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Grazing in a California silvopastoral system: effects of defoliation season, intensity, and frequency on deerbrush, *Ceanothus integerrimus* Hook. & Arn.

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Abstract. When understory species that suppress tree growth are preferred by livestock to tree species, selective herbivory has practical application for forest or woodland management as part of a silvopastoral agroforestry system. Results of two studies of the prescriptive application of selective grazing designed to suppress growth of a common understory shrub, deerbrush (*Ceanothus integerrimus* Hook. & Arn.), to favor growth of conifer species are presented. Grazing for vegetation manipulation requires the same information needed to apply any chemical or mechanical method: knowledge of the effective timing, frequency, and intensity of application, and the selectivity of impact. The first study, a two-year series of grazing trials, examined the degree of cattle preference for deerbrush as compared to conifers, and response of deerbrush to grazing on a forest site. The second, a three-year study based on grazing trial results, used clipping to examine the specifics of deerbrush response to patterns of herbivory. Deerbrush was highly preferred by cattle in the grazing trials. Even at 90% utilization of the shrubs, no conifers were browsed. High degrees of utilization did not suppress shrub growth in the grazing trials. The clipping study found deerbrush significantly responsive to frequency and intensity of defoliation ($P < 0.01$), but not to season of use ($P > 0.1$). High intensity, frequent grazing is required to suppress the shrub. Intermediate prescriptions can be used to manage for various combinations of wildlife, timber, or forage-related objectives. These results and methods are applicable to any silvopastoral system where prescriptive grazing is used in conjunction with tree crops.

Introduction

Herbivory is believed to affect the course of plant community succession through the selective grazing of preferred species (Ellison, 1960). When understory species that suppress tree growth are preferred by livestock to tree species, selective herbivory has practical application for forest or woodland plantation management as part of a silvopastoral agroforestry system. To implement grazing strategies, it is necessary to know the relative appeal to herbivores of the species present, and to understand the effects of different patterns of herbivory on plant community structure and in particular, on species targeted for control. This paper presents results of two related studies examining the use of grazing to manipulate successional patterns in a commercial timber forest in the Sierra Nevada range of California.

The Sierra Nevada has historically been an important source of timber for the United States. In the west central part of the 400 mile-long-range, where Douglas fir (*Psuedotsuga menzii*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), and white fir (*Abies concolor*) are major commercial species, shrubs are the form of vegetation foresters most often want to control to reduce competition with conifers (Allen, 1988). The commonly occurring deerbrush (*Ceanothus intergerrimus* Hook. & Arn.) is considered highly palatable forage for both wildlife and livestock (Sampson and Jesperson, 1963; Cronemiller, 1953), and a major retardant of conifer regeneration (by seed or planting) or harvested sites. If uncontrolled, shrubs and herbaceous species growing on California forest plantations following timber harvest or wildfire reduces projected timber volumes by up to 30% (United States Forest Service, 1986). Brush cover of over 30% appears to be sufficient to reduce conifer volume growth (Fiske, 1981). Until recently, on lands managed by the United States Forest Service and on private lands, herbicide application was the treatment of choice for controlling this 'unwanted vegetation' and accelerating succession to mature forest. But broadscale use of herbicides has become increasingly controversial, and is likely to become more so, particularly if trends in housing development continue bringing residential settlement to forest areas. People living near forests are often concerned about chemical pollution of air, water, and soils in areas near homes, and in some cases have found grazing a more acceptable alternative. Because grazing does not eliminate but instead only suppresses shrubs, a cover of grazed plants protects plant species diversity. Shrubs hold soil and provide cover and forage for wildlife. Grazing has been shown to improve the quality of forage produced by shrubs in a silvopastoral system (Rhodes and Sharrow, 1990).

Several studies have reported on the successful grazing of cattle and sheep in Sierra Nevada silvopastoral systems (Allen and Bartolome, 1989; Huntsinger, 1989; Grieman, 1988; Thomas, 1985) and western US conifer forests (Karl and Doescher, 1993; Lawrence et al., 1992). Historically, foresters have resisted grazing in pine plantations because of concerns that the livestock would browse the trees. In coastal forests of the Pacific Northwest, Sharrow et al. found that sheep browsed the terminal leaders of up to 9% of Douglas fir seedlings in one study (1992a) and up to 77% in another (1992b), although impacts were not considered significant in terms of timber production goals for either site. Results have shown that application of grazing for directed manipulation of vegetation requires the same information needed to effectively apply any chemical or mechanical control method: knowledge of the specificity of impact, and of the most effective timing, frequency, and intensity of application. The last three factors are typically identified by plant community ecologists as having major effects on the response of plants to herbivory, yet there is little understanding, particularly in the case of shrubs, of the relative role that each plays in plant response.

In general, studies of shrub response to defoliation are limited, but the effects of differing intensity, frequency, and season of defoliation have to a degree been explored for some species (Austin et al., 1994; Sharrow et al., 1989; Hardesty et al., 1988; Roundy and Ruyle, 1985; Schmutz, 1982; Trilca et al., 1977; Cook and Child, 1971; McArthur et al., 1988; Crisp, 1978), although no study has elucidated the relative importance of each factor. The effects of intensity, frequency, and season of defoliation vary by species (Hardesty et al., 1988; Trilca et al., 1977; Cook and Child, 1971). Shrub size has been found to be inversely related to intensity of grazing (Roundy and Ruyle, 1985; Schmutz, 1982; Cook and Child, 1971), even after seven years of rest in the case of Intermountain high desert shrubs (Cook and Child, 1971), and more than twenty years of rest in Pacific northwest coastal Douglas fir plantations (Sharrow et al., 1989). Season of grazing affected response of Intermountain high desert shrubs (Cook and Child, 1971), shortgrass prairie shrubs (Trilca et al., 1977), and Brazilian caatinga species (Hardesty et al., 1988), but apparently had little effect in coastal Douglas fir plantations (Sharrow et al., 1989). The frequency of defoliation has also been found to affect shrub response, with more frequently clipped shrubs showing lowered productivity (Trilca et al., 1977; Cook and Child, 1971).

Although deerbrush is well distributed throughout the west slope of the Sierra Nevada and the coast ranges at elevations ranging from 300 to 2200 m (Sampson and Jesperson, 1963), the central part of the Sierra Nevada is probably its optimum habitat (Cronemiller, 1953). Nutritious through the summer grazing season (Kie, 1986; Hagen, 1953; Bissell, 1952), deerbrush has higher nutrient values than many grasses. Left alone, it often grows to thick, impenetrable thickets over 1.8 m tall in five to eight years. Previous studies have shown that cattle and sheep preference for deerbrush is high (Allen and Bartolome, 1989; Thomas, 1985). Sampson and Jesperson (1963) estimated that up to 50% of young deerbrush seedlings could be utilized with little apparent impact on the plant (1963). But the response of deerbrush to different patterns of defoliation has not been evaluated. This paper presents results of two studies of the application of selective grazing in a silvopastoral system designed not only to provide livestock forage but to suppress growth of a common California understory shrub, deerbrush, and favor regrowth of conifer tree species. The first, a two-year pilot study conducted in 1983–5, used grazing trials to examine the degree of cattle preference for deerbrush compared to conifers, and response of deerbrush to grazing on a forest site. The second, a three-year study conducted in 1985–7, and developed from pilot study results, used clipping in a controlled setting to examine the specifics of deerbrush response to patterns of herbivory. Clipping allowed a replicated examination of deerbrush response to differing intensities, frequencies, and seasons of defoliation.

Study areas

Blodgett Forest Research Station is a 1200 ha forest on the western slope of the Sierra Nevada in El Dorado County, 24 km east of Georgetown, California, in the American River watershed. Slopes average less than 30% with few greater than 50%. Elevation averages 1300 m. Soils are erosion-resistant 1 to 2 meter deep Ultic haploxeralfs, well-drained loams or sandy loams of the Holland, Musick, or Bighill series. Timber site quality is high.

The climate is Mediterranean (Barbour and Major, 1977), with wet, mild winters of highly variable precipitation, and hot, dry summers. Total precipitation for each rain-year of the study was 1982–3, 2205 mm; 1983–4, 1838 mm; 1984–5, 1125 mm; 1985–6, 2034 mm; 1986–7, 784 mm; and 1987–8, 809 mm; compared to a 1962–1987 mean of 1570 mm. About 85% of precipitation falls between October and March, and soil moisture draw-down begins in late spring-early summer. Snow is common from November to April, with 172 frost-free days on average.

The vegetation is mixed conifer forest, the Coniferous Forest and Yellow Pine Forest of Munz and Keck (1973), interrupted only by harvested areas and narrow meadows along streams. Common understory species include deerbrush and other shrubs and herbs, all of which are most abundant where light reaches the forest floor. Most of the forest today is second growth, first harvested early in the twentieth century. Conifer rotation is about 60 to 90 years, and clear-cut harvest, followed by planting of selected stock of local origin, is the most common practice in this area, where the major timber species grow best at high light levels. Group selection and single tree selection also occurs. A mix of Douglas fir, white fir, ponderosa pine, sugar pine, and incense cedar (*Calocedrus decurrens*) is commonly planted. Seed tree and shelterwood harvests take place on the Station on a very limited basis. The forest provides maintenance forage for 70 free-ranging cows from June to September. The cows return to low elevation grasslands for calving in the fall, and calves are weaned and marketed in late spring before the cows are brought to the forest.

Grazing study

A 17 hectare shelterwood in an ungrazed part of the forest, on north-facing slopes of an average of 20 degrees, was selected. Soils are predominantly Holland loam. The overstory was harvested in 1980, leaving selected overstory trees standing to re-seed and shelter the site, with a residual mean basal area ranging between 2 and 2.5 m^2/ha. White fir was the major component of the pre-harvest stand, followed by sugar pine and Douglas fir, with scattered black oak (*Quercus kellogii*), and incense cedar. Deerbrush was present in the understory. Post-harvest, the area was cleared using a brush rake, providing a bare mineral seedbed for natural regeneration. Slash and residues were piled and burned. When this study began in spring of 1983, abundant but patchy stands of three-year-old deerbrush and conifer seedlings were established. Deerbrush height averaged 689 mm, compared to an average tree seedling height of 129 mm. The vast majority of seedlings on the site were white fir, which was ten times as frequent as the next most common species, Douglas fir. Also present were seedlings of ponderosa and sugar pine. The high proportion of white fir is probably because the post-harvest year was a good one for white fir seed production and white fir does well in shelterwood conditions.

Clipping study

Two ungrazed sites about 1 km apart on Blodgett Forest were selected. Site 1 was a level clearing created by a small-scale 'group selection' harvest in 1981. The site was cleared with a brush rake, the slash piled and burned, and a mixture of tree species planted. In 1986, when the study was initiated, a uniform stand of 5-year-old deerbrush, averaging 1102 mm in height, dominated the site. Scattered bull thistle (*Cirsium vulgare*) was the main herbeceous species. Soils were Holland loam, with some classed as Holland-Musick complex.

Site 2 was a level clearing by a seed tree harvest in 1985. The area was cleared by broadcast burning following harvest. One-year-old deerbrush were the most abundant vegetation on the site, averaging 148 mm tall in May 1986. Scattered herbs, particularly miner's lettuce (*Montia perfoliata*) and bull thistle, were also present. Soils are Holland Loam, with some Holland-Bighill. On either study area, there was no indication that deerbrush seedlings had been more than incidentally browsed during previous years, and there was no conifer overstory.

Methods

For the grazing study small groups of Hereford-Angus cows, randomly selected from the local herd, were fenced into three electrically-fenced shelterwood pastures averaging 2.3 ha during the summers of 1983 and 1984. The amount, timing, and extent of grazing was controlled. Control of animal numbers allowed examination of the effects of grazing on deerbrush during the summer grazing season at a known rather than inferred stocking rate, and provided opportunity to examine precisely the relative preference by cattle for deerbrush versus conifer species.

Plots of 2 m in radius were established in each pasture. Ungrazed plots were based on grid-point random plots established for an ongoing study of seedfall and regeneration, and were fenced temporarily with a ring of hogwire during each grazing trial. There were 15 of these plots in pastures 2 and 3, and 13 in the smaller pasture 1. The same number of grazed plots were established by randomly locating each within 10 meters of each of the ungrazed plots. For each plot, cover of all non-conifer species, and the height and condition of all conifers, were recorded immediately before and after grazing in 1983 and 1984, and in the summer of 1985. Cover was based on ocular estimation standardized with cards. Because of the short duration of the grazing trials, and the migratory habit of the local mule deer (*Odocoileus hemionus*), it was possible to distinguish between deer and cattle effects on young seedlings. The mule deer are only in the area in the very early spring and late fall, well outside of the period of the grazing trials.

One 30 meter transect was initiated at each ungrazed plot center, and measured out in a randomly selected compass bearing. The deerbrush twig crossing the tape closest to each meter mark was tagged prior to the beginning of each grazing trial in each year. Transects were surveyed at the beginning and end of each grazing trial and the proportion of tagged twigs browsed recorded.

During the first year of the pilot study, no differences in effects of treatment due to time of grazing were observed, and little impact on shrub growth from the intensities of grazing achieved was noted, so in 1984 higher stocking rates were used. Cattle were held on each pasture as long as possible, with the objective of observing an eventual shift to browsing of conifers. Grazing trials ended when the cattle could no longer be contained by the electric fence.

Pastures are treated as blocks in the analysis. Plots are the experimental unit for evaluation of understory cover changes. Trees are the experimental unit for evaluation of growth rates and browsing impacts. Analysis of covariance, with initial cover as the covariate, was used with independent samples, t-tests for paired-plots were used for before and after comparisons. The chosen level for significance is $P < 0.05$, but all results significant at $P < 0.1$ are reported.

Clipping study

Clipping of twigs was used to simulate the defoliation of deerbrush by herbivores. Preparatory to this study, random sampling of 331 browsed twigs throughout the Research Station revealed that deerbrush twigs were browsed to an average of 1.8 mm in diameter (SD = 0.72), similar to the observations of Kie (1985) in the southern Sierra Nevada. No significant difference in average stem diameter at browse point was found between lightly and heavily utilized shrubs ($P < 0.05$), indicating that twigs are generally browsed once, and that degree of utilization can be determined from the proportion of total stems browsed. For the purposes of this study, and for ease of measurement, 'available browse' from a deerbrush shrub was defined as all twig material of less than 2 mm in diameter, with attached leaf matter.

Shrubs were clipped for three grazing seasons, 1986–1988. Three defoliation intensities were defined: none (control), moderate, and heavy:

- *Control*: Shrubs are not clipped.
- *Moderate*: Removal of one-half of the available forage as defined above. Every other stem clipped to the 2 mm in diameter point; 50% utilization.
- *Heavy*: All available forage, every stem part of less than 2 mm in diameter, is removed; 100% utilization.

The clipping treatments resulted in plants resembling shrubs defoliated by grazing. The moderate treatment resulted in a raggedy look characteristic of the moderately grazed shrubs on the forest. The heavy treatment resulted in shrubs that resembled those found near saltlicks or closed gates on the forest, places where cattle congregate.

Three treatment dates were chosen: spring (May 15), midsummer (August 1), and fall (October 15) – the beginning, middle, and end of the grazing season. Finally, three grazing frequencies were defined: none, once, and 'repeated'. The 'repeated' treatment consisted of clipping three times over the course of the summer, and was carried out at the 'heavy' level of intensity. All of the shrubs on each site were numbered and a subset of 24 shrubs on site 1 and 26 (two extra shrubs in the repeat treatment were selected in anticipation of mortality, and in fact two did die) on site 2 were randomly selected and assigned to the following treatments:

1. Control:	No clipping
2. May-Moderate:	Moderate clipping May 15.
3. May-Heavy:	Heavy clipping May 15.
4. August-Moderate:	Moderate clipping August 15.
5. August-Heavy:	Heavy clipping August 15.
6. October-Moderate:	Moderate clipping October 15.
7. October-Heavy:	Heavy clipping October 15.
8. Repeat:	Heavy clipping May 15, Aug. 1, and Oct. 15.

At each treatment date, the height, crown diameter, and basal diameter of each shrub was measured. Clipped stems and leaves were dried for 48 hours at 65 degrees centigrade, separated, and weighed. A randomized block design was used, with individual shrubs as experimental units and the two sites treated as blocks. There were three replications of each treatment in each block.

Measurement of shrub response

Branch and twig diameters have been shown in previous studies to be useful predictors of shrub volume index and productivity (Bartolome and Kosco, 1982; Kie, 1986). Because of the irregular growth form and deciduous nature of deerbrush, volume measures tend to be inexact and to vary with season. In this study, the diameter of each shrub at its base, the basal diameter, was selected for evaluation of response to treatment. Regression analysis of the relation between the natural logs of basal diameter and volume index for shrubs on the two sites had an adjusted r^2 of 0.90 (SE = 0.82), while the natural logs of basal diameter and the dry weight of available browse, as defined in this study, had an adjusted r^2 of 0.95 (SE = 0.478) (see Table 4). Volume index was calculated using the formula for a cylinder with height and crown diameter. Clipping immediately affects forage weight and the calculation of volume index, confounding these measures with time since clipping. Instead, basal diameter provides a consistent indicator of potential productivity and treatment effects on growth. Basal diameters of all shrubs at the end of the third and final growing season were analyzed as the dependent variable. Analysis of covariance, and the LSD test of mean differences were used to test for results of treatment, with season, intensity, and frequency of clipping as independent variables, initial basal diameter as the covariate, and sites as blocks. The chosen level of significance is $P < 0.05$, but all results significant at $P < 0.1$ are reported.

Results: Grazing study

In May of 1983, deerbrush canopy cover averaged 23% over the three pastures, with no significant difference among them. Deerbrush was the tallest shrub on the site, and was found on 84 and 86 plots, with an average of approximately 11066 plants per hectare. There were 943 white fir and 93 Douglas fir seedlings on the plots, with an average of 10,404 conifer seedlings per ha. Other brush species on the site, although present in much smaller amounts, included manzanita (*Arctostaphylos viscida*) (56 out of 86 plots, 1581 per hectare) and gooseberry (*Ribes roezlii*) (53 out of 86 plots, 1581 per hectare). A variety of herbaceous grasses and forbs were also present, but based on ocular estimates totaled only 8% of the total cover on the site. About half of the herbaceous cover was annual plants.

Utilization of deerbrush

Cattle grazing significantly reduced cover of deerbrush during each trial ($P < 0.05$) (Table 1). The other major shrub species, manzanita and gooseberry, were only occasionally browsed and no change in cover was detectable through ocular estimate, although signs of browsing were noted.

Utilization of deerbrush, as measured by the number of browsed twigs, increased steadily throughout grazing trials in 1983, reaching 57 to 67% of tagged twigs in 1983, with an average of 63% (SD 3.7, n = 43). Utilization ranged from 87 to 91% of tagged twigs in 1984, an average of 89% (SD 13.6, n = 43).

There was an observed increased in grazing of alternate species as the season went on, particularly of black oak in the fall, but sample sizes of oak and other utilized shrub species such as *Symphoricarpos arctus, Cornus*

Table 1. Percent cover of *Ceanothus integerrimus* during grazing trials ($n = 43$).[1]

	Control plots	% Cover grazed plots	
Year	% Cover	Pre-grazing	Post-grazing
1983	17.3[a b]	23.1[a]	12.3[b]
1984	24.7[a]	26.7[a]	15.3[b]
1985	34.5[a]	32[b]	–

[1] Within rows, different superscripts indicate significant differences, $P < 0.05$, paired T-test.

nuttallii, Prunus emarginata, and *Rubus* spp. were too small to detect this shift statistically. The nutrient content of deerbrush drops in Fall, and in fact the plant may become somewhat toxic (Kie, 1986; Cronemiller, 1953). Nonetheless, it remained the major component of cattle diets through Fall, to no apparent ill effect.

Deerbrush response to defoliation

Deerbrush showed itself to be highly resilient under even intense browsing. Cattle removed more than 40% of the deerbrush crown cover in 1983 and 1984. But absolute cover of deerbrush increased on all plots through the course of the study, reaching a mean of 32% on the grazed plots (Table 1), compared to a mean of 34.5% on the control plots by 1985. By 1985, the average height of deerbrush on the grazed plots was 1238 mm, and 1210 mm on the ungrazed plots, an increase of more than 500 mm in two years, or almost twice the original average height at the beginning of the study. Since the control plots had less deerbrush than the grazed plots to begin with, analysis of covariance, with initial shrub cover as the covariate, was used to examine whether grazing slowed the growth of the shrub. There was no significant interaction between grazing treatment and block (pasture) ($P > 0.1$) and no significant block effect ($P > 0.1$). Grazing significantly reduced the growth of deerbrush over the period of the study ($P < 0.01$), with cover on grazed plots increasing 8.9%, and cover on control plots by 17.2%.

In 1983 pasture 1 was grazed early-, pasture 2 mid-, and pasture 3 late-season (Table 2). In 1984 the higher stocking rates shortened the grazing periods, so that all three pastures had been grazed by mid-season. No difference in response or use of the shrubs was observed, suggesting that the exact timing of the grazing trial probably had little effect. Seasonal effects were tested in the clipping study.

Stocking rates were high, ranging from 1 to nearly 2 mature cows per month per ha between 1983 and 1984 (Table 2). There was enough forage for one cow for about 4 months on each hectare of ground covered by deerbrush and herbaceous species in 1983, and for about 5 months in 1984.

Table 2. Stocking rates achieved in grazing trials.

	Hectares	1983			1984		
		Grazing period	Head	Head/ ha/mo	Grazing period	Head	Head/ ha/mo
Pasture 1	2.08	7–23 to 8–8	4	1.02	6–12 to 6–25	9	1.88
Pasture 2	2.17	8–27 to 9–20	4	1.47	6–30 to 7–15	8	1.83
Pasture 3	2.70	9–21 to 10–18	4	1.38	7–18 to 7–30	9	1.33

Effects on conifer seedlings

In no case was the attempt to get cattle to browse conifers successful. Each year, cattle killed 2 to 5% of the extremely dense seedlings by incidental trampling, affecting 1,084 of the 10,404 original seedlings per ha at the end of the two years of grazing trials. Unlike in a free-ranging situation, cattle spent 24 hours a day on the study site, creating an unusual intensity of trampling. In addition, as trees grow larger and become less dense on the site, trampling rates can be expected to decline significantly. Further, since the ideal conifer seedling stocking rate for this site is about 500 seedlings per ha (Heald, 1986, pers. comm.), this level of impact cannot be considered a threat to regeneration.

Pre-grazing inventories indicated that about half of the conifer seedlings were browsed each year by deer, removing the terminal bud. Within the short period of this study and considering the small size of the trees, this constant background level of browsing made it impossible to determine the effects of the treatments on conifer growth. White fir had a mean height of 106 mm in 1983 (SD = 51.6, n = 943), and 170 (SD = 92.3, n = 643) in 1985, while Ponderosa pine reached an average height of 296 mm (SD = 200.3, n = 35) in 1985. Douglas fir and sugar pine were slightly shorter than white fir on average. All seedlings on the site were shorter than normal for the area, where under typical conditions three times the growth would be expected (Bob Heald, 1986, pers. comm.).

Results: Clipping study

At the beginning of the study mean shrub basal diameter was 37 mm (SD = 7) on site 1 and 6 mm (SD = 2.3) on site 2. Although the size and age class of shrubs on each site was different, their rate of growth and response to treatment was similar. Maximum growth in basal diameter and volume on both sites was between May and August, presumably the time when warm temperatures and residual soil moisture permit rapid growth. The least growth occurred in winter.

Response to timing, intensity, and frequency of clipping

Shrub mean basal diameters remained significantly larger on site 1 (60 mm; SD 17.1) than site 2 (26 mm, SD 12.3) throughout the study ($P < 0.05$, ANCOVA). However, there was no interaction between site and any treatment ($P > 0.1$).

Analysis of covariance, excluding repeatedly-clipped shrubs, shows a significant difference in basal diameter by intensity of clipping (Table 3) ($P < 0.01$). Among shrubs clipped a single time, there was no significant difference in size due to season of clipping ($P > 0.1$), ANCOVA) (Table 3). Differences in size due to frequency of clipping were significant ($P < 0.001$, ANCOVA) (Table 3). Repeatedly clipped shrubs grew the least, from a mean basal diameter of 18 mm (SD = 13.2) to 24 mm (SD = 14.2), with two mortalities among the shrubs on site 2.

Table 3. Mean basal diameters of *Ceanothus integerrimus* by annual treatment after three years of treatment.[1]

Frequency						
	Controls	SD	Clipped once	SD	Clipped 3 times	SD
	60.3^a ($n = 6$)	26.3	42.9^b ($n = 35$)	21.1	24.1^c ($n = 6$)	14.2
Timing						
	May clipping	SD	August clipping	SD	October clipping	SD
	43^a ($n = 12$)	24.5	40.2^a ($n = 12$)	21.2	45^a ($n = 12$)	19.2
Intensity						
	Controls	SD	50% clipped	SD	100% clipped	SD
	60.3^a ($n = 6$)	26.3	49.2^b ($n = 18$)	22	36.9^c ($n = 18$)	19

[1] Within each row, different superscript indicates significantly different at $P < 0.01$, LSD.

Using the regression analyses developed for the study, the repeatedly clipped shrubs have the lowest potential productivity as measured by available browse and volume index, while controls have the greatest (Table 4).

Discussion

Intensity and frequency of defoliation have far greater impact on deerbrush growth than the season of defoliation. In the grazing study, observations indicated that the season of grazing made no difference in the results. In the clipping study, growth did not vary when tested by season. In the grazing study, the short duration grazing trials of the second year can be considered analogous to a single defoliation of as much as 90% of the twigs of three

Table 4. Predicted productivity of available browse and volume index of treated *Ceanothus integerrimus* shrubs after three years of treatment.

Annual treatment	Basal diameter, mm (SD)	Volume (m^3) as predicted by: ln(y) = 0.87376 + 2.8112ln(x) (r^2 = 0.90, SE 0.82)	Weight (gms dry wt) of available browse as predicted by: In(y) = –3.119 + 2.2361n(x) (r^2 = 0.95, SE 0.48)
Controls			
Site 1 (8 years old)	84 (5.2)	6.05	876
Site 2 (4 years old)	38 (9.3)	0.61	142
Clipped once, 50%			
Site 1 (8 years old)	69 (11.7)	3.51	568
Site 2 (4 years old)	32 (11.1)	0.4	101
Clipped once, 100%			
Site 1 (8 years old)	53 (11)	1.64	310
Site 2 (4 years old)	21 (9.9)	0.13	42
Clipped 3 times, 100%			
Site 1 (8 years old)	37 (2.8)	0.6	140
Site 2 (4 years old)	11 (3.3)	0.02	10

year old shrubs. This single but intense defoliation slowed shrub growth but did not result in any sustained difference in cover of grazed and ungrazed areas and all shrubs continued to increase in size, surpassing the 30% cover level believed to affect tree growth (Fiske, 1981). In the clipping study, both 50% and 100% twig removal did slow shrub growth, but unless repeated, not even 100% clipping prevented positive increase in shrub size. These results contrast sharply with studies showing sustained impacts to coastal Douglas fir forest shrubs from defoliation (Sharrow et al., 1989).

Summer regrowth of deerbrush is rapid and apparently limited only by moisture, but this hypothesis deserves further testing. Plant water potential measurements taken on site 1 in 1986 showed that water potential deficits increased through the summer, with an initial rapid draw-down during June through August, leveling off August through October. The period of most rapid draw-down coincided with the period of most rapid growth of deerbrush. The lack of response to season of clipping may be because even if regrowth is limited by water, plants defoliated once in early spring still have the opportunity to regrow, presumably in time to make use of canopy material to photosynthesize. Shrubs defoliated in August and October show little within-season regrowth, but a lack of moisture after August may permit little photosynthesis even for shrubs with an intact canopy. Their re-growth will also take place in early spring. In fact, deerbrush shrubs commonly begin to drop leaves in August, exhibiting typical 'drought-evader' behavior. It is probable that the degree to which defoliation impacts vary by season is to some extent a function of soil moisture conditions in that year.

Treatments apparently affected the reproductive capacity of the shrubs. In 1988, deerbrush on site 1 reached maturity and flowered prior to the first clipping treatment that year. All of the control shrubs and half of all shrubs clipped once flowered. Repeatedly clipped shrubs were the only treatment in which none of the shrubs bloomed, indicating that patterns of herbivory can strongly affect reproductive capacity, a topic for further study.

In managing for the long term productivity of deerbrush as a forage source, controlling the intensity and frequency of defoliation is more important than the season of defoliation. Particularly in environments where the within-season availability of water is a major control on shrub behavior, this may be the case more often than is now understood.

Prescriptions for grazing and research as part of agroforestry management can be proposed based on the results of this study (Figure 1). American silvopastoralists seek a mix of outputs from forest grazing (Hardesty et al., 1983). By manipulating grazing patterns, the system can be managed to emphasize different outputs. Long-term planning for a silvopastoral system such as this one would at best also include harvest, regeneration, and site preparation prescriptions to obtain a desired understory species mix. Harvest planning could be used to provide a continuous supply of forage and/or wildlife habitat diversity on a watershed or landscape basis.

Short-duration, high intensity grazing strategies, including close herding, can be employed to harvest a maximum amount of shrub matter without compromising the forage supply or significantly damaging trees (Figure 1). This strategy would be employed when growth of shrubs is desirable for wildlife or to enhance forage supplies. A balance of one heavy or moderate defolia-

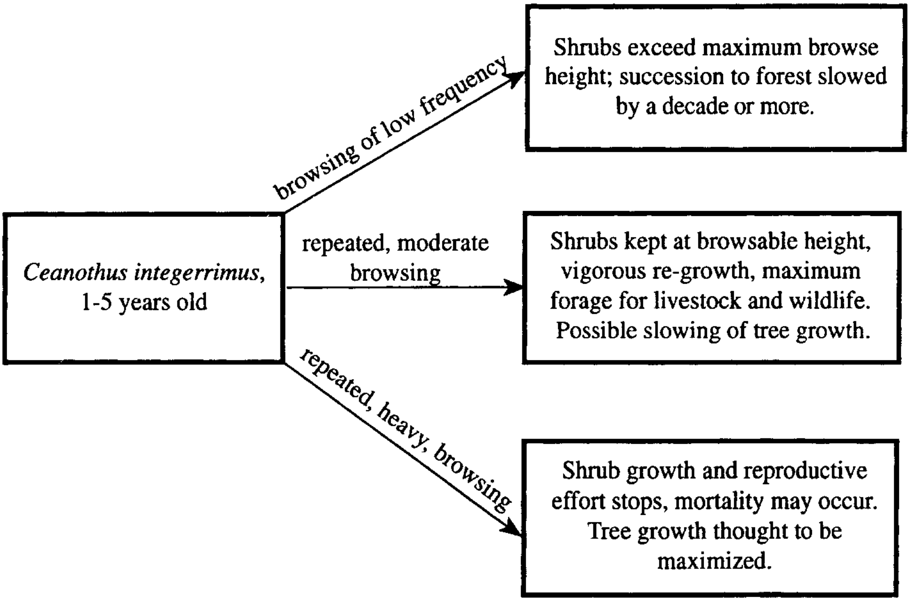

Figure 1. Grazing prescriptions for silvopastoral system with conifers and deerbrush (*Ceanothus integerrimus* Hook. & Arn.).

tion by livestock followed by light or moderate defoliations by wildlife through the season or in the fall could be used to maintain forage supplies at a given level, and to protect soils and wildlife habitat. As is common with shrubs, clipping treatments were observed to increase the leaf to stem ratios of the browse produced in this study. Deerbrush is also a nitrogen-fixer, and nitrogen-fixing vegetation combined with livestock grazing may actually increase the nitrogen uptake of associated trees (Carlson et al., 1994). Thus the slowing of tree growth suggested in Figure 1 for the intermediate level of grazing may not be significant – more research is needed on the response of young trees to intermediate levels of shrub co-occupation.

In range management, much effort is dedicated to mitigating undesirable effects of selective grazing pressure on rangeland plant community composition (Holechek et al., 1995; Heady and Child, 1994; Heitschmidt and Stuth, 1991). But if the major objective is timber or wood production, then heavy, repeated grazing, using animal selectivity to change plant community composition to favor trees, is desirable. Under the season-long grazing regimes typical of this area, maximum control of the competing shrubs will occur when grazing intensity is heavy, and when livestock visit the site regularly (Figure 1) through the grazing season. The shrubs in the high frequency clipping treatment had more apparent dead matter than other shrubs, consistent with observations elsewhere on the forest where even the largest deerbrush shrubs look half dead in highly localized places like water troughs with season-long cattle concentrations.

A majority of site 2's one-year-old shrubs survived repeated, heavy defoliation for three years. The unpalatable woody stems of the plant provide a reservoir for regrowth. It is probable that initiation of grazing at the time of first sprouting might result in mortality, as during the first season of growth the plant would not have woody parts. The best control strategy for this shrub, then, would be immediate post-harvest application of grazing treatments. Work on a site adjacent to site 2 has shown a reduction in cover and density of deerbrush plants and other common shrubs when grazing is initiated immediately post-harvest (Allen and Bartolome, 1989). Other shrub species that are not palatable at older stages are sometimes grazed during the highly succulent initial growth stages.

Conclusion

A better understanding of the relative importance of season, intensity, and frequency of defoliation, and the relative preference of livestock for trees versus understory vegetation, can lead to more precise, goal-oriented prescriptions for silvopastoralism. It is also apparent that the capacity for shrub control varies from place to place, and that shrub species in one area may have quite different responses than those in another area. Development of the types of grazing and forestry prescriptions that allow silvopastoralists the opportunity to manage for the spectrum of outputs desired requires understanding the dynamics of each particular system and its response to herbivory. Particularly in free range conditions, grazing impacts to non-target species and riparian or sensitive areas must also be considered.

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