EFFECTS OF VISION® APPLICATION ON MOOSE WINTER BROWSING AND HARDWOOD VEGETATION

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ABSTRACT: Two years after aerial spraying with Vision® (glyphosate) at 0.80, 1.06, and 1.60 kg acid equivalents (a.e.)/ha, we found live hardwood stem densities on 7 mixedwood clear-cuts reduced by 48, 65 and 61%, while those on controls had increased 19%. Winter browsing by moose (*Alces alces*) decreased both 6 and 18 months after spraying on all treatment units, including controls, but was consistently lower on sprayed areas. The two highest application rates resulted in the lowest browsing levels. Conversely, winter track data showed no differences in use among sprayed areas and controls, nor any differences among treatments. This finding suggested that moose still traveled through sprayed areas, but did not stop as frequently or as long to browse, or else that they browsed more in early winter before we began tracking. Since 0.80 kg a.e./ha controlled hardwood and herbaceous competition as well as 1.06 & 1.60 kg a.e./ha, and also showed signs of increased moose use two years post-spray (while the two higher rates did not), we recommend that where spray programs are concentrated in one management unit, application at 0.80 kg a.e./ha would be best for moose. However, the low browsing intensities found in this study suggested that moose densities were low enough that food would not be a limiting factor. Thus, the small percentage of forests currently treated with Vision® in Ontario would not be expected to affect moose populations.

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Kelly and Cumming (1992) found that experimental aerial treatment of boreal mixedwood sites with Vision® (formulated product of glyphosate, licensed for aerial and ground application in Ontario) for conifer release at 0.80, 1.06, and 1.60 kg acid equivalent (a.e.)/ha, decreased live hardwood stem densities after 10 months by 42, 61 and 42% respectively on treated units, while controls increased by 13%. Winter browsing rates decreased 6 months post-spray on all units, but were consistently higher on controls when compared with treated units. However, effects of glyphosate can change over time (Lautenschlager 1993).Therefore it is important to study effects of this herbicide on moose browse over several years. This paper reports pre-treatment and 2 year post-treatment results.

Vision® is a relatively non-selective herbicide used to injure or kill 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 (Canadian Pulp and Paper Association and Forestry Canada 1992, 1993).

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 with controls) at 0.83 kg a.e./ha, whereas the label rate for red maple is approximately 1.7 kg a.e./ha. Therefore, we believed that 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. For a more complete review of Vision® application and its associated short term effects, see Kelly and Cumming (1992).

Study objectives were to discover if hardwood competition could be controlled with lower than recommended rates, and if lower rates reduced the effect of chemical conifer release on moose browsing and behaviour.

STUDY AREA

The seven studied clear-cuts were all located within 150 km of Thunder Bay, Ontario, on upland sites and ranged in size from 44 - 95 ha (mean = 71 ha) with total area slightly exceeding 500 ha (Kelly and Cumming 1992). All study sites 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 spraying ranged from 10 - 26°C, and relative humidity from 48 - 94%.

Soils were generally dry, shallow, glacial tills over granite bedrock (the Canadian Shield), although bogs with sphagnum (*Sphagnum spp.*)/feathermoss (*Hylocomium spendens*, *Pleurozium schreberi*, *Ptilium crista-castrensis*) were common at the lower edges of clear-cuts. Soil was 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), another 25% of the plots were on shallow to moderately deep mineral soils (SS5, SS6 and SS7), yet another 25% were on deep mineral soils (S1, S2, S3 and S9), and 10% were on organic soil types (S12S and S12F). Topography was rolling. Mean daily temperatures for January and July were -18.5°C and +16.1°C, respectively. Precipitation averaged 50.5 mm in January and 77.5 mm in July (Environment Canada 1992). Kelly and Cumming (1992) provide a summary of soils, clear-cut size, site preparation, sampling intensity, harvest dates and planting dates. These sites were chosen for Vision application because competition was beginning to grow higher than the planted conifers. Residual white birch (*Betula papyrifera* Marsh.) and trembling aspen (*Populus tremuloides* Michx.) over-topped the cut areas during spraying.

METHODS

Spraying

In each of 7 clear-cuts (blocks), we established bisecting baselines from which we located 3 perpendicular boundaries subdividing the block into 4 experimental units. Glyphosate (Vision®) was sprayed at 3 application rates (0.8, 1.06, and 1.60 kg a.e./ha) on randomly selected units by helicopter (Bell 206 Jet Ranger) in late August, 1990, retaining 1 unit in each block as a control (0 kg a.e./ha).

Hardwood Winter Stem Density and 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 experimental unit within each block was surveyed independently. Browse survey lines as described by Cumming (1987) were run at right angles to the spray path. Using a random start from the baseline, 1x20 m sample plots were examined every 20-40 m, according to unit size. A minimum of 32 and a maximum of 64 sample plots were surveyed from each of the four units in each block.

Counts of browsed stems to compare moose browsing on different areas have been used for some time in Ontario, based on an early study that showed reasonable correlation between stem counts and twig counts (Cumming 1987). However, we re-examined the correlation between the two counting methods for data from this study with favorable results (F=538.9, P=0.0001, R=0.932, and R^2=0.868). Therefore, we concluded that counting of stems is still a reasonable method for estimating differences in browse intensity. Any estimates of browsing beyond the counts of browsed stems involve additional sources of error. Since counting all twigs on each plot would be impossible, at least an additional sampling error would be involved. Furthermore, little agreement has been achieved about what constitutes a twig, and our definition was somewhat arbitrary. A major step forward involved the regression of twig weights on diameters at point of browsing, but this does not apply to unbrowsed twigs. For these reasons, we thought that comparisons of browsing between treatment areas were best carried out at the level of the original counts: live, dead or browsed stems.

On each sample plot, hardwood density and browsing intensity were recorded 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 stems are covered by snow for the majority of the winter browsing season. Stems were classified as alive, alive browsed, dead or dead browsed. Only current year's browsing was considered. We analyzed data on browsing intensity for the top ranked browse species that constituted 90% of the browse removed, i. e., 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).

Available Hardwood Browse Biomass Calculations

On every 8th stem-count plot (every 6th if sampling intensity was low), the number and diameter of browsed (current year) and unbrowsed twigs were recorded for the first 10 stems encountered for each hardwood 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 6 mm. Moose rarely consume twigs or branches larger than this, except when feeding on mountain ash (Belovsky 1981). Samples of each twig diameter class were collected for most hardwood species and dried to constant weight for establishing species specific regression curves of weight. From these data, regression curves were calculated, following Smith (1992), for beaked hazel (*Corylus cornuta* Marsh.), trembling aspen, white birch, mountain maple *(Acer spicatum* Lam.), willow (*Salix spp.*), mountain ash , pin cherry (*Prunus pensylvanica* L. fil) and green alder (*Alnus crispa* (Ait.) Pursh). Data collected nearby by Stronks (1985) were used for mountain ash (*Sorbus americana* Marsh.) and red osier dogwood (*Cornus stolonifera* Michx.). Some regression curves were used for more than one species: results for green alder were also used for speckled alder (*Alnus rugosa* (Du roi) Spreng.); the curve for pin cherry was also used for choke cherry (*Prunus virginiana* L.) and service berry (*Amelanchier* spp.).

For each experimental unit an average stem biomass, per species and height class was calculated as follows. Diameters were entered into the appropriate regression equation to obtain a weight per twig. This number multiplied by the number of twigs/tree yielded available biomass. These values were averaged within species and height classes for each unit. The average biomass for species x, height y, unit z, was multiplied by the corresponding stem density for species x, height y, unit z. All species and height classes were added together to obtain total available browse biomass/ha per treatment replication.

Winter Tracks And Track Aggregates

During each winter, the 7 clear-cuts were surveyed for moose tracks either from helicopter or 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 cut-overs because of deep snow and crusting (Jackson *et al.* 1991). Seven flights were made during winter 1989-90, and six flights each in winters 1990-91 and 1991-92. Although there were more flights the first winter, timing of observations was spread evenly over the winter each year. Control areas for block #3 were erroneously excluded from aircraft observation; thus, only six replications of controls could be compared with the seven replications of treatment units.

Two to three days after a snowfall deep enough to permit identifying fresh tracks, all clear-cuts were circled until tracks had been transcribed onto aerial photographs. Ponds, swamps and clear-cut edges were used as location references. During 1991-1992, complexes of tracks too complicated to be represented as individual lines were delineated by the outside edges of the complexes to produce polygons, referred to as a track aggregates. The aerial photos and the winter moose tracks were digitized into Geographic Information System (GIS) coverages.

Precise boundaries of treatment blocks were overlaid on the track photos with the aid of a Global Positioning System (GPS). During fall 1992, each clear-cut was mapped with a GPS. Spray boundaries (i.e. the edge of the clear-cut was not necessarily the spray edge) and treatment (i.e. experimental unit) boundaries within the sprayed areas were located to within 5 m (Hurn 1989). For control areas the clear-cut was considered the edge of the experimental unit. Map information was then converted to GIS coverages and superimposed onto the corresponding aerial photo coverage using known points. Track density (m/ha) and track aggregate area (m^2/ha) within each treatment unit were calculated.

Conifer Regeneration Surveys

To evaluate effects of application rates on crop tree growth, circular sample plots (diameter = 2.2m) were located along transect lines. The crop tree (planted or volunteer) nearest the line at predetermined points served as the plot center. For each tree, internode lengths for the current and two previous years, total heights, and diameters at 1/3 total height (single measurement two growing seasons post-treatment) were measured. 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 a field guide prepared by Baldwin and Sims (1989). Herbs, including raspberry, and hardwood shrubs were assigned percent cover values as separate groups. Dead stems or herbs were not counted as competition. When crop trees were found dead, the plot was not included in cover or crop tree growth estimations.

Data Analysis

The experiment was analyzed as a randomized complete block design using repeated measures analysis of covariance. Prespray data were used as covariates to account for differences that may have existed prior to the experiment. 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 of variance to be met (Box *et al.* 1976).

Data for winter track aggregates were also transformed. Deviation from normal distribution 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 number of herb species (1992) did not fit the proper residual pattern (i.e. when residuals were plotted they did not produce the required even band indicating normality). 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 (= 0.05). This post-hoc test is fairly robust for data that violate assumptions regarding normality and homogeneity (Gagnon *et al.* 1989). Treatment means for all other dependent variables were compared using Fisher's protected LSD (= 0.05). Data analysis was performed using the SuperANOVA software package (Abacus Concepts 1989).

All figures presented include pre-spray data (i.e. the co-variate) for comparison, consequently error bars do not show the actual confidence intervals as calculated for repeated measures analysis of co-variance (Table 1). Figures show the error simply based on RCBD ANOVA. Thus some differences among treatment means that appear non-significant in the figures are, in fact, significant using the covariate (as shown in Table 1). The differences between these approaches highlight the importance of collecting pre-treatment data in large-scale field experiments where variance is expected to be high.

RESULTS

Hardwood Stem Density

Vision® treatment consistently reduced live stem densities (Table 1). For total stem densities, the only significant difference among treatments was between 0.80 kg a.e./ha and 1.06 kg a.e./ha (Table 1, Fig. 1). Initial analysis of the data suggested that plant species and height classes could be grouped into three categories (A, B, C) within which the plants responded to glyphosate treatment in similar ways. Following treatment, group A species, including mountain maple, green alder, trembling aspen, pin cherry, *Salix spp.*, and white birch, showed lower live stem densities on treated units than on controls, but little difference among treatments (Table 1). Notable exceptions to this generalization included height class 1-1.99m, where the lower application rate did not control hardwoods as well as the two higher rates. Group B (beaked hazel, mountain ash, service berry and speckled alder) densities increased in 1992 on treatment units with the two highest application rates. 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 2 application rates (i.e. the lowest rate provided the best control). Group C (choke cherry and red osier dogwood) varied widely from the general pattern. No differences among treatments were observed for the latter, and the only pairs 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 (Table 1). Kelly (1993) presents a more comprehensive review of the data.

Available Hardwood Browse Biomass Calculations

Calculation of biomass complicates direct comparisons of treated and untreated areas; for example, Fig. 2 shows a dramatic but unaccountable increase in biomass on the control area. However, biomass figures are useful for calculating losses of carrying capacity, calculations that are not simple (Connor 1992), and are beyond the scope of this interim paper. Biomass data are presented for comparisons with other studies. Biomass appears to have been reduced by about 2-5 times compared with the controls (Fig. 2).

Hardwood Winter Browsing Intensity

Browsing decreased on all treatment units during the first 3 years of the study, but moose browsed even less in sprayed areas than controls during the first two seasons after treatment. This is consistent with others who reported less use of sprayed areas by moose (Connor and McMillan 1990, Hjeljord and Grønvold 1988). Furthermore, treatment re-

Table 1. Treatment pairwise comparison of *P* values[1] for 2 years post-spray.

	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	-	-
beaked hazel	.0094	.0004	.0001	-	.0289	-
choke cherry -	-	-	-	-	**.0206**	-
green alder	NO SIGNIFICANT DIFFERENCES					
mountain ash -	.0355	-	-	-	-	-
mountain maple	-	-	.0259	.0488	.0087	-
pin cherry	.0006	.0006	.0035	-	-	-
red osier dogwood	NO SIGNIFICANT DIFFERENCES					
Salix spp.	.0069	.0020	.0243	-	-	-
service berry	.0040	.0013	.0122	-	-	-
speckled alder	.0466	.0311	-	-	-	-
trembling aspen	-	.0029	.0029	-	-	-
white birch	.0190	.0014	.0057	-	-	-
Total Browsed Stems/ha	-	.0050	.0018	-	.0424	-
beaked hazel	-	.0170	.0021	-	.0127	-
mountain ash -	.0482	-	-	-	-	-
mountain maple	-	-	.0408	-	.0108	-
pin cherry	.0002	.0001	.0015	-	-	-
Salix spp.	NO SIGNIFICANT DIFFERENCES					
trembling aspen	NO SIGNIFICANT DIFFERENCES					
white birch	.0250	.0078	.0019	-	-	-
Browse Biomass (kg/ha)	.0193	.0010	.0002	-	-	-
Regeneration Surveys:						
crop tree height	NO SIGNIFICANT DIFFERENCES					
crop tree diameter	NO SIGNIFICANT DIFFERENCES					
dead/lost crop trees	-	.0019	.0396	-	-	-
hardwood cover	.0001	.0001	.0001	.0345	-	-
herbaceous cover	NO SIGNIFICANT DIFFERENCES					
# herb species	NO SIGNIFICANT DIFFERENCES					

[1]Pairwise comparions of treatment *P*-values using repeated measures analysis of variance. Pre-spray data (1990) is the covariate. Non-significant *P* values were not included (-). **Bold** denotes low application rate with higher kill; all other comparisons have expected response of higher application rate with higher kill or less browsing. Comparisons are separated into control vs. treated units, and among treated units for simplicity.

duced browsing intensity both 6 and 18 months post-spray (Fig. 3). But differences were statistically significant only between non-adjacent application rates (i.e. differences were significant between application rates of 0 & 1.06, 0 & 1.60, 0.80 & 1.60 kg a.e./ha, Table 1).

Similar to the data on available stems, browse species could be classified according to the ways that moose response to spraying was manifested. Browsing on group X species (beaked hazel, mountain ash, and *Salix spp.*, Fig. 3), was lower on units that received

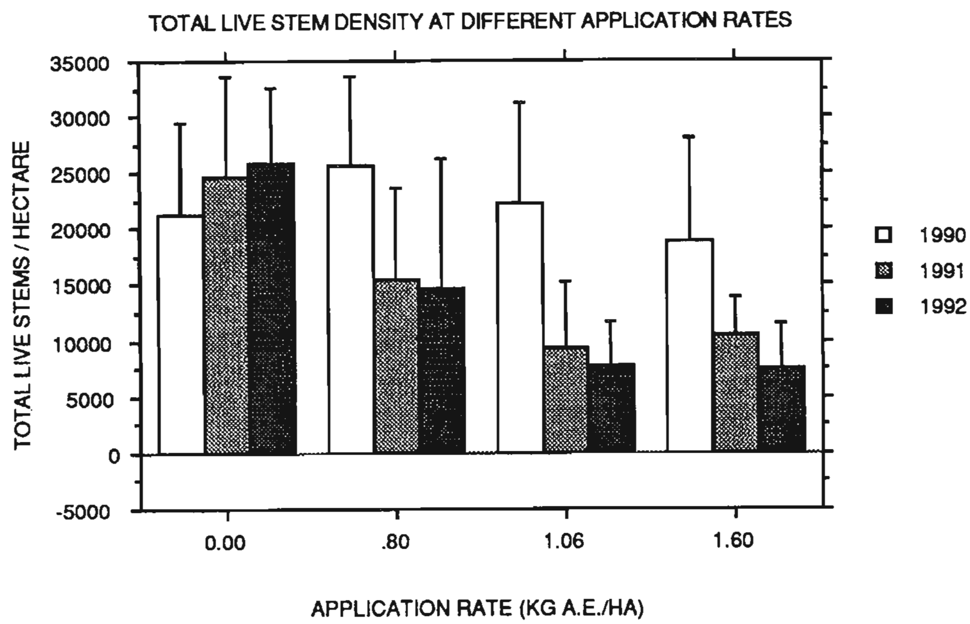

Fig.1. Total live stem density with 95% confidence error bars at three application rates of Vision® herbicide and a Control showing consistent reductions in live stem/ha at all application rates. 1990 = pre-spray.

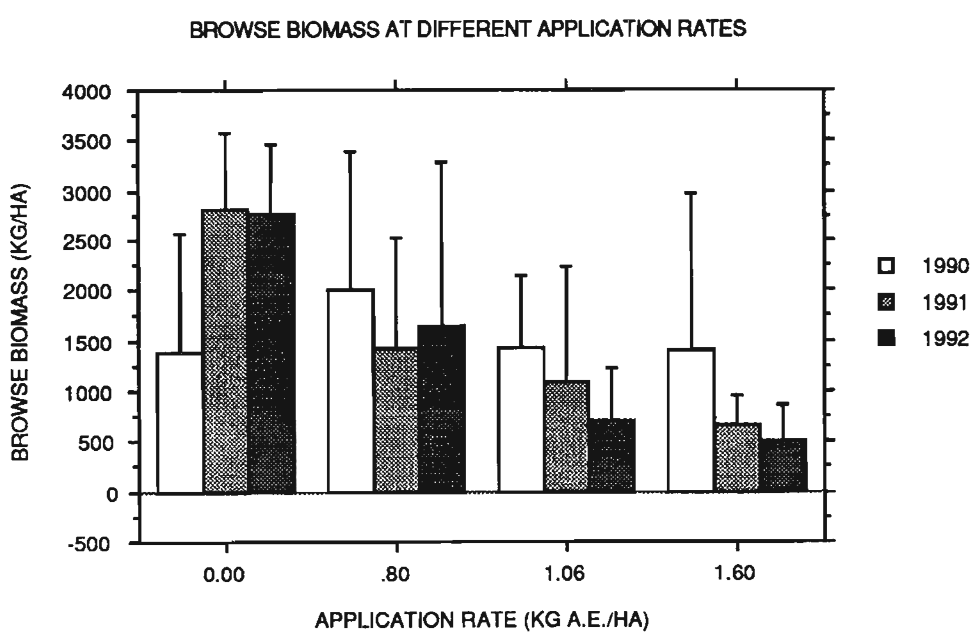

Fig. 2. Available browse biomass with 95% confidence error bars at three application rates of Vision® herbicide and a control showing significant reductions at all application rates (Table 1). 1990 = pre-spray.

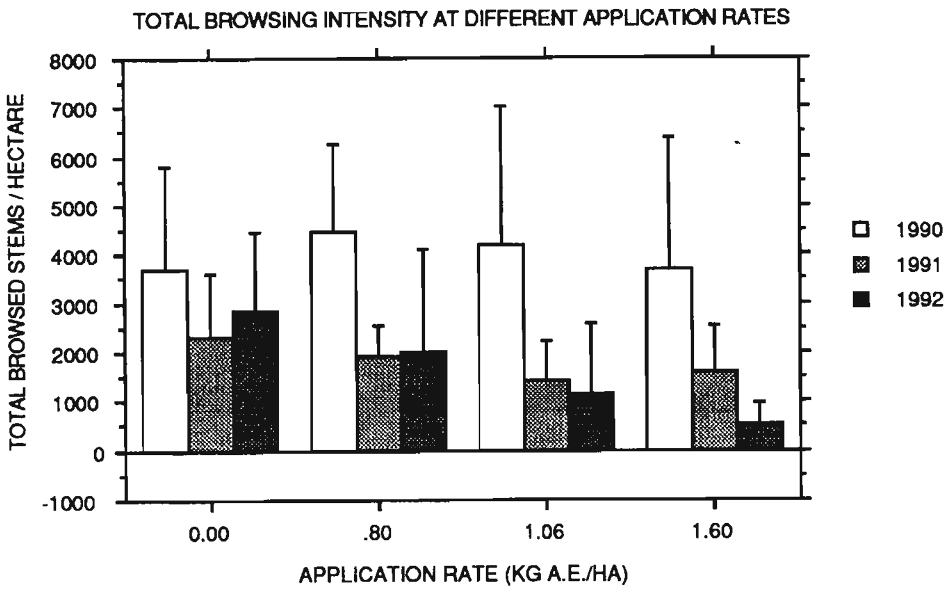

Fig. 3. Total browsing intensity of major browse species with 95% confidence error bars at three application rates of Vision herbicide and a control. 1990 = pre-spray. Although decreases were recorded for all treatments, only the 2 highest rates reduced browsing significantly below controls (Table 1).

the two highest application rates (1.06 and 1.60 kg a.e./ha) regardless of stem height, but not statistically different from controls on units that received the lowest application rate (0.80 kg a.e./ha, Table 1). Group Y species (pin cherry, white birch, and trembling aspen) showed more severe browsing reductions than group X. Browsing on 0.80 kg a.e./ha units was significantly less than on controls (Table 1). Although aspen responded similarly to pin cherry and white birch, unlike any other species, a remarkable browsing decrease also occurred for aspen on controls (Fig. 4); thus differences between treatments and controls were not significant. Conversely, group Z (mountain maple) was not reduced until application rates reached 1.60 kg a.e./ha. Group Z seemed to show a browsing rebound in 1992 at the two lower application rates (Table 1). For a more comprehensive presentation of data see Kelly (1993).

Winter Track And Track Aggregates

The different application rates did not significantly affect the density (m/ha) of tracks observed (P= 0.34). However, clear-cut location (blocks) did produce significant differences in track density (P= 0.01, Fig. 5), suggesting that site differences were more important to moose than any changes resulting from herbicide application. Moose were not deterred from entering sprayed areas, as track density was consistently, although not statistically, greater than pre-spray track densities at all application rates in year 1 post-spray, and approximately equal 2 winters after treatment.

Track aggregate area (m^2/ha), recorded in the second year post-spray only, was statistically equivalent on all treatments and all blocks. However, track aggregate area was considerably less on 1.06 kg a.e./ha treated units (approximately half) - the application rate that resulted in the greatest control of hardwood browse species (i.e. the lowest live stem density); yet, when aggregate area was regressed on percent live stems, no relationship was observed (R^2 = 0.00003).

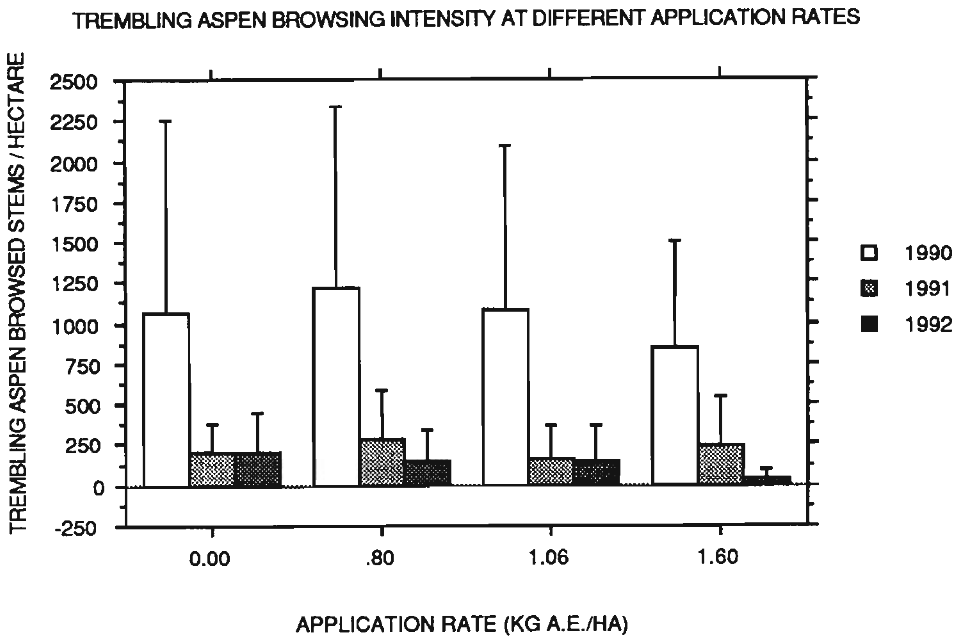

Fig. 4. Total browsing intensity Trembling Aspen with 95% confidence error bars at three application rates of Vision® herbicide and a control. Extreme reductions in browsing, even on controls, eliminated significant differences among treatments. 1990 = pre-spray.

Conifer Regeneration Surveys

Hardwood shrub cover (%) for conifers was reduced (*P*=0.0001, Table 1, Fig. 6) by application of Vision at all rates. Application at 1.06 kg a.e./ha controlled hardwood brush better than 0.80 kg a.e./ha and was equivalent to 1.60 kg a.e./ha (Table 1). Herbaceous cover (%), reduced considerably 1 year post-spray, rebounded within 2 years and by 1992 was almost identical on control and treated units (Fig. 7). This increase in herbaceous vegetation 2 years post-spray masked what would have been a significant difference in herbaceous cover in 1991. During the study there was a steady increase in the number of herbaceous species on both treated and control units that was not a result of the spray.

Application of Vision® did not increase survival of crop trees (Table 1, Fig. 8). Areas sprayed with 1.06 and 1.60 kg a.e./ha experienced more mortality than controls (*P*=0.0019, *P*=0.0396, respectively). Crop tree diameter was not affected by application of Vision® (Table 1, Fig. 9). 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.

DISCUSSION

Hardwood Stem Density

Hardwood density comparisons between treated and control units demonstrated the efficacy of treatments but also showed 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, even though hardwood shrub cover on treated units 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 experimental units, including controls two years after spraying.

Contrary to Pojar (1990) and others who

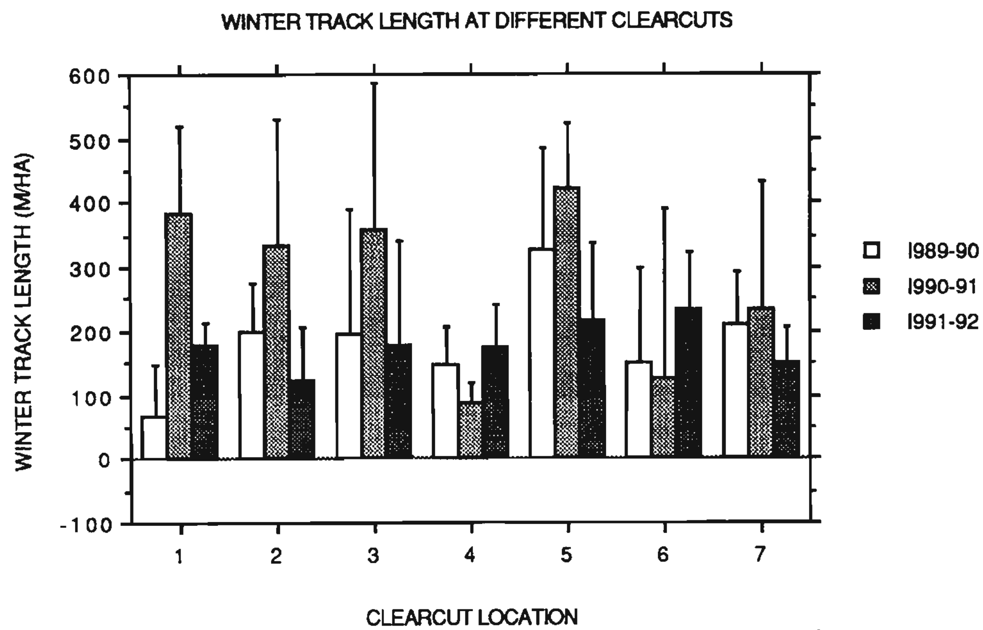

Fig. 5. Length of winter tracks with 95% confidence error bars at seven different study areas where 1989-90=pre-spray. Moose were not deterred from entering sprayed areas since track lengths increased after spraying. Treatments differences were not significant; blocks did differ significantly (Table 1).

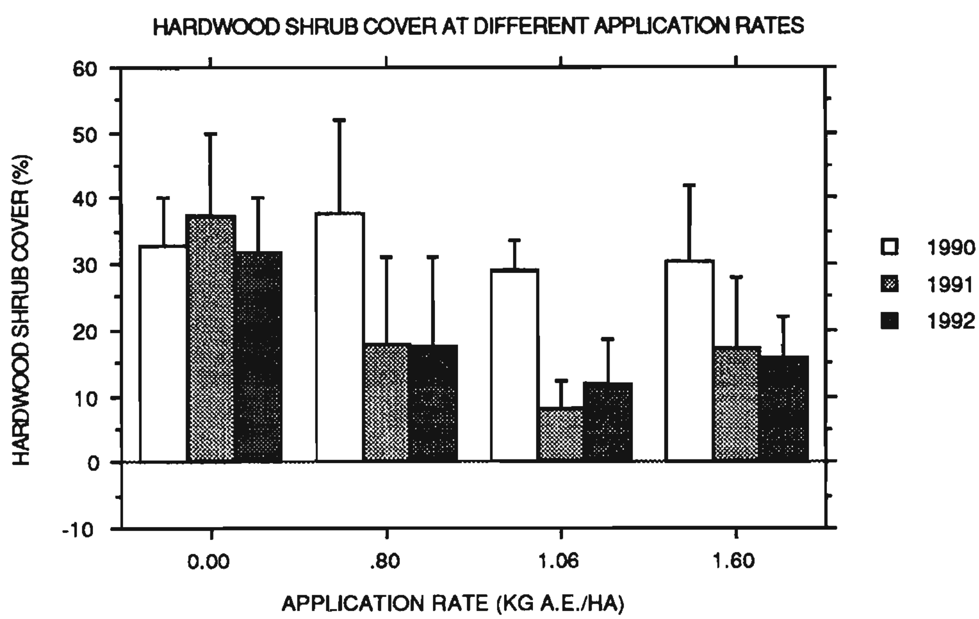

Fig. 6. Hardwood shrub cover with 95% confidence error bars at three application rates of Vision® herbicide and a control showing results similar to those for stem density and biomass. 1990 = pre-spray.

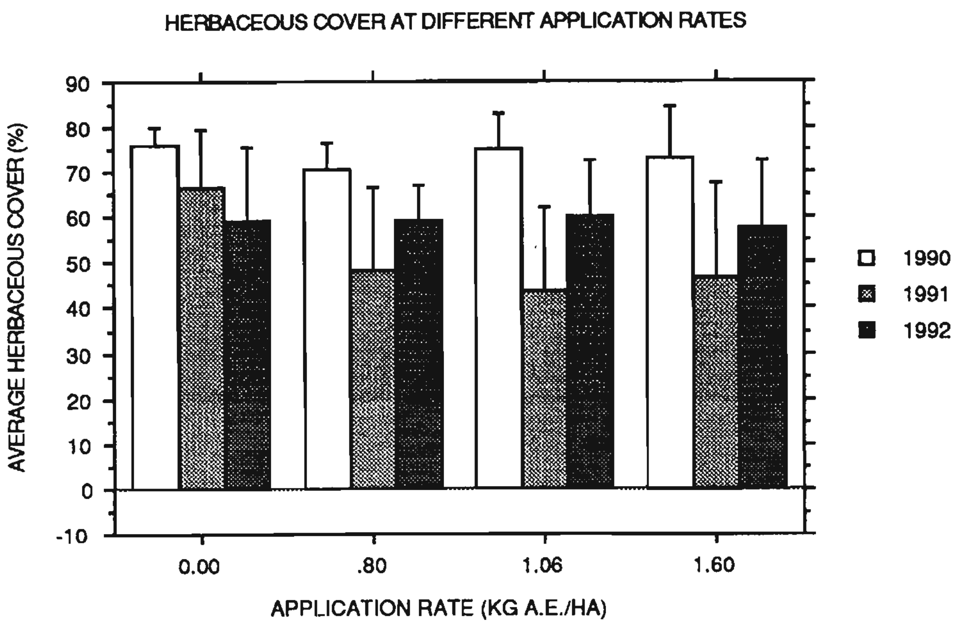

Fig. 7. Herbaceous cover with 95% confidence error bars at three application rates of Vision® herbicide and a control, showing reductions to nearly identical levels by 1992. 1990 = pre-spray.

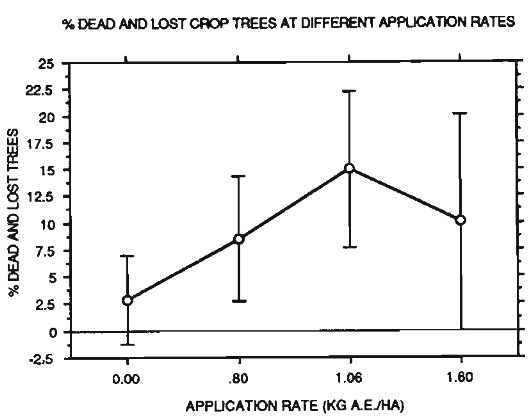

Fig. 8. Treatment means (%) of combined dead and lost conifer crop trees with 95% confidence error bars at three application rates of Vision® herbicide and a control. Highest crop tree mortality at 1.06 kg a.e./ha coincided with lowest stem densities and lowest hardwood cover.

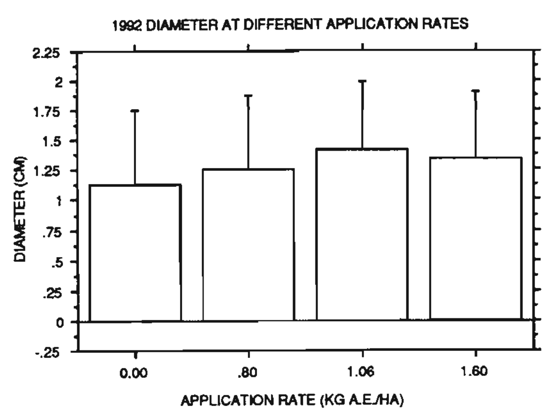

Fig. 9. Diameter of crop trees with 95% confidence error bars at three application rates of Vision® herbicide and a control showing no significant differences among treatments. (Data collected for 1992 only).

reported extremely variable response to glyphosate among species, stem density figures demonstrated similar response (plant mortality) by different species and at different heights. Typically, live stem density was reduced immediately post-spray (1991), followed by a smaller reduction the next year. Variability, however, was still common. Mountain ash and speckled alder both showed 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 because few studies used multiple application rates. Whitmore and Duinker (1992) presented models but did not incorporate experimental data. Reduced browse availability associated with herbicide applications in this study was similar to that reported by Kennedy and Jordan (1985), Cumming (1989), Newton *et al.* (1989), and Connor (1992). Certainly, reductions are not close to 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's (1990) study with five different application rates (0.71, 1.06, 1.42, 1.60 and 1.78 kg a.e./ha) had similar results to this study. Reduction was not as drastic as in Hjeljord and GrØnvold's (1988) and the heaviest application rate did not always exhibit the most control. Lloyd stated 0.71 kg a.e./ha caused as much damage as 1.6 kg a.e./ha and more than 1.42 kg a.e./ha (study area 1); 1.42 kg a.e./ha 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. Greater effectiveness of lower rates may be due to a phenomenon reported by Sutton (1978), who found that if application rates are too high glyphosate will kill tissue on contact preventing translocation and/or inhibiting control. Perhaps, due to impeded herbicide transport at high application rates, efficacy at 1.60 kg a.e./ha was reduced in this study

Hardwood cover was reduced at all application rates. The significant reduction of hardwood cover should result in increased conifer growth in the long term. Although differences in conifer seedling diameters were not significant, the application rate which killed the most stems (1.06 kg a.e./ha) did result in the largest diameter. Crop trees growing on units treated with the intermediate rate should perform as well or better than trees on units treated with the highest rate.

Hardwood Winter Browsing Intensity

Reduced browsing on both treatment and control units may have been related to: 1) shift in the moose population unrelated to the spraying, or 2) loss of interest by moose in large areas where browse availability was reduced. Some evidence is available for assessing the likelihood of the first possibility. Blocks 3, 4, and 5 were within a wildlife study area that has been surveyed extensively to estimate moose populations. Data from 1985-86 to 1992-1993 suggest that the population is stable and may be increasing (Gollat pers. comm.). Lowest densities of moose occurred in 1985-86 and 1986-87 (approximately 0.60 moose/km^2), while densities increased in subsequent years to approximately 1.0 moose/km^2. Therefore, the decreased browsing does not appear to have been the result of reduced moose populations.

The second possibility might relate to Belovsky's (1978) suggestion that moose forage optimally. It may be that spraying reduced browse availability enough so that the whole cut-over, treated and untreated, became less attractive than nearby unsprayed areas. Furthermore, when compared with controls, treatment units 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 cannot know the value (to moose) of the sprayed patches. Optimal foraging theory suggests that moose should forage in the highest quality patches first, and use lower quality patches only after higher quality patches become unavailable. Therefore, moose may be ignoring sprayed areas, even though they contain valuable browse items. Food availability may be high enough that only the highest quality patches are used.

Browsing (browsed stems/ha) for all species and heights decreased on all experimental units, including controls, 1 year post-spray

(1991). However, 2 years post-treatment (1992), browsing began to increase to pre-spray and/or higher levels on controls, while continuing to decline on sprayed areas. The lowest application rate (0.80 kg a.e./ha), while still declining overall, showed signs of rebounding before the other rates. Browsing on Mountain Maple and Beaked Hazel, species fairly resistant to Vision® increased in 1992. At the 2 highest rates, especially at 1.60 kg a.e./ha, browsing continued to drop sharply in 1992.

Although winter browsing decreased on sprayed areas, pre-spray browsing rates were very low. This suggests that moose have an abundance of winter food and that any reduction in browse on treated units may be compensated for by food elsewhere. Ontario has 383 000 km^2 of productive forest land (Forestry Canada 1988). In 1991, when herbicide treatments reached their maximum, only 1000 km^2 were treated (Paquette and Bousquet 1991). Thus, at most, spraying affects 0.26% of productive land each year, even less if the total forested area were included.

Lautenschlager's (1991) model suggests that sprayed areas have higher value than unsprayed areas for moose several years in the future, primarily because height growth of browse is delayed and browse remains in reach of moose for a longer period of time. His model suggests that 5 years post-spray browse availability on treated areas recovers and begins to exceed levels on controls. Thus sprayed area cannot be said to be cumulative in the long term.

In Ontario, the results of the Ontario Independent Forest Audit Committee (1992) suggest that, in general, regenerating forests in Ontario are increasingly becoming dominated by hardwoods (aspen and birch), which have higher browse values than the virgin, conifer dominated forests. Because herbicides are designed to suppress hardwoods, herbicide treated areas should have higher conifer components than unsprayed areas. These patches of conifers within areas with increasing hardwood cover should provide critical late winter cover (Jackson *et. al.* 1991) for moose, cover that seems to be disappearing as a result of current management practices.

Winter Tracks And Track Aggregates

The finding that winter track lengths (m/ha) indicated no significant reduction in moose use of sprayed areas contrasts with Connor and McMillan (1990) who reported less track length on treated sites 19, 31 and 43 months post-spray. But linear tracks are not strong evidence of feeding behaviour. Tracks may result from movement between areas. Complex, dense groupings or "aggregates" would be more indicative of feeding behaviour. Since no track sets in previous years were so extensive that they could not be mapped, the necessity for recording aggregates in 1992 may indicate increased use of the cut areas. Yet track aggregate and length data, contrary to browsing intensity results, yielded no conclusive information that moose were feeding less on sprayed patches . Perhaps these track aggregates do not truly represent browsing, but may be associated with other kinds of behaviour. The open areas might be used for late season displays by gathered bulls (as observed from aircraft), resulting in observed aggregates in 1992. This situation remains unclear.

FOREST MANAGEMENT IMPLICATIONS

Differences among application rates were relatively subtle. Vision®(glyphosate) applied at 1.06 kg a.e./ha when compared to the other rates (0.80 & 1.60 kg a.e./ha), provided marginally superior, or 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 missed spray strips associated with aerial applications, seemed to maintain sufficient winter browse for moose. However, moose browsed less on sprayed areas, and may return first to areas sprayed with lower than recommended rates of Vision®. In this study, some species on 0.80 kg a.e./ha units showed the first signs of returning to pre-spray use levels by 2 years post-treatment. Yet winter forage availability does not seem limiting in this area; pre-spray browsing rates rarely exceeded 10% of available stems. Low browsing rates in the study areas imply that moose populations are below carrying capacity. Several authors (e.g., Bergerud 1981, 1983; Crête 1989) have suggested that moose populations might be regulated by predation. All study areas maintained populations of wolves and black bears, and four of the seven blocks were open to hunting as well. If predation and/or hunting 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 is not expected to affect 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 cut-overs 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 2 years post-spray compared with the 2 higher rates. Consequently, if concern about local short term winter browse reduction exits and/or spray programs are concentrated in one management unit, applications at 0.80 kg a.e./ha could minimize potential browse reductions.

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REFERENCES

ABACUS CONCEPTS. 1989. Super-ANOVA. Abacus Concepts Inc., Berkeley, Calif.

BALDWIN, K.A. and R.A. SIMS. 1989. Field Guide to the Common Forest Plants in Northwest. Ont. For. Canada, Ontario Reg., Sault Ste. Marie, Ont. Northwest. Ont. For. Technol. Dev. Unit, tech. rep., Ont. Minist. of Nat. Resour., Thunder Bay, Ont. 344pp.

______, J.A. JOHNSON, R.A. SIMS and G.M. WICKWARE. 1990. Common Landform Toposequences of Northwestern Ontario. For. Can., Ont. Reg., Sault Ste. Marie, Ont. Northwest. Ont. For. Technol. Dev. Unit, tech. rep. 49., Ont. Minist. of Nat. Resour., Thunder Bay, Ont. 26pp.

BELOVSKY, G.E. 1978. Diet optimization in a generalist herbivore: the moose. Theor. Popul. Biol. 14:105-134.

______. 1981. Food plant selection by a generalist herbivore: the moose. Ecology, 62 : 1020-1030.

BERGERUD, A. T. 1981. The decline of moose in Ontario - a different view. Alces 17: 30-43.

______, W. WYETT, and B. SNIDER. 1983. The role of wolf predation in limiting a moose population. J. Wildl. Manage. 47:977-988.

BOX, G.E.P., W.G. HUNTER and J.S. HUNTER. 1976. Statistics for Experimenters: An Introduction to Design, Data Analysis and Model Building. John Wiley and Sons. Toronto, Ont. 653 pp.

CANADIAN PULP and PAPER ASSOCIATION and FORESTRY CANADA. 1993. Glyphosate. Tech. Reference: herbicides. For. Can. Sault Ste. Marie, Ont. 4 pp.

_______. 1992. Herbicides registered for forest and woodland management. Tech. Reference: herbicides. For. Can. Sault Ste. Marie, Ont. 6 pp.

CONNOR, J.F. 1992. Impacts of the herbicide Glyphosate on moose browse and moose use of four paired treated-control cutovers near Thunder Bay, Ontario. M.Sc.F. Thesis, Lakehead Univ., Thunder Bay, Ont.. 87 pp.

_______, and L.M. McMILLAN. 1990. Winter utilization by moose of glyphosate treated cutovers.Alces 26:91-103.

CRÊTE, M. 1989. Approximation of K carrying capacity for moose in Eastern Quebec. Can. J. Zool. 67: 373-380.

CUMMING, H.G. 1989. First year effects on moose browse from two silvicultural applications of Glyphosate in Ontario. Alces 25: 118-132.

_______. 1987. Sixteen years of moose browse surveys in Ontario. Alces 23: 125-155.

ENVIRONMENT CANADA. 1992. Thunder Bay, Ont. office. Statistics for Raith, Ont. Pers. comm.

FORESTRY CANADA. 1988. Canada's Productive Forest Landbase. FORSTAT Pamphlet. Petawawa Natl. For. Inst., Petawawa, Ont. 2 pp.

GAGNON, J., J.M. ROTH, R. HOFFMAN, K. HAYCOCK, D.S. FELDMAN, JR., and J. SIMPSON. 1989. SuperANOVA: Accessible General Linear Modeling. Abacus Concepts Inc., Berkeley Calif. 322 pp.

HJELJORD, O. and S. GRØNVOLD. 1988. Glyphosate application in forest-ecological aspects VI. Browsing by moose (*Alces alces*) in relation to chemical and mechanical brush control. Scandinavian J. For. Res. 3: 115-121.

HURN, J. 1989. GPS: A Guide to the Next Utility. Trimble Navigation. Sunnyvale Calif. 76 pp.

JACKSON, G.L., G.D. RACEY, J.G. McNICOL and L.A. GODWIN. 1991. Moose habitat interpretation in Ontario. Ont. Minist. of Nat. Resour., Northwest. Ont. For. Technol. Dev. Unit Tech. Rep. 52. 74 pp.

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

_______, and H.G. CUMMING, 1992. Effects of an aerial application of vision on moose browse- first year results. Alces 28: 101-110

KENNEDY, E.R. and P.A. JORDAN. 1985. Glyphosate and 2,4-D: The impact of two herbicides on moose browse in forest plantations. Alces. 21: 149-160.

LAUTENSCHLAGER, R.A. 1993. Response of wildlife to forest herbicide applications in northern coniferous ecosystems. Can. J. For. Res. 23: 2286-2299.

_______. 1991. Response of wildlife in northern ecosystems to conifer release with herbicides. Coop. For. Res. Unit, Coll. of For. Resour., Me. Agric. Exp. Stn., Univ. of Maine. Orono, Me. Misc. Rep. 362. 12 pp.

LLOYD. 1990. Impact on vegetation after operational Vision® treatment at varying rates in the Skeena region. B.C. Minist. Environ. Fish and Wildl. Branch.

MONSANTO CANADA INC. 1989. Vision® For Now and The Future. Technical Guide. Monsanto Canada, Inc. Mississauga, Ont.

16 pp.

NEWTON, M., E.C. COLE, R.A. LAUTENSCHLAGER, D.E. WHITE and M.L. McCORMACK, JR. 1989. Browse availability after conifer release in Maine's spruce- fir forests. J. Wildl. Manage. 53: 643-649.

NOVA SCOTIA DEPARTMENT OF LANDS AND FORESTS. 1989. Controlling competing vegetation with lower than recommended rates of glyphosate. N.S. Dep. Lands For., Truro, N.S., For. Res. Rep. 8. 7 pp.

ONTARIO INDEPENDENT FOREST AUDIT COMMITTEE. 1992. A report on the status of regeneration. Sault Ste. Marie, Ont. Queens Printer for Ont.

ONTARIO INSTITUTE OF PEDOLOGY. 1985. Field Manual for Describing Soils, 3rd Edition. Ont. Inst. Pedology and Univ. of Guelph, Guelph, Ont. Ont. Inst. Pedology, Publ. 85-3. 38 pp.

PAQUETTE, G. and J. BOUSQUET. 1991. Brief presented to the commission on forest protection. Pages 60-64 *in* Forestry on the Hill. 1991 (5). Special issue: herbicides. Can. For. Assoc., Ottawa, Ont. 65 pp.

POJAR, R. 1990. The effects of operational application of the herbicide Glyphosate on target brush species, selected browse species and conifer crop trees. B.C. Minist. For., Prog. Rep. 49 pp.

SIMS, R.A., W.D. TOWILL, K.A. BALDWIN and G.M. WICKWARE. 1989. Field Guide to the Forest Ecosystem Classification for Northwestern Ontario. Northwest. Ont. For. Technol. Dev. Unit, Tech. Rep., Ont. Minist. Nat. Resour., Thunder Bay, Ont. 19 pp.

SMITH, C. R. 1992. A comparative study of twig diameter-weight relationships for seven moose browse species in the Thunder Bay area. H.B.Sc.F. Thesis, Lakehead Univ., Thunder Bay, Ont. 54 pp.

STRONKS, G.C. 1985. Twig diameter and weight relationships for several important moose browse species in Northwestern Ontario. H.B.Sc.F. Thesis. Lakehead Univ., Thunder Bay, Ont. 19 pp.

SUTTON, R.F. 1978. Glyphosate herbicide: an assessment of forestry potential. For. Chron. 541: 24-28.

WHITMORE, G. and P. DUINKER. 1992. Forest management implications of alternative herbicide policies in Ontario. School For., Lakehead Univ., Thunder Bay, Ont.