USDA United States Department of Agriculture

Forest Service

Rocky Mountain Research Station

Research Paper RMRS-RP-40

July 2003

Countering Misinformation Concerning Big Sagebrush

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Abstract

Welch, Bruce L; Criddle, Craig. 2003. **Countering Misinformation Concerning Big Sagebrush**. Research Paper RMRS-RP-40. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 28 p.

This paper examines the scientific merits of eight axioms of range or vegetative management pertaining to big sagebrush. These axioms are: (1) Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis)* does not naturally exceed 10 percent canopy cover and mountain big sagebrush (*A. t.* ssp. *vaseyana)* does not naturally exceed 20 percent canopy cover; (2) As big sagebrush canopy cover increases over 12 to15 percent, bare ground increases and perennial grass cover decreases; (3) Removing, controlling, or killing big sagebrush will results in a two or three or more fold increase in perennial grass production; (4) Nothing eats it; (5) Biodiversity increases with removing, controlling, thinning, or killing of big sagebrush; (6) Mountain big sagebrush evolved in an environment with a mean fire interval of 20 to 30 years; (7) Big sagebrush is an agent of allelopathy; and (8) Big sagebrush is a highly competitive, dominating, suppressive plant species.

Keywords: range management, sagebrush control, wildlife, biodiversity, allelopathy, fire, cover

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Acknowledgments

We thank the following for providing reviews of this manuscript: Mr. Stanley G. Kitchen; Drs. John W. Connelly, John K. Francis, E. Durant McArthur, David L. Nelson, Michael F. Whiting, Joel G. Peterson, Carl L. Wambolt, and Darrell J. Weber.

Cover photographs by Dr. Bruce L. Welch

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Countering Misinformation Concerning Big Sagebrush

Bruce L. Welch
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Introduction

The range management community has been conducting a war against big sagebrush (*Artemisia tridentata*) for 50 years or more (Cornelius and Graham 1951; Hamner and Tukey 1944; Hull and Vaughn 1951; Pechanec and Stewart 1944a; Woolfolk 1949). During this period much rationalization has occurred to justify removing, thinning, controlling, or killing of big sagebrush. We call these rationalizations "range or vegetative management axioms." In this paper, we state the axiom, give one example of its use in the literature, and analyze whether it is based on science or a reflection of Box's (2000, p. 29) question to the range management community: "Do our gods get in the way of our science?" In short, most, if not all, the sins attributed to big sagebrush by the range management community are the result of livestock grazing.

Axiom Number 1

Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) does not naturally exceed 10 percent cover and mountain big sagebrush (*A. t.* ssp. *vaseyana*) does not naturally exceed 20 percent cover.

This axiom is best verbalized by Miller and others (1994, p. 115): "In the early to mid 1800s, much of the sagebrush steppe was probably composed of open stands of shrubs with a strong component of long-lived perennial grasses and forbs in the understory … Shrub canopy cover probably ranged between 5-10% in the drier Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) communities ..., to 10-20% on the more mesic sites, occupied by mountain big sagebrush." Speaking of the present, they noted (p. 119): "Wyoming big sagebrush cover has increased from less than 10% to 20%, and mountain big sagebrush cover from less than 20% to 30% and 40%." All due to overgrazing.

We believe this axiom is challengeable on three fronts: first, what do the animals that coevolved with big sagebrush suggest to us concerning canopy cover; second, what are the big sagebrush canopy cover values found in undisturbed relicts and kipukas; and third, what is the quality of the science that is used to support this axiom?

There are numerous studies (see Peterson 1995 for a review) that show animals of big sagebrush prefer living in big sagebrush canopy cover far above the levels set by Miller and others (1994), Baxter (1996), and Winward (1991). In fact, Rasmussen and Griner (1938) noted that the highest sage grouse (*Centrocercus urophasianus*) nesting success in Strawberry Valley of central Utah occurred in mountain big sagebrush stands having 50 percent canopy cover. They estimated that some 270 acres of big sagebrush habitat was in the 50 percent canopy cover class. We have, in the same valley, measured big sagebrush canopy cover at the same magnitude for three stands of 2 acres or less supporting broodless sage grouse hens, nesting habitat, and a male sage grouse loafing area. Ellis and others (1989) reported male sage grouse loafing in areas with 31 percent (probably Wyoming) big sagebrush canopy cover. In addition, Katzner and Parker (1997) reported that areas of high pygmy rabbits (*Brachylagus idahoenesis*) activity occurred in basin big sagebrush stands having 51.1 percent canopy cover, and areas of medium activity occurred in Wyoming big sagebrush stands of 42.7 percent canopy cover.

Still, other sagebrush obligates such as sage thrasher (*Oreoscoptes montanus*), Brewer's sparrow (*Spizella breweri*), and sage sparrow (*Amphispiza belli*) prefer big sagebrush canopy cover of 20 to 36 percent, which is much higher than the maximum allowable amount by the so called "law or axiom" (Best 1972; Feist 1968; Grinnell and others 1930; Knick and Rotenberry 1995; Petersen and Best 1986, 1991; Reynolds and Trost 1980, 1981; Winter and Best 1985). For sagebrush species other than big sagebrush, Walcheck (1970) reported that a population of Brewer's sparrows were living in an area of silver sagebrush (*Artemisia cana*) having a canopy cover of 53 percent. Petersen and Best (1985) studying nest site selection of sage sparrows, found that these birds nested where (probably Wyoming) big sagebrush cover was 23 percent in the vicinity of nests and 26 percent in the general study area. Further, they noted that all nests were situated in big sagebrush plants and that large, living shrubs were strongly preferred. Rotenberry (1980) found greater numbers of sage sparrow and western meadow lark (*Sturnella neglecta*) on sites where (probably Wyoming) big sagebrush canopy covers ranged from 25 to 30 percent than for sites with big sagebrush canopy cover of 0 to 1 percent and 5 to 10 percent. Also, Best (1972) and Feist (1968) found greater number of Brewer's sparrows and sage thrashers in stands of (probably Wyoming) big sagebrush with canopy cover at 36 percent than at 21 percent.

Thus, it appears to us that the axiom concerning sagebrush canopy cover as stated by Miller and other (1994) is based more on myth than ecological fact.

Big sagebrush canopy cover values on undisturbed relicts and kipukas does not support the axiom that big sagebrush canopy cover increase due to overgrazing. Daubenmire (1970) reported that big sagebrush canopy cover varied on his "virgin or near virgin vegetation" study sites from 5 to 38 percent – the technique used by Daubenmire (1970) tended to underestimate shrub cover by 3 to 5 percentage points (Floyd and Anderson 1987).

We have measured, using the line intercept method (300 ft), the cover of big sagebrush in four ungrazed kipukas and found that canopy cover ranged from 14 to 34 percent (table 1). Basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) was the dominant big sagebrush in two of the kipukas, one located about 20 miles

Table 1—Relation of big sagebrush cover to percent cover of perennial grass and bare ground based on Welch's Y2K and Y2K+1 big sagebrush odyssey through Idaho, Oregon, Utah, Washington, and Wyoming. Data on file at the Shrub Sciences Laboratory, 735 N 500 E, Provo, UT. Data were based on 300-foot line transects. Data for the first 12 transects were collected on ungrazed kipukas in southern Idaho. The three transects per kipuka were continuous.

Location and transect	Big sagebrush cover	Perennial grass cover	Bare ground
N43° 31.346'			
W112° 28.475'—1	14	56	11
Continuous—2	16	31	17
Continuous—3	23	43	12
N43° 19.306'			
W113° 38.257'—4	34	58	11
Continuous—5	30	58	14
Continuous—6	26	43	21
N42° 52.776'			
W113° 08.665'—7	28	41	5
Continuous—8	14	29	3
Continuous—9	23	31	4
N42° 52.478'			
W113° 07.547'—10	20	45	2
Continuous—11	24	42	1
Continuous—12	31	45	2
N43° 26.159'			
W112° 46.013'—13	0	43	41
Continuous—14	20	38	21
30 feet to the east			
N43° 28.815'			
W112° 50.296'—15	0	44	44
N42° 36.726'			
W113° 14.964'—16	8	10	1
N42° 31.036'			
W113° 19.869'—17	5	51	6
N42° 18.861'			

(con.)

Table 1 (Con.)

Location and transect	Big sagebrush cover	Perennial grass cover	Bare ground
W115° 49.612'—18	21	16	38
N42° 20.963' W115° 51.353'—19	26	33	11
N43° 19.778' W116° 57.576'—20	19	47	1
N43° 19.716' W116° 57.414'—21	3	20	21
N42° 54.357' W117° 16.888'—22	14	31	37
N42° 54.424' W117° 17.027'—23	13	54	19
?N ?W—24	31	12	41
N42° 52.202' W117° 57.389'—25	28	5	2
N43° 11.557' W118° 21.096'—26	41	38	5
N41° 46.191' W111° 09.274'–27	41	71	4
N41° 53.901' W109° 21.165'–28	22	42	15
N43° 12.303[a] W107° 55.298'–29	24	31	20
N43° 12.303'[a] W107° 55.298'–30	5	46	24
N44° 07.187' W107° 15.592'-31	38	67	3
N44° 08.807' W107° 11.830'–32	50	59	0.4
N42° 25.887'[b] W111° 08.002'—33	29	72	3

[a] Both line transects share the same starting point. Transect 29 was from south to north, whereas transect 30 was from north to south.
[b] Based on a 1,500 foot transect moving southeast; forb cover was also determined at 28 percent.

west of Idaho Falls, ID, and the other about 14 miles east of Carey, ID. On the first kipuka, big sagebrush cover was 14, 16, and 23 percent for the three 300 foot line intercept transects. These measurements would support the range management axiom except that a number of the big sagebrush plants along the transects had been killed by defoliators, thus reducing live canopy cover to the values given. Big sagebrush canopy cover values were based on live canopy intercepted, had we included portion of dead stems, as the United States Forest Service does, the cover values would had been higher (Goodrich and Huber 2001). Along the transects there were numerous big sagebrush seedlings enough to replace the dead and nearly dead big sagebrush plants to the point of a full recovery of canopy cover well above what we measured. Big sagebrush canopy cover values measured on the Carey kipuka were 26, 30, and 34. There were no signs of defoliators at work. The differences between our measurements and those of Tisdale and others (1965) at 13 percent are explainable: they took their measurements in areas heavily dominated with three-tip sagebrush, which occurs on the east side of the kipuka (Passey and others 1982); our measurements were taken in the center of the kipuka. For the two kipukas dominated by Wyoming big sagebrush west of America Falls, ID, Wyoming big sagebrush canopy cover values were 14, 23, and 28 percent and 20, 24, and 31 percent. It appears to us that the work done by Daubenmire (1970) and our kipukas measurements – June 2000 – do not support the range management axiom as expressed by Miller and other (1994).

In addition, Holechek and Stephenson (1983) found that big sagebrush canopy cover was higher inside the exclosure on their upland site and higher on the outside of their exclosure on their lowland site, meaning that grazing decreased big sagebrush cover outside of the exclosure in the upland site and increased it in the lowland site. Eckert and Spencer (1986) also reported inconsistences concerning big sagebrush canopy cover response to grazing. Pearson (1965), studying vegetative production in grazed and ungrazed plant communities, found that big sagebrush canopy in the ungrazed area was 34 percent and perennial grasses 39 percent compared to 11 percent big sagebrush canopy cover in the grazed area with 22 percent perennial grass cover. Similarly, Anderson and Holte (1981) reported that for an area in southeastern Idaho protected from grazing for more than 25 years, big sagebrush canopy cover increased from 15 to 23 percent with an increase in grass cover from 0.28 to 5.8 percent. Wambolt and Watts (1996, p.148) noted that "heavy stocking rates did reduce sagebrush cover primarily through mechanical damage, but some browsing was observed." These studies show that grazing may or may not increase big sagebrush cover, or in other words, no relationship exists between grazing and big sagebrush canopy cover.

Peterson (1995) noted greater big sagebrush canopy cover inside of an exclosure than outside due to heavy wild ungulate grazing. Wambolt and Sherwood (1999) found an average of three times as much big sagebrush canopy cover inside exclosures at 19 sites across the northern Yellowstone winter ranges as outside. Wild ungulate grazing decreases big sagebrush canopy cover.

The following articles are often cited to support the range management axiom that big sagebrush canopy cover increased above natural level due to overgrazing: Blaisdell (1949), Blaisdell and others (1982), Clark (1981), Cooper (1953), Daubenmire (1970), Hanson and Stoddart (1940), Laycock (1978), Pickford (1932), Robertson (1947), Stoddart (1941), Tisdale and others (1965), Winward (1991), Wright and Wright (1948), Young (1943), and Young and others (1976). These articles can be put into two classes: (1) those that represent statements of faith or in the words of Box (2000, p. 28): "core values (religion)" of range management – meaning that the articles lack any scientific investigations or data to substantiate the axiom; and (2) articles of science but of questionable applicability. An example of the first is Laycock's (1978, p. 232) statement: "Overgrazing has resulted in dense stands of sagebrush with little herbaceous understory in many areas." Note no citations, no data; just a statement of principle. Little herbaceous understory may be true, but overgrazing causing dense stands of sagebrush – whatever dense is? – is without foundation. Other articles that fall into statements of faith are: Blaisdell and others (1982), Clark (1981), Stoddart (1941), Winward (1991), and Young and others (1976). The remaining articles or citations do contain scientific data, but their applicability is questionable. One of them (Young 1943) was a study conducted on non big sagebrush sites within the Palouse grassland of eastern Washington and northern Idaho; another one was a study concerned with the impact of grazing on the root system of grasses (Hanson and Stoddart 1940); two (Blaisdell 1949; Robertson 1947) were studies concerned with measuring competition between big sagebrush and grasses; another study, Pickford (1932), uses ocular estimates, which are not reliable; one study (Wright and Wright 1948) was conducted in the transition zones between shrublands and grassland of Montana; Cooper (1953) expressed his data in percent composition, which would vary according to amount of grasses and forbs removed by grazing or reduced by drought; and the remaining two, Tisdale and others (1965) and Daubenmire (1970), have been discussed earlier. So the supporting evidence that big sagebrush or any sagebrush for that matter increases in canopy cover because of overgrazing is extremely weak.

Axiom Number 2

As big sagebrush canopy cover increases over12 to15 percent, bare ground increases and perennial grass cover decreases.

Baxter (1996, p. 60) states the axiom this way: "Dr. Alma Winward is a Plant Ecologist for the Intermountain Region of the U.S. Department of Agriculture, Forest Service, and a leading authority on the sagebrush-grass ecosystem. His opinion is that more acres of sagebrush-grass lands in the Western United States were held in low ecological status the past decade due to abnormally high sagebrush cover and density than currently occurring due to livestock grazing. He notes that when big sagebrush cover reaches 12 to 15 percent, the understory production of other plants decreases as canopy cover increases. This results in increased bare ground and a reduction of forage for livestock and wildlife."

The relationship between big sagebrush canopy cover and percent of bare ground can be seen in tables 1 and 2. Data contained in table 2 was collected during the 1998 Utah big game range trend studies and published by the Utah Department of Natural Resources-Division of Wildlife Resources (Davis and others 1999). We chose only those study sites, 26 in all, where big sagebrush canopy cover exceeded all other shrub species present on the sites. Subspecies of big sagebrush present on a given site are listed in the table. Percentages of big sagebrush canopy cover ranged from 3 to 24 percent; in 12 of the 26 sites selected canopy cover exceeded the recommended limits set by Baxter (1996). Correlation coefficient for this data set was r=-0.2883 and coefficient of determination was R^2= 0.08. Both values are not significant. Calculating r and R^2 for the 12 sites where big sagebrush cover was 15 percent or greater, r was + 0.02 with R^2 = 0.0003, or in other words, there is no significant relationship between big sagebrush cover and bare ground (see Tiedeman and others 1987 for supporting data).

On extended field trips in 2000 and 2001, we collected data concerning the relationship of big sagebrush cover and perennial grass and bare ground cover in Idaho, Oregon, Utah, Washington, and Wyoming. This data set is shown in table1. We used the line intercept method (300 foot) for determining percentage of cover for big sagebrush, perennial grass, and bare ground. The first 12 transects were from ungrazed kipukas in southeastern Idaho near Idaho Falls, Carey, and America Falls (Passey and others 1982). What does the kipuka data tell us about big sagebrush canopy cover in a protected environment of the kipukas? That it far exceeds the 15 percent cover that the range management community considers "abnormally high" (Baxter 1996). The relationship between big sagebrush canopy cover and bare ground was significant but weakly related in the negative direction—r = -0.5045; r^2 = 0.2546. The negative relationship means, as big sagebrush canopy cover increases, bare ground tends to decrease (also see Burke and others 1989, their table 1). Other factors,

Table 2—Relationship of big sagebrush canopy cover to percentage of bare ground on 26 Utah big game range trends study sites (Davis and others 1999). Page number where the data were obtained within the Davis and others (1999) report are listed alongside the data.

Pages	Subspecies	Percent big sagebrush cover	Percent of bare ground
7- 8	M*	16	8
50- 51	M	19	12
62- 63	W	18	22
71- 72	M	4	10
79- 80	W	11	7
87- 88	W	17	14
96- 97	W	14	18
113-114	W	15	12
119-120	M	15	21
128-129	M	24	6
137-138	W	3	29
143-144	W	16	13
152-153	W	9	18
167-168	W	9	8
177-178	W	7	44
187-188	W	12	33
193-194	W	13	21
249-250	M	15	7
263-264	M	9	19
274-275	W	12	18
294-295	M	14	4
313-314	W	14	20
335-336	M	20	29
371-372	W	9	13
379-380	W	17	4
386-387	W	18	20

* M=mountain big sagebrush-*Artemisia tridentata* ssp. *vaseyana*; W=Wyoming big sagebrush-*A. t.* ssp. *wyomingensis.*

such as precipitation, grazing history, soil properties, and community species composition have a greater influence on the amount of bare ground than big sagebrush canopy cover (Daddy and others 1988; Richardson and others 1986, Sneva 1972).

Branson and Miller (1981) studying the vegetative changes over 17 years in the Willow Creek basin near Glasgow, MT, found that in spite of a significant increase in big sagebrush canopy cover (23 to 30 percent), grass cover also increased significantly (3 to 41 percent) and bare ground decrease significantly (from 40 to 30 percent). They attributed these increases in shrub and grass cover to higher precipitation and better grazing management. Mueggler and Stewart (1980) reported for four big sagebrush habitat types, big sagebrush canopy covers of 18, 22, 21, and 24 percent and bare ground cover of 11, 4, 3, and 1 percent, respectively. These bare ground cover values compare to grass habitat types of 24, 9, 14, 7, 18, 9, 12, 12, 5, 5, 1, 1 percent, and so forth (Mueggler and Stewart 1980). Also, Mueggler and Harris (1969) found that bare ground in grasslands of central Idaho varied from 1 to 52 percent, with grass communities dominated by bluebunch wheatgrass (*Agropyron spicatum*) having greater percentages (22 percent) of bare ground than communities dominated by Idaho fescue (*Festuca idahoensis*) (6 percent – see Fosberg and Hironaka 1964; Mueggler and Stewart 1980; Tueller and Eckert 1987 for more data). In addition, Lusby (1970, p. 258), studying grazed and ungrazed watersheds, found "marked increase in bare soil and rock on all grazed watersheds, accompanied by a decrease in shrub overstory." So what is the point? The point is that factors other than big sagebrush canopy cover are involved in determining the amount of bare ground in a given area. These include precipitation, associated or understory species, grazing history, and soil properties. Three of these are interrelated – precipitation, species, and soil properties (Fosberg and Hironaka 1964) – and do not support the concept that big sagebrush canopy cover exceeding 15 percent cause increases in bare ground or decreases in perennial grass cover.

Calculated r and R^2 values between big sagebrush canopy cover and perennial grass cover for our data set in table 1, were not significant at +0.2130 and 0.0454, respectively. Mean big sagebrush canopy cover for this data set was 21.8 percent (range 0 to 50 percent) and for perennial grass cover 41.0 percent (range 5 to 72 percent). Highest perennial grass cover values were found in big sagebrush stands having above average canopy cover of 29 percent (transect 33-grass cover=72 percent), 41 percent (transect 27-grass cover=71 percent), and 38 percent (transect 31-grass cover=67 percent). This data set does not support the contention that big sagebrush canopy cover above 15 percent decreases perennial grass cover.

Supporting evidence of the above comes from the studies of Daubenmire (1970, p. 13) where he describes the lack of a relationship between big sagebrush coverage and the coverage of perennial grasses. He stated: "One might question whether the stands with more *Artemisia* also have less of the perennial forage grasses and more of the annuals favored by grazing... But when the stands are listed in order of the coverage of *Artemisia*..., there is neither positive correlation with the grazing increasers, nor negative correlation with the preferred forage species." R^2 and r values for his data were 0.0004 and 0.0208, respectively, or in other words, no relationship existed between big sagebrush canopy cover and perennial native grass cover (also see Baker and Kennedy 1985; Doescher and others 1986; Wambolt and others 2001).

Tart's (1996) report contained 29 data sets comparing mountain big sagebrush canopy cover with perennial grass and forb cover. These comparisons are listed in table 3 along with means, standard deviations, range, correlation coefficients, and coefficients of determination. Table 3 clearly shows no relationship between mountain big sagebrush canopy cover and perennial grass cover and between mountain big sagebrush canopy cover and perennial forb cover. Mean canopy cover of mountain big sagebrush was 28.03 percent, which is well above the 12 to 15 percent limits set by Baxter (1996). Mean cover of perennial grass was at 51.59 percent and cover of perennial forbs was at 34.10 percent. These values demonstrate that on 26 of these sites there was an abundance of big sagebrush (20 percent or more), perennial grass (50 percent or more), and perennial forbs (15 percent or more).

Tart's (1996, p. 42) data showed that stands of mountain big sagebrush with the highest canopy cover at 46 percent had grass and forb cover above the study averages. Conversely, stands of mountain big sagebrush with the lowest canopy cover at 17 percent (p.26) had below average grass and forb cover. This report does not support the contentions that mountain big sagebrush canopy cover above 20 percent suppresses grass and forbs species cover or species numbers.

Pearson (1965), studying vegetative production in grazed and ungrazed plant communities, found that big sagebrush canopy cover in the ungrazed area was 34 percent and perennial grasses 39 percent compared to 11 percent big sagebrush canopy cover in the grazed area with 22 percent perennial grass cover. Similarly, Anderson and Holte (1981) reported that for an area in southeastern Idaho protected from grazing for more than 25 years, big sagebrush canopy cover increased from15 to 23 percent with an increase in grass cover from 0.28 to 5.8 percent. McLean and Tisdale (1972) found that from 1959 to 1968 in their West Mara (British Columbia) exclosure that cover of perennial grasses increased from 51 to 67 percent in spite of a

Table 3—Relationship of mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) canopy cover to perennial grass cover and perennial forb cover and to number of grass and forb species and to total number of plant species. Data obtained from the report of Tart (1996). Page numbers within the Tart (1996) report are given alongside the data.

Page number	Mountain sagebrush cover	Grass cover	Forbs cover	Total number of plant species
	- - - - - - - - - - - - - *Percent*	- - - - - - - - - - - - -		
26	21	52 (11)[a]	17 (18)[b]	44[c]
	26	43 (10)	13 (18)	42
	17	38 (10)	22 (18)	44
31	21	48 (11)	27 (25)	45
	24	47 (11)	31 (25)	46
	23	36 (11)	35 (26)	47
37	30	55 (13)	20 (16)	35
	31	51 (9)	24 (18)	33
	22	22 (10)	19 (19)	36
42	31	61 (10)	25 (24)	46
	46	58 (10)	35 (25)	46
	34	40 (10)	33 (25)	47
47	22	79 (13)	27 (19)	39
	34	69 (16)	46 (19)	43
	17	41 (16)	47 (19)	43
52	27	67 (11)	22 (16)	33
	24	54 (11)	22 (13)	36
57	29	63 (14)	26 (19)	44
	30	49 (12)	34 (21)	43
	30	72 (14)	40 (21)	47
62	28	53 (9)	48 (19)	33
	31	57 (11)	79 (23)	39
	30	52 (11)	60 (23)	41
67	37	55 (8)	11 (17)	29
	34	53 (14)	29 (19)	40
	30	40 (12)	31 (21)	39
72	30	70 (9)	58 (21)	38
	26	40 (8)	67 (21)	36
	26	30 (8)	41 (16)	29
	—	—	—	
Mean	27.97	51.59	34.10	
S. D.	+6.15	+13.02	+16.32	
Range	17-46	22-79	11-79	

[a] Number of grass species
[b] Number of forb species
[c] Number of total plants species

r = 0.3289; R^2 = 0.1082 (mountain big sagebrush canopy cover versus perennial grass cover) ns.

r = 0.1092; R^2 = 0.0119 (mountain big sagebrush canopy cover versus perennial forbs cover) ns.

r=–0.0966; R^2=0.0093 (mountain big sagebrush canopy cover versus number of grass species) ns.

r=0.1933; R^2=0.0374 (mountain big sagebrush canopy cover versus number of forb species) ns.

r=–0.0738; R^2=0.0054 (mountain big sagebrush canopy cover versus total number of plant species) ns.

constant big sagebrush canopy cover at 31 to 34 percent. This was also true for the grazed area next to the exclosure. Another interesting data set comes from the study of Doescher and others (1984) where they selected two types of sites – those having high big sagebrush canopy cover and low grass cover, and those having low big sagebrush canopy cover and high grass cover. The calculated r and R^2 values were not significant, but what was most interesting is that for both types of sites, the study plot with the highest big sagebrush canopy cover for either site type also contained the highest grass cover for that site type (26.0 versus 8.2 percent and 20 versus 27.5 percent). Smith (1969) reported a big sagebrush canopy cover at his Soldier Creek site of 24 percent, but it produced 793 lbs/acre of grass versus his Buck Creek site of 14 percent big sagebrush cover that produced only 250 lbs/acre of grass. Do any of the above citations agree with axiom number 2? None!

Axiom Number 3

Removing, controlling, or killing big sagebrush will result in a two, three or more fold increase in perennial grass production.

Miller (1957, p. 18) states the axiom in these words: "Spraying sagebrush on a Washington range results in a three-fold increase of grass forage." On the surface this sounds great if you are interested in livestock grazing, but there are some problems with the science.

After reading the reports of Kissinger and Hurd (1953) and Hedrick and others (1966) concerned with controlling big sagebrush to improve perennial grass production, it became quite clear – judging by their figures – that the comparisons of treated and untreated big sagebrush plots were a comparison of overgrazed big sagebrush plots to treated plots with treated plots showing a substantial gain in perennial grass production. The question that came to our minds was: How much of a gain in grass production would be achieved by comparing nongrazed or undisturbed big sagebrush plots versus treated plots? Do we have data to allow such a comparison? We believe we do, to a limited degree.

Table 4, lists the results of 29 studies conducted to determine the amount of perennial grass production that was achieved by killing big sagebrush by various means, on varying sites, and for varying lengths of time after treatment. (The two McDaniel and others 1991, 1992 citations include production of forbs.) Some of the studies involved seeding perennial grasses and forbs – mostly nonnative – after the treatments and others did not. Table 5 displays the production of perennial grasses on ungrazed kipukas and relicts from the study of Passey and others (1982). Data in both tables are based on lb of air-dried perennial grass forage per acre (except as noted earlier). The yearly means (1, 2 to 3, 4 to 5, 6+ years after treatment) for the 29 studies were 284, 421, 598, and 438 lb. The range for these studies was 42 to1,805. These values compare closely with the overall 10-year mean of 455 and range of 90 to 1,169 for the Passey and others (1982) study. These data sets support the proposition that ungrazed or undistribed big sagebrush sites produce nearly the same amount of perennial grasses as treated sites where the big sagebrush has been destroyed.

West (1999, p. 16), concerning kipukas or relicts, states: "These relicts are not completely reliable as reference conditions because they are incomplete ecosystems." Yet, West (1999) is one of the others in Miller and others (1994) that cites Tisdale and others (1965) to support their (Miller and others 1994) claims that big sagebrush canopy does not exceed naturally 10 or 20 percent. Tisdale and others (1965) collected their data from the Cary kipuka located in south central Idaho.

For the kipukas I visited, there seem to be the usual complement of birds, small mammals (including foxes, rabbits, and coyotes), reptiles, insects, spiders, lichens, shrubs, grasses, forbs, and biological crusts. On one kipuka I observed deer tracks. For the kipuka, Passey and Hugie (1963, p. 114) studied they noted: "Deer and antelope occasionally cross the kipuka and there is evidence of a small rodent population." Because these kipukas are surrounded by lava flows, the fire return intervals are probably much longer than for nearby big sagebrush stands outside the kipukas. In spite of their minor short comings, kipukas represent our best reference of pristine big sagebrush stands.

The Harniss and Murray (1973) report is often cited by those trying to justify the use of fire to improve grass production in the big sagebrush ecosystem. If you read and study just the figures or graphs in their report, it appears fairly obvious that burning big sagebrush increases grass yield substantially. Their figures or graphs are constructed based on four data points of vegetation production for the years 1937, 1939, 1948, and1966, all of which are related back to the so-called base year of 1936 or 100 percent. We do not believe that four data points representing 30 years of vegetative growth constitute an adequate sampling size nor is expressing the data in relative terms of the1936 year or 100 percent appropriate because weather conditions vary greatly among years. In fact, Pechanec and Stewart (1949, p. 23; also see Pechanec and others 1937 for details) noted: "Records from these range pastures and from detailed plot studies showed that not until 1937 had perennial bunchgrasses fully recovered from the effects of the 1934 drought." A study of their data reveals an interesting contradiction. While their figures may portray accurately the relationship of grass production of 1936 or 100 percent to the other 4 years, they do not accurately represent the effects of burning or the killing of big sagebrush on grass production. What does their data tell us? Half of their data points show that the unburned plots (1937 and 1966) produced more grass than their burned plots; yet big sagebrush production was substantially lower in the burned plots that also produced less grass. It should be pointed out that during 1966, precipitation was 75 percent of the long-term average (Noaa 1966) and that they cannot take the alleged effects on grass production due to big sagebrush and separate those effects from drought. Also, there is a high

Table 4—The production of perennial grass on big sagebrush (*Artemisia tridentata*) controlled plots. Data expressed as lb/acre of air-dried grass. Perennial grass production was grouped according to number of years after treatment; 1, 2-3, 4-5, and 6 years or more.

		Perennial grass production					
Study	**Treatments**	**1**	**2-3**	**4-5**	**6+**	**Study range**	**Subspecies**
Baxter 1996	Teb				495	—	—
Olson and others 1996	Teb				725	582-819	—
Halstvedt and others 1996	Teb				536	368-750	—
Kay and Street 1961	24D				970	90-970	—
Miller and others 1980	24D		267	550	—	—	Mountain
			615	579	—	—	Mountain
Clary and others 1985	Teb	218	524	—	—	135-885	Mountain
Sturges 1986	24D	281	426	347	—	261-521	Mountain
Wambolt and Payne 1986	Burn	206	240	382	379	93-672	Wyoming
	24D	162	550	428	289	157-664	Wyoming
	Plow	144	255	365	200	74-540	Wyoming
	Rotocut	145	331	333	200	88-567	Wyoming
Murray 1988	Teb	—	331	493	—	160-605	Mountain
Thilenius and Brown 1974	24D	—	—	—	267	174-359	—
Evans and Young 1975	24D	276	503	508	—	339-677	—
	24D+Picl	588	913	1274	—	588-1381	—
Robertson 1969	24D	143	450	1163	—	143-1163	—
		291	429	798	—	291-798	—
Johnson 1969	24D	—	253	187	255	182-294	—
Tabler 1968	24D	310	400	800	410	—	—
Hedrick and others 1966	24D	375	343	743	358	300-910	—
	Rotobeat	388	405	643	276	285-725	—
Peek and others 1979	Burn	85	215	—	—	—	Wyoming
West and Hassan 1985	Burn	80	259	—	—	—	—
Alley 1956	24D	—	—	—	—	769-1347	—
Schumaker and Hanson 1977	24D	—	259	—	—	—	Wyoming
	Grubbed	—	308	—	—	—	Wyoming
	24D	—	442	—	—	400-473	Mountain
	Grubbed	—	412	400	—	400-424	Mountain
Tueller and Evans 1969	24D	326	325	461	517	110-910	—
	Picoram	260	308	971	510	250-1805	—
Olson and others 1994	Teb	—	—	—	724	582-819	—
Miller 1957	24D	—	780	—	—	—	—
Kissinger and Hurd 1953	245T	—	530	—	—	460-590	—
Hyder and others 1956	245T	501	324	—	—	—	—
	Grubbed	474	333	—	—	—	—
McDaniel and others 1991	24D	442[a]	338[a]	—	554[a]	327-554[a]	Wyoming
	Metsulfuron	510[a]	716[a]	—	558[a]	315-1185[a]	Wyoming
McDaniel and others 1992	Teb	—	678[a]	540[a]	492[a]	42-11344[a]	Wyoming
Raper and others 1985	Burn	192	—	—	—	144-240	Mountain
Blaisdell 1953	Burn	—	—	—	305	290-321	Mountain
	Burn	—	—	—	367	365-369	Wyoming
Harniss and Murray 1973	Burn	139	448	—	254		
Means		284	421	598	438	(42-1805)	—

[a] Values based on total herbaceous standing crop

Table 5—Production of perennial grasses on ungrazed kipukas and relict areas as determined by Passey and others (1982). Data expressed as pounds of air dried forage per acre and represents a 10-year mean, with arithmetic range in parentheses, per exhibit or stand.

Exhibit or stand	Subspecies of big sagebrush	10-year mean lb/acre
3A	Basin	563 (301-901)
4A	Basin	554 (245-781)
6A	Wyoming	160 (90-300)
8A	Basin	790 (435-1149)
9A	Basin	453 (168-764)
10A	Basin	672 (347-1169)
11A	Wyoming	390 (225-713)
12A	Wyoming	369 (195-553)
13A	Wyoming	426 (266-632)
14A	Wyoming	299 (152-424)
15A	Basin	665 (362-1033)
16A	Wyoming	439 (271-612)
17A	Wyoming	307 (171-420)
18A	Wyoming	316 (208-480)
19A	Wyoming	426 (288-732)
Means	Basin	616 (168-1169)
	Wyoming	348 (90-732)
	Overall	455 (90-1169)

probability that Harniss and Murray (1973) misidentified their big sagebrush since 11 inches of annual precipitation is more characteristic of Wyoming big sagebrush than mountain big sagebrush (Blaisdell 1953).

Peterson and Flowers (1984, p. 7) is a simulation model they developed to predict the effects of fire on range production in a number of ecosystems. One of these models was for the sagebrush ecosystem. In their own words: "The information used to simulate the effects of fire on sagebrush range is derived from long-term studies on sagebrush-grass range in Idaho (Blaisdell 1953; Harniss and Murray 1973; Mueggler and Blaisdell 1958) and Oregon (Hedrick and others 1966; Sneva 1972)." Unfortunately, two of the five studies used for their model development were not burns. Both Oregon studies used 2,4-D and other means to kill big sagebrush. The relationship between burning big sagebrush stands and spraying with 2,4-D and other means is unknown.

They chose a prefire production level of 280 lb of grasses and forbs per acre and a gain of 800 lb of grasses and forbs per acre until big sagebrush establishes dominance and forces production to the prefire level. The authors made a number of erroneous assumptions in developing their model. First, the 280 lb per acre of grasses and forbs probably reflects the level of production of grazed out, abused big sagebrush stands. If they had used the study average of Passey and others (1982) conducted in ungrazed big sagebrush stands, the prefire production level would have been 611 lb of grasses and forbs per acre instead of the 280 lb. Second, study average production of grasses and forbs for big sagebrush controlled sites for the five studies cited were: Blaisdell (1953)-507 lb per acre for his Fremont County site and 512 lb per acre for his Clark County site; Harniss and Murrary (1973)-534 lb per acre for 1939, and 508 lb per acre for 1948; Mueggler and Blaisdell (1958)-602 lb per acre; Hedrick and others (1966)-438 lb per acre; and Sneva (1972)-681 lb per acre. So, where did Peterson and Flowers (1984) come up with a postfire production of 800 lb per acre? Certainly not from the studies they cited. Third, the authors did not build into their model the effects of precipitation on grass and forb production. Holechek and others (1989, p. 21) state:"Precipitation is the most important single factor determining the type and productivity of vegetation in an area." (Also see Pechanec and others 1937.) This relationship is illustrated in the Sneva (1972) citation. In fact r and R^2 values are high at 0.9649 and 0.9311, respectively. If the authors (Peterson and Flowers 1984) had analyzed grass and forb yields for the years 1963 to 1969, where Sneva (1972) claimed that big sagebrush was reestablishing itself on the sprayed plots to the years 1954 to 1962, they would had discovered that the mean yields under the influence of big sagebrush was 680 lb per acre as compared to 672 lb per acre with reduced big sagebrush.

Peek and others (1979) show no significant increase in grass production 1, 2, and 3 years after a burn on Wyoming big sagebrush winter range. Similar results occurred in the study conducted by Raper and others (1985) 1 year after a burn in mountain big sagebrush. West and Hassan's (1985) report contains data that shows perennial grass production decreasing after wildfire. Blaisdell (1953) found no significant increase in total perennial grass production due to burning 15 years after the burn on his Fremont County (Idaho) site but did detect a significant increase in total perennial grass production due to burning 12 years after the burn on his Clark County (Idaho) site. Out of 12 data points, four sites, and 3 years, Cook and others (1994) found that perennial grass yields were higher on mountain big sagebrush burned sites versus unburned sites six times for 50 percent. Do you note a trend here? That 50 percent of the time killing big sagebrush results in no increase in perennial grass production?

Wambolt and others (2001, p. 243) studying 13 burned sites versus paired unburned sites noted: "Total perennial grass canopy coverage was not different ($P< 0.05$) between treatments over the 13 sites. Managers considering prescribed burning of big sagebrush communities should be aware that herbaceous plant responses may be minimal while shrub values will likely be lost for many years." Even where overall grass production has shown an increase, certain important species for wildlife and livestock (such as Idaho fescue, *Festuca idahoensis*) are frequently reduced (Peterson 1995).

It is interesting to note that it is a common practice before a prescribed fire to rest the proposed treatment area from livestock grazing for a year or two, to allow the buildup of fine fuels (grasses and forbs) – or, in other words, grasses and forbs increase in pound per acre and/or cover without prekilling big sagebrush (Bunting and others 1987). This could be considered as range improvement without killing big sagebrush.

It is not the presence of big sagebrush that limits grass production, but rather grazing that removes the grass component, leaving in some cases just big sagebrush, or as Peterson (1995, p. 34) puts it: "Sagebrush is a product of the range, range condition is not a product of sagebrush." The presence of big sagebrush is not an indicator of poor range conditions. Thilenius and Brown (1974, p. 224) made this interesting observation: "On three summer cattle ranges in the Bighorn, increased herbage production after sagebrush control with 2,4-D was a relatively short-lived phenomenon. Declines in production and the proportion of graminoids in the herbage did not appear to be related to reinvasion of sagebrush as this was minimal on all three sites even after 10 to 11 years." Also, Clary and others (1985) reported no significant increase in the production of perennial grasses in spite of significant reduction in shrub production (mainly mountain big sagebrush, killed by tebuthiuron treatments) of some 73 to 99 percent. Differences in perennial grass production in big sagebrush stands has less to do with shrub cover than it has with soils, moisture (wet or dry years), and especially grazing history differences (Peterson 1995; Pechanec and others 1937; Pechanec and Stewart 1949; Piemeisel 1945; Sneva 1972). So it appears that the recurrence of perennial grass after big sagebrush control may be a reestablishment of preexisting grass cover, unfortunately without big sagebrush.

A number of studies showed that total vegetative production, that is pounds of air-dried forage for all classes of plants, is reduced with big sagebrush control (Blaisdell 1953; Mueggler and Blaisdell 1958; Murray 1988; Pechanec and Stewart 1944a,b; Schumaker and Hanson 1977; Sturges 1986; Tabler 1968; West and Hassen 1985—minus the cheatgrass portion). Sites with big sagebrush are not only more productive, but the big sagebrush itself is important for the entire vegetative community by providing protection for understory plants, storing more snow, improving soil conditions at greater depth through root decay, and recycling deep soil moisture and nutrients (Peterson 1995).

Axiom Number 4

Nothing eats it, or as expressed by Tueller (1985, p. 29): "It is ironic that the dominant plant and highest producer on this area of 30,000 square miles is essentially unpalatable." This subject reminds us of an old bumper sticker that reads: "Eat lamb! A million coyotes can't be wrong!" Paraphrasing, we could say "Eat big sagebrush! 52 species of aphids can't be wrong!"

A host of organisms feed directly on big sagebrush, including large and small mammals, birds, insects, fungi, parasitic vascular plants, and lichens, which find support on the boles and larger branches of big sagebrush. All parts of big sagebrush are consumed – leaves and stems, pollen, achenes or seeds, root tissues, and so forth.

Large mammals known to consume big sagebrush in varying amounts include domestic sheep (*Ovis aries*—Nelson 1898), mule deer (*Odocoileus hemionus,* Leach 1956), pronghorn (*Antilocapra americana,* Ferrel and Leach 1952), elk (*Cervus canadensis*, Kufeld 1973), Rocky Mountain bighorn sheep (*Ovis canadensis,* Keating and others 1985), and desert bighorn (*Ovis canadensis nelsoni,* Browning and Monson 1981). A number of small mammals also consume big sagebrush. About 15 species of these are listed in table 6. Four species of birds have been reported as directly eating big sagebrush: sage grouse (*Centrocercus urophasianus*, Rasmussen and Griner 1938), dark-eyed juncos (*Junco hyemalis*, Welch 1999), horned larks (*Eremophila alpestris*, Welch 1999)), and white-crowned sparrows (*Zonotrichia leucophrys,* Welch 1999).

The largest number of species obtaining substance from big sagebrush are found in two groups of organism: fungi and insects. Fungus species isolated from big sagebrush plants, 31 in all, are listed in table 7. There are 52 species of aphids that receive nourishment from big sagebrush; these are listed in table 8 (Gillette and Palmer 1928; 1933; Knowlton 1983). Feeding upon these aphids and indirectly on big sagebrush are a number of parasitic insects including 10 species of hymenoptera (ants, wasps, bees, chalcids, sawflies, and ichneumons, Pike and others 1997) and an undetermined number of ladybird beetle species. At least 18 species of beetles are known to be associated with big sagebrush, most of which feed directly on this plant (Banham 1962*;* Barr and Penrose 1969; Blake 1931; Furniss and Barr 1975; Halford and others 1973; Massey and Pierce 1960; Pringle 1960; Rickard 1970; Rogers and Rickard 1975; Tilden and Mansfield 1944). Thirteen known species of grasshopper and shield-back katydids also feed on big

Table 6—Small mammals reported as consumers of big sagebrush. Common and scientific names are given as listed in the various cited articles; some repetition.

Species		% diet	Reference
Black-tailed jack	*Lepus californicus*	?	Severaid 1950
		?	McAdoo and Young 1980
Black-tailed hare		10	Uresk 1978
Black-tailed jackrabbit		1-8	MacCracken and Hansen 1984
		6-21	Fagerstone and others 1980
		?	McKeever and Hubbard 1960
		8	Gates and Eng 1983
Chisel-toothed			
Kangaroo rat	*Dipodomys microps*	5	Johnson 1961
Deer mouse	*Peromyscus maniculatus*	?	Parmenter and others 1987
Least chipmunk	*Eutamias minimus*	2	Johnson 1961
Long-tailed vole	*Microtus longicaudus*	?	Parmenter and others 1987
Ord's kangaroo rat	*Dipodomys ordi*	3	Johnson 1961
Pika	*Ochotona princeps*	?	Severaid 1950
Pika	*Ochotona schisticeps*	?	Linsdale 1938
Pygmy rabbit	*Sylvilagus idahoensis*	?	Severaid 1950
	Brachylagus idahoensis	51-99	Green and Flinders 1980
Sagebrush vole	*Lagurus curtatus*	?	Rickard 1960
		?	Parmenter and others 1987
	Lemmiscus curtatus	1	Mullican and Keller 1986
		?	Maser 1974
Townsend ground squirrel	*Spermophilus idahoensis*	?	Rogers and Gano 1980
	Citellus townsendi	2	Johnson 1977
		?	Rickart 1987
		?	Davis 1939
Western cottontail	*Sylvilagus nuttallii*	?	Severaid 1950
Nuttall Cottontail		3-4	MacCracken and Hansen 1984
Western harvest mouse	*Reithrodontomys megalotis*	12	Johnson 1961
White-tailed jack	*Lepus townsendi*	?	Severaid 1950
		?	McAdoo and Young 1980

Table 7—Pathogenic and nonpathogenic fungi collected from big sagebrush (Weber and others 2001).

Alternaria tenuis	*Leptosphaeria tumefaciens*
Camarosporium compositarum	*Odontotrema oregonense*
Cucurbitaria obducens	*Phoma terrestris*
Diplodina tridentatae	*Phyllosticta raui*
Discomycete sp.	*Puccinia absinthii*
Epicoccum nigrum	*Puccinia atrofusca*
Fusarium sp.	*Puccinia cnici-oleracei*
Glyphium corrugatum	*Puccinia similis*
Godronia montanensis	*Puccinia tanaceti*
Guepiniopsis buccina	*Pyrenopeziza artemisiae*
Guepiniopsis torta	*Stigmina sycina*
Heliocybe sulcata	*Syncarpella tumefaciens*
Heterobasidion annosum	*Teichospora obducens*
Leptosphaeria artemisiae	*Teichospora* sp.
Leptosphaeria preandina	*Typhula* sp.
	Uromyces oblongisporus

Table 8—Species of aphids collected from big sagebrush (*Artemisia tridentate* – Gillette and Palmer 1928, 1933; Knowlton 1983).

Anuraphis hermistonii
Anuraphis oregonensis
Aphis artemisicola
Capitophorus heterohirsutus
Epameibaphis atricornis
Epameibaphis frigidae
Epameibaphis utahensis
Flabellomicrosiphum knowltoni
Flabellomicrosiphum tridentatae
Hyperomyzus accidentalist
Macrosiphoniella frigidicola
Macrosiphum longipes
Microsiphoniella acophorum
Microsiphoniella artemisiae
Microsiphoniella oregonensis
Obtusicauda albicornus
Obtusicauda anomella
Obtusicauda artemisicola
Obtusicauda artemisiphila
Obtusicauda cefsmithi
Obtusicauda coweni
Obtusicauda essigi
Obtusicauda filifoliae
Obtusicauda flavila
Obtusicauda frigidae
Obtusicauda jonesi
Obtusicauda zerohypsi
Obtusicauda zerothermum
Pleotrichophorus decampus
Pleotrichophorus glandulosa
Pleotrichophorus heterohirsutus
Pleotrichophorus infrequens
Pleotrichophorus longipes
Pleotrichophorus pseudoglandulosus
Pleotrichophorus pullus
Pleotrichophorus quadritrichus
Pleotrichophorus quadritrichus ssp. *pallidus*
Pleotrichophorus spatulavillus
Pleotrichophorus wasatchii
Pleotrichophorus zoomontonus
Pseudoepameibaphis essigi
Pseudoepameibaphis glauca
Pseudoepameibaphis tridentatae
Pseudoepameibaphis xenotrichis
Pseudoepameibaphis zavillus
Zyxaphis canae
Zyxaphis filifoliae
Zyxaphis hermistonii
Zyxaphis infrequens
Zyxaphis minutissima
Zyxaphis oregonensis
Zyxaphis utahensis

sagebrush (Anonymous 1992; Hewitt and others 1974; Isely 1944; Johnson and Lincoln 1990, 1991; Scharff 1954; Sheldon and Rogers 1978; Tinkham 1944). Sixteen species of thrips have been collected from big sagebrush (Bailey and Knowlton 1949; Knowlton and Thomas 1933; Tingey and others 1972). Table 9 lists 32 species of midges that induce galls on big sagebrush. In addition to galls induced by midges, Foote and Blanc (1963) and Fronk and others (1964) described several species of fruit flies that also induce gall formation on big sagebrush: *Asphondylia* sp., *Aciurina maculata, Eutreta diana, E. oregona, Neotephritis finalis, Orellia undosa, Oxyna palpalis, O. utahensis,* and *Trupanea nigricornis*. Emlen (1992) described an additional gall inducing fruit fly, *Eutreta diana*.

Table 9—Midges that induce galls on big sagebrush (Felt 1916, 1940; Jones and others 1983).

Cecidomyia spp.
Diarthronomyia artemisiae
Diarthronomyia occidentalis
Rhopalomyia ampullaria
Rhopalomyia anthoides
Rhopalomyia brevibulla
Rhopalomyia calvipomum
Rhopalomyia conica
Rhopalomyia cramboides
Rhopalomyia culmata
Rhopalomyia florella
Rhopalomyia gossypina
Rhopalomyia hirtibulla
Rhopalomyia hirticaulis
Rhopalomyia hirtipomum
Rhopalomyia lignea
Rhopalomyia lignitubus
Rhopalomyia mammilla
Rhopalomyia medusa
Rhopalomyia medusirrasa
Rhopalomyia navasi
Rhopalomyia nucula
Rhopalomyia obovata
Rhopalomyia pomum
Rhopalomyia rugosa
Rhopalomyia sp.
Rhopalomyia sp. *near lignea*
Rhopalomyia tridentatae
Rhopalomyia tubulus
Rhopalomyia tumidibulla
Rhopalomyia tumidicaulis
Trypetid sp.

Associated with these gall-inducers are a number of parasitic insects (20) and even a few (six) that use the galls to hibernate in (Emlen 1992; Fronk and others 1964; Goeden 1990; Jones and others 1983; Santiago-Blay 1989).

With such a large number of insect species living off of big sagebrush, it is not surprising that a large number of predicator organisms are associated with big sagebrush and indirectly consume big sagebrush by feeding on the insects that directly feed on big sagebrush. For example, table 10 lists 72 species of spiders that are associated with big sagebrush and its host of insects (Abraham 1983; Allred 1969; Ehmann 1994; Hatley and MacMahon 1980). Also feeding on the insects of big sagebrush and indirectly on big sagebrush itself are a hosts of birds, small mammals, and reptiles.

Rosentreter (1990) reported finding 24 species of lichens (table 11) growing on the trunk of big sagebrush plants. Paintbrushes – *Castilleja* – are flowering facultative root hemiparastic plants; about 16 species are known to use big sagebrush as a host plant

Table 10—Spiders species associated with big sagebrush listed by guild (Abraham 1983; Allred 1969; Ehmann 1994; Hatley and MacMahon 1980).

Jumpers

Metaphidippus aeneolus
Oxyopes scalaris
Phidippus johnsoni
Sassacus papenhoei
Synageles idahoanus
Tutelina similis

Trappers

Dictyna idahoana
Dipoena nigra
Dipoena tibialis
Euryopis sp.
Hyposinga singaeformis
Metepeira foxi
Theridion neomexicanum
Theridion petraeum

Ambushers

Coriarachne sp.
Misumenops sp.
Xysticus cuncator
Xysticus gulosus
Xysticus montanensis

Pursuers

Anyphaena pacifica
Chiracanthium inclusum
Ebo sp.
Philodromus histrio

Additional species from Allred (1969)

Ceratinella acerea
Ceratinella parma
Circurina new species
Dictyna coloradensis
Drassyllus mannellus
Enophognatha wyuta
Gnaphosa
Haplodrassus eunus
Schizocosa avida
Tarentula kochi

Additional species from Allred (1969) (con.)

Xysticus knowltoni
Xysticus nigromaculatus
Zelotes pullatus

Additional species from Abraham (1983)

Aculepeira verae
Alopecosa kochi
Araneus gemma
Araniella displicata
Argiope trifasciata
Dictyna completa
Ebo evansae
Enoplognatha ovata
Erigone dentosa
Euryopis scriptipes
Herpyllus sp.
Latrodectus hesperus
Meioneta sp. *1*
Meioneta sp. *2*
Meioneta sp. *3*
Metaphidippus verecundus
Metaphidippus sp.
Micaria sp.
Misumenops asperatus
Misumenops lepidus
Neoscona arabesca
Pardosa wyuta
Pellenes hirsutus
Phidippus octopunctatus
Philodromus californicus
Philodromus rufus
Philodromus satullus
Philodromus speciosus
Spirembolus mundus
Steatoda americana
Synagales sp. *nov.*
Tetragnatha laboriosa
Thanatus formicinus
Tibellus chamberlini
Tibellus oblongus
Zelotes subterraneus

Table 11—Lichens species associated with big sagebrush (Rosentreter 1990).

Buellia punctata
Caloplaca fraudans
Candelaria concolor
Candelariella rosulans
Candelariella vitellina
Hypogymnia physodes
Lecanora cf. *varia*
Lecanora sp.
Lecidea plebeja
Lepraria neglecta
Letharia vulpina
Melanelia exasperatula
Melanelia incolorata
Physcia dimidiata
Physcia sp.
Physconia detersa
Physconia grisea
Physconia muscigena
Rinodina sp.
Usnea sp.
Xanthoria candelaria
Xanthoria fallax
Xanthoria polycarpa
Xanthoria sorediata

Table 12—Paintbrushes – *Castilleja* – associated with big sagebrush (Cronquist and others 1984; Goodrich and Neese 1986; Hitchcock and others 1959).

Castilleja	*angustifolia*
	applegatei
	aquariensis
	chromosa
	cusickii
	dissitiflora
	flava
	linariifolia
	miniata
	pallescens
	pilosa
	oresbia
	rustica
	scabrida
	thompsonii
	xanthotricha

(table 12, Cronquist and others 1984; Goodrich and Neese 1986; Hitchcock and others 1956). Owl-clovers – *Orthocarpus* – are facultative root hemiparasites, but unlike paintbrushes they are smaller and are annuals; seven species have been identified as perhaps using big sagebrush as a host plant (Cronquist and others 1984; Ducharme and Ehleringer 1996; Goodrich and Neese 1986; Taylor 1992). A number of others facultative root parasites may use big sagebrush as host plants: Bird's beaks – *Cordylanthus capitatus, C. kingii, C. parviflorus, C. ramosus, C. wrightii*; and Broomrapes – *Orobanche corymbosa, fasciculata, ludoviciana* (Cronquist and others 1984; Goodrich and Neese 1986).

The axiom that nothing eats big sagebrush is not based on science or even sound reasoning. Big sagebrush is a nursing mother to a host of organisms ranging from microscopic to large mammals. Many of these organisms society values, and they exist because of sagebrush and not in spite of it.

Axiom Number 5

Biodiversity increases with the removal, controlling, thinning, or killing of big sagebrush.

Olson and others (1994) reported that in their big sagebrush control plots, the number of plant species increased by three to four species over untreated big sagebrush plots, but they failed to name what species of plants and where they came from. Did the new unknown plant species seeds just float in, on the wind, like musk thistle (*Carduus nutans*), could or develop from long-lived dormant seeds formed from plants that have been grazed out before treatment? Are their comparisons between overgrazed big sagebrush sites versus treated sites proper, or should the comparisons be between undisturbed or never grazed by livestock big sagebrush sites versus treated sites? Should the measurement of biodiversity be determined only on number of plant species present or on total number of species of all life forms? What did the rebuttal of the last axiom number 4 tell us? That a large number of species consumes big sagebrush directly and indirectly. Is this not an expression of biodiversity?

We calculated correlation coefficients and coefficients of determination for the data published in Tart (1996), between canopy cover of mountain big sagebrush and number of perennial grass species, number of forb species, and total number of plants species present on his study sites. No significant relationships were detected (table 3). An interesting point of the Tart (1996) study is found on his page 42, where a stand of mountain big sagebrush with a canopy cover of 46 percent supported 48 species of grasses and forbs, while a stand of mountain big sagebrush (his page 26) with a canopy cover of 17 percent supported 33 species. A second mountain big sagebrush (his page 74) with a canopy cover of 17 percent supported 35 species.

The Goodrich and Huber (2001) study also demonstrates a lack of relationship between big sagebrush canopy cover and number of grass and forb species and total plant species:

31-4-exclosure 32.4 percent big sagebrush canopy cover-41-grasses & forbs-46-total plants,

32-66-grazed 16.4 percent big sagebrush canopy cover-38-grasses & forbs-41-total plants,

32-67-grazed 15.1 percent big sagebrush canopy cover-44-grasses & forbs-47-total plants,

31-35A-grazed 5.0 percent big sagebrush canopy cover-43-grasses & forbs-46-total plants,

32-78-grazed and burned 0.2 percent big sagebrush canopy cover-42- grasses & forbs-46 total plants.

Perryman and others (2002, p. 419) studying the response of vegetation to prescribed fire in Dinosaur National Monument found: "Mean numbrs of [plant] species on combined control and burn areas were 17 and 18, respectively." Only one comparison out of 20 showed a significant increase in plant species for the burned or control plots versus unburned plots. Tiedeman and others (1987) and Baker and Kennedy (1985) reported similar results. It appears highly unlike that big sagebrush canopy cover above 20 percent suppresses or reduces biodiversity.

Big sagebrush is the mother of biodiversity. It is what supports life in Bailey's (1896, p. 359) description: "One never recovers from his surprise that there should be so much life where apparently there is so little to support it."

Axiom Number 6

Mountain big sagebrush evolved in an environment with a mean fire interval of 20 to 30 years (Winward 1984), or as expressed by Winward (1991, p.4): "These ecosystems, which have developed with an historical 10-40 year fire interval, were dependent on this periodic removal or thinning of sagebrush crowns to maintain their balanced understories."

Of all the axioms we have challenged in this paper, none is more speculative, that is not based on scientific investigation, than this one. Mueggler (1976, p. 6) stated: "Judging from the reports of early explorers, these fires were not frequent enough to alter the vegetation in favor of more fire-enduring grasses." The height of rationalization is reached in this statement by Winward (1984, p. 3): "Normally sagebrush survives fires through rapid regeneration of seedlings and in this sense it may be called fire tolerant." How rapid is rapid? The answer to this question depends not on ecologically founded principles but more on what is best for private animals on the people's land (Vallentine 1989), or in the words of Box (2000, p. 30): "The credibility of range managers is questioned. We are accused of being captive of a single use – livestock grazing."

So how rapid can big sagebrush reestablish itself after a fire? Winward (1984, p. 3) says: "In most cases it is well on its return to the site 5-10 years after a burn. Normally enough sagebrush seed remains in the soil surface for rapid recolonization." Unfortunately, the phases "well on its return" and "rapid recolonization" were not quantitatively defined across the range of sagebrush habitats, and there is much evidence to the contrary. West and Yorks (2002, p. 175) noted: "*Artemisia* [Wyoming big sagebrush] has been slow to reestablish at our burned locations." None of 13 mountain and Wyoming big sagebrush burned sites studied by Wambolt and other (2001) support Winward's (1984) statement. Hanson (1929) noted that grasses were dominant over (probably mountain) big sagebrush 5 to 10 years after a fire. Pechanec and Stewart (1944a, p.13) stated the following concerning the recovery of big sagebrush after a burn: "Eleven years after burning almost no sagebrush has reoccupied the area." Blaisdell (1950), studying what was probably a mountain big sagebrush stand, noted some reestablishment 15 years after a fire. Blaisdell (1953) found little reestablishment of what was probably a Wyoming big sagebrush stand 12 years after a fire. Harniss and Murray (1973) noted that full big sagebrush recovery had not occurred even after 30 years on what was probably a Wyoming big sagebrush stand. Bunting and others (1987, p. 4) set mountain big sagebrush recovery at 15 to 20 years and observed that "Wyoming big sagebrush will establish readily from seed, if seed is available. Slow growth, however, reduces the rate at which it recovers compared to other big sagebrush subspecies." Eichhorn and Watts (1984, p. 32) stated: "burning removed big sagebrush (*Artemisia tridentata wyomingensis*) from the site and it has not reinvaded after 14 years." Wambolt and Payne (1986) reported that 18 years after a fire, Wyoming big sagebrush canopy cover was only 16 percent of control and significantly below other control methods. Fraas and others (1992) found little recovery of mountain big sagebrush on an 8 year old burn. Wambolt and others (1999, p. 239), studying the production of three subspecies of big sagebrush 19 years after a fire on the northern Yellowstone winter range, found: "recoveries of burned compared to unburned Wyoming, mountain, and basin big sagebrushes were...0.1, 1.4 and 11% for production of winter forage, respectively." They further studied seven other burn sites of mountain big sagebrush on the northern Yellowstone winter range and found no significant recovery of mountain big sagebrush 9 to15 years after prescribed burning. Humphrey (1984), studying the patterns and mechanisms of plant succession after fire in the big sagebrush habitat, found a pronounced delay of some 18 to 32 years in the establishment of big sagebrush. He attributed this delay to big sagebrush dependancy on the dispersal of its propagules, achenes, or seeds (big sagebrush seed moves about 100 feet from the mother plant, which means it could take some 105 to 211 years to spread 1 mile; Noste and Bushey 1987). Nelle and others (2000) noted that it required more than 20 year for burned-over mountain big sagebrush stands to recover sufficiently to support nesting habitat for sage grouse. We have cited 13 scientific articles–five published long before 1984—that do not support Winward's (1984) contention that big sagebrush "is well on its return" in 5 to 10 years after a burn.

However, Mueggler (1956, p. 1) noted on what was probably a Wyoming big sagebrush site: "Establishment of thick stands of big sagebrush (*Artemisia tridentata*) seedlings the year following planned burning of sagebrush range sometimes occurs despite all known precautions." The key word in his statement is "sometimes." Unfortunately, some workers such as Burhardt and Tisdale (1976, p. 478) have changed the word "sometimes" to "generally," which gives the erroneous impression that most burned big sagebrush stands can regenerate quickly, or in the case of Winward (1984, p.3), most of the time, as would be inferred by his statement that in most cases big sagebrush is well on its return 5 to 10 years after a fire.

In addition to the scientific articles cited above, we have measured the reestablishment of mountain big sagebrush on a 360+ acre, 14 year old burn known as the Grandine Fire some 3 miles east by northeast of Stone, ID (Klott and Ketchum 1991). We established a point – N 42° 01.545'; W 112° 38.283' – 300 feet from the western edge of the Grandine Fire and constructed a line running due east into the burned area for 3,300 feet (the line could have been continued for an additional 3,000 feet or more) and used this line to determine percent canopy cover of mountain big sagebrush and sprouting shrubs such as rabbitbrush (*Chrysothamnus* ssp.), snakeweed (*Gutierrezia* ssp.) and horsebrush (*Tetradymia* spp.). Mountain big sagebrush canopy cover for the unburned area – the first 300 feet – was 30 and 4 percent for the sprouting shrubs. For the first 300 feet into the burned area, mountain big sagebrush canopy cover was 3 and 2 percent for the sprouting shrubs. Some 3 percent mountain big sagebrush canopy cover continued to 600 feet and from 600 feet to the 3,000 foot point in the burned area, or for 2,400 feet our transect line did not intercept a single big sagebrush plant. Sprouting shrub canopy cover varied over the same distance from 8 to 26 percent. The rate of mountain big sagebrush reestablishment on this burn from the west to the east was about 42 feet per year. Reestablishment from the east to the west and from the north to the south was essentially nil, and the reestablishment rate from the south to the north was half of that of the west to the east. Based on these measurements, recovery of big sagebrush on the burn would take some 71 years to just reach the 3,000 foot point and would not include the time needed for full canopy recover. There were widely scattered mountain big sagebrush plants throughout most of the burn site that would help to reduce the 71-year recovery rate, but they too are subject to 42 feet per year spread in an easterly direction and even shorter distance in a northerly direction. These scattered plants were probably derived from soil-borne seeds that survived the burn. Two things are obvious from the measurements of this burn: (1) Winward's (1984) statement that big sagebrush "is well on its return" 5 to 10 years after a fire is a statement of oversimplification; and (2) the idea that fire stimulated mountain big sagebrush seed emergence was not supported on this fire (Hironaka and others 1983).

In an often cited article by Winward (1991, p. 4) he, in reference to the big sagebrush ecosystem, states: "These ecosystems, which have developed with an historical 10-40 year fire interval, were dependent on this periodic removal or thinning of sagebrush crowns to maintain their balanced understories." There is a lack of empirical evidence to support this assertion. In fact, a 31-year study of a mature big sagebrush stand (about 61 years old) in the Gravelly Mountains in Montana demonstrated the ability of a big sagebrush ecosystem to maintain itself without the occurrence of fire (Lommasson 1948).

Houston (1973) estimated the fire interval in what he termed "bunchgrass steppes" of northern Yellowstone National Park winter range to be from 53 to 96 years. Feeling that modern people have influenced the fire interval through fire suppression activities, he adjusted the interval by subtracting 80 years from the ages of living trees and came up with adjusted fire intervals of 32 to 70 years in the big sagebrush steppes of northern Yellowstone National Park. This reasoning suggests humans have had the capacity to significantly suppress fires starting in 1890. We believe that Houston (1973) was overoptimistic in his estimate on how soon modern people could significantly suppress fires. This ability may not have occurred until the 1950s (http://www.nifc.gov/stats/wildlandfirestats.html-Wildland Fire Statistics-Average number of fires and acres burned by decade), but even his adjusted fire intervals exceed those of Winward (1991). Wright and Bailey (1982, p.159) suggested a fire interval of 50 years "based on the vigorous response of horsebrush (*Tetradymia canescens*) to fire and the 30-plus years that are needed for it to decline to a low level after a fire in eastern Idaho." They further observed (p. 160): "If fires occurred every 20 to 25 years, as Houston implies, many sagebrush-grass communities in eastern Idaho could be dominated by horsebrush and rabbitbrush (*Chrysothamnus* ssp.)" (also see Young and Evans 1978 and Britton 1979 for supporting evidence). For Wyoming big sagebrush ecosystems, they, Wright and Bailey (1982), suggested a fire interval as long as 100 years. Whisenant (1990, p. 4) stated: "Prior to the arrival of white settlers, fire-return intervals in the sagebrush (*Artemisia*)-steppe probably varied between 60 and 110 years."

Winward (1984) suggests that mountain big sagebrush, which usually grows at higher elevations, has a burn cycle of 20 to 30 years. This is based on higher vegetative productivity of the mountain big sagebrush sites, or in other words, higher fine fuel accumulation and higher frequence of lightning strikes, which he believes results in a shorter fire cycle as compared to basin and Wyoming sites that produce less fine fuels and experience fewer lightning strikes. But should not the greater accumulation of biomass and higher number of lightning strikes on mountain big sagebrush sites be offset somewhat by lower temperature and higher humidity that occur on these sites? Monsen and McArthur (1985) and Goodrich and others (1999) reported average annual precipitation for mountain big sagebrush stands to be about 17 inches, 14 for basin big sagebrush, and 11 for Wyoming big sagebrush. Tisdale and Hironaka (1981) noted that stands dominated by Wyoming big sagebrush were the first to became water deficient (mid-July), basin big sagebrush stands were second (late July to early August), and mountain stands were the last to become water deficient (September). Meaning that mountain big sagebrush sites are the last to dry out and the first to wet-up, narrowing the window of opportunity for fire. We have observed on many mountain big sagebrush sites that understory species or fine fuels are still green during the late summer to early fall period making burning difficult.

Arno and Gruell (1983) found that the fire interval prior to 1910 at ecotones between mountain big sagebrush ecosystems and forest ecosystems ranged from 35 to 40 years (also see Gruell 1983). Miller and Rose (1999) suggest a fire interval of 12 to 15 years based on fire scars found on ponderosa pine (*Pinus ponderosa*). Neither Arno and Gruell (1983) nor Miller and Rose (1999) have linked fire scaring of trees to fire interval in mountain big sagebrush communities. We have found basal fire scaring on limber pine (*P. flexilis*), and Engelmann spruce (*Picea engelmannii*) trees, growing on talus not capable of carrying ground fires. (These observations occurred on the ridge just west of Brown Lake in the Great Basin National Park.) These scars were caused by lighting strikes. Can fire scarring due to ground fires be identified from scars due to lighting strikes? If not, would this result in overestimating fire numbers in a given period time?

Soils characteristics of the ponderosa pine clusters used in the Miller and Rose (1999) study may be dramatic different from those of the adjacent mountain big sagebrush stands (Billings 1950; DeLucia and others 1989; Gallardo and Schlesinger 1996; Schlesinger and others 1989). If so, what effects these differences might have on fire intervals on either plant community were not addressed? Also, Miller and Rose (1999) sampling method was not done in a randomized manner; they chose only trees bearing fire scars. In fact, they (Miller and Rose 1999, p. 553) stated: "In cluster I and IV, trees with the maximum number of fire scars visible on the surface were selected for sampling." Would this tend to overestimate fire numbers in a given period of time? Baker and Ehle (2001, p. 1205) states: "inadequate sampling and targeting on multiple- scarred trees and high scar densities bias mean FIs toward shorter intervals." They suggest mean fire interval for ponderosa pine may be 22 to 308 years.

However, the Miller and Rose (1999) report does present data which shows a major fire event occurring at a 50-year or more cycle. These major fire events could have burned over significant amount of mountain big sagebrush areas. A fire interval of greater than 50 years is probably compatible with maintaining a mountain big sagebrush community (Lommasson 1948).

In addition, 10 biological and ecological characteristics of mountain big sagebrush do not support the idea that mountain big sagebrush evolved in an environment of frequent fires of 20 to 30 years: (1) a life expectancy of 70+ years (Daubenmire 1975; Ferguson 1964; Fowler and Helvey 1974; Passey and Hugie 1963); (2) highly flammable bark (this stringy bark makes excellent fire starting material); (3) production of highly flammable essential oils (Buttkus and Bose 1977; Cedarleaf and others 1983; Charlwood and Charlwood 1991; Kelsey 1986; Kinney and others 1941; Powell 1970); (4) a low growth form that is susceptible to crown fires (Beetle 1960; McArthur and others 1979; (5) nonsprouting (Peterson 1995; West and Hassan 1985; Wright and others 1979; (6) seed dispersal occurs in late fall or early winter long after the fire season has ended (Beetle 1960; Young and Evans 1989); (7) lack of a strong seed bank in the soil (Beetle 1960; McDonough and Harniss 1974; Meyer 1990, 1994; Young and Evans 1989); (8) seed lack anatomical fire resistance structures or adaptations – that is, a thick seed coat (Diettert 1938); (9) seeds must lie on the soil surface, which exposed them to higher temperatures than seeds that occur deeper in the soil (Hassan and West 1986; Jacobson and Welch 1987); (10) seeds lack any adaptations for long distance dispersal, hence, mountain big sagebrush lack the ability for rapid reestablishment (Astroth and Frischknecht 1984; Chambers 2000; Frischknecht 1979; Johnson and Payne 1968; Walton and others 1986; Wambolt and others 1989; Young and Evans 1989).

Thus it appears that an estimated fire interval of 20 to 30 years for mountain big sagebrush is too low and that the natural or normal fire interval is much longer, perhaps 50 years or more. As more and more acres of the sagebrush ecosystem are converted into human development, pinyon/juniper woodlands, stands of annual weeds, and perennial grasses, the issue of how often to burn sagebrush sites supporting sagebrush obligates, such as sage grouse, could become so critical for the survival of these organisms as to question the advisability of any burning.

Axiom Number 7

Big sagebrush is an agent of allelopathy.

Most allelopathy research has been conducted under controlled or semicontrolled environments of the laboratory or greenhouse (Friedman 1995). To determine the allelopathic effects of a plant, germinating seeds are exposed to whole plant, specific plants parts (seeds, shoots, roots, and so forth), plant extracts, or to a specific phytochemical produced by the "aggressive" species (Friedman 1995). Table 13 lists the plant species showing an allelopathic reaction under laboratory (Rychert and Skujins 1974) or greenhouse environments to big sagebrush produced phytochemicals – terpenoids, phenolics, and so forth. Not included in the listing are blue-green algae-lichen crusts (Rychert and Skujins 1974).

Rychert and Skujins (1974) using laboratory techniques found that aqueous extracts from big sagebrush leaves inhibit nitrogen fixation or acetylene-reduction of the blue-green algae (now called cyanobacteria)-lichen crusts thus, providing evidence

Table 13—Species showing allelopathic effects under laboratory or green house conditions to big sagebrush chemicals (Groves and Anderson 1981; Hoffman and Hazlett 1977; Kelsey and others 1978; Klarich and Weaver 1973; McCahon and others 1973; Reid and others 1963; Schlatterer and Tisdale 1969; Weaver and Klarich 1977; Wilkie and Reid 1964).

Alfalfa	*Medicago sativa*
Barley	*Hordeum vulgare*
Bean	*Phaseolus vulgaris*
Bottlebrush squirreltail gr.	*Sitanion hystrix*
Bluebunch wheatgrass	*Agropyron spicatum*
Canada bluegrass	*Poa compressa*
Creeping juniper	*Juniperus horizontalis*
Crested wheatgrass	*Agropyron desertorum*
Corn	*Zea mays*
Cucumber	*Cucumis sativus*
Douglas-fir	*Pseudotsuga menziesii*
—	*Echinacea pallida*
Englemann spruce	*Picea engelmannii*
—	*Euphorbia podperae*
Fairway wheatgrass	*Agropyron cristatum*
Field pennycress	*Thlaspi arvense*
—	*Hedeoma hispida*
Giant wild rye	*Elymus cinereus*
Idaho fescue	*Festuca idahoensis*
Indian ricegrass	*Oryzopsis hymenoides*
Ironplant goldenweed	*Haplopappus spinulosus*
Limber pine	*Pinus flexilis*
Lodgepole pine	*Pinus contorta*
Mountain big sagebrush	*Artemisia tridentata* spp. *vaseyana*
Pennsylvania pellitory	*Parieteria pennsylvanica*
Ponderosa pine	*Pinus ponderosa*
Prairie sandgrass	*Calamovilfa longifolia*
Oats	*Avena sativa*
Radish	*Raphanus sativus*
Rocky Mountain juniper	*Juniperus scopulorum*
Rubber rabbitbrush	*Chrysothamnus nauseosus*
Slender wheatgrass	*Agropyron trachycaulum*
Silver sagebrush	*Artemisia cana*
Smooth brome	*Bromus inermis*
Subalpine fir	*Abies lasiocarpa*
Sunflower	*Helianthus annuus*
Thickspike wheatgrass	*Agropyron dasystachyum*
Thurber needlegrass	*Stipa thurberiana*
Western yarrow	*Achillea millefolium*
Western wheatgrass	*Agropyron smithii*
Wheat	*Triticum aestivum*

of possibly allelopathic effects. Kelsey and Everett (1995) suggest that litter of big sagebrush may have the same inhibitory effects. Yet five reports claim that soil nitrogen levels under big sagebrush plants are higher than in the interspace between plants (Charley 1977; Charley and West 1975; Charley and West 1977; Fairchild and Brotherson 1980; Wikeem and Pitt 1982). Charley and West (1977) reported total and nitrate nitrogen levels under big sagebrush canopy to be significantly higher – almost twice that of the interspaces. If the secondary metabolites of big sagebrush are inhibiting nitrogen fixation, how does one explain the results of these five studies? Perhaps Kelsey and Everett (1995, p. 482) offer a clue: "Because of the experimental difficulties and the complexity of biotic and abiotic factors influencing natural interactions, not all ecologists and biologists are convinced that allelopathy is a significant ecological phenomena in natural environments."

Hoffman and Hazlett (1977, p. 137) observed: "In our experiments the germination of *Parietaria pennsylvanica, Euphorbia podperae, Hedeoma hispida,* and *Achillea millefolium* was inhibited by litter extracts of *Artemisia tridentata*. Yet, in the field, these same species are most abundant directly under or very near *A. tridentata* shrubs." Further they stated (p. 137): "It is important to point out that most plant-plant interactions are not simple one factor interactions. A plant is influenced by a multiplicity of environmental factors." Krannitz and Caldwell (1995, p. 166), studying root growth responses of two grass species when their roots came into contact with mountain big sagebrush roots, observed: "Contrary to expectations, when roots of any test species contacted, or were in the vicinity of, *Artemisia* roots, their growth rate was not significantly affected." This "contrary to expectations" statement demonstrates the long-held prejudice that big sagebrush possess allelopathic powers over other range plants.

We have found in the field the seedlings of bigtooth maple-*Acer grandidentatum*, box elder-*Acer negundo,* singleleaf pinyon pine-*Pinus monophylla,* and Utah juniper-*Juniperus osteosperma* growing under the canopy of mature big sagebrush plants. Diettert (1938, p. 5) observed: "Not only is it of direct value as a forage crop but in many places it provides shelter for tender and perhaps more useful plants." Drivas and Everett (1987, 1988) and Callaway and others (1996) describe the use of big sagebrush as nurse plants for singleaf pinyon (*Pinus monophylla*) seedlings, Patten (1969) for lodgepole pine (*Pinus contorta*), and Schultz and others (1996) for curlleaf mountain mahogany (*Cercocarpus ledifolius*). Also in the field, we have noticed at various locations that the only grasses and forbs present on a site were to be found under the canopy of big sagebrush plants (also see Weaver and Albertson 1956). Figure 1 illustrates this point. This photograph was taken at the Benmore Experimental Range just south of Vernon, UT, where pastures of crested wheatgrass were established to determine how much grazing pressure the grass could tolerate. The increase in bare ground in the picture was due not to increasing big sagebrush canopy, as hypothesized by Baxter (1996), but by grazing.

Daubenmire (1975, p. 31) states: "Field observations in Washington indicate that not only is there no allelopathic influence from this species of *Artemisia*... but that it has a beneficial effect on other plants." Wight and others (1992) describe one of these "beneficial effects on other plants" as being in the area of water conservation and extending water near the soil surface by 2 weeks versus interspaces between plants (see also Chambers 2001). They noted that big sagebrush canopies reduce solar radiation and prolong the period favorable for seedling establishment for perhaps as long as 28 days (also see Pierson and Wight 1991; and Chambers 2001 for favorable soil temperatures under big sagebrush). Hazlett and Hoffman (1975) studied the pattern of plant species placement in relation to big sagebrush distribution in western North Dakota. Their study site was dominated by big sagebrush that had a canopy cover value of 29 percent. They counted the number of established plants found in three concentric zones under and beyond the individual big sagebrush plant canopies. Number of established plants (most forbs, 18 species) in the inner zone

Figure 1—A photo of a site where the only grass present is under the protective canopy of mature big sagebrush (*Artemisia tridentata*) plants (photo by Bruce L. Welch).

(zone 1), which is directly beneath the canopies, greatly exceeded the number of plants of the two outer most zones (3,145; 1,845; 325 plants for zones 1, 2, 3, respectfully). However, they felt that grass cover was greater in the outer zone. Eckert and others (1986) reported similar results for their Nevada sites.

Blaisdell (1953, p.1), speaking of big sagebrush, observed: “Even when livestock force their way into heavy sagebrush stands, they are often unable to reach more than half of the palatable grasses and forbs.” Or in other words, big sagebrush canopy forms a protective barrier (Costello 1944; Weaver and Albertson 1956). How then, can big sagebrush be both a protector of grasses and forbs and an agent of allelopathy?

Even the experts, Kelsey and Everett (1995, p. 518), have questions: “Can volatile terpenes adsorbed on soil particles the previous summer and fall, or leached during the winter, remain at toxic levels until spring germination? Does sagebrush litter, in spring, have sufficient concentrations of toxins to interfere with growth? What happens to the large quantities of sesquiterpene lactones in the foliage of sagebrush? Are they ever inhibitory?” It appears to-date that allelopathy of big sagebrush is based more on myth than science (Caldwell 1979; Daubenmire 1975; Peterson 1995).

Axiom Number 8

Big sagebrush is a highly competitive, dominating, suppressive plant species. Winward (1991, p. 5) states: “Mountain and basin big sagebrush sites in best condition have cover values between 15-20 percent. Those numerous sites that support cover values in the 30 to 40 percent category have a much restricted herbaceous production and are essentially closed to recruitment of new herbaceous seedlings. Some type of shrub removal process will be needed before understory forbs and grasses can regain their natural prominence in these communities.” He also states that Wyoming big sagebrush stands with canopy cover over 15 percent would, also, have “a much restricted herbaceous production.”.

During the 1940s and 1950s, the range management community recognized the protective barrier that the canopy cover of big sagebrush provided grasses and forbs from excessive livestock grazing (Pechanec and Stewart 1949). Big sagebrush forms such an effective protective cover for grasses and forbs that Pechanec and Stewart (1944b) estimated that 50 percent of the palatable grasses and forbs under big sagebrush is unavailable to grazing livestock. This is illustrated in figure 1. So how can big sagebrush be, at the same time, a protector of grasses and forbs and a highly competitive, dominating, suppressive plant species?

An untested hypothesis proposed by some in the range management community states: the surface roots of big sagebrush roots in the interspaces among big sagebrush plants has the capacity to capture water and nutrients to the point that it starves out associated herbaceous plant species. Data within the Tart’s (1996, p. 42) report refutes this hypothesis (see explanation given in axiom number 5). Stands of mountain big sagebrush with the highest canopy cover at 46 percent had grass and forb cover above the study averages. Conversely, stands of mountain big sagebrush with the lowest canopy cover at 17 percent (p. 26) had below average grass and forb cover. Also, this hypothesis ignores a number of ecological facts concerning the interactions of big sagebrush with its associated herbaceous plant species.

But first, this untested hypothesis brings up an interesting question: If big sagebrush roots are so competitive, why is it, in grazed out big sagebrush stands, that the only place grasses and forbs can be found is under the protective cover of big sagebrush plants (figure 1)? Daddy and others (1988) found that the greatest root concentration is under the canopy cover of big sagebrush. So why don’t the roots of big sagebrush starve out grasses and forbs under the canopy? Perhaps it is not the competitor the range management community claims it is.

There are four scientific articles that show when grazing is eliminated or reduced grass cover increases, in spite of high or increasing big sagebrush canopy cover. McLean and Tisdale (1972), studying the time it requires for land to recovery from overgrazing, found inside their West Mara (British Colombia) plot that perennial grass cover increased from 51 to 67 percent in 9 years with (probably mountain) big sagebrush canopy cover of 31 to 34 percent. Outside, big sagebrush canopy cover was 38 percent, and the cover of perennial grass increased from 35 to 51 percent. Branson and Miller (1981) found that after 17 years of improved grazing management, canopy cover of (probably Wyoming) big sagebrush increased from 23 to 30 percent, and grass cover increased from 3 to 41 percent. Three other study sites showed similar trends: below hill top-big sagebrush canopy cover increased from 15.1 to 30.7 percent, perennial grass cover increased from 2.8 to 33.3 percent; big sagebrush–big sagebrush canopy cover increased from 12.6 to 39.3 percent, perennial grass cover increased from 1 to 27.9 percent; and sagebrush strip–big sagebrush canopy cover increased from 31.9 to 36.6 percent, perennial grass cover increased from 10.1 to 36.3 percent. Pearson (1965) found big sagebrush canopy cover inside of an 11-year old exclosure to be 34 percent with 39 percent cover of perennial grasses. Outside his exclosure, canopy cover of big sagebrush was 11 percent with a perennial grass cover of 22 percent.

Anderson and Holt (1981) reported big sagebrush canopy cover increased with over 25 years of protection from grazing from 15 to 23 percent with perennial grass cover increasing from 0.28 to 5.8 percent. What we found interesting about this study was that perennial grasses showed any signs of recovery after starting at a cover value of less than three-tenths of a percent. Also, of interest is Daddy and others (1988) citation of the Anderson and Holt (1981) study. They, Daddy and others (1988, p. 415), stated: "Anderson and Holte (1981) reported that canopy cover of big sagebrush increased 54% with little change in cover of understory grasses after 28 years of complete protection from grazing in southern Idaho." Why did they express the increase of big sagebrush canopy cover as a percentage then change the terms for expressing grass cover increase as "little change"? Is this because the percentage increase in grass cover was 2,071 percent (from 0.28 percent to 5.8 percent)? Does this hint at the existence of bias against big sagebrush? Do any of these four studies support Winward's (1991) assertions concerning the relationship between canopy cover of big sagebrush and a suppressed understory? None do. In fact, these studies showed that as canopy cover of big sagebrush increased, perennial grass cover also increased. Are these the characteristics of a highly competitive, dominating, suppressive plant species. We think not.

Richards and Caldwell (1987) found that big sagebrush has the capacity to draw water from deep, moist soil layers, and at night redistribute water into the drier upper layers of the soil. Here, non-big sagebrush plants may parasitize this water (Caldwell and Richards 1989). They termed this phenomenon hydraulic lift. Caldwell and others (1991) listed the advantages for hydraulic lift as prolonging the activities of fine roots, mycorrhizae, and nutrient uptake in drying soils. Ryel and others (2002) listed another advantage, a delay in the development of xylem embolisms. They estimated that as much as 20 percent of the water used by non-big sagebrush plants can come from hydraulic lift on a given day. Are these the characteristics of a highly competitive, dominating, suppressive plant species or those of a nursing mother?

A number of studies show that big sagebrush is a soil builder (Chambers 2001; Charley and West 1975, 1977; Doescher and others 1984; Fairchild and Brotherson 1980). The nutrient content – nitrogen, phosphorus, potassium, calcium, and so forth – directly under the canopy of big sagebrush is higher than the nutrient content in the interspaces. For nitrogen, Charley and West (1975) suggested that three factors may be operating in concert to account for the accumulation: first, enhanced fixation by free-living microorganisms in or under litter; second, animal activity; and third, canopy-capture of wind-transported solids. Mack (1977) describes a fourth factor as absorbing minerals deeper in the soil and depositing them on the soil surface as litter. As a result, big sagebrush creates islands of fertility that can be utilized by other plant species. Krannitz and Caldwell (1995, p. 166) note: "Contrary to expectations, when roots of any test species contacted, or were in the vicinity of, *Artemisia* roots, their growth rate was not significantly affected." Are these the characteristics of a highly competitive, dominating, suppressive plant species.

Finally, from the allopathic section, Daubenmire (1975, p. 31) states: "Field observations in Washington indicate that not only is there no allelopathic influence from the species of *Artemisia*, but that it has a beneficial effect on other plants." Wight and others (1992) describe one of these "beneficial effects on other plants" as being in the area of water conservation (also Chambers 2001) and extending water near the soil surface by 2 weeks versus interspaces between plants. They noted that big sagebrush canopies reduce solar radiation and prolong the period favorable for seedling establishment for perhaps as long as 28 days (also see Pierson and Wight 1991 and Chambers 2001 for favorable soil temperatures under big sagebrush). Again, are these the characteristics of a highly competitive, dominating, suppressive plant species?

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ROCKY MOUNTAIN RESEARCH STATION

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals.

Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

Research Locations

Flagstaff, Arizona
Fort Collins, Colorado*
Boise, Idaho
Moscow, Idaho
Bozeman, Montana
Missoula, Montana
Lincoln, Nebraska
Reno, Nevada
Albuquerque, New Mexico
Rapid City, South Dakota
Logan, Utah
Ogden, Utah
Provo, Utah
Laramie, Wyoming

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