Journal of Wildlife Management 74(4):755–764; 2010; DOI: 10.2193/2009-143

Management and Conservation Article

Fire Effects on Cover and Dietary Resources of Sage-Grouse Habitat

EDWARD C. RHODES, *Texas A&M University, Center for Natural Resource Information Technology, Department of Ecosystem Science and Management, Texas AgriLife Research, 2138 TAMU, College Station, TX 77843-2138, USA*

JONATHAN D. BATES,[1] *United States Department of Agriculture-Agricultural Research Service, Eastern Oregon Agricultural Research Center, 67826-A Highway 205, Burns, OR 97720, USA*

ROBERT N. SHARP, *United States Department of Interior-Bureau of Land Management, Burns District Office, Highway 20, Burns, OR 97720, USA*

KIRK W. DAVIES, *United States Department of Agriculture-Agricultural Research Service, Eastern Oregon Agricultural Research Center, 67826-A Highway 205, Burns, OR 97720, USA*

ABSTRACT We evaluated 6 years of vegetation response following prescribed fire in Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) steppe on vegetation cover, productivity, and nutritional quality of forbs preferred by greater sage-grouse (*Centrocercus urophasianus*), and abundance of common arthropod orders. Habitat cover (shrubs and tall herbaceous cover [>18 cm ht]) was about 50% lower after burning compared to unburned controls because of the loss of sagebrush. Perennial grasses and an invasive annual forb, pale alyssum (*Alyssum alyssoides*), increased in cover or yield after fire. There were no increases in yield or nutritional quality of forb species important in diets of sage-grouse. Abundance of ants (Hymenoptera), a significant component in the diet of young sage-grouse, decreased after fire. These results suggest that prescribed fire will not improve habitat characteristics for sage-grouse in Wyoming big sagebrush steppe where the community consists of shrubs, native grasses, and native forbs.

KEY WORDS arthropods, bunchgrass, forbs, Oregon, prescribed burning, sage-grouse, Wyoming big sagebrush.

Big sagebrush (*Artemisia tridentata*) steppe plant communities are one of the major vegetation types of the western United States, particularly in the Intermountain and Columbia Basin regions (Anderson et al. 1998, West and Young 2000). Estimates of historic coverage of big sagebrush exceed 600,000 km^2 (West 1983). Since settlement of the western states, beginning 150 years ago, big sagebrush steppe has been fragmented and reduced in area (West and Young 2000, Knick et al. 2003, Wisdom et al. 2005). Causes of big sagebrush habitat loss are well documented and include altered fire regimes, invasive weed dominance, agricultural land conversion, nonnative grass seeding, sagebrush removal programs, piñon–juniper (*Pinus–Juniperus*) woodland expansion, poorly managed livestock grazing, and urban and industrial development (West 1983, Whisenant 1990, Knick et al. 2003, Rowland and Wisdom 2005).

Historic mean fire return intervals (MFRI) in big sagebrush steppe are influenced by several factors including site productivity and geographic location; however, MFRI are generally described by main big sagebrush cover types. In drier, less productive Wyoming big sagebrush (*A. tridentata* spp. *wyomingensis*) communities, MFRI have been estimated to span 50–240 years (Wright et al. 1979, Whisenant 1990, Baker 2006). Mean fire return intervals in more productive mountain big sagebrush (*A. tridentata* spp. *vaseyana*) steppe have been estimated to have been between 10 years and 100 years (Miller and Rose 1995, Miller et al. 2005, Baker 2006, Lesica et al. 2007, Miller and Heyerdahl 2008). Fires in these communities typically occur in midsummer to early fall following herbaceous dormancy (Wright 1974).

Fire in big sagebrush communities shifts vegetation from shrub-grass codominance to herbaceous dominance (Wright et al. 1979, Blaisdell et al. 1982, Wright and Bailey 1982, Bunting et al. 1987). Subsequent recovery of big sagebrush after fire may occur over short- to long-term time periods (Wambolt et al. 2001, Lesica et al. 2007, Beck et al. 2009, Ziegenhagen and Miller 2009). Loss or reductions in cover, structure, and forage provided by big sagebrush plant communities after fires may result in reduced populations and diversity of sagebrush obligate and facultative wildlife species (Welch 2002, Crawford et al. 2004). Active leks (breeding grounds) and abundance of greater sage-grouse (*Centrocercus urophasianus*) have decreased following prescribed fire in Wyoming big sagebrush communities of southeast Idaho (Connelly and Braun 1997, Connelly et al. 2000*a*). However, moderate fires resulting in a mosaic of burned and unburned patches in big sagebrush steppe may increase abundance and diversity of nongame avian species (Petersen and Best 1987).

Selective use of fire has been recommended as a management alternative for restoring sagebrush steppe in the context of limiting or reversing pinyon–juniper encroachment (Miller and Eddleman 2001, Miller et al. 2005). Pinyon–juniper expansion occurs primarily in higher elevation sagebrush steppe dominated by mountain big sagebrush. At lower elevations in drier and more xeric big sagebrush communities dominated by Wyoming big sagebrush and basin big sagebrush (*A. tridentata* spp. *tridentata*) large scale application of fire is not recommended (Connelly et al. 2000*b*, Helmstrom et al. 2002, Crawford et al. 2004). Large fires in Wyoming big sagebrush are detrimental to sage-grouse populations and other wildlife species because of the loss of structural cover for successful nesting and concealment as well as reductions in available forage

[1] *E-mail: jon.bates@oregonstate.edu*

provided by sagebrush (Crawford et al. 2004, Wisdom et al. 2005, Davies et al. 2007). Following fire, cheatgrass (*Bromus tectorum*) is a major invasive weed threat that may replace Wyoming big sagebrush communities, with the greatest susceptibility to replacement when the perennial understory is reduced or lacking (Whisenant 1990, Young and Allen 1997, Rowland and Wisdom 2005, Davies et al. 2008).

Use of small (<40.5-ha) patch fires or other manipulations to reduce big sagebrush cover has been suggested as a management option to improve sage-grouse prenesting and brood rearing habitat and provide a diverse habitat mosaic (Connelly et al. 2000*b*, Hagen 2005, Dahlgren et al. 2006). Thinning dense stands of sagebrush or creating small open patches of herbaceous vegetation by removing shrubs have been suggested as methods to increase herbaceous cover and forb production (Wirth and Pyke 2003, Dahlgren et al. 2006). Forbs are a critical component of sage-grouse diets during prelaying and brood-rearing periods, constituting 50–80% of the diet (Barnett and Crawford 1994, Drut et al. 1994).

Studies examining effects of big sagebrush removal on forb productivity have not produced consistent results. In Wyoming big sagebrush communities, burning has not been effective in increasing total forb diversity or abundance (Fischer et al. 1996, Nelle et al. 2000, Wrobleski and Kauffman 2003, Bates et al. 2009). However, productivity of individual forb species increased as measured by reproduction and crown volume (Wrobleski and Kauffman 2003). Insects are an important dietary component of young sage-grouse and may comprise 75–100% of the diet the first several weeks after hatching (Patterson 1952, Johnson and Boyce 1990). Young sage-grouse survival was positively correlated with high Lepidoptera availability and greater frequency of slender phlox (*Microsteris gracilis*; Gregg 2006). Without insects in the diet, mortality rates of 90–100% in juvenile sage-grouse have been reported (Johnson and Boyce 1990). Fire in a Wyoming big sagebrush community in Idaho was documented to have reduced abundance of ant (Hymenoptera) species (Fischer et al. 1996). Fire may reduce or have no effect on other important insect orders such as beetle (Coleoptera) and cricket and grasshopper (Orthoptera) species (Rickard 1970, Fischer et al. 1996).

We evaluated the impacts of prescribed fire on 1) productivity and nutritional quality of forb species preferred by sage-grouse, 2) abundance of arthropods, and 3) vegetation cover requirements developed for sage-grouse habitat guidelines (Connelly et al. 2000*b*). With the reduction in big sagebrush cover we expected that tall herbaceous cover and productivity and nutritional quality of sage-grouse dietary forbs would increase after fire. We expected perennial forb abundance to increase within the first several years after fire when new plants became established. We also predicted that fire would result in reduced arthropod numbers, particularly abundance of ants.

STUDY AREA

We conducted our study on the Northern Great Basin Experimental Range, 56 km west of Burns, Oregon, USA. Elevation is 1,400 m and topography was generally flat (<2° slope). Soils were a complex of 4 soil series sharing several attributes; all were Durixerolls, soil surface texture was sandy loam to loamy sand, and all were well drained with a duripan beginning at a depth of 40–75 cm (Lentz and Simonson 1986, Davies et al. 2007). Most precipitation arrived in winter and early spring, whereas summers were warm and dry. Annual precipitation averaged about 280 mm since measurements began in the 1930s. Drought occurred in 2000–2002 and in 2007 and precipitation was below average in 2003, 2004, and 2008 (Fig. 1). Precipitation was above average in 2005 and 2006.

The study area was dominated by Wyoming big sagebrush with basin big sagebrush and green rabbitbrush (*Chrysothamnus viscidiflorus*) as subdominant shrubs. Idaho fescue (*Festuca idahoensis*) and Thurber's needlegrass (*Achnatherum thurberianum*) were the main perennial bunchgrasses. Sandberg's bluegrass (*Poa secunda*), bluebunch wheatgrass (*Pseudoroegneria spicata*), prairie Junegrass (*Koeleria macrantha*), and bottlebrush squirreltail (*Elymus elymoides*) were present as subdominant perennial grasses. Sandberg's bluegrass was the most common grass species; however, because of its small stature it made up only a small portion of total standing crop (Davies et al. 2007, Bates et al. 2009). Perennial forbs mainly consisted of taper-tip hawksbeard (*Crepis acuminata*), milkvetch (*Astragalus* spp.), common yarrow (*Achillea millefolium*), and long-leafed phlox (*Phlox longifolia*). Annual forbs were mainly represented by little blue-eyed Mary (*Collinsia parviflora*), slender phlox, and nonnative pale alyssum (*Alyssum alyssoides*). General references used for plant identification were Hitchcock and Cronquist (1976) and the Natural Resource Conservation Service (2009), and for birds The American Ornithologists' Union Check List (American Ornithologists' Union 1998).

The site was representative of an intact Wyoming big sagebrush association with a mix of big sagebrush, native grasses, and native forbs. Cattle-grazing at the site was moderate under a rest rotation management system prior to livestock removal in 1999. Wyoming big sagebrush cover averaged 10% (range 6–17%) and grass-forb cover exceeded 15% (Davies et al. 2007). Big sagebrush and total herbaceous cover values were about average for Wyoming big sagebrush communities in eastern Oregon (Davies et al. 2006). Cheatgrass, now found in many high seral Wyoming big sagebrush communities of the northern Great Basin, was present in trace amounts (Davies et al. 2007). The site was located in year-round sage-grouse habitat and was within 5 km of several active leks. Vegetation cover values met sage-grouse brood-rearing requirements for arid big sagebrush sites as suggested by Connelly et al. (2000*b*). However, only portions of the area met sage-grouse nesting habitat requirements for arid big sagebrush sites.

METHODS

We used a randomized complete block design to compare vegetation response variables and arthropod abundance between burned (burn) and not burned (control) Wyoming big sagebrush steppe. We conducted blocking to remove

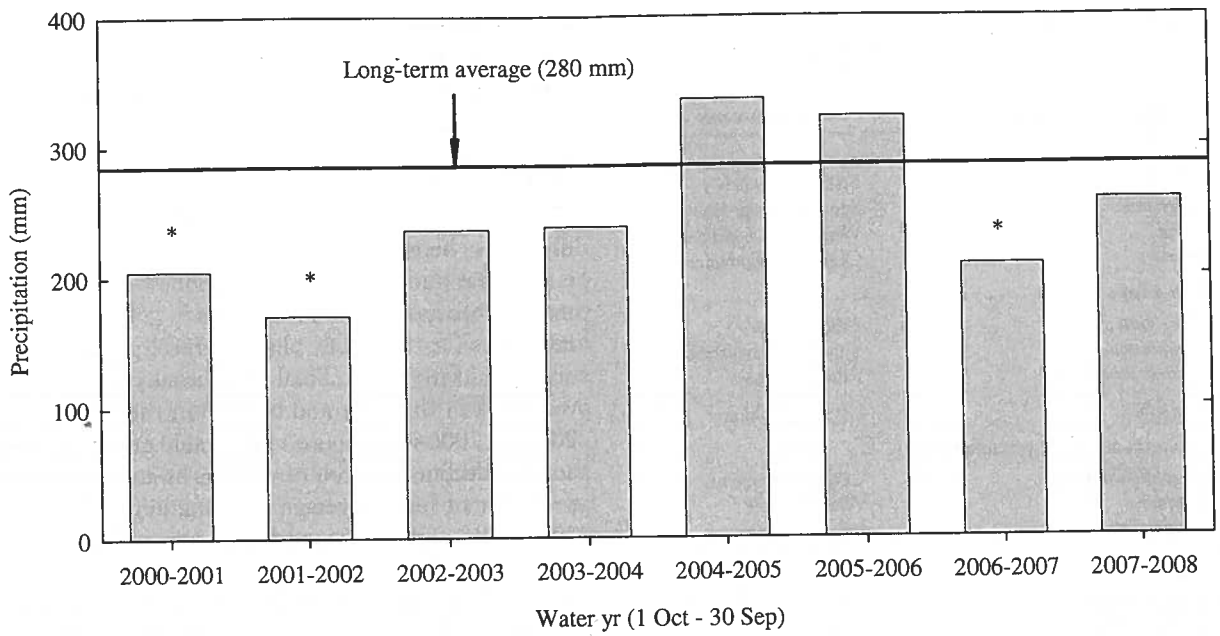

Figure 1. Annual precipitation for plant growth (1 Oct–30 Sep) for 2000–2008 at the Northern Great Basin Experimental Range, Oregon, USA. Asterisks indicate drought years.

differences associated with soils and dominant herbaceous vegetation and to increase precision of the results. We established 5 4-ha blocks in 2001. Within each block, we established 2-ha plots with one plot randomly assigned to be burned. We conducted prescribed burning in late September and early October 2002, which is typical for the northern Great Basin (Wright 1974, Bunting et al. 1987). The burn application was a strip head fire, ignited using a gel-fuel terra torch (Firecon, Inc., Ontario, OR). Wind speeds varied between 5 km/hr and 20 km/hr, air temperatures were 20–25° C, and relative humidity varied from 10% to 35% during prescribed burns. Moisture content of fine fuels (herbaceous vegetation) was 8–12% and fine fuel loads were 350–420 kg/ha. Burns were complete across treatment plots, killing about 92% of Wyoming big sagebrush present.

We evaluated vegetation response to treatment by quantifying herbaceous plant cover and yield. We randomly placed 6 50-m transects within each treatment plot in 2001. We permanently marked transects using rebar for measurement in subsequent years. We measured plant species cover in June from 2001 to 2006 and in 2008. Thus, we completed 2 years of pretreatment vegetation measurements (2001, 2002) prior to fire application. We measured shrub canopy cover by species using the line intercept technique and excluded canopy gaps >15 cm from measurements (Canfield 1941, Boyd et al. 2007). We visually estimated herbaceous canopy cover by species inside 40 × 50 cm frames (0.2 m^2) located at 3-m intervals on each transect line (starting at 3 m; 15 subsamples/transect).

We measured herbaceous yield by functional group (perennial bunchgrasses, perennial forbs, annual forbs, and cheatgrass) in mid-June 2002–2008. From 2004 to 2008, we measured forb yield by species in mid-April, mid-May, and mid-June. We collected data at these intervals to measure availability of dietary forbs used by sage-grouse from late breeding through brood rearing periods (Table 1). We determined dietary forbs from a review of the literature (Wallestad et al. 1975, Barnett and Crawford 1994, Drut et al. 1994, Nelle et al. 2000, Gregg 2006). We clipped perennial grasses to a 2-cm stubble height. We clipped cheatgrass and forbs (perennial and annual) to ground level. We collected grasses and perennial forbs from 15 1-m^2 randomly located frames per 2-ha plot each sampling period. We collected annual forbs and cheatgrass from 0.20-m^2 nested plots inside 1-m^2 frames. We oven-dried clipped samples at 106° C for 48 hours. We separated and weighed perennial and annual forbs by species or tribes. After weighing forb samples, we ground them by functional group (perennial and annual forb), sieved them through 2-mm mesh, and analyzed them for crude protein (CP) content. We calculated CP in 2004 and 2005 from total nitrogen analysis (%CP = 6.25 × %N) using a Leco CN analyzer (Leco Corp., St. Joseph, MI).

We sampled arthropods using pitfall traps containing a 1:4 mixture of antifreeze and water. Traps were 114-mm-diameter plastic pint containers (76-mm depth). We placed plastic plates 10 cm above traps to shield them from exposure to rain and sun. Within each plot we randomly placed 10 traps each collection period. We sampled traps once per week during 2-week periods in early May and early June of 2004 and 2005. We installed and sealed traps 1 week prior to sampling in May to allow soil to settle. We sealed traps between the May and June sampling periods. We identified captured arthropods to Order and counted them.

We used repeated measures analysis of variance (ANOVA) with the PROC MIXED procedure for a random-

Table 1. Dietary forb species we collected known to be utilized by sage-grouse. We collected forbs during yield measurements at the Northern Great Basin Research Center, Oregon, USA, 2004–2008.

Scientific name and grouping	Common name
Astragalus spp.	
A. curvicarpus	Sickle milkvetch
A. lentiginosus	Specklepod milkvetch
A. purshii	Wooly-pod milkvetch
A. obscurus	Obscure milkvetch
Cichorieae tribe	
Agoseris glauca	Pale agoseris
Crepis acuminata	Taper-tip hawksbeard
Microseris troximoides	False-agoseris
Phlox longifolia	Long-leaf phlox
Other sage-grouse dietary perennial forbs	
Achillea millefolium	Common yarrow
Allium spp.	Wild onion
Antenarria dimorpha	Low pussytoes
Erigeron linearus	Desert yellow daisy
Erigeron chrysopsidis	Golden daisy
Eriogonum ovalfolium	Oval-leaf buckwheat
Fritillaria pudica	Yellow bell
Lomatium nevadense	Nevada desert-parsley
Lomatium triternatum	Nine-leaf lomatium
Penstemon humilis	Lowly penstemon
Ranunculus glaberrimus	Sagebrush buttercup
Annual forbs	
Collinsia parviflora	Little blue-eyed Mary
Eriastrum sparsiflorum	Few-flower Eriastrum
Gayophytum spp.	Groundsmoke
Microsteris gracilis	Slender phlox

ized complete block design to compare time, treatment, and time by treatment interactions between burned and unburned sagebrush steppe for plant species cover, forb and grass yield, forb CP, and arthropod counts (SAS Institute, Cary, NC). We used an auto regressive order one covariance structure because it provided the best fit for data analysis. We evaluated vegetation canopy cover by grouping species according to sage-grouse habitat guidelines, including big sagebrush, green rabbitbrush, total herbaceous, tall herbaceous (≥18 cm ht), perennial grasses (≥18 cm ht), perennial forbs, and annual forbs (<18 cm ht; Connelly et al. 2000*b*). We did not measure herbaceous species heights; we instead used species height descriptions provided by Hitchcock and Cronquist (1976) to separate herbaceous plants into those typically >18 cm in height and those with growth heights <18 cm. We categorized yield response variables by perennial grass, total forb, perennial forb, annual forb, milkvetch (*Astragalus* spp.), Cichorieae tribe, long-leaf phlox, other sage-grouse dietary perennial forbs, sage-grouse dietary annual forbs, pale alyssum, and total herbaceous biomass. Because of strong year effects, we also analyzed measurement periods (yr or month) using ANOVA for randomized complete block design to simplify presentation of results and to assist in explaining interactions. Mean separation involved comparison of least squares using the LSMEANS procedure (SAS Institute, Cary, NC). We tested data for normality using the univariate procedure and arcsine–square root transformed data when normality failed to stabilize variance (SAS Institute). We report back transformed means in Results and set statistical significance of all tests at $P < 0.05$.

RESULTS

Values for cover response variables indicated several differences between treatments across the 6-year study period. Year and treatment interactions were significant for total herbaceous, perennial grass (≥18 cm ht), tall herbaceous (≥18 cm ht), big sagebrush, green rabbitbrush, and annual forb cover. Total herbaceous cover increased by over 100% in the burn and by 60% in the control between 2003 and 2006 in response to favorable growing conditions and then declined in both treatments by almost 60% in 2008 as a result of below-average precipitation ($P < 0.001$). In 2005, 2006, and 2008 total herbaceous cover was 50–80% greater in the burn than the control ($P < 0.001$). Wyoming big sagebrush cover was 90% lower in the burn after fire ($P < 0.001$; Fig. 2A). In 2006 and 2008, Wyoming big sagebrush cover in the burn was <1%, which was approximately 10% of preburn cover. This cover was provided by surviving plants because there was no recruitment of new individuals. Green rabbitbrush cover was reduced nearly 10-fold the first year ($P < 0.001$) after fire and recovered to preburn levels in 2005 ($P = 0.345$; Fig. 2B). Tall herbaceous (Fig. 2C) and perennial grass (Fig. 2D) cover were both about 45% lower in the burn than the control the first year postfire (2003). After 2003, there were no treatment differences for tall herbaceous ($P = 0.567$) and perennial grass cover ($P = 0.424$). Tall herbaceous cover was primarily composed of perennial grasses as tall forb cover did not exceed 1% in either treatment. Cover of perennial forb species and tall forbs (≥18 cm) did not differ between the burn and control ($P = 0.432$) or across years ($P = 0.789$). Annual forb cover was greater (300–1,100%) in the burn than the control in 3 of the 5 years following the fire ($P = 0.0171$; Fig. 2E). Nearly 98% of annual forb cover in the burn consisted of pale alyssum, an introduced Old World weed. Cover of other annual forbs did not increase in response to the fire and there were no differences compared to the control ($P = 0.631$).

Herbaceous yield was 44–80% greater in the burn than the control treatment after the second year after fire ($P < 0.001$; Fig. 3A). Most (70–90%) herbaceous yield in the burn was composed of perennial grasses. Perennial grass yield was about twice as great in the burn than the control from 2005 to 2008 ($P < 0.001$; Fig. 3B). Total forb (perennial and annual) yield was 110–167% greater in the burn than the control in 4 of 6 years after the burn ($P = 0.034$; Fig. 3C). However, perennial forb yield did not increase ($P = 0.863$) after the fire and in 2 of the sampling periods perennial forb yield was 30% greater in the control (Fig. 4A). Annual forb yield was 129% greater ($P < 0.001$) in the burn throughout the study, though not in every sample period (Fig. 4B).

Yield of milkvetch species was 20% greater after fire in the burn in the June sampling period ($P = 0.050$) but did not

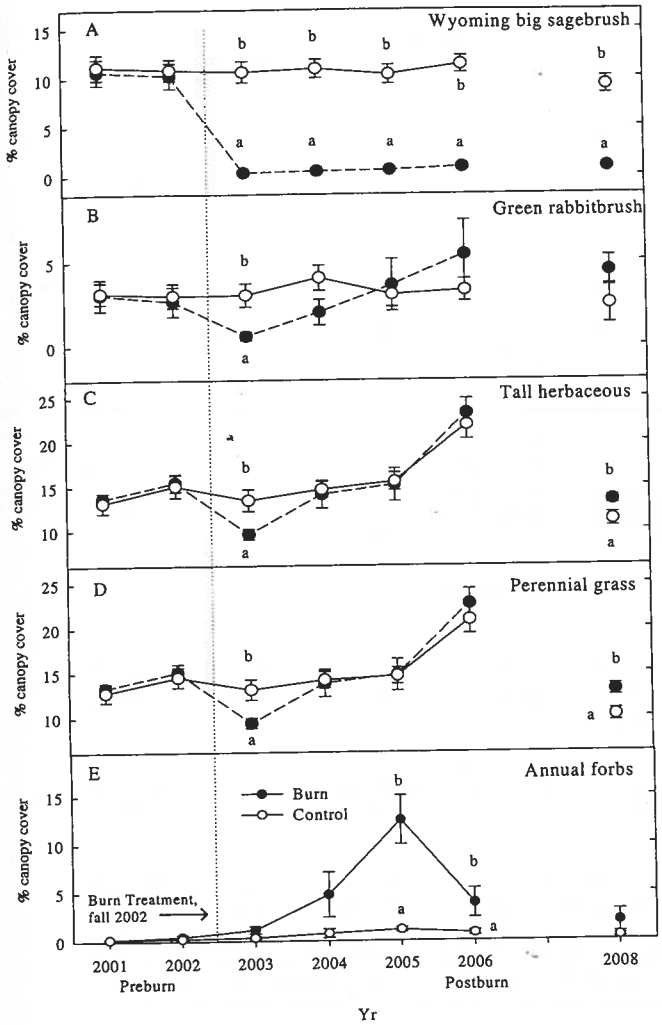

Figure 2. Canopy cover values (%) for the burn treatment and control in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, USA, June (2001–2006, 2008); (A) Wyoming big sagebrush, (B) green rabbitbrush, (C) tall herbaceous (<18 cm ht), (D) perennial grasses, and (E) annual forbs. Values represent means ± one standard error. Different lowercase letters indicate significant differences between treatments within year.

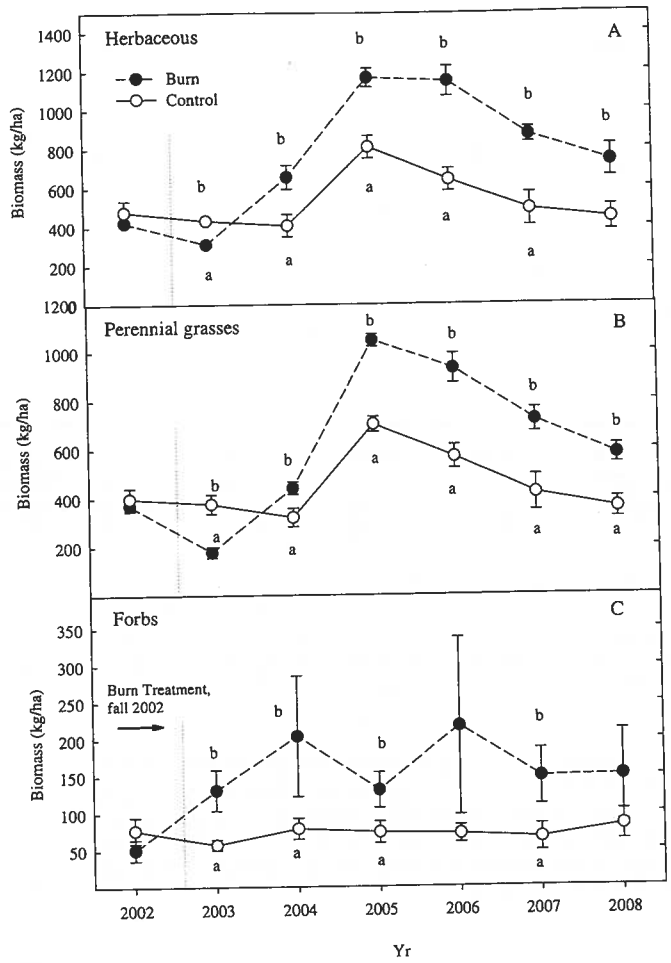

Figure 3. Yield (kg/ha) for (A) total herbaceous, (B) perennial grasses, and (C) forbs in the burn treatment and control in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, USA, June (2002–2008). Values represent means ± one standard error. Different lowercase letters indicate significant within year differences between treatments.

differ over the course of the study ($P = 0.756$) or during April ($P = 0.857$) or May ($P = 0.933$) sampling periods (Fig. 5A). Other perennial forb species known to be consumed by sage-grouse generally did not differ in yield between treatments, including yields of the Cichorieae tribe ($P = 0.278$), long-leafed phlox ($P = 0.774$), and other perennial forbs ($P = 0.224$; Fig. 5). Yield of annual forbs that sage-grouse typically utilize in their diet was 600–1,100% greater in the burn than the control in April–June 2004 (Fig. 6A). On other sample dates and across the study period ($P = 0.073$) sage-grouse dietary annual forbs did not differ in yield between the burn and control. Slender phlox and little blue-eyed Mary were the main dietary annual forbs we collected. Pale alyssum increased (300–1,300%) in the burn and comprised the bulk of forb (annual and perennial) yield (>90%) after fire ($P = 0.001$; Fig. 6B).

Perennial forb CP was greater ($P = 0.035$) in the burn than the control, though it was year dependent. In 2004, perennial forb CP in the burn (25.10 ± 2.14%, $n = 5$) was higher ($P = 0.011$) than the control (19.40 ± 1.27%, $n = 5$). We detected no treatment effects ($P = 0.934$) for dietary annual forb CP, but a time effect ($P = 0.002$) existed in both 2004 and 2005. Annual forb CP declined by 40% between April and June in both years as plants senesced.

We captured 50–67% fewer ants in the burn than the control ($P = 0.041$; Fig. 7A). Beetle captures did not differ between treatments ($P = 0.504$; Fig. 7B). We captured twice as many grasshoppers and crickets in the burn ($P = 0.014$) and twice as many moths and butterflies in the control ($P = 0.036$; Fig. 7).

DISCUSSION

Cover

Prescribed fire killed most of the Wyoming big sagebrush and reduced sagebrush cover by 95%. Loss of sagebrush cover in the burn was not compensated by an increase in tall herbaceous cover. Although total herbaceous cover increased in the burn, this increase was largely comprised of low growing pale alyssum, which provides no value as escape or

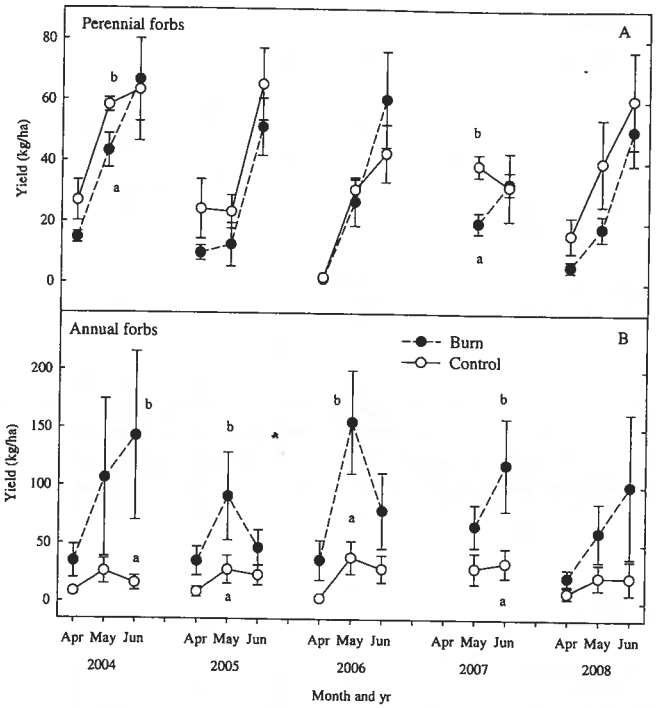

Figure 4. Monthly growing season yields (kg/ha) of (A) perennial forbs and (B) annual forbs for the burn treatment and control in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, USA (Apr, May, and Jun; 2003–2008). Values represent means ± one standard error. Different lowercase letters indicate significant within year differences between treatments.

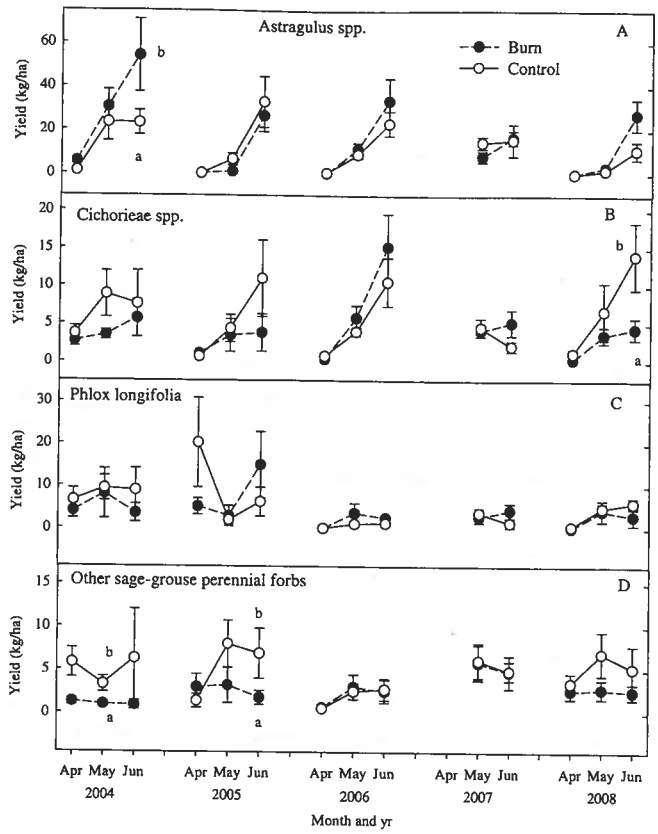

Figure 5. Yields (kg/ha) of (A) *Astragulus* spp., (B) Cichorieae tribe (*Asteraceae*), (C) *Phlox longifolia*, and (D) other sage-grouse perennial forbs by month (Apr, May, and Jun) for the burn treatment and control in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, USA (2003–2008). Values represent means ± one standard error. Different lowercase letters indicate significant within year differences between treatments.

nesting cover for sage-grouse (Connelly et al. 2000*b*, Crawford et al. 2004). Cover of perennial grasses and forbs recovered to preburn levels by the second year after fire. This response period was similar to herbaceous recovery after fire in big sagebrush steppe reported by Blaisdell (1953), Conrad and Poulton (1966), Uresk et al. (1976), and West and Hassan (1985).

Big sagebrush recovery after fire is dependent on establishment from seed and therefore sagebrush recovery often requires 35–200 years (Tisdale and Hironaka 1981, Baker 2006, Ziegenhagen and Miller 2009). In our study, surviving sagebrush were scattered throughout the burn and provided a potential seed source. However, Wyoming big sagebrush is the slowest of the big sagebrush species to recover from fire because of a lack of seed production in most years and because drier conditions make establishment of new plants difficult (Wright and Bailey 1982, Bates et al. 2005, Baker 2006). Recovery time of Wyoming big sagebrush to preburn levels is likely to surpass 50 years. Wambolt and Payne (1986) measured only a 12% recovery of Wyoming big sagebrush cover 18 years after burning in southwest Montana. Wambolt et al. (2001) measured a 72% recovery 32 years after early fall fire. Lesica et al. (2007) measured only a 5% recovery of Wyoming big sagebrush canopy after wildfires (time since fire was 7–23 yr) in southwestern Montana. In Idaho, sagebrush cover was about 20% of preburn levels 14 years after prescribed fire (Beck et al. 2009). In our study, Wyoming big sagebrush cover was <10% of preburn conditions 6 years after the fire.

Application of prescribed fire when fuel moisture and humidity are higher may result in lower mortality and earlier recovery of big sagebrush, as well as abbreviating the period of herbaceous dominance. Wyoming big sagebrush cover and density returned to preburn levels 9 years after spring-applied prescribed fires in Montana and late fall (Nov) fires reduced mortality of mountain big sagebrush (Pyle and Crawford 1996, Wambolt et al. 2001). Overall herbaceous recovery does not appear to be limited following late fall or early spring fire in big sagebrush habitat, though species-specific responses to fire may alter postfire composition (Cook et al. 1994, Pyle and Crawford 1996, Wambolt et al. 2001).

Green rabbitbrush cover was reduced 5-fold the first year after fire, returning to preburn levels by the second year after fire. Unlike big sagebrush green rabbitbrush is a vigorous resprouter, often increasing within a few years after fire (Tisdale and Hironaka 1981). Rabbitbrush (*Chrysothamnus* spp.) is utilized by sage-grouse; however, the shrub architecture of rabbitbrush does not provide optimum structural cover that big sagebrush conveys for nesting and roosting (Connelly et al. 2000*b*).

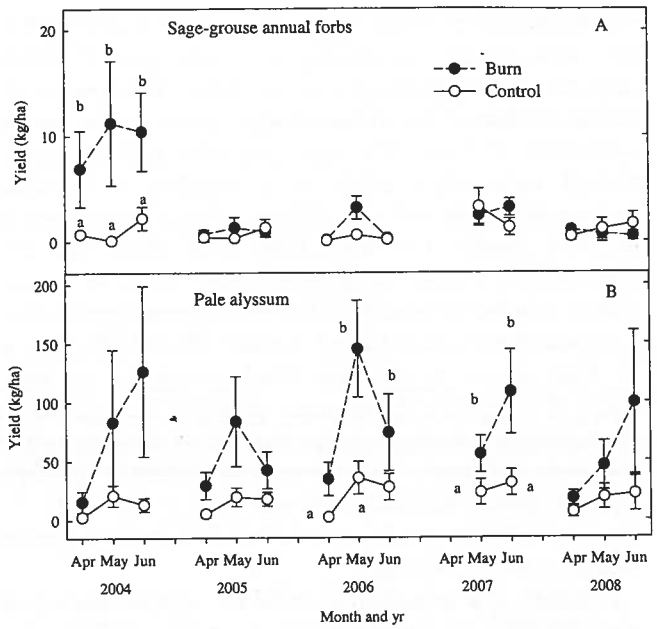

Figure 6. Yields (kg/ha) of (A) sage-grouse annual forbs and (B) pale alyssum by month (Apr, May, and Jun) for the burn treatment and control in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, USA (2003–2008). Values represent means ± one standard error. Different lowercase letters indicate significant within year differences between treatments.

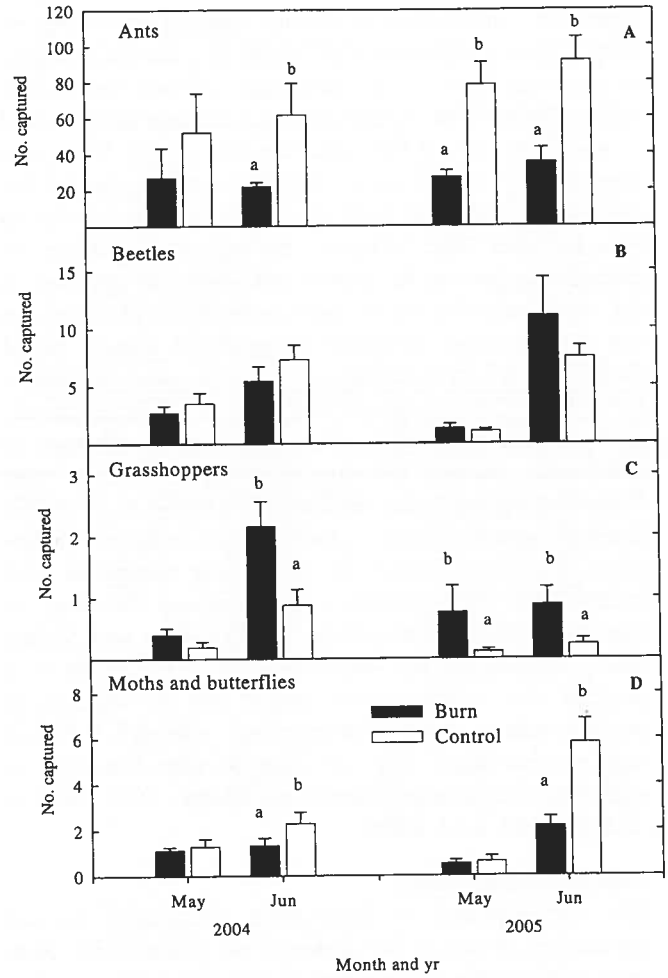

Figure 7. Arthropod abundance (no. captured) for (A) ants, (B) beetles, (C) grasshoppers, and (D) moths and butterflies for the burn treatment and control in Wyoming big sagebrush steppe, Northern Great Basin Experimental Range, Oregon, USA (2004–2005). Data are means ± one standard error. Lowercase letters represent significant differences between treatments.

Forb Yield and Nutritional Quality

Burning did not increase yields of perennial forb species or genera reported to be important in the diet of sage-grouse. Other studies failed to detect any increase in forb diversity or abundance after burning in Wyoming big sagebrush communities (Fischer et al. 1996, Wrobleski and Kauffman 2003, Beck et al. 2009). Even in mountain big sagebrush communities burning may not result in increased perennial forb abundance. Pyle and Crawford (1996) found that fall burning increased frequency of Cichorieae species but did not enhance abundance of other forbs consumed by sage-grouse. In southeastern Idaho, postfire forb abundance across different-aged burns was not different than adjacent unburned mountain big sagebrush communities (Nelle et al. 2000). Our data demonstrated that perennial forb CP was higher the second year after fire in the burn. However, the increase in CP appears to be short-lived because treatments did not differ following the second growing season after fire.

The increase in yields of annual forbs utilized by sage-grouse in the burn only occurred in the first year postfire. In mountain big sagebrush communities no change in dietary annual forb yield was reported after fall burning (Pyle and Crawford 1996). The increase of pale alyssum yield after fire may not provide any benefits to sage-grouse because diet studies do not indicate that sage-grouse consume this forb (Klebenow and Gray 1968, Peterson 1970, Wallestad et al. 1975, Barnett and Crawford 1994, Drut et al. 1994). However, prairie pepperweed (*Lepidium densiflorum*), a native species, was found to be a preferred spring forb utilized by juvenile sage-grouse in Montana (Peterson 1970). It is possible that sage-grouse may utilize pale alyssum, because it is also an annual mustard with a phenology similar to pepperweed.

There are several potential reasons for lack of native (perennial and annual) forb response to fire including postfire weather, site potential, interference by perennial grasses and pale alyssum, lack of forb propagules in the soil seed bank, and the short duration of our study. The amount and timing of precipitation and temperature can have a major influence on herbaceous productivity in big sagebrush steppe (Sneva 1982, Bates et al. 2005). In our study, weather did not appear to influence perennial forb production because yields did not differ across years despite 4 years of below-average precipitation and 2 years of above-average precipitation. Perennial forb cover on our study area and in most other high seral Wyoming big sagebrush communities comprises only a small proportion of the herbaceous layer (Davies et al. 2006). Prior to burning, perennial forb cover and biomass represented 14% and 13% of total herbaceous cover and biomass, respectively. These ratios of forb to total herbaceous cover and biomass are typical for Wyoming big

sagebrush communities in eastern Oregon (Davies et al. 2006, Davies and Svejcar 2008). After fire, the biomass ratio of perennial forbs as a percentage of total herbaceous declined below 10% as perennial grass and pale alyssum yield increased and native forb yield did not change. The rapid response of perennial grasses and pale alyssum after the fire most likely interfered with the ability of native forbs to respond after fire. Greater fire-induced mortality of perennial grasses could increase availability of openings in the community for native forbs to establish. However, on our site increased mortality of perennial grasses would probably only have benefited pale alyssum rather than native forbs. In addition, increased mortality of perennial bunchgrasses could potentially result in cheatgrass invasion or dominance, because this species is present within most Wyoming big sagebrush communities (Davies et al. 2006). Perennial grasses appear to be the most important herbaceous functional group for preventing cheatgrass and medusahead (*Taeniatherum caput-medusae*) invasion in sagebrush steppe (Davies et al. 2008, Davies and Svejcar 2008). Because of the short duration of our study it is possible that a longer time period will be required to properly assess native forb response, although evidence suggests that forbs may not increase after fire over an extended time horizon (Harniss and Murray 1973, Nelle et al. 2000, Beck et al. 2009).

Arthropod Abundance

The fire appeared to have been detrimental to ant populations; however, we gathered no pretreatment data, thus, it is possible that differences between treatment plots existed prior to burning. Nonetheless, our results are similar to declines in ant abundance after fire in a Wyoming big sagebrush community in Idaho (Fischer et al. 1996). Beetle abundance was low in our study and we measured no treatment differences. Results from other studies indicated that beetle abundance was either unaffected (Fischer et al. 1996) or reduced after fire (Rickard 1970). Grasshopper, cricket, moth, and butterfly captures were low in our study and we are not convinced that treatment differences were biologically meaningful. Fischer et al. (1996) also measured low numbers of grasshoppers and crickets using both pitfall traps and sweep nets and suggested that their low abundances in Wyoming big sagebrush plant communities may be typical.

Prescribed Burning of Sagebrush

Application of prescribed fire and other brush removal treatments in big sagebrush steppe has positive, neutral, and negative consequences for associated wildlife species. Reported benefits to wildlife numbers, diversity, and use tended to be in treatments where a heterogeneous landscape of herbaceous- and sagebrush-dominated areas were developed. Number and diversity of nongame avian species increased after a mosaic burn in big sagebrush habitat (Petersen and Best 1987). In mountain big sagebrush communities, sage-grouse brood-rearing and summer use increased following tebuthiuron application and 2 mechanical treatments to reduce sagebrush cover on small (<40.5-ha) areas created to develop a mosaic pattern within sagebrush steppe (Dahlgren et al. 2006). Dahlgren et al. (2006) attributed the increased sage-grouse use to greater availability of forbs. For large ungulates and granivores, burned areas often result in a doubling of available herbaceous forage and may triple grass seed yield (Cook et al. 1994, Davies et al. 2007, Bates et al. 2009). In other ecosystems a mosaic of different aged burns or greater habitat complexity resulted in increased invertebrate biomass and avian species diversity and numbers (Roth 1976, Pons et al. 2003, Noson et al. 2006, Reinkensmeyer et al. 2007, Engle et al. 2008). Seven years after the fire, our burns resembled grasslands; however, because of the presence of surviving sagebrush, long-term development will likely result in greater landscape heterogeneity in the form of a grass and shrub mosaic, which should benefit a greater variety of wildlife species.

However, it is important to consider negative impacts of prescribed fire on sagebrush obligate species, such as sage-grouse, which are threatened by loss of habitat throughout their historic range (Connelly and Braun 1997, Aldridge et al. 2008). In mountain big sagebrush habitat in Idaho nesting habitat for sage-grouse was reduced after fire (Nelle et al. 2000). Following prescribed fire in Wyoming big sagebrush communities of southeast Idaho numbers of sage-grouse decreased (Connelly and Braun 1997, Connelly et al. 2000*a*) and Fischer et al. (1996) concluded that fire did not enhance sage-grouse brood-rearing habitat. Burning Wyoming big sagebrush steppe will not only remove structural cover but will reduce or eliminate forage provided by sagebrush for sage-grouse, which would be especially damaging in year-round and wintering habitat. Burning at our sites reduced Wyoming big sagebrush forage production by about 450 kg/ha (prior to ephemeral leaf drop in Jul; Davies et al. 2007). A common assumption has been that burning big sagebrush communities will increase forb cover and productivity (Wirth and Pyke 2003). In our study and others (Fischer et al. 1996, Nelle et al. 2000, Wrobleski and Kauffman 2003, Beck et al. 2009), yields or cover of forbs used by sage-grouse in their diets have been largely unresponsive to prescribed fall burning. In our study, loss of sagebrush production was replaced by increased yields of perennial grasses and pale alyssum. Pale alyssum is not present within most Wyoming big sagebrush communities of the northern Great Basin; however, cheatgrass is frequently detected even in communities largely comprised of native vegetation and considered intact (Davies et al. 2006). The potential for a rapid increase in cheatgrass following fire necessitates careful consideration of the use of prescribed burning in this system. The danger of cheatgrass dominance is that wildfire frequencies are likely to increase substantially compared to historic MFRI resulting in further degradation or loss of sagebrush communities, particularly Wyoming big sagebrush (Whisenant 1990, Baker 2006). In the Snake River Plains of Idaho, fires typically occur about every 5 years as a result of cheatgrass dominance in former Wyoming big sagebrush communities (Whisenant 1990).

These fires are landscape level burns that limit recovery of big sagebrush and associated species (Wisdom et al. 2005). Historically the Wyoming big sagebrush cover type burned every 50–240 years and fires typically produced a mosaic of burned and unburned patches (Wright et al. 1979, West 1983, West and Hassan 1985, Baker 2006).

MANAGEMENT IMPLICATIONS

It is probably not necessary to apply extensive or small-scale brush control treatments for specifically improving sage-grouse habitat in intact Wyoming big sagebrush communities. Prescribed burning of Wyoming big sagebrush communities to enhance other species habitat requirements should be done so as to minimize mortality of native perennial grasses and forb species, result in a mosaic pattern of burned and unburned patches, and avoid areas with significant amounts of cheatgrass. Additionally, prior to burning sagebrush steppe, areas should be assessed and critical habitat, such as wintering grounds, identified to avoid potential negative impacts to sage-grouse populations and other sagebrush obligate species.

ACKNOWLEDGMENTS

We thank the numerous summer crew members for assistance in the field and laboratory: K. Adams, J. Anderson, G. Ash, A. Atchley, J. Davies, J. Duchene, E. Ersch, E. Hagerman, K. Haile, G. Hitz, J. Hobbs, E. Hugie, R. Kessler, K. Mumm, R. and E. O'Connor, L. Otley, G. Pokorny, J. Pyrse, K. Ralston, B. Smith, J. Svejcar, M. Villagrana, C. Williams, J. and M. Young, and D. Zvirdin. L. Ziegenhagen did much of the data compilation, insect collections, and running the field crews in 2003 and 2004. Many thanks to M. Carlon, L. Carlon, and C. Poulsen for assisting on the burn team. In addition, we thank C. Boyd, J. Connelly, M. Gregg, A. Apa, C. Aldridge, and J. Ganey for their review and valuable comments on previous drafts of our manuscript. The Eastern Oregon Agricultural Research Center is jointly funded by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) and Oregon State Agricultural Experiment Station. Mention of a proprietary product does not constitute a guarantee or warranty of the product by USDA-ARS, Oregon State University, Texas A&M University, or the authors and does not imply approval to the exclusion of other products.

LITERATURE CITED

Aldridge, C. L., J. W. Connelly, S. T. Knick, M. A. Schroeder, S. E. Nielsen, H. L. Beyer, and M. S. Boyce. 2008. Range-wide patterns of greater sage-grouse persistence. Diversity and Distributions 14:983–994.

American Ornithologists' Union. 1998. Check-list of North American birds. Seventh edition. Allen Press, Lawrence, Kansas, USA. <http://www.aou.org/checklist/north/>. Accessed 28 July 2009.

Anderson, E. W., M. M. Borman, and W. C. Krueger. 1998. High Desert Ecological Province. Pages 38–46 *in* The Ecological Provinces of Oregon. Oregon Agricultural Experiment Station, Corvallis, USA.

Baker, W. L. 2006. Fire and restoration of sagebrush ecosystems. Wildlife Society Bulletin 34:177–185.

Barnett, J. K., and J. A. Crawford. 1994. Pre-laying nutrition of sage grouse hens in Oregon. Journal of Range Management 47:114–118.

Bates, J. D., E. Rhodes, K. Davies, and R. Sharp. 2009. Grazing after fire in the sagebrush steppe. Rangeland Ecology and Management 62:98–110.

Bates, J., T. Svejcar, R. Angell, and R. Miller. 2005. The effects of precipitation timing on sagebrush steppe vegetation. Journal of Arid Environments 64:670–697.

Beck, J. L., J. W. Connelly, and K. P. Reese. 2009. Recovery of greater sage-grouse habitat features in Wyoming big sagebrush following prescribed fire. Restoration Ecology 17:393–403.

Blaisdell, J. P. 1953. Ecological effects of planned burning of sagebrush–grass range on the Snake River Plains. United States Department of Agriculture Technical Bulletin 1075, Washington, D.C., USA.

Blaisdell, J. P., R. B. Murray, and E. D. McArthur. 1982. Managing intermountain rangelands—sagebrush-grass ranges. United States Department of Agriculture Forest Service, Intermountain Research Station, General Technical Report INT-134, Ogden, Utah, USA.

Boyd, C. S., J. D. Bates, and R. F. Miller. 2007. The influence of gap size on sagebrush cover estimates using line intercept technique. Rangeland Ecology and Management 60:199–202.

Bunting, S. C., B. M. Kilgore, and C. L. Bushey. 1987. Guidelines for prescribed burning sagebrush-grass rangelands in the northern Great Basin. United States Department of Agriculture Forest Service, Intermountain Research Station, General Technical Report INT-231, Ogden, Utah, USA.

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

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biology 3:229–234.

Connelly, J. W., K. P. Reese, R. A. Fischer, and W. L. Wakkinen. 2000*a*. Response of a sage grouse breeding population to fire in southeastern Idaho. Wildlife Society Bulletin 28:90–96.

Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000*b*. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28:967–985.

Conrad, C. E., and C. E. Poulton. 1966. Effect of wildfire on Idaho fescue and bluebunch wheatgrass. Journal of Range Management 19:138–141.

Cook, J. G., J. J. Hershey, and L. L. Irwin. 1994. Vegetative response to burning on Wyoming mountain-shrub big game ranges. Journal of Range Management 47:296–302.

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Journal of Range Management 51:2–19.

Dahlgren, D. K., R. Chi, and T. A. Messmer. 2006. Greater sage-grouse response to sagebrush management in Utah. Wildlife Society Bulletin 34:975–985.

Davies, K. W., J. D. Bates, and R. F. Miller. 2006. Vegetation characteristics across part of the Wyoming big sagebrush alliance. Rangeland Ecology and Management 59:567–575.

Davies, K. W., J. D. Bates, and R. F. Miller. 2007. Short-term effects of burning Wyoming big sagebrush steppe in southeast Oregon. Rangeland Ecology and Management 60:515–522.

Davies, K. W., R. L. Sheley, and J. D. Bates. 2008. Does prescribed fall burning *Artemisia tridentata* steppe promote invasion or resistance to invasion after a recovery period? Journal of Arid Environments 72:1076–1085.

Davies, K. W., and T. J. Svejcar. 2008. Comparison of medusahead-invaded and noninvaded Wyoming big sagebrush steppe in southeastern Oregon. Rangeland Ecology & Management 61:623–629.

Drut, M. S., W. H. Pyle, and J. A. Crawford. 1994. Technical note: diets and food selection of sage grouse chicks in Oregon. Journal of Range Management 47:90–93.

Engle, D. M., S. D. Fuhlendorf, A. Roper, and D. M. Leslie, Jr. 2008. Invertebrate community response to a shifting mosaic of habitat. Rangeland Ecology and Management 61:55–62.

Fischer, R. A., K. P. Reese, and J. W. Connelly. 1996. An investigation on fire effects within xeric sage grouse brood habitat. Journal of Range Management 49:194–198.

Gregg, M. A. 2006. Greater sage-grouse reproductive ecology: linkages among habitat resources, maternal nutrition, and chick survival. Dissertation, Oregon State University, Corvallis, USA.

Hagen, C. A. 2005. Greater sage-grouse conservation assessment and strategy for Oregon; a plan to maintain and enhance populations and

habitat. Oregon Department of Fish and Wildlife, Salem, USA. <http://www.dfw.state.or.us/wildlife/sagegrouse/pdf/sage_grouse_plan_reduced.pdf>. Accessed 15 Oct 2006.

Harniss, R. O., and R. B. Murray. 1973. 30 years of vegetal change following burning of sagebrush-grass range. Journal of Range Management 26:322–325.

Helmstrom, M. A., M. J. Wisdom, W. J. Hann, M. M. Rowland, B. C. Wales, and R. A. Gravenmier. 2002. Sagebrush-steppe vegetation dynamics and restoration potential in the interior Columbia Basin, U.S.A. Conservation Biology 16:1243–1255.

Hitchcock, C. L., and A. Cronquist. 1976. Flora of the Pacific Northwest: an illustrated manual. University of Washington Press, Seattle, USA.

Johnson, G. D., and M. S. Boyce. 1990. Feeding trials with insects in the diet of sage grouse chicks. Journal of Wildlife Management 54:89–91.

Klebenow, D. A., and G. M. Gray. 1968. Food habits of juvenile sage grouse. Journal of Range Management 21:80–83.

Knick, S. T., D. S. Dobkin, J. T. Rotenberry, M. A. Schroeder, W. M. Vander Haegen, and C. van Riper, III. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. Condor 105:611–634.

Lentz, R. D., and G. H. Simonson. 1986. A detailed soils inventory and associated vegetation of Squaw Butte Range Experiment Station. Oregon State University Agricultural Experiment Station, Special Report 760. Oregon State University, Corvallis, USA.

Lesica, P., S. V. Cooper, and G. Kudray. 2007. Recovery of big sagebrush following fire in southwest Montana. Rangeland Ecology and Management 60:261–269.

Miller, R. F., J. D. Bates, T. J. Svejcar, F. B. Pierson, and L. E. Eddleman. 2005. Biology, ecology, and management of western juniper. Oregon State University Agricultural Experiment Station, Technical Bulletin 152, Corvallis, USA.

Miller, R. F., and L. L. Eddleman. 2001. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Oregon State University Agricultural Experiment Station, Technical Bulletin 151, Corvallis, USA.

Miller, R. F., and E. K. Heyerdahl. 2008. Fine-scale variation of historical fire regimes in sagebrush-steppe and juniper woodland: an example from California, USA. International Journal of Wildland Fire 17:245–254.

Miller, R. F., and J. R. Rose. 1995. Historic expansion of *Juniperus occidentalis* southeastern Oregon. Great Basin Naturalist 55:37–45.

Natural Resource Conservation Service. 2009. Plants database. United States Department of Agriculture. <http://plants.usda.gov/index.html>. Accessed 18 Feb 2009.

Nelle, P. J., K. P. Reese, and J. W. Connelly. 2000. Long-term effects of fire on sage-grouse habitat. Journal of Range Management 53:586–591.

Noson, A. C., R. A. Schmitz, and R. F. Miller. 2006. Influence of fire and juniper encroachment on birds in high elevation sagebrush steppe. Western North American Naturalist 66:343–353.

Patterson, R. L. 1952. The sage grouse in Wyoming. Sage, Denver, Colorado, USA.

Peterson, J. G. 1970. The food habits and summer distribution of juvenile sage grouse in central Montana. Journal of Wildlife Management 34:147–155.

Petersen, K. L., and L. B. Best. 1987. Effects of prescribed burning on nongame birds in a sagebrush community. Wildlife Society Bulletin 15:317–329.

Pons, P., B. Lambert, E. Rigolot, and R. Prodon. 2003. The effects of grassland management using fire on habitat occupancy and conservation of birds in a mosaic landscape. Biodiversity and Conservation 12:1843–1860.

Pyle, W. H., and J. A. Crawford. 1996. Availability of foods of sage grouse chicks following prescribed fire in sagebrush-bitterbrush. Journal of Range Management 49:320–324.

Reinkensmeyer, D. P., R. F. Miller, R. G. Anthony, and V. E. Marr. 2007. Avian community structure along a mountain big sagebrush successional gradient. Journal of Wildlife Management 71:1057–1066.

Rickard, W. H. 1970. Ground dwelling beetles in burned and unburned vegetation. Journal of Range Management 23:293–294.

Roth, R. R. 1976. Spatial heterogeneity and bird species diversity. Ecology 57:773–782.

Rowland, M. M., and M. J. Wisdom. 2005. The Great Basin at risk. Pages 83–93 *in* M. J. Wisdom, M. M. Rowland, and L. H. Suring, editors. Habitat threats in the sagebrush ecosystem. Alliance Communications Group, Lawrence, Kansas, USA.

Sneva, F. 1982. Relation of precipitation and temperature with yield of herbaceous plants in eastern Oregon. International Journal of Biometeorology 26:263–276.

Tisdale, E. W., and M. Hironaka. 1981. The sagebrush-grass region: a review of the ecological literature. Bulletin No. 33. University of Idaho College of Forestry, Wildlife and Range Science, Moscow, USA.

Uresk, D. W., J. F. Cline, and W. H. Rickard. 1976. Impact of wildfire on three perennial grasses in south-central Washington. Journal of Range Management 29:309–310.

Wallestad, R., J. G. Peterson, and R. L. Eng. 1975. Foods of adult sage grouse in central Montana. Journal of Wildlife Management 39:628–630.

Wambolt, C. L., and G. F. Payne. 1986. An 18-year comparison of control methods for Wyoming big sagebrush in southwestern Montana. Journal of Range Management 39:314–319.

Wambolt, C. L., K. S. Walhof, and M. R. Frisina. 2001. Recovery of big sagebrush communities after burning in south-western Montana. Journal of Environmental Management 61:243–252.

Welch, B. L. 2002. Bird counts of burned versus unburned big sagebrush sites. Rocky Mountain Research Station, Research Note RMRS-16, Fort Collins, Colorado, USA.

West, N. E. 1983. Western intermountain sagebrush steppe. Pages 351–374 *in* N. E. West, editor. Ecosystems of the world: temperate deserts and semi-deserts. Volume 5. Elsevier Scientific Publishing, Amsterdam, The Netherlands.

West, N. E., and M. A. Hassan. 1985. Recovery of sagebrush-grass vegetation following wildfire. Journal of Range Management 38:131–134.

West, N. E., and J. A. Young. 2000. Intermountain valleys and lower mountain slopes. Pages 255–284 *in* G. Barbour and W. D. Billing, editors. North American terrestrial vegetation. Cambridge University Press, Cambridge, United Kingdom.

Whisenant, S. G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implication. Pages 4–10 *in* Proceedings: symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. United States Department of Agriculture Forest Service, Intermountain Research Station, General Technical Report INT-276, Ogden, Utah, USA.

Wirth, T. A., and D. A. Pyke. 2003. Restoring forbs for sage grouse habitat: fire, microsites, and establishment methods. Restoration Ecology 11:370–377.

Wisdom, M. J., M. M. Rowland, L. H. Suring, L. Schueck, C. W. Meinke, and S. T. Knick. 2005. Evaluating species of conservation concern at regional scales. Pages 5–74 *in* M. J. Wisdom, M. M. Rowland, and L. H. Suring, editors. Habitat threats in the sagebrush ecosystem. Alliance Communications Group, Lawrence, Kansas, USA.

Wright, H. A. 1974. Range burning. Journal of Range Management 27: 5–11.

Wright, H. A., and A. W. Bailey. 1982. Sagebrush-grass. Pages 158–173 *in* Fire ecology U.S. and southern Canada. John Wiley and Sons, New York, New York, USA.

Wright, H. A., L. F. Neuenschwander, and C. M. Britton. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities, a state-of-the-art review. United States Department of Agriculture Forest Service, Intermountain Research Station, General Technical Report INT-58, Ogden, Utah, USA.

Wrobleski, D. W., and J. B. Kauffman. 2003. Initial effects of prescribed fire on morphology, abundance, and phenology of forbs in big sagebrush communities in southeastern Oregon. Restoration Ecology 11:82–90.

Young, J. A., and F. L. Allen. 1997. Cheatgrass and range science: 1930–1950. Journal of Range Management 50:530–535.

Ziegenhagen, L. L., and R. F. Miller. 2009. Postfire recovery of two shrubs in the interiors of large burns in the Intermountain West. Western North American Naturalist 69:195–205.

Associate Editor: Ganey.