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Sites, mowing, 2,4-D, and seasons affect bitterbrush twig morphology

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Abstract

Effects of site factors, mowing, 2,4-D, and seasons on antelope bitterbrush (*Purshia tridentata* Pursh.) twig length, basal and tip diameters, and weight were evaluated in southcentral Wyoming. Linear regression coefficients for twig length regressed on basal diameter were greater on productive sites than on less productive sites, greater on mowed areas than on sprayed or untreated areas, and greater in late fall because of leaves than in late winter. Twig elongation continued after data collection in early November. Twig length was more variable and more sensitive to different environmental conditions than twig basal diameter, tip diameter, or weight. Twig length accounted for 80–86% of the variation in twig weight. Sites, shrub management practices, and seasons do affect bitterbrush twig morphology, but habitat managers can use twig length-diameter-weight relations in this vegetation type to estimate utilization if the sampling is stratified along environmental gradients.

Key Words: bitterbrush, habitat improvement, *Purshia tridentata,* range improvements, shrub management, Wyoming

Antelope bitterbrush (*Purshia tridentata* (Pursh)DC.) is widespread in the western United States, occurring in numerous habitat types over about 140 million hectares (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, deer, and elk (*Cervus canadensis)* 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 in the winter by big game and again during summer by livestock. 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 (Basile and Hutchings 1966).

Twig diameter-length-weight relations of bitterbrush and other shrubs may vary with site, years, browsing pressure, overstory canopy, plant species and size, presence of leaves, phenological stage of growth, and twig location on the plant (Bartolome and Kosco 1982, Basile and Hutchings 1966, Ferguson and Marsden 1977, Halls and Harlow 1971, Jensen and Urness 1981, Lyon 1970, Peek et al. 1971, Peek et al. 1978, Provenza and Urness 1981, Rutherford 1979, Ruyle et al. 1983).

One additional factor not discussed in the literature is the effects of shrub manipulation practices, such as mowing or spraying with herbicides, on bitterbrush twig morphology. 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).

The objective of this study was to determine the effects of mowing and 2,4-D herbicide application on the twig length-diameter-weight relations of bitterbrush 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 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 winter in some years 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 and used as replications. Site 1 is a valley bottom (1–5% slope) with the highest percentage 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%) with relatively deep, gravelly—loam soils. Site 4 is on the toe slope of a broad, uniform slope (3–10%) with relatively deep, sandy-loam to gravelly-

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loam soils and occasional additional moisture from runoff.

Methods

Experimental Design

On each site, 3 relatively homogeneous areas of 3- to 6-ha in size were selected for treatment. The 12 plots were allocated to 4 replications 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 applied on each site included mowing, 2,4-D herbicide application, and untreated. Areas were mowed to a 2 to 3-dm 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 2 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. 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 growth twig for a total of 5 selected twigs from each of 30 plants or 150 twigs per plot per 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 of dense, hedged plants most closely approximated accessibility to grazing ungulates.

Each twig was cut 1 cm from the base to eliminate the swell and elliptical butt shape (Basile and Hutchings 1966) and placed in bags of composite samples. All twigs were refrigerated at 10° before measuring basal diameter (mm), tip diameter (mm), and length (mm) using the measuring procedures of Jensen and Urness (1981).

The composite samples per transect were kept separate and dried at 40° C to a constant weight. Average net weight per twig was calculated by dividing the weight of the composite sample by the number of twigs.

Statistical Analyses

Statistical differences in twig length, basal diameter, and tip diameter among the 3,600 twigs and among the 72 composite twig weight samples due to 4 sites, 3 treatments, and 2 seasons were determined using the GLM (General Linear Model) procedure of SAS (1985). The experiment unit was an individual twig for length, basal diameter, and tip diameter statistical analyses and a transect for weight statistical analyses.

Relations among twig length, basal diameter, tip diameter, and weight 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

Precipitation (1986/long-term mean) at the USFS Brush Creek Rancher 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 Septemer (44/44 mm). In general, growing conditions from date of treatment through the period of last bitterbrush measurements were above average.

Shrub Cover

Total shrub foliar cover was 38%, 16%, and 22% on untreated, sprayed, and mowed areas in fall 1987, respectively (Kituku 1988). Bitterbrush cover, averaging about 12% on all areas, was not reduced by either spraying or mowing. Bitterbrush was more accessible to grazing animals on all treated areas because of the 11 to 22% reduction in sagebrush foliar cover.

Twig Length

Mean twig length of unbrowsed twigs collected in late fall, 1986, and late winter, 1986–87, on all areas (4 sites, 3 treatments, and 2 seasons) was increased from 95 mm to 111 mm by mowing, but not by spraying with 2,4-D (Fig. 1). Twig length ranged from 91–93 mm on 2 sites to 112 mm on the most productive site. However, these differences were greatly influenced by site × treatment interaction.

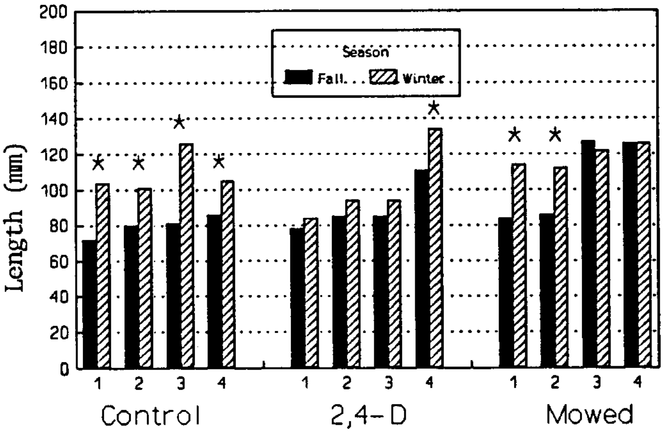

Fig. 1. Twig length (mm) site × treatment × season interaction for 4 sites (1–4), 3 treatments (Control; 2,4-D; and Mowed), and 2 seasons in southcentral Wyoming, 1986–87. Those means for seasons within a plot topped by an '*' are significant at $P<0.05$.

Twig length ranged from 72 mm to 134 mm on the 12 plots. Spraying decreased twig length on sites 1 and 3, but increased twig length on site 4. Mowing increased twig length on all 4 sites, but the difference was not significant ($P<0.05$) on site 2. The range in twig length within the same treatment but across sites was relatively low for untreated plots and relatively high on sprayed and mowed plots.

Additional growth on untreated areas between fall and late winter was about twice that on sprayed or mowed areas. Twig elongation was greater on treated areas during summer and early fall, but more prolonged on untreated areas over the total growing season. Differences among sites were similar in both seasons.

Twig length increased between late fall and late winter on untreated plots on all sites, only on the most productive sprayed plots, and only on the least productive mowed plots. Spraying apparently stifled the late season twig elongation on all except the most productive site, in contrast to mowing.

Basal Diameter

Ranges in basal diameter were relatively small compared to ranges in twig lengths (Fig. 2). The largest mean basal diameter of bitterbrush twigs on site 4 was only 0.10 mm greater than the smallest on site 2.

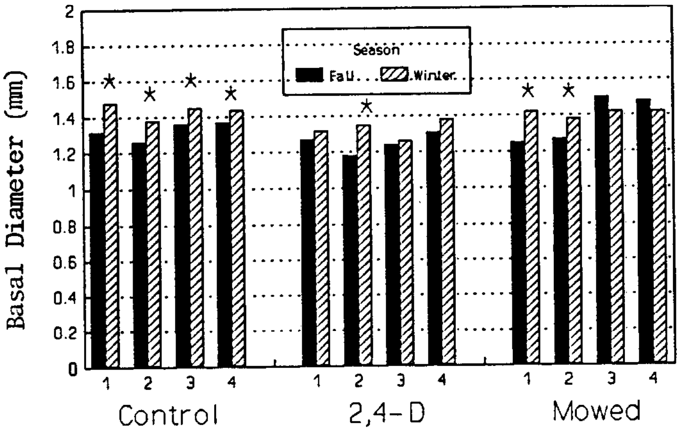

Fig. 2. Twig basal diameter (mm) site × treatment × season interaction for 4 sites (1–4), 3 treatments (Control; 2,4-D; and Mowed), and 2 seasons in southcentral Wyoming, 1986–87. Those means for seasons within a plot topped by an '*' are significant at $P<0.05$.

The mean basal diameter on sprayed plots was also only 0.10–0.11 mm smaller than those on untreated or mowed plots. Mean basal diameters on sprayed plots, however, were generally smaller than those on untreated or mowed plots on all sites except those in site 1, the least productive site with the greatest percentage of rocks in the soil profile.

The increase in basal diameter from fall to late winter was significant, but relatively small from a practical standpoint. Twig basal diameter increases were significant on sites 1 and site 2, but not on sites 3 or site 4. Mean basal diameters increased relatively more on untreated plots than on sprayed or mowed plots.

Differences in basal diameter due to site × treatment × season interaction were similar to those for twig length. Increases in basal diameter between late fall and late winter were most consistent on the untreated plots.

Tip Diameter

Differences in twig tip diameter due to sites, treatments, and site × treatment interaction were significant, but relatively small (Fig. 3). Twig tip diameters were also smaller on sprayed plots compared to those on untreated or mowed plots. However, in contrast to the effects of site factors on basal diameters, tip diameters on site 1 were larger than those on the other sites.

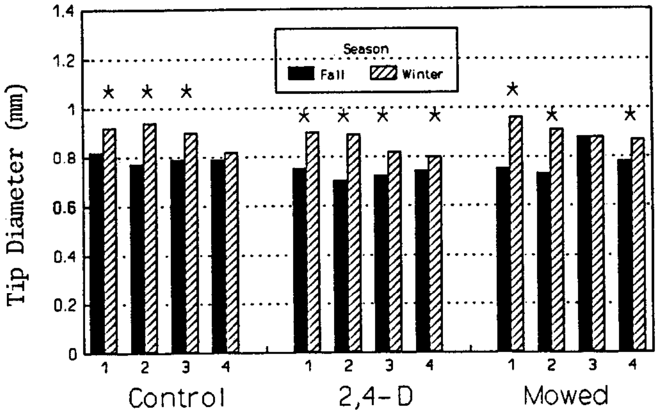

Fig. 3. Twig tip diameter (mm) site × treatment × season interaction for 4 sites (1–4), 3 treatments (Control; 2,4-D; and Mowed), and 2 seasons in southcentral Wyoming, 1986–87. Those means for seasons with a plot topped by an '*' are significant at $P<0.05$.

Twig tip diameters averaged 0.77 mm in late fall and 0.88 mm in late winter. Tip diameter increases on sites 1 and 2 were 2–3 × greater than those on sites 3 and 4. Increases due to treatment were similar.

Between fall and late winter, tip diameters increased significantly on all but 2 plots. Although there was a consistent increase in tip diameter through late winter, perhaps partly due to bud swell, the correlation coefficients between tip and basal diameters were only 0.36 for both seasons combined, 0.36 for late fall twigs, and 0.31 for late winter twigs. Correlation coefficients between tip and basal diameters for the 24 different sets of twig measurements ranged from −0.07 to +0.55.

Twig Weight

Mean twig weights were greater on sites 3 and 4 than on sites 1 and 2 and generally reflected corresponding differences in twig lengths, basal diameters, and site productivity (Fig. 4). For all sites, treatments, and seasons, correlation coefficients were 0.72 for twig weight and twig length and 0.61 for twig weight and twig basal diameter.

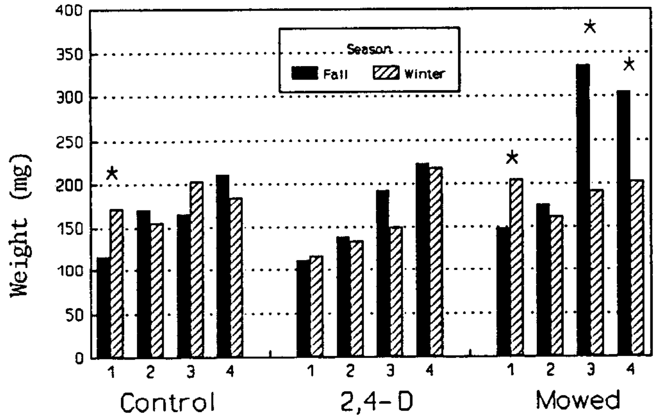

Fig. 4. Twig weight (mg) site × treatment × season interaction for 4 sites (1–4), 3 treatments (Control; 2,4-D; and Mowed), and 2 seasons in southcentral Wyoming, 1986–87. Those means for seasons within a plot topped by an '*' are significant at $P<0.05$.

Mean twig weights for all sites and seasons were greater on mowed plots than on untreated or sprayed plots. The site × treatment interaction for combined fall and winter twig weights was not significant.

Between fall and late winter, twig weights increased on site 1, decreased on site 4, and were not significantly different on sites 2 and 3. There was a major weight decline on mowed plots, but not on untreated or sprayed plots.

Twig weight changes with season were not consistent due to either site or treatment. By the end of late winter twig weights were most uniform across sites for mowed plots and least uniform across sprayed plots.

Regression Models for Length

For all sites, treatments, and seasons, twig lengths, and basal diameters were positively correlated ($r = 0.72$). Twig length influenced length:basal diameter regressions more than did basal diameter because of the relatively greater twig length differences. Correlation coefficients between twig length and twig length:basal diameter ratio ranged from 0.78 to 0.93 and averaged 0.87, whereas correlation coefficients between twig basal diameter and twig length:basal diameter ratio ranged from 0.00 to 0.58 and averaged 0.30.

Because of the significant site × treatment × season interaction for twig length:basal diameter ratios, different sets of linear regression equations were developed for sites, treatments, and sites ×

Table 1. Bitterbrush twig length (mm) prediction models based on twig basal diameter (mm) on 4 sites and 3 treatments in southcentral Wyoming, fall, 1986.

Plot	b_0	b_1	SE_{b1}	F	R^2	N	Range	
							Length	Basal diameter
							(mm)	(mm)
1C	-27	+ 75	12.4	37	0.36	67	22–138	1.0–2.0
1H	-46	+ 97	11.6	71	0.50	76	24–188	0.8–2.0
1M	-82	+133	8.4	248	0.75	84	24–217	0.7–2.0
2C	-36	+ 92	10.2	81	0.49	87	15–174	0.7–2.4
2H	-53	+119	13.5	77	0.44	100	22–175	0.6–1.7
2M	-68	+120	11.4	111	0.54	98	24–229	0.7–2.0
3C	-61	+104	9.5	119	0.49	126	20–191	1.0–2.1
3H	-79	+133	12.3	117	0.59	83	22–225	0.9–2.0
3M	-79	+137	12.5	121	0.65	66	35–285	0.9–2.7
4C	-81	+122	10.5	135	0.53	122	14–220	0.8–2.0
4H	-48	+121	9.3	172	0.60	118	22–230	0.5–2.0
4M	-97	+150	10.7	198	0.67	100	17–305	0.8–2.5
S1	-58	+106	6.4	274	0.55	227	22–217	0.7–2.2
S2	-44	+104	6.7	242	0.46	285	15–229	0.6–2.4
S3	-80	+128	6.6	373	0.58	275	20–285	0.9–2.3
S4	-74	+131	6.3	434	0.56	340	14–305	0.5–2.5
C	-55	+102	5.4	363	0.48	402	14–220	0.7–2.4
H	-57	+102	5.9	420	0.53	377	22–230	0.5–2.0
M	-90	+142	5.1	764	0.69	348	17–305	0.7–2.5
Mean	-68	+121	3.3	1372	0.55	1127	14–305	0.5–2.4

Plot—1–4 = sites; C = control; H = 2,4-D; M = mowed;
b_0 = intercept; b_1 = regression coefficient; F = F value;
SE_{b1} = standard error of regression coefficient;
R^2 = coefficient of determination; N = number of twigs

treatments in late fall (Table 1) and late winter (Table 2). In no case was curvilinearity indicated by scatter diagrams or nonrandom residuals for the ranges of length and basal diameter data used.

The coefficients of variation for twig length, basal diameter, tip diameter, and twig length:basal diameter ratio were all greater in the fall than late winter, but were not significantly different due to site, treatment, or any interaction.

Regression models developed for different sets of data (sites, treatments, site × treatment) from twigs collected in late fall (Table 1) generally had higher R^2 values than for similar sets of data for twigs collected in late winter (Table 2) because of the greater variation in twig length and basal diameter in late fall than in late winter.

When twig length and basal diameter for all twigs collected in late fall were used in a linear model, basal diameter accounted for 55% of the variation in twig length and predicted an increase of

Table 2. Bitterbrush twig length (mm) prediction models based on twig basal diameter (mm) on 4 sites and 3 treatments in southcentral Wyoming, late winter, 1986–87.

Plot	b_0	b_1	SE_{b1}	F	R^2	N	Range	
							Length	Basal diameter
							(mm)	(mm)
1C	-32	+ 95	12.4	107	0.47	120	25–239	0.8–2.3
1H	-25	+ 84	10.5	63	0.49	69	35–170	0.9–2.0
1M	-30	+101	8.4	70	0.46	84	50–240	1.0–2.2
2C	-32	+97	10.2	110	0.52	103	25–209	0.8–2.3
2H	-25	+88	13.3	95	0.57	72	40–156	1.0–2.0
2M	-42	+111	11.4	106	0.58	50	55–200	0.9–2.0
3C	-39	+114	11.8	98	0.50	98	53–260	0.9–2.0
3H	-49	+114	12.3	77	0.48	85	28–190	0.9–2.0
3M	-68	+135	12.5	142	0.62	88	30–260	1.0–2.0
4C	+ 3	+71	10.5	35	0.24	113	43–180	1.0–2.0
4H	-39	+125	9.3	106	0.62	61	63–240	1.0–2.0
4M	-57	+129	10.7	91	0.56	76	57–230	1.0–2.0
S1	-35	+ 98	6.2	246	0.48	272	25–240	0.8–2.3
S2	-35	+100	5.9	291	0.54	255	25–209	0.8–2.3
S3	-60	+127	6.5	379	0.58	273	28–260	0.9–2.0
S4	-24	+101	8.2	151	0.38	252	43–240	1.0–2.2
C	-28	+ 98	5.4	311	0.42	402	25–260	0.8–2.3
H	-46	+111	6.7	278	0.49	294	28–240	0.9–2.0
M	-51	+120	6.0	399	0.55	325	30–260	1.0–2.2
Mean	-40	+108	3.5	969	0.48	1052	25–260	0.8–2.3

Plot—1–4 = sites; C = control; H = 2,4-D; M = mowed;
b_0 = intercept; b_1 = regression coefficient; F = F value;
SE_{b1} = standard error of regression coefficient;
R^2 = coefficient of determination; N = number of twigs

Table 3. Bitterbrush prediction models for twig weight (WT, mg) based on twig length (L, mm) and basal diameter (BD, mm) in southcentral Wyoming, late fall, and late winter, 1986-87.

						Range	
X_1	b_0	b_1	SE_{b1}	F	R^2	X_1	Weight
						(mm)	(mg)
(Late Fall)							
L	-107	3.25	0.28	139	0.80	67-141	82-374
BD	-464	498	74	45	0.57	1.15-1.63	82-374
(Late Winter)							
L	- 31	1.86	0.13	201	0.86	76-144	94-231
BD	-187	260	54	24	0.41	1.17-1.53	94-231

b_0 = intercept; b_1 = regression coefficient; F = F value;
SE_{b1} = standard error of regression coefficient;
R^2 = coefficient of determination;

12.1 mm in length for each 0.1-mm increase in basal diameter. The R^2 values ranged from 0.36 on site 1 untreated plots to 0.75 on site 1 mowed plots.

Regression coefficients for twig length regressed on basal diameter increased with site productivity for the late fall site models. Regression coefficients were 106 and 104 for sites 1 and 2, respectively, and 128 and 131 for sites 3 and 4, respectively. Differences among regression coefficients due to sites were similar to those among twig length. Sites 1 and 2 had relatively short, thick twigs compared to those on sites 3 and 4 in late fall. Bitterbrush twig lengths ranged from 14 to 305 mm; twig basal diameters ranged from 0.5 to 2.4 mm.

Regression Models for Weight

Because all twigs per transect were weighed together, only 3 average twig weights per plot or 9 per site or 12 per treatment within a season were available for regression analysis. Therefore, prediction models for twig weight based on twig length and on basal diameter were calculated only for the late fall (N = 36) and late winter (N = 36).

For practical purposes twig length was clearly the most useful parameter measured for predicting twig weight in either late fall or late winter (Table 3). Twig length accounted for 80% of the variation in twig weight in late fall and 86% in late winter.

The regression coefficient for twig length in late fall (+3.25) was much greater than that in late winter (+1.86), primarily because of the additional weight of leaves in late fall per increment of additional twig length. In either case the standard error of the regression coefficient was only 7 to 9% of the regression coefficient indicating a relatively high degree of confidence in the predictions that twig weight increased 3.25 mg for each additional 1.0 mm of twig length in late fall and 1.86 mg/mm twig length in late winter.

Discussion

Spraying retarded twig length growth on shallow or rocky, less productive sites, but increased twig length on deeper, more productive sites. The reduction in soil water competition from reduced sagebrush cover allowed bitterbrush plants to respond on productive sites, but not on shallow or rocky sites (Powell and Kituku 1990). Mowing did not decrease twig length on less productive sites, and greatly increased twig length on the more productive sites.

The relationship between bitterbrush vigor and site productivity was also demonstrated by studies in Oregon and Washington. Bitterbrush maintained high productivity under 60-65% dormant season utilization on productive sites, but productivity declined on less productive sites if utilization exceeded 50% (Garrison 1953). Variation in crop-year (September through June) precipitation in southeastern Oregon accounted for about 40% of the variation in bitterbrush leader production (Kindschy 1982).

Twig length appears to be a good indicator of differences in growing conditions due to different soils and management practices. A similar relationship exists for *Quercus* (Powell and Lowry 1980).

From a seasonal standpoint, twigs collected in April 1987, were longer than those collected in fall 1986. This difference indicates continued growth very late in the season and confirms the value of bitterbrush as late summer/fall forage.

Although differences in shrub management practices, site conditions, and seasons apparently affect basal diameter, these relatively small changes do not appear to be as practical an indicator of differences in environmental conditions as the corresponding differences in twig length.

The seasonal effect on tip diameter was more pronounced and consistent than that on basal diameter indicating that bud swell may have influenced tip diameter measurements in late winter.

Mean twig weights in the fall were greater than those in late winter because of the loss of leaves between November and April. However, both the site × season and treatment × seasons interactions were significant. Both interactions indicate continued growth on the least productive site/treatment and a corresponding loss of leaves and/or stem material on the most productive site with the greatest fall twig weight.

From a management standpoint, data collected in late fall before deep snows occur on an area may not be reliable in terms of predicting twig data during the winter for those sites with slower, more prolonged growth, such as on site 1, or for those twigs stimulated to a high degree of growth on productive sites, such as mowed plants on sites 3 and 4.

Twig basal diameter regression coefficients developed to predict twig length were greater for twigs from both sprayed and mowed plots than on untreated plots, but not for the same reason. Twig lengths on sprayed plots were similar to those on untreated plots, but twig basal diameters were smaller on sprayed plots. On mowed plots both twig lengths and twig basal diameters increased, but the relative increase in twig lengths was much greater than that for twig basal diameters.

The range of these R^2 values and regression coefficients was very similar to those for bitterbrush twigs measured in southern Idaho (Basile and Hutchings 1966, Ferguson and Marsden 1977) and in northern Utah (Jensen and Urness 1981).

Scatter diagrams of residuals when twig lengths were plotted against basal diameters portrayed the greatest variation in residuals occurring in the lower range of basal diameters. This indicates a possible lower degree of accuracy and precision in measuring the basal diameter compared to the length of small twigs.

The negative intercept for each model (about half the magnitude of those reported by Jensen and Urness 1981) may indicate potential curvilinearity in situations where the minimum basal diameter approaches zero. Although we can not extrapolate beyond the range of our data, the smallest basal diameter of 1,127 twigs measured in the fall was 0.5 mm and the smallest of 1,052 twigs measured in late winter was 0.8 mm. Therefore, considering the wide variety of environmental conditions included in this study, it seems unlikely that any mature bitterbrush twig will have a basal diameter less than 0.5 mm or that a curvilinear model is more appropriate than the linear models shown in Tables 1 and 2.

The predictive value and reliability of regression models for twigs collected in late winter (higher standard error of regression coefficient; lower coefficient of determination) were somewhat less than those for twigs collected in late fall, but varied from plot to plot (Tables 1 and 2). This was partly because of a lower number of twigs measured in late winter and partly because of a very weak relationship between twig length and twig basal diameter on one plot (Table 2; 4C = site 4, untreated). An examination of twig length and basal diameter means, ranges, variation and residuals; site conditions, and collection and measurement procedures offered no logical explanation why this plot produced such a high random distribution of both "long, skinny" and "short, fat" twigs in late winter.

The set of data from a plot in late fall with the weakest relationship between twig length and basal diameter also came from an untreated plot (Table 2; 1C = site 1, untreated). Personal observations indicate considerable variation in bitterbrush plant morphology, leaf color, and animal preference among untreated plants on the same plot.

Interaction between season and ecotypic variation among plants on the same site is one explanation for the weak twig length-basal diameter relationships on certain untreated sites. The effects of spraying and mowing may have reduced the natural ecotypic variation in twig length-basal diameter relations.

Management Implications

Site productivity, habitat manipulation practices, and seasons all affected bitterbrush twig length, basal and tip diameters, and weight in the mountain brush vegetation type of southcentral Wyoming, but not to the same degree. Therefore, relations between length, basal and tip diameters, and weight should be verified for the specific conditions under which utilization equations are intended to be used.

The slower, more prolonged growth of twigs on less productive sites late into the fall indicates a limitation of the before and after method of estimating utilization. If twig elongation continues after the before measurements are taken, actual utilization will be underestimated.

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