Sheep as a Silvicultural Management Tool in Temperate Conifer Forest

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Summary
Sheep grazing is a traditional use of temperate coniferous forest in the United States and Canada. Like any management tool, prescription sheep grazing can be misused. Unacceptable damage to conifer regeneration can occur when sheep are poorly controlled or plantations are overgrazed. Relative attractiveness of trees compared to other forage available to sheep changes seasonally. Trees are most likely to be browsed during the spring when lush new twig and needle growth is present or at any time that other green feed becomes scarce. Sheep browsing of young trees has relatively little impact upon conifer growth unless the terminal leader or almost all of current year’s lateral branches are consumed. Properly applied sheep grazing often reduces competition between trees and other ground vegetation, thus increasing tree growth. Although prescriptions have yet to be fully determined for many forest sites, results to date suggest that prescription grazing may provide a socially acceptable alternative to herbicides for conifer release in many areas.

Key words: biological control, integrated pest management, brush livestock grazing, agroforestry.

Introduction
Forests have historically been important forage sources for both native herbivores and livestock in North America. Domestic livestock often accompanied settlers and were allowed to graze forested lands near homesteads in a largely uncontrolled or semi-controlled fashion. Rapid westward expansion of the range livestock industry during the period from just after the Civil War until the early 1900s saw large herds of cattle and sheep grazing the western range and forest lands (Stoddart et al., 1975). Increased soil erosion, reduction of desirable plant species and invasion of weeds associated with overgrazing during this period are still, in many places, evident today. The legacy of poor livestock management practices in the past persists in a general reluctance of foresters, wildlife biologists and some environmentalists to embrace large-scale forest grazing. Forest management, as discussed for U.S. Forest Service lands by Kosco (1980), has moved from an emphasis on issues related to livestock grazing as a principal land use (prior to 1910), through a period of emphasis on tree production (prior to 1960) and into the current period focused on multiple use management. Livestock grazing is one of these multiple uses.

Forests and forested rangelands in the U.S. occupy approximately 280 million hectares (700 million acres) or 31% of the nation’s total land area (USDA, 1982). Nationally, about 25% of forested land is grazed by livestock (USDA, 1982). The principal areas of temperate conifer forest grazed by sheep in North America are the Rocky Mountain and the Pacific Coastal zones of the U.S. and Canada which contain over 62 million hectares (99 million acres) of grazed forest land in the U.S. alone (USDA, 1986). Many of these lands, particularly in the Rocky Mountain region, provide the summer portion of a yearly forage budget which includes winter grazing of conserved forages or low elevation desert rangeland and transitional use of foothill ranges. The availability of forested rangelands, therefore, often directly impacts management decisions over a much larger landscape than just the forested land itself. Until recently, forest grazing has been on a steady decline since 1949 (Joyce, 1989). Grazing capacity of both open

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canopy and closed canopy coniferous forests have declined. Exclusion of fire in lodgepole pine (Pinus contorta), ponderosa pine (Pinus ponderosa) and other formerly open park-like forest types has allowed them to develop into closed canopy forests with much less grazable understory vegetation. Similarly, modern silvicultural practices such as replanting with dense stands of fast growing trees, suppression of competing vegetation, animal damage control and fertilization, have been very effective in reducing the grazable transition period between forest harvest and tree canopy closure. This situation may be beginning to change, however. Interest in livestock grazing as a component of silvicultural systems is currently increasing. Extensive timber harvest during the past decade has produced a substantial inventory of grazable coniferous forest. Public distrust concerning the wisdom of using chemicals to suppress unwanted vegetation in young tree plantations is prompting forest managers to critically examine livestock grazing as a more socially acceptable management tool. Increased success in planting high-quality young trees has reduced the number of trees needed to reestablish a new stand, thus delaying canopy closure and extending the grazable period. Insect outbreaks, which are generally considered to be a reflection of poor forest health, are prompting interest in reestablishing semi-arid coniferous forests to their original open canopy form. This is an opportune time, therefore, to review what is known about livestock grazing and the use of livestock as a management tool in coniferous forests.

### Literature Review

Competition between young conifer regeneration and resident ground vegetation often limits establishment and growth of young trees (Cleary, 1978; McDonald and Fiddler, 1989; Stewart et al., 1984; Waistad et al., 1986). Dense ground vegetation may also provide habitat for voles, hares and other small mammals which damage young trees (Lavender et al., 1990; Tonn and Graham, 1982). The potential for livestock to impact forest vegetation has long been recognized. Colville (1988), for instance, remarked upon browsing damage to young conifers in the Oregon Cascades by heavy sheep grazing which had been under way for about 11 years prior to his report. Sparhawk (1918) noted the usefulness of sheep grazing to reduce fire hazard in central Idaho. However, interest in sheep grazing as a potential tool to manage the rapid increase of ground vegetation following timber harvest has increased dramatically during the past decade, primarily as a result of public concern over human and ecosystem health issues related to the use of herbicides. Sheep appear to be viewed by the public as a more natural form of weed control than chemicals (Greiman, 1988).

### Vegetation Control

Sheep have been successfully used to reduce brush prior to tree planting (Timberman, 1975; Wood, 1987). Site preparation by grazing prior to planting trees is relatively simple because damage to conifers is not a consideration. Livestock grazing has also been successfully used to control both brush (Allen and Bartolome, 1989; Krueger and Vavra, 1984; Sharrow et al., 1989; Thomas, 1985; Wood, 1987) and herbaceous vegetation (Doescher et al., 1989; Kabzems, 1992; Sharrow et al., 1992a; Timberman, 1975) in young conifer plantations. Thomas (1985) reported that sheep grazing in newly established conifer stands in the Tahoe National Forest reduced deerbrush (Ceanothus spp.) canopy cover from 35 to 45% prior to grazing to 10 to 20% after grazing with only 1 to 2% of conifers damaged. Vine maple (Acer circinatum), salmonberry (Rubus spectabilis), thimbleberry (Rubus parviflorus) and red alder (Alnus rubra) were all substantially reduced by sheep grazing in Oregon's coastal forest with little accompanying damage to Douglas fir (Pseudotsuga menziesii) trees (Sharrow et al., 1989; Sharrow et al., 1992b). Agroforests (trees grown in improved pastures) in New Zealand (Knowles, 1991; MacBrayne, 1981), Australia (Anderson et al., 1988) and Chile (Penasoza et al., 1985) are grazed by sheep as a means of harvesting the understory grass crop without harming young radiata pine being grown as saw timber. In western Oregon, up to 50% of the grass-clover forage produced in young Douglas fir agroforests, where trees are planted into improved pastures, can be harvested by sheep without significant damage to trees (Sharrow et al., 1992b). Kabzems (1992) mentioned the successful use of sheep grazing in British Columbia boreal forests to reduce the height of grass (Calamagrostis canadensis) in young conifer stands, thus reducing the potential for young trees to be crushed by snow press.

### Conifer Growth

Increased conifer growth is often reported as a benefit of livestock grazing. Douglas fir has been the most intensively studied species in this regard (Table 1).

Increased diameter growth of conifers in grazed plantations is generally more prominent than is increased height growth, probably as a result of the indeterminate nature of diameter growth (Sharrow et al., 1992b).

### Table 1. Percentage increase in Douglas fir diameter and height growth as a result of livestock grazing.

<table>
<thead>
<tr>
<th>Livestock</th>
<th>Diameter, %</th>
<th>Height, %</th>
<th>Age</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheep</td>
<td>8</td>
<td>10</td>
<td>33</td>
<td>Jandl and Sharrow, 1988</td>
</tr>
<tr>
<td>Sheep</td>
<td>31</td>
<td>7</td>
<td>12</td>
<td>Hedrick and Keniston, 1966</td>
</tr>
<tr>
<td>Cattle</td>
<td>7</td>
<td>5</td>
<td>6 to 8</td>
<td>Doescher et al., 1989</td>
</tr>
<tr>
<td>Cattle</td>
<td>26</td>
<td>18</td>
<td>18</td>
<td>Sharrow et al., 1989</td>
</tr>
<tr>
<td>Sheep</td>
<td>22</td>
<td>6</td>
<td>11</td>
<td>Krueger and Vavra, 1984</td>
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<tr>
<td>Sheep</td>
<td>20</td>
<td></td>
<td>10</td>
<td>Sharrow et al., 1992b</td>
</tr>
</tbody>
</table>

*Years since planting, at time of measurement.*
Reported growth increases as a result of livestock grazing (Doescher et al., 1989; Krueger and Vavra, 1984) range from 15 to 15% height and 9 to 27% diameter for ponderosa pine, 38% height and 61% diameter for western larch (Larix occidentalis) and 44% height and 56% diameter for western white pine (Pinus monticola). Ellen (1990) reported a 5% increase in tree height, a 13% increase in diameter and a 5% increase in mortality of low elevation spruce as a result of grazing sheep for two years. One year of grazing in high elevation spruce forest in Ellen’s study increased tree height by 13%, diameter by 12% and tree survival by 9%. Increased conifer growth in grazed plantations is often credited to reduced competition between trees and shrubs (Allen and Bartolome, 1989; Krueger and Vavra, 1984; Sharrow et al., 1989), grass (Doescher et al., 1989; Hedrick and Keniston, 1966) or hardwood trees (Sharrow et al., 1992b). Several authors (Carlson, 1988; Doescher et al., 1989; Hall et al., 1959; Leininger 1984) have reported increased soil moisture and reduced moisture stress in trees during the summer in grazed compared to ungrazed plantations. Leininger (1984) and Carlson (1988) also observed increased foliage nitrogen levels in trees from grazed plantations, suggesting that grazing may play a role in increasing nutrient availability to trees, presumably through nutrients contained in feces and urine. Competitive exclusion, a process by which a competitor benefits associated plants by excluding a potentially more troublesome competitor, may also be important in longer-term benefits of grazing. A specific example occurred in Oregon where growth of Douglas fir trees was initially reduced by sheep browsing trees in a grass-seeded coastal forest clearcut. The combination of grass competition and grazing, however, slowed establishment of red alder, such that 10 years later Douglas fir timber basal area was 50% greater in grazed portions of the clearcut (Sharrow et al., 1992b).

**Tree Tolerance to Browsing**

Considerable browsing of conifer regeneration can occur, particularly when sheep are poorly controlled (Maki and Mann, 1951) or plantations are overgrazed (Black and Vladimiroff, 1963). Gill (1992a) noted that likelihood of tree seedling survival following browsing is directly related to tree size. Younger trees typically have poorer survival rates than older ones. Tree mortality is greatly reduced after trees reach a certain age (i.e., are established). This age varies with tree species and appears to be about one year for Douglas fir (Dimock, 1970) and slash pine (Lewis, 1980a). Since two-year-old trees are most commonly planted commercially, browsing seldom kills planted conifers unless trees are totally defoliated (Lewis, 1980a; Roy, 1960; Dimock, 1970; Neilson, 1981). For example, Sharrow et al. (1992b) reported no mortality of trees in a three- to four-year-old Douglas fir plantation heavily grazed by both deer and sheep even though some trees lost 90% of their new needles annually for two consecutive years. Pearson (1931) observed that ponderosa pine seedlings which were completely defoliated by livestock generally died, while those with even a single fascicle of needles remaining following grazing often survived. Reduced tree growth rather than mortality is the most likely result of browsing damage. Browsing of conifers is generally accompanied by considerable defoliation of associated understory plants. Reduced competition from grasses and shrubs often compensates for loss of tree foliage by browsing (Gourley et al., 1990; Hall et al., 1959). Loss of the terminal leader is much more detrimental to future tree growth than is loss of lateral foliage (Ericsson et al., 1985; Osman and Sharrow, 1993; Sharrow et al., 1992b), perhaps due to the role which the terminal buds play in hormonal regulation (apical dominance) or the potential for future growth which they represent (Sharrow et al., 1992b). Loss of a tree terminal leader forges that year’s height increment and can reduce diameter growth as well (Sharrow et al., 1992b). Conifers tolerate high levels of lateral branch defoliation, however, without appreciable loss of growth. Defoliation in excess of 50% of a tree’s foliage is required before growth is measurably reduced (Lewis, 1980a; Neilson, 1981) and even then reductions may not be dramatic. When the terminal leader remained intact, Osman and Sharrow (1993) found no reduction in height growth and only a 1.5% reduction in diameter growth following 75% defoliation of the current year’s lateral branch foliage on young Douglas fir trees. Silvicultural interest, therefore, is focused upon protection of tree terminal leaders rather than lateral branches. Loss of conifer terminal leaders to sheep browsing declines rapidly as tree height exceeds one meter (Leininger and Sharrow, 1989; Phelps, 1979; Gillingham et al., 1976; Pearson, 1931). Trees above one meter in height should be relatively immune to browsing damage by sheep. Trees growing on steep slopes may need to be considerably taller than one meter to be above the reach of sheep. Planting taller tree seedlings may reduce the period that regeneration is at risk. However, care must be taken because sheep may push down and graze tall but slender trees (Gillingham et al., 1976).

**Factors Related to Debarking by Sheep**

Incidence of sheep chewing or stripping bark from conifer trees is seldom reported. Both Anderson et al. (1985) and Sharrow et al. (1992a) have reported that 2 to 7% of trees growing in intensively grazed pastures were debarked to some extent by sheep. Debarking, like browsing, was concentrated on the smaller trees in the stand (Anderson et al., 1985) and tended to be concentrated on individual trees located near lounging areas which were habitually used by sheep (Sharrow et al., 1992a). In both of these studies, sheep impacts were concentrated on a relatively small number of trees by the high number of sheep per hectare supported by highly productive grass-clover pastures. Incidence of debarking in open forest grazing has generally been negligible except in areas of livestock concentration such as bedding grounds.

Debarking provides an opening for trees to be attacked by opportunistic insects or diseases. However, wounds quickly heal and tree growth is unaffected unless more than 50% of a
tree’s circumference is debarked (Lewis, 1980b; Brix and Mitchell, 1985; Sharro et al., 1992a).

Factors Related to Conifer Browsing by Sheep

Successful use of sheep as a biological forest weed control agent in young conifer stands is complex because it hinges upon the willingness of sheep to consume target weed species while avoiding damage to conifer regeneration. Although cattle may damage young conifers by both browsing and trampling them (Adams, 1975; Clark and McLean, 1978), sheep impacts upon trees are predominantly due to browsing (Black and Vladimiroff, 1963; Hall et al., 1959; Sharro et al., 1992a) and, to a lesser extent, bark stripping (Anderson et al., 1985; Sharro et al., 1992a).

Sheep are small ruminants which have a relatively limited stomach capacity compared to their body surface area. They must use their stomach capacity efficiently, so they are very selective feeders (Van Soest, 1982). Their diets are generally high in rapidly digestible forage such as young grasses and forbs, seasonally switching to woody plants when herbaceous forage begins to mature. Conifers are seldom actively sought out as feed by sheep when other green feed is available (Leininger and Sharro, 1987). Sheep will eat conifer foliage, however, when grasses are mature and other browse is unavailable (McKinnell, 1975). Sheep travel frequently while grazing, so browsing use of trees is generally spread relatively evenly among trees in grazed areas (Sharro et al., 1992a). This contrasts strikingly with the grazing habits of deer who typically stand and graze a spot for some time then travel to a new feeding station some distance away, leaving behind a pattern in which trees are either heavily grazed or untouched. Care must be taken when grazing sheep in young tree plantations to see that adequate palatable forage is available at all times. For, as Ellen (1990) pointed out, sheep use of trees is not linear with time during a grazing period. Amount of browsing on trees can change from inconsequential to substantial in a very short period of time. Given the opportunity, sheep often eat a small amount of browse even when young herbaceous forage is plentiful. This may explain the observation (Greiman, 1988; Sharro et al., 1992a; Rudeen, 1978) that conifer browsing by sheep is a greater problem when timber plantations lack alternative browse plants. Anderson et al. (1985) and Sharro et al. (1992a) noted a tendency for browsing on individual young conifers to increase as tree density in pastures decreased, suggesting that desire for browse was being concentrated on the reduced number of trees at the lower densities. Gill (1992a) also commented on the tendency of tree damage per tree by native forest mammals to decrease with increasing tree density.

Palatability of trees to sheep differs among species. Hardwoods in general are more readily browsed by sheep than are conifers (Lavender et al., 1990; Leininger and Sharro, 1987). This makes safe grazing of hardwood plantations more challenging (Japanese literature as reviewed by Adams, 1975) but provides a realistic opportunity to selectively control unwanted hardwoods in conifer plantations. Conifers are generally less palatable to livestock than is the associated vegetation. For example, Phelps (1979) reported little browsing on trees in a mixed stand of Pacific silver fir (Abies amabilis), Douglas fir and western hemlock in which herd sheep consumed approximately 47% of the understory vegetation. Among conifers, spruce is unlikely to be browsed even under high grazing pressure (Adams, 1976; MacBrayne, 1981) while Douglas-fir, ponderosa pine, western hemlock (Tsuga heterophylla), western white pine and western larch are frequently grazed by sheep (Graham et al., 1992). Ellen (1990) listed pine, Douglas fir and spruce in order of decreasing susceptibility to sheep browsing. White fir (Abies concolor) has been reported (Kosco, 1980; Pearson, 1950) to be more readily browsed than Douglas-fir, ponderosa pine or sugar pine (Pinus lambertiana). Western red cedar (Thuja plicata) is more palatable to sheep than is Douglas fir (Howell, 1948).

Although not thoroughly explored, there appears to be little practical difference in risk of livestock damage to young trees between different breeds of sheep (Gillingham et al., 1976; McKinnell, 1975). Yearling ewes, however, more readily browse both shrubs (McKinnell, 1975; Kells, 1990) and young conifers (McKinnell, 1975) than do older ewes or lambs (Greiman, 1988) of the same breed. Gillingham et al. (1976) observed that at least twice as many radiata pine trees were browsed when agroforests were grazed in the spring with yearling Romney ewes than when mature Romney ewes were used. Thomas (1985) expressed a preference for ewes four or more years old over younger sheep because they appeared to more selectively avoid browsing on conifers. Little information about grazing rams in timbered pasture is available. In western Oregon agroforests, rams are much more likely to both browse and strip bark from young Douglas fir trees than are experienced ewes, even in the presence of large quantities of green grasses and clovers. Practical differences in handling characteristics do occur between different breeds and classes of sheep and may play an important role in achieving safe and effective vegetation manipulation. Farm sheep breeds, such as Suffolk, Romney and Hampshire, have been successfully used both for agroforest grazing (Sharro et al., 1992a) and open-herd forest grazing (Leininger et al., 1989). However, their tendency to form numerous small groups makes controlling large numbers of them a challenge in steep, brushy country. Herding sheep breeds such as Columbia which contain some Merino or Rambouillet heritage have generally been found most satisfactory for open forest grazing because of their greater natural tendency to form a tight flock for herding. Likewise, non-lactating ewes are generally preferred over ewes with young lambs along side because of their lower nutritive requirements and greater ease in herding (Green, 1992; Moore, 1991).

Season of grazing is generally much more important than either breed or class of sheep in determining levels of
Conifer browsing. Palatability of conifer foliage rapidly declines as it matures (Leininger and Sharrow, 1987). Browsing of trees by sheep is most likely to occur shortly after budbreak in spring when new light green needles are present (Gillingham et al., 1976; Leininger and Sharrow, 1989). Mature needles (fully expanded and dark green) are much less attractive to sheep than are immature needles, and old needles from previous years’ growth are seldom consumed. Spring bud burst in conifers often coincides with initiation of spring growth of associated grasses and forbs, both of which are more palatable than young conifers. By the time grasses and forbs have matured, conifer foliage has also matured. Forest shrubs and young hardwood trees generally are more palatable to sheep than are conifers during the summer (Leininger and Sharrow, 1987). Therefore, while palatability of conifer foliage varies substantially seasonally, it is seldom sought out over other forage available to sheep (Leininger and Sharrow, 1987).

Response of trees to defoliation also varies somewhat with season. Gill (1992a) concluded that winter browsing is more detrimental to conifers (such as pines) than deciduous trees (such as hardwoods) and that summer browsing is more damaging to deciduous trees than it is to conifers. The fact that most deer browsing occurs in winter and early spring (Gill, 1992b) while sheep browsing is most common in the spring and summer (when sheep are present on forested ranges) suggests that sheep grazing should tend to favor conifer domination of young forests, while the reverse may be true for deer. It is also interesting to note that deer browsing of young conifer stands occurs prior to, and often exceeds, that incurred while grazing those same plantations with sheep (Hall et al., 1959; Sharrow et al., 1992a).

Livestock Production Aspects
Prescription grazing of forest lands in both the northwestern U.S. and Canada is presently limited by the availability of suitable bands of sheep. Open forest grazing may require increased costs for trucking and herding (Smith, 1990), increased risk of sheep death losses (Ohlson, 1989) or reduced livestock weight gain compared to grazing in pastures. Losses of sheep in good health to either accidents or predation have generally not exceeded that which occur in farm settings (Leininger et al., 1989; Green, 1992). Reduced weight gains, however, may be more of a problem. Woody vines, shrubs and young hardwood trees are often target species for biological control in Pacific Northwest forests. These plants are green in summer when grasses and forbs have matured and are most readily eaten by sheep at that time (Leininger and Sharrow, 1987). Many forest shrubs contain antiherbivory compounds such as tannins which greatly reduce their value as livestock feed (Li, 1974; Leininger et al., 1989). Salmonberry, huckleberry (Vaccinium parvifolium) and sword fern (Polystichum munitum) growing in forest openings have higher tannin contents than when growing under a forest overstory (Happe et al., 1990). Weight gains of sheep grazing browse on forest clearcuts, therefore, may be less than those obtainable from local pastures. Phelps (1979) reported that ewes lost an average of 10.5 kilograms per ewe during a summer of grazing Douglas-fir/western hemlock forest in the Cascade Mountains of Washington. Sheep producers grazing clearcut spruce forest in British Columbia (Smith, 1990) reported sheep liveweight gains of 160 to 205 grams per head per day compared to 270 grams per head per day for local irrigated pasture. Leininger et al. (1989) reported four-year average daily liveweight gains of sheep grazing early seral Douglas-fir forest in spring were only 70 grams per ewe per day and 145 grams per lamb per day compared to the 140 to 180 grams per ewe per day and over 200 grams per lamb per day gains expected from local improved pastures. Summer weight losses by dry ewes, however, were similar to those experienced for local pastures. They related poor animal performance to the generally low digestibility of browse plants available on grazed plantations. Biological control prescriptions in timber plantations often induce sheep to consume more brush or other low-quality forage than they would if allowed to select a diet which maximized their seasonal weight gains.

Cost of Prescription Grazing
Forest managers in some areas of Oregon (Ohlson, 1989), Washington (Kells, 1990) and British Columbia (Smith, 1990) have found it necessary to share the cost of reduced weight gains by paying a biological control fee to sheep owners for the use of their sheep. In Oregon’s coastal mountains, for instance, sheep producers were not charged grazing fees and their costs of trucking sheep to the forest and herding costs were paid by forest managers at a total cost of $25.00 per hectare ($10.00 per acre). Three successive years of grazing were required to release trees. Total cost of prescription grazing was $75.00 per hectare ($30.00 per acre) compared to an estimated cost of $225.00 per hectare ($110.00 per acre) for herbicidal vegetation control (Doeschel et al., 1987). In addition, opening up of the understory brush by grazing reduced the subsequent cost of bud capping trees for wildlife damage control (Ohlson, 1989) by $29.00 per hectare ($12.00 per acre). In British Columbia, sheep producers have been paid a use fee of $35.00 per sheep to allow their ewes to be grazed in conifer plantations (Smith, 1991). In areas with abundant high-quality forage, such as many open canopy forests, graziers may pay a fee for grazing (Doeschel et al., 1987; Greiman, 1988; Thomas, 1985).

Conclusions
Properly applied sheep grazing can be an effective biological control program to increase conifer growth. It has been successfully used in ponderosa pine (Rudeen, 1978), Douglas fir (Hall et al., 1959; Sharrow et al., 1989), radiata pine (McKinnell, 1975), sugar pine (Greiman, 1988), spruce (Ellen, 1990; Newsome and Sutherland, 1989) and western hemlock (Phelps, 1979) forests. Proper season of
grazing, degree of forage utilization, distribution of livestock and class of livestock are fundamental to achieving high use of target plants without incurring unacceptable levels of browsing on young trees. Costs of forest vegetation control for tree release have generally been substantially lower than alternative chemical or mechanical methods widely used in the U.S. Given the positive reception of the general public to the concept of domestic sheep as a biological control agent for forest weeds, forest grazing appears to be a viable tool for North American silviculture.

Research Needs

Forest managers' acceptance of sheep as a biological tool is currently limited by lack of site-specific data detailing the ecological and economic costs and benefits associated with prescription sheep grazing in forests. Forest managers currently have chemical (herbicides), mechanical (hand cutting, slashing, etc.), fire and biological (livestock, insects) tools to choose from for vegetation management. Unfortunately, direct comparisons of these competing tools are rarely undertaken. Quantification of the effectiveness, costs and natural resource impacts of prescription sheep grazing compared to other vegetation control methods are sorely needed to support rational decision making.

Skillful use of grazing animals to manipulate vegetation rests upon a fundamental understanding of plant-herbivore and plant-plant interactions. Most of these interactions are yet to be fully quantified in forests. Much remains to be learned about sheep diets and grazing behavior, especially as it relates to the willingness of sheep to consume specific unwanted target plants while ignoring commercially or ecologically valuable plants, such as rare or endangered species. Nutritional value of forest plants as food for sheep needs to be explored further. Although laboratory analyses have been reported for many common forest plants, little in vivo data are available to indicate the actual value of forest plants as food for domestic livestock. Alteration of the degree or nature of competition between forest plants by defoliation is an important aspect of biological vegetation control which needs additional study. The tolerance of individual forest plants to defoliation and their subsequent ability to compete with associated vegetation is known for relatively few forest plant species.

North American forestry is currently undergoing a period of rapid change. Widespread silvicultural practices which have formed the basis for forest management since the 1950s are coming under criticism for being too narrowly focused on commercial tree production at the expense of the forest ecosystem. Such traditional tools as clear cut harvesting, slash burning and herbicidal weed control are all under review. The role of sheep as a biological tool occurs within the broader context of forest ecosystem management as a whole. Biological control technology developed for today's forests will need to be modified to accommodate changes in forest structure and function resulting from changing forestry practices. A close on-going relationship between managers and researchers will be required to frequently update silvicultural grazing practices during this period of rapid change.

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