IMPACTS OF THE HERBICIDE GLYPHOSATE ON MOOSE BROWSE AND MOOSE USE OF FOUR PAIRED TREATED-CONTROL CUTOVERS NEAR THUNDER BAY, ONTARIO

by

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ABSTRACT

Re-assessment of the aerial and ground observations on four paired, glyphosate treated and control, cutovers near Thunder Bay, Ontario, indicated that aerial tending with glyphosate altered the use of these cutovers by moose.

The number of pellet groups favoured the control areas ($p < 0.05$) by 1.5 times. Additionally, the number of moose tracks and moose track aggregates were more prevalent ($p < 0.05$) on the controls for 2 to 3 years after treatment. Pre spray data on 2 areas suggested use shifted away from glyphosate treated areas.

Browse availability was significantly greater ($p < 0.05$) on the control plots by 18 times in the highest height class measured (201 - 350 cm), 5 times in the next highest (101 - 200 cm) but not statistically significant ($p > 0.05$) in the lowest (51 - 100 cm), 2 years after treatment. Due to too few replications, differences in availability 1 year after treatment were not statistically significant.

Biomass of browse removed by moose was 3 to 7 times greater on controls but again these differences were not statistically significant.

The average length of moose trails observed in the snow was shorter ($p < 0.05$) on the controls suggesting less travel time. The size (area) of moose track aggregates was the same ($p > 0.05$) between treatments indicating equal search time while browsing.

A carrying capacity model indicated that if all cutovers were sprayed, the treatment would have a negative impact on moose densities.

Glyphosate treatments should be dispersed to create a mosaic of glyphosate treated areas next to non-treated areas. Similarily, areas of seasonal importance such as aquatics, salt licks, and calving areas should have at least a non-sprayed buffer beside them if the adjacent cut area must be treated with glyphosate.

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J.F.C.

1.0.0 INTRODUCTION

"The harvest of wood, a foresters function, has greater influence on game than any active technique available to the wildlifer" (Giles, 1962). Harvesting creates openings in the forest where early successional tree and shrub species such as aspen (Populus tremuloides) and white birch (Betula papyrifera), which are essential winter foods for moose (Kelsall and Telfer, 1974), abound. Harvesting produces more moose (Alces alces) habitat than the traditional avenues of fire, and insect outbreaks (Brassard et al. 1974, Krefting 1974, Kelsall and Telfer 1974, Telfer 1978, Peterson 1955). Today, other forestry operations which affect moose habitat include site preparation (both mechanical and chemical), planting, and plantation tending (release and spacing).

Site preparation improves planter access and the possibility of establishing trees of the desired species while potentially reducing competition from naturally occuring "weeds". Yet site preparation can reduce the number of stems of those shrub species which act as winter food for moose. Stelfox (1974) noted that unscarified strips had 25 percent more browse than scarified. He also noted that poplar stems were more numerous on scarified than unscarified areas and willow (Salix sp) stems were more numerous on unscarified than on scarified.

Plantation tending involves the release of desirable tree species from overhead competing vegetation. Under current economic conditions in Ontario, tending requires use of herbicides. Herbicides reduce the density and biomass of early successional plant species allowing the conifer trees to grow more or less unimpeded to dominate the area. The most commonly used herbicide before 1984 was 2,4-D which afforded short term release but often allowed shrub species to resprout at densities that equalled or exceeded densities before release. Consequently the use of 2,4-D, if timed properly could benefit game management (Krefting, 1974). From a forester's point of view, using 2,4-D meant that the same area might require another herbicide treatment at some time in the near future.

In 1984, a new herbicide was registered for forestry use in Canada. This new herbicide, glyphosate, provided shrub control up to 6 years (Sutton, 1984). Glyphosate was unselective and systemic resulting in very little or no resprouting of shrubs after treatment. One application of glyphosate therefore had the potential to reduce browse availability for longer periods of time than 2,4-D. Kennedy (1986) suggested that the effects of using glyphosate for tending conifer plantations could last for up to 10 years.

As a result of studies such as Kennedy (1986) and Kennedy and Jordan (1985), the Ministry of Natural Resources (MNR) in Thunder Bay, Ontario, began a three year study to determine the effect of glyphosate on the use of cutovers by moose. They showed that moose used the glyphosate treated cutovers less than controls up to 31 months (Connor and McMillan, 1988) and 43 months (Connor and McMillan, 1990) following treatment.

As the project forester responsible for implementing the study, I was given permission to use the data for a Master's Thesis to answer the following questions:

1) To what extent did glyphosate spraying reduce browse availability on mixed wood cutovers?
2) How did browse reduction affect moose use of sprayed cutovers?
3) Did loss of browse reduce the carrying capacity for moose?

The two published papers answered the first 2 questions; however, subsequent considerations suggested that the data should be re-assessed with improved statistical treatment. The re-assessment plus the answer to the third question form the basis of this thesis.

2.0.0 LITERATURE REVIEW

Sutton (1979,1984) reported that a new herbicide; glyphosate, showed great promise for controlling deciduous vegetation in conifer plantations. Species such as aspen, white birch, and beaked hazel (*Corylus cornuta*) were killed and effectively controlled by glyphosate. Even fall treatments of glyphosate were effective in killing aspen (Sutton, 1984). Consequently when glyphosate was licensed for forestry purposes in 1984 it very quickly began to replace 2,4-D as the preferred herbicide for forestry operations.

It has been observed that black-tailed deer (*Odocoileus hemionus columbianus*), and moose, do not avoid using glyphosate treated plantations in the year immediately following application (Sullivan, 1985 and Connor, 1986). Hjelord and Gronvold (1988) however, using the number of pellet groups as an indicator of use, observed a decrease in use by moose in the first and third springs following glyphosate treatment in Norway. Use was similar in the second spring following treatment.

Kennedy and Jordan (1985), Kennedy (1986) and Cumming (1989) also studied the effects of glyphosate on browse availability within plantations. Kennedy and Jordan (1985) and Kennedy (1986) observed that glyphosate treated plantations in the Superior National Forest of Minnesota contained only 1/4 as much browse(kg/ha) as control plantations 4 years after treatment. Cumming (1989) found that glyphosate decreased the number of stems per hectare of deciduous browse by about 1/2 from pre-treatment levels.

Newton et al. (1989) working in the spruce forests of Maine observed that 9 years after spraying the glyphosate treated areas contained 3 to 7 times more available browse than control areas and could benefit ungulates. Kennedy (1986) on the other hand stated that glyphosate reduces the browse resource enough to have a negative effect on browsing conditions for 5 to 10 years. Studies which chart not only the short term but long term effects of glyphosate on moose habitat will be required to clarify the confusion. Authors so far have not estimated the impact of glyphosate on carrying capacity nor how this may affect present moose populations.

3.0.0 STUDY AREAS

3.1.0 Forest Description

The four study areas are located in the boreal forest region, superior section (Rowe, 1972). The major conifer species are black spruce (Picea mariana), white spruce (Picea glauca), jack pine (Pinus banksiana) and balsam fir (Abies balsamea). The major deciduous species are trembling aspen and white birch. Lowland areas are usually forested with mixtures of black spruce, tamarack (Larix laricina) and eastern white cedar (Thuja occidentalis). The 4 study areas are upland areas containing mixed-wood stands composed of coniferous and deciduous stems neither of which exceeds 75% of the total composition of the stand (McClain, 1980) (Table 1).

Table 1: Silvicultural Background of Four Paired Control (C) and Glyphosate-Treated (T) Study Areas in the Spruce River Forest of North Central Ontario. (Pers. Comm. J. Winkler., Forester, Abitibi-Price Inc., 1986).

Area	Size (ha)		Year	Dominant	Mechanical	Year	Release Treatment[3]	
	C	T	Cut[1]	Species[2]	Site Preparation	Planted	(kg/ha)	(year)
1	106	94	1973	*Pj*	1981	1982	1.44	1985
2	110	170	1982	*Po*	1983[4]	1984	1.53	1985
3	40	43	1983	*Po*	1984	1985	1.53	1986
4	56	76	1979	*Bw*	1982	1983	1.53	1986

[1] - Harvesting operations for merchantable timber were completed

[2] - Dominant tree component before harvest: *Pj*-Jack Pine, *Po*-Trembling Aspen, *Bw*-White Birch

[3] - August application of glyphosate (Trade name - Vision)

[4] - Chemical site preparation: 2,4-D applied at 2.89 kg/ha in 1982

3.2.0 Geology

The four study areas are located geographically within the precambrian shield. Granitic Archian bedrock predominates with some belts of volcanic rock (Zoltai, 1965). The surface relief is strongly controlled by the underlying bedrock but has been modified to varying degrees by glaciation (Zoltai, 1965). The most common glacial deposit is ground morainic till whose thickness varies locally and regionally (Zoltai, 1965). The soils of the area are generally classified as podzols (Rowe, 1972).

4.0.0 GENERAL METHODS

The study areas are located approximately 100 km north east of Thunder Bay, Ontario (Figure 1). Moose densities for these areas, based on the latest aerial inventory (1988), were estimated at 0.43 moose/km^2. The study was designed by the Ministry of Natural Resources (Timmermann et al., 1986) to investigate the results of glyphosate treatment, under field situations rather than carefully controlled experimental conditions. As a result, there were many sources of variation in the study which included differing years of glyphosate treatment, different methods of application, and too few replications; essentially an unreplicated experiment (Eberhardt and Thomas, 1991). This limited the experimental nature of the study, so the glyphosate areas and subsequent controls were surveyed and compared.

The study sites were chosen from areas that were proposed to be treated by Abitibi Price Incorporated as a part of their annual spray program. Application rates, technique and application times were at the discretion of the company and not dictated by the researchers. Thus, two of the areas were treated with fixed wing aircraft in 1985 and two were treated in 1986 with a helicopter. Forest Resource Inventory (FRI) maps and silvicultural records were consulted to ascertain if each member of a cutover pair received similar treatments (Table 1).

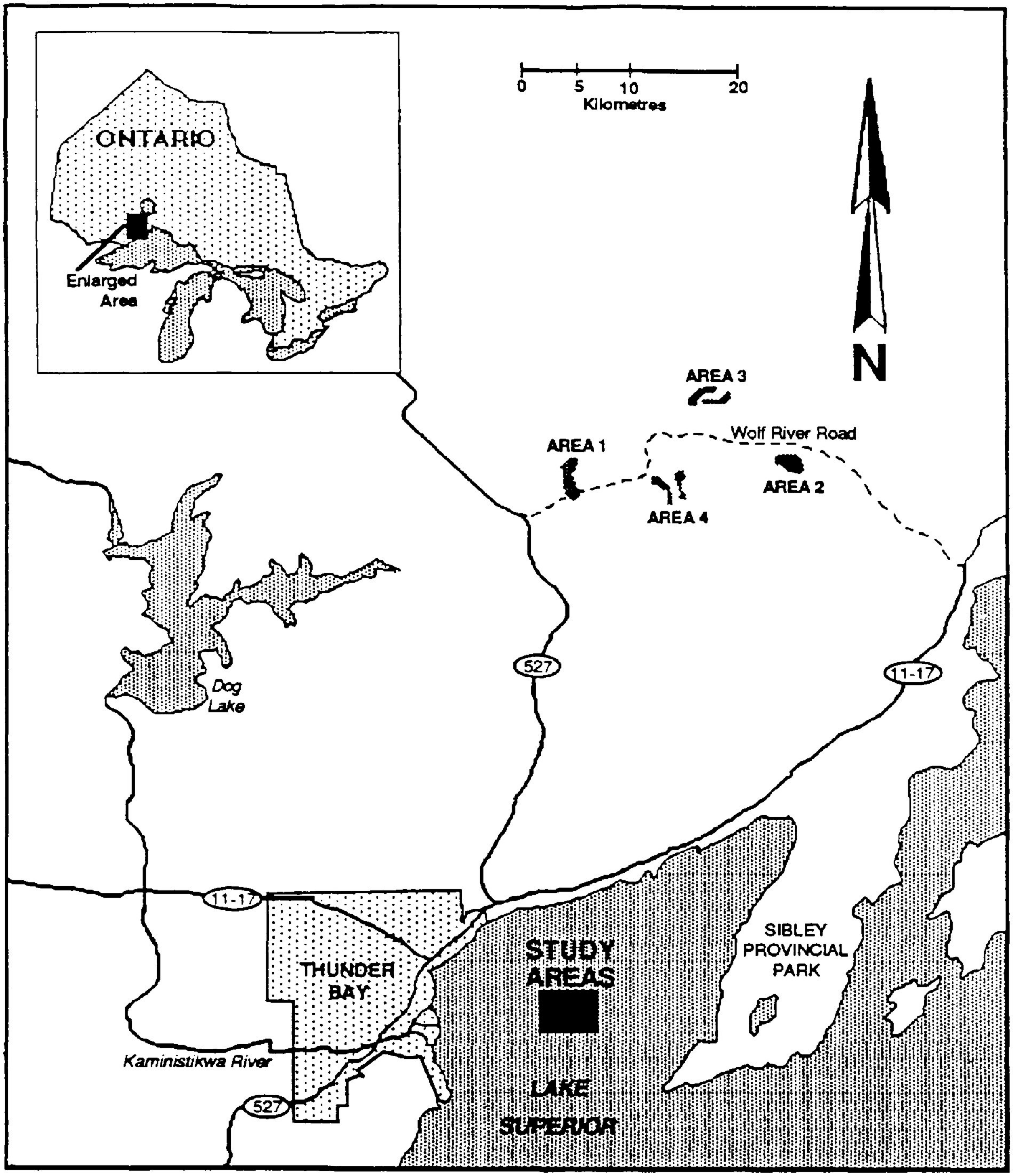


Figure 1. Location of four study cutovers near Thunder Bay, Ontario.

However, as seen in table 1, the total glyphosate treated area was 23% larger than the control. Cutovers 1 and 2 were visually inspected during the summer of 1985 by the MNR district wildlife biologist, and 3 and 4 were inspected in the summer of 1986 by the author to ocularly determine if shrub communities were similar between proposed spray sites.

Study areas 1 and 2 had half the pair treated with glyphosate, while the other half remained to provide a control. Study areas 3 and 4 had one cutover sprayed with glyphosate while the other was left as a control. In area 1, nearly half the control was lost as a result of spraying beyond the delineated boundary. In area 2, approximately 40 hectares of control was lost as a result of misinterpreting where the spray boundaries lay.

4.1.1 Location of Transects for Browse and Pellet Group Surveys

On aerial photographs of each study area a base line was arbitrarily located and oriented so that the longest possible line was obtained. 'L' shaped areas had two intersecting baselines on them. It was assumed that the flight path of aircraft applying the spray would be parallel to these baselines. Transects were drawn perpendicular to these baselines. The first transect was randomly placed within the first ten meters of the end of the baseline. Subsequent transects were then spaced a multiple of 30 meters apart for ease and speed of measurement. Transects were distributed along the entire length of the baseline. The number of transects ranged from 6 in area 2 to 12 in area 4.

4.1.2 Location of Plots for Browse Survey

Plots were located along each transect with a sampling intensity of 1 plot for every 2 hectares of cutover as outlined in the original design. The first plot was randomly located within the first ten meters of the first transect. Subsequent plots were spaced 30 meters apart for measurement convenience along the entire length of the transects.

Study area 1 deviated from this design. The pilot(s) applying the glyphosate crossed a road into the control. Consequently, a portion of the cutover adjacent to the control was included in the study and more transects and plots were added. The number of plots within each area by treatment are listed in table 2.

Table 2: Number of Plots Surveyed within each Area by Treatment

Area	Control	Treated
1	62	54
2	66	117
3	16	15
4	46	49

4.1.3 Data Analysis Techniques for this Study.

Statistical techniques for the data collected from each survey type are listed in table 3; ground: browse and pellet group, and aerial: moose tracks and aggregates.

Table 3: Data Analysis Techniques for this Study.

Survey	Analysis Technique
Browse	Analysis of variance
Pellet group	Chi square test for homogeneity then chi square test for goodness of fit
Number of moose tracks	Chi square test for homogeneity then chi square test for goodness of fit
Moose track length	Analysis of variance
Number of moose track aggregates	Chi square test for homogeneity then chi square test for goodness of fit
Moose track aggregate size	Analysis of variance

5.0.0 BROWSE SURVEY

5.1.0 Browse Survey Method

To determine browse reduction resulting from the glyphosate treatment, 4 x 4 m plots were assessed. The number of twigs available per stem, the number of twigs browsed per stem and the diameter at the point of browsing were recorded by species and height class.

Only the data collected during the 1987 and 1988 surveys were used for this analysis for the following reason. The initial survey design utilized 2 x 2 m square plots, and counts were made on every 5th plot. Little browsing was observed after 1 year of observation, so the plot size was increased to 4 x 4 m and every plot was assessed (425).

An available twig was defined as the distal part of any stem, branch or branchlet greater than or equal to 2.5 cm in length (Todesco, 1986) and could contain more than one year's growth. The definition of a utilized twig was any browsed twig and could include wood from more than one season's growth.

The ten shrub species most often browsed by moose: mountain maple (Acer spicatum), green alder (Alnus viridis ssp), june berry (Amelanchier sp), white birch, red osier dogwood (Cornus stolonifera), beaked hazel, trembling aspen, pin cherry (Prunus pennsylvanica), willow, and mountain ash (Sorbus sp) (Timmermann et al., 1986), were counted. Sampling was similar to Kennedy and Jordan (1985) with respect to height class differentiation. The three height classes into which stems of each species were classified were: 2 (51 cm - 100 cm), 3 (101 cm - 200 cm), and 4 (200 cm - 350cm). Height class 1 (0 cm - 50 cm) was not used, since no over winter browsing was observed.

5.1.1 Estimating Available and Used Browse Biomass

Biomass estimates were based on the mean diameter at the point of browsing (DPB). Ten stems from each species at each height class were collected and all twigs that met the availability criterion were clipped (DPB) and counted. Twigs were then oven-dried for twenty-four hours at 100 degrees celsius, weighed to the nearest milligram, and an average twig weight calculated.

The available browse biomass was calculated as: the number of twigs x weight per twig (g) resulting in an observation of grams per plot for each species at each height class. Similarily, the used browse biomass was calculated as: the number of browsed twigs x weight per twig.

Available and used browse biomass on all areas were measured twice, once in 1987 and again in 1988. Analysis of variance was used to test for significant differences between treatments (Table 4). The lack of replication resulted in no degrees of freedom in the error term for testing treatment effects, the mean square for the interaction term (Block x Treatment) was used. This results in a conservative test because there are few degrees of freedom in the denominator (3). Variance ratios must differ by a factor of about 10 to be declared significant.

Variables were assumed to be normally distributed. Homogeneity of variance was tested using Bartlett's Test of Homogeneity. If the variance was heterogeneous, variables were transformed using Ln(x+1) and tested again for homogeneity. If the variance was still heterogeneous treatment differences were tested by the Mann-Whitney U test (Steel and Torrie, 1980).

Table 4: Analysis of Variance Model.

Source of Variation	Degrees of Freedom
Blocks	3
Restriction Error	0
Treatment	1
Block x Treatment	3
Error	0
Sampling Error (Plots)	425

5.2.0 Browse Survey Results

5.2.1 Estimated Biomass of Available Browse

Biomass estimates for the browse survey conducted in 1987 showed that total availability in height class 2 was nearly equal between treatments (p=0.885), in height class 3 was 1.6 times greater (p=0.302) on controls, and in height class 4, 3.0 times more abundant (p=0.042) on controls (Table 5). Only the difference in height class 4 was significant.

Table 5: The Total Biomass Available for Browsing (g/16m^2) in 1987.

N	Height Class	Control Areas Mean	Control Areas Std Dev	Treated Areas Mean	Treated Areas Std Dev
4	2	30.359	19.142	28.702	19.157
	3	68.722	41.666	44.121	50.765
	4	64.951	44.924	21.705	24.562

The estimates of availability derived from the 1988 survey showed availability in height class 2 to be nearly twice as much on controls (p>0.05), in height class 3, 5 times greater (p<0.05) and in height class 4, 15 times more on controls (p<0.05) (Table 6).

Total biomass available was statistically greater on controls in height classes 3 and 4 in 1988 but statistically non-significant for all height classes in 1987 and height class 2, 1988. Biomass available on treatment areas decreased for all height classes by a much greater percentage than on control areas where only height class 2 decreased. Height class 3 and 4 actually increased (Table 7).

Table 6: The Total Biomass Available for Browsing (g/16m^2) in 1988.

		Control Areas		Treated Areas	
N	Height Class	Mean	Std Dev	Mean	Std Dev
4	2	25.081	12.236	12.174	7.623
	3 *	81.399	0.729	16.306	0.196
	4 *	75.468	0.998	4.253	1.872

* - transformed back to original units from Ln+1

Table 7: The Difference in Total Biomass Available for Browsing (g/16m^2) Between 1988 and 1987 for each treatment.

Control Areas			Treated Areas		
Height Class	g/16m^2	%	g/16m^2	%	Height Class
2	-5.278	-17.4	-16.528	-57.6	2
3	4.805	0.1	-29.642	-67.2	3
4	25.164	38.7	-15.570	-71.7	4

Of the 10 species most commonly browsed, only aspen and willow were significantly more available on controls (Appendix I). From 1987 browse surveys, available aspen browse in height class 2 was nearly equal (p=0.682), in height class 3, 2 times more available on controls (p=0.009) and in height class 4, 3.7 times greater (P=0.006) (Appendix I). In 1988, controls had 4.6 times more aspen browse available in height class 2 ($p<0.05$), 5.4 times more for height class 3 ($p<0.05$) and 23.5 times more on controls for height class 4 ($p<0.05$). Statistically significant differences in availability occurred within height classes 2 and 3. Willow height class 3 was significantly 6.4 times more available on controls in 1988.

Aspen availability between 1988 and 1987 decreased on the controls areas for height classes 2 and 3 but not 4 while availability decreased in all height classes on treatments (Table 8). However, differences between years were not significant ($p>0.05$) for controls or treatments.

Table 8: The Difference in Aspen Biomass Available for Browsing ($g/16m^2$) Between 1988 and 1987

Control Areas			Treated Areas		
Height Class	$g/16m^2$	%	$g/16m^2$	%	Height Class
2	-1.020	-23.0	-3.024	-81.1	2
3	-1.071	-6.0	-5.501	-64.0	3
4	17.745	36.0	-9.512	-71.0	4

5.2.2 Estimated Biomass of Utilized Browse

Total estimated biomass removed from control areas was 3 to 8 times more than on treatments but the difference was not statistically signifcant (Table 9). Estimated biomass removed from controls in 1987 was 4.6 times (height class 2), 3.5 times (height class 3) and 4.5 times (height class 4) greater than from treatments. Estimations for 1988 indicated browse removal from controls was 3.1 times greater for height class 2, 6.1 for height class 3 and 8.5 times greater for height class 4 (Table 9).

Table 9: The Total Biomass Removed By Browsing ($g/16m^2$) in 1987.

		Control Areas		Treated Areas	
N	Height Class	Mean	Std Dev	Mean	Std Dev
4	2	0.629	0.429	0.136	0.158
	3	1.108	0.704	0.313	0.462
	4 *	0.437	0.428	0.063	0.105

* - transformed back to original units from Ln+1

None of the ten species sampled were used to a significantly greater extent on the control areas than on the treated ones (Appendix II). The amount (g) of woody material removed from plots by moose favoured the control plots (Appendix II) with the following few exceptions: green alder, height class 4, sampled in 1988; mountain ash, height class 3, sampled in 1987; and height class 2 and 3 sampled in 1988 (Appendix II). The magnitude of the difference between control and spray depended upon the species, height class and the year sampled.

Use decreased from 1987 to 1988 for both the control and treatment areas although not significantly so. The rate of decrease in use was greater on treatment areas for height classes 3 and 4 but not 2 where the rate was greater on the controls (Table 11).

Table 10: The Total Biomass Removed By Browsing ($g/16m^2$) in 1988.

		Control Areas		Treated Areas	
N	Height Class	Mean	Std Dev	Mean	Std Dev
4	2	0.348	0.347	0.112	0.165
	3 **	0.881	0.693	0.145	0.137
	4 *	0.436	0.301	0.061	0.058

* - transformed back to original units from Ln+1
** - Mann Whitney U tested

The proportion of browse biomass available that was eaten on each treatment tended to be greater on the control areas than treatment except for height class 4 in 1988 (Table 12).

For both availablility and utilization large differences between treatment and control were observed that were not significantly different (Appendix I and II). This suggests that the power of the test was weak and the probability of a type II error was high (accepting H_o when in fact it is false). Using the error mean square calculated for ANOVA, the minimum detectable difference can be calculated for the design used in this study. The minimum detectable difference varied with species and by height class within each species (Appendix III). Minimum detectable were large; in most cases much larger than observed. The only trend appeared to be that as the height class increased so did the minimum; ie. for aspen, the largest difference for height class 2 was 14 g/16m^2, 17.7 g/16m^2 for height class 3 and 75 g/16m^2 for height class 4.

Table 11: The Difference in Total Biomass Used for Browsing (g/16m^2) Between 1988 and 1987 for both Treatments.

Control Areas			Treated Areas		
Height Class	g/16m^2	%	g/16m^2	%	Height Class
2	-0.281	-44.7	-0.024	-17.6	2
3	-0.227	-20.5	-0.168	-53.7	3
4	-0.089	-17.2	-0.061	-56.5	4

Table 12: Proportion Used of the Browse Available.

	1987		1988	
Height Class	Control Areas (%)	Treatment Areas (%)	Control Areas (%)	Treatment Areas (%)
2	2.07	0.47	1.39	0.91
3	1.61	0.71	1.20	1.00
4	0.75	0.50	0.45	0.77
Total	4.43	1.68	3.04	2.68

5.3.0 Browse Analysis Discussion

In general, more browse biomass was found on control areas than on treatment areas. Results of this study indicate that total browse availability differences are in the same range as those reported by Kennedy (1986) and Kennedy and

Jordan (1985). Newton et al. (1989) observed that availability was 1.5 times less than that of control areas.

This study, however, compared the availability of each species separately as well as totally. Aspen was the species that seemed most affected by the spray. This was no surprise since aspen appeared to be the most abundant shrub species in the tallest height class. Aspen, therefore, probably intercepted most of the spray. This may affect the efficacy of the spray in the lower height classes as suggested by Cumming (1989). Spray would have to penetrate the aspen canopy in sufficient quantity to be effective at the lower height classes, reflected in the fact that browse availability tended to decrease through the height classes. Control areas contained, about 3 (height class 3, 1987) to 19 (height class 4, 1988) times more browse. Browse availability for height class 2 was very nearly equal for the control and spray areas. This accentuates the notion that shrubs which comprise the main canopy within the cutover bear the brunt of the herbicide treatment; efficacy decreases moving down through the canopy.

Browse utilization was statistically similar between the two treatments. Observations of use were similar to those of availability in that most species were utilized to a greater extent on control areas. What is interesting to note here is that browsing was 3 to 7 times greater on control areas, yet, browsing was not statistically different. This lack of significance likely was a result of too few replications.

Biologically speaking differences this great should be significant to moose. If both treatment and control areas were equal in quality for browsing, the amount of browse removed should be proportional to the amount available, however, control areas had proportionately more browse removed; indicating that the controls were likely more important to moose.

Since the minimum detectable difference for both availability and utilization were much larger than observed differences, the probability of a type 2 error was likely high (Appendix III). Thus, the power of the test to detect real differences was low.

6.0.0 PELLET GROUP SURVEY

6.1.0 Pellet Group Survey Method

The pellet group survey, indicating use by moose, was conducted along transects which were located as described in section 4.1.1. Each transect ran from one edge of a study area to the other and served as the centre line for a 2 meter wide strip along which the pellet groups one meter either side of the centre were counted. Scattered pellet groups were included only if half the area delineated by the scattered group occurred within the 2 meter zone. It was assumed that the number of pellet groups observed would be proportional to use.

6.1.1 Chi-Square Analysis for the Number of Pellet Groups

Pellet group counts in areas 3 and 4 were carried out in 1986 to provide pre-spray data. A significant change following spraying would suggest an alteration in moose behaviour related to glyphosate spray.

Observations composed of counts, such as pellet groups, were analyzed using chi-square (Steel and Torrie, 1980). The initial hypothesis tested that the number of pellet groups was independant of years post spray (homogeneous). If they were independant, they were pooled and tested with a goodness of fit test on the totals (Neu et al., 1974, Byers et al., 1984).

Use within individual study areas was also tested with a chi-square goodness of fit test (Neu et al. 1974, Byers et al. 1984). For each year, the χ^2 was added together and the value gave a test of the hypothesis that use was in proportion to the area available within treatment for all years. This analysis would answer question number 2 concerning the use by moose of the sprayed cutovers.

6.2.0 Pellet Group Survey Results

Prior to treatment 49 pellet groups were observed on the areas to be treated and 8 pellet groups on the controls (Table 13). Post-treatment, the counts were 33 groups on the control areas and 19 on the treated areas (sum of 0.5 and 1.5, Table 13). The post-spray data showed that pellet group counts on treatment and control were independant (χ^2=0.367, p>0.05, df=1) and the data were pooled to test for pre- and post-spray interaction. This test indicated that after spray more use was made of the control areas (χ^2=28.31, p<0.05, df=1).

Table 13: Number of Moose Pellet Groups Observed on Cutovers Treated in 1986 (areas 3 and 4).

Years Post Spray	Control	Treated	Total
0	8	49	57
0.5	18	12	30
1.5	15	7	22
Total	41	68	109

Post-treatment comparison of the cutovers treated in 1985 (areas 1 and 2) showed 62 pellet groups on the controls and 45 on the treated areas (Table 14). Use of these two cutovers was statistically similar (χ^2=1.509, df=2, p>0.05) even though the controls had 22% less total area and contained nearly 1.5 times as many pellet groups (Table 14).

Table 14: Number of Moose Pellet Groups Observed on Cutovers Treated in 1985 (areas 1 and 2).

Years Post Spray	Control	Treated	Total
0.5	31	18	49
1.5	21	16	37
2.5	10	11	21
Total	62	45	107

There were 95 pellet groups observed on the control areas and 64 pellet groups observed on the treated areas. This was a significant difference between the two treatments (χ^2=13.974, df=1, p<0.05). Controls, which represented only 45% of the total area, were used more often than treatment areas.

6.2.1 Use Within Each Cutover

Except for the observations occuring in 1988 on area 1, the number of pellet groups tended to favour control areas and use decreased from the first spring in 1986 to 1988 (Fig. 2).

With the expected ratios for a goodness of fit test on each cutover calculated as the proportion of land area within

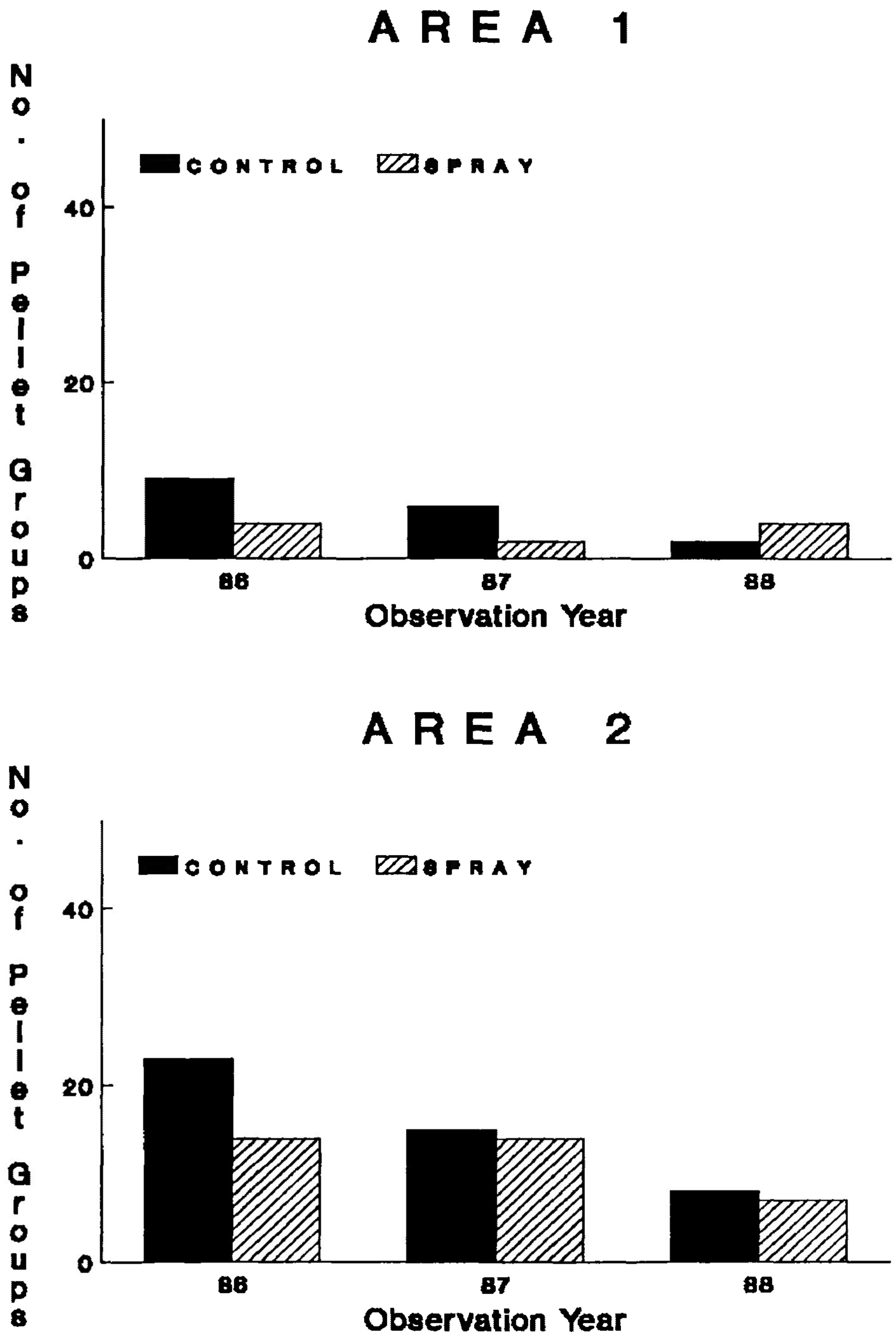


Figure 2: The Number of Moose Pellet Groups Observed Within Study Areas 1 and 2 for Each Treatment and Observation Year.

each treatment, the number of pellet groups (χ^2=2.746, df=2, p>0.05) was proportional to the habitat available in the control and treated portions of area 1 (Table 15).

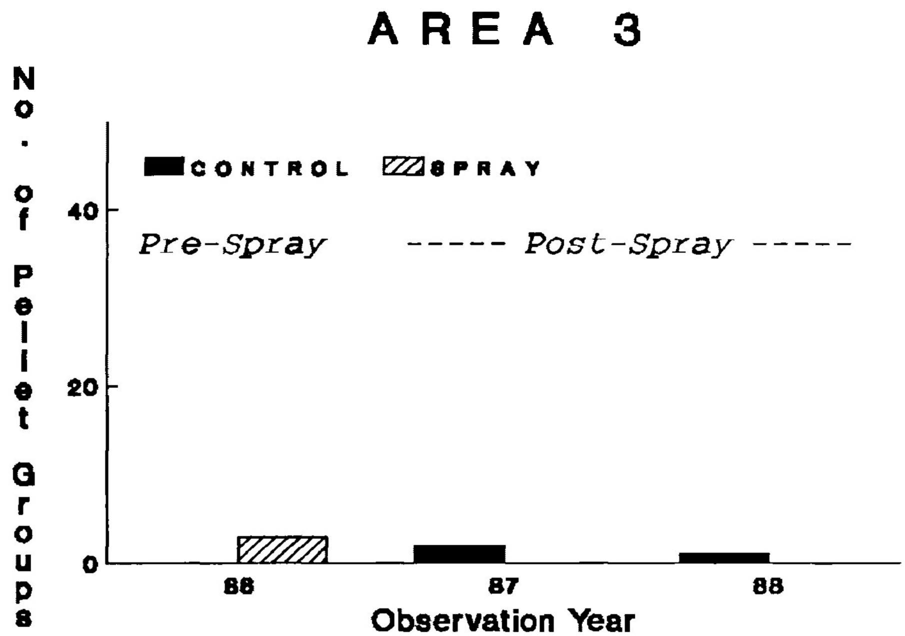
Table 15: The Number of Pellet Groups Observed on Areas 1 and 2 for the Three Year Study Period and the Proportion of Habitat Within Each Treated Area and Control.

Observation	Area	Years Post Spray	Spray (%)		Control (%)		
Number of Pellet Groups	1	1.5	4	(47)	9	(53)	
		2.5	2		6		
		3.5	4		2		
	2	1.5	14	(61)	23	(39)	*
		2.5	14		15		
		3.5	7		8		

* - significant (p<0.05)

Use of the control in area 2 was always greater than the glyphosate treated areas and decreased for both, from 1986 to 1988 (Figure 2). Within area 2, the number of pellet groups indicated that the post spray use of the controls was greater than the treatments (χ^2=16.182, df=3, p<0.05) (Table 15). However, only at 1.5 years post spray was use greater than expected (χ^2=11.065, df=1, p<0.05). At 2.5 and 3.5 year post spray, the number of pellet groups observed was proportional to the habitat available (χ^2=3.343, df=1, p>0.05 for year 2 and χ^2=1.974, df=1, p>0.05 for year 3).

No pellet groups were observed on the control area of cutover 3 prior to treatment (Figure 3). Post treatment observations for the number of pellet groups within area 3



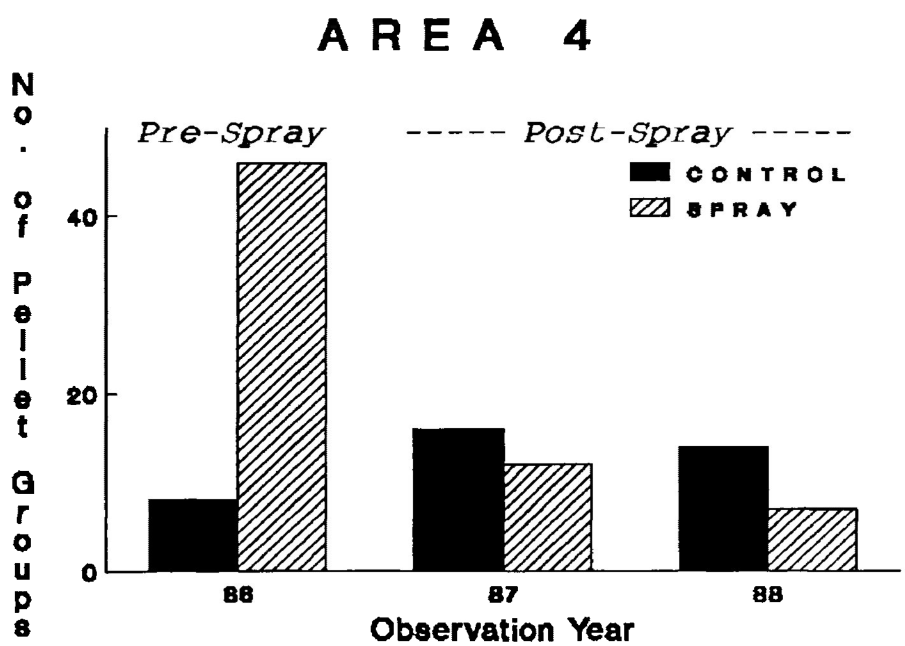


Figure 3: The Number of Moose Pellet Groups Observed Within Study Areas 3 and 4 for Each Treatment and Observation Year.

were pooled to provide enough observations to perform the chi-square analysis. After pooling, pellet groups were distributed in the proportions expected (χ^2=0.163, df=1, $p>0.05$) (Table 16).

Table 16: The Number of Pellet Groups Observed on Areas 3 and 4 for the Three Year Study Period and the Proportion of Habitat Within Each Treated and Control.

Observation	Area	Years Post Spray	Spray (%)		Control (%)		
Number of Pellet Groups	3	0	3	(44)	0	(56)	
		0.5	0		2		
		1.5	0		1		
	4	0	46	(49)	8	(51)	*
		0.5	12		16		
		1.5	7		14		*

* - significant ($p<0.05$)

Prior to treatment, pellet groups indicated that moose prefered the treated portion of area 4 (χ^2=28.934, df=1, $p<0.05$) (Figure 3). At 0.5 years after the glyphosate treatment, there were 1.3 times as many groups observed on controls as treated areas, although this was not significant (χ^2=0.423, df=1, $p>0.05$). At 1.5 years post spray, twice as many groups were observed on the controls with a significant difference (χ^2=5.245, df=1, $p<0.05$). When the data were tested for likeness (homogenity) to determine if pooling was possible, the number of pellet groups were not homogeneous (χ^2=23.151, df=3, $p<0.05$). This likely results from the fact that the portion of area 4 to be treated contained more pellet groups prior to glyphosate treatment than the control areas. After the glyphosate treatment, the reverse was observed. With the switch of preference on area 4, an expected significant interaction resulted from the chi square test (χ^2=23.160, df=2, p<0.05).

6.3.0 Pellet Group Analysis Discussion

This study, like that of Hjeljord and Grunvold (1989) in Norway, showed that moose use of glyphosate treated cutovers was significantly less after treatment. This study also showed that use shifted from areas that were treated to areas that were not. In areas 3 and 4, the non-significant result at 0.5 years post spray was similar to the results reported by Connor (1986) and Sullivan (1985) In areas 2 and 4 use of the controls was significantly greater at 1.5 years after spraying. The lack of statistical significance, in areas 1 and 3 at 1.5 years post spray, is likely a result of too few observations. At 2.5 and 3.5 years post spray use was similar between treatment and control areas as was reported by Hjeljord and Grunvold (1989). The lack of significance at these 2 periods may be due to the operational nature of the spray. Within each study area, small localized patches of browse were not contacted by the glyphosate. Typically these were areas along the edge, in the lee of residual standing timber and areas where the aerial spray passes did not overlap. Pellet groups observed on the treated areas appeared to be associated with these localized patches of browse. Therefore, post treatment use by moose of the treated cutovers was likely influenced by these patches which along with the small number of replications resulted in a lack of significance.

Unlike Hjeljord and Gronvald (1989) but similar to Sullivan (1985) and Connor (1986), there were no significant differences in use detected immediately after spray. Hjeljord and Grunvold (1989) counted the number of pellet groups on square plots. Both studies used an analysis of variance. Perhaps the difference in results, stems from the different methods used in analyzing the data. However, all 3 studies reported greater use of controls for post spray periods of greater than 2 years.

7.0.0 AERIAL SURVEY

7.1.0 Aerial Survey Methods

During aerial surveys, moose use was shown by mapping tracks and track aggregates on acetate sheets overlaying photomosaics (1:15840) of each area. Flights were made twice weekly (weather permitting) and conducted at an average airspeed of 120 kph and average altitude of 250 meters.

Tracks were readily observable as distinct paths through the snow and defined as a movement into and exit from the cutover or from one treatment to the next. In cases where the entire track length could not be mapped one track was tallied. A track aggregate was a set of looping, interconnecting tracks. These were recorded by drawing polygons on the photomosaic that were proportional in area and shape to the aggregates observed on the ground. Tracks and track aggregates were then transferred from the mosaics to maps of the same scale and then digitized into the Geographic Information System (GIS) by the staff at Lakehead University. Track lengths, aggregate areas, treatment areas and residual areas within treatments were ascertained by staff at Lakehead University using the GIS system.

Flight patterns over the cutovers for the purpose of mapping were similar to those described by McNicol (1976) and Todesco (1986). Each cutover was circled beginning at the periphery and the circles were decreased in size as the plane moved toward the centre of the cutover. Each cutover was circled until all tracks and aggregates were believed to be mapped. The last pass was a general pass over the middle of the cutover to ensure that no tracks or aggregates were missed.

The number of tracks, number of track aggregates indicated where and how often moose visited the study areas. Track aggregates also indicated where moose chose to browse intensively.

The number of moose tracks and number of moose track aggregates were analyzed in the same fashion (chi-square tests of independence and goodness of fit test) as was done for the number of pellet groups.

Behaviour was tested by making use of the average length of track (paths) observed within each treatment and average aggregate sizes. Treatment differences were tested using an analysis of variance.

7.2.0 Aerial Survey Results

During the three winters of the study, 48 flights were made; 15 the first winter, 17 the second and 16 the third. On the control areas 369 moose tracks were observed and 352 on the treatment areas (Table 18).

Within all areas, except area 4, the number of moose tracks was more common on the control areas (Table 17). Area 3 contained more tracks on the treated areas at 0.5 years post spray, but the reverse was observed at 1.5 and 2.5 years post spray. All areas contained more tracks on the control areas at 1.5 and 2.5 years post spray (Table 17). Three and one half years after spraying, study area 2 was observed to contain twice the number of tracks on the control area.

Table 17: Number of Moose Tracks and Moose Track Aggregates (Aggs) on Study Areas during the 1986, 1987 and 1988 Aerial Surveys.

Area	Years Post Spray	Tracks		Aggregates	
		Control	Treated	Control	Treated
3	0.5	6	9	2	0
	1.5	9	3	3	0
	2.5	10	3	1	2
4	0.5	46	57	9	8
	1.5	56	95	22	15
	2.5	6	7	7	4
1	1.5	50	38	10	4
	2.5	41	28	10	13
	3.5	1	2	1	0
2	1.5	57	56	12	12
	2.5	70	50	46	17
	3.5	17	4	8	1

Areas 1 and 2 were treated in the summer of 1985, so winter 1986 was 1.5 years post-spray, 1987 - 2.5, 1988 - 3.5.

Areas 3 and 4 were treated in the summer of 1986, so winter 1986 was 0.5 years post-spray, 1987 - 1.5, 1988 - 2.5.

The number of moose track aggregates observed was 131 on the controls and 76 on the treated areas. Within all areas, the number of moose track aggregates was more numerous on the control areas. Only areas 1 and 3 at 2.5 years post spray contained more track aggregates in the treatment area (Table 17).

7.2.1 Analysis of the Number of Moose Tracks

The number of moose tracks observed on the control was nearly equal to that observed on the treated areas the first year, 159 v.s. 160 (Table 18). During the second season of observation, the number of moose tracks was equal between the control and treated area, both 176. During the third winter, the number of moose tracks observed on the control areas, (34) was twice that seen on the treatment area (16) (Table 18).

Table 18: Number of Moose Tracks Observed on All Study Areas by Sample Year.

Sample Year	Control	Treated	Total
1986	159	160	319
1987	176	176	352
1988	34	16	50
Total	369	352	721

The cutovers that were treated in 1985 contained more tracks on the control areas (236) than on the treatment areas (178) (Table 19). The opposite situation was observed on the cutovers that were sprayed in 1986; control areas contained 133 moose tracks and treated areas 174 (Table 20). The cutovers that were sprayed in 1985 and the cutovers that were sprayed in 1986, were both independent of the year of observation and treatment, (χ^2=4.568, df=2, p>0.05 for 1985 and χ^2=4.328, df=2, and p>0.05 for 1986) and were therefore pooled. After pooling, there were more total tracks observed on the control areas than expected (χ^2=11.121, p<0.05, df=1).

Table 19: Number of Moose Tracks Observed on 2 Cutovers Treated in 1985.

Years Post Spray	Control	Treated	Total
1.5	107	94	281
2.5	111	78	179
3.5	18	6	24
Total	236	178	414

Table 20: Number of Moose Tracks Observed on 2 Cutovers Treated in 1986.

Years Post Spray	Control	Treated	Total
0.5	52	66	118
1.5	65	98	163
2.5	16	10	26
Total	133	174	307

Use within each cutover shown by moose tracks was examined further with goodness of fit chi-square analysis.

Fifty three percent of area 1 was control while 43% was treated. The number of tracks was proportional to the habitat available in the control and treated areas (χ^2=0.515 at 1.5, 1.142 at 2.5 and 0.466 at 3.5 years post spray, df=1, p>0.05) (Table 21). The data were independent (χ^2=0.835, df=2, p<0.05) and therefore pooled. Use was still in proportion to habitat available (χ^2=1.301, df=1, p>0.05). The observations during the third year were too few and therefore dropped from the analysis (Table 22).

Table 21: The Number of Moose Tracks Observed on Areas 3 and 4 for the Three Year Study period and the proportion of Habitat Within Each Treated and Control.

Observation	Area	Years Post Spray	Spray	(%)	Control	(%)	
Number of Tracks	3	0.5	9	(48)	6	(52)	
		1.5	3		9		
		2.5	3		10		*
	4	0.5	57	(58)	46	(42)	
		1.5	95		56		
		2.5	7		6		

* - significant (p<0.05)

Table 22: The Number of Moose Tracks Observed on Areas 1 and 2 for the Three Year Study period and the proportion of Habitat Within Each Treated and Control.

Observation	Area	Years Post Spray	Spray	(%)	Control	(%)	
Number of Tracks	1	1.5	38	(47)	50	(53)	ns
		2.5	28		41		ns
		3.5	2		1		na
	2	1.5	56	(61)	57	(39)	*
		2.5	50		70		*
		3.5	4		17		*

ns - not significant (p>0.05)

* - significant (p<0.05)

na - removed from the analysis

Fifty two percent of area 3 was control while 48% was treated. The number of tracks in study area 3 were not distributed in proportion to the available habitat (χ^2=1.781, df=1, p>0.05). Use during the first two winters was as expected, (χ^2=0.385, df=1, p>0.05) for year 0.5 and (χ^2=3.504, df=1, p>0.05) for year 1.5. During the third winter (1.5), more tracks were observed on control (χ^2=4.357, df=1, p>0.05) (Table 21). The data were homogeneous (χ^2=4.877, df=2, p>0.05) indicating use was similar between treatment and controls over the 3 winters.

Forty eight percent of area 4 was control and 52% treated. The distribution of moose tracks in study area 4 did not indicate any treatment effect (χ^2=0.264, df=1, p>0.05) (Table 21). Use during each year was also similar between control and treatment, (χ^2=0.299 at 0.5, 1.497 at 1.5, 0.092 at 2.5 years post spray, df=1, p>0.05). The data for area 4 also indicated similar use between treatments (χ^2=1.626, df=2, p>0.05).

Thirty nine percent of area 2 was comprised of control while 61% was treated. The number of tracks was consistently greater on the control portions of area 2, for all three years of the study (χ^2=6.219 at 1.5, 18.854 at 2.5 and 15.536 at 3.5 year post spray, df=1, p<0.05) (Table 22). The data were not homogeneous and could not be pooled (χ^2=7.186, df=2, p<0.05). Use of the control portion of area 2 was significantly greater than the treatment (χ^2=33.422, df=1, p<0.05).

Except for study pair 2, use between treatment and control was similar, and except for area 4, the trend was slightly more moose tracks observed on the control areas. When all the areas are pooled, as in the previous analysis, however, use was greater on the controls.

7.2.2 Analysis of the Number of Moose Track Aggregates

Even though the numbers of moose track aggregates were 1.5 times as numerous on control areas (131 v.s. 76), use was statistically independent of area (χ^2=0.707, df=1, p>0.05).

Use between treatments was similar for the cutovers treated in 1985 (χ^2=2.113, df=2, p>0.05) as well as in 1986, (χ^2=1.383, df=2, p>0.05) (Tables 23 and 24). However, the number of moose track aggregates was nearly double on the control areas for the second year of observation (81 vs 45) as well as the third (17 vs 7) (Table 25). Since the contingency test indicated independence, the data were pooled and tested with a goodness of fit test. The total number of moose track aggregates were more numerous than expected (χ^2=28.83, p<0.05, df=1) on the control areas.

Table 23: Number of Moose Track Aggregates Observed on Cutovers Treated in 1985 (areas 1 and 2).

Sample Year	Control	Treated	Total
1986	22	16	38
1987	56	30	86
1988	9	1	10
Total	87	47	134

Table 24: Number of Moose Track Aggregates Observed on Cutovers Treated in 1986 (areas 3 and 4).

Sample Year	Control	Treated	Total
1986	11	8	19
1987	25	15	40
1988	8	6	14
Total	44	29	73

Table 25: Number of Moose Track Aggregates Observed on All Study Areas.

Sample Year	Control	Treated	Total
1986	33	24	57
1987	81	45	126
1988	17	7	24
Total	131	76	207

There were not enough track aggregates observed in study area 3 to perform the chi-square analysis for each year (Table 27). Since the data were homogeneous (χ^2=5.563, df=2, p>0.05), they were pooled and use was greater on controls (χ^2=35.715, df=1, p>0.05) than on treatments.

The number of moose track aggregates on area 4 at 1.5 year post spray was greater on the control area (χ^2=4.409, df=1, p<0.05) but similar at 0.5 years (χ^2=0.835, df=1, p>0.05) and 2.5 (χ^2=2.114, df=1, p>0.05) (Table 27). The number of track aggregates in area 4 were homogeneous and therefore pooled. The total number of track aggregates within area 4 were not in proportion to the habitat available (χ^2=7.231, df=1, p<0.05) but were greater on controls.

Table 26: The Number of Moose Track Aggregates Observed on Areas 1 and 2 for the Three Year Study period and the proportion of Habitat Within Each Treated and Control.

Observation	Area	Years Post Spray	Spray	(%)	Control	(%)	
Number of Track Aggregates	1	1.5	4	(47)	10	(53)	ns
		2.5	13		10		ns
		3.5	0		1		na
	2	1.5	12	(61)	12	(39)	ns
		2.5	17		46		*
		3.5	1		8		*

ns - not significant (p>0.05)

* - significant (p<0.05)

na - removed from the analysis

Table 27: The Number of Moose Track Aggregates Observed on Areas 3 and 4 for the Three Year Study period and the proportion of Habitat Within Each Treated and Control.

Observation	Area	Years Post Spray	Spray	(%)	Control	(%)	
Number of Track Aggregates	3	0.5	0	(48)	2	(52)	na
		1.5	0		3		na
		2.5	2		1		na
	4	0.5	8	(58)	9	(42)	ns
		1.5	15		22		*
		2.5	4		7		ns

ns - not significant (p>0.05)

* - significant (p<0.05)

na - removed from the analysis

Use of area 1 was similar between treatments for each year post spray (χ^2=1.593 at 1.5, 0.813 at 2.5 and 0.225 at 3.5 years post spray, df=1, $p>0.05$) (Table 67). Since the data were homogeneous (χ^2=2.589, df=2, $p>0.05$), they were pooled and use was in proportion to habitat available (χ^2=0.042, df=1, $p>0.05$). Forty seven percent of area 1 was sprayed while 53% was control.

The spray area comprised 61% of area 2 while control was 29% of the total area. The number of track aggregate areas was greater than expected on the control portions of area 2 (χ^2=35.715, df=1, $p<0.05$), particularly during 2.5 (χ^2=30.641, df=1, $p<0.05$) and 3.5 years post spray (χ^2=9.416, df=1, $p<0.05$) (Table 26). Use was proportional to habitat availability 1.5 year post spray (χ^2=1.221, df=1, $p>0.05$). Since the data were homogeneous (χ^2=5.563, df=2, $p>0.05$), use of area 2 was consistently greater on the controls.

Except in area 1, the number of moose track aggregates indicates that use of the control areas was greater than the treatments. Consequenty, when all the areas are pooled as in the previous analysis, use was greater on the controls than treatment areas.

7.2.3 Average Track Length and Aggregate Size

Average track length and aggregate size were used to determine if moose browsing behaviour was similar between control and treatment areas. Average track length was longer (p=0.029) on the treated areas (x=0.476km) than the controls (x=0.271). However, average aggregate sizes were similar (p=0.797) between treatments (x=0.155 ha for the controls and x=0.162 ha for the treated areas), indicating moose travelled a little further in treatments but they still browsed a similar sized area.

7.3.0 Aerial Survey Discussion

The number of tracks indicated that the controls were used to a greater extent than the treatment areas. Crête (1989) observed that the number of visitations by moose to a cutover was related to the amount of available browse stems. Vivas and Saether (1987), on the other hand, observed that the number of visitations to plots containing different densities of birch stems was not related to the number of stems. If the assumption is that tracks are indicators of visitation by moose, then this study agrees with the findings of Vivas and Saether (1987). However, the present study only documents events over a short period of time, 3 years. Ozoga and Verme (1982) and Gillingham and Bennell (1989) observed that deer were able to learn where the good food patches were within deer yards where supplemental feeding occurred and in controlled experiments. It is reasonable to assume that moose have the same capability to learn where the good food patches are within their home ranges. Furthermore, the moose that do learn where the good patches are, are probably resident moose (non-dispersers) (Wilton and Bissett, 1988, Dalton, 1989). Resident moose will visit those cutovers with the most browse more often as observed by Crête (1989).

Therefore, as time since spray increases one might expect the number of tracks to decrease on spray areas as moose learn where browse exists or use more heavily those areas where browse remains within the spray area. In areas 2 and 3, the number of moose tracks observed on the treatment areas did decrease at a much faster rate than controls. Areas 1 and 4, however, did not exhibit the same pattern. In area 1 the number of tracks observed decreased at about the same rate as controls while in area 4 the number of tracks observed was consistently greater on the sprayed portions.

The number of track aggregates also indicated that use was greatest on the control areas over the winter period, which makes sense since the number of tracks indicated that moose visited the controls more often.

Moose use of their home range particularly in winter is affected by the distribution of available browse and snow depth. During the winter moose utilize habitats where snow depths are less even though browse availability may be greater in areas of deeper snow (Ballard et al., 1991). At excessive snow depths, > 90 cm (Coady, 1974), moose do not use the cutovers at all, but prefer habitats where snow depths are less. This would make sense since the most profitable patches would yield the greatest return (energy) per unit of search effort. Therefore, patches where movement through snow was less difficult may be more profitable even though browse availability is less (Pyke et al., 1977).

Therefore, cutovers that are used primarily in the early portion of the winter may not show large differences in use between the control and treated areas; as snow depths increase, use of the controls may be more prevalent, at excessive snow depths neither treatment may appear to be used.

In this study, it was observed that moose tended to travel farther in the treatment areas as average track lengths (paths) were longer. However, the search effort did not seem to alter drastically as the average track aggregate areas were quite similar in size. Since browse availabilities were less in the treatment areas, moose should have given up browsing in the treatment areas more often or sooner than in the controls (Pyke et al., 1977). This is what appears to have happened since the controls tended to have 1.5 times as many track aggregate areas as the treatment areas.

Areas of intense browsing, as denoted by track aggregates, were similar in size for both the control and treatment. Browse quality/quantity may have been similar enough in these small localized areas for moose to concentrate feeding there. Due to reduced browse availability, moose did not "find" as many of these "patches" within the spray areas as they did within the control. Consequently, the average track lengths (distance travelled) were greater on the spray areas.

8.0.0 CARRYING CAPACITY MODELS

A model was made to assess the following questions: Would the use of glyphosate affect the carrying capacity? If glyphosate does affect the carrying capacity, how much area must remain untreated to ensure there are no adverse affects on present moose density levels? The assumptions in model I are not realistic but provide an easy starting point. Model II goes on to refine the assumptions and create a model that is better suited to answering the above mentioned questions.

8.1.0 Model I

To begin model I construction, the following assumptions were made.

1) All browse of suitable height within a cutover is available for consumption.
2) Moose maintain their body weight throughout the winter season (weight stasis).
3) The observations of track lengths in this study are assumed to be time spent searching for areas to forage.
4) All browse species are equal.
5) Moose will not dig browse out from under the snow.

The four activities used in the model were: 1) foraging, 2) bedding, 3) ruminating, and 4) searching (Risenhoover, 1986). Energy values for each activity were taken from Renecker and

Hudson (1989). The values for bedding included bedding-alert and bedding-dozing, foraging included browsing at low (head of moose was below brisket level), middle (between brisket and top line) and high (above top line) (Renecker and Hudson, 1989). Energy expenditures for searching were equated with walking. The energy value for browse was an average taken from Hjeljord et al. (1982). Energy costs are based on a 410 kilogramme moose (Quinn and Aho, 1989). Energy expenditures for control areas are listed in table 28.

Table 28: The Daily Energy Budget for a 410 KG Moose. (Quinn and Aho, 1989)

Activity	Time Spent (hours/day)		Energy Cost ($kj*h \times kg^{-0.75}$)	Daily Cost (kj)
Foraging	4.944	[20.65%]	16.294	7339.966
Ruminating	11.712	[48.80%]	12.567	13410.673
Bedding	5.784	[24.10%]	12.184	6421.050
Searching	1.392	[5.80%]	28.000	3,551.282
TOTAL				30,722.971

The amount of energy available in a kilogram of average browse would equal 20,080 kj/kg (Hjeljord et al., 1982). However, browse is only 44.5% digestible (Renecker and Hudson, 1985) and only 82% of the digestible portion is metabolizable (Robbins, 1972, cited in Renecker and Hudson, 1989). Of the metabolizable portion, only 71% is used for maintenance (Hubbert, 1987, cited in Renecker and Hudson,1989). Therefore, the energy available for maintenance in a kilogram of browse would be: 20,080 kj/kg x 0.445 x 0.82 x 0.71 = 5202.306 kj/kg.

Therefore, to generate the carrying capacity (moose days/ha), the amount of browse available on a hectare of land is multiplied by 5202.306 and divided by the energy cost. Since average track lengths were 56.93% longer on treated areas, energy expenditures for searching were increased by 56.93% to 5,539.675. The Strategic Land Use Plan of the Ministry of Natural Resources (1982) set a target of 0.39 moose/km2 for the management area in which the study areas were located. Therefore to convert to moose/km^2, the number of moose days is then divided by 150 days; the number of days from Dec. 1 to April 30, and multiplied by 100; the number of hectares in a square kilometer.

Since we know the amount of browse available in the various height classes, we may estimate the effect of browse burial. Assuming that browse burial is linear then we can estimate how much browse remains above snow level and hence a carrying capacity for various snow depths. For the lower height class 50-100 cm a linear estimation may be conservative since Schwab et al. (1987), observed that in this height range, 50 cm of snow buries approximately 80% of the browse that is available on stems. Table 29, lists the carrying capacities for various levels of snow depth. Even at 110 cm (the maximum depth of snow observed during the study period) the model predicts that there is enough browse remaining above the snow to support the moose target (Figure 4) except during the second year following treatment (1988).

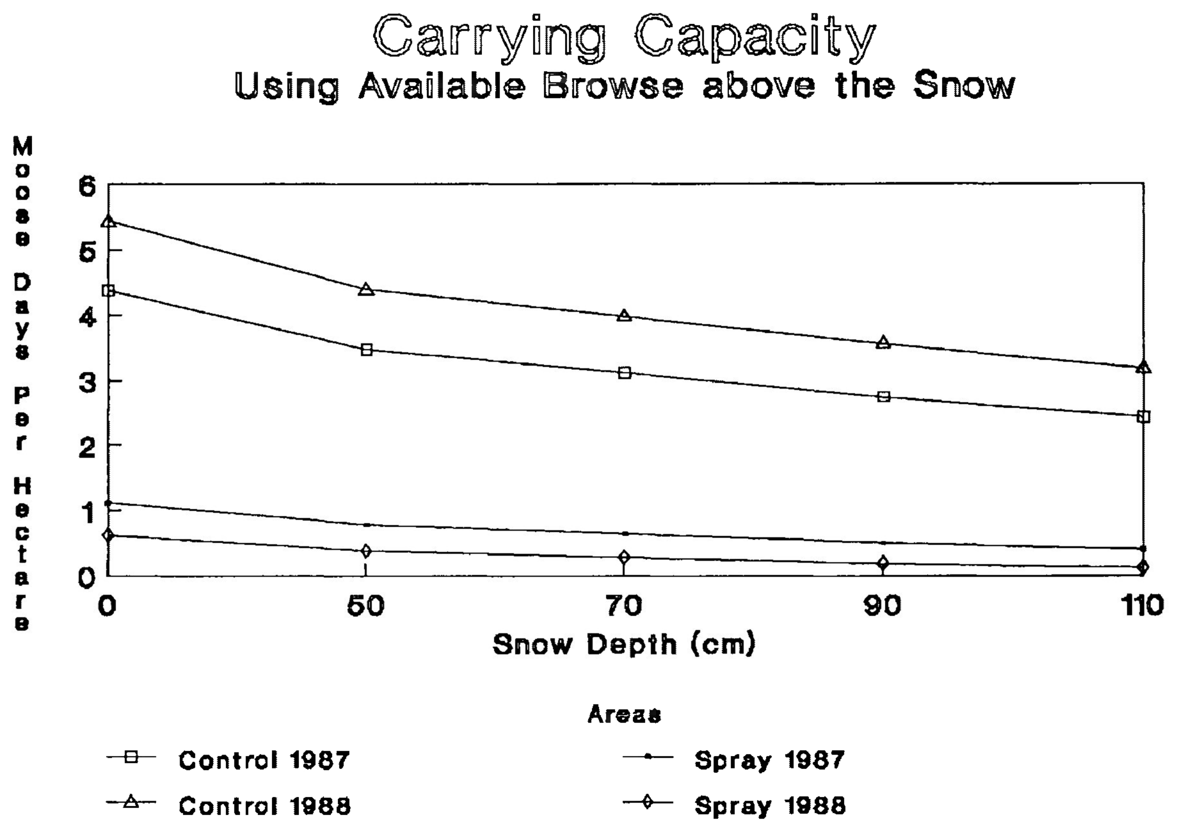


Figure 4: Carrying Capacity of Study Areas by Treatment in Relation to Snow Depth. Carrying Capacity is based on Available Browse Above the Snow Line.

Table 29: Carrying Capacity of Cutovers Based on the Available Browse within each Treatment at Various Snow Depths.

1987				
Snow Depth	Control		Spray	
(cm)	(moose days/ha)	($moose/km^2$)	(moose days/ha)	($moose/km^2$)
0	4.38	(2.94)	1.12	(0.75)
50	3.47	(2.33)	0.78	(0.52)
70	3.11	(2.08)	0.64	(0.43)
90	2.74	(1.84)	0.50	(0.33)
110	2.43	(1.63)	0.41	(0.27)
1988				
Snow Depth	Control		Spray	
(cm)	(moose days/ha)	($moose/km^2$)	(moose days/ha)	($moose/km^2$)
0	5.43	(3.64)	0.62	(0.41)
50	4.39	(2.94)	0.38	(0.25)
70	3.98	(2.66)	0.28	(0.19)
90	3.56	(2.38)	0.19	(0.13)
110	3.18	(2.13)	0.13	(0.09)

Since the definition of carrying capacity used here is essentially how many moose can fit on to a single unit of land for the winter season, moose consume all available browse in a single season. A more realistic model would predict carrying capacity as a sustainable population. This can be done by assuming that moose eat only the increment each year (Caughley, 1976). Caughley (1976) presents a model which he terms an interactive model, where browse growth proceeds logistically and then into this growth model we insert browsing moose. Crête

(1989) used this interactive model to estimate the sustainable harvest in Southwestern Quebec. However, to create this model as stated by Caughley, would require at least three years of observation to estimate the exponent r in the logistic equation, $N_t = Noe^{rt}$. Since we have only two years of observations we cannot use the logistic equation; however, if we assume a small time period then a straight line estimation is probably sufficient. The difference between year 2 and year 3 can be calculated and used as an estimate of the growth or increment of browse.

For the control areas, height class 2 appeared to decline in browse availability, therefore, to be conservative, a 0% increase in growth was used. Height class 3 increased by 5.0% and height class 4 by 38%. Spray areas actually decreased in availability in all height classes. Therefore, to be conservative, it was assumed that spray areas would exhibit similar growth responses as the controls.

Using this approach, the expected moose densities on the treatment areas are below the target value of 0.39, while the control areas can still support about 2.5 times as many moose as treated areas (Figure 5). Even at 110 cm of snow, the control areas are still able to support 0.98 moose/km^2. The sprayed areas on the other hand would only support 0.13 moose/km^2 (Figure 5).

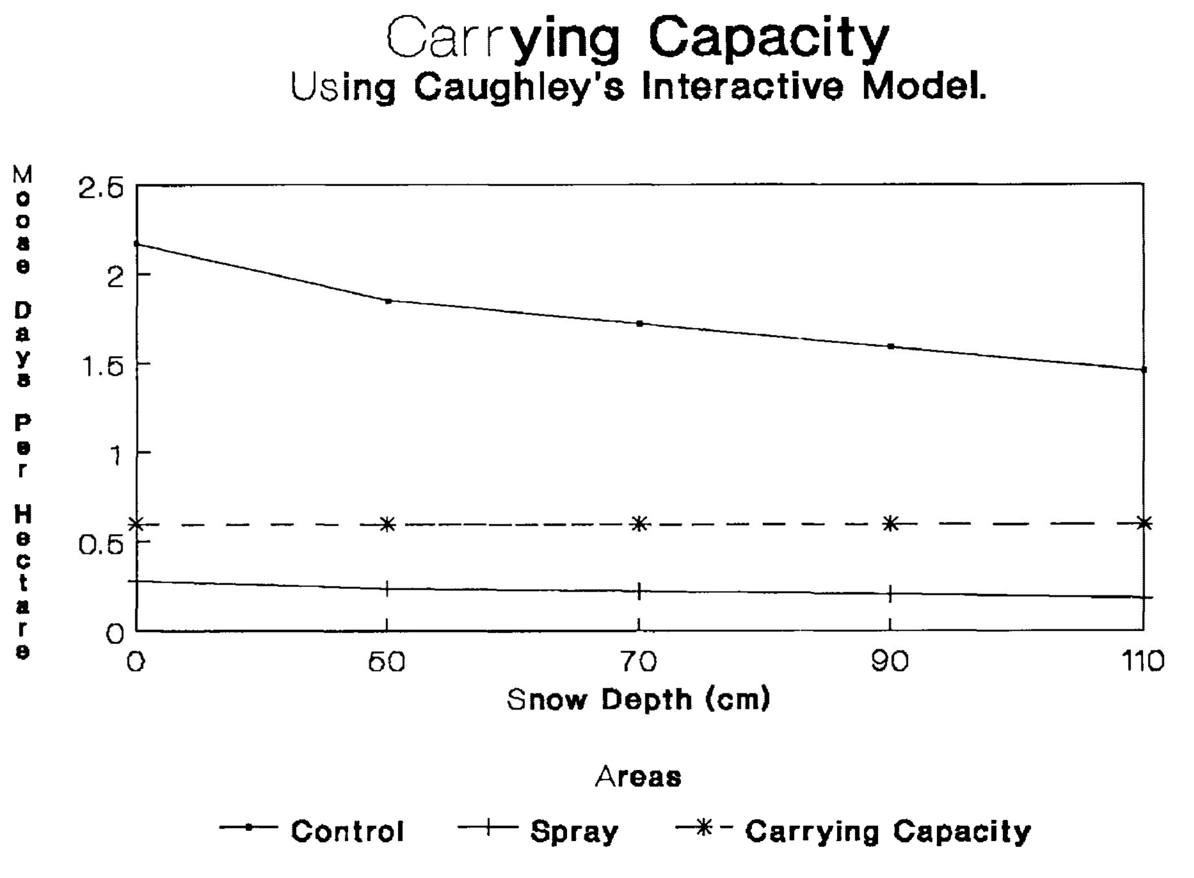


Figure 5: Carrying Capacity of Control and Spray Areas Using Caughley's Interactive Model. The Dashed Line Represents the Carrying Capacity Equivalent to 0.4 Moose/km^2, the Present Moose Density in the Study Area.

8.2.0 Model II

The first assumption, in model 1, can be modified to reflect the fact that moose prefer to stay near the edge of a cutover (Hamilton and Drysdale, 1975). Studies such as those by (Hamilton and Drysdale, 1975) have shown that the browse next to cover is preferred by moose while browse in the middle of the cutover is avoided. Therefore, the amount of browse available can be modified to follow the Ontario Timber Harvesting guidelines for the management of moose habitat. Under these guidelines, the largest recommended cutover size is 130 hectares. Assuming a square cutover shape for simplicity and an 80 meter "safe" browsing zone (Hamilton and Drysdale, 1975), the effective safe browsing area is 34 ha.

Weight loss is highly variable over the winter season. Bull moose lose as much as 12 - 17% of their pre-rut weight during the rut and over winter losses range from 7-23% (Schwartz et al., 1987). Cows lose 15-19% of their maximum weight from an early winter high to post-partum low (Schwartz et al., 1987). Weight loss will also vary with the quality and quantity of browse available on the winter range.

If the amount of energy obtained from dietary intake is subtracted from that required for maintenance, the weight loss over the winter period can be estimated. Schwartz et al. (1988) estimated that moose which consumed 72.4 kcal/kg $Bw^{0.75}$ of browse per day, but required 148 kcal/kg $Bw^{0.75}$/day would lose about 2 kg/day of body mass. This means 1 kg of tissue (fat and muscle) would yield about 14,410 kj/kg of energy. Renecker and Hudson's (1985, 1989) data yields estimates of 22,480 kj/kg for body tissue. Hobbs et al. (1982) use 20,083 kj/kg for lean body tissue and 25,104 kj/kg for fat tissue. Mautz et al. (1976) used 6 kcal/g (24,104 kj/kg) and Torbit et al. (1985) reported 9.4 kcal/g (39,330 kj/kg) for fat and 5.3 kcal/g (22,175 kj/kg) for protein. Using the value estimated from Schwartz et al. (1988) (14,410 kj/kg), moose would lose approximately 18% of their body weight on control areas, within the values reported by Schwartz et al. (1987), and 25% on the treatment areas, a value which is slightly greater.

Therefore, the second assumption relating to weight stasis can be modified to reflect weight loss over the winter by estimating energy needs at the end of the winter season (Potvin and Huôt, 1983) (Table 30).

The third assumption, that the track lengths were directly proportional to search time ties the observations of differing behaviour in this study to the carrying capacity model and remains unchanged.

Hjeljord et al. (1982) observed that mountain ash (Sorbus aucuparia) contained 4.35 kcal/g of dry matter, great willow (Salix capica) 4.87 kcal/g, and common birch (Betula pendula) 5.44 kcal/g. Digestabilities of these species were 41.3%, 48.6% and 39.2%, respectively. Thus, great willow would yield more energy/kg than the other species because of its greater

Table 28: Equations Used in the Carrying Capacity Model.

COMPONENT	EQUATION
Weight at end of winter	$WT = w - (wl \times w)$
Daily energy requirements	$Treatment = 24{,}760.49\ (Kj/day)$ $Control = 28{,}624.92\ (Kj/day)$
Daily energy acquired from catabolism of tissue	$WE = \frac{(wl \times w) \times 14{,}410\ (kg)}{sp}$
Daily energy requirements at end of winter	$WEND = Kj/day - WE$
Biomass of browse available	$BIO(kg) = \sum_{k=1}^{2} \sum_{l=1}^{2} \sum_{i=1}^{2} F_{kli} S_{kli}$
Energy available in browse	$EA = BIO \times 5202.31$

w - weight of a moose (410 kg)
wl - percent weight loss over a winter
sp - length of snow period, assumed to be 150 days, from Dec 1 to April 30
F_{kli} - proportion of total utilized browse composed of species i in height class l for treatment k
S_{kli} - biomass of species i in height class l for treatment k

digestability. Schwartz et al. (1988) in Alaska observed that paper birch contained 5.2 kcal/g of gross energy, aspen 5.0 kcal/g and willow 5.1 kcal/g of gross energy of dry matter. Digestabilities, however, were 37.4%, 50.5% and 42.5% respectively for digestion trials in March. A diet of aspen would be the most nutritious (Schwartz et al., 1988). Therefore, we cannot really say that all browse species are equal. However, there is a lack of nutritional data for the ten browse species sampled in this study, so the value presented by Hjeljord et al. (1982) was used as an average.

The equality of each browse species can be altered by introducing a factor that reflects the importance of each species in the diet sampled in this study (Table 31). The availability of a particular species was multiplied by the proportion of that species observed in the total amount of browse used, for each height class within each treatment. For example, red osier dogwood on sprayed areas composed 62% of all the browse consumed within height class 2. Therefore, browse availability for height class 2 red osier dogwood was multiplied by 0.62.

Using this model, treatment areas could not sustain the target moose population (0.39 moose/km^2) (Table 32). Controls on the other hand are well above the present population and would allow for an expansion; even at 110 cm of snow depth (Figure 6).

Table 31: Factors used in Estimating the Biomass of Available Browse for use in the Carrying Capacity Model.

	SPRAY		
	Height Class 2	Height Class 3	Height Class 4
Aspen	.03	.07	.16
Birch	.00	.06	.10
Red Osier Dogwood	.62	.29	.00
Pin Cherry	.05	.13	.10
Willow	.11	.10	.00
Hazel	.10	.07	.00
Alder	.00	.03	.60
Mountain Ash	.05	.25	.00
Mountain Maple	.00	.00	.04
June Berry	.03	.00	.00
	CONTROL		
	Height Class 2	Height Class 3	Height Class 4
Aspen	.03	.16	.43
Birch	.04	.05	.40
Red Osier Dogwood	.31	.09	.00
Pin Cherry	.07	.13	.09
Willow	.14	.20	.04
Hazel	.16	.21	.02
Green Alder	.04	.04	.03
Mountain Ash	.04	.02	.00
Mountain Maple	.06	.05	.00
June Berry	.11	.04	.00

Table 32: Carrying Capacity of Timber Harvesting Guideline Size (130 ha) Cutovers.

1987				
Snow Depth	Control		Spray	
(cm)	(moose/cutover)	(moose/km^2)	(moose/cutover)	(moose/km^2)
0	1.29	0.99	0.60	0.46
50	1.03	0.79	0.42	0.32
70	0.92	0.71	0.35	0.27
90	0.81	0.62	0.27	0.21
110	0.72	0.55	0.22	0.17
1988				
Snow Depth	Control		Spray	
(cm)	(moose/cutover)	(moose/km^2)	(moose/cutover)	(moose/km^2)
0	1.65	1.27	0.30	0.23
50	1.34	1.03	0.19	0.15
70	1.21	0.93	0.14	0.11
90	1.07	0.82	0.10	0.08
110	0.97	0.75	0.07	0.05

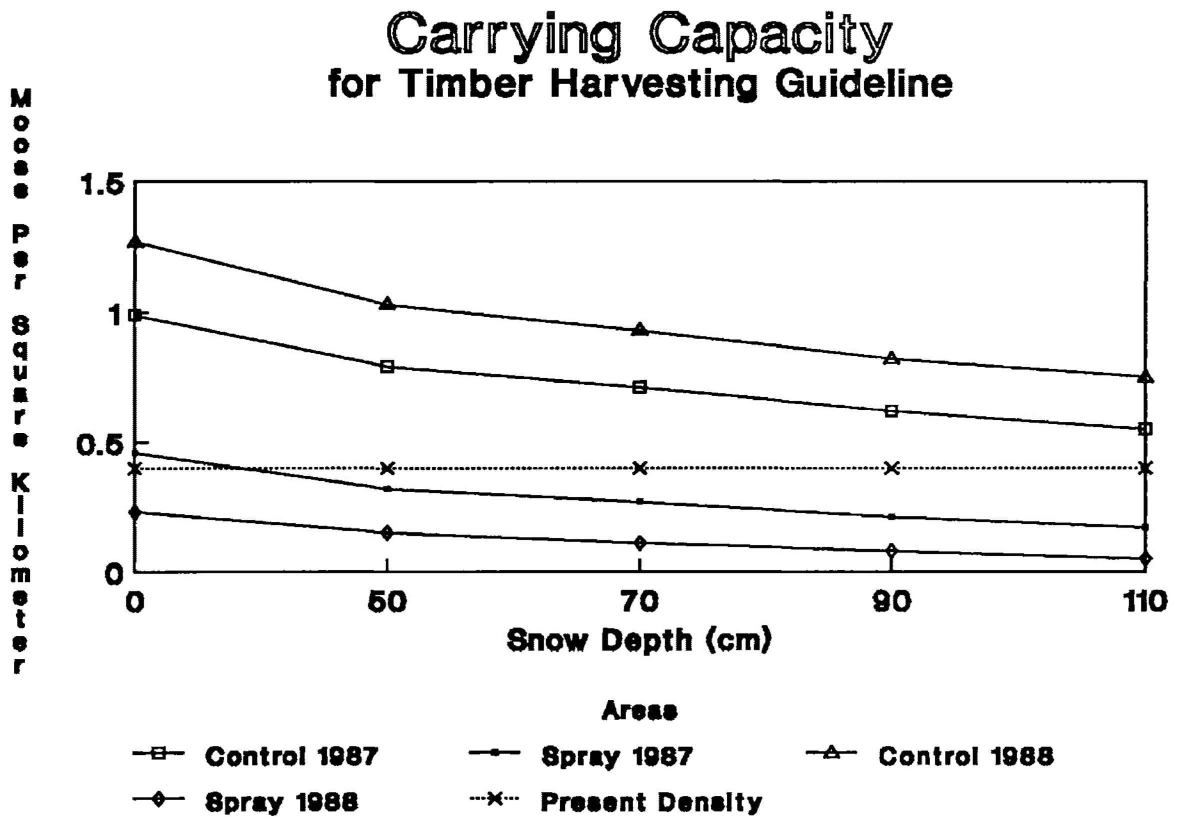


Figure 6: Carrying Capacity for Timber Harvesting Guideline Size (130 ha) Cutovers.

8.3.0 Carrying Capacity Models Discusssion

In reality, not every cutover will be sprayed. The results of this investigation and others seem to suggest that moose will spend the most time in areas where there is enough browse to meet their daily needs. Therefore, the negative effects of a herbicide application with glyphosate may well be mitigated by dispersing the sprayed areas in space and in time within the moose range. If there are non-sprayed cutovers in the vicinity of the sprayed cutovers, moose are likely to learn where these areas are and use them. If sprayed areas proved to be more useful 9 years after the original cut, as Newton et al. (1989) observed, ungulates may benefit from the herbicide application in years to come. The areas that were not sprayed, will by this time, become less desirable because the browse will have grown out of reach. The glyphosate treated areas may have enough browse within reach at this time to become the preferred areas of browse.

A curve for the expected use of non-treated and treated cutovers by moose may appear as in figure 7. Cutovers that are not sprayed likely receive the greatest amount of use from about 12 to 15 years post cut. Use begins to be more pronounced after about 5 years because browse density above about 50 cm of snow depth is great enough to sustain use well into the winter. Use then increases until about 15 years post

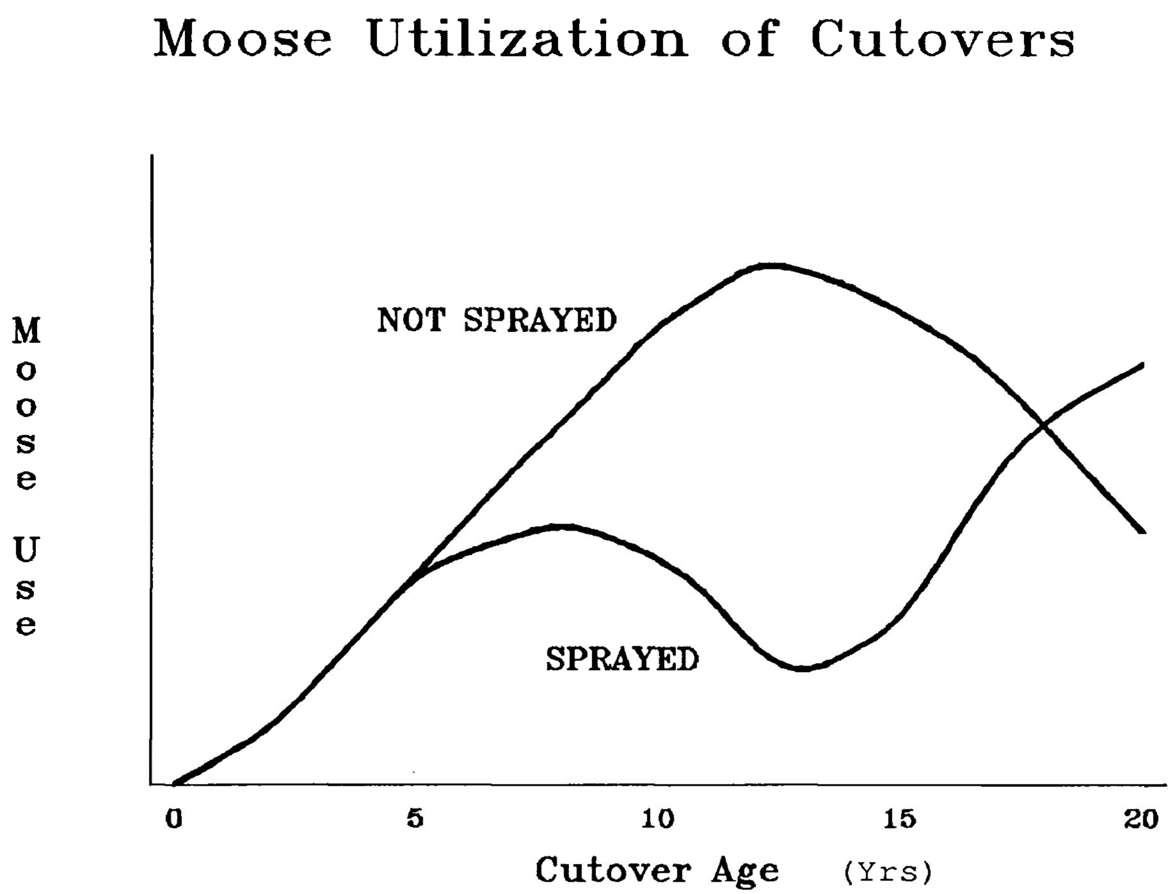


Figure 7: Moose Utilization of Cutovers - Sprayed and Not Sprayed - Over Time.

cut when it reaches a maximum and then declines as browse grows out of reach.

The areas treated with glyphosate, on the other hand, will exhibit similar patterns in use by moose up until the time they are sprayed at approximately 5 to 8 years post cut. Use then decreases as the glyphosate treatment drastically decreases browse availability especially above 50 cm. Browse densities continue to decrease for 2 or more years post spray, and use by moose will decrease. These cutovers may be at a minimum at about the time that use reaches a maximum on non-sprayed cutovers. Then as utilization is decreasing on the non-sprayed cutovers, it will likely be increasing on the sprayed cutovers as the density of browse above 50 cm increases on treatments and grows out of reach on controls. However, use of the sprayed cutovers is not likely to reach the same maximum as the non-sprayed, due to the fact that at approximately 18-20 years post spray conifers dominate the site. Growing space for the deciduous browse species will be limited and the maximum amount of browse available will not be similar to the maximum observed on the non-sprayed areas. Therefore, these areas may not be able to sustain as much use as did the non-sprayed cutovers. The question then would be: Is there enough browse remaining to sustain targeted moose densitites?

Assuming that the carrying capacity model developed to answer question number one is a good reflection of moose density behaviour in Northwestern Ontario, the use of glyphosate for the tending could jeopardize the moose management objectives of the Ministry of Natural Resources. However, caution is needed as the model does not consider predation and other mortality factors. Thus, if moose are managed over extensive areas such as the wildlife managements (10,0000 - 15,0000 km^2), spraying probably has minimal impact on M.N.R. targets. On a much smaller scale, the size of moose home ranges (15-25 km^2), spraying could drastically alter the size of a localized moose population. Since browse availability is so low, moose will likely emmigrate to areas of better browse availability.

The model also indicates that, above 50 cm, 6 kg of dried browse, which equates to 13 kg (adjusted for digestability) of green browse needs to be ingested to meet daily requirements. However, moose are only capable of ingesting approximately 6 kg of browse a day in the winter (Renecker and Hudson, 1985), therefore, they would lose weight over the winter period; weight loss would be greater on the spray areas due to extra search effort. Schwartz et al. (1988), studied the energy requirements of moose and concluded that there were two set points for body weight in moose. An upper one reached in the fall resulting in moose lowering their basal metabolic rate and daily intake of browse for the winter and a lower one occurring in the spring which reverses the process. They hypothesized that moose reach the lower set point just prior to a change in the availability of higher quality food; the upper set point is reached just as browse quality/quantity decreases. Moose, whose home range has been extensively sprayed and browse availability decreased may reach the lower set point earlier in the year, causing a change in forage intake before there is an abundance of good quality browse. During winters in which the amount of snow on the ground is deeper and energy expenditures greater; energy reserves of moose may be stressed as a consequence of the glyphosate treatment. However, the amount of spraying that would bring this about is not likely to occur, since the entire home range of moose would require treatment with glyphosate. Large contiguous spray areas, however, may result from successive years of treatment, especially if browse availability continues to decrease for at least 2 years after treatment. Moose will avoid these spray areas thus incurring extra energy expenditures for travelling. Moose, will over the course of time learn, where these spray areas are and avoid them (Ozoga and Verme, 1982, Gillingham and Bunnell, 1989).

An estimate of area that must remain untreated, so that present moose densities would not be affected, would be 1 in 3 cutovers. Since about 1/3 of the area of a cutover is "available" and will maintain a population of moose at 0.75 moose/km^2 on the controls, 1 out of every 3 cutovers would likely support present population levels.

Large contiguous areas of glyphosate treated cutovers can be mitigated during planning of forest operations. Glyphosate treated areas can be dispersed throughout the forest operation to create a mosaic of treated and non-glyphosate treated cutovers for moose to use and there by minimize energy expenditures for travel.

Areas of local significance, such as aquatic feeding areas and mineral licks, should be protected by leaving an unsprayed buffer next to it. If at all possible the entire adjacent cutover should be removed from the spray programme. Decisions for spraying should occur either pre-harvest or immediately post harvest to avoid investment in areas that should be protected for moose habitat.

The fact that browsing is related to the amount of browse available suggests that there may be a possibility of finding a rate of spray application that may meet both the needs of moose and the silvicultural objectives of the forest industry. Further study should be undertaken in this area to determine if this is feasible.

9.0.0 DISCUSSION AND CONCLUSIONS

The results of this study are summarized in Table 33 and indicate that browse availability, particularly between 101 cm and 350 cm, in control areas was 2 to 18 times greater than in treatment areas 2 years after treatment. However, with too few replications and exigencies that developed because the study was a field trial, statistical differences were not revealed.

Table 33: Impact of Glyphosate Treatment.

Comparison	Result	Interpretation
Browse Available	2 - 18 x > on control	treatment decreased browse available
Browse Utilized	3 - 7 x > on control	treatment decreased browse utilized
Number of Pellet Groups	1.5 x > on control	more time spent on controls
Number of Moose Tracks	369 (control) : 352 (treated)	with controls 22% smaller in size, indicates moose visited controls more often
Number of Moose Track Aggregates	1.5 x > on control	indicates moose browsed more often on controls
Length of Tracks	1.7 x < on control	indicates less intensive search for areas to browse
Track Aggregate Area	treatment = control	indicates equal search effort while browsing

Browse use was 3 to 7 times greater on controls, 2 years after treatement, but again not statistically different.

Of the ten browse species, only aspen exhibited any significant differences. Significant differences occurred between treatments for height class 3 in 1987 and 2, 3 and 4 in 1988. The magnitude of these differences ranged from approximately 2 fold to 5.4, with a high of 23.5 for height class 4 in 1988.

The number of pellet groups, moose tracks and moose track aggregates all indicated greater use of the control areas (Table 33). This finding was similar to the results reported by Hjeljord and Grunvold (1988) with respect to pellet groups. Since there was more browse available on the control areas, use measured by pellet groups, tracks and track aggregates should favour the controls.

Pre-spray pellet group data on study areas 3 and 4, indicated that moose shifted use from areas sprayed to control areas. This indicates an impact on use of these cutovers brought about by glyphosate application.

Moose behaviour on the control areas was also different from that of the treated areas. Moose did not search as long on the controls as on the spray areas as indicated by the short trail lengths (Table 33). Since browse densities were greater on the controls it could be expected that less searching would be required.

The area of each track aggregate, which was also used as an indicator of browsing behaviour, was similar between treatments (Table 33). If moose only browse intensively in areas where the density of browse is above some value, then it could be expected that moose would find more of these areas on the controls. Since the aggregates had approximately the same area, it is assumed browse densities may be similar in these "patches" although browse densities within an aggregate were never measured.

It was concluded that glyphosate application altered the use of treated cutovers since moose did not browse as often, nor did they remove as much browse from the glyphosate treated areas as they did from the control areas.

However, one initial question for this thesis was: would the application of glyphosate reduce the carrying capacity? The carrying capacity models indicated that carrying capacities could be reduced if all cutovers were sprayed. Fortunately not all cutovers will be sprayed. Reductions in the ability of the land to support moose though may result in lower populations in areas where spraying has occurred. Moose will not use these areas but will move to areas where browse is more plentiful.

The carrying capacity models indicated that moose needed to consume about 6 kg of dried browse per day to meet energy requirements. This was similar to observations by Renecker and Hudson (1985). Considering that woody shrubs favoured by moose are only 44.5% digestible, 6 kg of dried browse would equal about 13 kg of green browse.

Rates examined in this thesis were approximately 1.5 kg/ha. Suggested rates for comparison may be 0, 0.5, 1.0 and 1.5 kg/ha. These rates could be replicated once in each cutover. The design could be the same as the one attempted here with the same number of cutovers but some of the pitfalls in testing treatments should be avoided as significance testing for treatments would have 3 degrees of freedom in the numerator (4 treatments) and 9 degrees of freedom in the denominator. Resulting F ratios would only have to differ by a factor of 3.86 rather than 10. This design would be better able to detect differences than the one used in this thesis.

When designing impact studies such as this one, controlling the probability of making a type 2 error is easier if the magnitude of the difference in availability that brings about a change in utilization were known. In this study the probability of a type 2 error was high. This can be partially corrected by increasing the number of replications. By estimating the variance before hand, the correct number of replications can be derived to control type 2 errors at an appropriate level.

Studies of use by moose should be carried on for longer periods than the 2 years observed here. Moose may return to these cutovers as browse recovers from the glyphosate application. The extent to which the areas may be utilized in future and the point in time when moose may return to utilize the cutovers could then be estimated for moose range planning.

In conclusion, the application of glyphosate on mixed wood sites in the boreal forest, for the purpose of tending, may reduce the use of these cutovers by moose and the subsequent carrying capacity.

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APPENDICIES

APPENDIX I

BIOMASS AVAILABLE FOR EACH WOODY BROWSE SPECIES

Mean (g/16m^2) Biomass Available for Each Species and Height Class in 1987.

Species	Height Class	Control Areas	Sprayed Areas	Pr > F	
Aspen	2	4.508	3.784	0.682	
	3	17.674	8.561	0.009	*
	4	49.609	13.371	0.060	
White Birch	2	1.459	1.178	0.853	
	3	6.266	3.696	0.602	
	4	5.683	3.006	0.607	
Red Osier Dogwood	2	4.365	4.320	0.981	
	3	2.698	3.771	0.809	
	4	na	na	na	
Pin Cherry	2	1.531	0.806	0.427	
	3	6.961	3.549	0.563	
	4	3.856	2.322	0.292	
Willow	2	1.648	0.641	p>0.05	L
	3	3.938	1.047	p>0.05	L
	4	0.987	0.863	p>0.05	L
Hazel	2	9.121	13.395	0.406	
	3	16.445	17.073	0.895	
	4	0.562	0.000	0.339	
Green Alder	2	1.875	0.442	p>0.05	L
	3	7.056	2.037	0.170	
	4	3.032	2.253	0.668	
Mountain Ash	2	0.384	0.217	0.317	
	3	0.420	0.396	0.724	
	4	0.000	0.302	0.391	
Mountain Maple	2	1.172	2.517	0.475	
	3	2.248	3.149	0.798	
	4	0.168	0.056	0.316	
June Berry	2	2.553	1.146	0.340	
	3	1.626	0.675	0.391	
	4	0.718	0.268	0.231	

Pr > F - probability of attaining a greater F ratio

* - significant at the 95% confidence limit
L - transformed with Ln+1
na - not applicable (0 g/16m^2)

Mean ($g/16m^2$) Biomass Available for Each Species and Height Class in 1988.

Species	Height Class	Control Areas	Sprayed Areas	Pr > F	
Aspen	2	3.488	0.760	0.024	*
	3	16.605	3.061	0.039	*
	4	56.085	2.384	p<0.05	* L
White Birch	2	1.076	0.290	0.317	M
	3	3.103	0.729	p>0.05	L
	4	4.321	0.330	p>0.05	L
Red Osier Dogwood	2	4.796	4.862	0.958	
	3	2.579	2.153	0.898	
	4	na	na	na	
Pin Cherry	2	3.055	2.789	p>0.05	L
	3	1.368	1.028	p>0.05	L
	4	6.036	0.607	0.146	
Willow	2	1.516	8.312	p>0.05	L
	3	7.519	1.027	p<0.05	* L
	4	4.467	0.222	p>0.05	L
Hazel	2	6.968	2.905	0.489	
	3	5.175	3.117	p>0.05	L
	4	0.604	0.000	0.125	
Green Alder	2	0.476	0.102	p>0.05	L
	3	2.266	0.993	0.139	
	4	0.925	0.475	p>0.05	L
Mountain Ash	2	0.172	0.153	0.889	
	3	0.800	0.184	0.088	
	4	0.030	0.461	0.429	M
Mountain Maple	2	1.448	1.365	0.963	
	3	3.081	0.146	0.336	M
	4	0.184	0.031	0.195	
June Berry	2	2.361	0.995	0.208	
	3	2.033	0.703	0.265	
	4	1.225	0.000	0.073	

Pr > F - probability of attaining a greater F ratio

* - significant at the 95% confidence limit
L - transformed with Ln+1
M - Mann Whitney U test
na - not applicable (0 $g/16m^2$)

APPENDIX II

BIOMASS REMOVED FOR EACH WOODY BROWSE SPECIES

Mean ($g/16m^2$) Biomass Removed for
Each Species and Height Class in 1987.

Species	Height Class	Control Areas	Sprayed Areas	Pr > F	
Aspen	2	0.020	0.009	0.195	
	3	0.235	0.013	0.159	
	4	0.247	0.040	0.212	
White Birch	2	0.038	0.000	0.250	
	3	0.053	0.000	0.194	
	4	0.170	0.003	0.356	M
Red Osier Dogwood	2	0.149	0.085	0.610	
	3	0.137	0.112	0.843	
	4	na	na	na	
Pin Cherry	2	0.056	0.014	0.179	
	3	0.099	0.069	0.677	
	4	0.031	0.000	0.189	
Willow	2	0.072	0.005	0.383	M
	3	0.200	0.021	0.373	M
	4	0.005	0.000	0.391	
Hazel	2	0.078	0.019	0.296	M
	3	0.191	0.004	0.121	M
	4	0.009	0.000	0.391	
Green Alder	2	0.034	0.000	0.291	
	3	0.082	0.019	0.102	
	4	0.024	0.005	0.510	M
Mountain Ash	2	0.923	0.003	0.466	M
	3	0.019	0.072	0.558	
	4	na	na	na	
Mountain Maple	2	0.062	0.000	0.222	
	3	0.067	0.002	0.247	M
	4	0.000	0.010	0.391	
June Berry	2	0.087	0.000	0.196	
	3	0.024	0.000	0.243	
	4	na	na	na	

Pr > F - probability of attaining a greater F ratio

M - Mann Whitney U test
na - not applicable (0 $g/16m^2$)

Mean ($g/16m^2$) Biomass Removed for Each Species and Height Class in 1988.

Species	Height Class	Control Areas	Sprayed Areas	Pr > F	
Aspen	2	0.014	0.001	0.391	M
	3	0.128	0.006	0.092	M
	4	0.161	0.004	0.308	M
White Birch	2	0.002	0.000	0.391	
	3	0.052	0.029	0.230	
	4	0.153	0.017	0.391	M
Red Osier Dogwood	2	0.117	0.057	0.184	
	3	0.032	0.019	0.713	
	4	na	na	na	
Pin Cherry	2	0.013	0.004	0.234	
	3	0.030	0.019	p>0.05	L
	4	0.051	0.021	0.268	
Willow	2	0.045	0.016	0.391	
	3	0.158	0.002	0.391	M
	4	0.030	0.000	0.010	
Hazel	2	0.090	0.011	0.194	M
	3	0.254	0.026	0.243	M
	4	0.006	0.000	0.315	
Green Alder	2	na	na	na	
	3	na	na	na	
	4	0.000	0.005	0.391	
Mountain Ash	2	0.013	0.018	0.391	
	3	0.010	0.062	0.355	M
	4	na	na	na	
Mountain Maple	2	na	na	na	
	3	0.032	0.000	0.391	
	4	na	na	na	
June Berry	2	0.054	0.006	0.238	M
	3	0.051	0.000	0.218	
	4	0.002	0.000	0.391	

Pr > F - probability of attaining a greater F ratio

L - transformed with Ln+1
M - Mann Whitney U test
na - not applicable (0 $g/16m^2$)

APPENDIX III

MINIMUM DETECTABLE DIFFERENCE BETWEEN TREATMENT MEANS

Minimum Detectable Difference (M.D.Diff.) between Treatment Means for Browse Available, with Type 2 Error Rate at 0.20 ($g/16m^2$).

Species	Height Class	1987 Observed Diff.	1987 M.D. Diff.	1988 Observed Diff.	1988 M.D. Diff.
Aspen	2	0.7	5.4	2.7	2.2
	3	9.1	5.0	13.5	12.9
	4	36.2	41.4	53.7	75.0
White Birch	2	0.3	4.7	0.8	2.2
	3	2.6	14.9	2.4	13.9
	4	2.7	15.7	4.0	26.6
Red Osier Dogwood	2	0.1	5.7	-0.1	3.8
	3	-1.1	13.6	0.4	10.2
	4	na	na	na	na
Pin Cherry	2	0.7	2.7	0.3	3.8
	3	3.4	17.7	0.3	10.2
	4	1.5	4.0	5.4	9.2
Willow	2	1.0	1.0	1.2	1.7
	3	2.9	2.9	6.5	1.7
	4	0.1	0.3	1.4	1.5
Hazel	2	-7.3	14.9	4.1	17.3
	3	-0.6	14.8	2.1	14.5
	4	0.6	1.6	0.6	1.0
Green Alder	2	1.4	1.5	0.4	0.7
	3	5.1	9.4	1.3	2.1
	4	0.8	5.5	0.5	6.2
Mountain Ash	2	0.2	0.5	0.1	0.4
	3	0.1	0.2	0.6	0.8
	4	-0.3	1.0	M	M
Mountain Maple	2	-1.3	5.6	0.1	5.5
	3	-0.9	10.8	2.9	8.6
	4	0.1	0.3	M	M
June Berry	2	1.4	4.2	1.4	2.9
	3	1.0	3.2	1.3	3.3
	4	0.5	1.0	1.2	1.5

M - Mann Whitney U test
na - not applicable (0 $g/16m^2$)
Observed Diff.: Control Mean - Treated Mean

Minimum Detectable Difference (M.D.Diff.) between Treatment Means for Browse Removed, with Type 2 Error Rate at 0.20 ($g/16m^2$).

Species	Height Class	1987 Observed Diff.	1987 M.D. Diff.	1988 Observed Diff.	1988 M.D. Diff.
Aspen	2	0.01	0.02	M	M
	3	0.22	0.40	M	M
	4	0.21	0.44	M	M
White Birch	2	0.04	0.09	0.01	0.01
	3	0.05	0.11	0.02	0.05
	4	M	M	M	M
Red Osier Dogwood	2	0.06	0.38	0.06	0.12
	3	0.03	0.39	0.01	0.11
	4	na	na	na	na
Pin Cherry	2	0.04	0.08	0.01	0.02
	3	0.03	0.22	0.01	0.11
	4	0.03	0.06	0.03	0.23
Willow	2	M	M	0.03	0.10
	3	M	M	M	M
	4	0.01	0.02	0.03	0.04
Hazel	2	M	M	M	M
	3	M	M	M	M
	4	0.01	0.03	0.01	0.02
Green Alder	2	0.03	0.09	na	na
	3	0.06	0.09	na	na
	4	M	M	-0.01	0.02
Mountain Ash	2	M	M	-0.01	0.02
	3	-0.05	0.08	M	M
	4	na	na	na	na
Mountain Maple	2	0.06	0.14	na	na
	3	M	M	0.03	0.11
	4	-0.01	0.03	na	na
June Berry	2	0.09	0.20	M	M
	3	0.02	0.06	0.05	0.11
	4	na	na	0.01	0.01

M - Mann Whitney U test
na - not applicable ($0\ g/16m^2$)
Observed Diff.: Control Mean - Treated Mean