NUTRITIONAL QUALITY OF GLYPHOSATE-INJURED BROWSE FOR MOOSE IN MAINE

Kevin S. Raymond and Frederick A. Servello

Department of Wildlife Ecology, 5755 Nutting Hall, University of Maine, Orono, Maine 04469.

ABSTRACT: Live deciduous vegetation on regenerating clearcuts previously treated with the herbicide glyphosate frequently exhibits evidence of injury, which may affect the nutritional value of this vegetation for browsing herbivores such as moose. We compared the nutritional quality of glyphosate-injured and uninjured twigs (current annual growth) from red maple (*Acer rubrum*) and white birch (*Betula papyrifera*), two abundant and commonly used winter foods of moose in Maine, at 17 months posttreatment. For red maple, neutral and acid detergent fiber (NDF and ADF) concentrations were 18% less ($P < 0.001$), and lignin-cutin was 8% greater in injured than uninjured twigs. Predicted digestible dry matter (DDM) and digestible energy (DE) values were 7% greater ($P = 0.003$-0.014) in injured than uninjured twigs. Crude protein concentrations were low in red maple overall, but were greater ($P < 0.001$) in injured than uninjured twigs. In contrast, for paper birch, NDF and ADF concentrations were 6 and 8% greater ($P = 0.002$-0.011) and DDM and DE values were 8-11% less ($P = 0.001$-0.014) in injured than uninjured twigs. Lignin-cutin concentration was greater in injured than uninjured twigs. Crude protein content was not affected by injury ($P = 0.97$) in paper birch. Differences in the nature and magnitude of effects on nutritional quality for these two browse species demonstrates that there is not a generalized response to glyphosate injury. While measurable effects on nutritional quality of browse exist, absolute differences were generally small and may not represent important effects on diet quality of moose.

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In northern forests, the herbicide glyphosate is widely used to promote conifer growth and abundance on naturally-regenerating clearcuts and plantations (McCormack 1994). Aerial treatment with glyphosate decreases total cover or woody browse biomass of deciduous trees by approximately 70% during the first 1-3 years posttreatment (Connor and McMillan 1988, Newton *et al.* 1989, Kelly and Cumming 1994, Raymond *et al.* 1996). Live deciduous plants available as moose browse on these sites in the first few years after treatment are either: missed by spraying (Santillo 1994), survive treatment for one or more growing season (Newton *et al.* 1989), or resprout from injured plants (Newton *et al.* 1992). In the latter two cases these deciduous plants often exhibit signs of injury including discolored or deformed leaves and small current annual growth (Newton *et al.* 1989, Stasiak *et al.* 1991). The value of injured plants as food for browsing herbivores is frequently questioned by the public, but effects of herbicide treatment on the nutritional quality of browse has received limited study (Lautenschalger 1993, Cumming *et al.* 1995). For moose (*Alces alces*), which continue to forage on clearcuts after treatment (Connor and McMillan 1988, Eschholz *et al.* 1996, Raymond *et al.* 1996), a reduction in browse quality may exacerbate negative effects of glyphosate-induced reductions in browse availability. Our objective was to determine if the nutritional quality of two commonly used winter browse species of moose in Maine was affected by glyphosate injury.

STUDY AREA

The study was conducted in north-central Maine (Piscataquis county), USA. Forests in the region are classified as spruce

(*Picea* spp.)-balsam fir (*Abies balsamea*)-northern hardwoods (Westvald *et al.* 1956). Abundant tree species on regenerating clearcuts used in the study included paper birch, pin cherry (*Prunus pensylvanica*), red maple, aspen (*Populus spp.*), red spruce (*Picea rubens*), and balsam fir. White pine (*Pinus strobus*), northern white cedar (*Thuja occidentalis*), striped maple (*A. pensylvanicum*), sugar maple (*A. saccharum*), yellow birch (*B. alleghaniensis*), mountain ash (*Sorbus americana*), and willow (*Salix* spp.) also were common. Studies were conducted in 3 clearcuts that had received a single aerial application of glyphosate at a rate of 1.65 kg acid equivalents/ha in August 1991 and in 3 adjacent untreated clearcuts that had otherwise received similar management. Glyphosate was applied in the form of Roundup®. Clearcuts were 18-30 ha in area and 5-6 years post-harvest at the time of treatment. Descriptions of the vegetative responses to treatment on these sites can be found in Raymond *et al.* (1996).

METHODS

At the end of the first growing season (September 1992) after glyphosate treatment (August 1991), we marked a total of 10 clumps of 5 injured red maple stems and 10 clumps of 5 injured paper birch stems in the 3 treated clearcuts for sample collection in the following winter. Red maple and paper birch were abundant on regenerating clearcuts and heavily browswd by moose (Raymond *et al.* 1996, Eschholz *et al.* 1996). Stems were approximately 2-3 m in height. Injured plants were identified by their yellow or deformed leaves and twigs (Stasick *et al.* 1991). Red maple stems originated (prior to treatment) from stump sprouts, and paper birch stems appeared to have originated from seedlings. In January 1993, we collected all current annual growth twigs $\geq$ 5 cm in length between the heights of 0.5 to 3.0 m from all marked clumps of injured plants and from an equal number of randomly selected but equivalent-sized clumps on untreated clearcuts. All twigs in each clump were pooled to obtain sufficient sample for chemical analyses and resulted in n = 10 per treatment and species.

Browse samples were stored frozen until dried by lypholization. We determined average dry mass of twigs in each species/treatment group and ground samples through a 1 mm screen for chemical analyses. We analyzed samples for neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin-cutin (Mould and Robbins 1981), nitrogen (Assoc. Official Anal. Chemists 1970) and gross energy. We multiplied percent nitrogen by 6.25 to estimate percent crude protein. We calculated an index of the DDM content of samples based on fiber analyses using an equation developed for white-tailed deer (*Odocoileus virginianus*) (Robbins *et al.* 1987) and recommended for large cervids (Hanley *et al.* 1992). We did not correct DDM estimates for effects of tannins (Hanley *et al.* 1992) because browse stems contain low tannin concentrations (Robbins *et al.* 1987, Hanley *et al.* 1992). We assumed that %DE and %DDM were equivalent (Mould and Robbins 1982) to estimate DE in kcal/g from %DDM and gross energy (kcal/g). We analyzed for treatment effects for each species using a Mann-Whitney test (Zar 1984).

RESULTS AND DISCUSSION

Effects of glyphosate injury on nutritional quality varied greatly between these two browse species (Table 1). For red maple, DDM and DE were 7% greater (P = 0.003-0.014) in injured than uninjured twigs and were largely the result of lower ADF and NDF concentrations in injured twigs ($P <$ 0.001). Lignin-cutin concentrations were slightly greater (8%) in injured twigs than uninjured twigs (P = 0.016), and increases in lignin-cutin generally reduces fiber and dry matter digestibility (Mould and Robbins 1981,

Table 1. Nutritional quality of glyphosate-injured and uninjured browse from red maple and paper birch collected from regenerating clearcuts in Maine, January 1993. Collections of injured browse were made 17 months (includes one full growing season) after August 1991 treatment with glyphosate.

	Red maple			Paper birch		
	Injured (n = 10)	Uninjured (n = 10)	P	Injured (n = 10)	Uninjured (n = 10)	P
Neutral detergent fiber (%)						
$\overline{X}$	51.7	62.7	<0.001	59.3	55.9	0.011
SE	1.2	0.4		0.5	0.8	
Acid detergent fiber (%)						
$\overline{X}$	39.4	48.0	<0.001	44.3	40.9	0.002
SE	1.0	0.4		0.5	0.6	
Lignin-cutin (%)						
$\overline{X}$	16.0	14.8	0.016	23.9	20.7	<0.001
SE	0.3	0.4		0.4	0.5	
Crude protein (%)						
$\overline{X}$	6.0	3.7	<0.001	6.4	6.3	0.970
SE	0.2	0.4		0.3	0.2	
Gross energy (kcal/g)						
$\overline{X}$	4.67	4.67	0.257	5.43	5.24	0.007
SE	0.02	0.04		0.10	0.02	
Digestible dry matter (%)						
$\overline{X}$	45.2	42.1	0.003	34.4	38.8	<0.001
SE	0.7	0.4		0.5	0.7	
Digestible energy (Kcal/g)						
$\overline{X}$	2.11	1.96	0.014	1.87	2.03	0.014
SE	0.03	0.03		0.05	0.04	

Robbins *et al.* 1987). However, the mean difference in percent lignin-cutin between injured and uninjured twigs was small (1.2 percentage units), and at high lignin-cutin concentrations such as these (14-16%), incremental effects on fiber digestibility are relatively small because of the asymptotic relationship of lignin-cutin concentration in the ADF to ADF digestibility (Mould and Robbins 1981, Robbins *et al.* 1987). Crude protein concentration was low in red maple, but was greater ($P = 0.001$) in injured than uninjured twigs.

In contrast to red maple, DDM and DE for paper birch were 8-11% less ($P < 0.001$) in injured than uninjured browse. Greater fiber concentrations occurred in injured paper birch and accounted for the lower predicted digestibility values. Crude protein content was not affected by injury in paper birch (P = 0.97). We did not statistically analyze effects on twig mass because small twigs often co-occurred with deformed leaves (a sampling criterion). However twig dimensions for sampled injured plants were generally representative of all injured plants on the sites. In red maple, injured twigs ($\overline{X}$ = 0.18 g) tended to be smaller than uninjured twigs ($\overline{X}$ = 0.65 g); whereas, in paper birch twig mass was similar for injured ($\overline{X}$ = 0.31) and uninjured twigs ($\overline{X}$ = 0.33 g).

Glyphosate injury alters the nutritional composition of browse, but because the nature and magnitude of effects differed between the 2 species examined, there does not appear to be a consistent response to injury among browse species. In addition, absolute differences in DE and crude protein between injured and uninjured twigs were relatively small and may not have important consequences for moose nutrition. Digestible energy values for both injured and uninjured browse were in the range of values reported for winter browses commonly used by moose (Hjeljord *et al.* 1982, Risenhoover 1989). Only the protein content of red maple twigs seemed to be a substantially affected (37% reduction) by glyphosate injury. Crude protein content of injured red maple was low (3.7%) and below the range of values reported for winter forages commonly used by moose (Crête and Jordan 1982, Hjeljord *et al.* 1982, Risenhoover 1989). In this study, glyphosate-induced effects on the nutritional quality of injured browse appears to be less important for moose than the relatively large reduction in browse availability in the first few years after treatment (Cumming *et al.* 1995, Raymond *et al.* 1996). Cumming *et al.* (1995) compared the nutritional quality of willow, beaked hazel (*Corylus cornuta*), trembling aspen (*Populus tremuloides*), and red raspberry (*Rubus idaeus*) browse randomly collected in summer and/or winter from glyphosate-treated and untreated sites at 4 and 8 years posttreatment in Ontario. The Cumming *et al.* (1995) study, which may have included a mixture of all types of browse (injured, residual unsprayed, and new growth) in sample collections and the longer-term effects of altered vegetative competition and micro-environmental conditions, reached a similar conclusion that glyphosate has an insignificant effect on browse quality compared to changes in browse availability. Despite the conclusion that browse nutritional quality appears little affected by glyphosate, other factors may determine selection for or against use of injured browse by moose and therefore determine its actual availability as winter food. Use of injured browse may be more a function of plant characteristics that regulate bite size (Gross *et al.* 1993), such as the effects on twig size we observed, or factors that influence foraging decisions at the stand level (Danell *et al.* 1991), such as spatial variation in the density of injured browse on treated clearcuts.

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