FIRST YEAR EFFECTS ON MOOSE BROWSE FROM TWO SILVICULTURAL APPLICATIONS OF GLYPHOSATE IN ONTARIO

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ABSTRACT: Aerial application of glyphosate at 1.07 kg/ha on a conifer plantation released planted trees satisfactorily while reducing browse stems available to moose (*Alces alces*) by only 5-41%. Loss of biomass for 8 major browse species (90% of stems browsed) amounted to 96 kg/ha. Browsed stems/ha decreased from 15-82% on 5 of 6 sprayed strata, and increased by 130-3200 % in 5 of 6 control strata, BUT variability rendered differences insignificant. On a second study area, ground application of glyphosate at 2.7 kg/ha as pre-planting site preparation reduced available browse by 63-92%, resulting in a loss of 145 kg/ha (for 90% of the browsed stems). Apparently, some silvicultural objectives can be achieved while retaining substantial densities of browse plants for at least the first year, but other silvicultural applications may reduce browse availability more seriously.

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One of the newer chemicals for control of hardwood competition in silvicultural applications is N-(phosphonomethyl) glycine or glyphosate. This chemical has shown promise of being an excellent herbicide for such silvicultural applications as releasing conifer plantations and for pre-planting site preparation. Glyphosate was first available for experiment in 1971 (Kennedy 1986). It was registered for use in the United States in 1974, and registered under the Canada Pest Control Act in February 1976 (Sutton 1978). Kennedy (1986) reviewed current knowledge of glyphosate. The chemical is a systemic herbicide taken up by the leaves. It slowly depresses photosynthesis and nutrient transport, and this property allows it to be transported to all parts of the plant. Thus, although it is not taken up by the roots, it is transported by them, killing all shoots of a treated root system. It does not control herbaceous plants well because it becomes ineffective on contact with soil. Annual seeds will germinate the next year. Grass is controlled for about 1 year. Weather conditions may alter the effectiveness of spray programs. Maximum effectiveness occurs at air temperatures of 18-20° C, when relative humidity is high, and when transpiration is active. Effectiveness is reduced by rainfall soon after application. Early onset of dormancy during a dry summer may also render glyphosate ineffective. The chemical has a threshold effect, tending to be either fully effective or nearly ineffective.

Glyphosate appears to have few direct effects on mammals. The acute oral LD50 for rats is 4.3 g/kg, compared with 0.3 to 1.0 g/kg for 2,4-D, and is less than table salt and about half that of aspirin. It is only slightly irritating to the eyes of rabbits (Atkinson 1985). Atkinson (1985) concludes that both the short term and long term effects would seem to be outside those encountered by animals on normal diets, at permitted maximum residue tolerances, i. e. at about 1.5 kg/ha. Sullivan and Sullivan (1979) fed glyphosate treated food to black-tailed deer (*Odocoileus hemionus columbianus*) and found no adverse physiological effects or aversion from the taste. The deer actually ate slightly more of the treated foods. On the other hand, Sutton (1978) found that glyphosate quickly killed *Populus tremuloides*, *Betula papyrifera*, *Corylus cornuta* and *Acer spicatum*, and all these species are important moose foods (Cumming 1987). Thus the most likely possible of effect on moose would be indirect - through changes in the habitat.

Habitat is only one factor affecting moose. Under most circumstances, important immediate agents controlling moose populations are likely to be direct mortality factors, such as hunting and predation. However, habitat determines the long-term potential for any given area. Lautenschlager (1986) concluded from a literature review that among all the species of mammals and birds examined, successful conifer release would likely reduce moose populations the most. Therefore, as use of glyphosate has increased in frequency and scope, a question regarding integration of moose management with management of the forest for wood products has grown in importance: what effect would widespread use of this herbicide have on moose range, moose behaviour, and ultimately on moose populations? Due to the variety of forest types across the moose range, and the wide variety of plant responses possible when the herbicide is used under field conditions, this question cannot be answered by a single study. The only possible approach is to examine in the field the effects of glyphosate spraying under specified operational conditions until enough studies are completed to permit some generalizations.

A few studies have begun to address the question of effects on moose. Kennedy (1986) in northeastern Minnesota found browse biomass reduced to 1/4 that on control areas 4 years after spraying. Connor and McMillan (1988) found a similar reduction 21 months after spraying in a boreal mixed wood area of north-central Ontario . Further, they found the amount of browse eaten reduced to 1/12 that on unsprayed controls. Moose presence, estimated from pellet group counts, was only 1/3, and track incidence was significantly less. Hjeljord and Gronvold (1988) found more use of controls than treated areas in Norway.

This study attempts to further increase knowledge of the effects of glyphosate on moose browse and moose feeding behaviour by answering 2 specific questions: (1) What effect has glyphosate on the availability and use of browse by moose during the year following treatment, when the chemical is used for release of a plantation on a jackpine sand flat? (2) What effect has glyphosate during the year following treatment, when it is used for site preparation on a rich upland site?

STUDY AREAS

Study areas were chosen, with assistance from forestry staffs of the Ontario Ministry of Natural Resources (OMNR) administrative districts of Nipigon and Thunder Bay, on the basis of areas scheduled to be sprayed during August 1986.

Obonga Lake

On a jackpine (*Pinus banksiana*) sand flat in Nipigon District, glyphosate was scheduled to be used to release a 5-year old conifer plantation near Obonga Lake, 185 km due north of Thunder Bay (Fig. 1). On the study area located there, gently to steeply sloping sandy loam ridges were interspersed with some rock outcroppings and some flat boggy sections (Table 1). These sand flats supported mainly jackpine prior to cutting. The area was cut in 1980-81 and replanted the following year. Scattered, tall hardwoods, mainly *Populus tremuloides* and *Betula papyrifera*, over-topped thick hardwood regeneration up to 4 m high, that in turn considerably exceeded the height of the planted jackpine. The treated areas were sprayed from the air during August, 1986, with 1.07kg/ha of glyphosate (Table 2).

Fort William Crown Management Unit

On a rich upland site 50 km west of Thunder Bay in the Fort William Crown Management Unit (FWCMU) (Fig.1), competition from hardwoods had almost halted regeneration efforts . Here glyphosate was scheduled to be used as a pre-planting treatment . The topography was flat or rolling, and the soil was clay loam (Table 1). The areas chosen for study were cut during the winter of 1984-85. No treatment had been applied prior to the initial survey of this study. Subsequently, the treated areas were scarified in June and sprayed with glyphosate during Au-

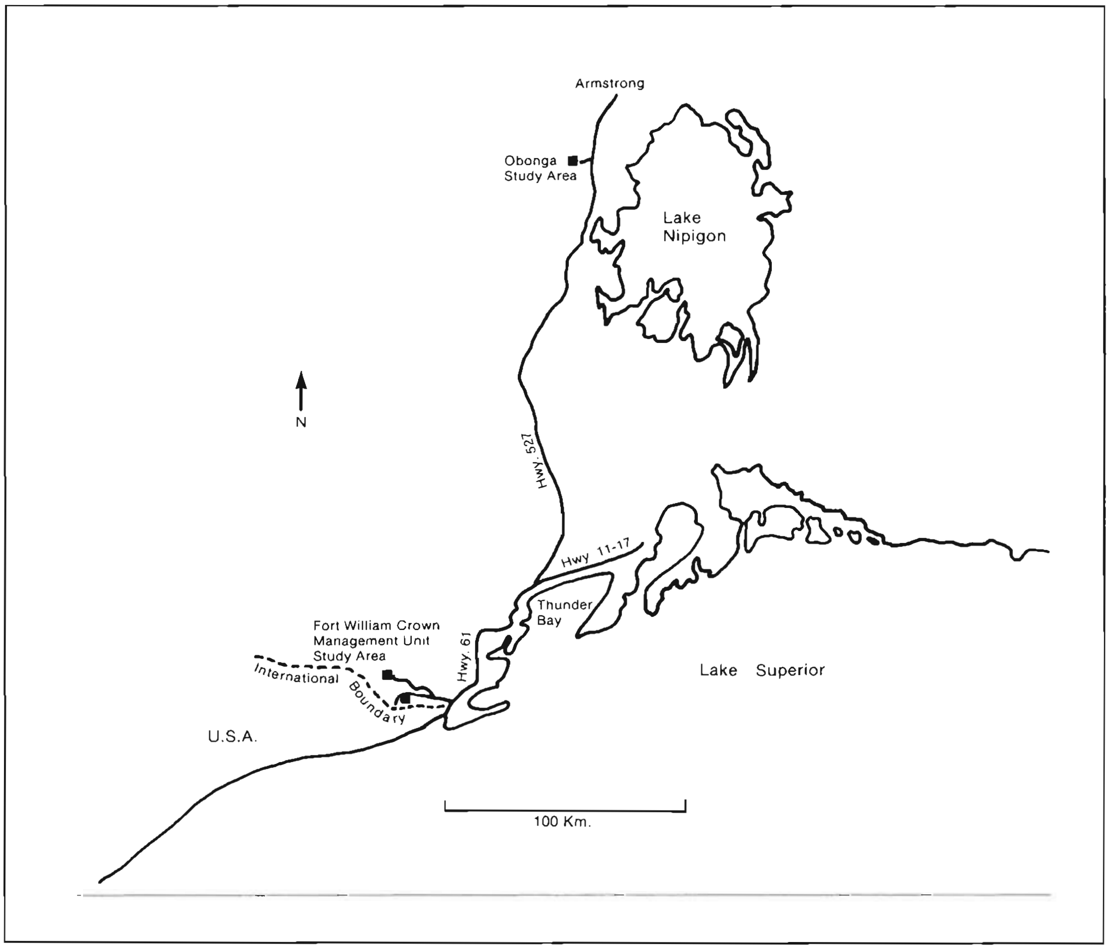

Fig. 1. Location of the study areas in northwestern Ontario.

gust, 1986, at the rate of 2.7 kg/ha. One area of 3 ha was resprayed (Table 2). All applications in this study area were from the ground using the Thunder Bay District sprayer with a cluster nozzle for a broadcast effect.

METHODS

Field Methods

During May and June, of 1986 (before treatment) and 1987 (9, 10 months after treatment), browse surveys were carried out using methods similar to those described by Cumming (1987). In both study areas measurements were made on treatment and control blocks before and after treatments were applied. Plots were located by establishing a baseline along one side of the cut area and choosing, from a table of random numbers, starting points along this baseline. Plots were then located systematically along these transect lines. The plot size was 1 x 20 m with 20 m between plot centers (Table 2). On each plot the numbers of browsed and unbrowsed stems of each species were tallied. On every fifth plot the number of browsed and unbrowsed twigs (>2.5 cm) on each stem was counted to provide estimates of biomass. Stems were recorded as alive only when they would not break off cleanly, and the cambium remained green; otherwise, they were recorded as dead. For each plot, basal area of nearby residual timber was determined using a 2 x2 basal area factor prism (total basal area equals number of trees counted times the prism factor) for a sweep from each end of the long axis. Soil pits were dug at each location

Table 1. Description of survey sites by block.

			Topography		Basal	
Block	Stratum	Year of cut	Relief	Aspect	Area (m^2)	Soil
Obonga Lake						
1	Treatment	1980-81	Gentle slope, steep slope in SE corner	West E. in SE corner	78	Sandy loam
	Control	1980-81	Flat, rocky outcrops in E., steeper to NW	NNW	29	
2	Treatment	1980-81	Gentle slope, 23 m cliffs of rock	SSE to the lake, N in northern section	154	Sandy loam
	Control	1980-81	Flat, boggy sections, E-W ridge	S to SW	73	
3	Treatment	1980-81	Flat, boggy steep slope in S	S	88	Sandy loam
	Control	1980-81	Rolling, bogs and ridges	S	81	
FWCMU						
1	Sprayed, Scarified	1984-85	Rolling, many small hills	N	49 74	Clay loam
	Control	1984-85	U-shaped valley, EW	N	37	
2	Sprayed, Scarified	1984-85	Flat, with deep steep side valleys	None	81 23	Clay loam
	Control	1984-85	Flat	None	20	

and soils described by horizon, texture, and moisture regimes (following Schmidt1986).

Ideally, the interpretation of browse survey data might be elucidated by results of aerial surveys during winter, but funding for such surveys was not available. An alternative was to find some corroboration of browse survey results from pellet group counts. This approach was attempted but numbers of pellet groups on the study areas were too few (30 in 1986 and 43 in 1987) to be useful.

Experimental Design

The study was originally set up with a split-plot design, pairing treated and control areas (Fig. 2). To avoid confusion with the plots on which counts were carried out, I shall refer to these treated or control areas as "blocks". Pre-treatment surveys were carried out on 5 replications of paired treatment/ control blocks in each of the Obonga Lake and FWCMU study areas, but only 3 of the Obonga Lake blocks designated for spraying actually proved useful, and only 2 of the FWCMU blocks were subsequently sprayed by OMNR. The resulting decrease in degrees of freedom over those originally planned created difficulties with the analysis.

Table 2. Dates and details of glyphosate applications and field surveys.

Block	Stratum	Proposed treatment	Actual treatment	Area surveyed	Dates surveyed	Sampling intensity
Obonga Lake						
1	Treatment	1.07 kg./ha glyphosate, aerially applied, Aug 86.	As proposed	20	86/06/12 87/05/12, 15	transect lines - 80m apart 20m between plots
	Control	None		19	86/06/13 87/05/13	transect lines - 80m apart 20m between plots
2	Treatment	1.07 kg./ha/ glyphosate, aerially applied, Aug 86.	As proposed	15	86/06/11, 12 87/06/10	transect lines - 80m apart 20m between plots
	Control	None		27	86/06/11, 12 87/05/20	transect lines - 80m apart 20m between plots
3	Treatment	1.07 kg./ha/ hlyphosate, aerially applied, Aug 86.	As proposed	41	86/06/24 87/05/1, 15, 19	transect lines - 80m apart 20m between plots
	Control	None		29	86/05/19, 26 87/05/14	transect lines - 80m apart 20m between plots
FWCMU						
1	Sprayed Scarified	Bracke scarification before 86/06/15 Ground application of glyphosate, 2.7 kg/ha. Aug 86. (half of area)	Scarified May 86 Sprayed 86/08/21, 22, 24 7.5 litres per hectare Uniform, except on steeper hills. Re-spray of 3 ha due to early rain after first application.	10	86/05/19, 26 87/05/22, 28	transect lines - 40m apart 20m between plots
	Control	None		10	86/5/28 87/6/24	transect lines - 40m apart 20 m between plots
2	Sprayed Scarified	Scarily w/Young's Teeth spring 1986. Ground appl. of glyphosate, 2.7 kg/ha., 15 Aug-1 Sept. 1986. (half of area)	Scarified. May 86. Sprayed 86/08/28, 31, 86/09/03 Uniform spray at 7.3 litres per hectare.	20	86/5/22, 23 87/5/25, 27	transect ines - 40m apart 60m between plots
	Control	None		15	86/5/29 87/6/23	transect lines - 40m apart 60m between plots

In each study area, data gathering began with pre-spray surveys. At Obonga Lake each treatment block was paired with one control block as close to it and as similar as possible. At the FWCMU study area, the discovery that scarification would be carried out before the spraying, led to an additional control block for every treatment block. This was accomplished by sub-dividing each scarified area into approximate halves, and arranging with OMNR spray control people to spray only one half. Thus, each treated block was compared with 2 control blocks: 1 that was scarified but not sprayed, and one that was not treated in any way (Fig. 2).

Since several studies have shown that moose use portions of clear-cuts differently according to the proximity of uncut trees (Hamilton and Drysdale 1975, McNicol and Gilbert 1980, Todesco *et al.* 1985), blocks were stratified into influence and open zones according to whether the plots fell < or > 40 m from uncut edges. Residual zones were also defined for trees left standing within the cut areas, but these tall hardwoods of varying densities defied the delimiting of boundaries.

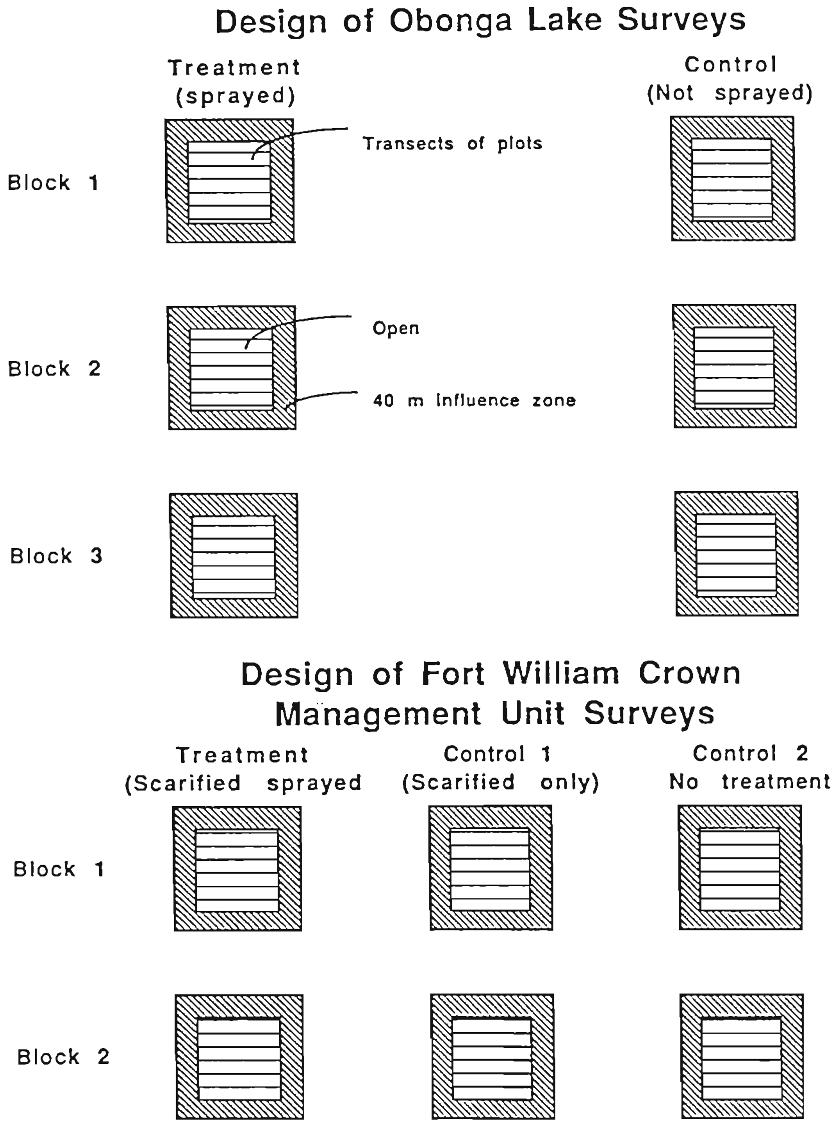

Fig. 2. Split plot design of glyphosate sprayed moose browse as it applied at Obonga Lake and Fort William

Therefore, residual zones were dropped from the analyses.

Analysis

Most analyses were applied to stem counts, the most basic data for determining the effects of spraying. However, a possible error might have resulted from changes in numbers of twigs per stem. Mean numbers of twigs per stem were calculated for 5 major browse species or genera (*Betula papyrifera*, *Populous tremuloides*, *Prunus pensylvanica*, *Salix spp.*, and *Sorbus spp.*) at Obonga Lake. Means did not vary significantly between treated and control areas either before (t= -1.60, d.f. 8, P=0.15) or after (t=0.31, d.f. 8, P=0.76) spraying.

The split plot design, and subsequent partial analyses, involved use of ANOVAS. A Kolmogorov-Smirnov test showed (K-s z = 0.954, P (two-tailed) = 0.323) that residuals were normally distributed, thus the data did not need to be transformed before testing.

An ANOVA showed that the total number of living stems before any treatments varied among the 5 study areas (F=4.762, *P*=0.011). Least significant difference (LSD) tests showed that the differences lay between the Obonga Lake study areas and the FWCMU study areas, rather than within either (Table 3). Because these study areas differed as expected, results from the Obonga Lake study were analysed separately from those for the FWCMU study area.

Available biomass (kg/ha) supplied by 8 major browse species was calculated following Todesco (1988). These species were chosen because formulae were available to estimate twig weights from twig basal diameters (Table 4).

RESULTS

The glyphosate treated blocks at Obonga Lake retained many living stems even after treatment, but these living stems were overtopped by higher dead stems. Apparently, the higher browse plants had sheltered the lower ones from the spray. The tall residual trees may also have provided some shelter from the aerial applied spray. At the FWCMU study area, on the other hand, no such sheltering from high shrubs or tree overstory intercepted the heavier ground applications, so plant mortality was high.

Table 3. Mean differences from a one factor ANOVA of available stems per ha before spraying (1986) for the Obonga Lake and FWCMU study areas.

Comparison	Mean difference
Obonga 1 vs Obonga 2	-998
Obonga 1 vs Obonga 3	858
Obonga 1 vs FWCMU 1	8331*
Obonga 1 vs FWCMU 2	10804*
Obonga 2 vs Obonga 3	1856
Obonga 2 vs FWCMU 1	9328*
Obonga 2 vs FWCMU 2	11802*
Obonga 3 vs FWCMU 1	7472*
Obonga 3 vs FWCMU 2	9945*
FWCMU 1 vs FWCMU 2	2473

*Significant at 95% with LSD test

Table 4. Regression equations of twig weight on twig basal diameter for 8 browse species, determined by Peek *et al.* (1974) and Stronks (1985).

Species	Regression Equation
Acer spicatum	y=0j.210(d)-0.034*
Betula papyrifera	y=e(2.65 In (d)-2.46)
Cornus stolonifera	y=e(2.79 In (d)-3.11)
Corylus cornuta	y=e(2.62 In (d)-2.65)
Populus tremuloides	y=e(2.41 In (d)-2.37)
Prunus pensylvanica	y=e(2.69 In (d)-2.59)
Salix spp.	y=e(2.86 In (d)-2.97)
Sorbus americana	y=e(2.44 In (d)-2.97)

*Peek *et al.* 1974

Obonga Lake Surveys

Stem Counts

Comparisons between 1986 and 1987 surveys at Obonga Lake showed decreases in total stems per hectare following spraying ranging from 4-46% (Table 5). Similar decreases in densities of stems (up to 45%) were found among some of the control areas; however, in 3 of the 6 control comparisons, increases were recorded. An ANOVA for data from Obonga Lake in 1986 making use of the split plot design showed no significant differences (*P*>0.05) among strata, blocks or treatments, but more degrees of freedom might have shown significance. Similarly, an ANOVA for 1987 showed no significant differences. A test of covariance to make use of the fact that data were gathered before and after treatment also failed to show any significant differences. Since neither blocks nor strata showed significant differences in these tests, I combined them for tests of all counts on the basis of treatments alone. An ANOVA for 1986 showed that areas designated for

Table 5. Available stems per hectare before aerial application of glyphosate (1986) and afterward (1987) at the Obonga Lake study area.

Block	Stratum	Living stems /ha (x1000) 1986	1987	Percent difference
		TREATMENT		
1	Influence	24	23	-4
	Open	24	14	-42
2	Influence	26	16	-38
	Open	25	19	-24
3	Influence	13	7	-46
	Open	18	15	-17
		CONTROL		
1	Influence	14	13	-7
	Open	5	12	140
2	Influence	14	8	-43
	Open	12	9	-25
3	Influence	17	21	24
	Open	16	17	6

treatment with glyphosate differed significantly from the areas that were not to be treated. Nearly double the number of stems per hectare was found on the treated blocks (treatment mean 21,550 stems/ha, control mean 13,186; F=9.196, P=0.039). In contrast, an ANOVA for 1987 after spraying showed no significant differences for treatment versus controls (treatment mean 15,770, control mean 13,379; F=1.45, P=0.295). Therefore these tests suggest that the spray reduced the numbers of stems on the areas designated for treatment from significantly higher densities to densities comparable with areas that were not sprayed.

Another approach was to assess relative change. Block differences having been proved insignificant were ignored in calculating an ANOVA of differences between counts for 1986 and 1987 taking into account zones and treatments. This calculation showed no significant difference for strata (F=0.19, P=0.683) or treatment by strata (F=0.42, P=0.551) but fairly strong evidence that the treatments had an effect (F=5.84, P=0.073).

Changes in browsing

The percentage of stems browsed on treated blocks at the Obonga Lake study area decreased from 13 to 11%, while the percentage on control blocks increased from 4 to 7%. Similarly, the actual numbers of stems browsed by moose showed substantial reductions after spraying in all but one of the treated areas; whereas, on the control areas they showed substantial increases (Table 6). Despite the large apparent differences, an ANOVA of these figures taking into account the split plot design again showed no significant differences among blocks, strata or treatments. However, a one-Factor ANOVA of the numbers of stems browsed before and after treatment showed nearly significant dif-

Table 6. Effect of glyphosate application on numbers of stems browsed by moose during the first winter after application at the Obonga Lake study area.

Block	Stratum	Browsed stems /ha (x100) 1986	1987	Percent difference
		TREATMENT		
1	Influence	33	28	-15
	Open	34	6	-82
2	Influence	18	25	39
	Open	21	13	-38
3	Influence	10	2.5	-75
	Open	40	33	-18
		CONTROL		
1	Influence	2.5	11	340
	Open	0.4	13	3200
2	Influence	2.6	6	130
	Open	1	3	200
3	Influence	7.7	0	-100
	Open	10	10	0

ferences (treatment mean -31, control mean +626, F=4.286, *P*=0.065), suggesting that additional degrees of freedom might have revealed significance.

A regression of browsed stems/plot on available stems/plot (data screened for abnormal values) showed a weak relationship (r=0.62, r^2=0.39), but the variations in these data were proportional to the number of stems available. Using dummy variables to partition the intercept and slope into components due to sprayed area and unsprayed area (Weisberg 1980) no differences could be found. A similar analysis comparing changes between years also showed no differences. Comparing treated and control areas, no differences were found between slopes or intercepts, but a joint difference was discovered (F=6.154, d. f. 2, 20, *P*<0.01). The effect of the non-constant variance was best reduced by a log-log transformation, but coefficients were only slightly improved (r=0.63, r^2=0.40). The low correlation values were at least partly the result of 1 stratum with no browsing. But for that zero value, the corelation would have been more impressive (about r=0.78, r^2=0.61).

Biomass calculations

One of the 8 species chosen for biomass calculations was not browsed by moose during this study, but the other 7 species constituted 90.3% of the stems browsed on Obonga Lake treatment areas before treatment. Biomass loss from glyphosate treatment amounted to only 21 kg/ha (Table 7) for these species. However, biomass gain on the control areas amounted to 75 kg/ha. Therefore, the loss of biomass due to spraying approximated the total of these two figures, 96 kg/ha.

Differential effects on plant species

Response of plants to treatment varied among species (Table 8). Glyphosate did not affect species in order of abundance (Kendall Coorelation Coefficient Tau=0.06), nor in the order that the species were eaten by moose (Tau=0.16). As was the intention of the release treatment, coniferous species other than *Abies balsamea*, which is not much sought after in northern Ontario, showed additional growth following treatment that brought more stems into our counts. As a result the application was considered to have met forestry objectives satisfactorily (Wachsmuth, pers. comm.).

Table 7. Available stems per hectare before aerial application of glyphosate (1986) and afterward (1987) at the Obonga Lake study area.

Replication	Stratum	Total biomass available (kg/ha) 1986	1987	Biomass difference (kg/ha)
		TREATMENT		
1	Influence	219	138	--81
	Open	197	138	-59
2	Influence	94	175	82
	Open	145	196	51
3	Influence	182	73	-109
	Open	146	142	-21
		CONTROL		
1	Influence	214	78	-136
	Open	96	224	128
2	Influence	188	97	-92
	Open	147	171	25
3	Influence	62	458	396
	Open	81	212	132
	Control average	131	207	75

Apart from some rare species and non-moose foods (e.g. *Ledum groenlandicum*), largest decreases between years among the hardwoods on treated areas were sustained by *Corylus cornuta*, *Betula papyrifera*, *Diervilla lonicera*, and *Amelanchier spp*. However, these figures do not take into consideration the possibility that some general factor may have reduced numbers of some species throughout the area (e.g. as a result of competition). Some of these possibilities are elimi-

Table 8. Changes in numbers of living stems and browsed stems per hectare by species as a result of glyphosate application at the Obonga Lake study area (listed in order of use on the treatment area before treatment).

Species	Density available before treatment		Percentage change from before treatment to 1 yr. after treatment		Change difference % treated - % control	Browsed stems/ha before treatment		Percentage change from before treatment to 1 year after treatment		Change difference % treated - % control
	Treatment	Control	Treatment	Control		Treatment	Control	Treatment	Control	
*Corylus cornuta**	3507	67	-24	27	-51	1106	0	-59	0	-59
*Populus tremuloides**	3020	2851	-27	-27	0	440	111	-53	31	-84
*Betula papyrifera**	1377	1132	-57	42	-99	302	36	-50	572	-622
*Prunus pensylvanica**	1335	1210	-35	-17	-18	260	135	-59	-44	-15
*Salix spp.**	979	776	-54	-37	-17	203	41	-89	59	-148
*Sorbus spp.**	315	419	92	49	43	166	41	54	439	-385
*Acer spicatum**	4192	1205	-7	-8	1	145	2	140	2850	-2710
Alnus crispa	1276	1661	-52	-8	-44	127	23	-41	352	-393
Abies balsamea	101	18	-5	-61	56	65	15	-72	-100	28
Amelanchier spp.	697	174	-64	13	-77	34	10	-77	130	-207
Pinus banksiana	1117	1888	72	9	63	31	2	-52	650	-702
Prunus virginiana	85	2	19	-2	21	18	0	-100	0	0
Alnus rugosa	135	195	35	-52	87	7	15	-100	-100	0
*Cornus stolonifera**	13	13	154	77	77	0	0	0	0	0
Diervilla lonicera	513	39	-99	-87	-12	0	0	0	0	0
Fraxinus nigra	2	0	-100	-	-	0	0	0	0	0
Ledum groenlandicum	125	132	-100	-90	-10	0	0	0	0	0
Lonicera canadensis	0	0	0	0	0	0	0	0	0	0
Lonicera dioica	10	2	-80	-100	20	0	0	0	0	0
Picea glauca	0	0	0	0	0	0	0	0	0	0
Picea mariana	96	187	30	7	23	0	0	0	0	0
Rhamnus alnifolia	7	0	-100	0	0	0	0	0	0	0
Ribes spp.	299	85	-59	-48	-11	0	0	0	0	0
Rosa spp.	283	195	-29	8	-37	0	0	0	0	0
Rubus spp.	2122	1731	-57	-22	-35	0	0	0	0	0
Vaccinium myrtilloide.	49	0	-100	0	0	0	0	0	0	0
Vibernum edule	361	145	-42	-23	-19	0	0	0	0	0

*Major browse species (Table 4).

nated by examining differences between treated and control blocks. *Betula papyrifera*, *Amelanchier spp.*, and *Corylus cornuta* showed the greatest decreases. On the other hand, some favoured moose foods decreased very little as a result of the herbicide (e.g. *Abies balsamea* and *Acer spicatum*) and some species actually increased in numbers (e.g. *Cornus stolonifera* and *Prunus virginiana*). In fact, glyphosate reduced less important browse species by 34%, but the 7 major browse species by only 23% (x^2=48.8, P=0.0001). The effect of glyphosate on species, such as *Salix* spp., remained unclear since numbers of stems decreased in both sprayed and unsprayed areas.

Fort William Crown Management Unit Surveys

Densities of stems in the more recently cut FWCMU blocks were noticeably lower than at Obonga Lake. Spraying reduced these densities by 63-92% (Table 9). Although both the scarified control and the untreated control showed lower densities of stems in 1 of 4 blocks, both showed gains between years for the other 3, as much as 60% in one instance (Table 9). An ANOVA arranged to account for the split plot design showed no significant differences in densities of stems among the components for the 1986 pre-treatment figures; however a similar ANOVA for the 1987 data following spraying showed a high F-value (F=13.5, P=0.069) approaching a significant difference for treatments. A test of the percent differences between years showed a significant difference for application (F=22.8, P=0.04). Results of this application were also considered satisfactory by silvicultural foresters (Kangas, pers. comm.). Browsing was too light on the newly cut FWCMU plots for further analysis (Table 10).

Even though total biomass available at the FWCMU study area (Table 11) was lower than at Obonga Lake (47-150 kg/ha), the loss of biomass on the sprayed area was greater (average 79 kg/ha). As at Obonga Lake, the control blocks produced more biomass rather than less the second year (66 kg/ha), and even on the scarified area biomass increased (26 kg/ha). Therefore total biomass loss to moose on the treated area as compared with the control was 145 kg/ha.

Table 9. Available stems per hectare before (1986) and after (1987) ground application of glyphosate at the Fort William Crown Mangement Unit study area.

Block	Stratum	Living stems /ha (x100) 1986	1987	Percent difference
		SCARIFIED AND SPRAYED		
1	Influence	85	15	-82
	Open	111	41	-63
2	Influence	39	3	-92
	Open	117	33	-72
		SCARIFIED ONLY		
1	Influence	140	196	40
	Open	131	159	21
2	Influence	92	125	36
	Open	110	71	-35
		CONTROL		
1	Influence	125	180	44
	Open	113	173	53
2	Influence	140	-	-
	Open	136	115	-15

DISCUSSION

All glyphosate treatments reduced availability of browse plants during the first year after application, but the extent of the reduction varied with site and application rate. The Obonga Lake studies showed less reduction of available browse than the literature on controlled experiments (e.g. Sutton 1978) would lead one to expect. The difficulty in finding significant differences between treated and untreated areas might have been viewed as evidence that reduction of browse was really quite minimal if pre-treat-

Table 10. Total stems browsed per hectare before and after ground application of glyphosate at Fort William Crown Unit study area.

Block	Stratum	Browsed stems Per Ha. 1986	1987	Percent difference
		SCARIFIED AND SPRAYED		
1	Influence	292	750	157
	Open	150	48	-68
2	Influence	0	0	-
	Open	29	8	-72
		SCARIFIED ONLY		
1	Influence	200	0	-100
	Open	13	58	346
2	Influence	100	250	150
	Open	61	48	-21
		CONTROL		
1	Influence	500	400	-20
	Open	154	93	-40
2	Influence	467	0-	-
	Open	30	47	57

Table 11. Difference in biomass available to moose from 8 major browse species (Table 3) at the FWCMU study area following ground application of glyphosate.

Block	Stratum	Biomass available (kg/ha) 1986	1987	Biomass difference
		SCARIFIED AND SPRAYED		
1	Influence	150	16	-134
	Open	68	7	-41
2	Open	68	7	-61
Treatmennt average		89	10	-79
		SCARIFIED NOT SPRAYED		
1	Influence	62	148	86
	Open	36	84	48
2	Open	73	17	-56
Scarified average		57	83	26
		CONTROL		
1	Influence	39	208	169
	Open	60	137	77
2	Open	81	35	-46
Control average		60	127	66

ment surveys had not revealed unsuspected initial differences. Possible reasons for the reduced plant mortality due to the aerial application of glyphosate at Obonga Lake include the relatively low application rate, interception of spray by the overstory, and shielding of low bushes by higher ones.

Since both spray programs met silvicultural objectives, the differences between them gave some indication of the kind of variation to be expected in practice. Stem densities on areas that the foresters chose for tending were reduced to about the levels of nearby areas that they had decided were not in need of treatment, exactly as planned. These results indicate that, in at least some instances, silvicultural objectives can be achieved while still retaining substantial densities of browse plants. On the other hand, the pre-treatment ground spraying on the FWCMU study area substantially reduced available browse, leaving little food for moose. If the ground application had not missed some areas, the reduction might have been even greater.

Sullivan (1985) suggested that dying twigs during the first year would not influence browsing behaviour of black-tailed deer (*Odocoileus hemionus columbianus*). In apparent support of this idea, Connor and McMillan(1988) found similar biomass densities on treated and control areas at 9 months post spray. At the Obonga Lake study area, stem densities were also similar on treated and control areas, but since they were greater on the sprayed areas before treatment, the total effect was a reduction in stem densities, and apparently also biomass, during the first year. A reduction was even more evident at the FWCMA study area. Furthermore, it was not entirely clear that there were no reductions in browsing at Obonga Lake, as Sullivan (1985) predicted. Perhaps climatic conditions resulted in the chemical working exceptionally quickly in 1986.

The possible changes in browsing may accord with optimal foraging theory (Pyke, *et al.* 1977). Moose should browse most where stems are densest. The density of stems on the treated blocks decreased and the density on the control blocks increased. Perhaps the moose responded by feeding less on the former and more on the latter. The regression analyses tended to support this idea, but more evidence will be required before it can be firmly established. If subsequent research should demonstrate that moose do indeed forage optimally, regardless of whether browse plant densities are determined by natural causes or by glyphosate application, it may become possible to predict the effects of spraying on moose behaviour much more accurately than we can at present.

Estimates of biomass on control blocks and treatment blocks after spraying at the Obonga Lake study area, as calculated for 90% of the browsing represented by 8 major browse species, were similar to those reported by Kennedy and Jordan (1985), but lower than figures for mixed uplands reported by Todesco (1988). Biomass on the FWCMU study area was much lower that at Obonga Lake, even though the site was richer, presumably, because the area had been cut only the previous year. At the FWCMU study area, biomass estimates on control areas and treated areas after spraying, were near those reported by Connor and McMillan (1988).

What do observed biomass reductions mean for moose populations? Current knowledge does not permit concise answers for such question of this paper, only a few intimations. Returning to the initial question of this paper, one might ask, what would be the effect if all the range were treated this way? Wolff (1980) considered that habitats producing <20 kg/ha were below optimum quality. Strandgaard (1982) placed high quality moose habitats between 100-150 kg/ha. By these criteria the Obonga Lake blocks all remained high quality moose habitat, even after glyphosate application, but the FWCMU treated blocks were reduced from moderately good to below optimum by the chemical treatment. Data reported by Schwartz, Hubbert, *et al.* (1988) suggest that an average (400 kg) moose will eat about 6 kg gross mixed browse per day. Thus, biomass losses reported here would represent losses of 16-24 moose days/ha. Schwartz, Reglin, *et al.* (1988) suggested that reducing diet to half the maintenance requirement, would result in loss of about 2 kg/day body weight, a loss that can be sustained for only 60 days, if maximum over-winter weight loss approximates 30%. Losses in this study averaged 13% for Obonga Lake and 89% for FWCMU. Thus, if all range were treated like the Obonga Lake blocks effects on moose might be minimal, but if all were treated like the FWCMU blocks, effects on moose could be more important.

These considerations assume total treatment of moose range. If treatment areas remained few and small, at the lower limit they would not measurably reduce the ability of the area to produce moose. Treatment of the entire area might be of concern. The effect in any one area, then, will probably be determined by a combination of such factors as application rates and the percentage of the area treated. With a proper rotation of well interspersed spray areas, production of browse from the area might be maintained; indeed, the duration of optimal browse production within the span of a forest rotation might be substantially elongated.

The varying effects of glyphosate on different plant species suggest that the overall impact of glyphosate treatment may not be directly related to total biomass reduction. If the lesser effect of glyphosate on major browse species found in this study proves to be true generally, the impacts on moose will be less than the overall reduction of biomass would suggest.

There might even be room for vegetation manipulation to qualitatively improve available browse as suggested by Sullivan (1985). This possibility should be followed up in future research.

This study only attempted to find the effects of glyphosate during the first year after spraying. These short term results might be misleading if projected over a span of years. Surveys during May of plants that were sprayed the previous August might have led to mis-classifying stems, calling some alive that were actually dying, and thus underestimating the impact on moose. The likelihood of such error was supported by the finding of Connor and McMillan(1988) that available browse decreased in subsequent years. Furthermore, a 2-year study such as this could not take into account factors such as possible increased rapidity with which released conifers might shade out the browse species. On the other hand, the first year data may have over- estimated the impact of glyphosate spraying on moose for longer periods. Newton, *et al.* (1989) found that available browse actually increased subsequent to the first year due to re-sprouting, and they suggested that the plants grown in more open sunlight would be nutritionally superior. They also maintained that the taller browse plants had been growing beyond the reach of moose and shading out the lower browse, so that moose actually benefited from their removal. That suggestion may have validity for the Obonga Lake study area. Only long term studies can answer such long term questions.

MANAGEMENT IMPLICATIONS

The results of these studies show that glyphosate used for silvicultural purposes need not completely remove moose browse from treated areas. The aim of glyphosate spraying in silvicultural applications is usually to prevent hardwood species from outcompeting planted conifers. This aim can be met without killing all hardwood browse. Foresters are already adjusting application rates to the requirements of individual competition problems. With further experience in the use of glyphosate, fine-tuning should provide more predictable results, so that only enough hardwood shrubs are killed to effect the necessary release, while, in many cases, leaving substantial browse biomass available for moose. Thus glyphosate carried out in a multiple use context may accomplish the goals of both timber and moose management.

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