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

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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 rangelands (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*, queenscup, *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 (*Geomyidae*) (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 Østbye, 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 northwestern 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 been 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; Bouissou *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 silvicultural 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 Gossow, 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 dissuade 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 forge 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 (scalping) 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 heterogonous 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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References

Adams, S.N. 1975 Sheep and cattle grazing in forests: a review. *J. Appl. Ecol.* **12**, 143–152.

Ager, A.A., Preisler, H.K., Johnson, B.K. and Kie, J.G. 2005 Movements and habitat use of rocky mountain elk and mule deer. In: *The Starkey Project: A Synthesis of Long-Term Studies of Elk and Mule Deer*. M.J. Wisdom, tech. ed. Alliance Communications Group, Lawrence, KS, 139–149.

Anderson, J.E. and Inouye, R.S. 2001 Landscape-scale changes in plant species abundance and biodiversity of a sagebrush steppe over 45 years. *Ecol. Monogr.* **71**, 531–556.

Ayotte, J.B., Parker, K.L. and Gillingham, M.P. 2006 Chemical composition of lick soils: functions of soil ingestion by four species of ungulate species. *J. Mammal.* **87**, 878–888.

Ayotte, J.B., Parker, K.L. and Gillingham, M.P. 2008 Use of natural licks by four species of ungulates in northern British Columbia. *J. Mammal.* **89**, 1041–1050.

Bailey, D.W., VanWagoner, H.C., Weinmeister, R. and Jensen, D. 2008 Comparison of low-moisture blocks and salt for manipulating grazing patterns of beef cows. *J. Anim. Sci.* **86**, 1271–1277.

Baker, F.S. 1934 *The Principles of Silvicuture*. McGraw-Hill, New York.

Bakker, J.P., De Bie, S., Dallinga, J.H., Tjaden, P. and De Vries, Y. 1983 Sheep-grazing as a management tool for healthland conservation and regeneration in the Netherlands. *J. Appl. Ecol.* **20**, 541–560.

Beckera, T., Dietza, H., Billetera, R., Buschmanna, H. and Edwards, P.J. 2005 Altitudinal distribution of alien plant species in the Swiss Alps. *Perspect. Plant Ecol. Evol. Syst.* **7**, 173–183.

Bedunah, D.J. and Schmidt, S.M. 2000 Rangelands of Gobi Gurvan Saikhan National Conservation Park, Mongolia. *Rangelands*. **22** (4), 18–24.

Bleich, V.C., Andrew, N.G., Martin, M.J., Mulcahy, G.P., Pauli, A.M. and Rosenstock, S.S. 2006 Quality of water

available to wildlife in desert environments: comparisons among anthropogenic and natural sources. *Wildl. Soc. Bull.* **34**, 627–632.

Bouissou, M.-F., Boissy, A., Le Neindre, P. and Veissier, I. 2001 The social behaviour of cattle. In: *Social Behaviour in Farm Animals*. L.J. Keeling and H.W. Gonyou (eds). CABI Publishing, CAB International, New York, pp. 113–145.

Boyer, W.D. 1967 Grazing hampers development of longleaf pine (*Pinus palustris*) seedlings in southwestern Alabama. *J. For.* **65**, 336–338.

Bryant, L.D., Thomas, J.W. and Rowland, M.M. 1993 *Techniques to Construct New Zealand Elk-Proof Fence*. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, p. 17.

Cook, J.G., Irwin, L.L., Bryant, L.D., Riggs, R.A. and Thomas, J.W. 2005 Thermal cover needs of large ungulates: a review of hypothesis tests. In: *The Starkey Project: A Synthesis of Long-Term Studies of Elk and Mule Deer*. M.J. Wisdom, tech ed. Alliance Communications Group, Lawrence, KS. 185–196.

Cooney, R.F. 1952 Elk problems in Montana. *J. Range Manage.* **5**, 3–7.

Cooper, S.V., Neiman, K.E. and Roberts, D.W. 1991 *Forest Habitat Types of Northern Idaho: A Second Approximation. General Technical Report INT-236*. US Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT. 143.

Coppock, C.E., Windle, L.M., Wilks, D.L., Wodfel, C.G. and Greene, W. 1988 Addition of salt to cattle diets based on sodium and chloride in feedstuffs and drinking water. *J. Anim. Sci.* **66**, 1592–1597.

Crouch, G.L. 1966 Effects of simulated deer browsing on Douglas-fir seedlings. *J. For.* **64**, 323–326.

DeByle, N.V. 1985 Animal impacts. In *Aspen: Ecology and Management in the Western U.S. General Technical Report 119*. N.V. DeByle and R.P. Winokur (eds). US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, pp. 115–123.

Decocq, G., Aubert, M., Dupont, F., Alard, D., Saguez, R. and Wattez-Franger, A. *et al.* 2004 Plant diversity in a managed temperate deciduous forest: understory response to two silvicultural systems. *J. Appl. Ecol.* **41**, 1065–1079.

DePerno, C.S., Jenks, J.A., Griffin, S.L. and Rice, L.A. 2000 Female survival rates in a declining white-tailed deer population. *Wildl. Soc. Bull.* **28**, 1030–1037.

Didier, L. 2001 Invasion patterns of European larch and Swiss stone pine in subalpine pastures in the French Alps. *For. Ecol. Manage.* **145**, 67–77.

Duddies, R.E. and Edge, W.D. 1999 *Understanding and Controlling Deer Damage in Young Plantations. The Woodland Workbook. EC 1201*. Oregon State University Extension Service, Corvallis, OR, p. 8.

Evelyn, J. 1664 *Sylva, or a Discourse of Forest-Trees, and the Propagation of Timber*. Royal Society Scholar Press, Jo. Martyn and Ja. Allestry Printers, London, p. 83.

Fischer, W.C. and Clayton, B.D. 1983 *Fire Ecology of Montana Habitat Types East of the Continental Divide. General Technical Report INT-141*. United States Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT, p. 83.

Fleischner, T.L. 1994 Ecological costs of livestock grazing in western North America. *Conserv. Biol.* **8**, 629–644.

Franklin, J.F., Spies, T.A., van Pelt, R., Carey, A.B., Thornburgh, D.A. and Rae Berg, D. *et al.* 2002 Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *For. Ecol. Manage.* **155**, 399–423.

Fraser, D. and Reardon, E. 1980 Attraction of wild ungulates to mineral-rich springs in central Canada. *Holarctic Ecol.* **3**(1), 36–39.

Frisina, M.R. 1992 Elk habitat use within a rest-rotation grazing system. *Rangelands*. **14**(2), 93–96.

Ganskopp, D. 2001 Manipulating cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. *Appl. Anim. Behav. Science*. **73**, 251–262.

Gelbard, J.L. and Belnap, J. 2003 Roads as conduits for exotic plant invasions in a semiarid landscape. *Conserv. Biol.* **17**, 420–432.

Gill, R.M.A. 1992 A review of damage by mammals in north temperate forests: 1. deer. *Forestry*. **65**, 145–169.

Gill, R.M.A. and Beardall, V. 2001 The impact of deer on woodlands: the effects of browsing and seed dispersal on vegetation structure and composition. *Forestry*. **74**, 209–218.

Graham, R.T. and Jain, T.B. 2004 Past, present and future role of silviculture in forest management. In: *Silviculture in Special Places: Proceedings of the National Silviculture Workshop, Granby, CO. Proceedings. RMRS-P-34. W.D. Shepperd and L. G. Eskew, compilers*. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, pp. 1–14.

Graham, R.T. and Jain, T.B. 2005 Application of free selection in mixed forests of the inland northwestern United States. *For. Ecol. Manage.* **209**, 131–145.

Graham, R.T., Jain, T.B. and Cannon, P. 2005 Stand establishment and tending in rocky mountain forests. In *Productivity of Western Forests: A Forest Products Focus, Kamiche, WA. General Technical Report PNW-GTR-642*. C.A. Harrington and T. Schoenholtz (eds). Pacific Northwest Research Station, Portland, OR, pp. 47–78.

Graham, R.T., Jain, T.B. and Sandquist, J. 2007 Free selection: a silvicultural option. In *Restoring Fire-Adapted Forested Ecosystems. 2005 National Silviculture Workshop, Lake Tahoe, CA. General Technical Report PSW-GTR-203*. R. Powers (ed). US Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA, pp. 121–156.

Graham, R.T., Kingery, J.L. and Volland, L.A. 1992 Chapter 17-Livestock and forest management interactions. In *Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests*. H.C. Black (ed). US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 351–364.

Hanks, J.P., Fitzhugh, E.L. and Hanks, S. 1983 *A Habitat Type Classification System for Ponderosa Pine Forests of Northern Arizona. General Technical Report RM-97*. US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, p. 22.

Helle, T.P. and Jaakkola, L.M. 2008 Transitions in herd management of semi-domesticated reindeer in northern Finland. *Ann. Zool. Fenn.* **45**, 81–101.

Heydlauff, A.L., Krausman, P.R., Shaw, W.W. and Marsh, S. 2006 Perceptions regarding elk in northern Arizona. *Wildl. Soc. Bull.* **34**, 27–35.

Holechek, J.L. 1984 Comparative contribution of grasses, forbs, and shrubs to the nutrition of range ungulates. *Rangelands*. **6**, 261–263.

Humphrey, R.R. 1958 The desert grassland a history of vegetational change and an analysis of causes. *Bot. Rev.* **24**, 193–252.

Johnson, B.K., Ager, A.A., Noyes, J.H. and Cimon, N.J. 2005a Elk and mule deer responses to variation in hunting pressure. In: *The Starkey Project: A Synthesis of Long-Term Studies of Elk and Mule Deer. M.J. Wisdom, tech ed*. Alliance Communications Group, Lawrence, KS, pp. 127–138.

Johnson, B.K., Wisdom, M.J. and Cook, J.G. 2005b Issues of elk productivity for research and management. In: *The Starkey Project: A Synthesis of Long-Term Studies of Elk and Mule Deer. M.J. Wisdom, tech ed*. Alliance Communications Group, Lawrence, KS, pp. 81–93.

Karhu, R.R. and Anderson, S.H. 2006 The effect of high-tensile electric fence designs on big-game and livestock movements. *Wildl. Soc. Bull.* **34**, 293–299.

Kauffman, J.B. and Kruger, W.C. 1984 Livestock impacts on riparian ecosystems and streamside management implications: a review. *J. Range Manage.* **37**, 430–438.

Kingery, J.L., Graham, R.T. and White, J.S. 1987 *Damage to First-Year Conifers under Three Livestock Grazing Intensities in Idaho. Research Paper INT-376*. US Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT, p. 8.

Knapp, P.A. 1996 Cheatgrass (*Bromus tectorum* L) dominance in the Great Basin Desert: history, persistence, and influences to human activities. *Global Environ. Change*. **6**, 31–52.

Kuiters, A.T., Mohren, G.M.J. and Van Wieren, S.E. 1996 Ungulates in temperate forest ecosystems. *Forest Ecol. Manage.* **88**, 1–5.

Laiolo, P., Dondero, F., Ciliento, E. and Rolando, A. 2004 Consequences of pastoral abandonment for the structure and diversity of the alpine avifauna. *J. Appl. Ecol.* **41**, 294–304.

Lewis, H.T. 1985 Why Indians burned: specific versus general reasons. In *Proceedings, Symposium and Workshop on Wilderness Fire: Missoula, Montana. General Technical Report INT-182*. J.E. Lotan (ed). US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT, pp. 73–80.

Lindsey, P.A., Roulet, P.A. and Romañach, S.S. 2007 Economic and conservation significance of the trophy hunting industry in sub-Saharan Africa. *Biol. Conserv.* **134**, 455–469.

Lyon, L.J. 1979 Habitat effectiveness for elk as influenced by roads and cover. *J. For.* **77**, 658–660.

Mackie, R.J. 1970 Range ecology and relations of mule deer, elk, and cattle in the Missouri river breaks, Montana. *Wildl. Monogr.* **20**, 3–79.

Marshal, J.P., Krausman, P.R., Bleich, V.C., Rosenstock, S.S. and Ballard, W.B. 2006 Gradients of forage biomass and ungulate use near wildlife water developments. *Wildl. Soc. Bull.* **34**, 620–626.

Mendl, M. and Held, S. 2001 Living in groups: an evolutionary perspective. In *Social Behaviour in Farm Animals*. L.J. Keeling and H.W. Gonyou (eds). CABI Publishing, CAB International, New York, pp. 7–36.

Merrill, E.H. 1991 Thermal constraints on use of cover types and activity time of elk. *Appl. Anim. Behav. Sci.* **29**, 251–267.

Meyer, S.E., Nelson, D.L., Clement, S. and Beckstead, J. 2008 Cheatgrass (*Bromus tectorum*) biocontrol using indigenous fungal pathogens. In: *Proceedings-Shrublands under Fire: Disturbance and Recovery in a Changing World, Cedar City, UT. Proceedings. RMRS-P-52. S.G. Kitchen, R.L.Pendleton, and T.A. Monaco, J. Vernon, compilers*. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, pp. 61–67.

Mitchell, F.J.G. and Kirby, K.J. 1990 The impact of large herbivores on the conservation of semi-natural woods in the British uplands. *Forestry*. **63**, 333–353.

Morris, J.G. 1980 Assessment of sodium requirements of grazing beef cattle: a review. *J. Anim. Sci.* **50**, 145–152.

Moser, W.K., Hansen, M.H., Nelson, M.D. and McWilliams, W.H. 2009 Relationship of invasive groundcover plant presence to evidence of disturbance in the forests of the upper Midwest of the United States, Chapter 3. In *Invasive Plants and Forest Ecosystems*. R.K. Kohli, S. Jose, H.P. Singh and D.R. Batish (eds). CRC Press, Boca Raton, FL, pp. 29–58.

Mysterud, A. and Østbye, E. 1999 Cover as a habitat element for temperate ungulates: effects on habitat selection and demography. *Wildl. Soc. Bull.* **27**, 385–394.

Nagy, L., Grabherr, G., Körner, C. and Thompson, D.B.A. 2003 *Alpine Biodiversity in Europe*. Springer, Berlin, Germany, p. 477.

Nakata, I., Yokoyama, C., Mori, K. and Shibata, Y. 1968 Cattle grazing in a new plantation of broad-leaved trees. *Annu. Rep. For. Exp. Sta Hokkaido*. **1967**, 61–63.

Nyland, R.D. 2002 *Silviculture: Concepts and Applications*. 2nd edn. McGraw-Hill, New York, p. 633.

Payette, S., Boudreau, S., Morneau, C. and Pitre, N. 2004 Long-term interactions between migratory caribou, wildfires and Nunivak hunters inferred from tree rings. *Ambio*. **33**, 482–486.

Pearson, H.A., Morrison, D.C. and Wolke, W.K. 1969 Trick tanks: water developments for range livestock. *J. Range Manage.* **22**, 359–360.

Peterson, M.N. 2004 An approach for demonstrating the social legitimacy of hunting. *Wildl. Soc. Bull.* **32**, 310–321.

Plumb, G.E. and Dodd, J.L. 1993 Foraging ecology of bison and cattle on a mixed prairie: implications for natural area management. *Ecol. Appl.* **3**, 631–643.

Poole, K., Serrouya, R. and Stuart-Smith, K. 2007 Moose calving strategies in interior montane ecosystems. *J. Mammal.* **88**, 139–150.

Porath, M.L., Momont, P.A., DelCurto, T., Rimbey, N.R., Tanaka, J.A. and McInnis, M. 2002 Offstream water and trace mineral salt as management strategies for improved cattle distribution. *J. Anim. Sci.* **80**, 346–356.

Puettmann, K.J., Coates, K.D. and Messier, C. 2008 *A Critique of Silviculture: Managing for Complexity*. Island Press, Washington, DC, p. 189.

Puscas, M., Choler, P., Tribsch, A., Gielly, L., Rioux, D. and Gaudeuls, M. *et al.* 008 Post-glacial history of the dominant alpine sedge *Carex curvula* in the European Alpine System

inferred from nuclear and chloroplast markers. *Mol. Ecol.* **17**, 2417–2429.

Putman, R.J. 1996 Ungulates in temperate forest ecosystems: perspectives and recommendations for future research. *For. Ecol. Manage.* **8**, 205–214.

Pyne, S.J. 1982 Fire in America: a cultural history of wildland and rural firePrinceton University Press, Princeton, NJ, p. 322.

Reimoser, F. 2003 Steering the impacts of ungulates on temperate forests. *J. Nat. Conserv.* **10**, 243–252.

Reimoser, F., Armstrong, H. and Suchant, R. 1999 Measuring forest damage of ungulates: what should be considered. *For. Ecol. Manage.* **120**, 47–58.

Reimoser, F. and Gossow, H. 1996 Impact of ungulates on forest vegetation and its dependence on the silvicultural system. *For. Ecol. Manage.* **88**, 107–119.

Rochelle, J.A. 1992 Chapter 16-deer and elk. In *Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests*. H.C. Black (ed). US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 333–348.

Roché, C. 1999 Squarrose knapweed. In *Biology and Management of Noxious Rangeland Weeds*. R. Sheley and J. Petroff (eds). Oregon State University Press, Corvallis, OR, pp. 362–371.

Rosenstock, S.S., Ballard, W.B. and Devos, J.C. 1999 Benefits and impacts of wildlife water developments. *J. Range Manage.* **52**, 302–311.

Rutherford, M.C. 1979 Plant-based techniques for determining available browse and browse utilization: a review. *Bot. Rev.* **45**, 203–228.

Sandström, P., Pahlén, T.G., Edenius, L., Tømmervik, H. and Hagner, O. *et al.* 2003 Conflict resolution by participatory management: remote sensing and GIS as tools for communicating land-use needs for reindeer herding in northern Sweden. *Ambio*. **32**, 557–567.

Schlich, W. 1906 *Manual of Forestry. Volume II. Silviculture*. Bradbury, Agnew & Co, London, p. 393.

Senft, R.L., Coughenour, M.B., Bailey, D.W., Rittenhouse, L.R., Sala, O.E. and Swift, D.M. 1987 Large herbivore foraging and ecological hierarchies. *Bioscience*. **37**, 789–799.

Sheley, R.L., Jacobs, J.S. and Carpinelli, M.F. 1998 Distribution, biology, and management of diffuse knapweed (*Centaurea diffusa*) and spotted knapweed (*Centaurea maculosa*). *Weed Technol.* **12**, 353–362.

Shepperd, W.D. 2001 Manipulations to regenerate aspen ecosystems. In: *Sustaining Aspen in Western Landscapes: Symposium Proceedings, Grand Junction, CO. Proceedings. RMRS-P-18. W.D. Shepperd, D. Binkley, D.L. Bartos, T.J. Stohlgren, and L.G. Eskew, compilers*. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, pp. 355–366.

Spörndly, E. and Wredle, E. 2005 Automatic milking and grazing effects of location of drinking water on water intake, milk yield, and cow behavior. *J. Dairy Sci.* **88**, 1711–1722.

Thomas, J.W. 1979 Introduction. In *Wildlife Habitats in Managed Forests, the Blue Mountains of Oregon and Washington. Agriculture Handbook No. 553*. J.W. Thomas (ed). US Department of Agriculture, Forest Service, Washington, DC, pp. 10–21.

Thomas, J.W., Black, H. Jr, Sherzinger, R.J. and Pederson, R.J. 1979a Deer and elk. In *Wildlife Habitats in Managed Forests, the Blue Mountains of Oregon and Washington. Agriculture Handbook No. 553*. J.W. Thomas (ed). US Department of Agriculture, Forest Service, Washington, DC, pp. 104–127.

Thomas, J.W., Maser, C. and Rodiek, J.E. 1979b Edges. In *Wildlife Habitats in Managed Forests, the Blue Mountains of Oregon and Washington. Agriculture Handbook No. 553*. J.W. Thomas (ed). US Department of Agriculture, Forest Service, Washington, DC, pp. 48–59.

Van Rees, H. and Hutson, G.D. 1983 The behaviour of free-ranging cattle on an alpine range in Australia. *J. Range Manage.* **36**, 740–743.

Vare, H., Ohtonen, R. and Mikkola, K. 1996 The effect and extent of heavy grazing by reindeer in oligotrophic pine heaths in northeastern Fennoscandia. *Ecography*. **19**, 245–253.

West, N.E. and Van Pelt, N.S. 1987 Successional patterns in pinyon-juniper woodlands. In: *Proceedings-Pinyon Juniper Conference, Reno, NV. General Technical Report GTR-INT-215. R.L. Everett, compiler*. US Department of Agriculture, Forest Service Intermountain Research Station, Ogden, UT, pp. 43–52.

Whisenant, S.G. 1990 Changing fire frequencies on Idaho's Snake River plains: ecological and management implications. *Proceedings-Symposium on Cheatgrass Invasion, Shrub Die-Off, and Other Aspects of Shrub Biology and Management, Las Vegas, NV. General Technical Report INT-276. E.D. McArthur, E.M. Romney, S.D. Smith, and P.T. Tueller, compilers*. US Department of Agriculture, Forest Service, Intermountain Research Station , pp. 4–18.

Wilkinson, T. 2000 The beef with livestock. *National Parks*. **74**, 5–6.

Willms, W.D., Kenzie, O.R., McAllister, T.A., Colwell, D., Veira, D. and Wilmshurst, J.F. *et al.* 2002 Effects of water quality on cattle performance. *J. Range Manage.* **55**, 452–460.

Wisdom, M.J., Johnson, B.K., Vavra, M., Boyd, J.M., Coe, P.K. and Kie, J.G. *et al.* 2005 Cattle and elk responses to intensive timber harvest. In: *The Starkey Project: A Synthesis of Long-Term Studies of Elk and Mule Deer. M.J. Wisdom, tech ed*. Alliance Communications Group, Lawrence, KS, pp. 197–216.

Young, B.A. 1988 Effect of environmental stress on nutrient needs. In *The Ruminant Animal: Digestive Physiology and Nutrition*. D.C. Church (ed). Prentice Hall, Englewood Cliffs, NJ, pp. 456–467.

Youngblood, A.P. and Mauk, R.L. 1985 *Coniferous Forest Habitat Types of Central and Southern Utah. General Technical Report GTR-INT-187*. US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT, p. 89.

Zeigenfuss, L.C., Singer, F.J., Williams, S.A. and Johnson, T.L. 2002 Influences of herbivory and water on willow in elk winter range. *J. Wildl. Manage.* **66**, 788–795.

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