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Sites, mowing, 2,4-D, and seasons affect bitterbrush values

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Abstract

This study was conducted in a sagebrush-bitterbrush vegetation type in southcentral Wyoming to compare the effects of mowing and 2,4-D application on shrub cover and bitterbrush (*Purshia tridentata* Pursh) use, preference values, browse values, and residual twig weight after summer/fall browsing by cattle and winter big game use. Areas 3 to 6 ha in size were mowed, sprayed with 2,4-D, or left untreated on 4 different sites. Total shrub cover was reduced from 38% (53% mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana*), 37% bitterbrush) to 23% (38% sagebrush, 52% bitterbrush) by mowing, and to 17% (18% sagebrush, 64% bitterbrush) by herbicide application. Twig weight use was greater on mowed areas, on the more productive sites, and during summer cattle browsing when leaves were present than during winter browsing by big game. Frequency of use was inversely related to bitterbrush availability, although the relationship was confounded by different snow depths on different sites. Utilization values based on basal diameter were more sensitive to site and treatment effects than length and weight utilization values, but were influenced by differences in twig morphology and did not reflect differences in twig use, preference values, browse values, or browsing residual weights. Mowing produced the greatest preference values and browsing residual weights for cattle browsing and the greatest browse values for both cattle and big game. Preference values, browse values, and browsing residual weight appear to be useful indicators of site, treatment, and browsing effects.

Key Words: habitat improvement, range improvements, shrub management, use

Antelope bitterbrush (*Purshia tridentata* Pursh) is widespread in the western United States, occurring in numerous habitat types over about 140 million ha (Hormay 1943). It is preferred by mule deer *(Odocoileus hemionus)* in the fall and winter and by cattle and domestic sheep in late summer. It is the most important browse plant for mule deer, pronghorn *(Antilocarpa americana)* and cattle in the mountain brush vegetation type in southcentral Wyoming because of its widespread abundance and forage value (Kituku et al. 1992, Ngugi et al. 1992).

Sheep and big game generally browse only current annual growth. However, cattle browsing can be detrimental to bitterbrush because they consume woody branches up to 6 mm in diameter as well as current annual growth (Hormay 1943). Serious bitterbrush deterioration can occur when it is utilized during summer by livestock and again in the winter by big game. Consequently, proper utilization and maximum productivity of bitterbrush are major concerns of habitat managers.

Actual utilization of bitterbrush is frequently determined by (1) measuring the length of tagged twigs before and after browsing in the dormant period as first suggested by Nelson (1930) and later modified by Aldous (1945), or (2) using regression equations comparing twig length, basal diameter, and tip diameter at the point of browsing (Jensen and Urness 1981). Percent utilization can be determined by measuring either twig length or weight after browsing and using regression equations to compare length or weight to unbrowsed leaders (Basile and Hutchings 1966).

Estimated utilization of bitterbrush and other shrubs may vary with site (Ferguson and Marsden 1977, Jensen and Urness 1981); years (Medin and Anderson 1966); overstory canopy (Peek et al. 1978); browsing pressure (Austin et al. 1984, Jensen and Scotter 1977, Roundy et al. 1989); availability (Burrell 1982, Griffith and Peek 1989); fertilization (Bayoumi and Smith 1976, George and Powell 1977); plant species and size (Lyon 1970, Peek et al. 1971, Provenza and Urness 1981); presence of leaves (Ruyle et al. 1983); and twig location on the plant (Basile and Hutchings 1966).

One additional factor not discussed in the literature is the effects of shrub manipulation practices, such as mowing or herbicide application, on bitterbrush utilization. These practices are frequently used to increase bitterbrush vigor and/or accessibility in stands of bitterbrush with low productivity or in plant communities dominated by big sagebrush (Ferguson and Basile 1966, Hyder and Sneva 1962, Schneegas and Zufelt 1965).

Various range improvement practices offer opportunities to improve forage quality for wildlife and livestock on summer and fall ranges. Selective control of species with herbicides allows the manager to maintain vegetation in almost any seral stage. Mixed stands of big sagebrush (*Artemisia tridentata* Nutt.) and bitterbrush may be sprayed with 2,4-D without excessive bitterbrush loss if sprayed before or during bitterbrush bloom (Hyder and Sneva 1962).

Mowing bitterbrush results in extensive root and leaf regeneration with subsequently greater utilization of rejuvenated browse. Rotocutting bitterbrush in early spring resulted in a 47% increase in leader growth during the first growing season (Schneegas and Zufelt 1965). In Texas, both protein content and herbivore utilization were greater on treated mixed shrub plant communities compared to untreated areas (Box and Powell 1965, Everitt 1983, Powell and Box 1966).

The objective of this study was to determine the effects of mowing and 2,4-D herbicide application on utilization of bitterbrush twigs on different sites following summer livestock browsing and winter big game use in the mountain brush vegetation type of southcentral Wyoming.

Study Area

This study was conducted on the Cedar Creek Ranch, 20 km east of Saratoga, Wyo., on the western edge of the Medicine Bow

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Mountain Range. Elevation ranges from 2,100 to 2,600 m. Soils are North Park Formation brown sandy loams developed on loess, limestone, sandstone, and tuff (Dunnewald 1957).

Dominant plant species include bitterbrush, mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* Nutt.), Idaho fescue (*Festuca idahoensis* Elmer), sandberg bluegrass (*Poa secunda* Presl.), canby bluegrass [*P. canbyi* (Scribn.) Howell], western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Love], bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Love], and thickspike wheatgrass [*Elymus lanceolatus* (Scriber and J.G. Smith) Gould].

Precipitation at the Saratoga weather station (lower and drier than the study site) ranges from 380 to 480 mm, falling mostly as snow. Annual depth and extent of snow coverage is highly variable. Elk and mule deer utilize the area during fall and some winters depending on snow depth and duration. Cattle graze the area from early June to mid-October.

Four different sites, all facing south to southwest, were selected within the general study area. Site 1 is a valley bottom (1–5% slope) with the highest percentage of rock (10–60%) in the soil profile and greatest snow cover. Site 2 is on the upper slope (10–30%) of an east-west ridge with generally sandy-loam soils. Site 3 is a mountain terrace (1–5% slope) with relatively deep, gravelly-loam, or loam soils. Site 4 is on the toe slope of a broad, uniform slope (3–10%) with relatively deep, sandy-loam to gravelly-loam soils, and occasional additional moisture from runoff. In general, site productivity increased from site 1 to site 4 because of a combination of deeper soils and/or less rock where soil textures allowed greater moisture-holding capacity.

Methods

Experimental Design

Twelve relatively homogenous plots of 3 to 6 ha in size were allocated to 4 replications (sites) of 3 treatments in a completely randomized block design. Sampling the same plots during 2 seasons resulted in a split-plot in time (Steel and Torrie 1980).

Treatments

Treatments included untreated, mowing, and 2,4-D herbicide application. Areas were mowed to a 20 to 30-cm stubble height with a rotary blade shredder in late May 1986 as soil moisture conditions permitted. Butyl-amine of 2,4-D at 1 kg acid equivalent/ha in water without surfactant at a total volume of 20 liters/ha was aerially applied in mid-May 1986.

Data Collection

Three permanent line transects, each 100-m long, were established in each of the 12 units after treatment. Total shrub canopy cover and bitterbrush canopy cover were determined in the fall, 1987, using the line intercept method (Canfield 1941).

Along each 100-m transect, the nearest bitterbrush plant corresponding to multiples of 10 m on the tape (i.e., 10-, 20-, 30-, ...) was sampled in late October and early November, 1986 (late fall) before all leaves dropped, but after cattle grazing and before elk and deer use. The same plants were sampled again in early April, 1987 before bud swell (late winter). A metric rule was placed across the top of each plant, and the crown diameter divided into 5 equidistant points across the crown. An imaginary line was dropped from each point to the highest and nearest unbranched, current annual growth twig for a total of 5 selected twigs from each of 30 plants or 150 twigs per plot season. Although bitterbrush twig length-diameter relations differ with position on the plant (Basile and Hutchings 1966, Jensen and Urness 1981), selecting the highest and nearest twig across the crown dense, hedge plants most closely approximated accessibility to grazing ungulates.

Each twig was 1 cm from the base to eliminate the swell and elliptical butt shape (Basile and Hutchings 1966) and placed in bags of either browsed or unbrowsed composite samples. During the late fall collection it was relatively easy to determine a browsed, current growth twig. Most of the browsing by fall was assumed to have been by cattle. During the late winter collection, only those twigs browsed during dormancy by big game were counted as browsed. This approach biased sampling against current growth twigs previously browsed during the growing season; however, (1) it was assumed that once a twig had been browsed in the summer, it would not be browsed again in the winter, and (2) the primary emphasis in this study was to compare the relative effects of sites and treatments on preference by the 2 classes of animals (livestock vs. big game) during the seasons in which they normally browsed bitterbrush.

All twigs were refrigerated at 10° C before measuring diameter (mm), tip diameter (mm), and length (mm) of unbrowsed and browsed twigs using the procedures of Jensen and Urness (1981).

Composite samples were dried at 40° C to a constant weight. Average net weights for unbrowsed and browsed twigs were calculated by dividing weights of composite samples by the number of twigs in each sample.

Twig *actual use* was calculated as the actual amount of twig length (mm) and weight (mg) removed and reflected effects of sites and treatments on the amount consumed by animals. Twig length use and weight use were calculated as the difference in length and weight between unbrowsed and browsed twigs.

Browse *utilization* (%) was calculated for twig numbers, length, basal diameter, and weight and reflected potential effects of sites, treatments, animal preference, and browsing pressure on the plant. Browsing frequency (%) was the utilization based on numbers of browsed twigs per transect (Stickney 1966) and was determined by dividing the number of browsed twigs per transect by 50 (i.e., total possible). Length utilization was determined by dividing actual length use by length of unbrowsed twigs. Basal diameter utilization was determined by the procedures of Jensen and Urness (1981). Weight utilization was determined by dividing the actual weight use by weight of unbrowsed twigs.

Two additional sets of factors were calculated because of effects

Table 1. Mean bitterbrush canopy cover (%), total shrub cover (%), and percentage of total cover comprised of bitterbrush on 4 sites and 3 treatments in southcentral Wyoming, late fall, 1986. Those means for different sites, different treatments, or different treatments within a site followed by a different letter are statistically different at $P<0.05$.

	Treatment			Site
Site	Control	2,4-D	Mowing	mean
	(Bitterbrush Cover)			
1	4	7	10	7 b
2	21	13	16	17 a
3	17	12	12	14 a
4	15	16	9	13 a
Mean	14	12	12	
	(Total Shrub Cover)			
1	26 a	19 a	21 a	22 c
2	42 a	15 b	32 a	30 a
3	41 a	14 b	17 b	24 bc
4	45 a	18 b	22 b	28 ab
Mean	38 a	17 c	23 b	
	(Bitterbrush Composition)			
1	16 b	31 ab	49 a	32 c
2	51 b	89 a	49 a	63 ab
3	41 b	89 a	71 ab	67 a
4	32 b	86 a	44 b	54 b
Mean	35 c	74 a	53 b	

of browse availability on preference values and browse values (Powell and Box 1966). *Preference values* for bitterbrush on each site × treatment combination based on length and weight were calculated by multiplying actual length use and weight use each by browsing frequency. *Browse values* for each site × treatment combination were calculated by multiplying actual length use and weight use each by browsing frequency and bitterbrush canopy cover. The same browsing frequency values and bitterbrush canopy cover values per plot were used to calculate both length browse values and weight browse values.

Average twig *browsing residue* was also calculated because the capacity of a bitterbrush plant to remain vigorous is more dependent on growing conditions (Garrison 1953b) and the absolute amount of current growth residue than on the degree of utilization (the relative amount of current growth removed). Twig browsing residue weight was calculated as the weighted average of unbrowsed and browsed twig weights per transect.

Statistical Analyses

Statistical differences in all twig parameters among the 3,600 twigs and among the 72 composite transect samples due to 4 sites, 3 treatments, and 2 seasons were determined using the GLM (General Linear Model) procedure of SAS (1985). Relations among twig parameters for different sites, treatments, and seasons were determined by first plotting scatter diagrams of raw data and of residuals from linear regression models (Draper and Smith 1981). If curvilinearity was not evident, linear relations were quantified using the REG procedure of SAS (1985). All differences discussed in this paper are significant at the 5% level of confidence unless otherwise indicated.

Results and Discussion

Precipitation (1986/Long-term mean) at the USFS Brush Creek Ranger Station, located 10 km southeast of the study area, was above average in June (69/37 mm) and July (73/40 mm), below average in August (14/34 mm), and average in September (44/44 mm). In general, growing conditions from date of treatment through the period of last bitterbrush measurements were above average.

Shrub Cover

Bitterbrush canopy cover, averaging about 12–14% on all areas, was not reduced by either spraying or mowing (Table 1). Bitterbrush cover, however, was much lower on site 1 than on the other 3 sites. Bitterbrush grows best on well-drained, moderately deep and fine or coarse textured soils and on more isolated southerly and southeasterly slopes (Driscoll 1963). Bitterbrush yields increase with increasing annual precipitation (Garrison 1953a, Kindschy 1982, Nord 1965), and the amount of new leader growth and seed production increases with increasing soil water availability McKean 1964). Site 1 soils were extremely rocky and had low effective rooting depth and available soil water.

Total shrub cover was reduced to the target levels of about 20% on sprayed, and mowed areas. Differences in total cover among sites were significant, but not large. Within the different sites, treatments had the lowest relative effect on site 1. Across sites within the same treatment, total shrub cover was relatively low on the untreated area on site 1, similar on all sprayed areas, and higher on site 2 mowed area than on mowed areas of other sites. In general, bitterbrush was more accessible to grazing animals on all treated areas because of the 11 to 22% reduction in sagebrush foliar cover.

The effects of treatments and sites also affected the percentage of bitterbrush within total shrub cover. Bitterbrush composition was greatest on sites 2 and 3 and about half that on site 1. Bitterbrush composition was greatest on sprayed plots and least on untreated plots. Although the 2,4-D herbicide "burned" the tops off some bitterbrush plants, they had recovered by the end of the growing season. The significant site × treatment interaction resulted from bitterbrush composition on sprayed areas being lower than on mowed areas on site 1, but higher on all other sites.

Actual Use

Twig Length

Neither bitterbrush twig actual length use or twig length utiliza-

Table 2. Mean bitterbrush twig weight use (mg) and frequency of use (%) on 4 sites and 3 treatments in southcentral Wyoming, late fall and late winter, 1986–87. Those means for different sites, different treatments or different treatments within a site followed by a different letter and comparable means in different seasons followed by an "*" are statistically different at $P<0.05$.

	Weight Use				Frequency of Use			
	Treatment			Site	Treatment			Site
Site	Control	2,4-D	Mowing	mean	Control	2,4-D	Mowing	mean
	(mg)				(%)			
(Late Fall)								
1	23	28	15 *	22 c	55 a*	49 a	44 aa	50 a*
2	34	43	70	49 bc	42 a	33 a	35 a	37 b
3	41	57	126 *	75 ab	16 b	42 a	56 a	38 b
4	58	63 *	169 *	97 a	14 b	21 a*	33 a	23 c*
Mean	39 b	48 b	95 a*	61 *	32	37 *	42	37 *
(Late Winter)								
1	37 a	29 a	77 a*	47	21 *	54	44	40 *
2	39 a	17 a	30 a	29	31	52	47	43
3	56 a	33 a	50 a	46	35	42	41	39
4	35 b	113 a*	22 b	57	25	56 *	51	44 *
Mean	42	48	45 *	45 *	28 b	51 a*	46 a	42 *
Mean (Late Fall + Late Winter)								
1	30	29	46	35 c	38	52	44	45 a
2	37	30	50	39 bc	37	43	41	40 ab
3	48	45	88	60 ab	25	42	49	39 ab
4	47	88	96	77 a	19	39	42	33 b
Mean	40 b	48 b	70 a		30 b	44 a	44 a	

tion differences due to sites, treatments, seasons, or any interaction were statistically significant at $P<0.05$. For the 12 areas samples, twig length use over both seasons averaged 33.3+/-15.6 mm and ranged from 23 to 44 mm. Twig length utilization over both seasons averaged 32.2+/-12.4% and ranged from 29 to 39%. The actual length difference consumed was 36 mm for big game and 31 mm for cattle ($P<0.12$).

The coefficients of variation (CV) for twig length use (47%) and utilization (39%) were consistently lower than CV's for use and utilization for basal diameter and weight, and the relative differences due to sites, treatments, and/or seasons were smaller than for other parameters. Therefore twig length use and utilization were not sensitive parameters for reflecting differences in browsing due to environmental conditions (sites and treatments) or animal preference (seasons) in this study.

Twig Weight

The average weight (mg) of twig consumed for both seasons combined was much greater on the more productive sites 3 and 4 than on the less productive sites 3 and 4 than on the less productive sites 1 and 2 (Table 2). Most of this difference was because of differential consumption by cattle resulting in a significant site × season interaction. Assuming that the average weight removed was a bite, the weight of a bite on the most productive site was about 4.5 times that on the least productive site. Bite size was highly correlated to unbrowsed twig weight ($r = 0.81$, summer; $r = 0.70$, winter). Increasing bite size from site 1 to site 4 was consistent across all treatments during the summer.

In eastern Oregon and Washington, clipping 75% of annual leader growth resulted in the greatest productivity in bitterbrush. Removal of 50% annual leader growth on poor sites and 60 to 65% on good sites permitted sustained production (Garrison 1953b). In California, approximately 40% utilization of current annual leader growth is recommended to maintain plant vigor and to ensure adequate seed production (Hormay 1943).

The difference due to seasons probably reflects differences in animal feeding behavior (bite size of cattle and big game), succulence and palatability, and presence of leaves during the summer. The nutrient quality and palatability of bitterbrush varies among plant parts, with age, season, or phenology, and habitat improvement practices, and often influences utilization (Giunta et al. 1978, Jensen et al. 1972, Kituku et al. 1992, Tueller 1979).

Cattle also consumed greater amounts per twig on mowed areas than on untreated or sprayed areas. This was especially true on mowed areas on sites 3 and 4. A significant treatment × season

Table 3. Mean bitterbrush browsed twig tip:basal diameter ratios on 4 sites and 3 treatments in southcentral Wyoming, late fall and late winter, 1986–87. Those means for different sites, different treatments, or different treatments within a site followed by a different letter and comparable means in different seasons followed by an "*" are statistically different at $P<0.05$.

	Treatment			Site
Site	Control	2,4-D	Mowing	mean
	(Tip:Basal D. Ratio)			
	(Late Fall)			
1	22 a	16 a	18 a	19 b
2	22 a	17 a	20 a	20 ab
3	30 a*	7 b	12 b	16 b
4	27 ab	36 a*	14 b	26 a
Mean	25 a	19 b	16 b	20 *
	(Late Winter)			
1	16	8	11	12 b
2	13	6	11	10 b
3	13 *	10	8	10 b
4	32	13 *	18	21 a
Mean	18 a	9 b	12 ab	13 *
	(Mean) (Late Fall + Late Winter)			
1	19 a	12 a	14 a	15 b
2	17 a	11 a	15 a	15 b
3	22 a	9 b	10 b	13 b
4	29 a	25 a	16 a	23 a
Mean	22 a	14 b	14 b	

Table 4. Mean bitterbrush twig length (mm) and weight (mg) preference values[1] on 4 sites and 3 treatments in southcentral Wyoming, late fall and late winter, 1986–87. Those means for different sites, different treatments or different treatments within a site followed by a different letter and comparable means in different seasons followed by an "*" are statistically different at $P<0.05$.

	Length Preference Value				Weight Preference Value			
	Treatment			Site	Treatment			Site
Site	Control	2,4-D	Mowing	mean	Control	2,4-D	Mowing	mean
	(mm)				(mg)			
	(Late Fall)							
1	8 a	15 a	7 a*	10	13 a	15 a	8 a	12 b
2	13 a	11 a	9 a*	11	15 a	14 a	27 a	19 ab
3	4 b	9 b	27 a*	13	7 b	24 b	73 a*	34 a
4	4 b	7 b*	18 a	9	8 b	15 b*	55 a*	26 ab
Mean	7 b	10 ab	15 a	11 *	11 b	17 b*	41 a*	23
	(Late Winter)							
1	7	18	21 *	15	10 a	16 a	35 a	20
2	10	16	21 *	16	14 a	9 a	14 a	12
3	16	10	14 *	13	19 a	16 a	19 a*	18
4	8	24 *	17	16	9 b	63 a*	11 b*	28
Mean	10 b	17 a	19 a	15 *	13 b	26 a*	20 ab*	19
	Mean (Late Fall + Late Winter)							
1	8	17	14	13	11 a	15 a	21 a	16 b
2	12	13	15	13	14 a	11 a	21 a	15 b
3	10	10	20	13	13 b	20 b	46 a	26 a
4	6	15	18	13	9 b	39 a	33 a	27 a
Mean	9 b	14 a	17 a		12 c	21 b	30 a	

[1]Length use × Frequency of use; Weight use × Frequency of use.

resulted because cattle bite size on mowed areas was greater than on other treatments. However, big game bite size during the winter was more consistent across all treatments. The exception to this was the relatively large bite size of big game on the site 4, sprayed area. Big game also tended to increase bite size with increasing weight of the available twig (r = 0.70).

Utilization

Browsing Frequency

Frequency of use varied from 45% on site 1 (probably because of the low bitterbrush availability) to 33% on site 4 and from 30% on untreated areas to 44% on sprayed and mowed areas (Table 2). This was not true for both collection periods. A significant site × treatment × season interaction resulted from browsing frequency being 34% greater on the site 1, untreated area in late fall after cattle browsing than in late winter after big game browsing.

Frequency of use was also 35% lower on the site 4, sprayed area in late fall after cattle browsing than in late winter after big game browsing. By late fall, cattle browsing frequency on site 3 was relatively low on the untreated area as compared to that on treated areas. In general, the lower the bitterbrush cover and more accessible to browsing, the higher the percentage of browsed available twigs (r = -0.43).

Cattle had equal access to bitterbrush plants on all sites during the summer, but apparently browsed a greater percentage of twigs on the site 1, untreated area due to a lower number of available plants. However, snow cover was deeper on the site 1, untreated area than on other areas during the winter (personal observations). During winter, big game may have displayed the same tendency to browse a higher number of twigs on a limited number of plants, but because of deeper snow cover, fewer of the bitterbrush plants normally available to the cattle were exposed to big game.

Browsing frequency differed due to the site × treatment × season interaction was because of relatively low browsing frequency on 3 areas by cattle during the summer and fall. Big game tended to prefer treated areas across all sites more than cattle.

Basal Diameter

The basal diameter of browsed twigs was consistently greater than that of unbrowsed twigs regardless of site, treatment, or season. The difference in basal diameter for all sites, treatments, and seasons averaged 0.19+/-0.12 mm. The only difference (P<0.05) due to any main effect or interaction was because of treatments. The difference between browsed and unbrowsed twig basal diameter was 0.25 mm for untreated, 0.19 mm for mowed, and 0.14 mm for sprayed plants.

The difference (0.08 mm) between basal diameter of untreated, unbrowsed twigs (1.37 mm) and sprayed, unbrowsed twigs (1.29 mm) was much smaller than the difference (0.20 mm) between basal diameter of untreated, browsed twigs (1.63 mm) and sprayed, browsed twigs (1.43 mm). The basal diameter of mowed, unbrowsed twigs was 1.39 mm, and the basal diameter of mowed, browsed twigs was 1.58 mm. The relative increase in basal diameter due to browsing compared to the basal diameter of unbrowsed twigs was 18% for untreated, 14% for mowed, and 11% for sprayed twigs. Apparently, spraying retarded twig growth on unbrowsed twigs (Kituku et al. 1992) both before and after browsing.

The ratio of the tip diameter and basal diameter of browsed twigs is sometimes used as a measure of the degree of utilization such that the greater the ratio, the greater the degree of utilization. Jensen and Urness (1981) recommend that the tip diameter of unbrowsed twigs be subtracted from both tip and basal diameters of browsed twigs as a correction factor. When using this method, differences in tip:basal diameter ratios for browsed twigs were significant for sites, treatments, seasons, and the site × treatment × season interaction (Table 3).

Browsed twig tip:basal diameter ratios were much higher on site 4 than on other sites. This was generally consistent for summer cattle and winter big game browsing. The major exception occurred on site 4, where ratios for sprayed plants were much greater than those for mowed plants after cattle browsing but relatively low for sprayed plants after big game browsing.

The degree of browsing based on tip:basal diameter ratios was also greater on untreated plants than on treated plants during both seasons, but consistently greater across all treatments for cattle browsing in summer than for big game browsing in winter. This seasonal difference in degree of browsing implies that cattle browse thicker twigs than big game.

A comparison of tip and basal diameters for unbrowsed and browsed twigs on different plots showed significant differences, whereas there were no differences in basal diameters for either unbrowsed or browsed site 4, sprayed twigs. The tip diameters of unbrowsed twigs on site 4, sprayed plants were generally the smallest of twigs on all plots during late fall and late winter. Although the unbrowsed twig tip diameter is subtracted from both the numerator and denominator in this ratio, mathematically, the ratio increases as the unbrowsed twig tip diameter decreases.

Therefore, the degree of browsing will appear to be greater for twigs with relatively small tip diameters. Correlation coefficients between the degree of browsing based on tip:basal diameter ratios and browsing frequency (r = -0.47), length utilization (r = -0.15), and weight utilization (r = -0.15) were relatively low and negative.

Weight

Differences in utilization based on weight due to sites, treatments, or seasons were not significant. Weight utilization by cattle averaged 29+/-19% and ranged from 17 to 55%. Weight utilization by big game averaged 24+/-16% and ranged from 7 to 52%. Differences among sites ranged from 22 to 31% and differences among treatments ranged from 22 to 28%.

Utilization by weight was relatively similar on all areas. The only significant interaction was site × treatment × season. Weight utilization by big game on site 4, sprayed areas (52%) was much higher than on other treatments on this site during late winter and much higher than that by cattle (28%) on the same area during summer. This is consistent with the higher browsing frequency and weight use shown by big game on this particular area.

Preference Values

Length

Combining browsing frequency and length difference to produce preference values based on length (Table 4) did tend to accentuate the differences between treatments. Mowing and spraying increased preference values based on length for both cattle and big game. In addition, preference values for big game were greater than those for cattle. Cattle in this study may have had adequate herbaceous material available and exercised more selectivity by consuming fewer twigs and less length, but more weight (Table 2) because of the presence of leaves than big game with only other shrubs to select.

The site × treatment × season interaction for length preference values also involves the sprayed area on site 4 and mowed areas on sites 1, 2, and 3. Differences between big game and cattle browsing on these areas for length differences (P<0.11) accentuated those for browsing frequency (P<0.05) resulting in significant (P<0.01) differences for length preference values. Apparently the combination of site geographic location and vegetation structure resulting from treatment and site conditions produced certain areas preferred by cattle and other areas preferred by big game. Managers can treat areas differently within a large area used by both cattle and big game at different seasons and still be confident that increased browse intended for one animal species will not be exploited by other species.

Weight

In contrast to the minimal effects of sites, treatments, or season on utilization by weight, these main effects and all interactions were significant for weight preference values (Table 4). Browsing frequency and weight use were not highly correlated ($r = 0.09$), and browsing frequency tended to negate large differences in weight use across sites but accentuated the differences in weight use across treatments.

Preference values based on weight were highest on the 2 most productive sites, primarily because of cattle preference in the summer. Weight preference values were lowest on untreated areas for both cattle and big game, but cattle preferred mowed areas over sprayed areas. Big game also tended to prefer mowed areas except for an exceptionally high preference value on the site 4, sprayed area. Cattle preferred the mowed areas on site 3 and 4; big game preferred the site 4, sprayed area.

Comparing differences in preference values based on length and weight indicates that weight preference values are probably more accurate than when leaves are present. However, length preference values may be acceptable as indicators of preference among different areas when the costs of measuring length and weight are considered. Correlation coefficients for length preference values and weight preference values were slightly higher for cattle browsing ($r = 0.76$) than for big game browsing ($r = 0.70$).

Browse Values

Browse values based on length and weight are shown in Table 5 only for the average of summer cattle browsing and winter big game browsing because bitterbrush canopy cover was determined only once (late fall) during the study. Length use and length browse values were not closely correlated ($r = 0.67$) with weight use or weight browse values for either cattle or big game browsing. The weight:length ratio varies depending on the amount of leaves and diameter of the twig part consumed.

Table 5. Mean bitterbrush twig browse values based on twig length (mm) and twig weight (mg) on 4 sites and 3 treatments in southcentral Wyoming, late fall and late winter, 1986-87. Those means for different sites, treatments, or treatments within a site followed by a different letter are statistically different at $P<0.05$.

Site	Treatment: Control	2,4-D	Mowing	Site mean
	(Length Browse Values[1]) (mm)			
1	0.31 b	0.98 ab	1.43 a	0.91 b
2	2.46 a	1.78 a	2.38 a	2.21 a
3	1.73 a	1.26 a	2.22 a	1.74 a
4	0.88 b	2.35 a	1.80 ab	1.68 a
Mean	1.34 b	1.59 ab	1.96 a	
	(Weight Browse Values[2]) (mg)			
1	0.44 a	0.83 a	2.38 a	1.22 b
2	2.82 a	1.46 a	2.88 a	2.39 ab
3	2.17 a	2.40 a	5.06 a	3.21 a
4	1.33 b	5.98 a	3.24 ab	3.51 a
Mean	1.69 b	2.67 ab	3.39 a	

[1]Length preference value × Canopy cover
[2]Weight preference value × Canopy cover

Length and weight browse values were lowest on site 1 because of the much lower bitterbrush canopy cover and lowest on untreated areas because of relatively lower length use, weight use, and browsing frequencies. Both spraying and mowing increased bitterbrush browse values for both cattle and big game regardless of length or weight criteria.

Length browse values are less expensive to obtain in terms of time; however, weight values provide more distinctive differences. Weight browse values appear to be more sensitive to differences in environmental conditions and animal preference. However, the relative difference in sensitivity may not be worth the additional time necessary to collect and weigh twigs if the habitat manager needs to collect numerous samples under a variety of site, treatment, or browsing conditions.

Browsing Residue

The average browsing residues for both cattle browsing in summer and fall and big game browsing in winter were higher on the more productive sites (Table 6) even though weight use (Table 2) and weight preference values (Table 4) were also higher on these sites. Browsing residue differences among sites were relatively greater (site × season; $P<0.05$) for summer cattle browsing than for winter big game browsing because of an apparent differential weight loss of leaves among sites and the increase in twig weight on the least productive site from late fall to late winter (Kituku et al. 1992).

Table 6. Mean bitterbrush twig residual[1] weights (mg) after browsing on 4 sites and 3 treatments in southcentral Wyoming, late fall and late winter, 1986-87. Those means for different sites, different treatments, or different treatments within a site followed by a different letter and comparable means in different seasons followed by an "*" are statistically different at $P<0.05$.

Site	Treatment: Control	2,4-D	Mowing	Site mean
	(mg)			
	(Late Fall)			
1	114	96	141	117 b
2	152	123	147	141 b
3	158	168	262 *	196 a
4	203	207 *	249 *	219 a
Mean	157 b	149 b	200 a*	168 *
	(Late Winter)			
1	162	100	169	144 b
2	141	124	147	137 b
3	185	136	172 *	164 a
4	175	155 *	191 *	173 a
Mean	165 a	129 b	170 a*	155 *
	(Mean) Late Fall + Late Winter			
1	138	98	155	130 b
2	147	123	147	139 b
3	171	152	217	180 a
4	189	181	220	197 a
Mean	161 b	139 c	185 a	

[1](Weight of unbrowsed twigs × percentage of unbrowsed twigs) + (Weight of browsed twigs × percentage of browsed twigs)

In late fall, browsing residue was greater on mowed areas than on untreated or sprayed areas; however, these differences were not as large in late winter (treatment × season; $P<0.05$) because browsing residue values increased slightly on untreated areas and decreased on mowed and sprayed areas. The site × treatment × season interaction ($P<0.05$) appeared to be a function of slower, more prolonged growth on the less productive sites and a greater weight loss between late fall and late winter on the more productive sites.

Management Implications

The relative success of shrub habitat improvement practices depends not only on the site and vegetation conditions under which different treatments are applied, but also on the management objectives, the criteria for measuring success, seasons, and factors affecting site preference by different kinds of animals. Both spraying and mowing reduced sagebrush cover to the target level without reducing bitterbrush cover, but the relative impact increased with increasing site productivity. If treatment location is not a factor, economics dictate treating the most productive sites first.

Spraying greatly increased bitterbrush composition, which will favor cattle, sheep, and big game. Mowing, however, produces larger twigs in the year of treatment and foraging efficiency in terms of bite size per twig.

Browse values based on both twig length and weight were also greater on mowed areas. Because the longevity of the mowing treatment with greater residual sagebrush cover will, no doubt, be less than that of the spraying treatment, browse values may eventually be greater over the life of the treatment on sprayed areas. Therefore, mowing is best as a short-term management practice to attract animals into an area and/or provide maximum browse for a short period of time.

Utilization values based on twig numbers, length, basal diameter, and weight were relatively low compared to maximum, sustainable values recommended by the literature. Frequency of use and basal diameter utilization were more sensitive to site and treatment effects than length and weight utilization. Frequency of use was influenced by bitterbrush availability, and basal diameter utilization appeared to be affected by differences in unbrowsed twig tip diameter on different areas.

Because bitterbrush growth and maximum recommended utilization values vary with growing conditions, such as seasonal precipitation and effective soil-water capacity, bitterbrush browsing residual weight or length may be a more useful and accurate measure of optimum use for a particular site. Measuring residual length or weight against long-term standards will always be much easier and more straightforward than trying to estimate how much twig length, diameter, or weight has been removed.

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