Evaluation of Techniques to Protect Aspen Suckers from Ungulate Browsing in the Black Hills

Andrew M. Kota and Dale L. Bartos

ABSTRACT

Excessive browsing by cattle (*Bos taurus* L.) and wild ungulates, particularly elk (*Cervus elaphus* L.), sometimes inhibits growth and maturity of quaking aspen (*Populus tremuloides* Michx.) suckers in Western North America. In areas where aspen stands are in poor condition or declining, protecting suckers from ungulates may be necessary. This study compared the utility of livestock fences, complete wildlife exclosures, barriers created from slash debris, and tree hinging during 2004 and 2005 in the Black Hills of South Dakota. All of the barriers significantly reduced percentage browsing of aspen suckers compared with the pretreatment average (78%) and posttreatment control (79%). Slash treatments and livestock fences decreased ungulate browsing by 19%, hinge treatments decreased it by 39%, and wildlife fences eliminated nearly all incidences of sucker browsing. The average length removed per terminal stem for aspen suckers decreased from 20.8 to 14.4 cm across all treatments. After 1 year, the mean number of suckers above 100 cm height in both the hinge and slash treatments were significantly greater than both the fence treatments and control. Data showed that autumn and winter browsing was primarily by wild ungulates. Slash barriers can replace livestock fences where cattle affect aspen suckers. Hinge barriers are more useful than both slash barriers and livestock fences in areas where wild ungulates are the primary browsers.

Keywords: hinging, quaking aspen, restoration, wildfire, wildlife

Quaking aspen (*Populus tremuloides* Michx.) distribution is decreasing in many areas throughout the western United States (Kay 1997, Bartos and Campbell 1998a). This widespread stand reduction can be largely attributed to a reduction in ecosystem disturbance from fire since European settlement (Bartos 2001), and it eventually results in succession to conifer-dominated systems. As a disturbance-dependent species, aspen regenerates by producing new clonal suckers that are initiated by natural or anthropogenic perturbation. However, when aspen suckering does occur in many locales throughout the western United States, these ramets, or individual stems, are preferred browse resources that in some areas receive particularly heavy pressure from elk (*Cervus elaphus* L.) (Bartos et al. 1994). We define browse as any woody vegetation consumed or fit for consumption by livestock or wild ungulates.

Protecting new suckers from ungulate browsing is often necessary to sustain the existence of declining aspen stands in the western United States (Ripple and Larsen 2001). Fence construction is a useful method to achieve protection but is often impractical because of sparse funding or inaccessibility to areas in need on the landscape. These obstacles led to investigating the use of on-site forest materials to construct ungulate barriers to promote aspen sucker survival in the Black Hills, South Dakota (Kota 2005). The particular techniques used in this study could be applied elsewhere in the west where aspen suckers are at risk and sufficient tree materials are available.

Approximately 4% of the Black Hills is classified as aspen forest type (Rumble et al. 1996). Most stands are in seral stages precursory to ponderosa pine (*Pinus ponderosa* P&C Lawson), the dominant species on the landscape (Thilenius 1972, Kranz and Linder 1973). Aspen communities are vital to enhancing the diversity of landscape biota in numerous ways. Increased abundance and variety of local birds, ungulates, and insects was recorded in pure aspen stands compared with stands with assorted quantities of conifers (Rumble et al. 2001). Understory plant productivity and diversity is also greater under aspen-dominated canopies. In the Black Hills, Severson and Thilenius (1976) reported over 130 plant species for aspen systems, whereas Hoffman and Alexander (1987) found fewer than 45 plant species associated with the conifer habitat types. Forage production in unmanaged aspen stands in the Black Hills was documented as 676–1,226 kg/ha, a range surpassed only by moist meadows dominated by Kentucky bluegrass (*Poa pratensis* L.) (Severson 1982). As competition with shade-tolerant conifer species occurs, the type of undergrowth forage among/beneath aspen changes (Mueggler 1988), and its abundance decreases exponentially (Stam et al. 2008). Some conifer-dominated forest types may require more water annually (Gifford et al. 1984), and this results in decreased water availability for streamflow or soil recharge compared with nearby aspen-dominated forest types (Bartos and Campbell 1998b).

Aspen stems and leaves are highly preferred forage for white-tailed deer (*Odocoileus virginianus* Zimmerman) (Gastler et al. 1951) and elk (Bailey and Whitham 2002). Aspen suckers are at the

Manuscript received January 16, 2009, accepted January 19, 2010.

Dale L. Bartos (dbartos@fs.fed.us), Forestry Sciences Laboratory, US Forest Service, 860 North 1200 East, Logan, UT 84321. Andrew M. Kota, Foothills Conservancy of North Carolina, Morgantown, NC 28680. *Field data collection assistance was provided by Shauna Rae Brown, Paul Rogers, Nathan Kota, and Shelly Deisch. Manuscript reviewers were Dr. Gary Brundige, Shelly Deisch, Dr. David Turner, and Dr. Dan Uresk. Dr. David Turner provided assistance on statistical analysis. Further assistance for this study was provided by Randy Griebel; Brad Phillips; Phil Grumstrup; Dr. Mark Rumble; Dee McCarthy; US Forest Service, Rocky Mountain Research Station, Rapid City, SD; South Dakota Department of Game, Fish and Parks; and Custer State Park, Morgantown, NC 28680.*

This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; square kilometers (km^2): 1 km^2 = 0.3861 mi^2; hectares (ha): 1 ha = 2.47 ac.

greatest risk from browsing when they are within reach of ungulate species, that is, from the time of early development until they exceed heights of 1.5 m for domestic livestock (Sampson 1919, Smith et al. 1972) and 4 m for wild ungulates (DeByle 1985). Shepperd (2004) reported that aspen suckers require 8–10 years of normal growth to attain sufficient size to avoid impact by ungulates. Suckers can actually withstand some lateral shoot browsing and even terminal stem removal during early development, but repeated browsing is the most detrimental to their persistence and survival (Bartos el al. 1994). Repeated browsing results in a shrubby aspen growth form (Keigley and Frisina 1998) from which suckers seldom recover to develop as typical mature trees.

Elk seem to have a greater preference for aspen than deer do (Shepperd and Fairweather 1994, Kay 1997), and elk can be especially damaging to aspen suckers because of their capacious food intake, lofty reach, and ability to remain in aspen zones throughout the winter (DeByle 1985). Even areas with abundant aspen suckers and moderate elk densities (<5 elk/km^2) often experience heavy browsing, and these stands decline over time (White et al. 2003).

Many aspen stands in the Black Hills will not successfully regenerate and mature after a disturbance because of ungulate browsing. The objective of this study was to assess and compare the effectiveness of five types of ungulate barriers. In addition, a cursory attempt was made to determine which animals were responsible for the browsing.

Methods

Treatments

The treatment barriers enclosed patches of aspen suckers that varied in size from 0.04 to 1.65 ha (Kota 2005) and were intended to deter wild and domestic ungulates from accessing and browsing aspen suckers. Three methods most commonly used for excluding ungulates were used. Livestock fences consist of three or four strands of barbed wire and averaged approximately 1.2 m in height. Complete wildlife exclosures were constructed from woven wire fencing extended from the ground to about 2.4 m high. The slash treatment consists of stacking and piling downed trees and brush among patches of aspen suckers. Small-diameter (<15 cm dbh) live ponderosa pines, where available, were used to create the slash barriers. In areas devoid of ponderosa pine, standing dead aspen were cut and compiled with downed aspen for slash barriers.

The fourth and perhaps most novel approach to excluding ungulates was the hinge treatment, which consists of felling trees at approximately 0.9–1.2 m above the ground while maintaining stem connection to the stump. The resulting barrier consisted of the lateral bole and full canopy of the downed tree. In areas with mostly dead aspen, it was nearly impossible to maintain the bole to stump attachment. In these cases, to mimic "hinging" the boles were completely detached then propped onto the stump in a v-shaped notch. Live pines were used to produce hinge barriers where they were plentiful.

An unprotected control area was available to all ungulates. In addition, an unofficial survey of staff responsible for construction of fences and barriers was carried out to determine cost estimates for each type of treatment. These costs were expressed on a per unit basis.

Study Sites

Four treatments and a control were established in six locations in the southern region of the Black Hills National Forest and Custer State Park. Two of the treatment compliments were randomly placed in three major areas. Each of these areas had similar (1) disturbance history, (2) aspen suckers, (3) overstory, (4) ungulate species, and (5) materials to construct the slash and hinge barriers.

Silver Mountain

The universal transverse mercator (UTM) was 4867481.051N, 628027.14E. An area of approximately 8.1 ha was set aside in an area moderately burned in the 2002 Battle Creek Fire. The fence exclosures were constructed at this site between spring and fall 2004. Slash treatments were completed in December 2003, and hinge treatments were completed in spring 2004. All hinge and slash treatments at this location were created by felling live ponderosa pines.

Jasper

The UTM was 4859619.783N, 628027.14E and 4856298.767N, 596787.002E. The treatments were installed within an area of extensive aspen suckering after the Jasper fire burned in the summer of 2000. Exclosures were constructed in summer 2003, and the other treatments were created from fallen or standing dead aspen in November 2003.

Custer

The UTM was 4852951.095N, 624854.365E and 4848481.55N, 623294.599E). The Custer State Park study area borders the southeastern section of the Black Hills National Forest. It is the only area with bison (*Bison bison* L.) present and domestic livestock excluded. Fence exclosures were constructed in May 2004, slash treatments were completed in December 2003, and the hinge treatments were built in spring 2004. The hinge and slash treatments were created by felling live ponderosa pines.

Data Collection

Sampling to estimate sucker densities and browsing occurred in May 2004, August 2004, and May 2005. Within each treatment, a 1-m^2 plot frame was systematically placed every 3 m on alternating sides of a randomly positioned 60-m transect tape. All suckers occurring within the frame were counted. These numbers were used to establish estimates of sucker abundance and were expressed on a per hectare basis. Each sucker was assigned a size class: size class 1 suckers were <50 cm in length, size class 2 suckers were between 50 and 100 cm, and size class 3 suckers were >100 cm. Each sucker measured was characterized as browsed or unbrowsed. A sucker was considered browsed if (1) the terminal was removed, (2) any lateral shoots were removed, (3) the leaves were stripped from any part of the sucker's shoot(s), or (4) a combination of any of the previous three occurred. These types of browsing were attributed to ungulates.

We estimated the average length (cm) of aspen suckers being browsed by ungulates in each treatment by comparing browsed to unbrowsed sucker heights. Unbrowsed individuals were selected by first visually separating the 1-m^2 frame into quarters and then selecting the sucker closest to the center of each quadrant for measurement. If an unbrowsed sucker did not exist within a compartment, the closest unbrowsed sucker to that section outside of the plot frame was chosen for measurement. Fifty browsed suckers were chosen at random within each study area, and their heights measured during each sampling period.

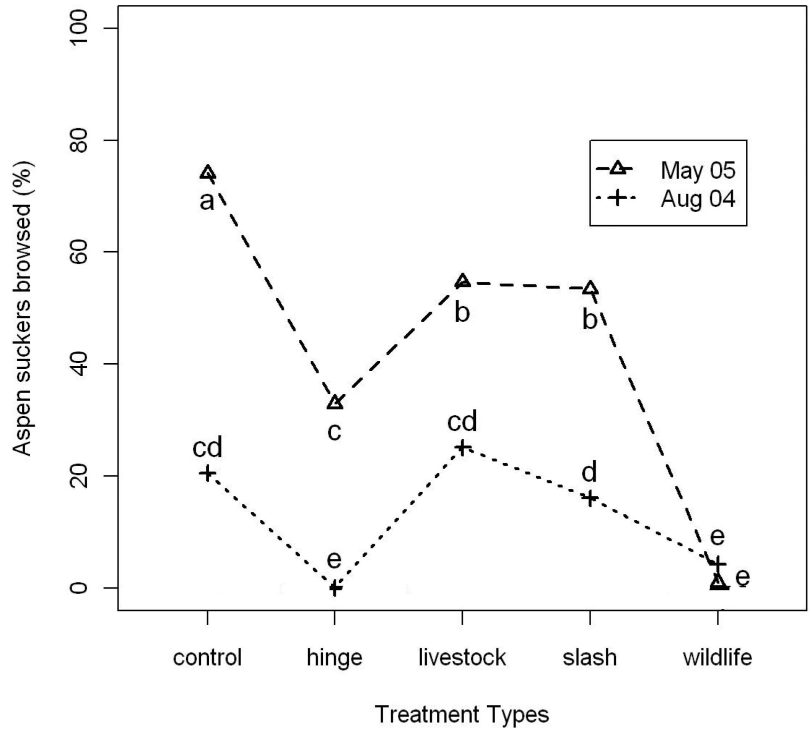

Figure 1. Proportion of aspen suckers browsed (adjusted for number of suckers in May 2004) by five barrier treatments in the Black Hills and their Tukey-Kramer groupings. Means with different letters are statistically different.

Fecal deposit tallies were recorded at each of the three major areas/data collection sites in August 2004 and May 2005, both to determine the presence of ungulates and to identify the species that were using aspen suckers as browse. Fecal piles observed (while collecting aspen sucker data) within or adjacent to the six locations were recorded by species and sprayed with paint to prevent their tally in subsequent surveys. Fecal deposits were counted only if they were determined to be from the current season when summer measurements were taken or from the previous season when spring measurements were taken.

Baseline data were measured as pretreatment values, even in the Jasper area, where the wildlife and livestock fences had been constructed 1 year before sampling. This was done to minimize the differences in both site manipulations and treatment implementations. Determining previous seasonal browsing is possible with aspen suckers because of their relatively straight growth form. The method used to make pretreatment estimates of ungulate browsing was adopted from Keigley and Frisina (1998).

Data Analysis

The experimental design for this study was a randomized complete block design with repeated measurements. Treatment and time were considered fixed effects, and the locations were random effects.

All data were analyzed using PROC MIXED or PROC GLIMMIX in SAS version 9.1. Browsed and unbrowsed height data were compared by analysis of least squares means. Percentage browsing data and size class data were analyzed by analysis of covariance, which was used to adjust posttreatment means to common pretreatment values. When the analysis of covariance assumption of equality of slopes was violated, a heterogeneous slopes model was applied. The posttreatment predicted values for all variables were calculated from the PROC MIXED or PROC GLIMMIX model, holding the covariate values equal to their means.

Posttreatment least square means were compared between treatments. Best linear unbiased predictors were used to compare sites because sites were considered a random effect. Multiple comparisons of the least square means for the posttreatment data were made using the Tukey-Kramer adjustment to control experiment-wise error rates at $\alpha = 0.05$. The normality of the residuals was tested using the Shapiro-Wilks test in the PROC UNIVARIATE procedure. Quantile normal plots were visually assessed to determine whether the distribution of the residuals was normal and within acceptable confidence intervals. All outliers were included in the statistical analyses because their removal did not change any of the significant ($\alpha = 0.05$) interactions, trends in the values, or data interpretations.

Results

Browsing

Before barriers were constructed, 78% of the pretreatment aspen suckers among the sites were browsed by ungulates. This covariant value was applied to improve precision in estimating posttreatment browse percentages. After barriers were constructed, browsing percentages were lowest in August 2004 (Figure 1). At that time, no difference in browsing of aspen suckers by ungulates occurred among the livestock fence, slash, or control treatments. These three treatments resulted in greater browsing compared with the wildlife fence and hinge treatments.

One year after barrier construction, the control browsing mean was 79%, 1% higher than the overall pretreatment average. All treatment browsing percentages at that time were significantly lower than the pretreatment average and the posttreatment control average (Figure 1). The livestock fence and slash piling treatments

Table 1. Height differences between the browsed and unbrowsed aspen suckers that were compared (1) at each study site across all dates, (2) across all study sites by date, and (3) across all study sites and dates.

Study site	Date	Height difference (cm)
Custer	All	13.1
Jasper	All	25.3
Silver Mountain	All	8.65
All	May 2004	20.8
All	May 2005	14.4
All	August 2004	11.8
All	2004–2005	15.7

Table 2. Fecal deposit tallies of the different ungulate species recorded by sites and date.

Study site	Area within site	Date	Elk	Deer	Cow
Jasper	Road 469	August 2004	23	1	3
Jasper	Gillette	August 2004	22	1	0
Custer	Powerline	August 2004	5	0	0
Custer	Shoemaker	August 2004	0	0	0
Silver Mountain	Lower	August 2004	0	2	7
Silver Mountain	Upper	August 2004	0	6	0
Jasper	Road 469	May 2005	44	0	5
Jasper	Gillette	May 2005	25	0	0
Custer	Powerline	May 2005	4	3	0
Custer	Shoemaker	May 2005	4	9	0
Silver Mountain	Lower	May 2005	2	5	1
Silver Mountain	Upper	May 2005	1	2	0

showed no difference in the percentage of browsed aspen. The hinge treatment mean was significantly lower than those means, and the wildlife fence treatment browsing percentage mean was significantly lower than every other treatment mean (Figure 1).

The highest average height difference between the browsed and unbrowsed suckers (20.8 cm) was measured during the pretreatment sample interval in May 2004 (Table 1). After 1 year, this value declined by 6.4 cm. The lowest average difference between the heights of browsed and unbrowsed suckers occurred in August 2004.

Ungulate Species

Fecal deposit tallies suggested varied ungulate presence and activity at the study sites. Counted piles at the Jasper sites indicated primarily elk presence (Table 2). Custer treatment sites showed approximately equal deer and elk activity, and no bison. Fecal deposits recorded at the Silver Mountain study sites were mainly from deer and cattle, with very few piles from elk.

Sucker Abundance

Total sucker abundance calculated across all research sites and sucker abundance at the Jasper and Silver Mountain sites decreased over the course of this study (Table 3). Sucker density increased at the Custer study site from May to August 2004; it then decreased by the May 2005 survey, but to an amount greater than the first round of sampling there (Table 3). These numbers are consistent with what Shepperd (1993) reports as the overall trend seen in aspen regeneration after treatment. Aspen regeneration numbers peak within 1–2 years after treatment and then decline exponentially after that. Peak numbers were observed on the Jasper and Silver Mountain sites, but aspen numbers had not peaked on the Custer site because of the more recent treatment.

Table 3. Mean sucker densities pre- and posttreatment for each treatment by study site.

Study site	May 2004	August 2004	May 2005
	....	(suckers/ha)	....
Custer			
Control	15,250	7,500	7,500
Hinge	6,750	7,750	4,250
Livestock	9,750	17,250	14,250
Slash	8,000	8,500	5,250
Wildlife	11,750	8,500	28,000
Mean	10,300	16,320	11,850
Jasper			
Control	39,500	48,000	23,000
Hinge	52,250	31,500	28,250
Livestock	42,250	30,500	30,000
Slash	41,000	30,500	24,250
Wildlife	57,500	43,750	24,750
Mean	46,500	38,850	26,050
Silver Mountain			
Control	44,750	29,250	21,500
Hinge	64,750	50,250	58,000
Livestock	78,500	36,000	33,500
Slash	44,500	37,750	32,750
Wildlife	25,500	30,500	12,000
Mean	51,600	36,750	31,550

Size Class

Pretreatment measurements indicated that 62% of the estimated 108,000 aspen suckers/ha at all of the study sites were in size class 1, 33% were in size class 2, and 5% were in size class 3 (Figures 2–4). During both posttreatment intervals, the highest percentage of aspen suckers in size class 1 occurred in the control group. After 1 year, the four treatments contained lower percentages of suckers in size class 1 than the control. Although the hinged and slash percentages in May 2005 were both lower than the wildlife and livestock treatments, this difference was not significant (Figure 2).

The percentage of aspen suckers browsed in size class 2 across all treatments was slightly higher in 2005 than was recorded in 2004 (Figure 3). However, there was no significant difference for any of these calculated percentages for the 2 years.

During both posttreatment interval measurements, there was no statistically significant difference among the number of size class 3 suckers recorded in the control groups compared with the livestock and wildlife fence treatments (Figure 4). In contrast, the mean number of size class 3 suckers within the hinge and slash treatments were significantly higher than the control, as well as the other two fencing treatments during both posttreatment measurement intervals (Figure 4). In 2005, the size class 3 category for the hinge and slash treatments mirrors what was observed in size class 1.

Cost

Cost estimates to construct each type of barrier were calculated from personal communication with managers from Custer State Park, US Forest Service Mystic Ranger District, and Hell Canyon Ranger District. The complete wildlife exclosure fences proved the most expensive treatment to create, followed by the livestock fences (Table 4). The two nonfence treatments were considerably cheaper to construct than the fences.

Discussion

Aspen depend on disturbances to stimulate new sucker production. Without disturbance, aspen typically are replaced by more shade-tolerant conifer species (Mueggler 1985). Historically, fire is

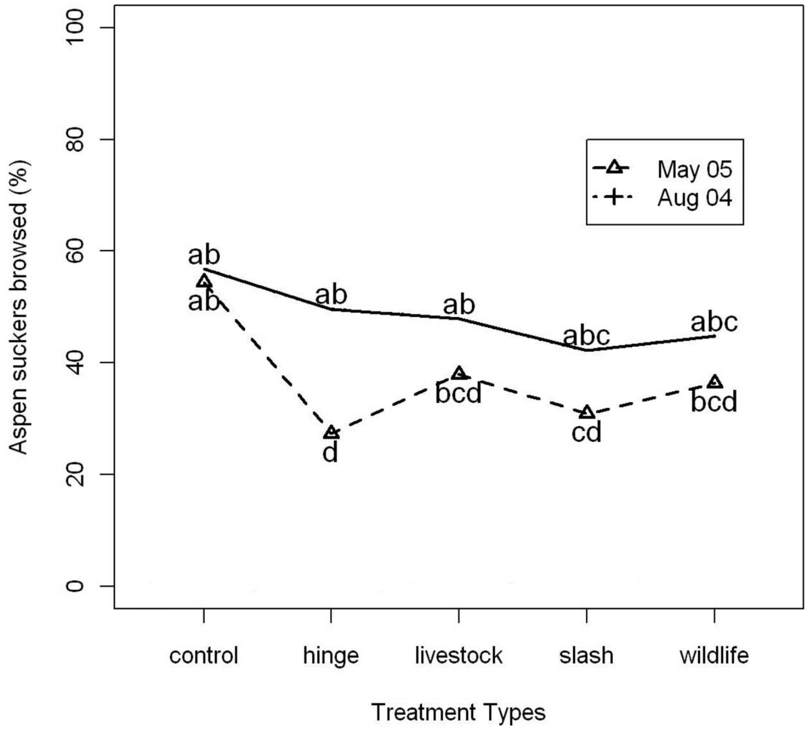

Figure 2. Aspen suckers in size class 1 (adjusted for number of suckers in May 2004) by five barrier treatments in the Black Hills and their Tukey-Kramer groupings. Means with different letters are statistically different.

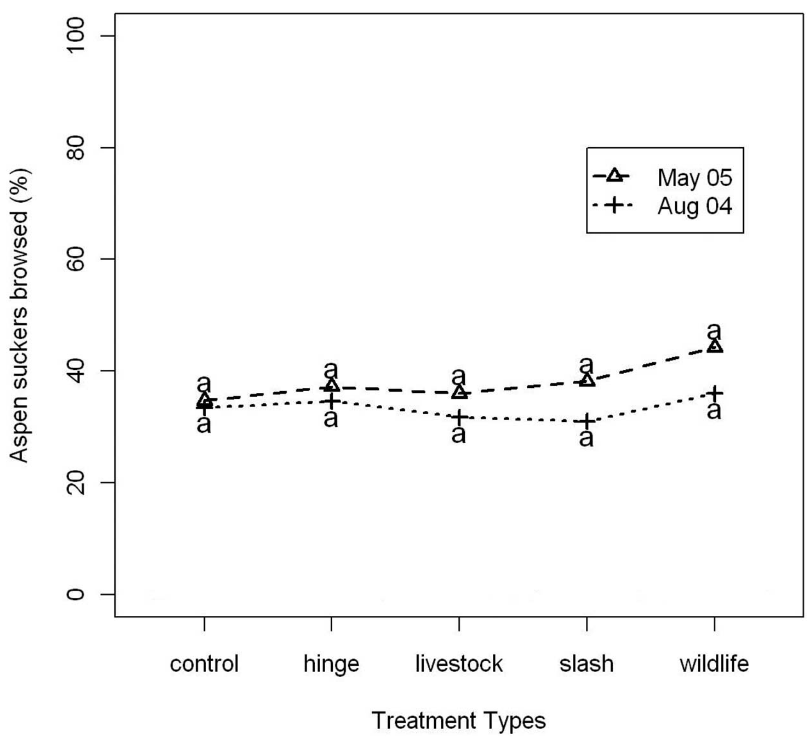

Figure 3. Aspen suckers in size class 2 (adjusted for number of suckers in May 2004) by five barrier treatments in the Black Hills and their Tukey-Kramer groupings. Means with different letters are statistically different.

perhaps the most important force promoting suckering events, and the fire regime in the western United States has been decidedly altered since European settlement. Combined with a decline in fire occurrence are drastic impacts to aspen suckers and their survival from livestock grazing and wild ungulate browsing in overpopulated areas (Bartos et al. 1994, Shepperd et al. 2006). Fencing cattle, deer, and elk out of valuable areas with aspen suckers can be a successful method to regulate browsing of aspen ramets, but funding and access often limit fence construction and maintenance. Investigations into economically viable and ultimately useful alternatives to

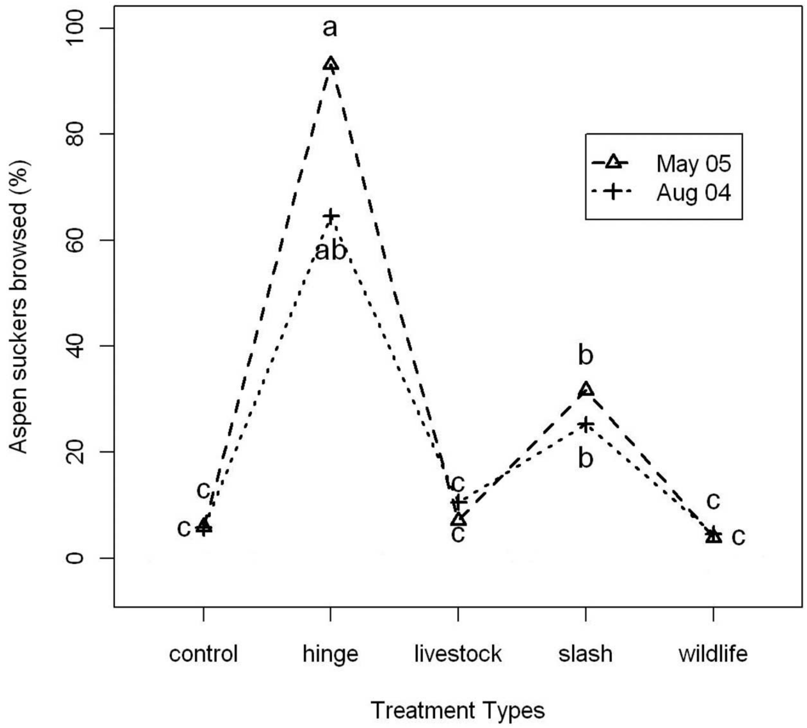

Figure 4. Aspen suckers in size class 3 (adjusted for number of suckers in May 2004) by five barrier treatments in the Black Hills and their Tukey-Kramer groupings. Means with different letters are statistically different.

Table 4. Estimated costs for materials and labor to construct each of the four different treatments.

Treatment barrier	Cost/ha (cost/ac)
Wildlife	>$10,000 (>$6,500)
Livestock	>$2,250 (>$1,400)
Hinge/slash	<$500 (<$200)

fences are currently needed, especially if aspen restoration projects across the west are successful on landscapes that include livestock and that support large populations of either deer or elk.

Browsing

In this study, all four barriers effectively regulated ungulate browsing on aspen suckers. As expected, the most successful treatment was the wildlife fence exclosure. Unless a tree falls on the fence or someone intentionally disassembles it, large ungulates are typically unable to access aspen suckers within this type of exclosure. Small mammals such as rabbits (*Lepus* spp. and *Sylvilagus* spp.) and pocket gophers (*Geomys bursarius* Shaw) are able to enter and potentially use aspen suckers (DeByle 1985), but their effects are rarely as extensive as browsing from large ungulates (Kay and Bartos 2000).

Although the hinge treatment proved more successful in this study than the livestock fences and slash piles, protection of browse was not as effective as wildlife fences after 1 year. The abundance, positioning, and form of the on-site forest materials were essential factors in the success of the slash and hinge treatments. Hinge barriers constructed from live pine likely were more effective at reducing ungulate browsing compared with the same treatment with dead trees, because they allowed a more continuous perimeter of hinged trees around a regenerated clone. Furthermore, their live crowns remained intact when the tree was felled. The branches and needles that persisted over the course of the study likely deterred accessibility and blocked visibility of the animals to the abundant aspen suckers within the treatments. Needles and leaves can stay on the hinged trees for approximately 2 years, and the bole and branches should continue to provide protection for at least 10 years.

Hinge barriers that were created with standing dead trees offered protection to aspen suckers in patches rather than uniform coverage throughout each treatment area. This aspect was related to abundance and position of standing dead trees at the treatment site. Other factors that detract from protection when using standing dead materials include massive disintegration of tree crowns when the brittle trees are felled and a deficiency of leaves on dead crowns that would obstruct ungulate browsers from perceiving aspen suckers within. Protection occurred in patches where several boles were stacked on a single stump, where several stumps were in close proximity, or where crowns remained relatively intact.

Browsing in the slash and livestock fence treatments was equal. Livestock were unable to enter areas protected by livestock fences and apparently were unwilling to enter areas protected by slash. Deer and elk were observed jumping livestock fences. Although wildlife sometimes use logging slash for cover and foraging opportunities (Severson and Medina 1983, Shirley and Erickson 2001), the slash treatments still provided some measure of protection to interior aspen suckers, results that concur with Rumble et al. (1996) in the Black Hills. Protection by slash treatments was also not uniform throughout the treatment area but seemed to occur in patches where accumulated materials discouraged ungulate access to aspen suckers.

Summer browsing by ungulates occurred at all treatment sites, but browsing percentages at that time were far lower than estimates chronicled in spring. Because the lowest browsing percentages occurred for the wildlife and hinge treatments, it seems that ungulates probably browsed more easily accessible aspen suckers, such as those in the livestock and slash treatments, and the controls. During autumn and winter, when forbs and grasses are less available and palatable, domestic and wild ungulates consume trees, shrubs, and aspen suckers (Bailey et al. 1990). Browsing and height differences found in this study suggest that most browsing was occurring over the autumn and winter before the treatments were constructed. Ungulates had other abundant forage, such as forbs and grasses, to browse during late spring, summer, and early autumn, thus reducing browsing pressure on aspen suckers during these times. An average decrease of more than 6 cm of aspen sucker growth browsed from pretreatment estimates indicates that on average, less length and therefore less biomass were removed by ungulate browsers after the treatments were on the landscape for 1 year.

Ungulate Species

Comparing fecal deposit tallies to the estimated height differences between browsed and unbrowsed suckers suggested that elk in Jasper, where their densities were appreciably greatest, were responsible for removing the largest portions of aspen biomass. At sites where the number of fecal deposits suggested deer or livestock as the primary aspen browsers, the average sucker length clipped was less than half (at Custer), and one third (at Silver Mountain) of the amount removed in Jasper.

Sucker Abundance

The estimated declines that occurred in sucker abundance at the Silver Mountain and Jasper sites over 1 year were expected. The burns there occurred more than 2 years before sampling began. The Custer site experienced an initial posttreatment surge in aspen sucker abundance, but a disturbance had not occurred in that area for approximately 40 years. Initially, no new suckers were observed in May 2004, when contractors began building fences. Measurements and observations in July of that year showed a new cohort of aspen suckers sprouting within the completed fences. This suckering event was probably initiated by disturbance to the roots from the machinery used during fence construction.

Size Class

The percentage of aspen suckers in size class 1 decreased in all treatments and control after 1 year, implying an overall recruitment of suckers into larger size classes. The most striking difference regarding the change in the mean number of suckers recruited into size class 3 over the course of 1 year occurred in the slash and hinge treatments. Although those treatment averages were significantly greater than the control, by contrast, the means of both of the fence treatments (wildlife and cattle exclosures) were not. In fact, very few size class 3 suckers were recorded in the livestock fences, presumably because elk and deer could easily access and browse those aspen suckers. Both the abundance of suckers in size class 1 within the wildlife fences in Custer and the access that ungulates had to areas where wildlife fences were constructed on Silver Mountain probably diminished the size class 3 percentage means on those two study sites. Greater aspen sucker growth in the slash and hinge treatments may also be attributed to greater soil moisture or nutrient availability. Aspen suckers occur primarily on an established root system that may "mine" an area much larger than the treatment footprint. Also, ground shading from the slash debris and hinged trees may have decreased evapotranspiration rates when air temperatures were high (Rumble et al. 1996).

Cost

The cost to create ungulate barriers from on-site forest materials was less than that of constructing permanent fences. In areas where cattle are not suspected of heavy aspen browsing, livestock fences could be replaced by less expensive hinge treatments. If wildlife fences are unaffordable, hinge barriers may offer some protection at a fraction of the price. Although hinge treatments are not quite as effective as wildlife fences, levels of elk browsing in this study declined significantly compared with a more expensive livestock fence, a slash treatment, or a completely unprotected area. However, in stands with minimal suckering after a disturbance, a more complete protection option may be necessary to sustain those stands.

Implications

Study results suggest that hinge and slash treatments can successfully deter livestock, deer, and elk from accessing and browsing aspen suckers. Throughout the western United States, increasing elk densities may be the greatest threat to aspen recruitment and survival after disturbances (Bartos and Mueggler 1981, Kilpatrick and Abendroth 2001, Kaye et al. 2005). In areas with elevated elk densities, the only viable option to protect a regenerating aspen clone from browsing is likely an expensive wildlife exclosure. Where elk and deer densities have not yet become excessive, hinge treatments may be a successful alternative to a wildlife exclosure. Slash barriers provided less protection than hinge barriers, but this study suggests that they could be used as a cheaper, maintenance free alternative to a livestock fence. In places where wildlife populations are browsing aspen suckers heavily, livestock fences are not recommended. A hinge treatment would provide better protection at less cost, and a larger area could be treated. This study found that if cattle are the primary cause of aspen sucker browsing, a slash barrier might be as effective as a livestock fence, again, at less cost so a larger area could be treated.

Hinge and slash treatments should only be implemented as protection treatments after aspen have suckered from a disturbance because forest materials used to construct the treatments will shade the soil surface and hinder sucker initiation. Neither of the treatments should be constructed until adequate time is permitted for sufficient suckering to restock a stand (1–2 years). Each site must be assessed separately to achieve the best possible results. Where materials are adequate to construct a slash or hinge barrier, logistical costs for aspen restoration projects can be considerably reduced without sacrificing functional protective ability. Further research into proper hinge cutting techniques will be useful in providing information on safety and success during tree felling, and it may guide successful treatment construction in the future.

Literature Cited

BAILEY, A.W., B.D. ERVING, AND R.D. FITZGERALD. 1990. Regeneration of woody species following burning and grazing in aspen parkland. *J. Range Manag.* 43:212–215.

BAILEY, J.K., AND T.G. WHITHAM. 2002. Interactions among fire, aspen, and elk affect insect diversity: Reversal of a community response. *Ecology* 83:1701–1712.

BARTOS, D.L. 2001. Landscape dynamics of aspen and conifer forests. P. 5–14 in *Proc. symp. on sustaining aspen in western landscapes, June 13–15, 2000, Grand Junction, CO.* US For. Serv., Rocky Mountain Res. Stn., Ft. Collins, CO. RMRS-P-18.

BARTOS, D.L., J.K. BROWN, AND G.D. BOOTH. 1994. Twelve years biomass response in aspen communities following fire. *J. Range Manag.* 47:79–83.

BARTOS, D.L., AND R.B. CAMPBELL. 1998a. Decline of quaking aspen in the interior west-examples from Utah. *Rangelands* 20:17–24.

BARTOS, D.L., AND R.B. CAMPBELL. 1998b. Water depletion and other ecosystem values forfeited when conifer forests displace aspen communities. P. 427–434 in *Rangeland management and water resources*, D.F. Potts (ed.). Proceedings of the American Water Resources Association Specialty Conference, May 27–29, 1998, Reno, NV. American Water Resources Association, Herndon, VA. TPS-98-1.

BARTOS, D.L., AND W.F. MUEGGLER. 1981. Early succession in aspen communities following fire in western Wyoming. *J. Range Manag.* 34:315–318.

DEBYLE, N.V. 1985. Animal impacts. P. 115–123 in *Aspen: Ecology and management in the western United States*, DeByle, N.V., and R.P. Winokur (eds.). US For. Serv. Gen. Tech. Rep. RM-119. US For. Serv., Ft. Collins, CO.

GASTLER, G.F., A.L. MOXON, AND W.T. MCKEAN. 1951. Composition of some plants eaten by deer in the Black Hills of South Dakota. *J. Wildl. Manag.* 15:352–357.

GIFFORD, G.F., W. HUMPHRIES, AND R.A. JAYNES. 1984. A preliminary quantification on the impacts of aspen to conifer succession on water yield. II. Modeling results. *Water Res. Bull.* 20:181–186.

HOFFMAN, G.R., AND R.R. ALEXANDER. 1987. *Forest vegetation of the Black Hills National Forest of South Dakota and Wyoming: A habitat type classification*. Research Paper RM-276. US For. Serv., Rocky Mountain Res. Stn., Ft. Collins, CO. 48 p.

KAY, C.E. 1997. The condition and trend of aspen, *Populus tremuloides*, in Kootenay and Yoho National Parks: Implications for ecological integrity. *Can. Field Nat.* 111:607–616.

KAY, C.E., AND D.L. BARTOS. 2000. Ungulate herbivory on Utah aspen: Assessment of long-term exclosures. *J. Range Manag.* 53:145–153.

KAYE, M.W., D. BINKLEY, AND T.J. STOHLGREN. 2005. Effects of conifer and elk browsing on quaking aspen forests in the Central Rocky Mountains, USA. *Ecol. Applic.* 15:1284–1295.

KEIGLEY, R.B., AND M.R. FRISINA. 1998. Browse evaluation by analysis of growth form: Vol. 1. Methods for evaluating condition and trend. Montana Fish, Wildlife and Parks, Butte, Mont. 153 p.

KILPATRICK, S., AND D. ABENDROTH. 2001. Aspen response to prescribed fire and wild ungulate herbivory. P. 387–394 in *Proc. symp. on sustaining aspen in western landscape, June 13–15, 2000, Grand Junction, CO.* US For. Serv., Rocky Mountain Res. Stn., Ft. Collins, CO. RMRS-P-18.

KOTA, A.M. 2005. Fences and on-site forest materials as ungulate barriers to promote aspen persistence. M.S. Thesis. Utah State University, Logan, Utah. 74 p.

KRANZ, J.J., AND R.L. LINDER. 1973. Value of Black Hills forest communities to deer and cattle. *J. Range Manag.* 26:263–265.

MUEGGLER, W.F. 1985. Vegetative Associations. in N.V. DeByle and R.P. Winokur (EDS). Aspen: Ecology and management in the western United States. Ft. Collins, CO. US For. Serv. Gen. Tech. Rep. RM-119. p. 45–55.

MUEGGLER, W.F. 1988. Aspen community types of the intermountain region. Gen. Tech. Rep. INT-250. Ogden, UT, USA: US For. Serv., Intermountain Res. Stn. 135 p.

RIPPLE, W.J., AND E.J. LARSEN. 2001. The role of postfire coarse woody debris in aspen regeneration. *West. J. Appl. For.* 16:61–64.

RUMBLE, M.A., A.V. CARTER, J.B. PARRISH, T. PELLA, AND J.C. SHARPS. 1996. Effects of logging slash on aspen regeneration in grazed clearcuts. *Prairie Naturalist* 28:199–210.

RUMBLE, M.A., L.D. FLAKE, T.R. MILLS, AND B.L. DYKSTRA. 2001. Do pine trees in aspen stands increase bird diversity? P. 185–191 in *Proc. symp. on sustaining aspen in western landscapes, June 13–15, 2000, Grand Junction, CO*. US For. Serv., Rocky Mountain Res. Stn., Ft. Collins, CO. RMRS-P-18.

SAMPSON, A.W. 1919. *Effects of grazing upon aspen reproduction.* USDA Bull. 741. Washington D.C. 29 p.

SEVERSON, K.E. 1982. Production and nutritive value of aspen understory, Black Hills. *J. Range Manag.* 35:786–789.

SEVERSON, K.E., AND J.F. THILENIUS. 1976. *Classification of quaking aspen stands in the Black Hills and Bear Lodge Mountains.* Res. Paper RM-166. US For. Serv., Rocky Mountain Res. Stn., Ft. Collins, CO. 24 p.

SEVERSON, K.E., AND A.L. MEDINA. 1983. *Deer and elk habitat management in the Southwest*. Journal of Range Management Monograph 2. Society for Range Management, Denver, CO. 64 p.

SHEPPERD, W.D. 1993. *Initial growth, development, and clonal dynamics of regenerated aspen in the Rocky Mountains.* Res. Pap. RM-RP-312. US For. Serv., Rocky Mountain For. Range Exp. Stn., Ft. Collins, CO. 8 p.

SHEPPERD, W.D. 2004. Techniques to restore aspen forests in the western U.S. P. 52–60 in *Trans. West. Sect. Widlife Soc.* 40.

SHEPPERD, W.D., AND M.L. FAIRWEATHER. 1994. Impact of large ungulates in restoration of aspen communities in a southwestern ponderosa pine ecosystem. P. 333–347 in *Sustainable ecological systems: Implementing an ecological approach to land management*, Covington, W.S., and L.F. DeBano (eds.). US For. Serv. Gen. Tech. Rep. RM-247. US For. Serv., Ft. Collins, CO.

SHEPPERD, W.D., P.C. ROGERS, D. BURTON, AND D.L. BARTOS. 2006. *Ecology, biodiversity, management, and restoration of aspen in the Sierra Nevada.* US For. Serv. Gen. Tech. Rep. RMRS-GTR-178. US For. Serv., Rocky Mountain Res. Stn., Ft. Collins, CO. 122 p.

SHIRLEY, D.M., AND V. ERICKSON. 2001. Aspen restoration in the Blue Mountains of Northeast Oregon. P. 101–116 in *Proc. symp. on sustaining aspen in western landscapes, June 13–15, 2000, Grand Junction, CO*. US For. Serv., Rocky Mountain Res. Stn., Ft. Collins, CO. RMRS-P-18.

SMITH, A.D., P.A. LUCAS, C.O. BAKER, AND G.W. SCOTTER. 1972. *The effects of deer and domestic livestock on aspen regeneration in Utah*. Utah Division of Wildlife Resources, Logan, UT. Publication No. 72-1. 32 p.

STAM, B.R., J.C. MALECHEK, D.L. BARTOS, J.E. BOWNS, AND E.B. GODFREY. 2008. Effect of conifer encroachment into aspen stands on understory biomass. *Rangeland Ecol. Manag.* 61:93–97.

THILENIUS, J.F. 1972. *Classification of deer habitat in the ponderosa pine forest of the Black Hills, South Dakota*. US For. Serv. Res. Pap. RM-91. US For. Serv., Rocky Mountain Res. Stn., Ft. Collins, CO. 28 p.

WHITE, C.A., M.C. FELLER, AND S. BAYLEY. 2003. Predation risk and the functional response of elk-aspen herbivory. *For. Ecol. Manag.* 181:77–97.