Modifying roadside vegetation management practices to reduce vehicular collisions with moose Alces alces

Author: Rea, Roy V.

Source: Wildlife Biology, 9(2) : 81-91

Published By: Nordic Board for Wildlife Research

URL: https://doi.org/10.2981/wlb.2003.030

REVIEW

Because of its applied character, wildlife science needs opportunities to summarise existing knowledge by reviewing, either by presenting leading ideas and results of study teams, or summarising advanced knowledge of selected scientific or management problems.

Modifying roadside vegetation management practices to reduce vehicular collisions with moose *Alces alces*

Roy V. Rea

Rea, R.V. 2003: Modifying roadside vegetation management practices to reduce vehicular collisions with moose *Alces alces*. - Wildl. Biol. 9: 81-91.

Vegetation management practices currently used within transportation corridors are primarily aimed at minimising encroaching shrub and tree growth in order to increase driver visibility and road safety. Such practices create prime foraging habitat for ungulates such as moose *Alces alces* by inhibiting forest succession and maintaining early seral shrub communities. Increased foraging activity within the corridor increases the likelihood of encounters between moose and motorists. Moose-related vehicular collisions are costly in terms of material damage claims and have significant negative impacts on public safety and moose populations in many parts of their range. Although several countermeasures have been developed in an attempt to reduce the frequency of these collisions, few have proven effective and even fewer have taken into consideration possible links between roadside vegetation management, the quality of browse regenerating from cut vegetation, and how moose use browse within the transportation corridor. To better understand these relationships, I reviewed the literature on ungulate-related vehicular collisions in combination with literature on plant response to mechanical damage. Many authors recognise the need to reduce the attractiveness of vegetation growing within transportation corridors. To date, diversionary feeding, forage repellents, establishment of unpalatable species and elimination of roadside brush have been used. Unfortunately, such techniques are only semi-effective or are not cost-efficient when applied across the landscape. It has long been recognised that the ability of plants to regenerate following mechanical damage is influenced by the timing of damage. Current research suggests that the quality of regenerating plant tissues for herbivores also depends on when plants are cut. Plants cut in the middle of the growing season produce regrowth that is high in nutritional value for at least two winters following brush-cutting as compared to plants cut at other times of the year, and uncut controls. Because roadside brush is generally cut during mid-summer, possible links between the quality of regenerated browse and increases in ungulate-related vehicular collisions during the autumn and winter should be elucidated. Based on this review, I recommend cutting brush early in the growing season and emphasize the need for collaborative long-term research to properly address this issue.

Key words: browse quality, brush-cutting, plant response, roadkill, road safety, ungulate, wildlife collision

Roy V. Rea, Faculty of Natural Resources and Environmental Studies, Uni-

versity of Northern British Columbia, 3333 University Way, Prince George, BC, Canada, V2N 4Z9 - e-mail: reav@unbc.ca

Received 8 June 2001, accepted 3 July 2002

Associate Editor: John D.C. Linnell

Vehicular collisions with moose *Alces alces* are currently a serious problem throughout much of the range of moose (Oosenbrug, Mercer & Ferguson 1991, Rattey & Turner 1991, Gundersen & Andreassen 1998). Collisions with moose and other ungulates appear to be on the rise worldwide (Groot Bruinderink & Hazebroek 1996) and have increased by more than 200% in some regions in less than a decade (Cook & Daggett 1995).

It is estimated that 29,000 humans are injured and 211 die annually in the US due to vehicular collisions with deer (the term deer in this work refers to members of the genus *Odocoileus*) alone (Conover, Pitt, Kessler, DuBow & Sanborn 1995). In France, approximately 50 people die and 2,500 are injured in ungulate-related vehicular collisions each year (Groot Bruinderink & Hazebroek 1996). In Sweden, 5-20 deaths and 500 injuries are reported each year as a direct result of moose-related vehicular collisions (MRVCs; Lavsund & Sandegren 1991). In northern New England, one in every 50 MRVCs results in a human fatality (Forman & Deblinger 1998).

Material damage claims following ungulate collisions cost billions of dollars each year; more than USD 50 million were spent on deer collision repairs in a single year in the state of New York alone (Decker, Loconti-Lee & Connelly 1990). The average cost for repairing vehicles can run from USD 4,000 per vehicle following a collision with a deer (Del Frate & Spraker 1991) to USD 15,150 per vehicle following a collision with a moose (Thomas 1995).

Wildlife-related vehicular collisions negatively impact animal numbers (Harrison, Hooper & Jacobson 1980, Cook & Daggett 1995, Thomas 1995) and are considered a long-term threat to populations of ungulates in certain areas (Jackson & Griffin 1998). In Newfoundland, Canada, approximately 4,800 moose roadkills were reported between 1988 and 1994 (Joyce & Mahoney 2001). These numbers are generally considered conservative because up to half of the ungulates killed by vehicles are never reported (Allen & McCullough 1976, Lavsund & Sandegren 1991); animals involved in collisions may wander from the corridor before dying (Moen 1979, Del Frate & Spraker 1991), are salvaged or scavenged (Child, Barry & Aitken 1991) or simply go undetected (Sielecki 2000). In some areas, collisions kill more ungulates than do hunters (Cook & Daggett 1995). In some parts of North America, roadkills are often reported as the chief cause of moose mortality second only to legal hunting (Del Frate & Spraker 1991) and may exceed 10% of the total annual harvest (Belant 1995). On a yearly basis, collisions with moose (automobiles and trains combined) claim approximately 6% of the annual allowable harvest nationwide in Canada (Child 1998).

Animal losses to road traffic can in part be attributed to the placement of human transportation corridors. These corridors tend to be routed through lowlands that follow the natural contours of the land (Thomas 1995) and often bisect or parallel prime habitat and natural routes traditionally used by ungulates and other wildlife for travel and migration (Andersen, Wiseth, Pedersen & Jaren 1991). Because of this overlap, road corridors are an integral part of many species' home range (Case 1978).

Roadsides often comprise remnants of natural vegetation in areas that tend to otherwise be heavily developed. Corridors provide islands and conduits of habitat for a variety of species and are used for feeding, breeding, nesting, dispersal and recolonisation (Bennett 1991). Some species rely exclusively on roadside habitat (Oetting & Cassell 1970, Way 1977). Roadside areas can also harbour feral animals and noxious weeds (Saunders & Hobbs 1991), creating a paradox for managers faced with the task of managing corridors with multiple objectives in mind (Bennett 1991).

Although reindeer *Rangifer tarandus fennicus* and caribou *R. t. tarandus* tend to avoid transportation corridors (Curatolo & Murphy 1986, Klein 1971), many ungulates, including moose (Kelsall & Simpson 1987, Thomas 1995), are known to use corridors for a variety of purposes (Table 1). For example, corridors may be used by ungulates for travel during periods of deep snow, but appear to be used predominantly for feeding (Peek & Bellis 1969, Puglisi, Lindzey & Bellis 1974, Groot Bruinderink & Hazebroek 1996).

Table 1. Various corridor activities engaged in by ungulates.

Corridor activity	Reference
Use of roadside watering holes	Groot Bruinderink & Hazebroek 1996
Use of natural mineral licks, highway de-icing compounds, sodium-rich pools	Grenier 1973, Damas & Smith 1983, Hardy 1984, Jolicoeur & Crête 1994
Use of aquatic feeding areas	Hardy 1984
Insect avoidance	Kelsall & Simpson 1987
Pavement warming	Kelsall & Simpson 1987
Use of roadside cover	Thompson & Stewart 1998
Use for migration and travel (especially in winter when snow is deep)	Andersen et al. 1991, Child et al. 1991, Del Frate & Spraker 1991, Schwartz & Bartley 1991
Loafing	Pils & Martin 1979
Use of edge	Bashore et al. 1985, Finder et al. 1999
Avoidance of hunters	Pils & Martin 1979
Use of roadside vegetation and slash	Pils & Martin 1979, Schwartz & Bartley 1991, see text

Roadside forage

Ungulate activity in utility and transportation corridors increases in spring and autumn and appears to be linked to the utilisation of early greening and late senescing forages that are found in these areas (Harrison et al. 1980, Bashore, Tzilkowski & Bellis 1985, Kelsall & Simpson 1987, Lavsund & Sandegren 1991). These peaks in foraging activity correspond with those times of year when most collisions with moose and other ungulates occur (McDonald 1991, Gleason & Jenks 1993, Sutton 1996, Sielecki 2000). In general, clearings and corridors provide an abundant source of preferred foods for ungulates (Bédard, Crête & Audy 1978, Thompson & Stewart 1998, Finder, Roseberry & Woolf 1999) that are superior in nutritional quality (Hughes & Fahey 1991, Ricard & Doucet 1999) and more spatially concentrated than those found in adjacent woodlands (Carbaugh, Vaughan, Bellis & Graves 1975, Groot Bruinderink & Hazebroek 1996).

The quality and availability of browse along managed roadsides tend to remain relatively constant. This is largely due to roadside brush-cutting that is aimed at increasing sight lines and driver visibility by suppressing plant maturation and forest succession. Although this is done to increase road safety, this practice perpetuates the growth of early successional vegetation that is attractive to herbivores like moose. For this reason, highway transportation corridors have been described as long pastures bisected by highspeed lanes (Bellis & Graves 1971) and serve as foraging grounds for elk *Cervus elaphus* (H. Flygare, unpubl. data), mountain goats *Oreamnos americanus* (Leedy & Adams 1982), bighorn sheep *Ovis canadensis* (Harrison et al. 1980, Leedy & Adams 1982), wild boar *Sus scrofa* (Groot Bruinderink & Hazebroek 1996), bison *Bison bison* (Damas & Smith 1983), deer (Puglisi et al. 1974, Carbaugh et al. 1975, Waring, Griffis & Vaughn 1991), moose (Kelsall & Simpson 1987, Child et al. 1991, Thomas 1995) and other herbivores (Arnold, Weeldenburg & Steven 1991, Bennett 1991).

Ungulates increase their foraging activities between dusk and dawn when they can move about under the protective cover of darkness (Peek & Bellis 1969, Carbaugh et al. 1975). Given that dark coloured animals such as moose are more difficult for motorists to see at night (Moen 1979, Thomas 1995, Sutton 1996), increased foraging activity and ungulate mobility between dusk and dawn are, not surprisingly, intimately tied to peaks in ungulate-related collisions (Carbaugh et al. 1975, Jaren, Andersen, Ulleberg, Pedersen & Wiseth 1991). Ungulate collisions appear to occur consistently between dusk and dawn regardless of the time of year or the ungulate population in question (Grenier 1973, Oosenbrug, McNeily, Mercer & Folinsbee 1986, Rattey & Turner 1991, Waring et al. 1991, Garrett & Conway 1999).

I reviewed the literature on patterns of ungulate-related collisions, plant response to tissue removal and vegetation management in transportation corridors as well as ungulate foraging behaviour. My objective was to elucidate new ways to manage roadside vegetation to reduce corridor attractiveness and moose utilisation of roadsides with an aim to reduce collisions with moose.

Countermeasures

A variety of countermeasures have been used in an attempt to reduce collisions with ungulates (Damas & Smith 1983). Many of these countermeasures, however, have proven ineffective. Deer reflectors, for example, are commonly installed on roadsides in an attempt to scare ungulates but have proven to be ineffective (see Groot Bruinderink & Hazebroek 1996) and cost USD 7,500 per km to install (Sielecki 2000). Exclusionary fencing is extremely effective at keeping ungulates out

of transportation corridors but costs USD 45,000 per km to install. Furthermore, fencing is unsightly, requires frequent repair, and often prevents animals that make it into the corridor from escaping (Kent 1994, Sielecki 2000). In addition, the widespread use of fencing can greatly increase the fragmentation effect of transportation corridors on the movements of various species. On the other hand, managing corridor vegetation in a way that makes the corridor less attractive to species such as moose appears to be a more practical and promising tool for mitigation (Jaren et al. 1991, Lavsund & Sandegren 1991, Gundersen, Andreassen & Storaas 1998).

Planting unpalatable species within the corridor and luring animals away to strategically located feeding areas far from the road is an effective means of reducing wildlife collisions (Harrison et al. 1980, Cook & Daggett 1995, Romin & Bissonette 1996), as is completely eliminating palatable corridor brush such as birch *Betula* spp., poplar *Populus* spp. and willow *Salix* spp. (Jaren et al. 1991, Lavsund & Sandegren 1991). Unfortunately, these strategies are generally cost-prohibitive (Jaren et al. 1991, Sielecki 2000) and, in some cases, destroy habitat for other wildlife on a long-term basis (Oetting & Cassell 1970).

Manipulating the existing forage base within the corridor to produce low-quality browse may be a more cost-effective alternative for deterring feeding within the corridor (Sielecki 2000). Reducing the quality of roadside vegetation can be accomplished through applying noxious chemicals such as lithium chloride directly to the browse (Harrison et al. 1980). However, such strategies tend to be expensive and environmentally unsound. Although previously unreported, stimulating the growth of less palatable roadside browse through more carefully designed brush-cutting may prove less costly and equally, or more, effective.

Plant response to damage

It has long been established that mechanical damage to plants alters plant morphology, chemistry, the overall growth patterns and subsequently, the palatability of plant tissues for herbivores (Bryant, Danell, Provenza, Reichardt, Clausen & Werner 1991, Singer, Mark & Cates 1994). This type of response appears to have evolved as part of a generalised adaptive response against tissue removal by herbivores (Rhoades 1985, Bryant et al. 1991, Whitham, Maschinski, Larson & Paige 1991) but also occurs following other forms of stem breakage or tissue removal, including pruning, wind-breakage, snow press, ice scouring (Danell, Elmqvist, Ericson & Salomonson 1987), and brush-cutting (Oldemeyer & Regelin 1987, Nellemann 1990, Rea 1999). The morphology of current annual shoots (hereafter referred to as shoots) of broadleaf trees and shrubs often changes in response to damage. Plants generally respond to damage by producing large shoots (Willard & McKell 1978, Hjeljord & Grønvold 1988, Rea 1999) or by producing shoots that are more heavily armed (Gowda 1997). Depending on the intensity of damage, the overall architecture of the plant (tree-like vs hedge or shrub-like) may also be altered (Rea 1999).

Plants regenerating from mechanical damage also tend to produce shoots that are chemically different from the shoots of undamaged plants. Some woody browse plants, for example, produce shoots that contain higher concentrations of plant defensive compounds such as tannins, and are less digestible and contain lower concentrations of mineral elements following damage (Scotter 1980, Rhoades 1985), albeit plant chemical responses to damage vary significantly (Bryant, Wieland, Clausen & Kuropat 1985, Rhoades 1985, Singer et al. 1994).

Changes in the leafing phenology of plants also occur in response to mechanical damage. Plants can delay leaf senescence in the autumn and flush leaves earlier in the spring following damage relative to undamaged plants (Danell & Bergström 1985, Rea & Gillingham 2001). These changes alter the availability of leafy vegetation for herbivores at times of the year when nutritious plants are generally scarce (Renecker & Schwartz 1998).

Extensive research on plant response to damage (see Rhoades 1985, Bryant et al. 1991, Whitham et al. 1991) has shown that plant response varies with, among other things, the intensity, timing and frequency of damage (Danell & Bergström 1985, Whitham et al. 1991). For example, the timing of cutting (DeBell & Alford 1972, Harrington 1984, Kays & Canham 1991, Lepage, Pollack & Coates 1991) and clipping (Willard & McKell 1978, Bergström & Danell 1987a) stimulates plants to alter the morphology of browse shoots produced following damage. It has recently been concluded that the timing of browsing affects the chemistry of regenerating shoots and thus their palatability to ungulates (Alpe, Kingery & Mosley 1999), as does the timing of brush-cutting (Rea & Gillingham 2001).

Ungulate forage preferences and the corridor

Ungulates such as moose select browse based predominantly on quality (Thompson & Stewart 1998). Ungulates prefer browse plants that delay leaf senescence

in the autumn and possess large shoots high in digestible energy and protein but low in plant defensive compounds (Bergström & Danell 1987b, Singer et al. 1994). Because late autumn and winter are times of nutritional deprivation for ungulates (Hobbs, Baker, Ellis & Swift 1981), roadside brush-cutting operations that inadvertently stimulate nutritious regrowth may act to increase the attractiveness of roadsides to moose. If corridors become more attractive to moose, roadside utilisation would tend to increase, as would the likelihood of collision.

Inarguably, other landscape features and animal behaviours influence ungulate use of areas such as roadsides (Treweek, Watt & Hambler 1997, Finder et al. 1999) and subsequently the frequency of collision. For example, collisions with moose often occur at distinct locations such as drainages (Thomas 1995) and the outlets of side valleys (Gundersen et al. 1998). The risk of ungulate collisions may also be greater near wooded, rather than open areas such as fields (Damas & Smith 1983). However, some authors report that deer collisions are randomly scattered within transportation corridors, with little concentration according to landscape features (Allen & McCullough 1976, Gleason & Jenks 1993). This suggests that other small-scale attributes such as browse diversity (R.V. Rea, unpubl. data) or other forage-based features of the corridor might influence animal activity.

Design features such as ditch depth and cut slope as well as corridor width may also influence how animals use the corridor (Kelsall & Simpson 1987, McGuire & Morrall 2000). Moose are particularly influenced by corridor width, for example, given that they predominantly use forest edges (Child 1998), and narrower corridors contain relatively more edge per cleared area (Bashore et al. 1985, Finder et al. 1999).

Driver visibility as well as the proximity of animals using the forest edge to the roadbed also varies with corridor width. Edge location in the corridor is generally considered fixed following corridor construction. Because it is not practical to relocate corridor edges, reducing browse attractiveness at the forest edge-corridor interface through post-construction vegetation management practices may be the only practical way to reduce the use of corridor edge by herbivores (Harrison et al. 1980, Damas & Smith 1983, Kelsall & Simpson 1987). Reducing the quality of forages growing near the corridor edge has been recommended by several authors studying the problem of ungulate-related vehicular collisions (Jaren et al. 1991, Cook & Daggett 1995, Ricard & Doucet 1999).

To date, studies on reducing the appeal of roadside forage for reducing ungulate collisions have primarily focused on the removal of browse from corridors. Cutting (Jaren et al. 1991, Lavsund & Sandegren 1991) and steam killing (Schwartz & Bartley 1991) vegetation within transportation corridors, for example, have proven effective (as much as a 56% reduction in train collisions; Jaren et al. 1991), but costly when practised repeatedly (Jaren et al. 1991, Sielecki 2000).

Cutting time as a countermeasure

Although several studies report the effects of the timing of cutting on shrub and tree regeneration, most have focused on how the physical and not the chemical characteristics of shoots and sprouts change following coppicing or silvicultural treatments (Belanger 1979, Kays & Canham 1991, Lepage et al. 1991, Babeux & Mauffette 1994). And while the nutritional quality of browse shoots is generally correlated with shoot morphology (Danell & Bergström 1985), this is not invariably true, particularly in the first two years after cutting when the effects of cutting time are considered (Rea & Gillingham 2001).

It is known that the quality of regenerating shoots of willow *Salix scouleriana* increases in the first two years after cutting when willows are cut during the middle of the growing season. Willows cut in mid-July produce shoots that, when collected in winter, are low in plant defensive compounds (tannin/lignin) and high in digestible energy and protein and delay leaf senescence into late autumn relative to plants cut at other times of the year and uncut controls (Rea & Gillingham 2001). These findings suggest that summer roadside brush-cutting operations could, inadvertently, be stimulating plants to produce nutritious regrowth that is attractive to moose.

Delays in leaf senescence due to roadside brush-cutting could alone be problematic where concerns for collisions with ungulates exist. Moose prefer greener vegetation (Bergerud & Manuel 1968, Hobbs et al. 1981) and, like other ungulates, will concentrate foraging efforts on leaves rather than shoots in autumn as long as leaves are available (Hobbs et al. 1981, Renecker & Schwartz 1998). Delayed leaf senescence in corridor plants could potentially extend the period of increased foraging activity and mobility that moose demonstrate when switching from decomposing summer forages to nutrient-rich browse shoots (Kelsall & Simpson 1987), thereby increasing their exposure to vehicular traffic. Similar problems are likely to occur in the spring given that ungulates are attracted to early-greening road-

side forages (Kelsall & Simpson 1987, Anderson 1991, Renecker & Schwartz 1998) and the timing of brush-cutting alters the timing of leaf flush in spring (Rea 1999).

Altering the timing of brush-cutting can stimulate the production of less nutritious browse by willow (Rea & Gillingham 2001). Cutting plants at a time that reduces plant quality could potentially discourage moose from foraging in the corridor and decrease the probability of collision. Brush-cutting in early June for example, results in the production of browse that is significantly less nutritious for the first two years after brush-cutting than browse produced by plants cut later in the growing season or by uncut controls (Rea & Gillingham 2001). Although it has yet to be tested, cutting immediately following leaf flush could result in the production of even lower quality regrowth. Plant resources flushed into newly expanding leaves would be lost to early cutting before photosynthesis could restore root reserves (Bryant et al. 1991, Kays & Canham 1991). Reduced nutrient stores weaken the plant's capacity for vegetative regrowth and the building of nutrient-rich shoots (Kays & Canham 1991). Plants cut earlier in the year are also less likely to delay leaf senescence when compared to later cutting dates that tend to promote delayed senescence for at least two years after brush-cutting (Rea & Gillingham 2001).

Recommendations

I recommend cutting brush in early spring shortly after woody plants have flushed their leaves. For reasons previously discussed, regrowth from this treatment regime should be lower in nutritional value and palatability for moose relative to plants cut in the middle of the growing season, when most roadside brush-cutting operations are currently carried out. The later in the season that plants are cut, the more likely it is that they will produce nutritious regrowth in the years following brush-cutting. Although regrowth from plants cut later (e.g. autumn) will not be available to moose in the first winter after brush-cutting and is not as nutritious as regrowth from plants cut in July in the second winter after cutting, such regrowth, when available, is more nutritious than regrowth from plants cut early in the year (Rea & Gillingham 2001). Based on my review of the literature, cutting from July to March is not recommended in areas where concerns for collisions with ungulates exist.

Cutting roadside brush in the early spring means that conventional, tractor brush-cutting practices may not be feasible to use. If the corridor is too wet and the ground too soft for tractors to be used, other techniques such as manual brush-cutting may be required. Using manual brush-cutting would not only allow brush management regardless of season but would also allow further experimentation with the height and angle of the stump cut, which is also known to alter plant response (Belanger 1979, Harrington 1984, Babeux & Mauffette 1994). Techniques such as girdling and torching permanently kill woody browse species (Olson, Macrigeanis & Davis 1981, Danell et al. 1987) and could also prove effective means, either alone or in combination with specific cutting times, for reducing the appeal of the roadsides to ungulates. Although 'ecological side-effects' should be considered prior to use, silvicultural herbicides may also prove useful in some situations where other techniques fail to reduce collisions with moose. The use of any or all of these alternatives as countermeasures should be applied across the entire width of the corridor section being treated (including highway medians) and should be closely monitored. This strategy will ensure that the efficacy of the treatment and its implications for road safety can be tested in isolation.

Practices such as cutting only tall-growing plants under corridor utility lines (pers. obs.) should be discouraged. Such practices may promote the growth of low-growing, palatable species in the corridor that must no longer compete with taller plants and can utilise nutrients from the decomposing slash (plant cuttings) of taller cut plants (Payne & Bryant 1998). Furthermore, because slash is attractive to ungulates (Alkon 1961, Renecker & Schwartz 1998), all slash should be mulched or removed from the corridor. Incidentally, similar measures should be considered when more mature vegetation is felled during corridor construction and widening given that the crowns of many tree species are attractive forage for moose (pers. obs.).

Although cutting brush in corridors more than once per season can be expensive, inhibiting regrowth through repeated brush-cutting may also prove feasible (Jaren et al. 1991) if limited to areas where ungulate collisions are recurrent, assuming such management does not simply displace moose to the next section of the corridor. It should be kept in mind, however, that the consequence of multiple cuttings can lead to carbon exhaustion of the plants being cut (DeBell & Alford 1972), killing shrubs and altering roadside plant composition and seral trajectories (Parr & Way 1988, Anderson & Katz 1993). Understanding the effects of repeated cuttings on corridor vegetation is relevant considering that browse diversity appears to influence the number of collisions per site (R.V. Rea, unpubl. data).

Currently, no information exists on changes in plant quality or moose foraging behaviour relative to the

length of the vegetation control cycle (Ricard & Doucet 1999). Although the effects of brush-cutting on plant quality can last for at least five years (Rea 1999), precisely how long the effects of the timing of cutting on quality persist are unknown. Preliminarily, control cycles should be scheduled on a three-year rotation to test the effect of treatments because plants can reassume some characteristics of their pre-treatment growth form in as little as two to three growing seasons following brush-cutting (Rea 1999). Assessing plant response on a yearly basis could help to determine the long-term effects of brush-cutting on plant quality and help to determine how often roadside plants should be cut.

Regardless of the brush management strategy employed, corridor vegetation must be managed in a way that considers both the forage and non-forage values of the corridor for other organisms as well as moose. Even closely-related species of ungulates may respond to similar management strategies in different ways (Kent 1994), emphasizing the need to understand and manage for multiple values (Anderson 1991, Lautenschlager, Bell, Wagner & Reynolds 1998). This may mean concentrating brush management activities in certain sections of the corridor or within a specified distance from the road surface while employing current or alternative practices aimed at conserving other habitat values elsewhere in the corridor.

It must be remembered that these recommendations are based largely on mechanical brush-cutting operations that were tested in a conifer plantation setting. Plantation brush-cutting differs from roadside brush-cutting in two important ways. Firstly, during roadside cutting all plants are removed. In the plantation setting, however, conifers (and deciduous plants that are not in direct competition with conifers; Härkönen 1998) are left uncut and continue to grow, consuming surrounding resources. This makes nutrient acquisition easier for plants cut in plantations versus transportation corridors (Blair 1971) and may, therefore, in part determine the plants ability to compensate for damage. Secondly, although brush in plantations may be cut more than once before the conifers reach a free-to-grow stage, it is rarely cut more than two or three times. Roadside plants, alternatively, tend to be cut back on a regular basis for the life of the corridor. For these reasons, spring cuttings can be implemented but their effects should be tested using long-term monitoring programs to assess the quality of various browse species regenerating from cutting. Because ungulate food preferences and plant responses vary by both species and geographic area (Kelsall & Simpson 1987), indiscriminate implementation of these and future research findings to all possible management areas is not recommended and should be approached with caution.

Conclusions

Current vegetation management practices in transportation corridors are often based on operational and logistical constraints; roadsides are cut when the ground is dry and brush-cutting tractors can be used. Although these maintenance practices are aimed at increasing road safety, they may also inadvertently, create ideal foraging habitat for animals such as moose (Damas & Smith 1983) depending on the time of the year that vegetation management is performed (Fig. 1). Understanding the effects of these management activities in relation to plant response and ungulate behaviour should therefore be considered by agencies responsible for managing vegetation in and near transportation corridors (Cook & Daggett 1995, Romin & Bissonette 1996, Jackson & Griffin 1998). Several authors have suggested that highway authorities, state/provincial and federal agencies, insurance companies, conservation groups and industry must collaborate more closely on research that aims to reduce such collisions (Scotter 1980, Kent 1994, Cook & Daggett 1995, Child 1998) before impacts to animal populations, the danger to motorists and pub-

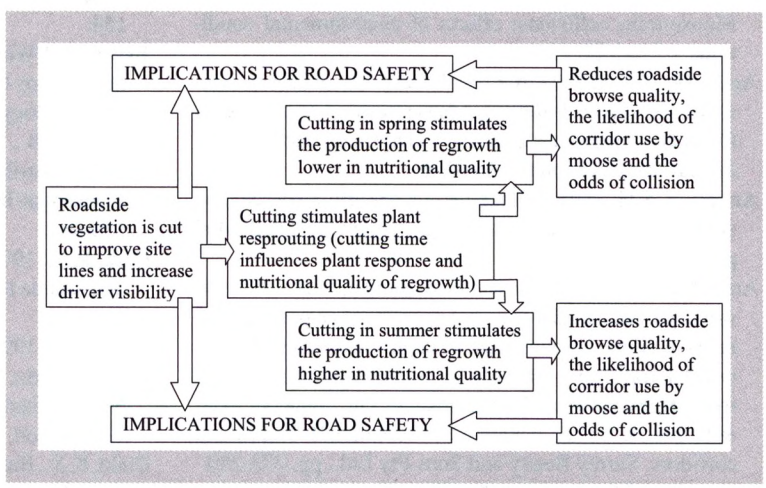

Figure 1. Theoretical relationships developed for application to roadside vegetation management as a result of a review and synthesis of currently published works on ungulate-related vehicular collisions and plant response to the timing of cutting.

lic costs escalate further (Child et al. 1991, Groot Bruinderink & Hazebroek 1996, Thompson & Stewart 1998).

Finally, there will always be a risk of collision where moose and vehicles co-exist (Jaren et al. 1991) and no countermeasure, forage-based or otherwise, will ever completely eliminate MRVCs. However, even a small reduction in collision frequency substantially reduces societal costs and the deleterious effects on animal populations (Gleason & Jenks 1993). In this respect, management strategies aimed at reducing MRVCs can only provide positive returns and should, therefore, be viewed in terms of an investment for current and future generations of both humans and moose.

Acknowledgements - I would like to thank John Vavrik and the Insurance Corporation of British Columbia for funding the research that led to the formulation of the ideas expressed in this paper. I would also like to thank Ken Child, The University of Northern BC, Michelle Oster, Scott Emmons, Julie Ephrom, Kristin Maitland, Dan and Yvonne Rea and the staff at the Shields Library, UC Davis. Additionally, I thank Andreas Seiler and an anonymous referee for their comments on this manuscript.

References

Alkon, P.U. 1961: Nutritional and acceptability values of hardwood slash as winter deer browse. - Journal of Wildlife Management 25: 77-81.

Allen, R.E. & McCullough, D.R. 1976: Deer-car accidents in southern Michigan. - Journal of Wildlife Management 40: 317-325.

Alpe, M.J., Kingery, J.L. & Mosley, J.C. 1999: Effects of summer sheep grazing on browse nutritive quality in autumn and winter. - Journal of Wildlife Management 63: 346-354.

Andersen, R., Wiseth, B., Pedersen, P.H. & Jaren, V. 1991: Moose-train collisions: effects of environmental conditions. - Alces 27: 79-84.

Anderson, R.C. & Katz, A.J. 1993: Recovery of browse-sensitive tree species following release from white-tailed deer Odocoileus virginianus Zimmerman browsing pressure. - Biological Conservation 63: 203-208.

Anderson, S.H. 1991: Managing our wildlife resource. 2nd edition. - Prentice-Hall, Inc. Engelwood Cliffs, N.J., 492 pp.

Arnold, G.W., Weeldenburg, J.R. & Steven, D.E. 1991: Distribution and abundance of two species of kangaroo in remnants of native vegetation in the central wheatbelt of western Australia and the role of native vegetation along road verges and fencelines as linkages - In: Saunders, D.A. & Hobbs, R.J. (Eds.); Nature Conservation 2: The role of corridors. Surrey Beatty and Sons Pty Ltd., pp. 273-280.

Babeux, P. & Mauffette, Y. 1994: The effects of early and late spring cuts on the sprouting success of red maple (Acer rubrum) in northwestern Quebec. - Canadian Journal of Forest Research 24: 785-791.

Bashore, T.A., Tzilkowski, W.M. & Bellis, E.D. 1985: Analysis of deer-vehicle collision sites in Pennsylvania. - Journal of Wildlife Management 49: 769-774.

Bédard, J., Crête, M. & Audy, E. 1978: Short-term influence of moose upon woody plants of an early seral wintering site in Gaspé peninsula, Quebec. - Canadian Journal of Forest Research 8: 407-415.

Belanger, R.P. 1979: Stump management increases coppice yield of sycamore. - Southern Journal of Applied Forestry 3: 101-103.

Belant, J.L. 1995: Moose collisions with vehicles and trains in northeastern Minnesota. -Alces 31: 45-52.

Bellis, E.D. & Graves, H.B. 1971: Deer mortality on a Pennsylvania interstate highway. - Journal of Wildlife Management 35: 232-237.

Bennett, A.F. 1991: Roads, roadsides and wildlife conservation: a review. - In: Saunders, D.A. & Hobbs, R.J. (Eds.); Nature Conservation 2: The role of corridors. Surrey Beatty and Sons Pty Ltd., pp. 99-118.

Bergerud, A.T. & Manuel, F. 1968: Moose damage to balsam fir-white birch forests in central Newfoundland. - Journal of Wildlife Management 32: 729-746.

Bergström, R.K. & Danell, K. 1987a: Effects of simulated winter browsing by moose on morphology and biomass of two birch species. - Journal of Ecology 75: 533-544.

Bergström, R.K. & Danell, K. 1987b: Moose winter feeding in relation to morphology and chemistry of six tree species. - Alces 22: 91-112.

Blair, R.M. 1971: Forage production after hardwood control in a southern pine-hardwood stand. - Forest Science 17: 279-284.

Bryant, J.P., Danell, K., Provenza, F., Reichardt, P.B., Clausen, T.A. & Werner, R.A. 1991: Effects of mammal browsing on the chemistry of deciduous woody plants. - In: Tallamy, D.W. & Raupp, M.J. (Eds.); Phytochemical induction by herbivores. John Wiley and Sons, Inc., New York, USA, pp. 135-154.

Bryant, J.P, Wieland, G.D., Clausen, T. & Kuropat, P. 1985: Interactions of snowshoe hares and feltleaf willow in Alaska. - Ecology 66: 1564-1573.

Carbaugh, B., Vaughan, J.P., Bellis, E.D. & Graves, H.B. 1975: Distribution and activity of white-tailed deer along an interstate highway. - Journal of Wildlife Management 39: 570-581.

Case, R.M. 1978: Interstate highway road-killed animals: a data source for biologists. - Wildlife Society Bulletin 6: 8-13.

Child, K.N. 1998: Incidental mortality. - In: Franzmann A.W. & Schwartz, C.S. (Eds.); Ecology and management of the North American moose. Smithsonian Institution Press, Washington, DC, pp. 275-301.

Child, K.N., Barry, S.P. & Aitken, D.A. 1991: Moose mortality on highways and railways in British Columbia. - Alces 27: 41-49.

Conover, M.R., Pitt, W.C., Kessler, K.K., DuBow, T.J. & Sanborn, W.A. 1995: Review of human injuries, illnesses and economic losses caused by wildlife in the United States. - Wildlife Society Bulletin 23: 407-414.

Cook, K.E. & Daggett, P-M. 1995: Highway roadkill, safety, and associated issues of safety and impact on highway ecotones. - Task Force on Natural Resources (A1F52). Transportation Research Board, National Research Council, 33 pp.

Curatolo, J.A. & Murphy, S.M. 1986: The effects of pipelines, roads, and traffic on the movements of caribou Rangifer tarandus. - Canadian Field Naturalist 100: 218-224.

Damas & Smith Company 1983: Wildlife mortality in transportation corridors in Canada's national parks. Impact and mitigation. - Consultants report to Parks Canada, Ottawa, 397 pp.

Danell, K. & Bergström, R. 1985: Studies on interactions between moose and two species of birch in Sweden: a review. - In: Provenza, F.D., Flinders, J.T. & McArthur, E.D. (Eds.); Proceedings-Symposium on Plant-Herbivore interactions. USDA Forest Service Intermountain Research Station Publication, Ogden, UT, pp. 48-57.

Danell, K., Elmqvist, T., Ericson, L. & Salomonson, A. 1987: Are there general patterns in bark-eating by voles on different shoot types from woody plants? - Oikos 50: 396-402.

DeBell, D.S. & Alford, L.T. 1972: Sprouting characteristics and cutting practices evaluated for cottonwood. - Tree Planters Notes 23 (4): 1-3.

Decker, D.J., Loconti-Lee, K.M. & Connelly, N.A. 1990: Deer-related vehicular accidents in Tompkins county, New York: incidence, costs, and implications for deer management. - Transactions, Northeast Section of the Wildlife Society 47: 21-26.

Del Frate, G.G. & Spraker, T.H. 1991: Moose vehicle interactions and an associated public awareness program on the Kenai peninsula, Alaska. - Alces 27: 1-7.

Finder, R.A., Roseberry, J.L. & Woolf, A. 1999: Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. - Landscape and Urban Planning 44: 77-85.

Forman, R.T.T. & Deblinger, R.D. 1998: The ecological road-effect zone for transportation planning and Massachusetts highway example. - In: Evink, G.L., Garrett, P., Zeigler, D. & Berry, J. (Eds.); Proceedings of the International Conference on Wildlife Ecology and Transportation. FL-ER-69-98, Florida Department of Transportation, Tallahassee, Florida, pp. 78-96.

Garrett, L.C. & Conway, G.A. 1999: Characteristics of moose-vehicle collisions in Anchorage, Alaska, 1991-1995. - Journal of Safety Research 30: 219-223.

Gleason, J.S. & Jenks, J.A. 1993: Factors influencing deer/vehicle mortality in east central South Dakota. - Prairie Naturalist 25: 281-288.

Gowda, J.H. 1997: Physical and chemical response of juvenile Acacia tortilis trees to browsing. Experimental evidence. - Functional Ecology 11: 106-111.

Grenier, P. 1973: Moose killed on the highway in the Laurentides Park Quebec, 1962 to 1972. - Proceedings of the North American Moose Conference and Workshop 9: 155-193.

Groot Bruinderink, G.W.T.A. & Hazebroek, E. 1996: Ungulate traffic collisions in Europe. - Conservation Biology 10: 1059-1067.

Gundersen, H. & Andreassen, H.P. 1998: The risk of moose Alces alces collision: a predictive logistic model for moose-train accidents. - Wildlife Biology 4: 103-110.

Gundersen, H., Andreassen, H.P. & Storaas, T. 1998: Spatial and temporal correlates to Norwegian moose-train collisions. - Alces 34: 385-394.

Hardy, R.A. 1984: Resource management plan moose-vehicle collisions Terra Nova National Park, 20 pp.

Härkönen, S. 1998: Effects of silvicultural cleaning in mixed pine-deciduous stands on moose damage to Scots pine (Pinus sylvestris). - Scandinavian Journal of Forest Research 13: 429-436.

Harrington, C.A. 1984: Factors influencing initial sprouting of red alder. - Canadian Journal of Forest Research 14: 357-361.

Harrison, G., Hooper, R. & Jacobson, P. 1980: Trans-Canada highway wildlife mitigation measures, east gate to Banff traffic circle. - Banff National Park, Parks Canada, Western Region, Calgary, 88 pp.

Hjeljord, O. & Grønvold, S. 1988: Glyphosate application in forest-ecological aspects VI. Browsing by moose (Alces alces) in relation to chemical and mechanical brush control. - Scandinavian Journal of Forest Research 3: 115-121.

Hobbs, N.T., Baker, D.L., Ellis, J.E. & Swift, D.M. 1981: Composition and quality of elk winter diets in Colorado. - Journal of Wildlife Management 45: 156-171.

Hughes, J.W. & Fahey, T.J. 1991: Availability, quality, and selection of browse by white-tailed deer after clearcutting. - Forest Science 37: 261-270.

Jackson, S.D. & Griffin, C.R. 1998: Toward a practical strategy for mitigating highway impacts on wildlife. - In: Evink, G.L., Garrett, P., Zeigler, D. & Berry, J. (Eds.); Proceedings of the International Conference on Wildlife Ecology and Transportation. FL-ER-69-98, Florida Department of Transportation, Tallahassee, Florida, pp. 17-22.

Jaren, V., Andersen, R., Ulleberg, M., Pedersen, P.H. & Wiseth, B. 1991: Moose - train collisions: the effects of vegetation removal with a cost-benefit analysis. - Alces 27: 93-99.

Jolicoeur, H. & Crête, M. 1994: Failure to reduce moose-vehicle accidents after a partial drainage of roadside salt pools in Québec. - Alces 30: 81-89.

Joyce, T.L. & Mahoney, S.P. 2001: Spatial and temporal distributions of moose-vehicle collisions in Newfoundland. - Wildlife Society Bulletin 29: 281-291.

Kays, J.S. & Canham, C.D. 1991: Effects of time and frequency of cutting on hardwood root reserves and sprout growth. - Forest Science 37: 524-539.

Kelsall, J.P. & Simpson, K. 1987: The impacts of highways on ungulates; a review and selected bibliography. - Prepared

for Ministry of Environment and Parks, Kamloops, BC, 105 pp.

Kent, M.J. 1994: Wildlife impact assessment and mitigation for the Okanagan. - In: Radwan, A.E. (Ed.); Roads to the 21st century: A key to competitiveness. International Road Federation Conference and Exposition, Proceedings, Volume 7, Calgary, Alberta, Transportation Association of Canada, Ottawa, Ontario, pp. A.29-A.38.

Klein, D.R. 1971: Reaction of reindeer to obstructions and disturbances. - Science 173: 393-398.

Lautenschlager, R.A., Bell, F.W., Wagner, R.G. & Reynolds, P.E. 1998: The fallingsnow ecosystem project: documenting the consequences of conifer release alternatives. - Journal of Forestry 96: 20-27.

Lavsund, S. & Sandegren, F. 1991: Moose-vehicle relations in Sweden: a review. - Alces 27: 118-126.

Leedy, D.L. & Adams, L.W. 1982: Wildlife considerations in planning and managing highway corridors. - US department of Transportation, Federal Highway Administration Report No. FHWA-TS-82-212, 103 pp.

Lepage, P., Pollack, J.C. & Coates, K.D. 1991: Chemical and manual control of thimbleberry (Rubus parviflorus) in northwestern British Columbia: a rate and timing trial. - Western Journal of Applied Forestry 6: 99-102.

McDonald, M.G. 1991: Moose movement and mortality associated with the Glenn highway expansion, Anchorage Alaska. - Alces 27: 208-219.

McGuire, T.M. & Morrall, J.F. 2000: Strategic highway improvements to minimise environmental impacts within the Canadian Rocky Mountain National Parks. - Canadian Journal of Civil Engineering 27: 523-532.

Moen, O. 1979: Risks of collision between moose and vehicles. - Meddelelser Fra Norsk Viltforskning 3: 41-48.

Nellemann, C. 1990: Vegetation management to improve moose browse in interior Alaska. - M.Sc. thesis, Agricultural University of Norway, Ås, Norway, 48 pp.

Oetting, R.B. & Cassell, J.F. 1970: Effects of interstate corridor mowing on wildlife, snow buildup, and motorist opinion in North Dakota: a preliminary report. - National Research Council, Highway Research Board. Report Number IRN 10063353, pp. 52-59.

Oldemeyer, J.L. & Regelin, W.L. 1987: Forest succession, habitat management, and moose on the Kenai national wildlife refuge. - Swedish Wildlife Research, Supplement 1: 163-179.

Olson, D.P., Macrigeanis, S. & Davis, W.J. 1981: Use of hand-held torches in managing woody vegetation on corridors. - In: Tillman, R.E. (Ed.); Environmental concerns in corridors management. Electric Power Research Institute, Palo Alto, CA, pp. 28.1-28.10.

Oosenbrug, S.M., McNeily, R.W., Mercer, E.W. & Folinsbee, J.F. 1986: Some aspects of moose-vehicle collisions in eastern Newfoundland, 1973-1985. - Alces 22: 377-393.

Oosenbrug, S.M., Mercer, E.W. & Ferguson, S.H. 1991: Moose-vehicle collisions in Newfoundland - management considerations for the 1990's. - Alces 27: 220-225.

Parr, T.W. & Way, J.M. 1988: Management of roadside vegetation: the long-term effects of cutting. - Journal of Applied Ecology 25: 1073-1087.

Payne, F. & Bryant, F.C. 1998: Wildlife habitat management of forestlands, rangelands, and farmlands. - Krieger Publishing Co., Malabar, Florida, 850 pp.

Peek, F.W. & Bellis, E.D. 1969: Deer movements and behavior along an interstate highway. - Highway Research News 36: 36-42.

Pils, C.M. & Martin, M.A. 1979: The cost and chronology of Wisconsin deer-vehicle collisions. - Department of Natural Resources Report 103, 5 pp.

Puglisi, M.J., Lindzey, J.S. & Bellis, E.D. 1974: Factors associated with highway mortality of white-tailed deer. - Journal of Wildlife Management 38: 799-807.

Rattey, T.E. & Turner, N.E. 1991: Vehicle-moose accidents in Newfoundland. - The Journal of Bone and Joint Surgery 73: 1487-1491.

Rea, R.V. 1999: Response of Scouler's willow (Salix scouleriana) to mechanical brushing: implications to the quality of winter browse for Moose (Alces alces). - M.Sc. thesis, University of Northern British Columbia, Prince George, BC, 103 pp.

Rea, R.V. & Gillingham, M.P. 2001: The impact of the timing of brush management on the nutritional value of woody browse for moose Alces alces. - Journal of Applied Ecology 38: 710-719.

Renecker, L.A. & Schwartz, C.S. 1998: Food habits and feeding behavior. - In: Franzmann, A.W. & Schwartz, C.S. (Eds.); Ecology and management of the North American moose. Smithsonian Institution Press, Washington, DC, pp. 403-439.

Rhoades, D.F. 1985: Offensive-defensive interactions between herbivores and plants: their relevance in herbivore population dynamics and ecological theory. - American Naturalist 125: 205-236.

Ricard, J-G. & Doucet, G.J. 1999: Winter use of powerline corridors by moose (Alces alces). - Alces 35: 31-40.

Romin, L.A. & Bissonette, J.A. 1996: Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. - Wildlife Society Bulletin 24: 276-283.

Saunders, D.A. & Hobbs, R.J. 1991: The role of corridors in conservation: what do we know and where do we go? - In: Saunders, D.A. & Hobbs, R.J. (Eds.); Nature Conservation 2: The role of corridors. Surrey Beatty and Sons Pty Ltd., pp. 421-427.

Schwartz, C.C. & Bartley, B. 1991: Reducing incidental moose mortality: considerations for management. - Moose conference workshop, Anchorage, May 17, Alces 27: 227-231.

Scotter, G.W. 1980: Management of wild ungulate habitat in the western United States and Canada: A review. - Journal of Range Management 33: 16-27.

Sielecki, L.E. 2000: WARS Wildlife accident reporting system 1999 annual report (1995 - 1999 Synopsis). - Environmental Management Section, Engineering Branch, B.C.

Ministry of Transportation and Highways, Victoria B.C., 84 pp.

Singer, F.J., Mark, L.C. & Cates, R.C. 1994: Ungulate herbivory of willow on Yellowstone's northern winter range. - Journal of Range Management 47: 435-443.

Sutton, J.E. 1996: Car vs. moose. - Emergency Medical Services 25: 47-50.

Thomas, S.E. 1995: Moose-vehicle accidents on Alaska's rural highways. - Alaska Department of Transportation and Public Facilities, Division of Design and Construction, Anchorage, AK, 58 pp.

Thompson, I.D. & Stewart, R.W. 1998: Management of moose habitat. - In: Franzmann A.W. & Schwartz, C.S. (Eds.); Ecology and management of the North American moose. Smithsonian Institution Press, Washington, DC, pp. 377-401.

Treweek, J.R., Watt, T.A. & Hambler, C. 1997: Integration of sheep production and nature conservation: experimental management. - Journal of Environmental Management 50: 193-210.

Waring, G.H., Griffis, J.L. & Vaughn, M.E. 1991: White-tailed deer roadside behavior, wildlife warning reflectors, and highway mortality. - Applied Animal Behavior Science 29: 215-223.

Way, J.M. 1977: Roadside verges and conservation in Britain: A review. - Biological Conservation 12: 65-74.

Whitham, T.G., Maschinski, J., Larson, K.C. & Paige, K.N. 1991: Plant responses to herbivory: the continuum from negative to positive and underlying physiological mechanisms. - In: Price, P.W., Lewinsohn, T.M., Fernandes, G.W. & Benson, W.W. (Eds.); Plant-Animal Interactions. John Wiley and Sons, Inc. New York, New York, U.S.A., pp. 227-253.

Willard, E.E. & McKell, C.M. 1978: Response of shrubs to simulated browsing. - Journal of Wildlife Management 42: 514-519.