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EFFECTS OF GLYPHOSATE ON WINTER HABITAT OF MOOSE IN MAINE

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Glyphosate applied at 1.65 kg/ha decreases deciduous browse availability 60-70% for moose by the second winter after treatment.

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This initial reduction in deciduous browse density has potential negative effects on food intake rates of moose and, therefore, may reduce the value of regenerating clearcuts for moose during this period.

Glyphosate has little effect on browse availability at 7-11 years after treatment.

Browse Quality In Winter

The nutritional quality of glyphosate-injured browse is slightly different than untreated browse, but effects vary among browse species and are unlikely to influence moose nutrition. Smaller twig size may reduce use of some injured browse.

Glyphosate does not affect the proportion of relatively high quality winter browse in the first two years after treatment.

High quality browse was more abundant on treated clearcuts at 7-11 years after treatment than untreated clearcuts, but this effect may not consistently occur because it is dependent on browse species composition.

Browse Utilization And Diet Quality

Moose appear to eat less total browse on glyphosate-treated clearcuts at two years after treatment than untreated clearcuts, but the proportion of available browse eaten is not affected.

Moose eat a high proportion of deciduous browse on older (years 7-11) treated sites and appear to prefer these sites despite no difference in available browse and diet quality between treated and untreated clearcuts.

Glyphosate treatment does not affect the nutritional quality (digestible energy and protein content) of moose diets.

Winter Cover

Glyphosate appears to improve winter cover for bedding by 7-11 years after treatment compared to untreated clearcuts.

Winter Habitat Use

Glyphosate reduces winter foraging activity of moose in clearcuts 1-2 years after treatment and appears to be the result of decreased browse availability.

Glyphosate increases foraging and bedding activity at 7-11 years after treatment and appears to be the result of more abundant winter cover.

SUMMARY

We studied short-term and long-term effects of aerial treatment of clearcuts with the herbicide glyphosate on moose *(Alces aloes)* habitat and activity in winter. For short-term (1-2 years posttreat-ment) studies, we measured browse availability, use and nutritional quality, winter cover, and moose activity on six treated and six untreated clearcuts. For long-term studies (7-11 years posttreatment), we sampled 14 clearcuts that had been treated 7-11 years earlier and five similarly aged untreated clearcuts.

In years 1-2 posttreatment, deciduous browse was less abundant (70% in year 2) on treated than untreated clearcuts. There was evidence that red maple *(Acer rubrum)* and paper birch *(Betula papyrifera),* two species consistently used by moose on these sites, decreased less than pin cherry *(Prunus pensylvanica)* and possibly aspen *(Populus* spp.). Glyphosate had little effect on the nutritional quality of browse available to moose and did not affect the quality of moose diets. The percentage of available browse eaten by moose was not affected by treatment, but counts of tracks of foraging moose were less on treated clearcuts.

At 7-11 years posttreatment, treated clearcuts and similarly aged untreated clearcuts had similar amounts of deciduous browse. Treated clearcuts had more browse with a relatively high digestible energy content; however, glyphosate treatment did not effect the nutritional quality of moose diets on these clearcuts. In contrast to effects observed in years 1-2, percentage use of deciduous browse, track counts of foraging moose, and counts of moose beds were greater on treated than untreated clearcuts.

We concluded that the reduction in moose activity 1-2 years after treatment was the result of less deciduous browse because we found little evidence for changes in browse or diet quality. Moose appeared to prefer treated clearcuts 7-11 years after treatment because the dense conifer cover allowed foraging and bedding on the same site. We discuss management options for minimizing effects of glyphosate treatment on moose habitat.

INTRODUCTION

The herbicide glyphosate is widely used for managing forest vegetation in northern coniferous forests of the U. S. and Canada (Campbell 1990; McCormack 1994). In Maine, 13,000-35,000 ha of forestland were treated annually from 1987 to 1992 (McCormack 1994) with an estimated 80% by aerial application of glyphosate (M. L. McCormack Jr., pers. comm.). Glyphosate is used on young plantations or naturally regenerating clearcut sites to promote production of conifer trees. After planting or clearcut harvesting, rapidly growing deciduous trees and shrubs shade and suppress growth of regenerating conifer crop trees (Newton et al. 1992a). Glyphosate reduces competition from deciduous cover and allows increased growth of conifers (Newton et al. 1992b). Toxic effects of glyphosate on wildlife are minimal (Atkinson 1984), but effects on habitat can be important.

Moose prefer to feed in young regenerating clearcuts in winter because deciduous browse is abundant on these sites (Peek et al. 1976; Telfer 1978; Monthey 1984). For at least two to three years after treatment, glyphosate reduces the total amount of deciduous browse in clearcuts (Connor and McMillan 1988; Gumming 1989; Newton et al. 1989), and there are concerns that the remaining browse may be lower in nutritional quality. However, the denser conifer growth on treated sites may provide better thermal cover for moose in winter. Plant species composition and structure change rapidly in young clearcuts, whether treated or untreated. Therefore, the relative effects (treated vs untreated) of glyphosate on moose habitat may depend on clearcut age. For example, Newton et al. (1989) found that clearcuts treated with some herbicides contained more available browse than untreated sites at 9 years after treatment because crowns of deciduous saplings on untreated sites had grown out of reach (>2.5 m) of moose. These authors proposed that herbicide use could improve foraging conditions for moose by extending the period of browse availability after timber harvest.

While use of glyphosate for vegetation management on clearcuts has several potential negative or positive effects on moose habitat, it is not clear whether these effects are significant enough to affect moose nutrition or behavior. The objectives of this study were to determine effects of glyphosate treatment of naturally regenerating clearcuts on browse availability, browse use, nutritional quality of browse, diet quality of moose, conifer cover, and use of clearcuts by moose during two time periods, 1-2 and 7-11 years after treatment.

Study Area

We conducted the study in northern Somerset and Piscataquis counties, Maine. Forests in the region were managed for timber production and were a mixture of clearcuts, partial harvests, regenerating stands, and older second-growth stands. Forests are classified as spruce *(Picea* spp.) - balsam fir *(Abies balsamea)* - northern hardwoods (Westvald et al. 1956). Abundant tree species on regenerating clearcuts in the region were paper birch, pin cherry, red maple, aspen *(Populus tremuloides* or *P. grandidentata),* red spruce *(Picea rubens),* and balsam fir. White pine *(Pinus strobus),* northern white cedar *(Thuja occidentalism,* striped maple *(A. pensylvanicum),* sugar maple (A. *saccharum),* yellow birch (B. *alleghaniensis),* mountain ash *(Sorbus* *americana),* and willow *(Salix* spp.) also were common. Plant nomenclature follows McMahon et al. (1990). Moose were abundant and the population density was 1.2-1.8/km^2 in the region (unpubl. data, Maine Dept. Inland Fish, and Wildl.).

Study Design

1b study effects of glyphosate at 1-2 years posttreatment, we selected 12 clearcuts that were dominated by deciduous regeneration (1-3 m tall). Clearcuts were 18-89 ha in area, harvested 4.5-8.5 years prior to treatment, had tall (>12 m) conifer or mixed conifer-deciduous forest around at least 75% of their perimeters and were located in the vicinity of Moosehead Lake, Maine. We sampled browse availability and use, conifer cover, and habitat use on all 12 clearcuts between January and March, 1991, the winter prior to glyphosate treatment. Six of these clearcuts were treated in August 1991, and we conducted posttreatment sampling from January to March, 1992 and 1993. We refer to the first and second winters posttreatment as years 1 and 2, respectively. We paired clearcuts according to vegetation, age, and location, to reduce variation between treatment and control clearcuts, and we randomly assigned one clearcut from each pair to receive a single application of glyphosate (1.65 kg acid equivalents/ha). Sites were treated by helicopter by Scott Paper Co. in an operational manner.

We used 19 clearcuts that had been harvested 12-22 years prior to initial sampling (1992) to study effects of glyphosate at 7-11 years posttreatment. Clearcuts were 16-73 ha in area and had tall conifer or mixed conifer-deciduous cover around at least 75% of their perimeters. Fourteen of the 19 clearcuts had received a single aerial application (1.65 kg acid equivalents/ha) of glyphosate 6.5-9.5 years prior to initial sampling (1992). Six clearcuts were located in the Moosehead Lake area, and eight clearcuts were located approximately 40 km northeast in the Telos area. The five other clearcuts, all located in the Moosehead Lake area, had not been treated. Mean age since harvest for these five untreated clearcuts (19 years) was greater than treated clearcuts in Moosehead Lake (16 years) and Telos (14 years) areas. This increased the likelihood that we would observe greater browse availability on treated than untreated sites as reported by Newton et al. (1989) because deciduous trees had longer to grow beyond the reach of moose on untreated sites. We measured browse availability and use and conifer cover a single time on these clearcuts between January and March, 1992 or 1993 and habitat use in both 1992 and 1993. For studies of browse utilization and habitat use, we excluded treated clearcuts from the Telos area because there was evidence that moose density was lower there despite similar vegetative composition and structure, and we did not have untreated sites in that area (Eschholz 1993; Raymond 1994).

BROWSE AVAILABILITY

Several studies have quantified reductions in total browse availability 1-2 years after glyphosate use (Connor and McMillan 1988; Gumming 1989; Newton et al. 1989), but longer-term research is limited to Newton's et al (1989) study at 9 years posttreatment. Effects of glyphosate also varies among deciduous species (Pitt et al. 1992), which may influence the relative availability of high- and low-value browse species for moose. Our objective was to determine effects of glyphosate on the availability of total deciduous browse and important browse species of moose at 1-2 and 7-11 years after treatment.

Methods

We counted live twigs (browsed and unbrowsed) of deciduous browse species on 1x5 m quadrats randomly located on transects distributed systematically on each clearcut. We sampled 24 quadrats per clearcut in 1991 and 40 per clearcut in 1992 and 1993. The 12 younger clearcuts were sampled each year, and the 19 older clearcuts were sampled in either 1992 or 1993. We defined available browse for each year as current-annual-growth (CAG) twigs ^5 cm in length plus previously browsed CAG twigs in a 0.5-3.0 m height stratum (Crete and Jordan 1982). Deciduous browse species included paper birch, pin cherry, aspen, red maple, yellow birch, striped maple, sugar maple, mountain maple, willow, and mountain ash. Available browse biomass (kg/ha) was calculated by multiplying total counts of browsed and unbrowsed twigs by average dry mass of twigs for each species. We determined average twig mass for young clearcuts and dder clearcuts separately, but averaged across treatments because glyphosate did not affect mean twig biomass on sites (K. S. Raymond, unpubl. data). We also estimated available biomass (kg/ha) of balsam fir browse by determining mean dry mass of browse (CAG ^5 cm in a 0.5-3.0 m height strata) on trees in each of four height classes (0.5-1.0, 1.1-2.0, 2.1-3.0, >3.0 m) and multiplying these means by counts of trees in each size class in quadrats. We measured mean browse biomass per tree for 30 to 60 trees per height class equally distributed among treatment groups.

We used analysis of variance (ANOVA) on ranks (Zar 1984) to test effects at 1-2 years for treatment and year using a two-factor repeated-measures ANOVA. Because there was a pretreatment year, a year by treatment interaction was evidence for a treatment effect. We tested effects at 7-11 years posttreatment using a one-factor ANOVA. We used an alpha level of 0.10 to reduce the probability of a type II error (failure to reject the null hypothesis of no effect from glyphosate treatment when it is false).

Results

Years 1-2

Deciduous browse biomass decreased (P < 0.001) on treated clearcuts compared to untreated clearcuts (Figure 1). Deciduous browse biomass on treated clearcuts was 30% (58 kg/ha) less than on untreated clearcuts in year 1 and 70% (96 kg/ha) less in year 2. Paper birch, pin cherry, aspen, and red maple constituted 88%-93% of deciduous browse on untreated clearcuts each year. Yellow birch, striped maple, sugar maple, mountain maple, willow, and mountain ash constituted the remainder of deciduous browse (Raymond 1994). Paper birch, pin cherry, and red maple browse biomass decreased (P < 0.01) 63%-94% from pretreatment to year 2 and was 67%-88% less than on untreated clearcuts at year 2 (Figure 2). Availability of aspen exhibited a similar trend, but was not statistically different (P = 0.103). Balsam fir was not affected (P = 0.23) by treatment (Figure 3). Effects on other species were not clear because of low and variable availability (Raymond 1994).

Years 7-11

Biomass of total deciduous browse, three of four common deciduous browse species (aspen was the exception), and balsam fir did not differ between Moosehead Lake and Telos areas for treated clearcuts (Raymond 1994); therefore, we pooled data from these areas for statistical analyses. Tbtal deciduous browse biomass did not differ (P = 0.29) between treated (44 kg/ha) and untreated (47 kg/ha) clearcuts (Figure 1). Red maple and paper birch were consistently abundant on clearcuts, but biomass did not differ (P = 0.3-0.8) between treated and untreated sites (Figure 4). Biomass of willow and aspen was greater (P = 0.01-0.05) on treated clearcuts and biomass of mountain maple, striped maple, and yellow birch was greater (P = 0.01-0.05) on untreated clearcuts. Balsam fir browse was abundant and two times greater (P = 0.02) on treated (3656 kg/ha) than untreated clearcuts (1690 kg/ha) (Figure 3).

Discussion

Years 1-2

The 70% decrease in deciduous browse biomass we observed in the second winter after treatment with an application rate of 1.65 kg/ha was in the range of values reported in other studies. Connor and McMillan (1988) reported a 77% decrease in available deciduous browse biomass compared to control sites for the second •winter posttreatment with application rates of 1.44 to 1.53 kg/ha, and Gumming (1989) reported 5%-41% and 63%-92% reductions in deciduous stem densities from pretreatment to June of the first year posttreatment for sites receiving glyphoeate at rates of 1.07 and 2.70 kg/ha, respectively. Tbtal deciduous cover on plots studied by Newton et al. (1989) decreased 60% and 73% during the first year after treatment for application rates of 1.65 and 3.3 kg/ha, respectively. The reductions measured by Conner and McMillan (1988) and Gumming (1989) were not statistically different because of small sample sizes, and Newton et al.

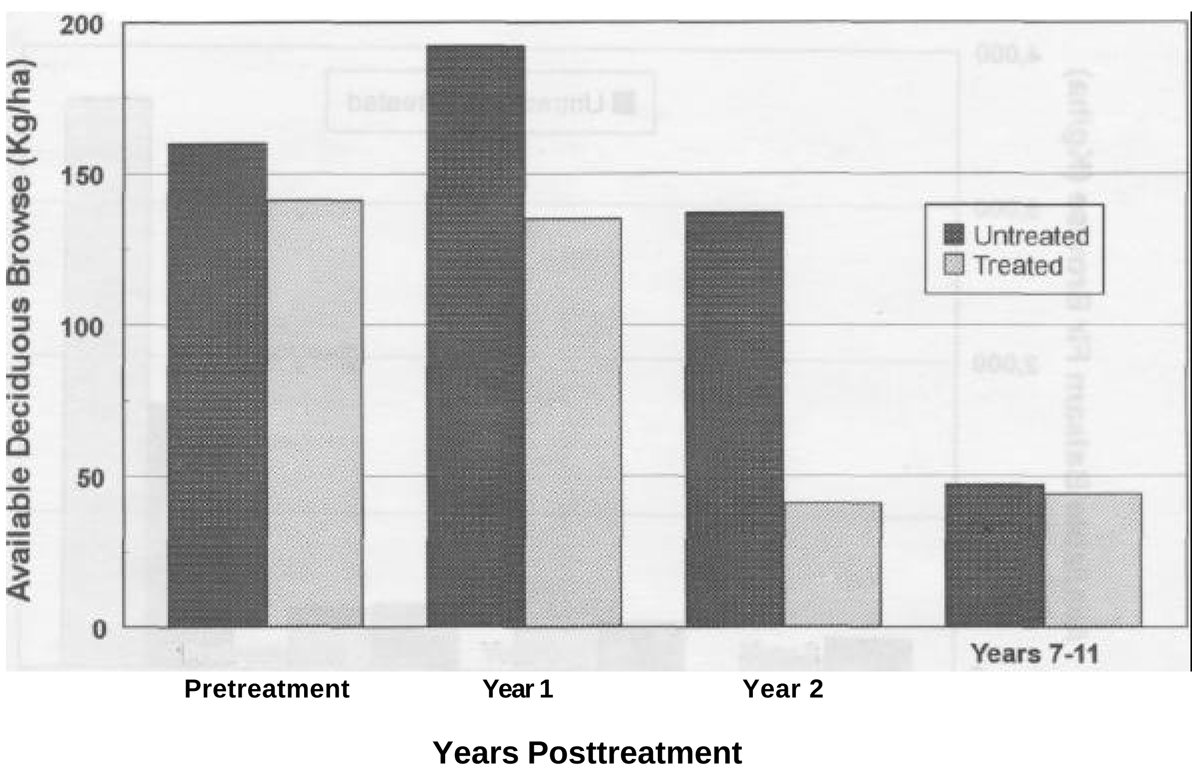

Figure 1. Availability of deciduous browse in glyphosate-treated and untreated clearcuts from pretreatment to year 2 and at 7-11 years posttreatment in Maine, January-March, 1991-93. Clearcuts used to study 1-2 year effects were treated in August after pretreatment sampling between January and March, 1991.

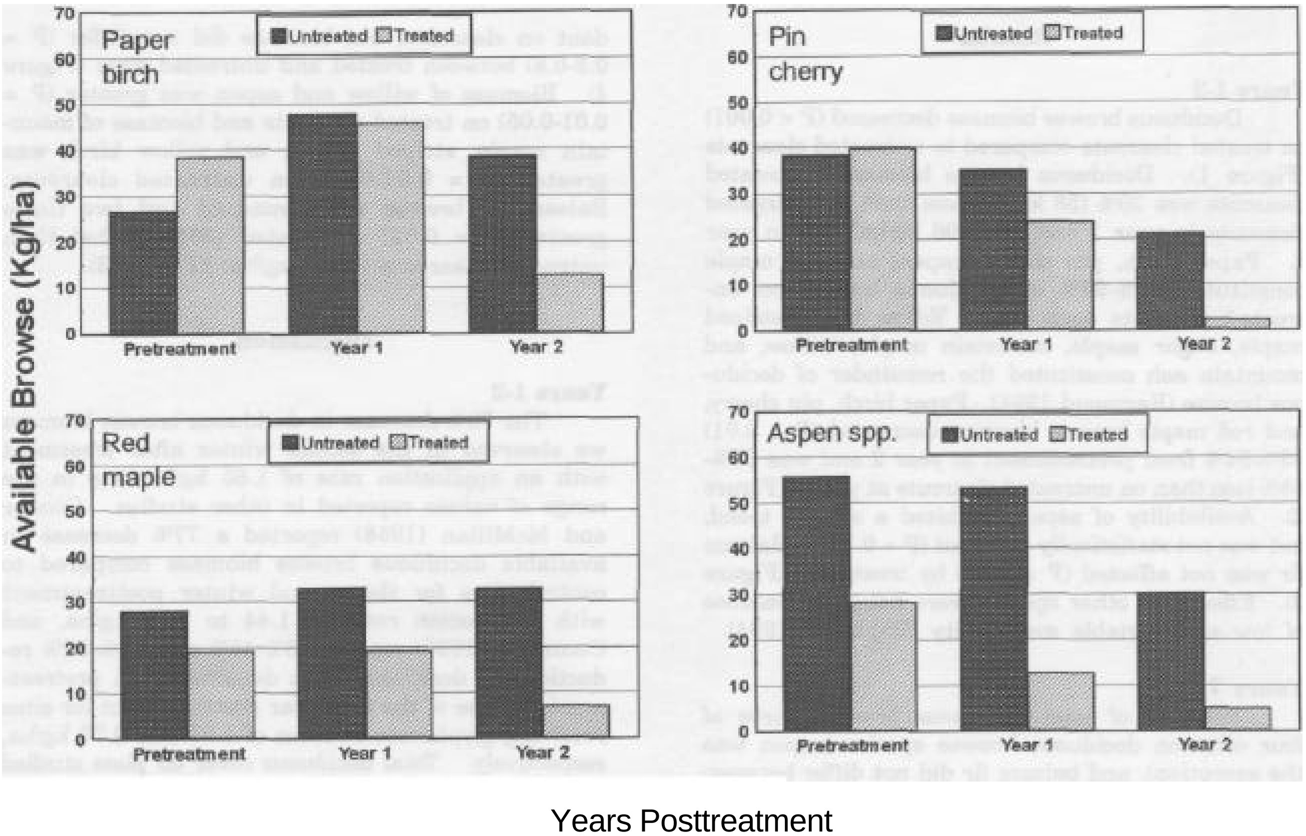

Figure 2. Available browse of four common deciduous species in glyphosate-treated (n=6) and untreated (n=6) clearcuts from pretreatment to year 2 posttreatment in Maine, January-March, 1991-93. Clearcuts were treated in August after pretreatment sampling from January to March, 1991.

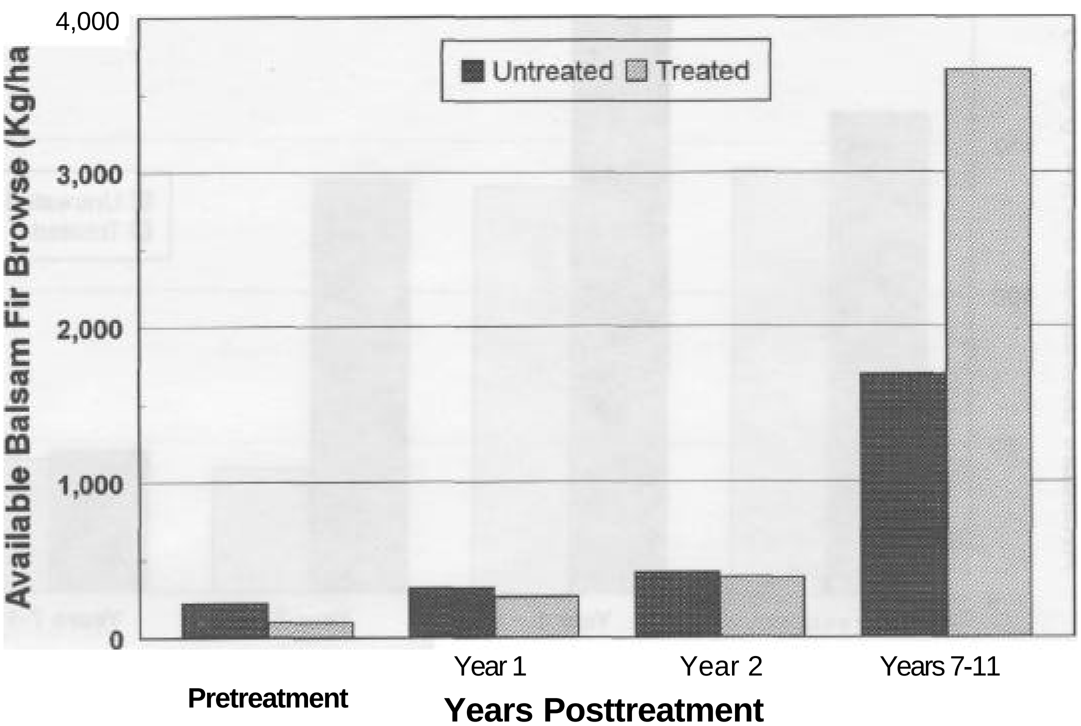

Figure 3. Available balsam fir browse on glyphosate-treated and untreated clearcuts from pretreatment to year 2 and at 7-11 years posttreatment.

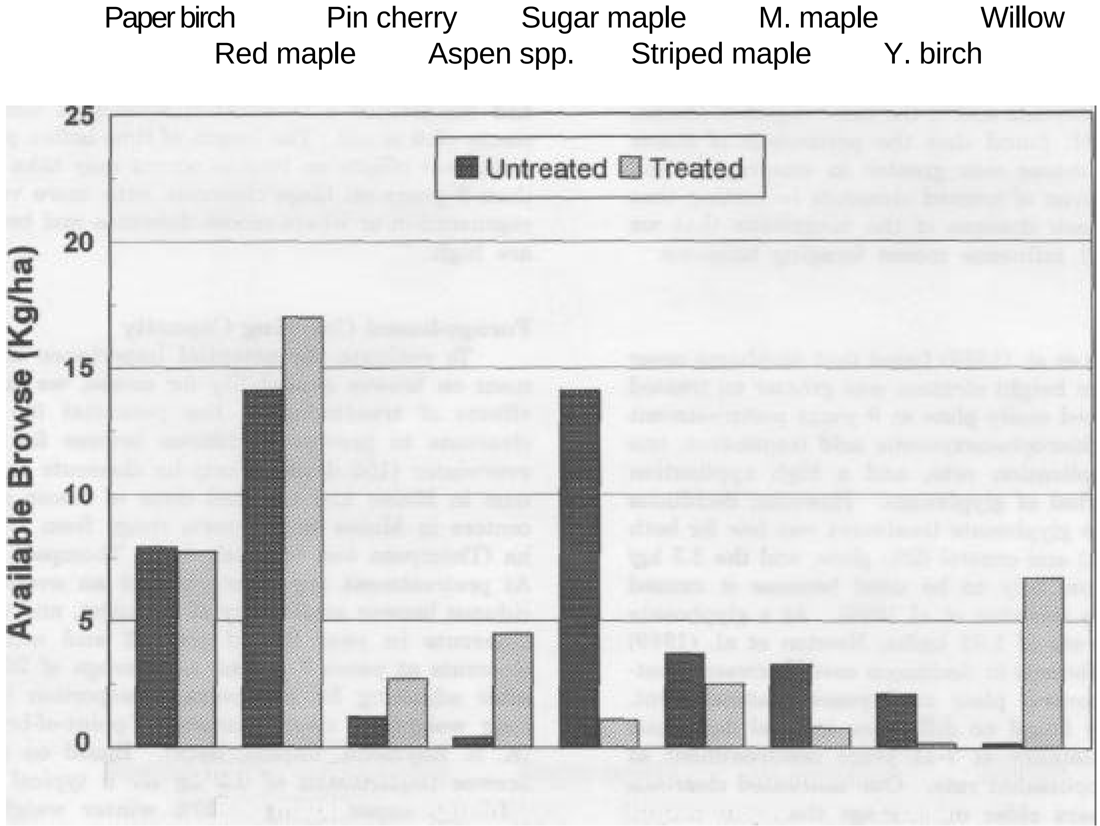

Figure 4. Available browse from common deciduous species in glyphosate-treated (n=14) and untreated (n=5) clearcuts at 7-11 years posttreatment in Maine, January-March, 1992-93.

(1989) did not statistically analyze 1-year treatment effects. However, 60%-70% reductions in browse availability appear to be typical, though application rate and other factors influence effects.

While much of the deciduous vegetation on treated clearcuts exhibited signs of glyphosate injury (e.g., color and morphological changes) during the first winter after treatment, only 25% of deciduous stems was dead (lack of a green cambium) compared to 9% on untreated clearcuts (Eschholz 1993). *As* a result, browse availability decreased over two winters. Mortality from glyphosate is a consequence of a variety of metabolic effects including inhibited protein synthesis, inhibited enzyme activity and/or prevention of secondary compound formation (Cole 1984). With treatment in late summer, plant mortality likely occurs slowly because of winter dormancy.

Aspen, pin cherry, paper birch, and red maple were all commonly available (19-56 kg/ha) prior to treatment and comprised most (89%-93%) of the deciduous browse on young clearcuts. Glyphosate efficacy on pin cherry and aspen is known to be greater than for paper birch and red maple (Pitt et al. 1992), a trend we also observed in our data. Browse reductions (compared to pretreatment) were 94%, 82%, 69%, 63%, respectively, for these four species, although the effect on aspen was not statistically significant. Stasiack et al. (1991) similarly found mortality of 94% and 87% for pin cherry and trembling aspen with a glyphosate application rate of 2.1 kg/ha. Relative differences in efficacy among these species may influence the magnitude of glyphosate effects on browse availability for individual clearcuts. For example, clearcuts dominated by pin cherry and/or aspen would have greater proportional reductions in browse availability than clearcuts dominated by paper birch or red maple.

Renecker and Hudson (1986) reported that dry matter intake rates (g/min) of moose were asymptotic when usable browse biomass -was greater than approximately 1,000 kg/ha and that intake rate was 50% of the asymptotic value at an availability of 150 kg/ha. From pretreatment to year 2, mean deciduous browse biomass on untreated clearcuts in the present study ranged from 137 to 192 kg/ha and glyphosate treatment reduced availability to 40 kg/ha. Therefore, foraging rates (g/min) of moose may be relatively low on untreated clearcuts, and treatment may reduce foraging rates even further by reducing browse density. Furthermore, our biomass availability estimates, which included all current annual growth, are likely greater than the actual availability of usable browse because moose ate only an average of 60% of the biomass of individual twigs (K. S. Raymond, unpub. data). Functionally lower availability increases the probability that glyphosate-induced reductions in browse availability would reduce foraging efficiency. However, moose using treated sites may still be able to achieve adequate daily food intake by foraging longer if they are not limited by total browse availability or foraging time. On similar clearcuts and in the same region of Maine, Santillo (1994) found that the percentage of stems browsed by moose was greater in unsprayed than sprayed sections of treated clearcuts indicating that browse biomass changes of the magnitude that we observed will influence moose foraging behavior.

Years 7-11

Newton et al. (1989) found that deciduous cover in a 1.0-2.5 m height stratum was greater on treated than untreated study plots at 9 years posttreatment for 2,4,5-trichlorophenoxyacetic acid treatments, one triclopyr application rate, and a high application rate (3.3 kg/ha) of glyphosate. However, deciduous cover for this glyphosate treatment was low for both treated (13%) and control (2%) plots, and the 3.3 kg/ha rate is unlikely to be used because it caused conifer injury (Newton et al 1989). At a glyphosate application rate of 1.65 kg/ha, Newton et al. (1989) found no difference in deciduous cover between treatment and control plots at 9 years posttreatment. We similarly found no difference in total deciduous browse availability at 7-11 years posttreatment at the same application rate. Our untreated clearcuts were 3.6 years older on average than our treated clearcuts (19 vs 16 years) which may have masked a small negative treatment effect on browse availability. At 16 years of age our untreated clearcuts may have had more available browse than at 19 years because less browse may have grown out of reach of moose, but we do not believe this small difference in stand age had a large effect.

Newton et al.'s (1989) conclusion that herbicide treatment in general increases available browse 9 years after treatment was based in part on their observation that >95% of deciduous cover on untreated study plots had grown out of reach of moose. We did not find that nearly all browse had grown out of reach of moose on our untreated clearcuts as Newton et al. (1989) observed, despite the older age of our sites. Our untreated clearcuts had 30% of the deciduous browse biomass found on our younger clearcuts at pretreatment compared to approximately 5% in Newton et al (1989). We believe that our results differed from Newton et al. (1989) because we used large entire clearcuts as experimental units as opposed to the 1-ha study plots in a single clearcut used in the earlier study. Treatment and control plots in Newton et al. (1989) were initially placed in parts of their clearcut study area that had relatively uniform regeneration for the purpose of studying herbicide efficacy (M. L. McCormack Jr., pers. comm.). Vegetation in large clearcuts is typically patchy, and areas with little deciduous regeneration initially may take longer than 9 years to grow entirely out of the reach of moose. In our study, two untreated clearcuts had relatively few deciduous stems <3.0 m tall as predicted, but vegetation in other clearcuts was less uniform and contained patches of available browse. Also on two of our untreated clearcuts heavy browsing and stem breakage by moose had maintained a substantial density of deciduous stems <3.0 m tall. The length of time before positive treatment effects on browse occurs may take longer than 9 years on large clearcuts with more variable regeneration or where moose densities and browsing are high.

Forage-based Carrying Capacity

To evaluate the potential importance of treatment on browse availability for moose, we assessed effects of treatment on the potential for 40-ha clearcuts to provide deciduous browse for moose overwinter (150 days). Forty-ha clearcuts are common in Maine and reported sizes of moose activity centers in Maine and Ontario range from 25 to 52 ha (Thompson and Vukelich 1981; Thompson 1987). At pretreatment our clearcuts had an average deciduous browse availability of 90 kg/ha, and treated clearcuts in year 2 and treated and untreated clearcuts at years 7-11 had an average of 26 kg/ha after adjusting for the average proportion (0.6) of twig weight at mean diameter-of-point-of-browsing (K. S. Raymond, unpubl. data). Based on a daily browse requirement of 4.6 kg for a typical moose (350 kg) experiencing a 20% winter weight loss (Schwartz et al. 1988), young untreated clearcuts had sufficient browse to support 5.2 moose per 40 ha compared to 1.5 moose for treated sites at both time periods. These are overestimates of forage-based carrying capacity in part because foraging efficiency decreases as moose reduce browse density (Renecker and Hudson 1986). However, a forage-based carrying capacity value near one for treated clearcuts suggests that sites of this size do not have sufficient deciduous browse to solely support an individual moose overwinter. Therefore, effects of glyphosate use on individual moose will depend on the number of available foraging sites because moose use several activity centers within their winter home range (Thompson and Vukelich 1981). Moose also could increase use of balsam fir as fir is frequently reported in the diet of moose in areas where deciduous availability is low (Peek 1974). Moose apparently can subsist on diets with high proportions of balsam fir; however, avoidance of fir in our study area (see "Browse Utilization And Diet Quality," p. 9) suggests such a foraging shift would represent a decline in diet quality because of plant secondary compounds (Robbins et al. 1987a).

Conclusions

- Glyphosate applied at 1.65 kg/ha decreases deciduous browse availability 60% to 70% for moose by the second winter after treatment.

- Availability of red maple and paper birch browse appears to decrease less than pin cherry and possibly aspen, which can influence the magnitude of glyphosate effects on browse availability for individual clearcuts.

This initial reduction in deciduous browse density has potential negative effects on food intake rates of moose and therefore may reduce the value of regenerating clearcuts for moose during this period.

Glyphosate has little effect on browse availability at 7-11 years after treatment.

The deciduous browse on a 40-ha treated clearcut is insufficient to support one moose overwinter. However, actual effects on moose depend on the number and distribution of alternative foraging sites because moose move among activity centers in winter.

BROWSE QUALITY

Glyphosate may affect the nutritional quality of browse for moose in two ways. Some deciduous trees survive treatment and have yellow deformed leaves and small CAG twigs in the next year (Newton et al. 1989), and these injured plants may differ in nutritional quality from untreated plants. Because browse species vary in nutritional quality, differences in glyphosate efficacy on browse species also may effect the relative abundance of high- and low-quality foods available to moose on clearcuts. Our objectives were to (1) compare the nutritional quality of glyphosate-injured and untreated browse in winter and (2) determine effects of glyphosate treatment of regenerating clearcuts on the proportion of relatively high quality browse available at 1-2 and 7-11 years posttreatment.

Methods

Quality of Glyphosate-injured Browse

At the end of the first growing season after treatment (September 1992), we identified ten groups of five red maple stems and ten groups of five paper birch stems that had survived treatment and exhibited typical injury (small CAG twigs and yellow deformed leaves). Stems were on two clearcuts and were marked for winter collections. Maple stems were stump sprouts and birch stems appeared to have originated from seedlings. Stems averaged about 2 m in height. In January 1993, we collected all CAG twigs ^5 cm in length in a height stratum of 0.5 to 3.0 m from these stems and pooled them by group (n = 10 per species). We also randomly collected an equal number of samples from groups of red maple and paper birch stems on adjacent untreated sites. We kept samples frozen until they were freeze-dried. We determined the average dry mass of twigs in each sample and analyzed samples for fiber composition (Mould and Robbins 1981), percent nitrogen (A.O.A.C. 1970), percent protein-precipitating phenolic compounds by the radial diffusion method (Hagerman 1987), and gross energy. We multiplied percentage nitrogen by 6.25 to estimate crude protein. We calculated the digestible energy (DE) content (kcal/g) of samples based on fiber composition, crude protein, and protein-precipitating phenolics using an equation developed for white-tailed deer *(Odocoileus virginianus)* (Robbins et al. 1987a, 1987b) and recommended for large cervids (Hanley et al. 1992). To use this equation, we converted percentage phenolic data determined from the radial diffusion method to bovine serum albumin precipitating equivalents by regression (Hagerman 1987). We tested for treatment effects using a Mann-Whitney test (Zar 1984).

Quality of Available Biomass

We conducted the nutritional analyses described above on a composite sample of each browse species on each clearcut used to study 1-2 and 7-11-year effects in 1991 and 1992. Because we saw little variation in mean nutritional quality values of browse species within and among treatment groups and years (K.S. Raymond, unpubl. data), we used corresponding mean values for treatment groups from 1991 to 1992 in 1993. Composite samples consisted of CAG >5 cm in length and in a 0.5-3.0 m height stratum from 12 randomly selected stems.

We examined browse availability relative to nutritional quality using the method of Hobbs and Swift (1985). In this analysis, forage biomass available at specified average diet quality levels is calculated by cumulative addition of forage biomass in decreasing order of forage quality. Using this method, we calculated the available biomass of deciduous browse with an average DE content of 1.8 kcal/g for each clearcut. This value was at the upper quartile of the range of DE values for deciduous browse species on our sites (Raymond 1994). We then calculated the proportion of available deciduous browse on clearcuts with a mean DE content of 1.8 kcal/g. We omitted balsam fir from this analysis because its exceptionally high availability would mask effects on deciduous browse, and its use by moose was generally low. Treatment and year effects were statistically analyzed using analysis of variance on ranks as described in the section titled "Browse Availability," p. 2.

Results

Quality of Glyphosate-injured Browse

For red maple, DE, crude protein, and protein-precipitating phenolics were greater ($P < 0.05$) for injured than untreated browse (Table 1). Mean dry mass for injured twigs was 0.47 g less ($P < 0.001$) than untreated twigs. For paper birch, percentage DE and protein-precipitating phenolics were greater ($P < 0.05$), and gross energy was lower ($P = 0.005$) for untreated twigs. Mean dry mass did not differ ($P = 0.880$) between injured and untreated twigs. For both browse species effects on DE were largely the

Table 3. Digestible energy (kcal/g) and protein (%) content of total browse biomass (includes balsam fir) and deciduous browse biomass eaten by moose in glyphosate-treated and untreated clear-cuts in Maine, January-March, 1991-1993[1].

	Pretreatment and 1-2 years posttreatment						7-11 years posttreatment			
	Pretreatment		Year 1		Year 2		Moosehead Lake area		Telos area	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Digestible energy (kcal/g										
Treated										
Total diet	1.67	0.07	1.67	0.06	1.81	0.08	1.59	0.01	1.76	0.16
Deciduous diet	1.67	0.07	1.59	0.01	1.59	0.04	1.57	0.01	1.62	0.05
	(n=5)		(n=3)		(n=6)		(n=5)		(n=5)	
Untreated										
Total diet	1.83	0.16	1.63	0.06	1.55	0.02	1.71	0.20		
Deciduous diet	1.58	0.07	1.58	0.07	1.54	0.02	1.47	0.02		
	(n=4)		(n=5)		(n=5)		(n=3)			
Protein (%)										
Treated										
Total diet	5.72	0.18	5.70	0.04	5.77	0.32	4.94	0.15	5.33	0.28
Deciduous diet	5.72	0.18	5.61	0.06	5.59	0.33	4.91	0.15	5.18	0.22
	(n=5)		(n=3)		(n=6)		(n=5)		(n=5)	
Untreated										
Total diet	5.91	0.44	5.53	0.17	5.52	0.12	5.62	0.61		
Deciduous diet	5.63	0.41	5.46	0.20	5.50	0.14	5.14	0.31		
	(n=4)		(n=5)		(n=5)		(n=3)			

[1] Only clearcuts with $\geq$2% utilization of total deciduous browse were included.

ity of red maple and paper birch appeared to be affected less by glyphosate than pin cherry and possibly aspen (see "Browse Availability," p. 2). Therefore, treatment appears to favor species used more consistently by moose.

The relatively high rate of browse utilization (21%) we observed 7-11 years posttreatment in the Moosehead Lake area suggests that these older treated clearcuts are preferred for foraging. However, since deciduous browse availability did not differ between treated and untreated clearcuts, availability apparently was not a factor. It also did not appear that browse nutritional quality influenced utilization rates. The proportion of deciduous browse biomass at 1.8 kcal/g DE was greater on treated clearcuts (see "Browse Quality," p. 7), but mean DE of deciduous browse eaten by moose was similar on treated (1.57 kcal/g) and untreated (1.47 kcal/g) clearcuts and similar to the overall mean DE of available deciduous biomass (1.54 kcal/g), suggesting that there was not strong selection for browse species with higher DE content.

Moose likely were eating more than 50% of the usable browse on these older treated sites because our utilization estimate (21%) was for one-half of the winter period, and actual available biomass may be 40% less than our estimate, which was based on CAG rather than at mean diameter at point of browsing (see "Browse Availability"). Also, heavy browsing may influence future browse availability on older treated clearcuts by slowing vertical growth of deciduous stems and prolonging the period of browse availability. Bergerud and Manuel (1968) and Hjeljord and Gronvold (1988) observed growth stagnation in heavily browsed species, and patches of deciduous stems on our older treated sites and those of Santillo (1994) exhibited evidence of heavy repeated (annual) browsing.

Conclusions

- Moose appear to eat less total browse on glypyhosate-clearcuts at two years after treatment, but the proportion of available browse eaten is not affected.
- Moose eat a high proportion of deciduous browse on older treated sites and appear to prefer these sites despite no difference in available browse and diet quality between treated and untreated clearcuts.
- Glyphosate treatment does not affect the nutritional quality (digestible energy and protein content) of moose diets.

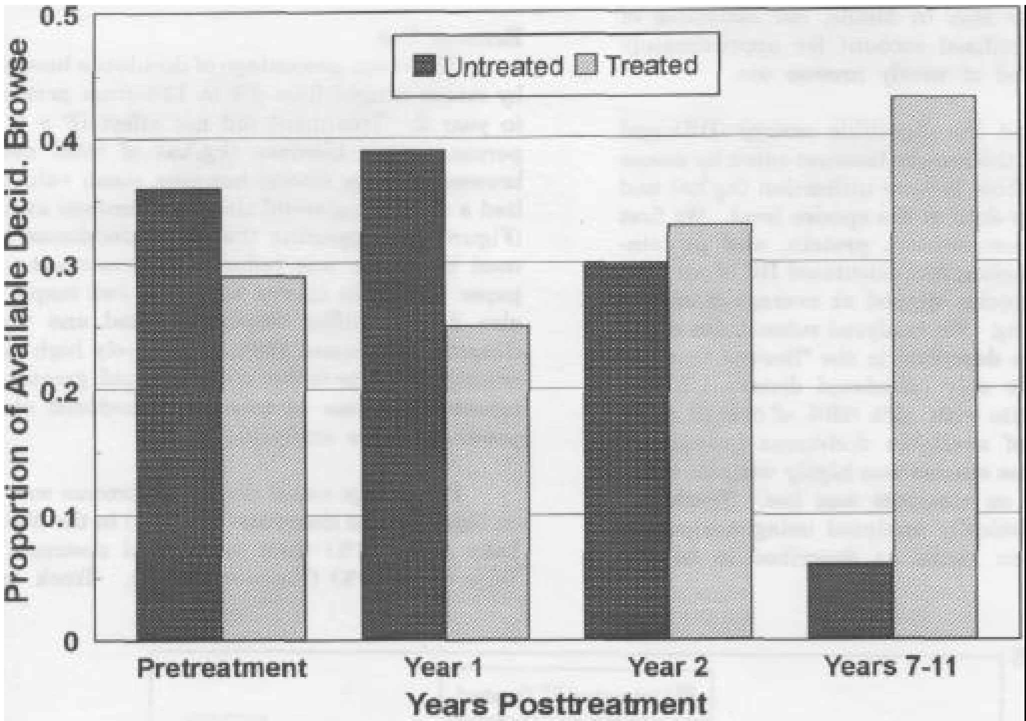

Figure 5. Proportion of available deciduous browse biomass with relatvely high digestible energy content (1.8 kcal/g) for glyphosate-treated and untreated clearcuts from pretreatment to year 2 posttreatment and at 7-11 years posttreatment. Clearcuts used to study 1-2 year effects were treated in August after pretreatment sampling, January-March, 1991.

Conclusions

Nutritional quality of glyphosate-injured browse is slightly different than untreated browse, but effects vary among major browse species and are unlikely to influence moose nutrition. Smaller twig size may reduce use of some injured browse.

Glyphosate does not affect the proportion of relatively high quality winter browse in the first two years after treatment.

High-quality browse was more abundant on treated clearcuts at 7-11 years after treatment, but this effect may not consistently occur because it is dependent on browse species composition.

BROWSE UTILIZATION AND DIET QUALITY

One approach we used to evaluate the importance of changes in browse availability after treatment was to examine effects on the use of browse by moose. Changes in browse use after treatment are an indicator of glyphosate effects on moose foraging behavior. We also measured the nutritional quality of browse eaten by moose on clearcuts to determine if treatment effects on the quality and availability of browse affected the quality of moose diets. Our specific objectives were to determine effects of glyphosate treatment of regenerating clearcuts on (1) use of browse and (2) diet quality of moose in winter during two time periods, 1-2 and 7-11 years posttreatment.

Methods

We counted browsed twigs by species on the 1x5 m quadrats used to measure browse availability on each clearcut. We sampled 24 quadrats per clearcut in 1991 and 40 per clearcut in 1992 and 1993. We estimated biomass (kg/ha) eaten by moose for each species by measuring twig diameters at point of browsing and converting diameter measurements to twig mass using twig diameter-mass regressions. Diameter-mass regressions were based on samples of 150 to 640 twigs per species and had R^2 values of 0.76 to 0.92 (Raymond 1994). For analysis of the percentage of total deciduous browse eaten, we calculated values for all clearcuts, but for individual browse species we only calculated percentage use on clearcuts where total deciduous browse availability was i.1.0 kg/ha. Sample dates for clearcuts in treatment groups were evenly distributed from January to March with mean sampling dates in mid-

February. Because moose likely feed on woody twigs from November to May in Maine, our estimates of browse biomass utilized account for approximately one-half the period of woody browse use.

We calculated the digestible energy (DE) and protein content of the browse biomass eaten by moose on each clearcut from browse utilization (kg/ha) and nutritional quality data at the species level. We first measured fiber composition, protein, and protein-precipitating phenolics, and calculated DE of samples of each browse species clipped at average-diameter-at-point-of-browsing. We analyzed subsamples of the composite samples described in the "Browse Quality" section, p. 7. We only calculated dietary DE and protein for clearcuts with ^2% (25% of overall mean utilization) use of available deciduous browse because use of browse species was highly variable when total browse use on clearcuts was low. Treatment effects were statistically analyzed using analysis of variance based on ranks as described in browse availability.

Results

Browse Use

The mean percentage of deciduous browse eaten by moose ranged from 4% to 13% from pretreatment to year 2. Treatment did not affect ($P > 0.10$) the percentage or biomass (kg/ha) of total deciduous browse eaten by moose; however, mean values exhibited a decreasing trend similar to browse availability (Figure 6), suggesting that total deciduous biomass used by moose was reduced by treatment. Use of paper birch, pin cherry, aspen, or red maple browse also did not differ between treated and untreated clearcuts (Raymond 1994). Relatively high variation among clearcuts (some clearcuts had greater use by moose regardless of treatment) reduced statistical power of these analyses.

Percentage use of deciduous browse was greater on older treated clearcuts ($P = 0.04$) in the Moosehead Lake area (21%) than on treated clearcuts in the Telos areas (5%) (Raymond 1994). Track data col-

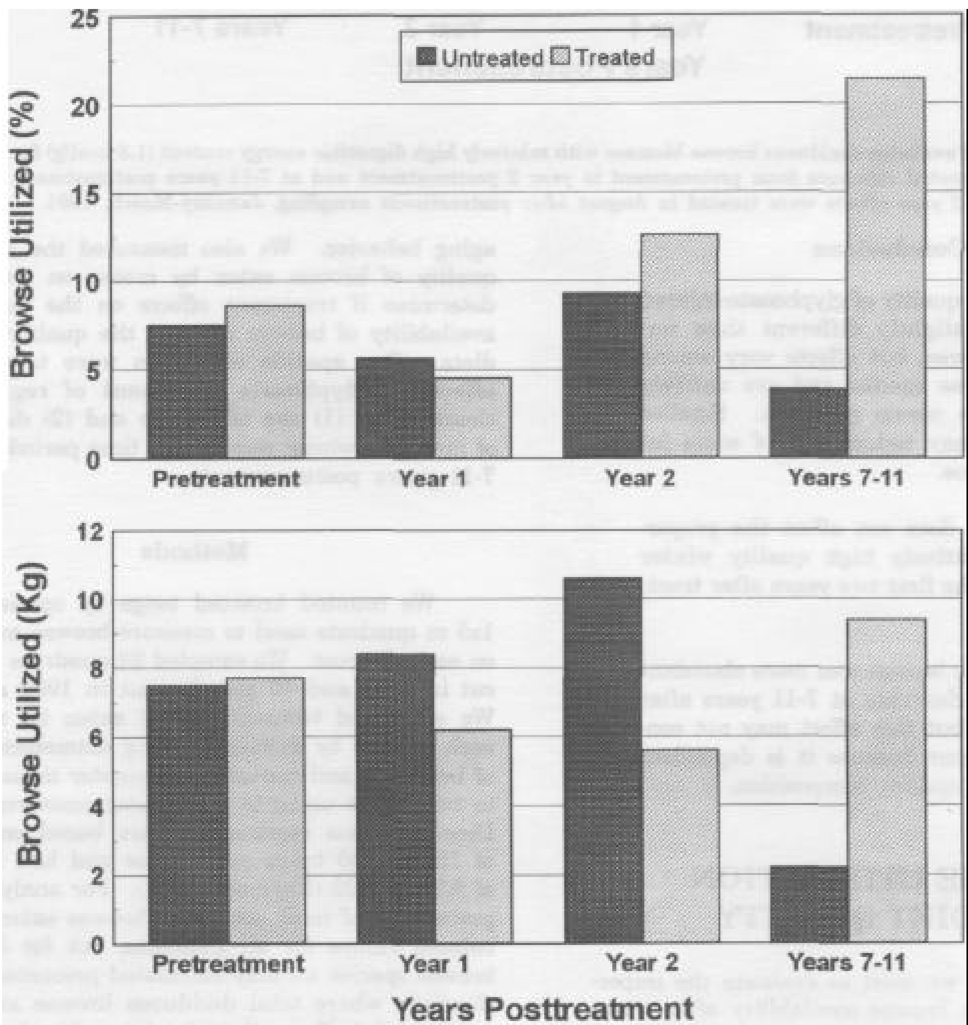

Figure 6. Biomass and percentage of available deciduous browse eaten by moose on glyphosate-treated and untreated clearcuts from pretreatment to year 2 posttreatment and at 7-11 years posttreatment. Clearcuts used to study 1-2 year effects were treated in August after pretreatment sampling, January-March, 1991.

also showed there was less moose activity on clearcuts in the Telos area. Therefore, we only included data from the Moosehead Lake area in analyses of browse use and diet quality data because we did not have control clearcuts in the Telos area. Percentage use of deciduous browse was greater (P = 0.036) on treated (mean = 21%) than untreated (mean = 4%) clearcuts (Figure 6). This pattern was similar for relatively abundant species (red maple, paper birch), but utilization rates were variable for other browse species (Raymond 1994). However, there was only a treatment effect for red maple (P = 0.04). Aspen, red maple, willow, striped maple, mountain maple, and paper birch all received relatively high use on older treated clearcuts. Percentage use of balsam fir was low for both treatments (<O.S

Diet Quality

From pretreatment to year 2, deciduous browse constituted >80% of diets of moose (Table 2). Red maple and paper birch -were the most common browse species in diets. Use of other species was variable. At 7-11 years, deciduous browse constituted 97% and 81% of average diets on treated clearcuts in the Moosehead Lake and Telos areas, respectively (Table 2). On older untreated clearcuts, balsam fir constituted 41% of diets. The DE and protein content of moose diets and the deciduous component of moose diets varied little and were not affected (P = 0.14-0.94) by treatment in years 1-2 or 7-11 (Table 3). Mean dietary DE values tended to be slightly greater in years and treatments in which the biomass of balsam fir eaten by moose was relatively high because balsam fir has a high DE (2.45 kcal/g, [Raymond 1994]).

Discussion

On younger clearcuts, percentage utilization rates in both treatments and all years were similar, suggesting that moose consumed browse proportional to its availability on clearcuts. We saw no evidence that moose avoided feeding on injured plants during the first winter after treatment. However, lower utilization rates in areas with injured plants may have been offset by greater utilization rates in small patches missed by treatment (Santillo 1994). A major portion of available browse on treated clearcuts may be in areas unintentionally missed by treatment. Preferential use of these patches may decrease effects on percentage utilization on the entire clearcut. However, biomass utilized (kg/ha) would be reduced as our data and Connor and McMillin's (1988) results suggest, but in both cases differences in biomass utilized were not statistically significant.

In younger clearcuts, paper birch and red maple are consistently used browse species. Aspen, pin cherry, and balsam fir were important in some years and treatment groups, but they were inconsistent in diets. Compared to deciduous species, the percentage of available fir eaten is low (<1%). Low use of balsam fir despite its abundance suggested that it was avoided on these clearcuts as has been found in other areas where deciduous browse was abundant (Telfer 1967; McNicol and Gilbert 1980; Thompson et al. 1989). Of the four commonly occurring deciduous browse species on clearcuts, the availabil-

Table 2. Food habits (mean percentage in diet) of moose on glyphosate-treated (T) and untreated (UT) clearcuts from pretreatment to year 2 posttreatment and at 7-11 years posttreatment in Maine, January-March, 1991-93. Clearcuts used to study 1- to 2-year effects were treated in August after pretreatment sampling from January to March, 1991.

	Pretreatment and 1-2 years posttreatment						7-11 years posttreatment		
	Pretreatment		Year 1		Year 2				
	UT		UT		UT		UT	MLA[1]	TA[2]
Paper birch	8	14	15	23	25	47	10	23	20
Pin cherry	16	5	20	3	11	0	5	2	0
Aspen spp.	4	35	11	6	3	3	0	4	8
Red maple	43	29	37	23	42	16	28	52	38
Yellow birch	2	1	1	1	1	0	0	0	0
Striped maple	8	6	0	7	9	3	5	4	0
Sugar maple	1	1	3	13	7	6	8	0	0
Mt. maple	0	5	3	4	0	0	3	5	0
Willow	0	1	1	1	0	0	0	10	15
Mt. ash	0	0	1	7	0	4	0	0	0
Balsam fir	19	1	5	11	1	20	41	3	19
Deciduous	81	99	95	89	99	80	59	97	81

[1] Moosehead Lake Area
[2] Telos Area

Table 3. Digestible energy (kcal/g) and protein (%) content of total browse biomass (includes balsam fir) and deciduous browse biomass eaten by moose in glyphosate-treated and untreated clear-cuts in Maine, January-March, 1991-1993[1].

	Pretreatment and 1-2 years posttreatment						7-11 years posttreatment			
	Pretreatment		Year 1		Year 2		Moosehead Lake area		Telos area	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Digestible energy (kcal/g										
Treated										
Total diet	1.67	0.07	1.67	0.06	1.81	0.08	1.59	0.01	1.76	0.16
Deciduous diet	1.67	0.07	1.59	0.01	1.59	0.04	1.57	0.01	1.62	0.05
	(n=5)		(n=3)		(n=6)		(n=5)		(n=5)	
Untreated										
Total diet	1.83	0.16	1.63	0.06	1.55	0.02	1.71	0.20		
Deciduous diet	1.58	0.07	1.58	0.07	1.54	0.02	1.47	0.02		
	(n=4)		(n=5)		(n=5)		(n=3)			
Protein (%)										
Treated										
Total diet	5.72	0.18	5.70	0.04	5.77	0.32	4.94	0.15	5.33	0.28
Deciduous diet	5.72	0.18	5.61	0.06	5.59	0.33	4.91	0.15	5.18	0.22
	(n=5)		(n=3)		(n=6)		(n=5)		(n=5)	
Untreated										
Total diet	5.91	0.44	5.53	0.17	5.52	0.12	5.62	0.61		
Deciduous diet	5.63	0.41	5.46	0.20	5.50	0.14	5.14	0.31		
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[1] Only clearcuts with ≥2% utilization of total deciduous browse were included.

ity of red maple and paper birch appeared to be affected less by glyphosate than pin cherry and possibly aspen (see "Browse Availability," p. 2). Therefore, treatment appears to favor species used more consistently by moose.

The relatively high rate of browse utilization (21%) we observed 7-11 years posttreatment in the Moosehead Lake area suggests that these older treated clearcuts are preferred for foraging. However, since deciduous browse availability did not differ between treated and untreated clearcuts, availability apparently was not a factor. It also did not appear that browse nutritional quality influenced utilization rates. The proportion of deciduous browse biomass at 1.8 kcal/g DE was greater on treated clearcuts (see "Browse Quality," p. 7), but mean DE of deciduous browse eaten by moose was similar on treated (1.57 kcal/g) and untreated (1.47 kcal/g) clearcuts and similar to the overall mean DE of available deciduous biomass (1.54 kcal/g), suggesting that there was not strong selection for browse species with higher DE content.

Moose likely were eating more than 50% of the usable browse on these older treated sites because our utilization estimate (21%) was for one-half of the winter period, and actual available biomass may be 40% less than our estimate, which was based on CAG rather than at mean diameter at point of browsing (see "Browse Availability"). Also, heavy browsing may influence future browse availability on older treated clearcuts by slowing vertical growth of deciduous stems and prolonging the period of browse availability. Bergerud and Manuel (1968) and Hjeljord and Gronvold (1988) observed growth stagnation in heavily browsed species, and patches of deciduous stems on our older treated sites and those of Santillo (1994) exhibited evidence of heavy repeated (annual) browsing.

Conclusions

- Moose appear to eat less total browse on glypyhosate-clearcuts at two years after treatment, but the proportion of available browse eaten is not affected.
- Moose eat a high proportion of deciduous browse on older treated sites and appear to prefer these sites despite no difference in available browse and diet quality between treated and untreated clearcuts.
- Glyphosate treatment does not affect the nutritional quality (digestible energy and protein content) of moose diets.

WINTER COVER

Moose prefer mature conifer habitat when snow is deep. During other periods they may travel between bedding areas in mature conifer habitat to foraging areas in open habitats or bed and forage in clearcuts (Peek et al. 1976). Bedding sites in regenerating clearcuts are associated with clumps of taller conifers (McNicol and Gilbert 1978). Our objective was to determine effects of glyphoeate treatment of regenerating clearcuts on winter cover during two time periods, 1-2 and 7-11 years posttreatment.

Methods

Conifers densities were measured each year during January-March 1991-1993 on clearcuts used to study 1-2 year effects and once during January-March 1992 or 1993 on clearcuts used to study 7-11 year effects. We counted live stems of conifers by height class (2.0-2.9, 3.0-3.9, and 2.4.0 m) on 2 x 5 m quadrats randomly located on transects distributed systematically on each clearcut. We sampled 24 quadrats per clearcut in 1991 and 40 quadrats per clearcut in 1992 and 1993. Treatment effects were statistically tested using analysis of variance based on ranks as described in "BROWSE AVAILABILITY," (p.2).

Results

From pretreatment to year 2, conifer densities in height strata >2 m were relatively low compared to older clearcuts, and treatment did not affect (P > 0.10) density of conifer stems at any height class (Figure 7). At 7-11 years posttreatment, density of conifer stems 2.0-2.9 m tall were approximately three times greater (P < 0.10) on treated than untreated clearcuts, but densities did not differ for other height classes (P > 0.10).

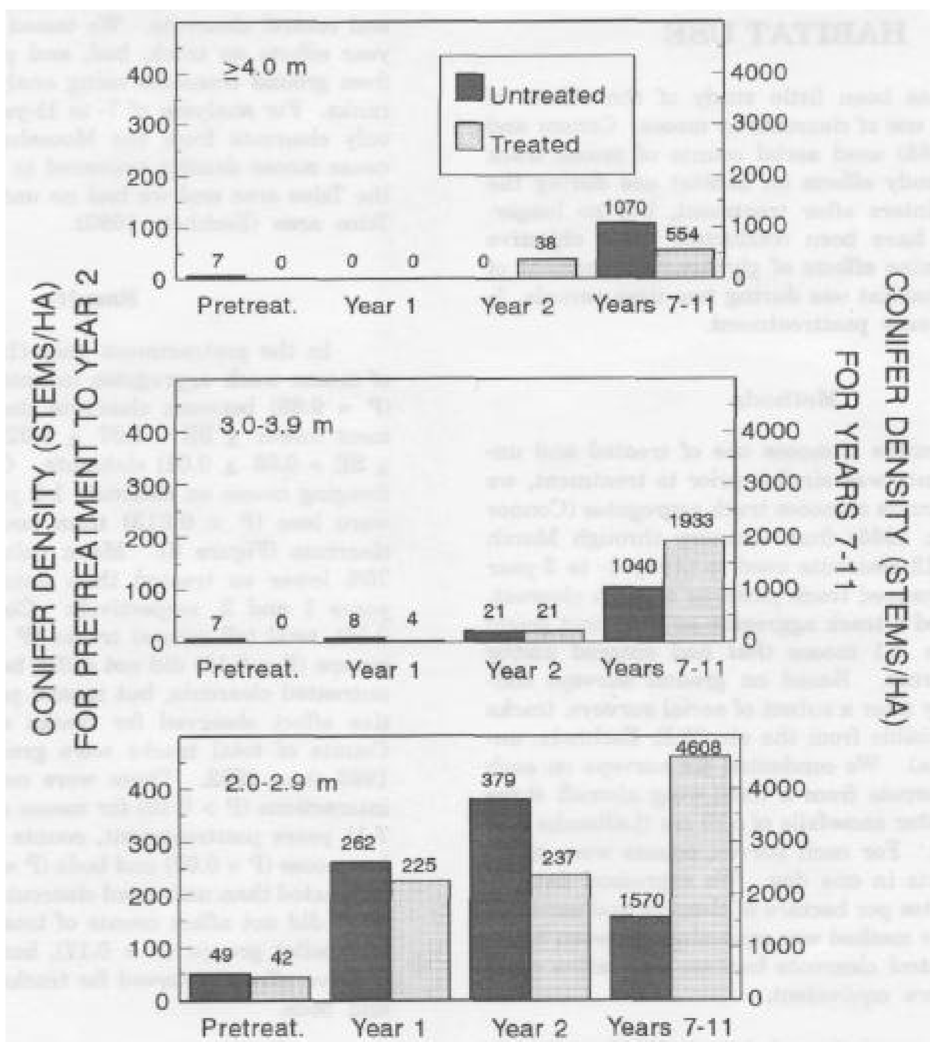

Figure 7. Densities (stems/ha) of conifer tree stems by height class for glyphosate-treated and untreated clearcuts at pretreatment and 1, 2, and 7-11 years posttreatment in Maine, January-March, 1991-1993. Clearcuts used to study 1- to 2-year effects were treated in August 1991 after pretreatment sampling between January and March, 1991.

Discussion

Glyphosate treatment appears to improve winter cover for bedding by 7-11 years posttreatment in regenerating clearcuts. McNicol and Gilbert (1978) found that 80% of moose beds in 10- to 15-year-old clearcuts were associated with immature (2.5-7.6 cm dbh) conifer clumps, and beds were positioned to take advantage of wind-breaking cover and exposure to the sun. Densities of conifer trees of approximately this size (>2-3 m in height) were substantially greater on treated than untreated sites in years 7-11 years. We did not measure the growth form of conifers, but trees on older treated clearcuts generally had more canopy cover than conifers on untreated sites because released conifers were less influenced by competition from tall deciduous tree cover (Newton et al. 1992). In contrast, young clearcuts (treated and untreated) would provide little winter cover because conifer trees were small and deciduous trees (live and/or dead stems) dominated sites.

HABITAT USE

There has been little study of the effects of glyphosate on use of clearcuts by moose. Connor and McMillan (1988) used aerial counts of moose track patterns to study effects on habitat use during the first three winters after treatment, but no longer-term studies have been conducted. Our objective was to determine effects of glyphosate treatment of clearcuts on habitat use during two time periods, 1-2 and 7-11 years posttreatment.

Methods

Tb determine if moose use of treated and untreated clearcuts was similar prior to treatment, we made aerial counts of moose track aggregates (Connor and McMillan 1988) from January through March 1991 on the 12 clearcuts used to study 1- to 2-year effects. We mapped track patterns on each clearcut, and we defined a track aggregate as a distinct group of tracks from £.1 moose that had entered and/or exited a clearcut. Based on ground surveys conducted the day after a subset of aerial surveys, tracks were highly visible from the air (WE. Eschholz, unpublished data). We conducted six surveys on each of the 12 clearcuts from a fixed-wing aircraft three to five days after snowfalls of >10 cm (LaResche and Rausch 1974). For each survey, counts were made on all clearcuts in one day. We expressed data as track aggregates per hectare of clearcut and assumed any bias in our method was equivalent between treatment and control clearcuts because vegetative characteristics were equivalent.

From January through March, 1992 and 1993, we made ground counts of track crossings (tracks), beds, and pellet groups on permanent 2-m-wide transects on the 12 clearcuts used to study 1 to 2-year effects and on 11 clearcuts (six treated and five untreated) used to study 7- to 11-year effects. We located transects along the entire perimeter of each clear-cut. We also located additional parallel transects in the interior of larger clearcuts to provide equal transect density (75 m/ha) on all clearcuts. We conducted counts 3 to 7 days (mean = 4) after each snowfall >10 cm. We back-tracked all track crossings for 20 m and classified moose activity as foraging if there was £.1 instance of browsing activity. We expressed all data as counts/km of transect. We conducted counts six to seven times on all clearcuts from January through March, 1992 and five times from January through March, 1993. Snowfall was below average in 1992 and 1993 and did not appear to limit use of clearcuts by moose except in March 1993. We suspended counts in mid-March 1993 because snow depths were >90 cm and may have restricted movements by moose (Coady 1974).

We used a paired fc-test to test for pretreatment differences in aerial counts of track aggregates between clearcuts designated for glyphosate treatment and control clearcuts. We tested for treatment and year effects on track, bed, and pellet group counts from ground transects using analysis of variance on ranks. For analyses of 7- to 11-year effects, we used only clearcuts from the Moosehead Lake area because moose density appeared to be greater than in the Telos area and we had no untreated sites in the Teles area (Eschholz 1993).

Results

In the pretreatment year (1991), aerial counts of moose track aggregates (counts/ha) did not differ ($P = 0.69$) between clearcuts designated for treatment (mean ± SE = 0.07 ± 0.02) or control (mean ± SE = 0.08 ± 0.01) clearcuts. Counts of tracks of foraging moose on clearcuts 1-2 years posttreatment were less ($P = 0.013$) than counts on untreated clearcuts (Figure 8). Mean values were 57% and 75% lower on treated than untreated clearcuts in years 1 and 2, respectively. Counts of beds ($P = 0.10$), total (all moose) tracks ($P = 0.14$), and pellet groups ($P = 0.12$) did not differ between treated and untreated clearcuts, but means paralleled the negative effect observed for tracks of foraging moose. Counts of total tracks were greater ($P < 0.10$) in 1993 than 1992. There were no treatment x year interactions ($P > 0.10$) for moose activity counts. At 7-11 years posttreatment, counts of tracks of foraging moose ($P = 0.05$) and beds ($P = 0.06$) were greater on treated than untreated clearcuts (Figure 8). Treatment did not affect counts of total tracks ($P = 0.19$) and pellet groups ($P = 0.17$), but means paralleled positive effects observed for tracks of foraging moose and beds.

Discussion

Glyphosate treatment reduces, but does not

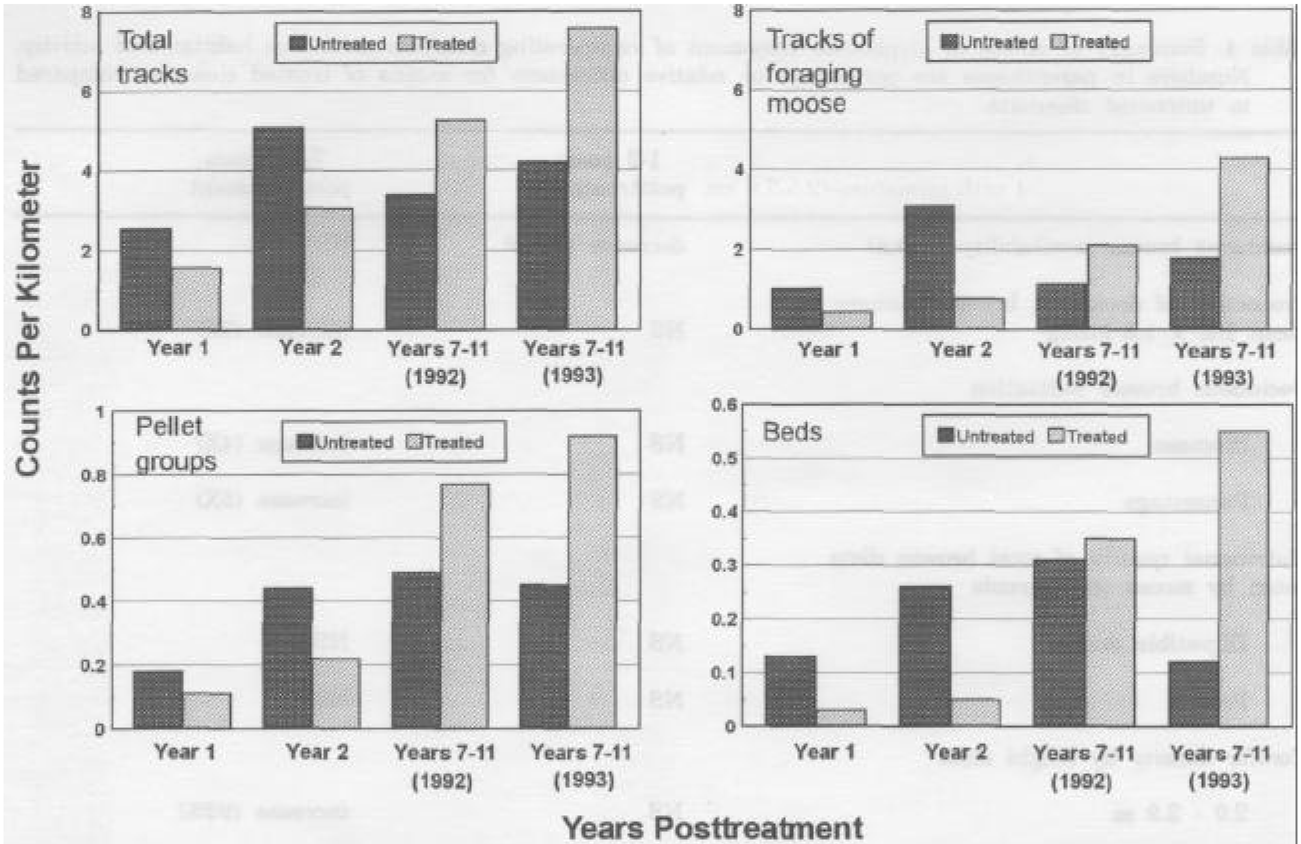

Figure 8. Counts (per km of transect) of moose track crossings, beds, and pellet groups on glyphosate-treated and untreated clearcuts 1, 2, and 7-11 years postreatment and similarly aged untreated clearcuts in Maine, January-March, 1992-93.

eliminate, use of clearcuts by moose in the first one to two years after treatment. Connor and McMillan (1988) found a decline in track counts from aerial surveys during the third winter posttreatment and decreasing trends in the first and second winters similar to the 57%-75% reduction in tracks of foraging moose we observed during years 1 and 2. In contrast to negative effects on habitat use in years 1 and 2, moose used older treated clearcuts at least as much as untreated sites and some measures indicated greater use of older treated clearcuts than other treatment/age types.

Several factors may influence the magnitude or importance of glyphosate effects on moose habitat use. In some years or regions, deep snow may reduce use of all clearcuts (Coady 1974) and make our observed effects of treatment less important. Snow depths were <80 cm except for one short period in late 1993 in the present study and likely did not limit use of clearcuts (Coady 1974). Moose also use several activity centers in winter (Thompson and Vukelich 1981); therefore, the number and distribution of alternative foraging sites (i.e., from timber harvest or natural disturbance) in winter home ranges may influence the magnitude of observed effects on habitat use. For example, in our study area, approximately 50% of the area was comprised of stands <20 years old. The magnitude of glyphosate effects on use of sites may differ in regions with less foraging habitat.

A combination of coniferous cover and browse availability appears to explain the pattern of habitat use we observed after treatment (Table 4). We found there was a 70% decrease in available deciduous browse from pretreatment to year 2 on these clearcuts. We also found little evidence for important effects on the nutritional quality of available browse or diet quality of moose in years 1 and 2 (Table 4). With dead deciduous stems largely still standing and conifer height little changed, physical cover is unaffected by treatment in the first few years, and therefore, the decrease in track counts of foraging moose appears to be the result of decreased browse availability. At 7-11 years posttreatment, greater counts of tracks of foraging moose and beds on treated sites appeared to be the result of more abundant tall conifer cover rather than differences in browse availability. Browse availability was similar for treated and untreated clearcuts and was similar to treated sites at year 2. The proportion of browse biomass with a relatively high mean digestible energy content (1.8 kcal/g) also was greater on older treated clearcuts, but this apparently was not a factor because it did not influence diet quality of moose. We hypothesize that moose made greater use of older treated clearcuts for foraging because they can bed and forage in one area. The high

Table 4. Summary of effects of glyphosate treatment of regenerating clearcuts on moose habitat and activity. Numbers in parentheses are percentage or relative differences for means of treated clearcuts compared to untreated clearcuts.

	1-2 years posttreatment	7-11 years posttreatment
Deciduous browse availability (kg/ha)	decrease (70%)[2]	NS[2]increase
Proportion of deciduous browse biomass with mean DE = 1.8 kcal/g	NS	(7X)
Deciduous browse utilization		
Biomass Percentage	NS	increase (4X)
Nutritional quality of total browse diets eaten by moose on clearcuts	NS	increase (5X)
Digestible energy		
Protein Conifer density by	NS	NS
height class	NS	NS
2.0 - 2.9 m		
3.0 - 3.9 m	NS	increase (93%)
£ 4.0 m Habitat	NS	NS
use indices	NS	NS
Counts of total tracks		
Counts of tracks of foraging moose	NS	NS
Pellet group counts	decrease (75%)	increase (2X)[3]
Bed counts	NS	NS
	NS	increase (3X)[3]

[1] Differences between means are for year 2 posttreatment.
[2] Treatment effect was not statistically significant at $P < 0.10$.
[3] Mean increase over 2 years.

percentage of browse utilization observed on these clearcuts also suggest intensive use. Risenhoover (1986) reported that moose fed five to six times per day, feeding periods averaged approximately one hour each, and moose alternated resting and feeding during the entire day. High interspersion of bedding cover and browse on treated clearcuts reduces travel to and from foraging sites, which allows shorter foraging bouts and maximizes time for rest and rumination.

Whether greater use of older treated clearcuts indicates better habitat quality is not clear though. With browse availability relatively low and biomass of browse utilized (kg/ha) on these clearcuts similar to levels on both treated and untreated younger clearcuts, any energetic advantage for moose using older treated clearcuts appears to result from bedding and foraging habitat being in close proximity. The value of this habitat characteristic is unknown.

Conclusions

Glyphosate reduces winter foraging activity of moose in clearcuts 1-2 years after treatment and appears to be the result of decreased browse availability.

Glyphosate increases foraging and bedding activity at 7-11 years after treatment and appears to be the result of more abundant winter cover.

MANAGEMENT AND RESEARCH IMPLICATIONS

Because we found little evidence that glyphosate treatment has significant negative effects on diet quality of moose, habitat management for moose can focus on maintaining adequate browse availability at the landscape level. In the absence of data for years 3-6 posttreatment, we would assume that browse density on treated clearcuts remains approximately stable from year 3 to years 7-11, while browse density on untreated sites decreases gradually. Nearly all deciduous tree mortality occurs by the end of the first growing season after treatment (Stasiak et al. 1991) indicating that additional reductions in the third winter would be small. Less vigorous growth of injured plants in subsequent years (Stasiak et al. 1991) may offset new regeneration on treated sites initially as well. Moose use several activity centers within their home range (Thompson and Vukelich 1981); therefore, the question of whether total browse supply may be limiting after treatment will depend on the total area of foraging habitat (treated and untreated) in their home range, the number and distribution of foraging sites, and the density of moose in the area.

One management strategy would be to reduce long-term fluctuations in browse availability for moose populations by managing the number and location of treated and untreated clearcuts on the landscape. Effects of treatment on browse availability for moose populations may be most pronounced when all similar-aged clearcuts in a locality are treated simultaneously to achieve cost efficiency from a central helicopter landing site. This scenario would produce the greatest reduction in browse availability for local moose populations. Alternatively, maintaining a diversity of stand age and treatment classes will tend to stabilize browse availability over time in an area. With assumed stable browse production in years 2 to 7-11 posttreatment, browse production after year 2 posttreatment would not offset reductions that occur during the first two years posttreatment. Clearcuts at >10 years posttreatment may produce more available browse than untreated clearcuts as suggested by Newton et al. (1989), but the absolute biomass difference may be insignificant. Managing the number and location of pretreatment and posttreatment clearcuts is a more certain approach for maintaining browse availability.

If greater use of treated clearcuts by moose at 7-11 years after treatment is an indication of increasing habitat quality as these treated sites continue to develop vegetatively, then benefits of improved habitat at approximately 7-11 years after treatment may partially offset negative effects on browse availability and habitat use the first few years after treatment. Assuming that greater use of older treated clearcuts indicates some benefit for moose, timber harvest and treatment strategies that result in pretreatment and 7-11 year posttreatment forest stands in close proximity to recently treated stands would help to stabilize overall habitat quality for moose.

We suggest staggering treatment times of neighboring clearcuts by >3 years to help reduce fluctuations in overall browse availability and provide a mixture of younger clearcuts (treated and untreated), older treated clearcuts, and unharvested stands to minimize effects of treatment on moose. Greater compensation for treatment effects may be needed when pin cherry and aspen dominate clearcuts because browse reductions may be greater. If staggering treatment dates of similar-aged clearcuts are not feasible because of reduced silvicultural effectiveness, then management of initial timber harvest may be required to achieve this objective.

There may be options for increasing the value of treated clearcuts as foraging habitat for moose, but these methods need direct study. There is evidence that moose browse more intensively in sections of clearcuts unintentionally missed by aerial spraying than in treated sections (Santillo 1994). Santillo (1994) estimated that unsprayed areas accounted for 1%-10% of treated clearcuts in his study and suggested that intentionally leaving narrow strips of untreated browse may be beneficial to moose and may not substantially decrease conifer regeneration. Leaving areas of untreated browse near clearcut edges, where it is more accessible to moose in winter (Thompson and Vekelich 1981) also may increase the value of untreated strips. A 10% increase in browse availability on a 40-ha clearcut will not increase forage based carrying capacity greatly (<0.5 moose) for winter, but it may allow short-term use of sites as winter activity centers in the home ranges of moose. More information is needed on conifer regeneration and moose foraging behavior in untreated strips to understand trade-offs between conifer release and browse production.

Our conclusions regarding effects of glyphosate treatment are only applicable to the period <11 years posttreatment. We hypothesize that bedding cover will continue to increase on treated clearcuts as conifer height and canopy cover increase. We also hypothesize that browse availability will decrease on treated clearcuts after 11 years as a result of understory shading by released conifers, but it may not differ from untreated sites. However, potential effects of heavy browsing on treated clearcuts also complicates predictions on browse availability. In addition, treated clearcuts in Maine often are thinned to reduce tree density approximately ten years after glyphosate application. Studies of longer-term effects also will need to evaluate thinning, which is a consequence of vegetation management with glyphosate.

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