there may be a lower threshold level of live stem density that, once exceeded, will preclude moose from using the area. However, what that threshold is, or indeed if there is one, will be difficult to determine as the relationship between live stems and aggregate area was not linear.

## 2. VISION® CONTROL OF HARDWOOD COMPETITION

### 2.1 Hardwood Stem Density

Hardwood density comparisons between treated and control sub-blocks demonstrate the efficacy of treatments but also show that when Vision® is used for conifer release it does not totally eliminate potential moose browse. With treatment means of 8 100 - 14 300 (1991) and 6 800 - 12 900 (1992) living stems/ha remaining after spraying, food was still available on treated areas. Hardwood shrub cover on treated sub-blocks was substantially reduced in 1991 and remained low in 1992. Herbaceous cover and species richness were not significantly reduced by Vision® and were almost identical on all sub blocks, including controls.

Contrary to Pojar (1990) and others who reported extreme variability to glyphosate among species, figure 15 demonstrates the similar response (plant mortality) of different species and heights to spray. This may be a result of sampling methodology (plants were classed into one of only two categories: alive or dead), but the fact that there is a pattern cannot be denied. Even though severity of reduction may vary between species and height classes, a general trend was evident. Typically, there was a sharp reduction in live stem density immediately post spray (1991) followed by a smaller reduction in the next year. However, even in this experiment there was some variability. Mountain Ash and Speckled Alder both show pronounced recoveries in 1992. The recovery of Alder is consistent with Monsanto recommendations that Alder species need to be sprayed at the highest label rate (2.1 kg a.e./ha) as it is very resistant to the herbicide (Monsanto Canada 1989).

Comparison with other studies is difficult as few studies used multiple application rates. Whitmore and Duinker (1992) present data using models but it is not actual experimental data. In this study, reduction in browse availability associated with herbicide application is reasonably similar to reductions reported by Kennedy and Jordan (1985), Newton et al. 1989, and Connor (1992). Certainly, reductions are no where near those reported by Hjeljord and GrØnvold (1988), who stated that browse production (kg/ha) on glyphosate treated areas was less than 1% of controls. Lloyd (1990b) conducted a study with five different application rates (0.71, 1.06, 1.42, and 1.60 kg a.e./ha-study area 1; 1.06, 1.42, and 1.78 kg a.e./ha- study area 2; 1.06 and 1.78kg a.e./ha-study areas 3 and 4). Similar to this study, reduction was not as drastic as in Hjeljord and

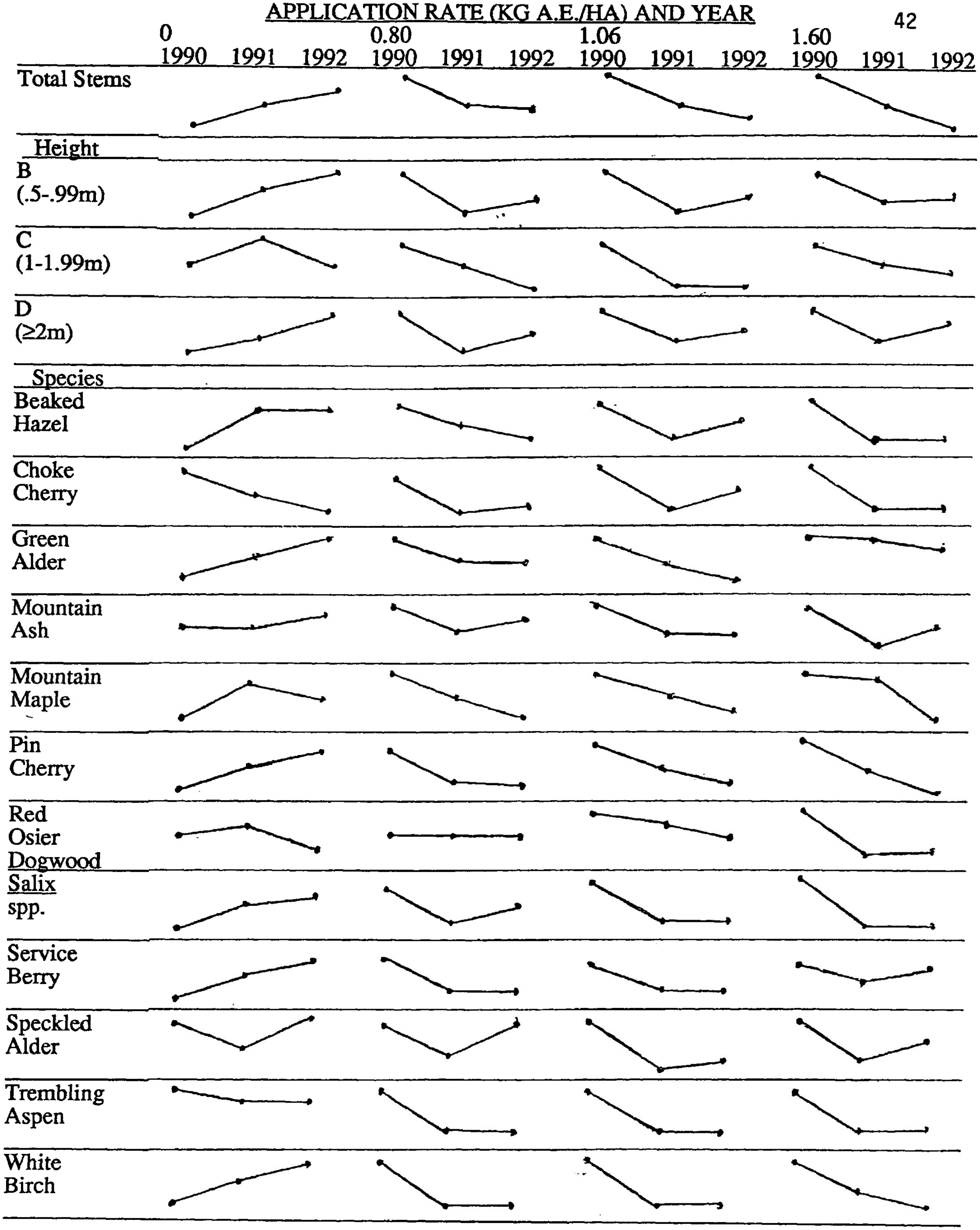


Figure 15. "Trend sketch" (not to scale) to demonstrate live stem densities at three application rate of Vision® herbicide and a control (1990 = pre spray data).

GrØnvold's, but another important similarity emerged. The heaviest application rate did not always exhibit the most control. In my study 1.06 kg a.e./ha controlled brush as well or better than 1.60 kg a.e./ha; in hers Lloyd stated 0.71 caused as much damage as 1.6 and more than 1.42 kg a.e./ha (study area 1); 1.42 provided superior control than 1.78 kg a.e./ha (study area 2); and little difference was detected between the two application rates in study areas 3 and 4. This may be due to a phenomenon reported by Sutton (1978), who found if application rates are too high glyphosate will kill tissue on contact preventing translocation and/or inhibiting control. Perhaps, due to impeded herbicide transport as suggested above, efficacy at 1.60 kg a.e./ha is delayed.

## 2.2 Available Hardwood Browse Biomass

Stem density is not the only measure of efficacy of glyphosate. Biomass may be a more accurate variable to measure. Plant morphology could cause erroneous conclusions if stem density is used. For example, bushy species may have a lower stem density than others but equivalent biomass. As well, biomass provides for a response gradient to Vision®, rather than the simplified dead/alive scenario in this study's stem counts. Methodology used in this study provide estimates of available biomass, not biomass consumed. Twig counts every 6-8th plot did not provide a large enough sample size of browsed plants to calculate consumption.

Available biomass reductions [figure 9] followed a more linear pattern than live stem density [figure 6]. It would appear that 1.06 kg a.e./ha plots had many stems classed as alive, yet in poor health. Thus, although the intermediate rate had more live stems, there was less available biomass per stem for moose to consume.

Live stem density was a better predictor of browsing than biomass. Density increased consistently over two years on controls and decreased on all sprayed areas [figure 6]. Browsing followed a similar pattern, except for decreases in 1991 and 1992 on controls from pre-spray levels [figure 2]. The important difference between biomass and density as predictors for browsing is that biomass showed a definite increase in biomass at 0.80 kg a.e./ha in 1992, but browsing continued to decline at this rate, despite a mild increase for two species. If browsing was proportional to biomass, one would have expected browsing to increase on 0.80 kg a.e./ha areas in 1992, not decrease.

## 2.3 Conifer Regeneration Surveys

Treatment with Vision® did not have an impact on height growth or diameter growth of conifer crop trees. In fact, it would appear that during the survey period survivorship is not improved either (figure 13). This contradicts the convention of long term studies (Newton et. al. 1992, Stanclik 1991, Thompson et al. 1991, Nova Scotia Department of Lands and Forests 1990) that crop tree volume increases with application of the herbicide. Lack of response is probably due to several reasons. Because of the abnormal spray pattern, (three application rates; atypical of regular forestry operations), this experiment had high variance which may have masked any treatment effects. Additionally, inadequate time may have elapsed since application of Vision® to evoke any measurable response, especially with planted paper pot black spruce container stock. Most (6 out of 7) blocks were planted with this stock, which has notoriously slow growth due to reduced vigor of this species when outplanted in containers (Columbo and Glerum 1984). Glyphosate is known to reach maximum efficacy 2-3 years following treatment (Vanden Born 1984). It is quite likely that height and diameter growth of seedlings has not responded to treatment yet. However, mortality increased on treated plots. It has been speculated by CPFP foresters that release operations may "shock" conifer seedlings as it removes a proctective layer of vegetation. If weed control is too severe, crop tree mortality can increase (Wainright 1993).

Hardwood cover was reduced at all application rates. The significant reduction of hardwood cover should result in increased growth later in the conifers' life. If this is the case one would expect crop trees at the intermediate rate to perform at least as well as trees at the highest rate but although 1.06 kg a.e./ha controlled hardwood cover better than 0.80 kg a.e./ha, 1.60 kg a.e./ha did not. Herbaceous cover decreased sharply on sprayed areas one growing season post spray, but recovered to control levels in 1992. This increase in herbaceous vegetation two years post spray may mask what would have been a significant difference in herbaceous cover in 1991.

**3. CONCERNS**

Difficulties with data collection emerged. Data collected from study area one were completed before bud break (late May - early June), consequently it was difficult to determine if stems were actually dead. The inner cambium was still green in many stems, yet upon returning after bud break it was obvious that stems that were recorded as alive were actually dead. This difficulty may be reflected in the lower mortality figures for this site. Conversely, is the possible bias of recording browse in areas with high plant mortality. After leaf flush is complete (mid June), heavy foliage can make it difficult to notice browsing, thus when heavily sprayed areas are compared with controls they will have misleading high browse use. This could be countered by surveying controls before leaves are completely formed (but after bud break to avoid the problem stated earlier).

Although Lloyd (1989) and Bell (1989) present a range of possible effects of herbicides on plant condition, all stems were classified as alive, alive browsed, dead or dead browsed. This could lead to erroneously high biomass estimates post spray as plants classed as alive could still be adversely affected by the herbicide. Often residual timber seemed to protect pockets of vegetation. Shorter hardwood browse was shielded from spray by taller browse stems, most often Aspen. Additionally, during application some strips of ground were missed, which resulted in some strips of healthy vegetation amid that killed by the herbicide. Although some would argue that these problems affected this study's results, I believe this result represents field conditions and is a necessary source of variance to include. These realities allow sprayed areas to continue providing browse following conifer release, especially if application rates are moderate.

A problem with scale could limit management implications generated by this study. Experimental units, even though increased in size from the original design, may still have been too small to measure moose response. If moose were choosing feeding patches on a larger scale than experimental units used in this study, browsing rates may not be a result of the spray.

**4. PUTTING HERBICIDE USE IN PERSPECTIVE**

Today, aerial application of herbicides is the most common form of vegetation management in Canadian forestry. Nationally, 200 000 ha are sprayed annually. At 60 000-100 000 ha/year, Ontario sprays the most area with herbicides. Of the five herbicides commonly used in Canadian forests, defined as wooded areas greater than 500 ha (CPPA 1992), glyphosate (as Vision®) accounts for 81% of treated regions (Paquette and Bousquet 1991). A recent survey by Forestry Canada (1989) revealed that 70% of the Canadian public opposes the use of herbicides in forests.

In response to the demand to reduce dependence on herbicides, the 1991 national sustainable forestry initiative (Canadian Council of Forest Ministers 1992) called for all provinces to reduce their use of herbicides. Ontario responded by creating it's own sustainable forestry program (OMNR 1992, 1991). Glyphosate, as Vision®, has been the most common herbicide used by foresters because of it's environmental safety record and biological performance. However, this new initiative will lead to Vision® being targeted for reductions. Before Canadians change management policies regarding herbicides, we must determine if "the use of chemical herbicides in the forest is compatible with the underlying principles of sustainable development?" (Blouin 1991).

From a purely scientific perspective, worries concerning herbicide use in forestry are not proportionate to the rate of use, nor to risks considered acceptable in daily activities. Actually, more herbicide is used by homeowners than in forestry operations. Forest industry in North America consumes less than one half of one percent of the herbicides that agriculture does, and forest herbicides are applied 1-2 times per 40-80 year rotation versus 1-3 times per year directly to agricultural crops (Thompson et al. 1991). Agricultural crops, which are directly consumed (i.e. eaten by the general public), are also sprayed with fungicides and insecticides which are much more toxic to human and non human animals than herbicides. If the public wishes to curtail pesticide use, forestry is not the logical place to start.

Due to the history of undesirable non-target effects of herbicides and other pesticides (witness agent orange and DDT), it is often forgotten that today's herbicides are often designed specifically to affect chemical pathways unique to plants. Control (reduction in weed cover) is usually accomplished by inhibiting photosynthesis and consequently such herbicides are rarely toxic to animals. Often overlooked are actions that use herbicides to directly benefit wildlife. The public's fear of forest herbicides might be lessened if they were made aware of projects that use herbicides such as glyphosate for wildlife restoration projects. Glyphosate has been used to restore and protect habitat for flying foxes in Australia, waterfowl in the Canadian prairies, Rhinos in Kenya, and restore natural vegetation in estuaries in Washington State (Monsanto, 1991). Related herbicides 2,4-D and 2,4,5-T have been used to increase browse production for deer in the lake states of the U.S. (Krefting et. al. 1956).

Toxicity concerns of the public are not consistent with risks considered acceptable in everyday activities. Vision® (i.e. the active ingredient plus the more toxic surfactant) has an $LD_{50}$ that lies between alcohol and baking soda (Monsanto Canada, Inc. 1992). The World Health Organization (1987) reported that over 70% of cancer deaths are due to smoking, alcohol abuse and poor dietary habits. Less than 1% of cancer deaths are thought to be due to all synthetic additives and pesticides combined.

Irrespective of the above facts, forest herbicide use in Canada is under severe restriction. Quebec and Manitoba have prohibited, while Alberta has severely restricted aerial application of herbicides. Saskatchewan and Newfoundland have virtually banned the use of herbicides in forestry (Wagner 1991, Government of Saskatchewan 1991). Considering current public opinion, and witnessing events in other provinces and countries, it appears that herbicide use in forestry will be reduced. In a world of increasing business competition and global recession, Canadian forest managers may not be able to bear the additional cost of alternative management options. These options may be too costly, more of an environmental risk, and may not provide the performance of herbicides. Forest policy in Canada and Ontario should reflect these ideas. Rather than adopting a policy that bans herbicides outright or seeks to gradually eliminate them as an option, governments should introduce policy that accurately reflects current facts, not ill-founded public fears. Results from this study indicate that, far from public perception, glyphosate does not denude the landscape, and has minimal effect on moose.

## FOREST MANAGEMENT IMPLICATIONS

Differences among application rates were very subtle when compared with differences between sprayed areas and controls. Application at a rate of 1.06 kg a.e./ha of glyphosate when compared to the other rates (0.80 & 1.60 kg a.e./ha) provided marginally superior to equivalent control of hardwood competition. No application effectively controlled herbaceous vegetation for more than one year. All application rates, combined with shielding effects of existing over-story vegetation and striping associated with aerial applications, seemed to maintain sufficient winter browse for moose. However, moose browsed less on sprayed areas, and are likely to return first to areas sprayed with lower than recommended rates of glyphosate. In this study some species on 0.80 kg a.e./ha plots showed the first signs of returning to pre-spray use levels. Yet forage is not a limiting factor; pre-spray browsing rates rarely exceeded 10% of available stems, so it would appear that moose were not food limited in these study areas. Low browsing rates in the study areas imply that moose populations are below carrying capacity. In the presence of wolves and black bears, Crête (1989) suggests moose populations seem to be regulated by predation. All study areas maintained populations of wolves and black bears, and four of the seven blocks were open to human predation as well. If predation is limiting these moose populations, the effect of glyphosate may be negligible (i.e. there are sufficient unsprayed areas to provide forage for populations of moose kept low by predators). The small amount of spraying in Ontario (1000 km2 per year (Paquette and Bousquet 1991) Vs 383 000 km2 of productive forest land base (Forestry Canada 1988)) is not expected to effect moose populations. Future food value (for moose) of sprayed areas is expected to increase, thus sprayed areas cannot be said to be cumulative in the long term (Lautenschlager 1991). However, in areas with high concentrations of sprayed cutovers there should be concern about short term browse reductions. Results of this study suggest that 0.80 kg a.e./ha controlled hardwood and herbaceous competition as well as 1.06 & 1.60 kg a.e./ha. However, the lowest application rate showed signs of increased moose use two years post spray compared with the two higher rates. Consequently, when spray programs are concentrated in one management unit it is recommended to spray at 0.80 kg a.e./ha. This recommendation is tempered by the fact that until further studies (i.e. long term) document the growth response of crop trees the effectiveness of these treatments for conifer release remains unknown.

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# APPENDICES

## APPENDIX A

## SOILS

### METHODS

For each browse survey plot the soil at the center of the plot was classified as a soil type of the Forest Ecosystem Classification of Northwestern Ontario (Sims et. al. 1989). Due to the large numbers of plots it was impossible to dig a soil pit at each plot, as Sims et al. (1989) require for proper soil classification, thus a more general approach was adopted. Using the publication Common Landform Toposequences of Northwestern Ontario (Baldwin et al. 1990), each clearcut was divided into it's representative toposequences. Defining the toposequence was done using both visual queues (i.e. presence of bedrock and/or organic soils) and soil pits. Once toposequences were defined, soil types could be applied to each plot, depending on plot position in the toposequence. Baldwin et al. (1990) divide each toposequence into discrete segments (i.e. crest, mid slope, lower slope, toe, and depression). Each of these divisions within a toposequence is given it's own soil type. Once the position of the plot was identified on the toposequence, the corresponding soil type was applied. To verify the results of the toposequence system of soil classification, a shallow (20cm deep) pit was dug at the center of each plot. At best, this test could only differentiate between very shallow and deeper mineral soils, and between organic and mineral soils. From the soil type assigned using Baldwin et. al. (1990), moisture regime and depth to bedrock were the variables chosen to explain variance in stem density using simple regression. Other variables did not provide enough information to be used as regressors. Appendix B provides results from these soil surveys.

**RESULTS**

Multiple regression using moisture regime and depth to bedrock as regressors could not explain the variation in pre-spray (1990) stem density on different plots. This model produced an R-squared value of only 0.007. When each independent variable was surveyed separately, the lack of correlation with stem density can be represented graphically. R-squared values for depth to bedrock and moisture regime were .022 and .085, respectively. The low $R^2$ values are probably more indicative of a non linear relationship than of lack of influence of the independent variables on stem density. Figures 21 and 22 demonstrate that highest stem densities occur at the mid ranges of depth to bedrock and moisture regime. Lowest numbers of stems were found on shallow soils as expected; however, stem density unexpectantly decreased on the deepest soils [figure 21].

Different soil types and toposequences demonstrated significant differences in productivity. Generally, soil type reinforced depth and moisture regime findings. Shallow (SS1, SS2) and wet (S12S, S12F) soils had the lowest numbers of stems [figure 23]. Toposequences demonstrated more subtle differences [figure 24]. The deep coarse loamy ablation till (DCLAT) possessed greatest stem density. Surprisingly, the bedrock knob (BED KNOB) had approximately equal stem density to the deep sandy ablation till (DSAT).

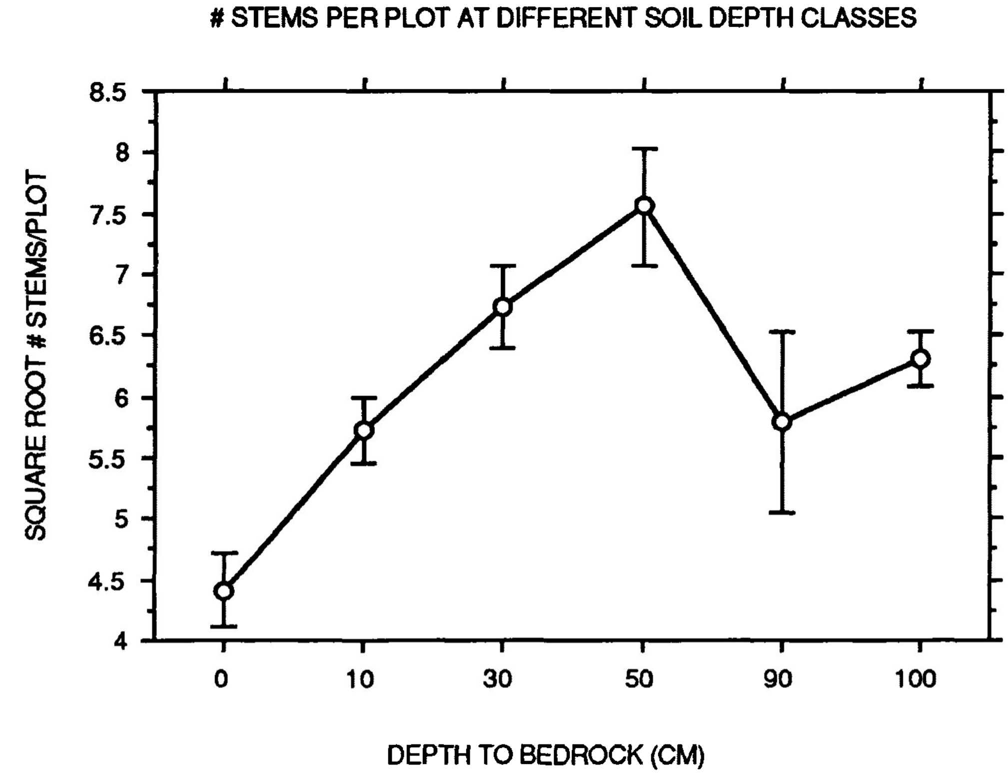


Figure 16. Number of live stems per plot with 95% confidence error bars at different depth to bedrock classes.

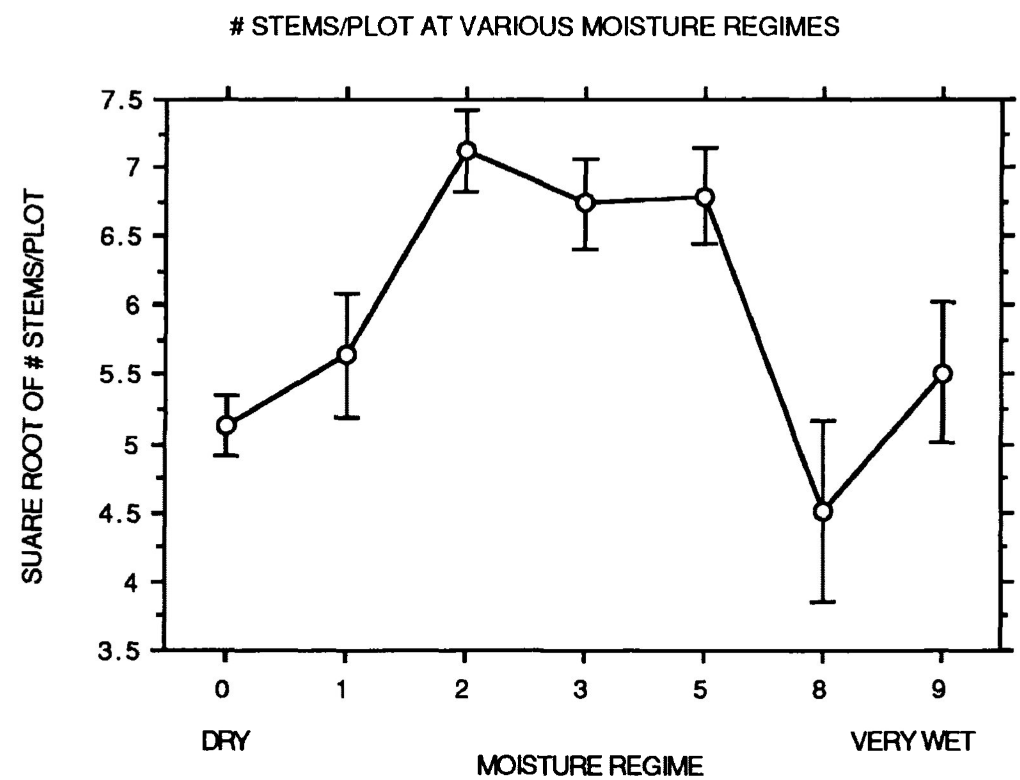


Figure 17. Number of live stems per plot with 95% confidence error bars at different moisture regime classes.

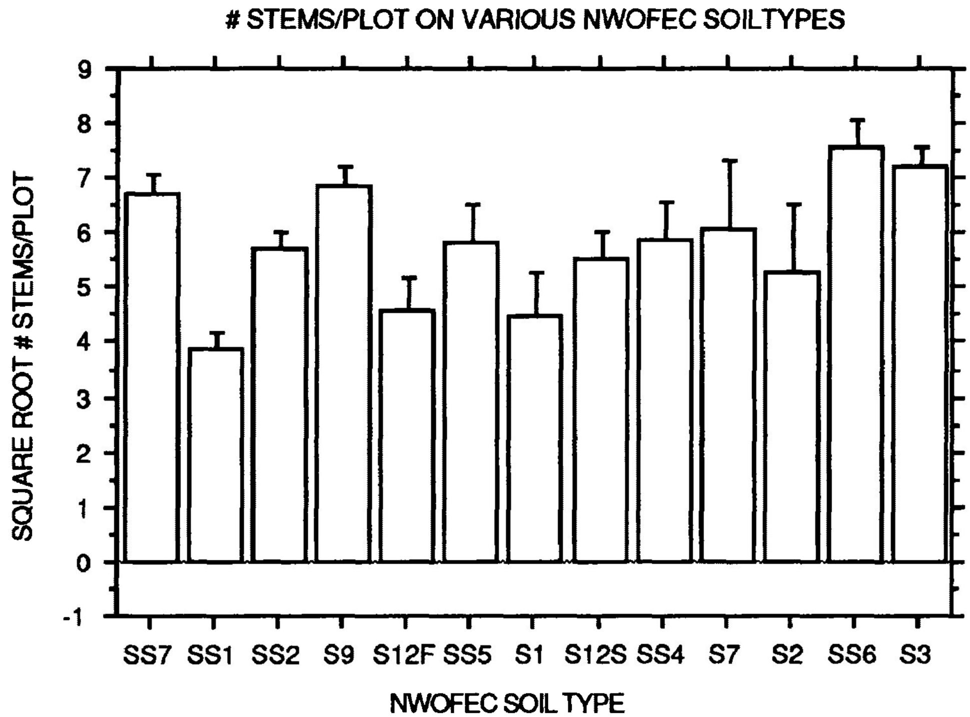


Figure 18. Number of live stems per plot with 95% confidence error bars at different NWOFEC soil types.

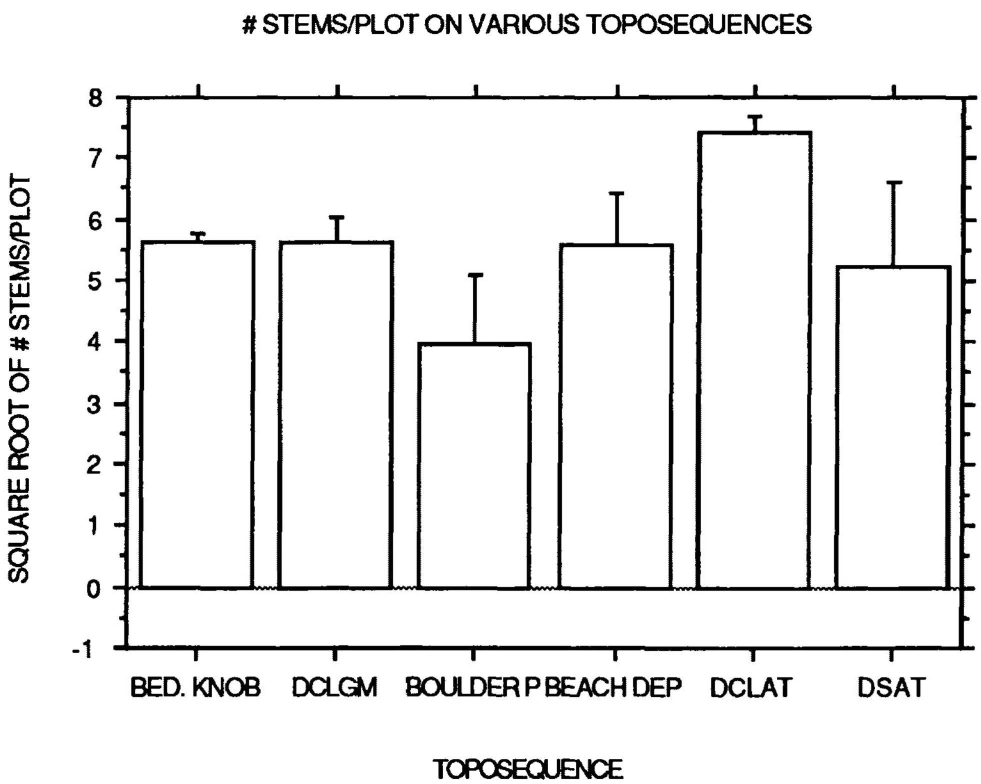


Figure 19. Number of live stems per plot with 95% confidence error bars at different toposequence types.

## DISCUSSION

Lowest numbers of stems were found on shallow soils as expected; however, stem density surprisingly decreased on the deepest soils [figure 20]. Further inspection revealed that most of the deep soils recorded were very wet organic soils. These very wet soils (moisture regimes 8 and 9) had very low numbers of stems, similar to densities recorded for the driest sites (moisture regimes 0 and 1) [figure 21]. Inexplicably, the deep soil types with excellent drainage (S1 and S2) had low stem densities as well. Surprisingly, the bedrock knob (BED KNOB) toposequence had approximately equal stem density to the deep sandy ablation till (DSAT). This could be the result of two factors: 1) the low sample size of DSAT (n=18), and 2) only the top of the bedrock knob toposequence is composed of shallow soils, as one moves down the toposequence soil depth increases.

# APPENDIX B

## WINTER TRACK AND TRACK AGGREGATES AT SEVEN DIFFERENT CLEARCUTS (1989-90) TO (1991-1992).

Figure 20. Winter track (1989/90 to 1991/92) and track aggregates (1991/92) at seven (a-g) different clearcuts with different application rates of Vision® Herbicide in the Thunder Bay region.

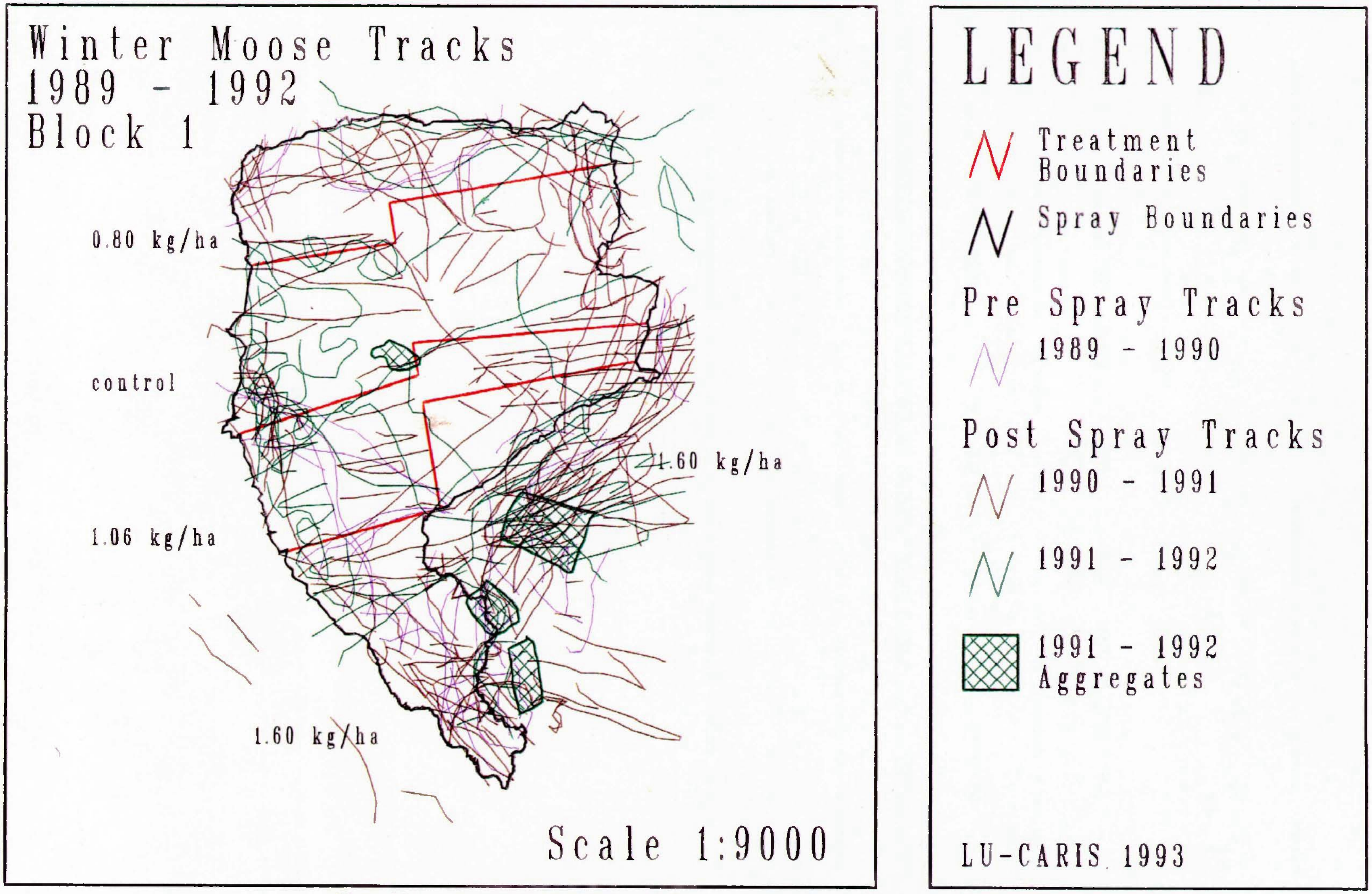


Figure 20a. Winter track (1989/90-1991/92) and track aggregates (1991/92) at study area 1.

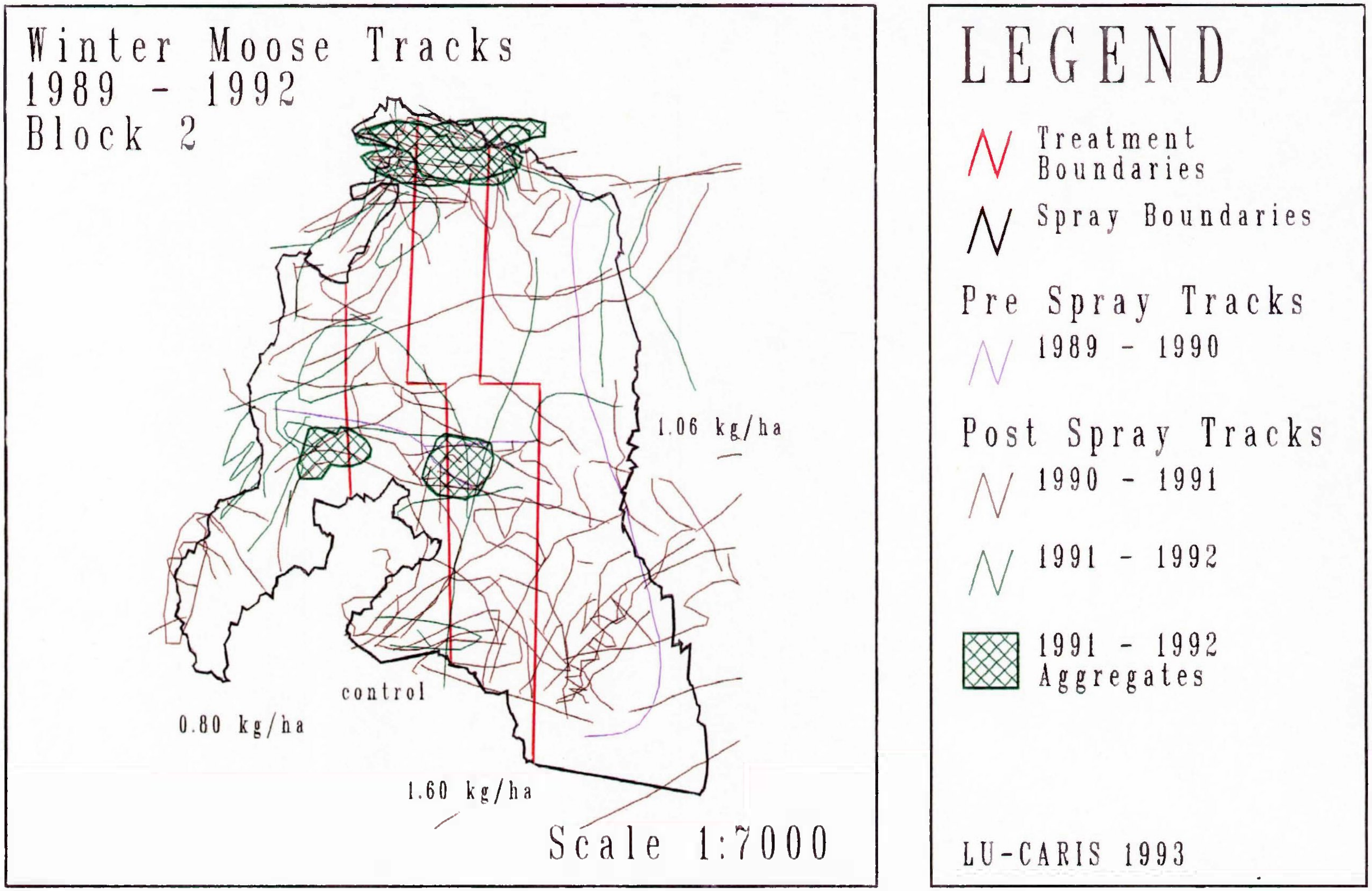


Figure 30b. Winter track (1989/90-1991/92) and track aggregates (1991/92) at study area 2.

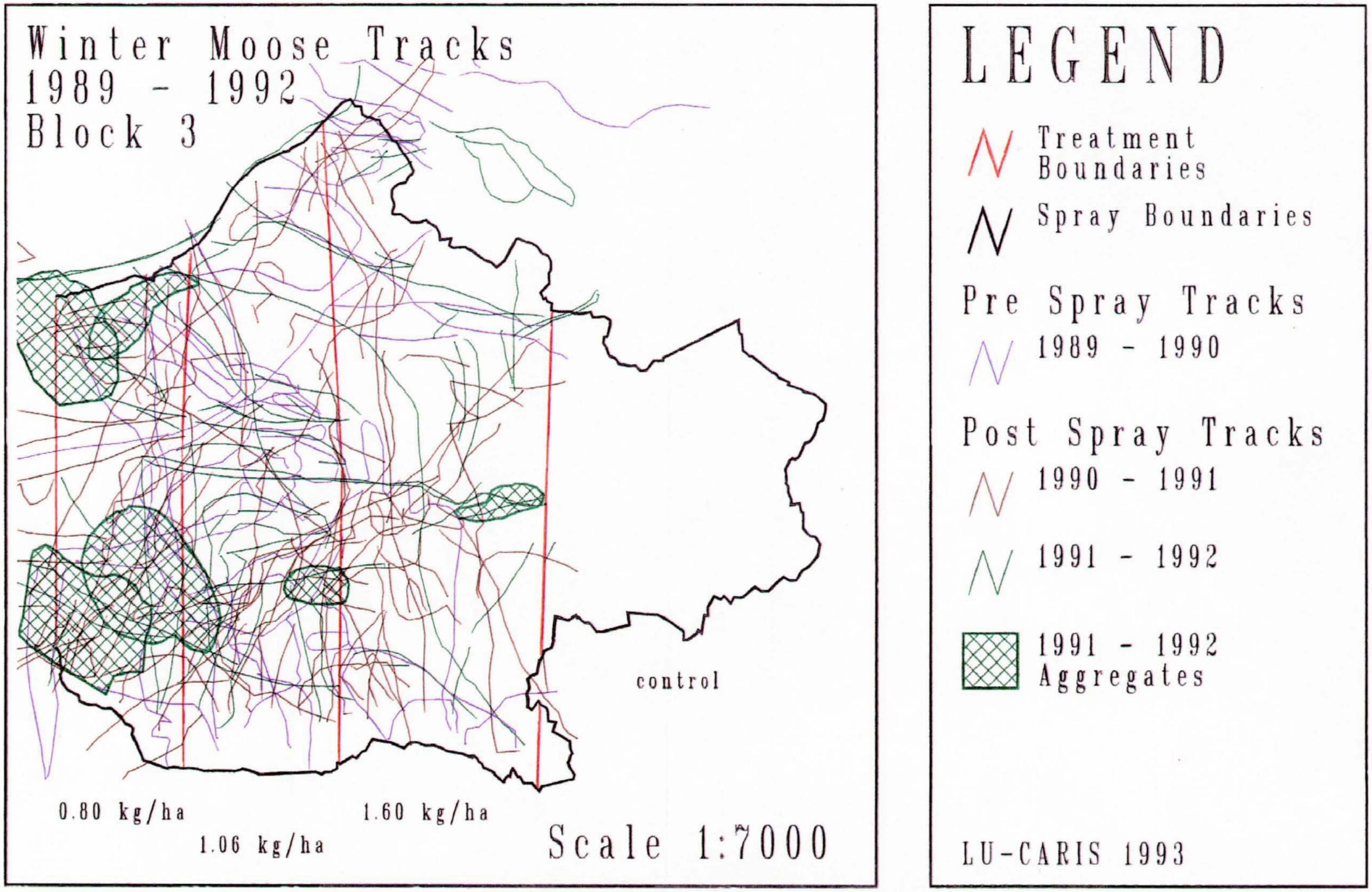


Figure 20c. Winter track (1989/90-1991/92) and track aggregates (1991/92) at study area 3.

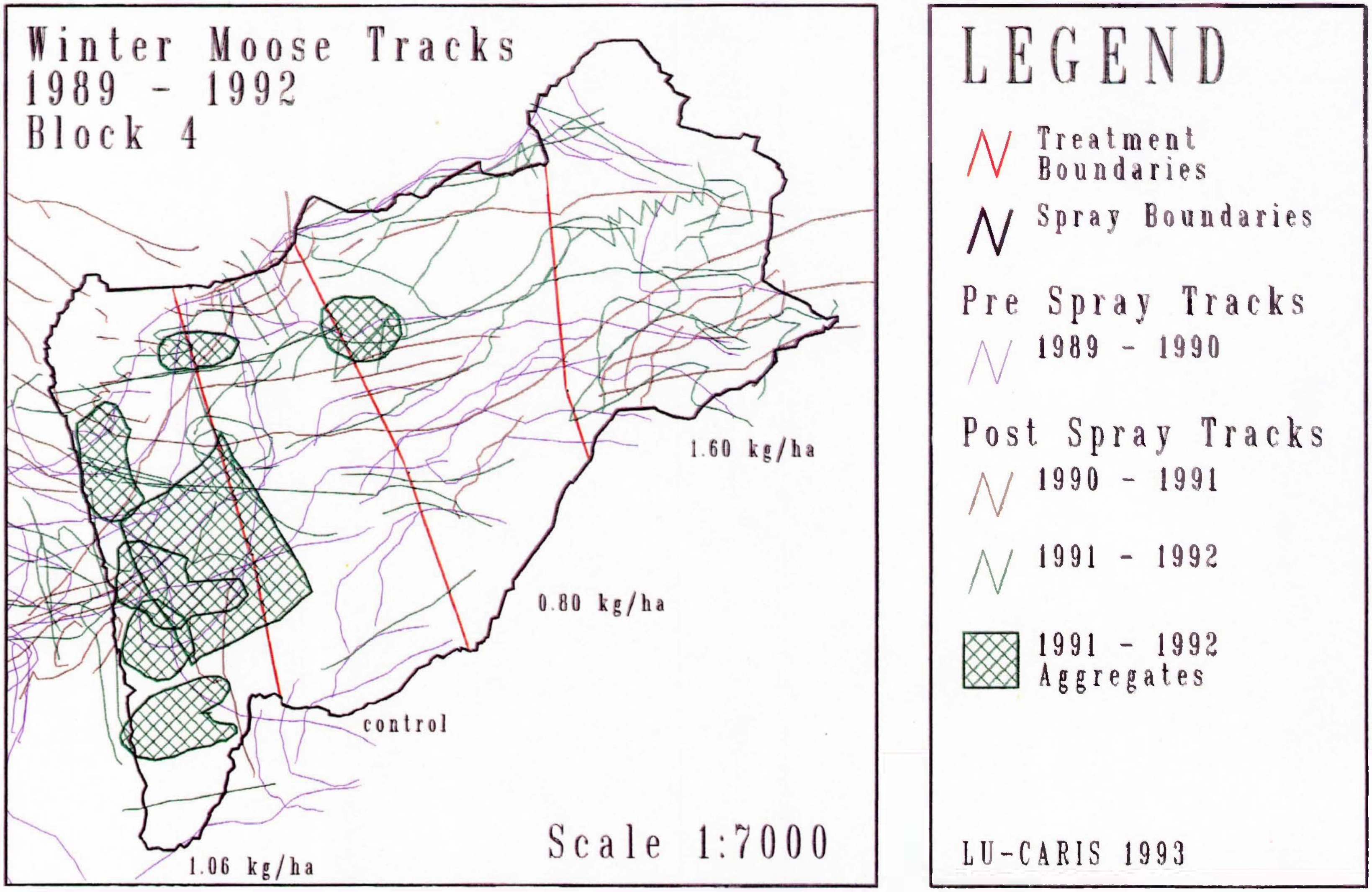


Figure 20d. Winter track (1989/90-1991/92) and track aggregates (1991/92) at study area 4.

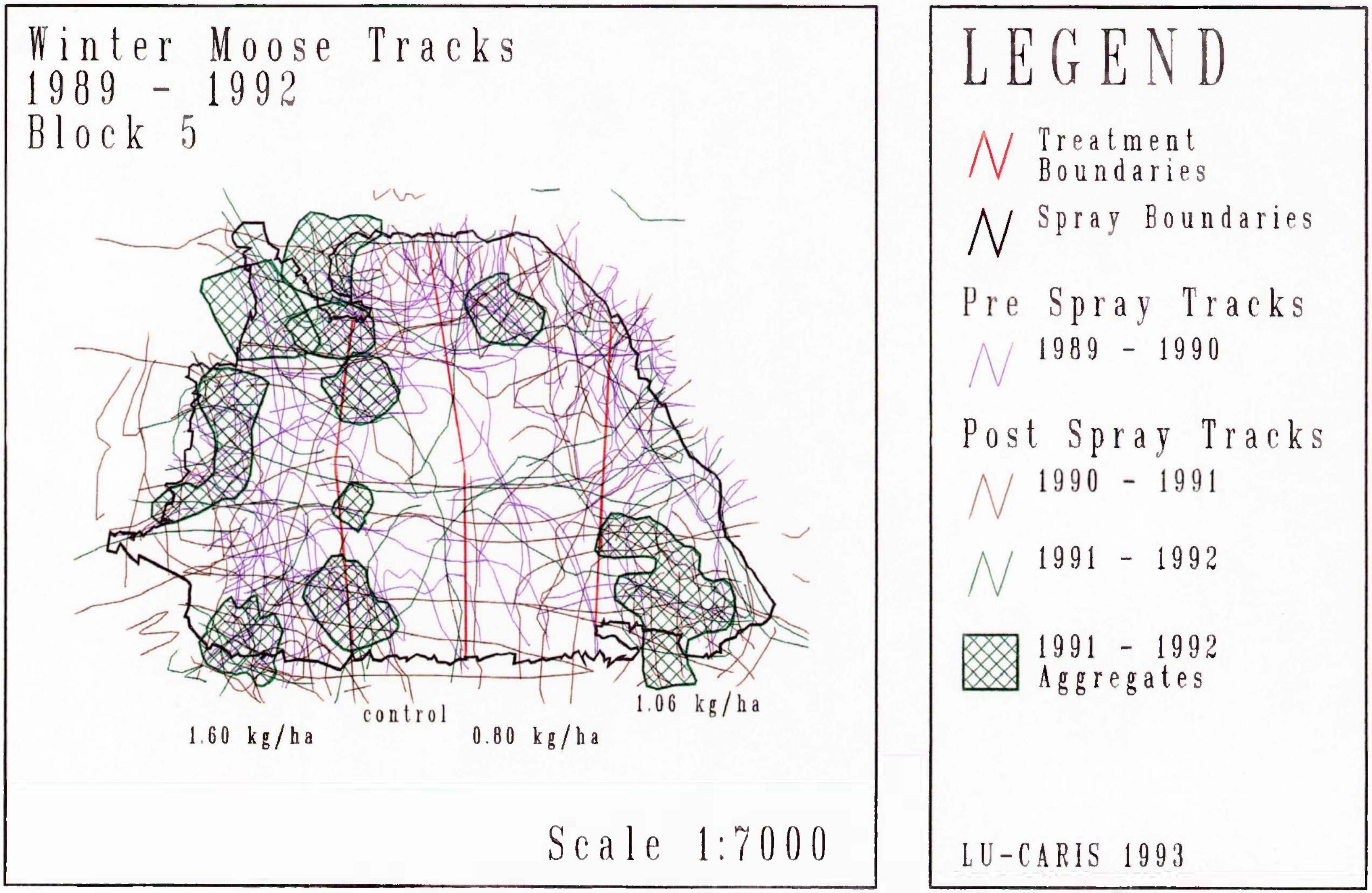


Figure 20e. Winter track (1989/90-1991/92) and track aggregates (1991/92) at study area 5.

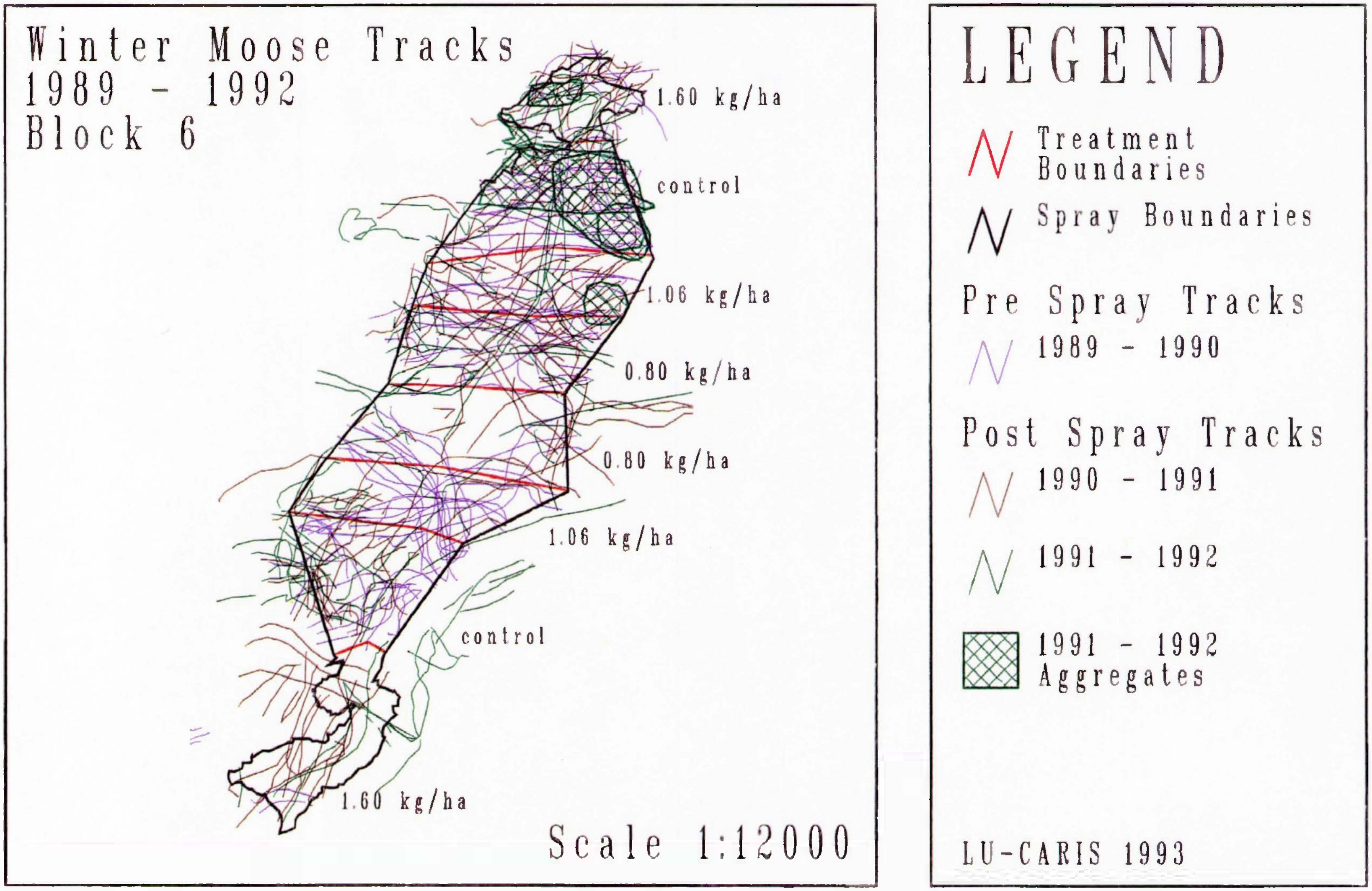


Figure 20f. Winter track (1989/90-1991/92) and track aggregates (1991/92) at study area 6.

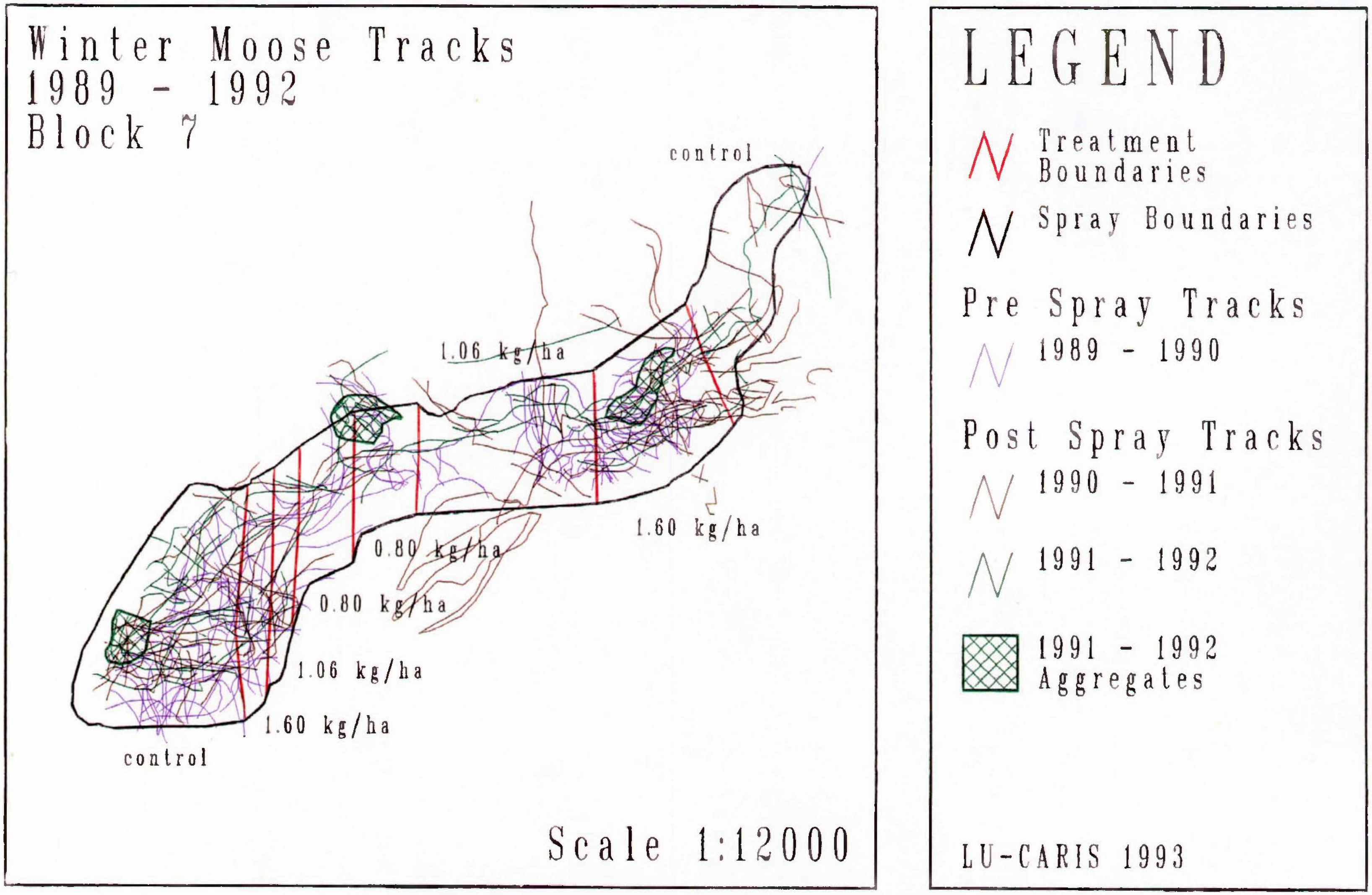


Figure 20g. Winter track (1989/90-1991/92) and track aggregates (1991/92) at study area 7.

# APPENDIX C

## KEY TO COMMON AND SCIENTIFIC NAMES
## ANIMALS, TREES, AND SHRUBS

### ANIMALS

| | |
|---|---|
| Moose | *Alces alces* |
| Black Bear | *Ursus americanus* |
| Wolf | *Canis lupus* |

### PLANTS

**Other Studies**

| | |
|---|---|
| Bitterbrush | *Purshia tridentata* |
| Cliffrose | *Cowania stansburiana* |
| Western Snowberry | *Symphoricarpos occidentalis* |

**This Study**

**Trees**

| | |
|---|---|
| Balsam Fir | *Abies balsamea* (L.) Mill. |
| Black Spruce | *Picea mariana* (Mill.) BSP. |
| Jack Pine | *Pinus Banksiana* Lamb. |
| Trembling Aspen | *Populus tremuloides* Michx. |
| White Birch | *Betula papyrifera* Marsh. |

**Shrubs**

| | |
|---|---|
| Beaked Hazel | *Corylus cornuta* Marsh. |
| Choke Cherry | *Prunus virginiana* L. |
| Green Alder | *Alnus crispa* (Ait.) Pursh |
| Mountain Ash | *Sorbus americana* Marsh. |
| Mountain Maple | *Acer spicatum* Lam. |
| Pin Cherry | *Prunus pensylvanica* L. fil |
| Red Osier Dogwood | *Cornus stolonifera* Michx. |
| Service Berry | *Amelanchier spp.* |
| Speckled Alder | *Alnus rugosa* (Du Roi) Spreng. |
| Willow | *Salix spp.* |

# APPENDIX D

## KEY TO COMMON AND SCIENTIFIC NAMES OF HERBACEOUS SPECIES

| | |
|---|---|
| **MOSSES AND LICHENS** | |
| Feather moss | Hylocomium spendens, Pleurozium schreberi, Ptilium crista-castrensis |
| Reindeer Lichens | Cladina spp. |
| Sphagnum moss | Sphagnum spp. |
| **FERNS AND ALLIES** | |
| Ferns | Many genera, including Athyrium, Polypodium, Pteridium |
| Ground Pine | Lycopodium obscurum L. |
| Horsetail | Equisetium spp. |
| Running Clubmoss | Lycopodium clavatum L. |
| Stiff Clubmoss | Lycopodium annotinum L. |
| **GRAMINOIDS** | |
| Grasses and Sedges | Many species, including Calamagrostis canadensis (Michx.) Beauv., Carex spp., Oryzopsis asperifolia Michx. |
| **VARIOUS** | |
| Blue Bead Lily | Clintonia borealis (Ait.) Raf. |
| Blueberry | Vacinium spp. |
| Bog Cranberry | Oxycoccus microcarpus Turcz. |
| Bog Laurel | Kalmia polifolia Wang. |
| Bunchberry | Cornus canadensis L. |
| Bush Honeysuckle | Diervilla lonicera (Mill.) |
| Canada Mayflower | Maianthemum canadense Desf. |
| Ciliolate Aster | Aster ciliolatus Lindl. |
| Cow Wheat | Melampyrum lineare Desr. |
| Creamy Peavine | Lathyrus ochroleucus Hook. |
| Creeping Snowberry | Gaultheria hispidula (L.) Muhl. |
| Currant | Ribies spp. |
| Fireweed | Epilobium angustifolium L. |
| Fragrant Bedstraw | Galium triflorum Michx. |
| Goldthread | Coptus Trifolia (L.) Salisb. |
| Labrador Tea | Ledum groenlandicum Oeder. |
| Large Leaved Aster | Aster macrophyllus L. |
| Leatherleaf | Chamaedaphne calyculata (l.) Moench |
| Northern Bluebell | Mertensia paniculata (Ait.) G. Don |
| Prickly Wild Rose | Rosa acicularis Lindl. |
| Raspberry | Rubus spp. |
| Rose Twisted Stalk | Streptopus roseus Michx. |
| Spreading Dogbane | Apocynum androsaemifolium L. |
| Starflower | Trientalis borealis Raf. |
| Strawberry | Fragaria spp. |
| Swamp Honeysuckle | Lonicera oblongifolia (Goldie) Hook. |
| Sweet Coltsfoot | Petasites palmatus (Ait.) Gray. |
| Twinflower | Linnea borealis L. |
| Violets | Violaceae family |
| Wild Sarsaparilla | Aralia Nudicaulis L. |
| Wood Anemone | Anemone quinquefolia L. |

# APPENDIX E

## HARDWOOD SPECIES COMPOSITION AT DIFFERENT APPLICATION RATES BY YEAR

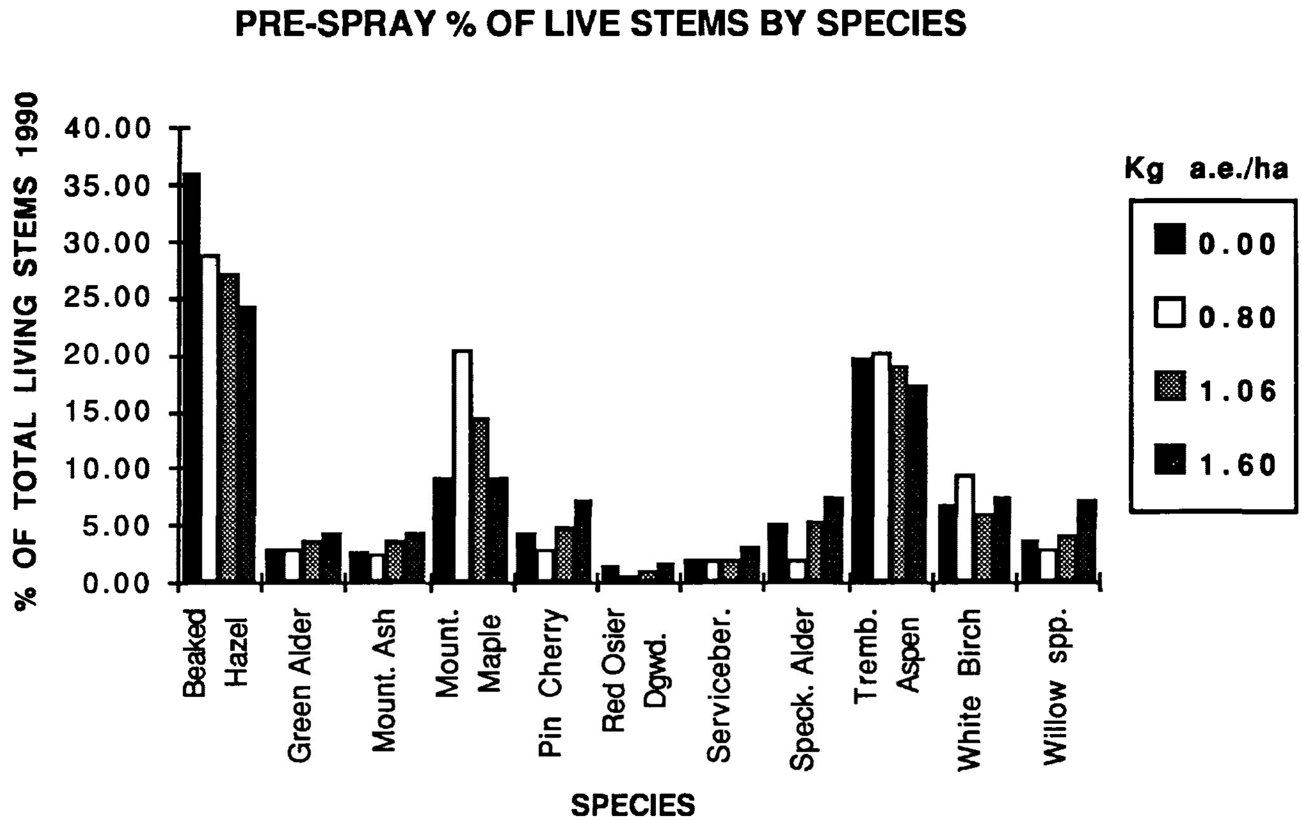


Figure 21. Hardwood species composition, pre-spray (1990), at different application rates

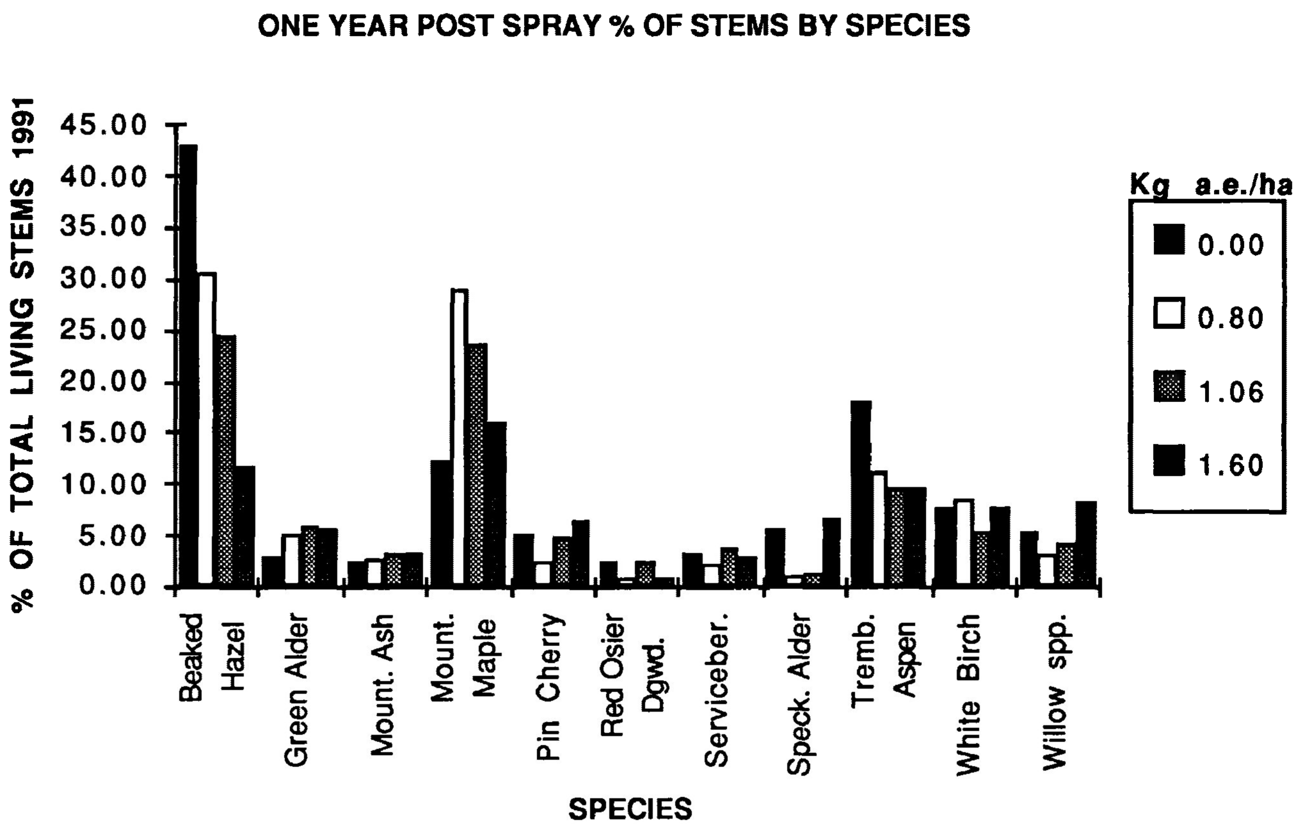


Figure 22. Hardwood species composition, first year post spray (1991), at different application rates.

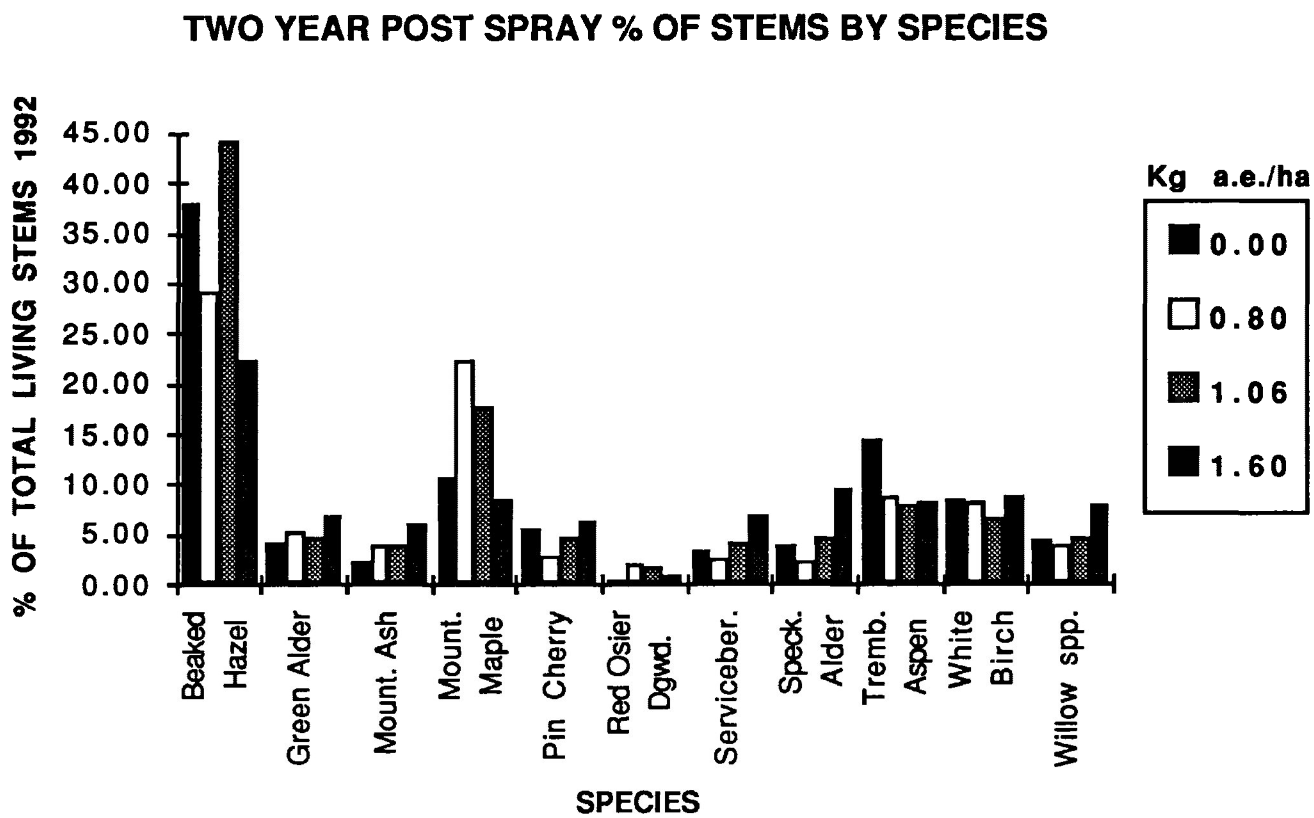


Figure 23. Hardwood species composition, second year post spray (1992), at different application rates.

# APPENDIX F
# EXAMPLE OF AN ANCOVA TABLE (REPEATED MEASURES)

**Type III Sums of Squares**

| Source | df | Sum of Squares | Mean Square | F-Value | P-Value | Error Term |
|---|---|---|---|---|---|---|
| B | 6 | 11589.905 | 1931.651 | 1.543 | .2240 | Subject(Group) |
| TRT | 3 | 39474.804 | 13158.268 | 10.509 | .0004 | Subject(Group) |
| L/HA 90 | 1 | 11130.614 | 11130.614 | 8.890 | .0084 | Subject(Group) |
| Subject(Group) | 17 | 21285.077 | 1252.063 | | | |
| L/HYEAR | 1 | 797.690 | 797.690 | 3.564 | .0762 | L/HYEAR * Subjec... |
| L/HYEAR * B | 6 | 4999.177 | 833.196 | 3.722 | .0151 | L/HYEAR * Subjec... |
| L/HYEAR * TRT | 3 | 775.761 | 258.587 | 1.155 | .3556 | L/HYEAR * Subjec... |
| L/HYEAR * L/HA 90 | 1 | 647.579 | 647.579 | 2.893 | .1072 | L/HYEAR * Subjec... |
| L/HYEAR * Subject(Gro... | 17 | 3805.062 | 223.827 | | | |

Dependent: LIVE / HECTARE

(the covariate is represented by L/HA 90- Live stems per hectare in 1990)