Ameliorating conflicts among deer, elk, cattle and/or other ungulates and other forest uses: a synthesis

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Summary
In many boreal and temperate forests, ungulates are an important feature valued by many stakeholders. However, conflicts often arise due to the use of a forest by both domestic and wild ungulates and other uses such as timber production, recreation and conservation. In this paper, we present and synthesize several concepts and suggestions that have applicability for ameliorating these conflicts. The amount, location and juxtaposition of forage, water, minerals (e.g. salt, molasses blocks) and cover are major determinants of range quality and, in turn, influence how ungulates use forests. Moreover, by strategically dispersing these key elements throughout a landscape will also disperse animal use by decreasing ungulate numbers in a given area thus reducing potential conflicts with other forest uses. Other approaches such as fences, herding, coarse woody debris dispersion, stand regeneration methods and site preparation methods can also be used to influence animal movement and use. By far, the most important aspect of minimizing ungulate conflicts is to integrate their use and requirements into a silvicultural system that is planned, executed and evaluated within and among landscapes and is developed to meet non-conflicting forest management objectives.

Introduction
Deer (elk, moose, reindeer, caribou and others of the family Cervidae), cattle (Bos spp.), sheep (Ovis spp.) and other ungulates are often important features of many forests throughout the world. Their importance ranges from providing subsistence level of food for human consumption to providing lucrative high-priced trophy hunting opportunities (Peterson, 2004; Lindsey et al., 2007). However, conflicts among ungulates (i.e. domestic, semi-wild, wild) living within forests and other uses (e.g. timber production, recreation etc.) frequently occur (Thomas, 1979; Kauffman and Kruger, 1984; Fleischner, 1994). Ungulates can damage trees through browsing, bark stripping, trampling and fraying trees with their antlers. As such, trees can be deformed, growth retarded and, if damage is severe enough, trees can be killed (Crouch, 1966; Gill, 1992). Because of such damage, especially to trees grown for timber, conflicts between animal use and wood production often occur. In addition to this conflict, domestic animal use of forests can conflict with recreational activities, watershed protection or sense of place values (Fleischner, 1994). These kinds of conflicts are heightened when domestic animals use riparian areas and degrade water quality (Kauffman and Kruger, 1984). Similarly, wild ungulates using forests often conflict with farming, ranching and conservation values (Wilkinson, 2000; Heydlauff et al., 2006). Conflicts between cattle and wild ungulate use within a forest can occur, as can conflicts between different species of wild ungulates such as white-tailed deer (Odocoileus virginianus), mule deer (Odocoileus hemionus) and elk (Cervus elaphus) (DePerno et al., 2000; Ager et al., 2005). The larger the number of animals and/or their lack of dispersion, the more likely there will be conflicts among the different types of animals or between the animals and the users of a forest (Fleischner, 1994; Vare et al., 1996; Wilkinson, 2000).

Even though there are a wide variety of ungulates and forests throughout the world, there are several inherent animal traits, habitat preferences and management actions that can be utilized to influence animal behaviour as to minimize the deleterious effects real or perceived ungulates may cause within forests regardless of their location. As such, with this paper, we use information from several continents to describe forest ranges and key elements within them that ungulates use. Over this geographic extent, we describe how ungulates both negatively and positively impact forest establishment and development, show how ungulates use forest elements and synthesize this information into several approaches that show promise in ameliorating ungulate conflicts. Most importantly, we provide innovative
suggestions within the context of a well-planned, executed and integrated silvicultural system. Others have offered solutions for producing timber in the face of ungulate damage (e.g. Boyer, 1967; DeByle, 1985; Putman, 1996); however, the approaches we provide are applicable for a variety of forest management objectives (e.g. timber production, restoration, recreation scenery, etc.). Forest and range mangers can use our suggestions to make informed land management decisions and scientists can see where future research work might be warranted on an ever-increasing information need aimed at minimizing the conflicts among ungulates and other forest values.

Types of forest ranges

Forests produce two types of ranges that ungulates use: permanent and successional (transitory) ranges (Graham et al., 1992; Kuiters et al., 1996; Reimoser and Gossow, 1996). Permanent forest ranges are those typified by grassland savannahs intermixed with individual trees or groups of trees. These permanent ranges are common in the western US and along the foothills of mountain ranges containing temperate forests bordering on grasslands (Anderson and Inouye, 2001). Also, the alpine zone often has abundant permanent ranges such as those dominated by the alpine sedge (Carex curvula) that occurs throughout the European Alpine System (Puscas et al., 2008). In the southwestern US, the tree and shrub lands typified by pinyon pine (Pinus edulis) and juniper (Juniperus spp.) trees also tend to have large amounts of permanent range lands (Youngblood and Mauk, 1985). Similarly, within the transition zone between the upper montane forest and alpine zone within the European Alpine System, where the flora of the forests and alpine grass and sedge heaths meet, considerable permanent ranges occur (Nagy et al., 2003). Historically and currently, many of these unique habitats for ungulates are also popular for domestic animal grazing (Humphrey, 1958; Nagy et al., 2003).

Transitory (successional) ranges are created when a disturbance such as fire, timber harvest, disease or insects kill trees and produce soil and light conditions conducive for the establishment and development of early seral vegetation (Graham et al., 1992; Kuiters et al., 1996). For example, fireweed (Epilobium angustifolium) readily establishes after a fire in the northern Rocky Mountains which is often succeeded by other ground-level vegetation (e.g. sedges, Carex spp., pine grass, Calamagrostis rubescens, quenscup, Clintonia uniflora) which in turn is succeeded by shrubs (e.g. buck brush, Ceanothus spp., huckleberry, Vaccinium spp.; Cooper et al., 1991). Such early seral vegetation supplies abundant food and cover, which many ungulates, both wild and domestic, prefer until it is replaced by trees in later successional stages (Kuiters et al., 1996). The longevity of these transitory ranges, as defined by this early successional vegetation, is dependent on the rate of forest development. For example, within the moist forests of the northern Rocky Mountains and moist forests of western Washington in the US, transitory range longevity can be relatively short (e.g. <10 years) (Cooper et al., 1991; Franklin et al., 2002).

In contrast to the moist forests, transitory ranges in the dry ponderosa pine (Pinus ponderosa) forests of the western US can last for decades (20–60 years) (Hanks et al., 1983). In Europe, after pasture abandonment in the French Alps, over 50 years passed before European larch (Larix decidua) and Swiss stone pine (Pinus cembra) began to dominate the once heathlands and meadows (Didier, 2001). As such, transitory ranges can be rather permanent as a result of chronic disturbances such as grazing and fire. Most likely ungulates maintained the pastures studied by Didier (2001) for at least 2000 years. Similarly, prior to European settlement (e.g. 1900), frequent wildfires in some western ponderosa pine forests in the US perpetuated mixed tree and grassland savannahs (Fischer and Clayton, 1983). In addition, there is evidence that Native Americans augmented natural fire ignition within these pine forests to refresh the ranges and keep them dominated by grasses, forbs and shrubs (Pyne, 1982; Lewis, 1985).

In many forests, timber harvesting is a major creator of transitory ranges especially if the clear-cut silvicultural method is used which allows forbs and grasses to be the first to colonize the open conditions (Reimoser and Gossow, 1996). Also, the timing and intensity of the intermediate (tending) treatments (e.g. cleaning, weeding, thinning) of a silvicultural system have a major impact on the longevity of transitory ranges (Reimoser, 2003; Graham et al., 2005). The associated rise of light availability to the forest floor as the result of tree thinning generally increases the amount of available forage in transitory ranges but does not necessarily increase flora diversity (Decocq et al., 2004). However, in all forest types, once trees dominate a site and high canopy closure is obtained, most range quality is minimal until a mature forest stage is reached. During these older developmental stages, tree canopies tend to thin, allowing light to reach the forest floor, which allows a ground-level plant community to establish, thereby increasing forage availability (Kuiters et al., 1996; Franklin et al., 2002).

Ungulate and forest development interactions

Ungulates have been an integral part of forests for millennia and have contributed to sustaining both the humans and ecosystems (Bedunah and Schmidt, 2000; Laiolo et al., 2004). The growth form, life history dynamics and physiological function of many plant species have developed in response to selection pressures by large herbivores (Putman, 1996). Grazing by ungulates has been shown to locally increase species diversity, produce diverse vegetation types and maintain heterogeneity in the vertical and horizontal distribution of plants, which in turn can lead to greater biodiversity compared with areas not grazed (Bakker et al., 1983; Laiolo et al., 2004). By using different grazing regimes, ungulates have been used in semi-natural woodlands, pastoral landscapes, ancient parkland woods and wood-pastoral settings to maintain traditional land uses.
(Kuiters et al., 1996). These and other examples have led to the assertion that a low level of grazing is considered to have a positive impact on structure and species diversity in many forests (Mitchell and Kirby, 1990).

Domestic cattle, sheep and goats (Capra spp.) frequently forage in forests all year or seasonally depending on the forest location and the availability and amount of forage the forest produces. Many deer species use a particular forest setting all year while other species such as caribou or reindeer often migrate long (>1200 km) distances depending on the climate, the onset of winter and the amount of snow covering their forage (Payette et al., 2004). Ungulates can be grazers that primarily eat grasses and forbs while others are browsers that primarily consume woody plants (Holechek, 1984). They may have a forage preference but most species will consume both grasses and woody plants, and depending on forage availability, both grazers and browsers will consume or damage deciduous and coniferous trees (Rochelle, 1992).

Ungulates can both directly and indirectly damage trees. In addition to browsing tree foliage, ungulates can trample, pull and debark seedlings and rub, bend, fray or otherwise deform saplings and small trees (Adams, 1975; Gill, 1992). The surface soil mixing by ungulates can keep the lower vegetation dominated by forbs which often favours tree-damaging rodents such as mice (e.g. Microtus spp., Peromyscus spp.) and pocket gophers (Geomysidae) (Kingery et al., 1987). However, the cause of tree damage requires careful diagnosis as rodents, diseases, drought and wild and domestic ungulates in combination often damage trees. It is easy to attribute tree damage to one or two ‘obvious’ causes without a thorough analysis (Kingery et al., 1987; Reimoser et al., 1999).

Soil mixing not only provides for rodent habitat, it also provides conditions for the colonization of the site by exotic (alien) plant species (Beckera et al., 2005; Moser et al., 2009). Exotic species, those which are not native to a forest, are often supreme competitors to the native vegetation (Meyer et al., 2008). These species often disrupt or displace native vegetation which can disrupt successional pathways and modify fire regimes (Anderson and Inouye, 2001). For example, in the southwestern US, cheatgrass (Bromus tectorum) has replaced the native grasses in many pinyon/juniper forests (West and Van Pelt, 1987). In shrub-dominated plant communities, the presence of cheatgrass often creates a very flammable continuous fuel bed. In many of these communities, pre-cheatgrass fire return intervals of 60–110 year have been reduced to less than 5 years (Whisenant, 1990). As animals move throughout their range or migrate from one range to another, they have the potential to disperse plant species (which could be exotic) by passing seeds through their gut, carrying them on their coats, or between their hooves, or spitting out seeds after mastication or rumination (Fleischner, 1994; Gill and Beardall, 2001). The transportation of forage (hay) from one location to another by humans also has the potential to spread invasive plants (Gelbard and Belnap, 2003). Even though there are rules preventing the movement of weeds, they are not always enforced. More importantly, not all invasive species such as cheatgrass are considered weeds because the species is palatable and used by domestic livestock (Knapp, 1996).

Not only do exotic plants alter fire regimes and successional pathways, they often severely reduce the quality of the forage available on forest ranges (Sheley et al., 1998). For example, the spotted knapweeds (Centaurea spp.) native to Europe have invaded and displaced native range vegetation throughout the US (Roché, 1999). These lands are severely impacted because grazing animals pass over knapweed in favour of native grasses and herbs thus removing its competition and favouring its abundance (Sheley et al., 1998). Therefore, in transitory and permanent forest ranges, exotic plants are a threat to the amount and quality of the forage available to both wild and domestic animals and, because they disrupt disturbance regimes and plant dynamics, they threaten the existence of many plant communities (Sheley et al., 1998; Anderson and Inouye, 2001).

Forest range elements important to ungulates

Forage

The amount, availability and type of forage, water, cover, minerals (salt) and the physical setting within a forest range interact and subsequently determine the quality and utility of a forest landscape for use by both domestic and wild ungulates (Thomas et al., 1979a; Mysterud and Ostbye, 1999; Ayotte et al., 2008). The quantity of forage on both permanent and transitory ranges is determined by the biophysical conditions of a site (e.g. interaction of precipitation, temperature, sunlight and soils) and the frequency and intensity of disturbances (e.g. grazing, fire, silvicultural practises) which determines the vegetative successional pathways and the rate of succession (Didier, 2001; Laiolo et al., 2004). In addition, the vegetative successional stage of a forest range determines whether the forage is dominated by forbs, grasses, shrubs or other vegetation (Cooper et al., 1991; Kuiters et al., 1996; Franklin et al., 2002, Decocq et al., 2004).

The suitability of a range for grazing and/or browsing is dependent on the ungulate species and its forage preference (Thomas et al., 1979a; Van Rees and Hutson, 1983; Johnson et al., 2005b). Even when an animal prefers one type of forage over another, they often will consume a variety of non-preferable woody and succulent vegetation depending on what is presented (Holechek, 1984; Gill, 1992). Moreover, the size and vegetative condition of shrubs often determines their value as forage (Gill and Beardall, 2001). As shrubs age and develop, their stems become decadent and the amount of new growth each year can be minimal, making them poor quality forage (Holechek, 1984). If the palatable portion of a tall shrub is beyond the reach of a browsing animal, they may look for alternate food sources such as trees, exacerbating timber production and animal use conflicts (Rutherford, 1979; Rochelle, 1992).
Water

Water, in conjunction with the quantity and quality of forage present in a range, also determines the overall usability of a forest setting by ungulates (Senft et al., 1987). Where water is relatively scarce in the southwestern US, elk tend to use habitats within 1.6 km of water and white-tailed deer select areas within 0.4 km of water (Rosenstock et al., 1999). In general, an adult domestic cow needs 45–57 l of water per day and they usually remain within 1.6 km of a water source (Ganskopp, 2001; Spörndly and Wredle, 2005). The source of the water may be from springs, streams, lakes and rivers or from developed sources for animal use (Rosenstock et al., 1999; Marshal et al., 2006). Developed water sources include constructed ponds and reservoirs that range from small earthen depressions that capture rainwater to the damming of streams to create large (multiple hectares in size) pools of water (Porath et al., 2002; Marshal et al., 2006). The smallest water developments are tanks usually made of metal, wood or plastic and hold in the range of 400–76 000 l. Such tanks can capture and store well, rain and spring water and in some circumstances transported water (Pearson et al., 1969; Willms et al., 2002). Especially small tanks offer flexibility of locating water strategically throughout forest ranges.

Minerals

Salt dependency appears to be shared by all ruminants and some non-ruminant herbivores (e.g. rabbits, Leporidae) with sodium, carbonate, magnesium and sulfate critical to maintain the health of wild ungulates (Fraser and Reardon, 1980). Salt licks are used by all North American species of wild ungulates and lick use appears to compensate for mineral deficiencies or imbalances in ungulates and decrease the adverse effects of digestive disorders and toxic plants (Ayotte et al., 2008). In forests, these minerals can be found in both wet and dry licks. Wet licks are associated with groundwater springs that bring the minerals to the earth’s surface as water passes through underlying rocks. Dry licks usually occur along streams or riverbeds where unweathered deposits of soluble elements have concentrated above less impervious layers and become exposed by soil erosion (Ayotte et al., 2006). Minerals are used by wild ungulates throughout the year but are especially critical during the spring when they transition from low-quality winter forage to the more nutritious spring forage.

Salt has been provided as a feed supplement to cattle for over 2000 years. Cattle appear to have an innate desire to consume quantities of salt even though the actual requirement for salt to maintain cattle health is rather low and below or comparable to that of non-ruminant animals such as rats (Rattus spp.), pigs (Sus spp.) and chickens (Gallus spp.) (Morris, 1980). Strategically placing salt within large pastures is frequently used to disperse animal use (Ganskopp, 2001). In addition, the necessary mineral requirements for cattle health and for that matter many wild ungulates are often sufficiently provided for in their feed and/or water (Morris, 1980; Coppock et al., 1988). Liberal salt feeding does not appear to cause adverse physiological responses (e.g. regurgitation and diarrhoea followed by circling and blindness) in cattle as long as adequate water is available.

Cover

Cover includes anything which influences climate, predation risk, food quantity and quality and can include vegetation and topographical location (Mysterud and Østbye, 1999). Vegetative cover includes both ground-level and high canopy cover which influences the security of an animal and climate of a setting (Thomas et al., 1979a; Rosenstock et al., 1999). Vegetative cover influences temperature, wind speed, radiation, snow depth, snow consistency (e.g. fluffy, dense, crusty) and juxtaposition of snow banks that occur on a site. In general, these factors, along with the ability of vegetation to intercept both rain and snow, offer protection to animals from heat loss and is often referred to as thermal cover (Mysterud and Østbye, 1999). However, a thermal cover benefit for deer and elk attributed to dense forest cover is probably not operative across a considerable range of climate including those in boreal ecosystems of the northeastern United States, maritime ecosystems of the inland Pacific Northwest and cold, dry ecosystems of the central Rocky Mountains (Cook et al., 2005). Heat stress has been shown to affect the performance of high-producing milk cows but heat within the montane forest zones of the northwestern US has not been shown to impact the performance (e.g. birth rates, mortality) of elk even if shade was unavailable (Young, 1988; Merrill, 1991).

The term ‘hiding cover’ generally refers to the role that vegetative cover plays in preventing predators from spotting, harassing and attacking prey or in other terms, providing them security (Thomas et al., 1979a; Mysterud and Østbye, 1999). Hiding cover is of particular importance to animals that are hunted for both sport and food. Domestic animals often use protected areas along stream courses and along valley bottoms more frequently than upland settings. These protected areas provide a respite from the heat and some protection from wind (Kauffman and Kruger, 1984). However, canopy openings and riparian areas used by domestic livestock are more likely related to the availability of forage rather than offering protection from adverse weather (Van Rees and Hutson, 1983).

How ungulates use forest range elements

Forage, water, minerals and cover are the determinants of the quality and quantity of range for sustaining populations of ungulates (Senft et al., 1987; Rosenstock et al., 1999; Ayotte et al., 2008). The amount of each element is significant to range integrity but their distribution and juxtaposition are also important (Ganskopp, 2001). The rarity of an element in a forest most often determines the intensity of its use and is especially true for forage (Graham et al., 1992). How rare food is in a landscape can be viewed in two ways. For example, small openings in a dense forest which contains early seral forbs, grasses,
shrubs or deciduous sprouts will attract both grazing and browsing ungulates because the forage is rare in an otherwise tree-dominated landscape (Shepperd, 2001). In the western US, quaking aspen (Populus tremuloides) sprouts readily after disturbance (e.g., timber harvest, fire) but very often such regeneration is browsed by elk to such an extent that few sprouts develop into trees (DeByle, 1985). Not only are animals attracted to rare occurrences of food in large landscapes but they are also attracted to less or secondary palatable plants when the preferred vegetation is rare (Gill, 1992). For example, solitary trees planted after timber harvests are often located in areas devoid of any competing vegetation (Rochelle, 1992). As a consequence, the only green plants in the disturbed areas are the planted trees and both wild and domestic animals will often pull the seedlings from the planting spots or browse the foliage (Kingery et al., 1987; Reimoser and Gossow, 1996). Rare water sources within forested landscapes, especially if associated with forage, often concentrates animal use (Fleischner, 1994; Marshal et al., 2006). The herding or grouping instinct in both domestic and wild ungulates can exacerbate such animal behaviour (Bouissou et al., 2001).

Water and forage are major determinants of how animals use a range but cover and its transition to openings are important determinants of range quality (Senft et al., 1987; Ganskopp, 2001). These transitions or forest edges along with their inherent ecotones are rich in wildlife, both in numbers of individuals and number of species (Thomas et al., 1979b). The greatest forage utilization by elk and deer in the northern US occurs within ~125 m of a forest edge (Rochelle, 1992). Cover, combined with its location and juxtaposition to water, forage and salt, influences how an ungulate moves through its range (Ganskopp, 2001). During hunting seasons, cover often dictates animal movements and as hunting seasons begin animals tend to move to areas that give them security (Lyon, 1979; Johnson et al., 2005a). But how cover is used by ungulates can be highly variable even within a given species. Some moose (Alces alces) have been known to select areas for calving with minimum cover to favour the visual sighting of predators while others select areas with abundant forage and plentiful hiding cover (Poole et al., 2007).

Suggestions for avoiding ungulate conflicts within forest ranges

Even though ungulates are inherent and have positive influences to forests of the world, their presence and impacts often conflict with other forest uses such as conservation, tourism, recreation and water production (Fleischner, 1994). Moreover, the concept of ‘damage’ and ‘benefit’ depends on resource targets set by different interest groups. The many land users with different objectives for the same land area (e.g., foresters, hunters, farmers, tourists and conservationists) add to the forest-ungulate problem (Reimoser, 2003).

Ungulates negatively impacting the production of timber or other forest products were noted as early as the middle of the 17th century (Evelyn, 1664; Gill, 1992; Putman, 1996). These conflicts can be exacerbated when policy decisions are aimed at maximizing both animal and timber production. This is especially true when one agency controls animal numbers and another agency controls land use as is the case in much of the western US (Thomas, 1979). For example, the US Forest Service manages forests (habitat) while elk and deer populations are controlled by states such as Arizona and South Dakota (DePerno et al., 2000; Heydlauff et al., 2006). In addition, diagnosing or ascertaining the cause of tree damage and/or mortality caused by ungulates is often uncertain and often intermixed with other causal agents such as rodents and weather (Kingery et al., 1987; Reimoser et al. 1999). Even though, the conflicts between ungulates and other uses within forests are very complex and difficult to ascertain, we offer some suggestions that we feel can be used to lessen these conflicts.

Animal numbers

Controlling animal numbers has the potential for decreasing ungulate conflicts within forests. However, there is poor correlation between the number of cattle using a range and the damage they cause to trees or riparian areas. Reducing cattle numbers who are using riparian areas has been shown to reduce damage (e.g., loss of stream side cover, sloughing of stream banks, urine and dung pollution) to the forest streams but selectively culling individuals (e.g., dominant cows) has also been shown to reduce riparian damage (Kauffman and Kruger, 1984). Nevertheless, Fleischner (1994) argued that total cattle removal was necessary for riparian areas to recover from being used by cattle. Within transitory ranges in Japan, Nakata et al. (1968) reported unacceptable damage to birch (Betula spp.) plantations when grazed by cattle at an intensity of 198 cow days ha⁻¹ but acceptable tree damage levels were observed when similar plantations were grazed at an intensity of 91 cow days ha⁻¹. In contrast, in the southern US, 0.05 cow ha⁻¹ grazing within a longleaf pine (Pinus palustris) plantation yearlong for 5 years killed 23 per cent of the seedlings and damaged another 13 per cent (Boyer, 1967). In addition to describing grazing intensity by animal numbers, forage utilization is frequently used. The tree damage observed by Boyer (1967) occurred when forage utilization was relatively light (21–29 per cent) and Kingery et al. (1987) in northern Idaho found less than 6 per cent of the of newly planted seedlings damaged by cattle with forage utilization ranging between 68 and 81 per cent.

In most of Fennoscandia, semi-wild reindeer numbers are controlled, however, often at high population levels (Vare et al., 1996). Similarly, in the US, high numbers of deer and elk are often desired in many locales because of the economic benefit they provide from hunting permit sales and associated hunting activities (e.g., lodging, transportation, etc.; Heydlauff et al., 2006). Even if wild ungulates numbers are controlled, ungulate conflicts with other forest uses may not be reduced. In most temperate systems, the actual density of large herbivores is relatively low and the correlation between ungulate density and tree
damage is often very weak (Gill, 1992; Putman, 1996). For example, Reimoser and Gossow (1996) found a negative correlation between game density and browsing damage which appeared to be primarily a function of forest structure. As such, tree damage caused by both wild and domestic ungulates is not readily controlled by modifying animal numbers and other methods may produce better results.

Dispersal

Ungulate dispersal throughout forested ranges generally will decrease the conflicts between animal use and other forest uses especially if range element (e.g. water, forage, minerals) rarity is minimized (Graham et al., 1992; Ganskopp, 2001). In both transitory and permanent ranges, the general management concept to decrease ungulate and other forest conflicts is to disperse animals throughout the extent of their range so no one locale is over used by animals for foraging, bedding or resting.

Transitory ranges with their early successional vegetation and riparian areas are preferred areas for ungulates to concentrate which often causes tree damage and/or other conflicts (Fleischner, 1994; Kuiters et al., 1996). Created openings in the range of 4–16 ha favour cattle and elk use as do forest edges (Thomas et al., 1979a, b; Reimoser and Gossow, 1996; Wisdom et al., 2005). Therefore, dispersing early vegetative successional stages and forest edges throughout a forested landscape, and avoid making either of these elements rare, will provide opportunities for animal dispersal and potentially reduce damage to timber crops (Reimoser, 2003). If these preferred ungulate habitats are integrated into landscapes containing meadows, arable fields and/or settlements, their importance as the preferred ungulate habitat will decrease (Reimoser and Gossow, 1996). Depending on the amount of high forest cover in permanent ranges, timber harvesting would have a minimal impact on forage production and the other methods of encouraging animal dispersal would take precedent (Ganskopp, 2001).

Water sources for animals are usually more fixed in forested landscapes than forage, minerals or cover. Because stream courses and their associated riparian areas provide both forage and water, they are the most difficult from which to disperse animals (Fleischner, 1994; Marshal et al., 2006). However, providing quality water through the use of tanks and ponds in conjunction with dispersing forage within forest ranges has the potential to increase animal distribution and reduce animal overgrazing and concentrations within riparian areas (Bleich et al., 2006). In particular, Ganskopp (2001) showed that by moving water throughout a range, cattle would tend to follow the water movement and forage within 250 m of the water. Similarly, Zeigenfuß et al. (2002) suggested that elk would respond to water developments and decrease their use of riparian areas. In contrast both mule deer and elk in Montana did not appear to modify their movements in response to the availability of water; however, cattle did respond (Mackie, 1970).

Throughout the world, wild ungulates are attracted to naturally occurring ‘mineral licks’ for reasons which are not entirely clear (Fraser and Reardon, 1980). In addition, domestic ungulates have an innate desire to consume salt and other minerals (Morris, 1980). Herbivores living in areas well removed from marine influence generally have little sodium in their diet and are attracted to salt (Fraser and Reardon, 1980). With the exception of ranges located within marine air, strategically placing salt and/or minerals within foraging areas has the potential to disperse animal use (Morris, 1980; Ayotte et al., 2008). By colocating water tanks and mineral blocks (4.5 m apart) 500 m from a stream in a forested range in Oregon decreased the number of cattle using the adjacent riparian area. This dispersion was most pronounced in the spring of the year when forage was abundant (Porath et al., 2002). Similarly, in Montana, salt dispersed throughout an elk range was effective in reducing animal concentrations (Cooney, 1952). In addition to salt, mineral supplements alone or in combination with salt can be used to modify ungulate behaviour (Bailey et al., 2008). Low-moisture blocks (LMBs) are molasses-based supplements that contain fat, provide energy and can be used to entice cattle to visit rugged forested areas they would not normally use. Cattle have traveled over 4 km a day to reach LMB and tended to spend time resting in the area of the blocks, which further reduced their time spent near water and within foraging areas (Bailey et al., 2008).

Each class (e.g. yearlings, cow–calf pairs) of domestic cattle has traditional grazing patterns and this trait can be used to disperse animals throughout forest ranges (Graham et al., 1992; Boussou et al., 2001). For example, by releasing cow–calf pairs at different places within a forest range at the beginning of each grazing season will entice them to develop diverse grazing patterns (Mendl and Held, 2001). Changing from grazing cow–calf pairs to yearlings on a range will also alter how forage is utilized as yearling cattle are supreme non-conformists. Placing yearling cattle on a range without a cow or cows is similar to letting teenage boys roam freely in a large shopping mall without adult supervision. Herders can also be used to move stock from one portion of the range to another during the grazing season (Graham et al., 1992).

Type of livestock

Each type of livestock (e.g. cattle, sheep, goats) has a different forage need, grazing pattern and management requirement (Mackie, 1970; Bakker et al., 1983; Plumb and Dodd, 1993). Changing the type of livestock using an area will allow flexibility in the amount and kind of forage consumed and the damage caused to tree seedlings. Domestic sheep graze more efficiently than cattle and can graze on steeper slopes and generally cause less damage to trees because they do not rub and trample trees as readily as cattle (Adams, 1975). In addition, because sheep are small, they tend not to damage tall seedlings and sapling-sized trees (Graham et al., 1992). However, grazing of young plantations by either cattle or sheep may
not be compatible with minimizing tree damage (Adams, 1975).

Exclusion

A variety of methods can be used to restrict and/or deter animals from moving within their ranges or impacting desired structures or conditions (e.g. seedling, riparian area, urban area). Permanent forest ranges can be divided into pastures using fences allowing the timing and intensity of forage utilization to be controlled. Pastures can be rested and rotated among grazing seasons or within one grazing season (Graham et al., 1992; Karhu and Anderson, 2006). A rest/rotation grazing system for cattle pastures in Montana was very compatible with managing elk herds (Frisina, 1992). Because woven (15- to 30-cm square mesh) fences for controlling deer, elk and other wild ungulates need to be tall (~2.4 m), elastic and are expensive (e.g. $3000–5000 1993-USD km^{-1}) to build and maintain (e.g. frequent to weekly inspections), the use of fences to control wild ungulates is problematic. However, in many areas of the western US, fences have been used to protect quaking aspen sprouts from intense elk browsing and fenced pastures have been used in Fennoscandia to manage semi-domesticated reindeer (Bryant et al., 1993; Shepperd, 2001; Helle and Jaakkola, 2008).

Fences have been used to protect stream courses and forest plantations from cattle and in some situations wild ungulates (Zeigenfuss et al., 2002; Karhu and Anderson, 2006). Fences need to stay in place until trees are of sufficient size (e.g. 3–5 cm d.b.h. and/or taller than feeding height of the ungulate browser) to withstand animal damage (e.g. browsing, rubbing, trampling) (Adams, 1975; Gill, 1992, Duddies and Edge, 1999). Similarly, individual trees can be protected with both chemical and physical barriers. For instance, polypropylene mesh tubes can be used to protect small seedlings as well as the terminal leaders of established trees from browsing. These protections are costly, often difficult to apply and require maintenance to ensure they do not interfere with tree development. Repellents made of bone meal or putrefied egg solids or fish have been found successful in preventing browsing of seedlings by ungulates, but their reapplication may be necessary over several years (Duddies and Edge, 1999).

Silvicultural systems and methods applicable for managing forest ranges

Assimilating ungulates into forests is yet another objective for which the practise of silviculture is well suited, and systems and methods can be developed to facilitate this integration (Schlich, 1906; Nyland, 2002; Graham et al., 2005; Puettmann et al., 2008). Even though the practise of silviculture, and its inherent methods, have been honed and developed for over a century to primarily produce forest crops, innovative systems can be developed to meet a variety of objectives ranging from sustaining wildlife habitat to maintain a ‘sense of place’ within forests that many humans cherish (Graham and Jain, 2004). Baker (1934) suggested that silvicultural systems (e.g. clear-cut, shelterwood, selection) are often confused with rigidity when actually they can be as flexible as the silvical conditions require. He further stressed that there are not 3 or 4 or 10 or a 100 separate and discrete silvicultural systems, rather silvicultural systems are more or less classifications of the almost infinite number of possible combinations under which a forest may be tended. Most importantly, a silvicultural system does not stop with a regeneration harvest but it outlines a series of treatments through the life of a forest to create and maintain desired conditions (Nyland, 2002). In addition, silvicultural systems can, and should, include all forest attributes (e.g. forest floor, snags, down wood, wildlife, decadence, etc.) and be adaptive to changing forest conditions and disturbances (Franklin et al., 2002; Graham and Jain, 2005; Puettmann et al., 2008). As such, silvicultural systems can be developed and implemented for ungulate–forest–environment–human systems (Reimoser, 2003).

Regeneration methods such as clear-cut, group selection and seed tree which remove the majority if not all high forest cover will create early seral vegetation that favour ungulate use, especially if the treatments are small and abundant edge is present (Thomas et al., 1979a, b; Cooper et al., 1991; Kuiters et al., 1996; Reimoser and Gosow, 1996; Franklin et al., 2002; Decocq et al., 2004). In contrast, individual tree selection systems, because they maintain high forest cover, can be used to minimize early seral vegetation which will disuade animal use (Graham et al., 1992; Reimoser, 2003; Graham and Jain, 2005). Key components of silvicultural systems are intermediate treatments such as cleanings, weedings and thinnings that also need to be planned and executed to maintain desired conditions over time (Reimoser, 2003; Graham et al., 2005). In addition to having application for mitigating ungulate and other forest use conflicts, individual and irregular selection systems can produce conditions ‘closer to nature’ which many forest stakeholders desire (Reimoser, 2003; Graham and Jain, 2005).

The site preparation used to establish tree regeneration determines the amount of forest floor disturbance and the amount and kind of forage available for animal use (Graham et al., 2005). Site preparation strategies used for artificial regeneration (planting) can have inadvertent consequences for animal use. Hand grubbing or clearing (scraping) small areas of competing vegetation to plant individual trees is a common practise (Graham et al., 2005). But these ready-made ‘steps’ can be used by cattle, elk and deer as they move through plantations, encouraging them to trample and/or browse the planted seedlings (Graham et al., 1992). In addition, machine site preparations (e.g. slash windrows, sod raking) provide animal travel ways which also promotes animal damage to seedlings (Kingery et al., 1987). Severe prescribed fires and herbicides often leave a rather barren forest floor in which trees are planted. As mentioned before, the planted trees are often the rare green foliage on the site that will attract animals and the damage they cause (Graham et al., 1992; Reimoser and
Gossow, 1996). However, by leaving 10–15 metric tons of large (>8 cm diameter) woody debris per hectare has been shown to decrease forage utilization and, in turn, decrease damage to planted seedlings. By creating heterogenous forest floor, tree, woody debris and ground-level vegetation complexes will also minimize animal concentrations and subsequent seedling damage (Graham et al., 1992).

Conclusions

The keys to mitigating ungulate conflicts with other forest uses is to avoid creating rarity of desirable animal habitat features, disperse animal habitat features throughout landscapes and, most importantly, integrate animal use and their impacts into the design and implementation of silvicultural systems (Reimoser and Gossow, 1996; Reimoser, 2003). In addition, by including stakeholder expectations, whether from a forest product or wild game perspective into a silvicultural system, a more holistic solution may be achieved (Reimoser, 2003). Spatially explicit information illustrating how forest structures and compositions would change over time as the silvicultural system is applied can encourage stakeholder participation (Graham et al., 2007). Also spatial information can show the complexity of how ungulates use diverse landscapes over time and space and aid conflict resolution (Sandström et al., 2003).

Forest stands are usually the basic unit at which silviculture is practised, but herbivore foraging most often operates at larger and over multiple spatial scales (Senft et al., 1987; Nyland, 2002; Ager et al., 2005). As such, a silvicultural system (a planned series of treatments through the life of a forest) that will mitigate ungulate and other forest use conflicts needs to be applied at the landscape level or at least recognize how the created and maintained forest structures and compositions will function within the surrounding landscape. Such landscapes can include, but are not limited to, semi-natural woodlands, pastoral settings, parklands, riparian areas, patches of early seral vegetation, water developments, salt placement and dense forest patches (Senft et al., 1987; Kuiters et al., 1996). In addition, Puettmann et al. (2008) suggested that forests be managed as complex adaptive systems and allow stands to develop within an envelope of all possible conditions. Creating and maintaining such complex forests and landscapes would invariably minimize the conflicts between ungulates and other forest uses.

The presence and quantity of the above landscape elements not only influence how ungulates use forest ranges but also their location and juxtaposition are major determinants of ungulate use (Graham et al., 1992). Forage and habitat edge within transitory ranges can be actively managed and located to influence ungulate use as can salt and to some extent water (Thomas et al., 1979b; Ganskopp, 2001; Porath et al., 2002; Reimoser, 2003). The location, distribution and juxtaposition of these elements along with fencing have successfully altered the distribution of cattle and have had some success with modifying the dispersal of elk and deer (Mackie, 1970; Duddies and Edge, 1999; Zeigenfuss et al., 2002).

Successful forest management requires ecologically sound silvicultural systems that are innovative, socially acceptable, adaptable and applicable on a landscape level (Graham and Jain, 2004; Puettmann et al., 2008). Animal use conflicts occurring within a forest often have their genesis in conflicting management objectives arising among different agencies, land owners and stakeholders (Reimoser, 2003). The resolution of such conflicts will increase the likelihood of finding silvicultural solutions for minimizing animal use conflicts on both transitory and permanent forest ranges.

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Conflict of Interest Statement

None declared.

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