Journal of Environmental Management (2001) **61**, 243–252
doi:10.1006/jema.2000.0411, available online at http://www.idealibrary.com on IDEAL

Recovery of big sagebrush communities after burning in south-western Montana

C. L. Wambolt†*, K. S. Walhof† and M. R. Frisina‡

*Prescribed burning of big sagebrush (*Artemisia tridentata *Nutt.) communities is conducted with the intention of increasing either the productivity of the understory plants or the big sagebrush. It was our objective to compare the recovery of big sagebrush communities from prescribed fire at as many sites as we could locate in south-western Montana with environmentally paired unburned portions. We located and sampled 13 sites that had been burned over a span of two to 32 growing seasons earlier. Big sagebrush canopy cover, density, and production of winter forage were significantly greater* ($P \leq 0{\cdot}05$) *in the unburned portions in 34 of 38 comparisons. Canopy coverage of Idaho fescue (*Festuca idahoensis *Elmer), the dominant herbaceous species, was greater in the burned portion at only one site while it was less* ($P \leq 0{\cdot}05$) *at four sites. Total perennial grass canopy coverage was not different* ($P \leq 0{\cdot}05$) *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. The loss of the dominant shrubs in any ecosystem will affect many other organisms and severely impact species that have an obligate habit with the shrubs.*

Keywords: *Artemisia tridentata*, big sagebrush, bitterbrush, burning, *Festuca idahoensis*, Idaho fescue, livestock forage, prescribed fire, *Purshia tridentata*, wildlife habitat.

Introduction

Big sagebrush (*Artemisia tridentata* Nutt.) is arguably the most important plant species on rangelands in the western United States. It was estimated by Beetle (1960) to occupy approximately 60 million hectares in the region. Since that estimate there have been significant reductions in the species distribution. A large portion of the species decline can be traced to its low preference for forage by cattle, despite a variety of ecosystem values the species offers. The impact of big sagebrush reduction has been especially negative to many native wildlife species, including a number of obligates such as the threatened sage grouse (Welch and McArthur, 1979; Wambolt, 1998; Welch, 1999). During the last 50 years the loss of millions of hectare of big sagebrush in the western United States from burning or other treatments to provide an anticipated advantage for herbaceous understory species and thereby livestock forage has occurred. It is interesting that big sagebrush reduction by a variety of treatments has not always resulted in anticipated increases of herbaceous production (Blaisdell, 1953; Daubenmire, 1975; Peek *et al.*, 1979; Anderson and Holte, 1981; Kuntz, 1982; McNeal, 1984; Mangan and Autenrieth, 1985; Sturges and Nelson, 1986; Wambolt and Payne, 1986; Fraas *et al.*, 1992; Wambolt and Watts, 1996). Where herbaceous production has increased following sagebrush reduction, the cause of the increase is often difficult to determine. In general, changes in grazing management or other improvements accompany the sagebrush treatment.

It is somewhat of a paradox that more recently, land managers have often stated an objective to increase productivity of big sagebrush taxa through prescribed burning programs similar to those practiced in the past to eliminate the same taxa. It is interesting that they usually cite all the values of a mature sagebrush community as their

Email of corresponding author: cwambolt@montana.edu

* Corresponding author

† Department of Animal and Range Sciences, Montana State University, Bozeman, MT 59717, USA

‡ Montana Fish, Wildlife and Parks, 1330 W. Gold Street, Butte, MT 59701, USA

Received 9 March 2000; accepted 5 December 2000

0301–4797/01/030243+10 $35.00/0

Relationship of Wyoming Big Sagebrush Cover to Herbaceous Vegetation

Bok F. Sowell[1], Carl L. Wambolt[2], Jennifer K. Woodward[2], and Vanessa R. Lane[2]

ABSTRACT

We measured 328 sites in northern, central, and southern Montana and northern Wyoming during 2003 to test the relationship of herbaceous cover to Wyoming big sagebrush (Artemisia tridentata wyomingensis*) cover. Long term annual precipitation at all sites was approximately 31 cm. Sagebrush and total herbaceous cover varied from 5 to 45 percent and 3.5 to 55 percent, respectively. Simple linear regression was the best fit model for predicting herbaceous cover from sagebrush cover using the highest R_a^2 values as the model selection criteria. In northern Montana, herbaceous vegetation was predicted by sagebrush cover with the following model: $Y = 37.4 - 0.61X$ ($R_a^2 = 0.16$, $P < 0.001$, $n = 87$). In central Montana, the model was $Y = 14.0 - 0.00X$ ($R_a^2 = 0.00$, $P = 1.0$, $n = 155$). In southern Montana, the model was $Y = 35.9 - 0.39X$ ($R_a^2 = 0.14$, $P < 0.001$, $n = 86$). When all sites were combined, the best fit model was $Y = 23.7 - 0.15X$ ($R_a^2 = 0.01$, $P < 0.061$, $n = 328$). This analysis determined that only 1 percent of the variation in herbaceous vegetation cover was associated with Wyoming big sagebrush cover. Management suggestions to reduce Wyoming big sagebrush in order to increase herbaceous production for greater sage-grouse (*Centrocercus urophasianus*) or livestock do not appear to be biologically sound.*

Keywords: Artemisia tridentata wyomingensis, *line intercept, grass cover,* Centrocercus urophasianus, *forb cover, greater sage-grouse, sage-grouse habitat.*

INTRODUCTION

It has been suggested that dense sagebrush (*Artemisia*) cover lowers greater sage-grouse (*Centrocercus urophasianus*) habitat quality and biological diversity (SRM 2006). The same publication states that sagebrush control can be used to enhance sage-grouse habitat by reducing sagebrush cover, which limits understory grass and forb production. Wright and Bailey (1982) recommended that removal of tall, thick sagebrush would release grasses and forbs from competition and result in increased yields for livestock grazing. In contrast, Miller and Eddleman (2001) concluded that there was little evidence that fire could be used to enhance sage- grouse habitat where there was a balance of native shrubs and perennial grasses and forbs. This statement implies there are conditions where shrubs and herbaceous vegetation were "unbalanced" and therefore might be manipulated. Welch and Criddle (2003) examined the relationship between big sage cover and percent bare ground from several data sets and concluded that the calculated R^2 values averaging 0.05 for mountain big sagebrush (*A. tridentata vaseyana*) and Wyoming big sagebrush (*A. t. wyomingensis*) cover and perennial herbaceous cover were not significant. We modeled the data from 328 sites to determine the best-fit relationship between Wyoming big sagebrush cover and herbaceous cover.

MATERIALS AND METHODS

Study Sites

Our three study areas were separated by a total of approximately 355 km from the northern most to the southern most locations sampled. Northern Montana samples were taken approximately 80 km south of Malta in southern Phillips County. Approximately 60 percent of this area is publicly owned by the U.S. Bureau of Land Management (BLM), the U.S. Fish and Wildlife Service (FWS), and the state of Montana (Moynahan 2004). Annual precipitation averaged 31 cm with peak precipitation between April and July (WRCC 2004). Soil taxonomic units that characterized this area included Absher, Elloam, and Thoeny (USDA 1981). Elevation varied from 600 – 1,060 m. Wyoming big sagebrush was the dominant shrub at all sample locations. Plains silver sagebrush (*Artemisia cana*), greasewood (*Sarcobatus vermiculatus*), and rubber rabbitbrush (*Chrysothamnus nauseosus*) were relatively common at many sites. Western wheatgrass (*Pascopyron smithii*), and blue grama (*Bouteloua gracilis*) were the common dominant grasses, while Sandberg bluegrass (*Poa secunda*), needle-and-thread (*Hesperostipa comata*), and threadleaf sedge (*Carex filifolia*) were measured frequently. American vetch (*Vicia americana*), scarlet globemallow (*Sphaeralcea coccinea*), yellow sweetclover (*Melilotus officinalis*), and dandelion (*Taraxacum officinale*) were the most common forbs. Fringed sagewort (*Artemisia frigida*), clubmoss (*Selaginella densa*), and prickly pear (*Opuntia polycantha*) were also common.

Measurements in the central Montana counties of Golden Valley and Musselshell were taken in an area centered about 30 km northwest of Roundup, Montana. Precipitation in this area averages 31 cm annually (NOAA 2004). Soil taxonomic units common to this area include Abor, Neldore, and Vanda (USDA 2003). Elevation is 826-1495 m. Wyoming big sagebrush was the dominant shrub although greasewood and plains silver sagebrush were also present. Western wheatgrass, Sandberg bluegrass, and blue grama were the dominant grasses, while green needlegrass (*Nassella viridula*), needle-and-thread, and threadleaf sedge

In: Wambolt, C.L. et al. comps. 2011. Proceedings – Shrublands: wildlands and wildlife habitats; 2008 June 17-19; Bozeman, MT. NREI, volume XVI. S.J. and Jessie E. Quinney Natural Resources Research Library, Logan, Utah, USA.

[1]Bok F. Sowell, Department of Animal and Range Sciences, Montana State University, Bozeman, Email: bok@montana.edu

[2]Carl L. Wambolt, Professors, Jennifer K. Woodward and Vanessa R. Lane, graduate research assistants, Department of Animal and Range Sciences, Montana State University, Bozeman, MT

were also common. Scarlet globemallow, wild onion (*Allium*), Hood's phlox (*Phlox hoodii*), and American vetch were the most abundant forbs.

Sampled sites in Bighorn County in southern Montana and adjacent Campbell County, Wyoming were mostly on private ranchland with some BLM and state land. Annual precipitation averaged 31 cm with peak precipitation occurring from April to June (NOAA 2003). Soil taxonomic units which characterize this area include Midway, Pierre, and Thedalun (USDA NRCS 2004). The elevation range is 762–1,314 m. Wyoming big sagebrush was the dominant shrub, although plains silver sagebrush, skunkbrush sumac (*Rhus aromatica*), common juniper (*Juniperus communis*) and rubber rabbitbrush were also present. Sandberg bluegrass, western wheatgrass, and Japanese brome (*Bromus japonicus*) were the dominant grasses, although green needlegrass, prairie junegrass (*Koeleria macrantha*), and bluebunch wheatgrass (*Psuedoroegneria spicata*) were also common. Desert alyssum (*Alyssum desertorum*), Hood's phlox, scarlet globemallow, American vetch, dandelion, and western yarrow (*Achillea millefolium*) were the most common forbs.

Sampling and Analysis

All sampling was conducted during late spring and early summer of 2003. Sagebrush cover was measured with the line-intercept method (Canfield 1941) using the procedures recommended as a standard and discussed by Connelly and others (2003) and Wambolt and others (2006). Line-intercepts were measured on two perpendicular 30 m N-S and E-W oriented transects. We measured sagebrush intercept in 3 cm units. We recorded openings in live foliage > 3 cm as nonsagebrush intercepts. Thus, we excluded both open spaces and dead portions of the plant. We obtained all measurements by vertically projecting a plumb bob from the transect line to plants to determine what intercepts from ground level to crown were directly beneath the line.

Herbaceous understory cover was measured using twenty 20 x 50 cm quadrats (Daubenmire 1959). The same N-S, E-W transects used to measure sagebrush cover were used to locate the quadrats for herbaceous sampling at 3 m intervals.

A number of linear and non-linear models were tested to determine the "best fit" relationship between sagebrush cover and herbaceous cover. Linear, quadratic, cubic, inverse, first order, sigmoidal, exponential decay, exponential growth and polynomial models were tested using Sigma Plot (2004). Maximum R_a^2 values were used to determine which model best fit our data.

RESULTS AND DISCUSSION

Simple linear regression models for all data sets resulted in the maximum R_a^2 values. In northern Montana, as sagebrush cover increased, herbaceous cover decreased ($R_a^2 = 0.16$, $P < 0.001$, $n = 87$), but only 16 percent of the variation in herbaceous cover was accounted for with change in sagebrush cover (figure.1). Although the regression is significant, this relationship indicates that if sagebrush cover at 20 percent were reduced to 5 percent, herbaceous cover would only be increased from 25 to 35 percent.

In central Montana, we found no relationship ($R_a^2 = 0.00$, $P = 1.0$, $n = 155$) between Wyoming big sagebrush cover and herbaceous cover (figure 1). We conclude that in this region, herbaceous cover is not influenced by Wyoming big sagebrush cover.

In southern Montana, herbaceous cover declined as sagebrush cover increased, but, 86 percent of the variation in herbaceous cover was not accounted for by sagebrush cover ($R_a^2 = 0.14$, $P < 0.001$, $n = 86$) (figure 1). Thus, if a site with 20 percent sagebrush cover was treated to reduce this cover to 5 percent, herbaceous cover would be expected to increase only 6 percent.

When all 328 sites were combined, a simple linear equation best explained the relationship between Wyoming big sagebrush cover and herbaceous cover (figure 1). There is a slight inverse relationship between the two variables (figure 1), but the $R_a^2 = 0.01$, ($P < 0.06$) indicates that across Montana and adjacent Wyoming, the variability in herbaceous cover cannot be explained by the amount of sagebrush cover. The model for all sites ($n = 328$) determined if an area had 20 percent sagebrush cover, the average herbaceous cover would be 20 percent. Thus, if sagebrush cover were reduced to 5 percent, our model predicts the herbaceous cover would only increase to 23 percent.

Some authors (Baxter 1996; SRM 2006) indicated that when big sagebrush cover increases over 12 to 15 percent, the understory production of other plants decreases as cover increases. However, Welch and Criddle (2003) found no significant relationship between sagebrush cover and bare ground ($R^2 = 0.0003$), which supports our conclusions with data from other regions. An additional concern arises from the fact that Baxter (1996) and SRM (2006) do not clarify the details of their sagebrush cover measurements and, therefore, it is possible, if not probable, that their 12 to 15 percent sagebrush cover would be much less using our methodology (Wambolt and others 2006).

Moynahan (2004) examined grass and forb cover from 2001 to 2003 in our northern Montana study area as part of a sage-grouse brood survival study. Perennial grass cover

did not change appreciably in three years, but forb cover nearly doubled, largely due to the biennial yellow sweetclover responding to favorable growing conditions. Brood survival rates increased 3.5 fold from 2001 (drought year) to 2003 likely due to the increased abundance of herbaceous cover. Moynahan's (2004) findings in combination with our results indicate that precipitation has a much greater influence on herbaceous cover than does the amount of sagebrush cover. Welch and Criddle (2003) also concluded that precipitation, plant species, and soil properties influenced ground and perennial grass cover more than sagebrush cover.

MANAGEMENT IMPLICATIONS

It has been suggested that sagebrush control can be used to enhance herbaceous vegetation (SRM 2006). We determined that across our 328 study sites that a weak linear relationship exists between Wyoming big sagebrush cover and herbaceous cover ($Y = 23.7 - 0.15X$). However, 99 percent of the variation in herbaceous cover (3.5 to 55 percent) is not accounted for by changes in sagebrush cover (5 to 45 percent) alone ($R_a^2 = 0.01$, $P < 0.061$). Our data indicate a large majority of sites would fail to respond to sagebrush treatments as predicted with conventional wisdom (SRM 2006). Prescribed burning, prescribed grazing, herbicides and mechanical treatments have all been advocated to improve sage-grouse habitat where it is hypothesized that dense sagebrush cover limits herbaceous biomass (SRM 2006). Removing Wyoming big sagebrush cover to increase herbaceous vegetation for any purpose, including enhancing sage-grouse brood survival, does not appear to be biologically sound.

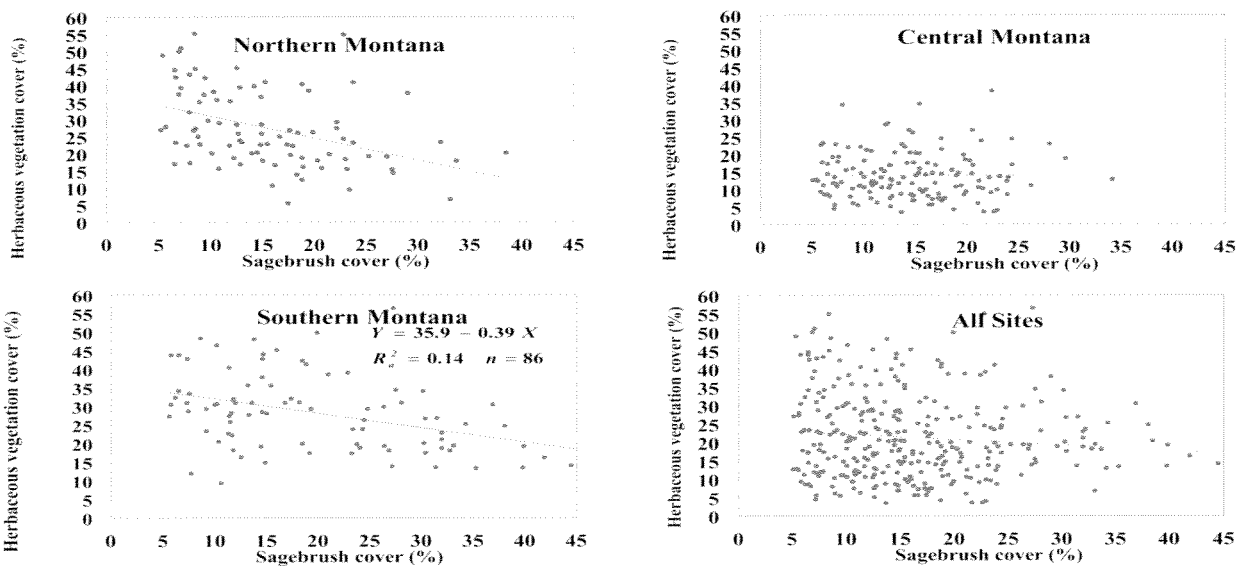

Figure 1—Relationship of Wyoming big sagebrush cover to herbaceous cover in northern, central, and southern Montana and over all sites. Funding and land for this research was provided by the Bureau of Land Management field offices in Montana, Montana Fish, Wildlife and Parks, and the Montana Agricultural Experiment Station.

REFERENCES

Baxter, G. 1996. Improving rangeland health by thinning dense sagebrush stands with tebuthiuron (spike 20P). *In*: Evans, K.E., comp. Sharing common ground on western rangelands: proceedings of a livestock/big game symposium; 1996 Feb 26-28; Sparks, NV. INT-GTR-343. Ogden, UT: Intermountain Research Station: 60-62.

Canfield, R.H. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry 39: 388-394

Connelly, J.W., Reese, K.P., Schroeder, M.A. 2003. Monitoring of greater sage-grouse habitats and populations. University of Idaho, College of Natural Resources Experiment Station Bulletin 80, Moscow.

Daubenmire, R.F. 1959. A coverage method of vegetation analysis. Northwest Science 33: 43-64.

Miller, R.F., Eddleman, L.L. 2001. Spatial and Temporal Changes of Sage Grouse Habitat in the Sagebrush Biome. Oregon State University Agricultural Experiment Station Technical Bulletin 151. Corvallis.

Moynahan, B.J. 2004. Landscape-scale factors affecting population dynamics of greater sage-grouse in north-central Montana, 2001-2004. [Thesis]. University of Montana, Missoula.

NOAA. 2003. [Online] *Annual climatological summary, Decker, Montana.* Available: http://cdo.ncdc.noaa.gov/ancsum/ACS.

NOAA. 2004. [Online] *Annual climatological summary, Roundup, Montana.* Available: http://cdo.ncdc.noaa.gov/ancsum/ACS.

Sigma Plot 6.0. 2004. Users Guide. SPSS Inc. 233 South Wacker Drive, 11th Floor, Chicago, IL 60606-6307.

SRM. 2006 Ecology and Management of Sage-Grouse and Sage- Grouse Habitat, An issue paper created by the Society for Range Management. 10030 W 27th Ave. Wheat Ridge, CO 80215.

USDA. 2003. Soil survey of Musselshell County, Montana. NRCS office, Bozeman, Montana.

USDA. 1981. Technical guide. Section II-E-8. USDA-SCS-MT.

USDA NRCS. 2004. [Online] *Soil data mart.* Available: http://soildatamart.nrcs.usda.gov.

Wambolt, C.L., Frisina, M.R., Knapp, S.J., Frisina, R.M. 2006. Effect of method, site, and taxon on line-intercept estimates of sagebrush cover. Wildlife Society Bulletin. 34:440-445.

Welch, B.L., Criddle, C. 2003. Countering Misinformation Concerning Big Sagebrush. Research Paper RMRS-RP-40. Ogden, UT: USDA, Forest Service, Rocky Mountain Research Station. 28p.

WRCC. 2004. [Online] *Malta 35S, Montana climate summary.* Available: http://www.wrcc.dri.edu/summary/climsmmt.html.

Wright, H.A., Bailey, A.W. 1982. Fire Ecology, United States and Southern Canada. John Wiley & Sons, New York.

Natural Resources and Environmental Issues

Volume 16 *Shrublands: Wildlands and Wildlife Habitats*

Article 14

1-1-2011

Relationship of Wyoming Big Sagebrush Cover to Herbaceous Vegetation

Bok F. Sowell

Carl L. Wambolt

Jennifer K. Woodward

Vanessa R. Lane

PACWPL Policy Paper SG-02-02

Conservation of Greater Sage-Grouse on Public Lands in the Western U.S.: Implications of Recovery and Management Policies

Policy Analysis Center for Western Public Lands
16952 S. Tenth Avenue
Caldwell, ID 83607-8249
Phone: (734) 340-4203 / (208) 459-6365
Fax: (734) 340-4376 / (208) 454-7612

director@pacwpl.nmsu.edu

ment in these areas results in habitat characteristics that support sage-grouse populations. However, low density or declining sage-grouse populations also occur in some areas characterized by depleted herbaceous understories that may be the result of past or present grazing practices. Changes in grazing management may be necessary to increase these sage-grouse populations, but experimental data are lacking to guide these management decisions.

The empirical data we have on sage-grouse habitat includes some uncertainties. Nonetheless, we have good data on the vegetative characteristics necessary for sage-grouse success, regardless of land use. We can manage grazed areas for those characteristics if we choose to do so.

In the final analysis, grazing considerations will always be important to maintain habitat quality, but, do not appear as important in the next three to five years for the recovery of sage-grouse as are fire, habitat loss, invasive species and the other alternatives that we discuss in other sections. In the long run, ranchers and the communities in which they live need to make some difficult and complex decisions about how to achieve the mix of vegetative characteristics that best support sage-grouse population growth.

4.2. Fire

In recent years, the size and frequency of wildfires have increased significantly in many areas that provided important breeding and winter habitats for sage-grouse (Crowley and Connelly 1996, Knick and Rotenberry 1997). In 1999 alone, wildfires burned 1.7 million acres in Idaho's Great Basin (USDI Bureau of Land Management, 1999). At least in some areas, the frequency of prescribed burning has also increased.

Although prescribed burning is routinely used by some agencies to manage sagebrush habitats (Byrne 2002), numerous studies have recently documented the negative effects of fire on sage-grouse populations and habitat (Byrne 2002; Connelly et al. 2000b, c; Fischer et al. 1996; Nelle et al. 2000; Peterson 1995). To our knowledge, there is no empirical evidence supporting the notion that fire has positive effects on sage-grouse over the short or long term. Fire removes large sagebrush plants that provide thermal and security cover and food, and reduces important insect populations vital to sage-grouse diets. Fire tends to burn the most productive and best grouse habitats within an area — where grasses and forb cover are greatest — leaving unburned, less productive sites of inferior habitat value (Connelly et al. 2000c). Benson et al. (1991) reported that sage-grouse use only the remaining sagebrush stands in burned habitat and Byrne (2002) documented avoidance of burned areas less than 20 years old by radio-marked female sage-grouse. Fischer et al. (1996), working in Wyoming big sagebrush, found that a prescribed fire did not enhance sage-grouse brood-rearing habitat, and actually reduced the abundance of ants *(Hymenoptera)* that are important food items for sage-grouse. Nelle et al. (2000) reported similar observations for a mountain big sagebrush (*Artemisia tridentata vaseyana*) site supporting sage-grouse nesting and brood-rearing habitats. They argued that burned areas did not become adequate nesting or brood-rearing habitat for more than 20 years.

Fire and Forb Production: Forbs are a vital component of sage-grouse diets. During late spring and early summer, phosphorus and protein content is greater in forbs than in sagebrush (Welch 1989). No scientific data identifies the pounds per acre of forbs that sage-grouse require, and no scientific study concludes that forbs limit sage-grouse production. Pyle and Crawford (1996) argue that reducing sagebrush canopy cover increases forb production and thereby improves sage-grouse habitats. However, Pyle and Crawford (1996) did not provide any data demonstrating that sage-grouse increased their use of burned areas as a result of increased forb production.

The relationship between forb production and sagebrush canopy cover has also been evaluated. Blaisdell (1953) found forb production on sites with 35 to 40% sagebrush canopy cover ranged from 104 to 127 pounds per acre. Goodrich and Huber (2001) reported forb production to be 179 pounds per acre on sites with a shrub canopy cover greater than 20%. Thus, some available evidence suggests that adequate production of forbs can occur in areas with relatively high canopy coverage of sagebrush.

Following fire, increased forb production may be influenced by factors other than sagebrush canopy cover. Passey et al. (1982) clearly show that soil type and precipitation plays major roles in forb production. Their data were collected on a site that had never been grazed by domestic livestock. Forb production varied from 138 to 296 pounds per acre (10-year mean) across six soil groups. Across soil types, forb production varied between 99 and 245 pounds per acre over the 10 years. Differences in annual precipitation may account for this, but no direct relationship was documented between sagebrush production and forb production. Available evidence does not support the use of fire to specifically increase forb production.

Fire Frequency: Fire intervals are important to sage-grouse management policies because their interpretation has direct consequences for how fire is used and/or managed by agencies and landown-

ers. Sagebrush may require 40 to >100 years after fire to provide habitat capable of supporting sage-grouse (Houston 1973, Whisenant 1990, Wright and Bailey 1982). Natural fire frequency in the sagebrush ecosystem has been estimated to range from 10 to 110 years depending on species, subspecies and habitat (Britton 1979, Houston 1973, Whisenant 1990, Winward 1991, Wright and Bailey 1982, Young and Evans 1978). It is logical that considerable variation in fire frequency exists due to the continuum of environments found in sagebrush communities. The relationship of fire frequency to grazing history and invasive species is considered in other sections of this paper.

Much of the research on fire in big sagebrush ecosystems has focused on members of the big sagebrush complex, mountain and Wyoming big sagebrush. Winward (1991) suggests a fire interval of 10 to 40 years. 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 (Gruell 1983). Wambolt et al. (2001) collected data on 13 mountain and Wyoming big sagebrush burn sites. Big sagebrush at the 13 sites, burned as much as 32 years earlier, had not recovered to the levels growing in unburned portions of each study site. Also, the long-term decrease in sagebrush from burning did not result in the generally anticipated increase of herbaceous species. Hanson (1929) noted that grasses were dominant over big sagebrush 5 to 10 years after a fire. Pechanec and Stewart (1944) noted that little sagebrush had returned 11 years after fire. 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 recovery of big sagebrush had not occurred after 30 years. Bunting et al. (1987) set mountain big sagebrush recovery at 15 to 20 years, and further argued that Wyoming big sagebrush takes even longer to recover than other taxa. Eichhorn and Watts (1984) stated that Wyoming big sagebrush was removed from the site by burning and had not reinvaded after 14 years. Wambolt and Payne (1986) reported that, 18 years after a fire, Wyoming big sagebrush canopy cover was only 16% of the control area. Fraas et al. (1992) found little recovery of mountain big sagebrush on an 8-year-old burn, where the burned portion of the site had only 1% canopy cover of sagebrush compared to 12% where unburned. Wambolt et al. (1999) reported that, for three subspecies of big sagebrush 19 years after a fire on the northern Yellowstone winter range, recoveries of burned compared to unburned Wyoming, mountain and basin (*Artemisia tridentata tridentata*) big sagebrushes were 0.1, 1.4 and 11% for production of winter forage, respectively. They also studied seven other burn sites of mountain big sagebrush on the northern Yellowstone winter range and found no significant recovery 10 and 14 years after prescribed burning. On these seven sites, sagebrush canopy on unburned portions averaged 12 times that of burned portions, and sagebrush densities were 15 times greater on unburned portions. Humphrey (1984) found a pronounced delay of some 18 to 32 years in the establishment of big sagebrush after fire in big sagebrush habitat. He attributed this delay to big sagebrush dependency on the dispersal of its propagules, achenes or seeds. Big sagebrush seed dispersal could take from 105 to 211 years to spread 1 mile (Noste and Bushey 1987).

A 31-year study of a mature big sagebrush stand in the Gravelly Mountains in Montana demonstrated that a big sagebrush ecosystem could 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 53 to 96 years. Arguing that suppression policies have affected the fire interval, he adjusted the interval by subtracting 80 years from the ages of living trees and came up with an adjusted fire interval of 32 to 70 years in the big sagebrush steppes of northern Yellowstone National Park, an area dominated by mountain big sagebrush. Wright and Bailey (1982) suggested fire intervals of 50 years because gray horsebrush (*Tetradymia canescens*) responds vigorously to fire and can require more than 30 years to decline following fire. They further argued that a fire frequency of 20 to 25 years could result in sagebrush being dominated by gray horsebrush and rabbitbrush (*Chrysothamnus* spp.) in eastern Idaho. For Wyoming big sagebrush ecosystems, they suggested a fire interval as long as 100 years.

Under some conditions, mountain big sagebrush can have a burn cycle of 20 to 30 years (Miller et al. 1999b). This is based on higher vegetative productivity of the mountain big sagebrush sites producing higher fine fuel accumulation, and higher frequency of lightning strikes, which some believe result in a shorter fire cycle compared to basin and Wyoming sites with less fine fuels and fewer lightning strikes. However, the greater accumulation of biomass and higher number of lightning strikes on mountain big sagebrush sites may be offset somewhat by lower temperature and higher humidity that occur on these sites. Monsen and McArthur (1985) and Goodrich et al. (1999) reported average annual precipitation of 17 inches