WINTER UTILIZATION BY MOOSE OF GLYPHOSATE-TREATED CUTOVERS

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ABSTRACT: Glyphosate (N-(phosphonomethyl) glycine) is an important silvicultural tool used in the boreal forest. This study was undertaken to determine if the use of this herbicide for controlling competing shrubs in plantations is significantly reducing forage resources and subsequent overwinter utilization by moose (*Alces alces*) up to 3 years post-spray. Observations were carried out on 4 glyphosate-treated and control paired cutovers near Thunder Bay, Ontario.

Moose presence and feeding activity throughout winter, as measured by periodic, systematic aerial track counts, indicated that the numbers of overwinter moose tracks were not significantly different ($P > 0.05$) after 0 and 1 growing seasons post-spray, but they indicated a preference for the non-sprayed control areas ($P < 0.05$) at 2 and 3 growing seasons post-spray. The number of moose track aggregates were similar in all control and treated cutovers ($P > 0.05$), prior to the first growing season post-spray, but were more numerous ($P < 0.05$) on control portions, 1, 2, and 3 growing seasons after treatment. Available moose browse, on control areas, was four times greater, and browse utilized was 32 times greater, than that in treated areas ($P < 0.05$) after 1 growing season post-spray. Estimated winter moose presence, calculated from pellet counts, was almost two times greater on untreated than treated areas after 1 growing season ($P < 0.05$) and similar at 2 growing seasons post-spray.

The effect of major habitat changes brought about by forestry activities on the total moose population is discussed. It is difficult in a 3-year study to formulate conclusions based on results that take many more years to manifest themselves. Further research is recommended to determine the long-term impact of glyphosate application on wildlife habitat.

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The herbicide glyphosate was approved for forest management applications in Ontario in 1984. It is applied aerially to release natural and planted conifers from competing vegetation after logging. Glyphosate is a systemic herbicide that is absorbed into the foliage and translocated throughout the target plants. It tends to kill all portions of plants, thus largely precluding regrowth or resprouting; especially in deciduous woody plants, many of which comprise the most important food resources for moose. Little research has been conducted on the effects of glyphosate on the habitats of boreal forest wildlife. Consequently, moose managers are concerned that glyphosate application will reduce available browse, and thus, moose habitat quality.

Kennedy and Jordan (1985) studied the impact of 2,4-D and glyphosate on moose browse in the Superior National Forest of northern Minnesota. They found that glyphosate, when used for conifer release, not only reduced browse resources in subsequent years, but encouraged heavy stands of grasses, forbs, and raspberries (*Rubus* spp.). Three years after spraying, the glyphosate-treated plantations averaged only one-half of the available browse contained within similar 2,4-D-treated plantations, and only one-quarter of the available browse contained within control plantations (Kennedy 1986). Similar differences were found in the first 3 years post-spray by Newton *et al.* (1989) in a nine-year study in Maine.

An effort was made to obtain a better understanding of glyphosate effects on moose habitat in a 3-year study initiated in 1986 in northcentral Ontario. Objectives were:

1. To monitor changes in available

browse biomass on glyphosate-treated sites over 3 years and compare with untreated controls; and

2. To examine whether possible glyphosate-induced changes in vegetation have altered patterns of winter browsing by moose.

Interim findings on winter moose utilization following glyphosate application have been reported by Connor and McMillan (1988). This paper details the results over the entire 3-year study period.

STUDY AREA

The study area lies within the Abitibi-Price Inc. Spruce River Road Forest Management area, approximately 100 km north-east of Thunder Bay, Ontario (Fig. 1). It is located within the Superior zone of the Boreal Forest Region (Rowe 1972). The vegetation is classified as boreal mixedwood, generally dominated by conifers. The principal tree species present are black spruce (*Picea mariana*), white spruce (*P. glauca*), jack pine (*Pinus banksiana*), balsam fir (*Abies balsamea*), white birch (*Betula papyrifera*), and trembling aspen (*Populus tremuloides*).

Four cutover areas, treated aerially with glyphosate (1.44-1.53 kg active ingredient per ha), and with a known history of harvest and silvicultural treatment, were selected (Table 1). All cutovers had been planted with black spruce. Areas 1 and 2 were single cutovers that were subdivided, with approximately one-half treated and the remainder left as a control. Areas 3 and 4 comprised two adjacent cutovers, one of which, for both areas, was left untreated as a control.

Herbicide application was carried out in mid-August after the conifers have hardened off and while woody and herbaceous vegetation was still green. The use of a fixed-wing aircraft in 1985 resulted in some strips within the Area 1 and 2 treated zones that were not contacted by the spray. Application by helicopter in 1986 resulted in substantially fewer missed strips for Areas 3 and 4 (Table 1).

Areas 1, 3, and 4 are comprised of shallow morainal deposits underlain by early Precambrian bedrock, consisting of light-coloured metamorphic rock, mostly granitic schist and gneiss. The soils are coarse-loamy in texture, derived primarily from granitic parent materials. Area 2 is located over a late Precambrian sedimentary formation consisting of red shale. The soils derived from this material are of much finer texture than those in the other three areas, though they can be quite gravelly. Ground moraines are more dominant here and the tills tend to be deeper (Anon. 1984).

The general study area is considered to be good-quality moose habitat, due in part, to a history of periodic logging disturbance. Areas adjacent to the project sites have average moose densities of 0.43 moose/km^2, based on a standard aerial inventory conducted in 1987-88 (OMNR 1981).

METHODS

Winter utilization by moose of each cutover pair was assessed by an annual spring (May - June) browse and pellet group survey after snow melt, and weekly observational flights during the winter period, December to March.

Pellet Survey

A baseline was arbitrarily established along the longitudinal axis of each cutover, and parallel transects were laid out perpendicular to this, spaced at 150 m apart to ensure uniform coverage. Moose pellet groups were counted along each transect on a 2 m wide strip. Only those deposited since the previous autumn were tallied, being distinguished by their colour and position on top of current leaf litter and grass. Only groups with > half the pellets within the strip were counted. Overwinter moose densities, on treated and control areas, were estimated using an average daily deposition rate of 13.0 pellet groups

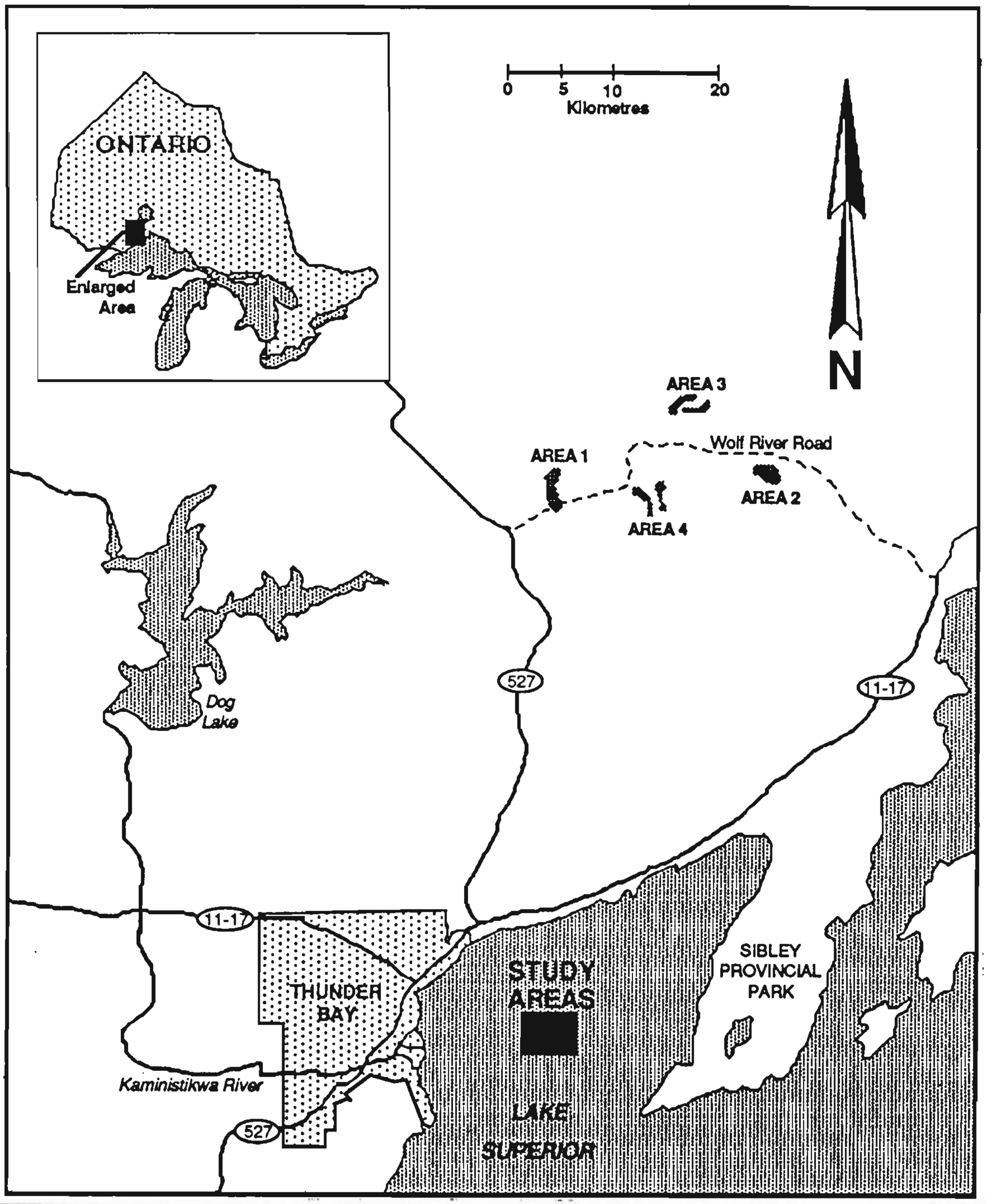

Fig. 1. Location of four study cutovers near Thunder Bay, Ontario.

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	Pw	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

per moose per day (Timmermann 1974) over an average 198-day period for the three winters of the project.

Browse Survey

Permanent sample plots were established along the transect lines in each of the four paired cutovers. Fifty-nine 2 x 2 m permanent sample plots were established in 1986. For 1987 and 1988, plot size and number were 4 x 4 m and 425, respectively. Plots were spaced at 60 m, using a random start, and the centre was permanently marked by a numbered stake. Each plot was searched for the following 10 common deciduous tree and shrub species whose twigs are generally eaten by moose in winter : *Acer spicatum, Alnus viridis* ssp. *crispa, Amelanchier* spp., *Betula papyrifera, Cornus sericea, Corylus cornuta, Populus tremuloides, Prunus pensylvanica, Salix* spp., and *Sorbus* spp. (Timmermann and McNicol 1988). Sampling twig density was modified after Passmore and Hepburn (1955). A twig was considered to be any shoot at least 2.54 cm in length, occurring either lateral to, or at the end of a branch, with no differentiation between current year's growth and twigs including more than one year's growth. Twig counts were tabulated for stems occurring in each of three height classes: 51-100 cm, 101-200 cm, and 201-350 cm. For each browsed twig on the 425 plots assessed in 1987 and 1988, the diameter at point of browsing (dpb) was measured, and mean dpb was calculated for each species in each height class.

An available twig was defined as that portion of the shoot that was distal to the mean dpb and that is "acceptable" to moose. Representative browse currently available was the weight of woody material distal to the mean dpb. To produce estimates of available biomass (kg/ha), 10 stems of each height class for each species were collected, and all twigs at dpb or less, and greater than 2.54 cm, were clipped off. These were then oven-dried at 70°C for at least 24 hours, removed, and weighed (0.001 g). A mean weight of representative browse currently available per stem by species and height class was then calculated. Available browse biomass was subsequently calculated as number of stems by species and height class, multiplied by the mean weight per stem for that species and height class. Represenative biomass currently being removed by browsing was calculated as the number of bites, by moose, times the average weight per twig for each species at each height class for both treatments. An average was used in this particular instance because twigs from each stem were weighed as a unit, therefore, there was no estimate of the variation between individual twigs. If a stem or twig weight observation was missing, then the average of all other treated or control areas, respectively, for that particular species and height class, was used.

Aerial Survey

Weekly reconnaissance flights were conducted over all study areas mid-December to mid-March, 1986-87, 1987-88, and 1988-89, with the number of flights per winter being 15, 17, and 16, respectively. Flights were made with either a Cessna 180, a DeHavilland Turbo Beaver aircraft, or a Bell 206 helicopter, between 1000 and 1500 hours, at an average altitude of 250 m and an average airspeed of 120 km/hr. Search patterns were similar to those of McNicol (1976) and Todesco et al. (1985). The location of tracks, track aggregates, and moose were recorded on acetate that overlaid aerial photomosaics (scale 1:15,840). A "track" was defined as a direct movement of one or more animals between two points, while a "track aggregate" was a looping, over-crossing set of tracks (McNicol 1976, Todesco 1988). To avoid duplicate recording, the same overlay was used on successive flights until a major snowfall obliterated old tracks.

Data that resulted from the weekly flights were entered into a geographic information system (GIS) for measurement of cutover areas, habitats within cutovers, and track aggregate areas.

The null hypothesis that neither track density nor density of aggregates differed between treatments and controls was tested. A track aggregate was considered to be a particular location in the cutover where a moose had searched for and/or consumed browse. We interpreted this to be a place of concentrated feeding activity (Fig. 2). The area of track aggregates was assumed to be representative of the amount of time spent feeding and/or searching on either the treated or control area, hence the forage-value of the stand over the winter period. Generally, the greater the amounts of aggregates, summed over time, the more use a stand is getting. Average track aggregate size was calculated as the total track aggregate area divided by the number of track aggregates. The average size of a track aggregate was assumed to be proportional to the time spent searching and/or browsing during each feeding session.

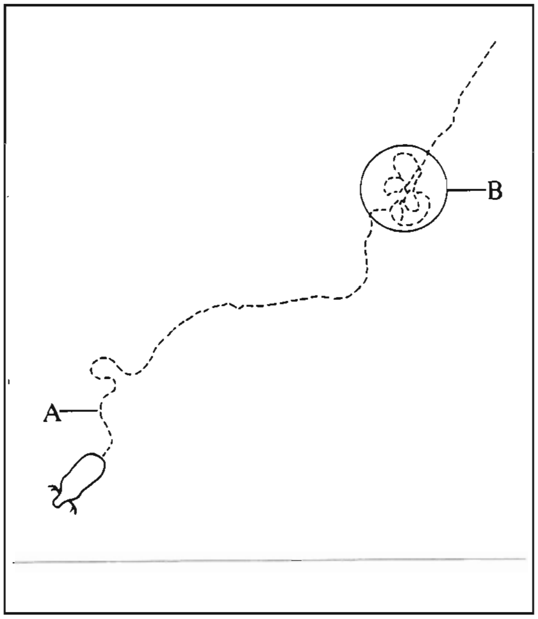

Fig. 2. Examples of a moose track (A) and a moose track aggregate (B).

Straight-line tracks represent a moose crossing from one place to another without regard for what is contained within the stand. Therefore, this is not as reliable a method of determining stand usage as track aggregates, but indicate moose presence in the area and that the animals are at least exposed to potential browse in the cutovers.

Snow Conditions

Snow stations were monitored on areas 1 and 4. Each consisted of 10 points, 30 metres apart, where weekly snow depth was measured and crust strength estimated as described by Passmore (1953). Average snow station depths were calculated for the period, mid-December to mid-March, 1986-87, 1987-88, and 1988-89.

Data Analysis

For the purpose of analysis, winter aerial survey observations were organized beginning the year in which the treatment was applied, or number of growing seasons post-spray. There is a one-year difference in data from areas 1 and 2 that are combined with those from areas 3 and 4. The individual year-effects were ignored when the years post-spray were combined for analysis. Observations occurring for 0 growing seasons after treatment were made during the winter of 1986/87 on areas 3 and 4 only. To obtain data for 1 growing season post-spray, observations from the 1986/87 aerial survey over area 1 and 2 were combined with the observations from areas 3 and 4 obtained during the winter of 1987/88. The same pattern was repeated to acquire data for 2 growing seasons after treatment: observations from the 1987/88 aerial survey of areas 1 and 2 were combined with the observations from areas 3 and 4 obtained during the winter of 1988/89. Data for 3 growing seasons post-spray came from the aerial survey conducted during the winter of 1988/89 for areas 1 and 2 only.

Pellet group density, as well as available and utilized biomass, were also analyzed by time period since treatment. Pre-spray data were compiled from the surveys occurring in areas 3 and 4 during the spring of 1986. Data for 0 and 1 growing seasons analyses were obtained by grouping the data from the surveys in areas 1 and 2, spring 1986, with the data from areas 3 and 4, spring 1987, and then, areas 1 and 2, spring 1987, with areas 3 and 4, spring 1988. Observations for 2 growing seasons post-spray were collected on areas 1 and 2 during the spring of 1988.

Pellet groups that fell on transects in portions of the cutover that had not been contacted by the spray were not apparent until after the first-year survey was carried out (prior to leaf flush). Consequently, pellet groups landing on missed strips in treated zones in subsequent years were not handled separately from the rest of the treated area pellet groups.

Tracks and track aggregate areas were analyzed using a chi-square goodness-of-fit test and a Bonferroni z test to determine utilization (Neu *et al.* 1974, Byers *et al.* 1984). The average track aggregate size, browse available and utilized, and pellet groups per hectare were analyzed using an analysis of variance. All testing was carried out at $P < 0.05$. Data were tested for homogeneity of variances using the $F_{\max}$-test (Sokal and Rohlf 1981), and transformed to the normal distribution using either Ln $(x + 1)$ or the square root transformation (Steel and Torrie 1980).

RESULTS AND DISCUSSION

Maximum snow depths in the first two winters were < 60 cm with minimal crusting. Such conditions, according to Coady (1974), do not hinder free movement of moose. Therefore, we concluded that snow depth during the first two winters of the study was not a factor influencing an animal's ability to select feeding sites. In the third winter, maximum snow depths were > 100 cm for 3 months. Snow depths exceeding 90 cm were considered to be severely restricting to moose, therefore, moose utilization of cutovers was probably restricted by snow depths during the third winter.

First winter post-spray data indicated moose track density was not significantly different for areas 3 and 4 (Table 2). Treatment had been applied in late summer 1986. Connor (1986) reported no difference in moose usage of glyphosate-treated cutovers for a similar 7 to 8 month post-spray period. He studied 7 cutovers, geographically located in the same area, 100 km northeast of Thunder Bay. Sullivan (1985) observed that black-tailed deer (*Odocoileus hemionus columbianus*), in British Columbia, did not avoid glyphosate-treated cutovers in the year

Table 2. Numbers of moose tracks, moose track aggregates, and average track aggregate size for paired control (C) and glyphosate-treated (T) study areas.

Time since treatment:	0 Growing Seasons[1]		1 Growing Season[2]		2 Growing Seasons[2]		3 Growing Seasons[3]	
Observation	C	T	C	T	C	T	C	T
Numbers of Tracks	42	62	168	178	127	88*	18	6*
Number of Aggregates	11	8	46	30*	55	33*	9	1*
Average Aggregate Size (ha)	0.24	0.12	0.42	0.49	0.15	0.10	0.40	0.15
- Standard Deviation	0.04	0.17	0.35	0.45	0.06	0.12	0.41	0.21

1 - Areas 3 and 4 2 - Areas 1 to 4 3 - Areas 1 and 2 * - Significant ($P < 0.05$)

immediately following application. The similar use of the treated and control portions in our study at 0 growing seasons post-spray, therefore, would be expected.

After one full growing season post-treatment, the numbers of tracks and average track aggregate size on treated and control areas were similar. The number of track aggregates, however, suggested a preference for the control areas (Table 2).

After 2 growing seasons post-spray, the number of tracks, and the number of track aggregates were significantly greater on the control than on the treated areas (Table 2). The average track aggregate size was greater, although not significantly so, on the control areas. This post-spray data indicated that moose visited and browsed more often on the control areas and less on the treated areas than expected. Three growing seasons after treatment, number of tracks and track aggregates were all significantly greater on the controls than the treated areas (Table 2). The average track aggregate size was 2.7 times larger on control areas than treated. No significant difference was determined due to insufficient sample size. Table 3 presents the increasing use made of the portions of the study areas that were missed by herbicide application.

The pellet group and browse surveys conducted in areas 3 and 4 during the spring of 1986 were carried out prior to treatment (Table 4). Analysis of the transformed data indicated that moose utilized the areas that were scheduled to be treated more than the areas that were to remain as controls. The available browse and the amount of browse utilized by moose, however, were statistically similar between the areas to be treated and the control areas prior to treatment.

Post-spray data collected before the next growing season indicated that there were significantly more pellet groups per hectare on the controls than treated areas (Table 4). This

Table 3. Track aggregate area (ha) that occurred in non-spray (missed) portions of the four glyphosate-treated study areas, 1, 2, and 3 growing seasons (GS) post-spray.

GS Post-Spray	Total Track Aggregate Area (ha)	Total Track Aggregate Area in Non-Spray (ha)	% of Total Agg. Area
1	10.216	0.894	8.75
2	6.841	1.159	16.94
3	0.300	0.184	61.33

Table 4. Numbers of moose pellet groups per hectare, representative biomass currently available, and representative biomass currently being removed for paired control (C) and glyphosate-treated (T) study areas.

Time since treatment:	0 Growing Seasons[1]		1 Growing Season[2]		2 Growing Seasons[2]		3 Growing Seasons[3]	
Observation	C	T	C	T	C	T	C	T
Pellet groups per hectare	2.90	28.08	20.62	7.75*	14.27	7.28	6.86	6.01
- Standard Deviaton	1.93	2.00	11.55	6.28	7.92	6.75	2.61	1.26
Biomass Available (kg/ha)	169.21	112.28	146.70	105.08	135.31	36.92*	151.67	45.81
- Standard Deviation	101.96	37.75	90.46	96.28	0.36	0.16	30.90	13.84
Biomass Removed (kg/ha)	0.50	1.50	1.21	0.33	1.62	0.05*	1.20	0.27
- Standard Deviation	0.50	1.50	0.88	0.47	0.14	0.14	0.23	0.11

[1] - Areas 3 and 4, [2] - Areas 1 to 4, [3] - Areas 1 and 2, * - Significant ($P < 0.05$)

pattern was similar to that observed by Hjeljord and Gronvold (1988) on control and glyphosate-treated plantations in Norway. Representative currently available and removed biomass were statistically similar for this post-spray time period (Table 4).

After 0 growing seasons post-spray, the lack of differences in representative currently available biomass were expected since glyphosate, when used for the release of young conifer plantations, is applied in the late summer, August to early September. By that time, the shoot growth on the deciduous shrubs is complete, or nearly so. The only noticeable effect of the herbicide application was an early leaf fall, and thus, it appeared as though the deciduous twigs were not initially affected to a great degree by the chemical. Since glyphosate does not render forage totally unpalatable (Sullivan and Sullivan 1979, Campbell *et al.* 1981), the relative overwinter browse availability, at 0 growing seasons post-spray and preceding the next growing season, was not expected to be greatly altered by the herbicide application.

The pellet group survey after 0 growing seasons, however, indicated that moose preferred the control areas; utilized or removed biomass was also twice as great on the control areas, although this difference was not significant. These results were not entirely anticipated since browse availability/palatability was expected to be similar. If the summer's growth is completed, but the plant was not dormant when herbicide application was made, some tissue death can result. If the twigs have lost some of their viability, they are likely to be less attractive to browsers. Campbell et al. (1981) noted some rejection of glyphosate-treated foliage of Douglas fir (*Pseudotsuga menziesii*) by black-tailed deer. They postulated that it may be due to physiological changes in the plants, brought about by the glyphosate treatment. Perhaps, in our study, translocation of glyphosate in the treatment year was sufficient to initiate a physiological change in the plants that was detectable to moose as they browsed but not to observers in the spring when browse surveys were carried out. This alteration may have caused moose to spend more time on controls as indicated by the pellet group survey and utilized biomass. Further field trials, however, would be needed to test this hypothesis.

After one growing season post-spray, all variables were significantly greater on controls. There was an almost 4-fold difference observed in browse availability, a 32-fold difference in browse utilized, and a 2-fold difference in the number of pellet groups per hectare on controls versus treated areas (Table 4). This implies that the treatment had influenced moose utilization. Two growing seasons after treatment, there were no significant differences between control and treated areas for pellet groups per hectare, and available and utilized biomass (Table 4). However, differences in availability and utilization were 3.4 times and 4.4 times greater on controls, respectively. The lack of significance for these values is due to an absence of sensitivity in the experimental design. *F*-ratios needed to exceed 161 to be declared significant. There is no explanation as to why the number of pellet groups per hectare are similar, other than 25% of all groups observed within the treatments were in areas missed by the spray.

Pellet counts were used to estimate differences in overwinter moose densities. Intensity of use on the control plots was almost twice that of the treated areas after 1 growing season post-spray, based on moose densities (0.50 moose/km^2 versus 0.28 moose/km^2). Inherent in these estimates are the problems associated with estimating moose densities using pellet group counts as described by Neff (1968) and Timmermann (1974). Based on the estimated densities of moose, controls appeared to be the preferred areas, and moose spent relatively more time there. Vivas and Saether (1987) observed that moose in Norway (*Alces alces*) spent more time on plots containing high forage density compared to plots containing low forage density. Two growing seasons after treatment, the values for control and treated areas were 0.27 moose/km^2 and 0.23 moose/km^2, respectively, based on pellet group counts. A portion of these pellet groups fell in missed areas within treated blocks as previously described. This, however, does not explain the entire difference between the 340 - 440% change in browse availability and the 17% change in moose density for control versus treated areas.

The numbers of moose tracks gave no clear indication that moose preferred either the treated areas or the control areas for 0 and 1 growing seasons post-spray. This time lag may be related to an adjustment period by moose to the new disturbance, or the time required for full treatment effect to manifest itself. Vivas and Saether (1987) observed that moose visited plots containing low stem densities as often as they visited plots of high stem density. Therefore, the fact that the number of tracks did not clearly indicate a preference for either treatment suggests a random distribution of tracks. The relative increase in track density in control areas after 2 and 3 growing seasons suggests an increasing preference for these over the paired treatment sites.

The aerial surveys, in fact, indicated increasing use of control areas through time. During the first winter, none of the parameters indicated preference for control areas. After one growing season, however, moose preferred controls for browsing as indicated by the greater number of track aggregates there. After 2 growing seasons, moose visited and browsed on controls more often as both the number of tracks and aggregates indicated a preference for controls. After 3 growing seasons, moose spent significantly more time as well on the controls.

The pattern of increasing use of controls is also evident in the browse survey data. The number of pellet groups per hectare and amount of browse utilized indicate a switch in preference from treated areas before spray to controls immediately after spray. This preference persisted for one growing season post-spray (Table 4). After 2 growing seasons post-spray, there was still greater use of controls. A similar pattern was noted by Hjeljord and Gronvold (1988) in Norway. The missed or non-sprayed strips also had a similar pattern of use. As the years progressed, use of the missed strips increased (Table 3). This may partially explain why utilization on the treated areas, which included missed strip data, increases between 2 and 3 growing seasons after treatment. After 3 growing seasons, we believe the more severe winter conditions, compared to the previous two winters of the project, led to an overall decrease in moose activity in all of our study cutovers.

The problem of the missed strips occurring in treated parts of our study areas provides an illustration of what can actually happen with chemical application in an operational setting. Timing relative to weather and plant growth, topography of the spray site, and missed strip occurrences can all affect the final outcome of a spray program and how it influences the local habitat and moose population.

Forage utilized was much less on the treated areas than on the controls in all time periods post-spray. Thus, the amount of forage consumed per unit of time spent in searching must have been less. Consequently, net energy returns on the treated areas must also have been less (Vivas and Saether 1987). This could be especially important for the productive component of the population, particularly cows with calves, and may help explain why the number of track aggregates and pellet density were greater on the controls. It could have accounted for the almost 2-fold difference in density estimates between the treatments after 1 growing season post-spray.

An issue not addressed in our study is the impact of glyphosate reduction on summer browse resources. Since most winter forage species are also important summer forage species (Belovsky and Jordan 1978, Timmermann and McNicol 1988), then a reduction in winter range quality resulting from the application of glyphosate likely affects summer range quality and quantity as well (Kennedy and Jordan 1985).

SUMMARY AND MANAGEMENT IMPLICATIONS

Moose preferred the non-sprayed control areas to the treated areas after 1 growing season. The number of moose track aggregates and pellet groups ($P < 0.05$), and browse consumed on controls was greater on the control areas than on the treated areas. Estimated densities of moose were greater on the control areas, after 1 growing season, indicating that moose spent relatively more time on the control areas than on the treated areas. It was postulated that increased browse availability on the non-sprayed controls reduced search effort, resulting in higher energy returns per unit of search time.

After 2 growing seasons, however, the difference in utilization between the two treatments had decreased to 4 times greater usage on the controls from 32 times greater use. This may be due, in part, to a greater utilization of the non-sprayed strips within treated areas.

This study, however, only presents the results of observations occurring on 4 cutovers. For management purposes, both wildlife and forestry, an important issue that needs to be considered is the effect of spraying sizable contiguous areas. What happens if large tracts are sprayed, thereby substantially affecting food supplies within the home ranges of a number of moose? Will moose abandon these locations and disperse to other nearby areas, if such are available? Will moose have to increase their home range size in order to include enough non-sprayed (untreated) areas for maintenance? How long does it take before sufficient browse is re-established on these sites so that moose can use them in an energy-efficient manner?

Newton *et al.* (1989) observed an increase in available browse in treated areas over controls of the same age, 9 years after treatment. Control plots contained 5% cover in available browse (< 2.5 m in height) at year 16. The lower glyphosate rate used (1.65 kg active ingredient/ha) resulted in 3 times as much, or 15% cover, in available browse. The higher glyphosate rate (3.3 kg active ingredient/ha) produced 7 times, or 35% cover. However, Newton *et al.* did not measure use; thus, is a 7-fold increase at year 16 enough available browse? Representative browse currently available was very low on controls due to the growth of browse above the reach of ungulates and the subsequent shading out of understory plants. Therefore, to determine if a 3- or 7-fold increase is beneficial, one must measure the treatment area usage and compare this to that found on to the controls. Consequently, there is need to continue these studies for 15 to 20 years to verify results such as those obtained by Newton *et al.*

Managers have a poor understanding of how moose respond to major habitat changes within their home range. If moose choose, or have no choice but, to remain after the glyphosate treatment, then the affected browse resource could be limiting to a greater extent. This may contribute to added winter mortality and/or reduced production, and hence, a declining population. If moose are displaced from a portion of their home range, they must compensate by adding new territory.

Winter can be a difficult time of year for ungulates in the northern hemisphere. Animals that weigh more at the beginning of winter generally are in better condition and have a greater chance of surviving than those in poorer condition (Schwartz *et al.* 1988). Summer range, therefore, plays an important role in survival. This raises the question of what proportion of stands can be treated while still not seriously decreasing carrying capacity for moose, and what spatial patterning of treatments can be accomodated by moose, in order to effectively integrate moose habitat needs with ongoing forestry activities. Over the course of 3 or 4 years, aerial applications of glyphosate may result in large contiguous areas with reduced availability of seasonal moose forage.

There are studies which show that habitat utilization by moose is related to browse availability, suggesting that moose distribution can be altered by manipulating browse supply (Telfer 1978, Crête 1989). Therefore, the impact of glyphosate could be reduced by dispersing the glyphosate treatments over a larger area resulting in a mosaic of sprayed, unsprayed cut area, and shelter patches. This can be best achieved by initially dispersing the harvest blocks. In this manner, the necessary food component is available and accessible throughout the home ranges of moose, reducing the need for long, energy-consumptive movements between food and cover.

Areas next to critical habitat features, such as mineral licks and summer aquatic feeding areas, should not be treated with glyphosate. Wildlife corridors, residual shelter patches, and winter concentration areas should also be protected in a similar fashion. Where it is necessary to spray cutovers adjacent to these types of habitat, a buffer strip should be left, such as Hamilton and Drysdale (1975) proposed, to ensure accessible browse close to cover.

The final issue is whether a reduction in browse, in summer or winter, will indeed affect moose populations. This may only be possible if the herd density is at or near the carrying capacity of the existing browse resources. If so, any treatment may reduce numbers. If other factors, such as predation and hunting, are influencing the herd population, then browse may not be a limiting factor and altering the amount of browse available, even substantially, may have little effect. Relatively large adjoining treated areas may have more of an impact on local moose populations.

Wildlife managers must work closely with forest managers to produce suitable moose habitat, and to determine where spray patterns can and should be modified so that sufficient browse is retained along prime habitats associated with the uncut forest edge, or within partially cut areas. The planning necessary to achieve moose habitat and forest management objectives must take place before investments have been made (i.e. scarification, planting) to renew the forest. Newton et al. (1989) reported on recovery of vegetation up to 9 years post-spray with glyphosate in Maine. Further research of our study areas is recommended to determine the long term (20 year) impact of glyphosate on browse biomass production after treatment.

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