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RESEARCH ARTICLE

Recovery of Greater Sage-Grouse Habitat Features in Wyoming Big Sagebrush following Prescribed Fire

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Abstract

The ability of prescribed fire to enhance habitat features for Greater Sage-Grouse (*Centrocercus urophasianus*) in Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) in western North America is poorly understood. We evaluated recovery of habitat features important to wintering, nesting, and early brood-rearing Sage-Grouse in Wyoming big sagebrush following prescribed fire. Our case study included 1 year of preburn (1989) and 10 years of postburn data collected over 14 years (1990–2003) from control and burned study areas in the Big Desert of southeastern Idaho, U.S.A. We compared recovery and rate of change for 12 features in four categories between burned and control transects and recovery in burned transects including change in variation. Our results indicate that prescribed fire induced quantifiable changes in wintering, nesting, and early brood-rearing Sage-Grouse habitat features 14 years after fire in Wyoming big sagebrush in our study area. Specifically, grass and litter required by Sage-Grouse for nest and brood concealment recovered relatively rapidly following fire; major forb cover was similar between burned and control sites, but the rate of increase for major forb cover and richness was greater in control transects, and structurally mediated habitat features required by Sage-Grouse for food and cover in winter and for nest and brood concealment in spring recovered slowly following fire. Because shrub structural features in our study did not recover in magnitude or variability to preburn levels 14 years after fire, we recommend that managers avoid burning Wyoming big sagebrush to enhance Sage-Grouse habitat, but rather implement carefully planned treatments that maintain Sagebrush.

Key words: ***Artemisia tripartita wyomingensis*, *Artemisia tripartita*, *Bromus tectorum*, *Centrocercus urophasianus*, Cheatgrass, fire ecology, forbs, Greater Sage-Grouse, nesting cover, shrub canopy cover, shrub height, Threetip sagebrush, Wyoming big sagebrush.**

Introduction

Sagebrush (*Artemisia* spp.) is one of the predominant landscapes in western North America, historically covering more than 600,000 km^2 (Küchler 1970; West 1983; Connelly et al. 2004, unpublished report). The most common subspecies of Big sagebrush (*Artemisia tridentata*) form the dominant coverage of the Sagebrush biome, inhabiting areas according to climatic and topoedaphic conditions (Tisdale & Hironaka 1981; Bunting et al. 1987). Herbaceous development is typically higher in mesic Mountain big sagebrush (*A. t. vaseyana*) communities than in the more xeric Basin big sagebrush (*A. t. tridentata*) and Wyoming big sagebrush (*A. t. wyomingensis*) communities (Bunting et al. 1987).

Prior to European settlement, climate and fire frequency were primary factors influencing plant species composition within Sagebrush communities (Miller et al. 1994). Landscape-scale changes since European settlement including agricultural development, altered fire frequencies, climate change, introduction of alien weeds, mining, overgrazing by livestock, recreation, and water extraction have induced dramatic changes in community compositions across the biome (Miller et al. 1994; Connelly et al. 2004, unpublished report). Invasion of weedy exotics, especially Cheatgrass (*Bromus tectorum*), has led to increasing wildfire frequencies and subsequent loss and degradation of Big sagebrush communities, particularly in Wyoming big sagebrush (Baker 2006).

Fire kills Sagebrush plants and suppresses recovery because Basin, Mountain, and Wyoming big sagebrush are not root-sprouting shrubs (Pechanec et al. 1965; Tisdale & Hironaka 1981). Postburn recovery periods for these three Big sagebrush taxa can be long because they must reestablish from seed. For example, Baker (2006) approximated postfire recovery for Mountain big sagebrush (35–100 or more years) and Wyoming big sagebrush (50–120 years) based on a combination of cover and density values from various studies.

Prescribed burning is recognized as an effective and inexpensive method of removing Big sagebrush cover on large tracts (Pechanec et al. 1965). Prescribed fire can

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modify specific features and functions of Big sagebrush communities by reducing woody and invasive plants, increasing establishment and productivity of herbaceous plants, and providing different seral communities (Bunting et al. 1987; Riggs et al. 1996; Knick et al. 2003; Wrobleski & Kauffman 2003). Fire in Big sagebrush communities can also lead to increased establishment and productivity of shrubs such as *Chrysothamnus* spp. and *Ericameria* spp. (rabbitbrush) and Horsebrush (*Tetradymia* spp.), which often are indicative of reduced ecological status (Tisdale & Hironaka 1981; Bunting et al. 1987; Wambolt et al. 2001).

Grouse (*Tetraonidae*) populations across the northern hemisphere are most threatened by habitat degradation, loss, and fragmentation related to human land uses (Storch 2000). In North America, large-scale habitat loss and change are associated with declines in populations of Sagebrush-obligate wildlife species including Greater Sage-Grouse (*Centrocercus urophasianus*; Braun et al. 1976; Knick et al. 2003; Connelly et al. 2004, unpublished report). Large fires in Big sagebrush have been implicated as one of the major factors contributing to declines of Sage-Grouse (Connelly & Braun 1997; Connelly et al. 2000*b*). For example, in our study area, male lek attendance and number of active leks declined 5 years after burning at greater levels in a 58-km^2 burned area than in a 50-km^2 control area (Connelly et al. 2000*a*). Nevertheless, burning programs continue in spite of limited evidence linking prescribed fire with direct benefits to Sage-Grouse in Wyoming big sagebrush habitats (Fischer et al. 1996*b*; Wambolt et al. 2001).

Habitat features reflect food, cover, or other physical factors necessary for reproduction and survival of wildlife species (Anderson & Gutzwiller 2005). Sage-Grouse habitat features in Sagebrush communities include structurally mediated features related to height and cover of herbs and shrubs and forage-mediated features, largely associated with forb abundance (Riggs et al. 1996). To understand the effects of prescribed fire on Sage-Grouse habitat in Wyoming big sagebrush, we monitored 12 features in burned and unburned study areas following a prescribed fire in 1989 in southeastern Idaho, U.S.A. We selected specific features of Wyoming big sagebrush habitats that reflect physical factors necessary for the reproduction and survival of Greater Sage-Grouse from winter through early brood-rearing or that are useful indicators of ecological status. We define recovery as a comparison of postburn to preburn levels in habitat features in our study area, avoiding comparisons to published sources. Our specific research objectives were to (1) compare postburn changes and rates of recovery in Sage-Grouse habitat features following prescribed fire in Wyoming big sagebrush in burned transects to those in unburned transects; (2) describe recovery of habitat features in burned transects including specific aspects of observed recovery response and variability in recovering habitat features; and (3) assess postburn recovery of habitat features relative to habitat requirements for Greater Sage-Grouse.

Study Area

Our study area was within the Big Desert in Blaine and Butte counties, Idaho, approximately 60 km west of Blackfoot, Idaho, U.S.A. (lat 43°24′N, long 113°07′W; altitude 1,536–1,640 m). The Big Desert encompasses 2,409 km^2 of the Upper Snake River Plain of southeastern Idaho. Topography varies from flat to gently rolling, interspersed with exposed silicic and basaltic volcanic outcrops and craters. We obtained climatic data from a weather station situated at 1,625 m in Arco, Idaho, north of our study area (Western Regional Climate Center 2006). Mean annual precipitation from 1948 through 2005 was 245 mm (Western Regional Climate Center 2006), with 40% of annual precipitation falling from April through June (Yanskey et al. 1966). Average monthly temperatures from 1948 to 2005 were coldest in January (−16°C) and warmest in July (30°C).

Our study area was characterized as a Wyoming big sagebrush (*A. t. wyomingensis*)–Bluebunch wheatgrass (*Pseudoroegneria spicata*) habitat type, with a light-colored silt loam surface soil overlaying a weakly developed B horizon and a strongly calcareous C horizon (Hironaka et al. 1983). Threetip sagebrush (*A. tripartita tripartita*) was a common component of the Sagebrush complex comprising our study area, typically growing in association with Wyoming big sagebrush. Threetip sagebrush differs from Wyoming big sagebrush in that it sprouts following fire (Pechanec et al. 1965). Other important shrubs and subshrubs included Yellow rabbitbrush (*C. viscidiflorus*), Rubber rabbitbrush (*Ericameria nauseosa*), Granite prickly phlox (*Linanthus pungens*), Antelope bitterbrush (*Purshia tridentata*), and Spineless horsebrush (*Tetradymia canescens*). Common grasses included Squirreltail (*Elymus elymoides*), Needle and thread grass (*Hesperostipa comata*), and Sandberg bluegrass (*Poa secunda*). Plant nomenclature follows USDA Natural Resources Conservation Service (2006). Cattle grazed the entire study area, but were excluded from grazing the burned area for 1 year prior to and 2 years following the burn (Fischer et al. 1997).

As part of a larger study to investigate Sage-Grouse response to fire (Robertson 1991; Fischer 1994), the U.S. Bureau of Land Management burned 58 km^2 of the northern portion of a 200-km^2 study area in late August 1989. The burn prescription specified removal of 60% of Sagebrush cover in an irregular pattern. Postburn measurements indicated that the burn removed 57% of the Sagebrush covering the burned study area (Connelly et al. 1994). Our unburned control area was 6 km south of the burned treatment area, encompassing approximately 50 km^2 of U.S. Bureau of Land Management lands used by Sage-Grouse that also used the treatment area (Fischer et al. 1996*b*; Connelly et al. 2000*a*). Our study area provided winter, breeding, and early brood-rearing habitats for Sage-Grouse (Robertson 1991; Fischer et al. 1997; Connelly et al. 2000*a*). Grouse broods typically moved 1–69 km from breeding and nesting areas (Fischer 1994) to access higher-elevation meadows or mesic sites near agricultural fields along traditional migration routes (Wakkinen 1990) when vegetal moisture content declined to $\leq$60% water (Fischer et al. 1996*a*).

Methods

Experimental Design

Our study was designed as a before-after-control-impact quasi-experiment that was not replicated in time or space (Green 1979). Environmental impact studies such as ours are often designed as quasi-experiments because treated areas cannot be randomized as they are in manipulative experiments (Green 1979). Because we did not replicate treatment areas in space, our research is a case study wherein we provide results of postburn recovery from a single fire in Wyoming big sagebrush in the Big Desert of southeastern Idaho. Furthermore, because we repeatedly measured habitat features, our study provides a 14-year perspective of temporal recovery of Greater Sage-Grouse habitat features following prescribed fire in a portion of Wyoming big sagebrush in southeastern Idaho.

In late June and early July 1989, we established 18 randomly located, 50-m transects. Nine transects were established within the area to be burned (treatment area) and nine were within the unburned area (control area). We did not set a minimum or maximum distance from burn edges for our burned transects because transects were randomly placed before the burn and the irregular nature of the burn meant most treatment transects were relatively close to an edge. We collected data from 1989 through 1993, 1995 through 1999, and 2003. These collection periods corresponded to 1 year of preburn baseline data (1989) and 10 years of postburn data collected over 14 years (1990–2003). Our response variables included the 12 major habitat features for 1 year of preburn and 14 years of postburn data and Cheatgrass cover data spanning 5 years (1998–2003). Because we did not observe Cheatgrass in our study area until the mid-1990s, we only estimated canopy cover of Cheatgrass (%) in 3 years (1998, 1999, and 2003); thus, we did not include Cheatgrass cover as one of our 12 major habitat features.

We placed each habitat feature into one of the four categories representing similar groupings of features reflective of Sage-Grouse habitat components. Ecological status included bare ground (percentage bare soil, biological soil crusts, and rocks) and Rabbitbrush canopy cover (%). Forage-mediated features were major forb canopy cover (%), species richness of major forbs, and total forb canopy cover (%). Nesting cover consisted of grass canopy cover (%), grass height (cm), and litter cover (%). Shrub structural features were shrub height (cm), Threetip sagebrush canopy cover (%), total shrub canopy cover (%), and Wyoming big sagebrush canopy cover (%).

Data Collection

We collected data once per year in late June or early July (range 15 June to 10 July), and each year sampled transects within 3.4 ± 0.3 days (range 2–5 days). At each sampling location, we stretched a 50-m surveyor's tape N–S along each transect and positioned a 20 $\times$ 50–cm quadrat at each 1-m mark to ocularly estimate canopy cover of grasses, forbs, bare ground, and litter according to six classes (Daubenmire 1959). We estimated canopy cover of Cheatgrass in 1998, 1999, and 2003. We designated cover classes as: 1 = 0–1%, 2 = 1.1–5%, 3 = 5.1–25%, 4 = 25.1–50%, 5 = 50.1–75%, and 6 = 75.1–100%. We used midpoints of 0.5, 3.5, 15.5, 38.0, 63.0, and 88.0%, respectively, to estimate cover percentages.

We categorized 19 forb taxa as major forbs because they are eaten by Sage-Grouse or may provide habitat for insects eaten by Sage-Grouse: Yarrow (*Achillea* spp.), Agoseris (*Agoseris* spp.), Onion (*Allium* spp.), Pussytoes (*Antennaria* spp.), Milkvetch (*Astragalus* spp.), Burningbush (*Bassia scoparia*), Sego lily (*Calochortus nuttallii*), Indian paintbrush (*Castilleja* spp.), Hawksbeard (*Crepis* spp.), Fleabane (*Erigeron* spp.), Buckwheat (*Eriogonum* spp.), Prickly lettuce (*Lactuca serriola*), Lupine (*Lupinus* spp.), Penstemon (*Penstemon* spp.), Phlox (*Phlox* spp.), Globemallow (*Sphaeralcea* spp.), Goatsbeard (*Tragopogon* spp.), Vetch (*Vicia* spp.), and Deathcamas (*Zigadenus* spp.; Patterson 1952; Klebenow & Gray 1968; Peterson 1970; Wallestad et al. 1975; Barnett & Crawford 1994). Although we estimated canopy cover of major forbs by species, we summed them as one group. We computed total forb canopy cover as the sum of major and minor forb cover with minor forbs defined as nonfood or scarce species of forbs, typically annuals.

We measured height of tallest shrubs and grasses at each 1-m mark along each transect with a meter stick. We employed line intercept sampling along each transect to estimate canopy cover of shrubs, excluding gaps in shrubs that were approximately 3 cm or larger (Wambolt et al. 2006). We recorded cover for Antelope bitterbrush, Granite prickly phlox, Rabbitbrush (irrespective of species), Spineless horsebrush, Threetip sagebrush, Wyoming big sagebrush, and unknown shrub cover at each transect. We report canopy cover for Rabbitbrush, Threetip sagebrush, and Wyoming big sagebrush separately.

Statistical Analyses

Changes in Habitat Features following Prescribed Fire

We evaluated repeated measures of habitat features (response data) using mixed-model analyses of variance (ANOVAs) with the fixed effect being treatment (burned or control) and random effects being transect and year. We assessed assumptions of normality and homogeneity of variance with appropriate plots and conducted tests for all ANOVAs with Statistical Analysis System software

(SAS, PROC MIXED; SAS Institute 2003). To meet the assumptions of ANOVA, we used appropriate transformations of the habitat feature response data including arcsine square root of proportionate cover data and square root and $\log_{10}$ transformations of height data.

We evaluated the influence of preburn values on postburn values with repeated-measures ANOVA modeling considering 1990 data with 1989 data as covariates prior to conducting repeated-measures ANOVA models. We detected preburn influences when p values for ANOVA tests of 1990 features between burn and control transects indicated that including 1989 data as a covariate changed statistical significance (i.e., from significant to nonsignificant or vice versa). Consequently, we standardized Rabbitbrush cover estimates by incorporating 1989 data as a covariate after finding that 1989 preburn Rabbitbrush cover influenced the estimate of 1990 postburn Rabbitbrush cover.

To evaluate differences in habitat features between burned and unburned transects, we used univariate, mixed-model ANOVAs with year and treatment as main effects and treatment × year as the interaction. We used Akaike's information criterion (AIC) to determine whether autoregressive or heterogeneous autoregressive time series covariance structures best fit our data; we selected the covariance structure with the lowest AIC value (Burnham & Anderson 2002). We used the Tukey–Kramer honest significant difference (HSD) test to conduct post hoc multiple comparisons to separate means when significant main effects or interactions were detected. We report all estimates as raw means or least squares means ± SE, and we set statistical significance at $\alpha = 0.05$.

Recovery of Habitat Features in Burned Transects

We calculated the median year for those habitat features that recovered on all burned transects within 14 years to 100% of preburn levels based on 1989 measurements and computed 95% confidence intervals in Minitab (Minitab Incorporated 2000). To further assess postburn recovery for each habitat feature, we report the proportion of all burned transects recovering to 25, 50, 75, and 100% of preburn levels in each transect 1–7, 8–14, and >14 years postburn.

We used linear regressions (SAS, PROC REG; SAS Institute 2003) to estimate the rate of change in habitat features per year from 1990 to 2003 between control and burned transects. We used independent sample t tests to evaluate differences in rate of change in habitat features between control and burn transects (PROC TTEST; SAS Institute 2003). We evaluated equality of variances with the folded F method and used the Satterthwaite (1946) method to calculate t values in those instances where variances were unequal. The Satterthwaite statistic is an approximate t statistic and is used if the population variances of two groups are unequal. We computed degrees of freedom for this statistic with the Satterthwaite (1946) approximation.

We evaluated effect sizes in mean SDs of habitat features to assess recovery in the natural variation of Sage-Grouse habitat features. Our basis for this evaluation was based on our assumption that Grouse make specific habitat selection decisions from among the natural variability of habitat features to help them optimize reproduction and survival. We computed effect sizes in feature variability as mean SD across transects in year X − mean SD across transects in preburn year Y (1989) from preburn (1989) to 1 (1990), 7 (1996), and 14 years (2003) postburn for features from transects in burned Wyoming big sagebrush. We did not compute effect sizes for major forb richness because it was computed on a transect basis, thus providing no variability from which to compute SDs across transects. Because X and Y were sampled independently, the SE for effect sizes was computed as $\mathrm{SE}[X - Y] = \sqrt{\mathrm{var}\,[X - Y]} = \sqrt{SE_X^2 + SE_Y^2}$. Negative effect sizes indicate that postburn variation in habitat features was less than preburn habitat conditions; positive effect sizes indicate that variation in postburn habitat features was greater than preburn variation, and effect sizes of 0.0 indicate postburn variation in habitat features was equal to preburn variation.

To provide a probabilistic evaluation of recovery in variation, we computed 95% confidence intervals for the effect size of mean SDs for each habitat feature 1, 7, and 14 years postburn. Effect sizes with confidence intervals that include zeros are not considered statistically detectable from preburn variation in habitat features at the 0.95 probability level. Because SDs do not typically follow a normal distribution (Zar 1999), we assessed normality of SDs with appropriate tests and diagnostic plots (PROC MIXED, PROC CAPABILITY, PROC UNIVARIATE; SAS Institute 2003) to properly apply confidence intervals to estimated effect sizes. With the exception of canopy cover of Threetip sagebrush, total shrubs, and Wyoming big sagebrush, SDs for each habitat feature adequately approximated a normal distribution. Normality was questionable for these shrub structural features due to sparse data and outliers, resulting in slightly skewed distributions. Consequently, we can discuss with confidence our results in the recovery of variation for all but these three shrub structural habitat features.

Results

Changes in Habitat Features following Prescribed Fire

There were no preburn differences in habitat feature estimates between burned and control transects (Table 1). Forage-mediated features and grass cover did not differ between treatments across the 14-year postburn period (Table 2). Wyoming big sagebrush cover did not differ between years (Table 2); however, all other year and treatment main effects differed ($p \leq 0.05$). Grass height (1.1-times) was higher and ecological status lower (1.6-, and 2.1-times greater bare ground and Rabbitbrush cover, respectively) in burned transects than in control transects

Table 1. Means (± SE) for Greater Sage-Grouse habitat features in nine unburned control and nine burned transects in Wyoming big sagebrush in late June to early July before prescribed fire in late August 1989, Big Desert, Idaho, U.S.A.

Habitat Feature	*Control*	*Burn*
Ecological status		
Bare ground (%)*	32.5 ± 3.5	36.5 ± 2.6
Rabbitbrush cover (%)	2.5 ± 0.6	4.5 ± 1.3
Forage-mediated features		
Major forb cover (%)	3.9 ± 1.2	6.3 ± 1.2
Major forb richness	3.2 ± 0.4	3.1 ± 0.4
Total forb cover (%)	9.6 ± 2.2	12.8 ± 0.9
Nesting cover		
Grass cover (%)	11.6 ± 1.5	11.4 ± 1.1
Grass height (cm)	24.6 ± 2.1	20.7 ± 0.8
Litter (%)	41.0 ± 2.9	38.0 ± 2.9
Shrub structural features		
Shrub height (cm)	46.8 ± 4.1	52.9 ± 4.6
Threetip sagebrush cover (%)	9.8 ± 2.9	7.7 ± 2.3
Total shrub cover (%)	25.1 ± 1.1	27.2 ± 2.1
Wyoming big sagebrush cover (%)	9.7 ± 2.2	13.1 ± 2.5

Estimates do not differ ($p > 0.05$).
* Includes bare soil, biological soil crusts, and rock.

over the 14-year postburn period (Table 2). Litter and shrub structural features were higher in control transects than in burned transects across the 14-year postburn period (Table 2). The most dramatic differences between control and burned treatments were 11.8-times and 2.9-times greater cover of Wyoming big sagebrush and Threetip sagebrush, respectively, in control transects compared to burned transects (Table 2).

Recovery of Habitat Features in Burned Transects

Each habitat feature occurred on all nine transects before the burn except Threetip sagebrush, which was found on seven of nine transects. All features showed a recovery response on all burn transects except in one of seven (0.14) and three of nine (0.33) transects where Threetip sagebrush and Wyoming big sagebrush, respectively, were found before the burn. Rabbitbrush cover (median = 4.0 years [95% CI: 2.0–5.5]), grass cover (median = 1.0 year [95% CI: 1.0–1.0]), grass height (median = 2.0 years [95% CI: 1.0–2.0]), and major forb richness (median = 1.0 year [95% CI: 1.0–3.3]) recovered on all burn transects to 100% of preburn levels (Fig. 1). Although bare ground generally increased following the burn (Tables 1 & 2), it decreased to 100% of preburn levels in eight of nine (0.89) transects by 14 years postburn. Litter (0.56), major forb cover (0.89), total forb cover (0.89), and total shrub cover (0.11) increased to 100% of preburn levels within the postburn period (Fig. 1). Shrub height, Threetip sagebrush cover, and Wyoming big sagebrush cover never reached 100% of preburn levels on any transect where they were found before the burn (Fig. 1). In 2003, mean shrub height was 21.6 ± 2.1 cm, Threetip sagebrush cover 1.1 ± 0.6%, and Wyoming big sagebrush cover 0.8 ± 0.4% at burned transects.

Rate of change (increase or decrease) in features over the 14-year postburn period did not differ for grass cover, grass height, total forb cover, or Threetip sagebrush cover in burned or unburned transects (Table 3). Declining rates of bare ground and increasing rates of Rabbitbrush cover in burned transects indicated changing ecological status. The annual rate of increase for litter in burned transects was 2.3-times higher than in unburned transects (Table 3). The rate of change for major forb cover was nearly static in burned transects but increased about 0.3% per year in unburned transects, although the annual increase of major forb richness in unburned transects was 2.6-times higher than in burned transects (Table 3). Rate of change for shrub height and cover of total shrubs and Wyoming big sagebrush decreased in control transects but increased in burned transects following the burn (Table 3). Rate of change for shrub structural features in burned transects was highest for shrub height, slightly exceeding 0.9 cm/yr. Rate of increase for Threetip sagebrush cover was twice as high as Wyoming big sagebrush cover in the burn, but both species increased more than 0.1% per year (Table 3).

Bare ground was the only habitat feature that maintained variation similar to preburn variation 1, 7, and 14 years postburn, although variation in Rabbitbrush cover recovered to preburn variation by 7 years following fire (Fig. 2). Variation in the forage-mediated features, major and total forb cover, 1 and 7 years following fire was equivalent to variation before the fire but decreased to levels below preburn variation in year 14. Variation in nesting cover was variable, but for grass cover, variation was consistently greater than preburn variation. Variation in grass height was similar to preburn variation in year 1, was above preburn variation in year 7, and was less than preburn variation in year 14. Litter recovered to preburn variation by 7 years (Fig. 2). Variation in shrub structural features was less than preburn variation 1, 7, and 14 years after fire; however, shrub structural variation generally increased through year 14 except total shrub cover, which had lower variation in year 14 than in year 7 (Fig. 2).

Cheatgrass Cover

We did not detect a difference ($p > 0.05$) in the treatment main effect or the treatment × year interaction for Cheatgrass cover. We did detect a difference for the year main effect ($F_{[2,20]} = 48.32, p < 0.001$); however, Tukey–Kramer HSD tests indicated that yearly estimates did not differ. Least squares means for Cheatgrass cover were 7.2 ± 1.7% in 1998, 14.3 ± 1.7% in 1999, and 2.3 ± 1.7% in 2003.

Discussion

In our study, nesting cover and Rabbitbrush cover rapidly recovered to preburn levels, although shrub structural features did not recover to preburn levels 14 years after fire in Wyoming big sagebrush. Forage-mediated features

Table 2. Least squares means (± SE) and test statistics for Greater Sage-Grouse habitat features between nine unburned control and nine burned transects in Wyoming big sagebrush from repeated-measures ANOVA modeling, Big Desert, Idaho, U.S.A., 1990–2003.

Habitat Feature	*Term*	*Control*	*Burn*	*F*	*df*	*p*
Ecological status						
Bare ground (%)[a]	Year			32.51	9,90	<0.001
	Treatment	29.5 ± 2.7	46.0 ± 2.7	157.26	1,60	<0.001
	Treatment × year			9.82	9,60	<0.001
Rabbitbrush cover (%)[b]	Year			14.92	9,90	<0.001
	Treatment	2.6 ± 0.5	5.5 ± 0.5	39.97	1,59	<0.001
	Treatment × year			4.23	9,59	<0.001
	1989 cover			11.03	1,59	0.002
Forage-mediated features						
Major forb cover (%)	Year			15.15	9,90	<0.001
	Treatment	6.2 ± 0.5	6.0 ± 0.5	0.07	1,60	0.789
	Treatment × year			3.26	9,60	0.003
Major forb richness	Year			26.77	9,90	<0.001
	Treatment	5.6 ± 0.2	5.2 ± 0.2	3.84	1,69	0.054
	Treatment × year			—	—	[c]
Total forb cover (%)	Year			42.44	9,90	<0.001
	Treatment	11.1 ± 0.5	9.9 ± 0.5	3.29	1,69	0.074
	Treatment × year			—	—	[c]
Nesting cover						
Grass cover (%)	Year			20.23	9,90	<0.001
	Treatment	27.1 ± 1.9	26.7 ± 1.9	0.14	1,69	0.714
	Treatment × year			—	—	[c]
Grass height (cm)	Year			29.43	9,90	<0.001
	Treatment	27.8 ± 0.7	31.1 ± 0.8	6.15	1,69	0.016
	Treatment × year			—	—	[c]
Litter (%)	Year			26.43	9,90	<0.001
	Treatment	47.7 ± 2.6	29.6 ± 2.6	157.53	1,60	<0.001
	Treatment × year			6.20	9,60	<0.001
Shrub structural features						
Threetip sagebrush cover (%)	Year			4.33	9,90	<0.001
	Treatment	5.6 ± 1.0	1.9 ± 1.0	122.14	1,69	<0.001
	Treatment × year			—	—	[c]
Shrub height (cm)	Year			10.62	9,90	<0.001
	Treatment	33.8 ± 1.4	21.1 ± 1.4	124.58	1,60	<0.001
	Treatment × year			6.47	9,60	<0.001
Total shrub cover (%)	Year			15.03	9,90	<0.001
	Treatment	14.9 ± 1.2	9.0 ± 1.2	63.64	1,60	<0.001
	Treatment × year			5.93	9,60	<0.001
Wyoming big sagebrush cover (%)	Year			0.49	9,90	0.879
	Treatment	5.9 ± 0.5	0.5 ± 0.3	162.82	1,69	<0.001
	Treatment × year			—	—	[c]

[a] Includes bare soil, biological soil crusts, and rock.
[b] Includes 1989 data as a covariate.
[c] Denotes that nonsignificant interaction terms were pooled into sampling error.

required by Grouse for food during nesting and brood-rearing did not exhibit long-term enhancement by fire. Median recovery for grass cover, grass height, major forb richness, and Rabbitbrush cover to preburn levels was 0–4 years following the burn. In comparison, three shrub features (shrub height, Threetip sagebrush cover, and Wyoming big sagebrush cover) did not recover in magnitude or variability to preburn levels 14 years after fire. Moreover, Threetip and Wyoming big sagebrush cover exhibited very low rates of change and were lowest in change in variability over the postburn period. Total shrub cover and shrub height in the burned treatment were among the highest in increasing rate of change; however, much of this change was due to increasing cover and height of Rabbitbrush and Horsebrush that are less desirable to Sage-Grouse.

Fire is an important disturbance in shrubland habitats used by other Grouse species. For example, Red Grouse (*Lagopus lagopus scoticus*), which are endemic to the British Isles, depend year-round on Heather (*Calluna vulgaris*) for food and cover (Madge & McGowan 2002). To enhance habitat conditions, managers routinely burn older patches of Heather to produce small patches of young plants that are preferred by Red Grouse for food (Miller & Watson 1978; Savory 1978). Whereas prescribed fire in Heather provides food resources for Red Grouse, in our study area, prescribed fire in Wyoming big sagebrush

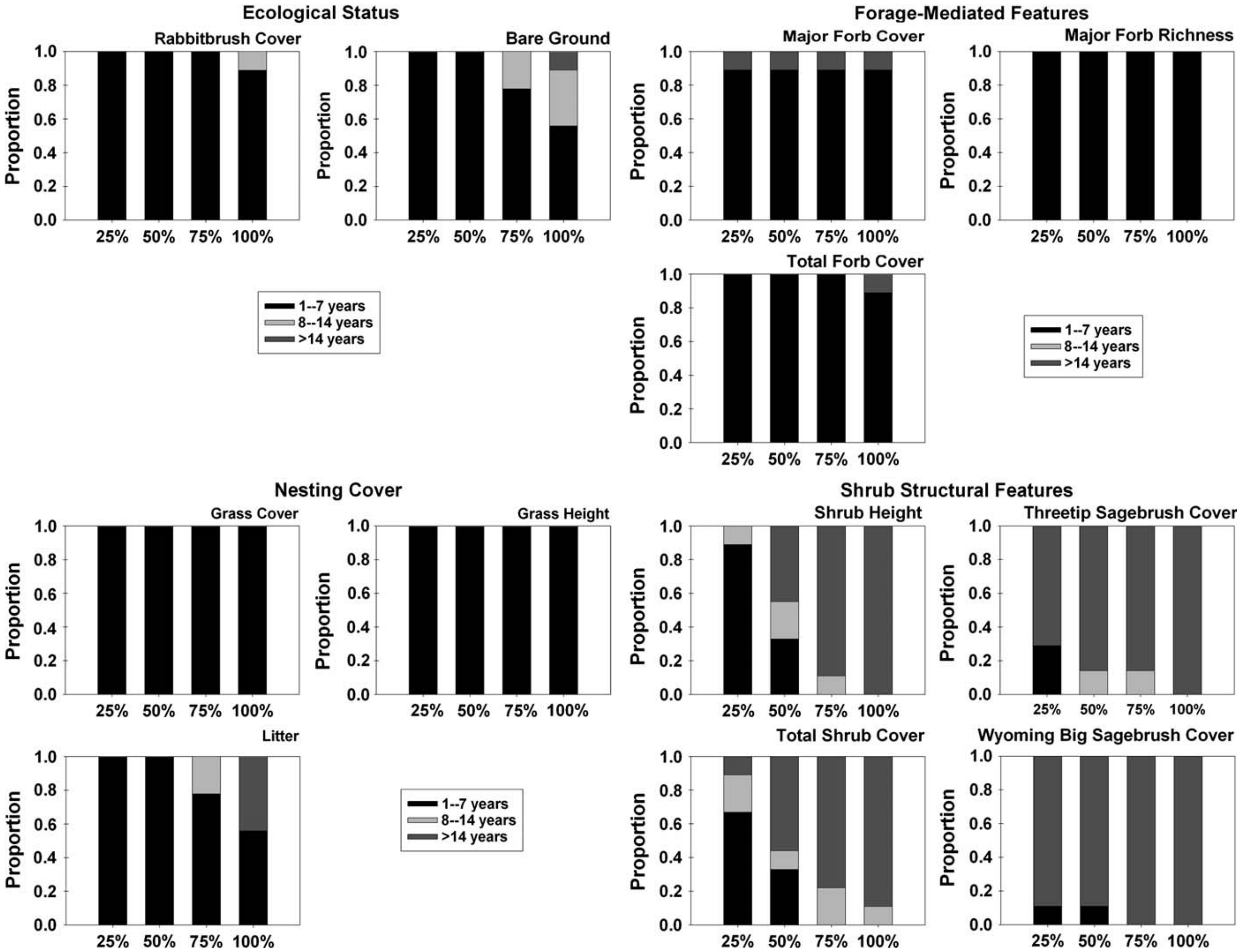

Figure 1. Proportion of Greater Sage-Grouse habitat features in nine transects in burned Wyoming big sagebrush with 25, 50, 75, and 100% recovery to 1989 preburn levels within 1–7, 8–14, and >14 years of prescribed fire, Big Desert, Idaho, U.S.A., 1990–2003. Bare ground includes bare soil, biological soil crusts, and rock.

reduced nest and brood concealment cover and winter cover and winter food used by Greater Sage-Grouse.

Although we did not detect a treatment difference in Cheatgrass cover, we did document a very rapid expansion of this species 9 years after burning. It is unclear why Cheatgrass increased in our study area in burned and control transects because we typically only observed it along roadways prior to expansion in the mid-1990s. Other studies have found increased abundance of Cheatgrass or other annual grasses immediately following fire in Wyoming big sagebrush (e.g., West & Hassan 1985), which often increases fire frequencies (Knick et al. 2003; Baker 2006). Due to this aspect of Sagebrush fire ecology, we caution managers against frequent or large burns in Wyoming big sagebrush.

Our study provides further support that burning in Wyoming big sagebrush greatly reduces Sagebrush (West & Hassan 1985; Wambolt & Payne 1986; Bunting et al. 1987; Watts & Wambolt 1996), can promote rapid recovery or increases in many perennial grasses (West & Hassan 1985; Wambolt & Payne 1986; Bunting et al. 1987), promotes rapid recovery of many forbs used by Sage-Grouse (Fischer et al. 1996*b*; Wrobleski & Kauffman 2003), and produces increases in shrubs that are less desirable to Sage-Grouse (Bunting et al. 1987). Most importantly, our results provide additional understandings of how recovery of burned Sagebrush habitats affects several habitat features needed by Sage-Grouse for reproduction and survival. Because our study evaluated a single fire, we advocate spatially replicated studies in Wyoming big sagebrush to provide inferences of the effects of burning on Sage-Grouse habitat features to larger spatial scales to compare with our findings.

Most measures of litter and grass height and cover recovered or exceeded preburn levels providing nesting and early brood-rearing cover. We focus our discussion on shrub structural features because our results provide strong

Table 3. Mean (± SE) slope estimates from linear regressions between Greater Sage-Grouse habitat features and year measured over 10 years from 1990 to 2003 in nine unburned control and nine burned transects in Wyoming big sagebrush, Big Desert, Idaho, U.S.A.

Habitat Feature	*Control*	*Burn*	*t*	*df*	*p*
Ecological status					
Bare ground (%)*	−0.192 ± 0.183	−1.644 ± 0.240	−4.82	15	<0.001
Rabbitbrush cover (%)	−0.003 ± 0.031	0.406 ± 0.097	4.02	9.7	0.003
Forage-mediated features					
Major forb cover (%)	0.295 ± 0.084	−0.033 ± 0.126	−2.16	13.9	0.048
Major forb richness	0.180 ± 0.032	0.068 ± 0.024	−2.80	15	0.014
Total forb cover (%)	−0.367 ± 0.135	−0.471 ± 0.120	−0.57	15.8	0.574
Nesting cover					
Grass cover (%)	0.526 ± 0.149	0.548 ± 0.220	0.08	14.1	0.935
Grass height (cm)	−0.231 ± 0.093	−0.500 ± 0.225	−1.11	10.7	0.293
Litter (%)	1.168 ± 0.220	2.670 ± 0.451	2.99	11.6	0.012
Shrub structural features					
Shrub height (cm)	−0.231 ± 0.249	0.903 ± 0.171	3.76	14.2	0.002
Threetip sagebrush cover (%)	0.172 ± 0.124	0.064 ± 0.034	−0.84	9.2	0.420
Total shrub cover (%)	−0.088 ± 0.167	0.583 ± 0.094	3.50	12.6	0.004
Wyoming big sagebrush cover (%)	−0.115 ± 0.070	0.032 ± 0.016	2.06	8.8	0.071

Independent sample *t* tests evaluate differences in rate of change in habitat features between control and burn transects.
* Includes bare soil, biological soil crusts, and rock.

evidence of effects of prescribed burning on these habitat features in our study area. We also discuss the effects of prescribed burning on forage-mediated features of forbs because our results point to limited benefits of burning to enhance forbs for Sage-Grouse in Wyoming big sagebrush.

Adequate Sagebrush canopy cover and height are required by Sage-Grouse for winter cover, winter food, and nest and brood cover. To counter effects of snow in winter, Sage-Grouse select Sagebrush characterized by relatively high cover (12–43% average canopy cover) and height (20–56 cm average; reviewed in Connelly et al. 2000*b*). In winter, foraging Sage-Grouse prefer specific subspecies and accessions of Big sagebrush (Welch et al. 1991) and browse on plants with higher protein levels and reduced levels of monoterpenes (Remington & Braun 1985). The absence of necessary Sagebrush cover in burned transects indicates that winter habitat conditions would not meet Sage-Grouse food or cover requirements 14 years after fire in our study area.

To successfully conceal nests from predators, nesting female Sage-Grouse select areas within landscapes where height and canopy cover of Sagebrush and residual grasses are greater than randomly available (Sveum et al. 1998; Holloran et al. 2005). Although female Sage-Grouse will place nests under other shrubs, nests placed under Sagebrush are more successful, suggesting the relative importance of Sagebrush to nesting Sage-Grouse over other shrubs (Connelly et al. 1991). Connelly et al. (2000*b*) suggested that productive Sage-Grouse breeding habitats in arid sites should provide 15–25% Sagebrush canopy cover. Our study area provided productive nesting habitat before the burn (Wakkinen 1990); however, our evaluations show that Sagebrush structural characteristics selected by nesting Sage-Grouse did not recover in magnitude or variability after 14 years to levels available to female Grouse selecting nest sites before prescribed fire. Furthermore, rate of increase for Threetip sagebrush cover was twice as high as Wyoming big sagebrush cover in burned transects, and the rate of increase of Threetip sagebrush was higher in control than in burned transects. This may result in relatively long-term problems for Sage-Grouse production because Lowe (2006) found that Sage-Grouse used Threetip sagebrush as nest cover less than expected and Sage-Grouse that used Big sagebrush as nest cover had greater nest success than Grouse using Threetip sagebrush in mixed Sagebrush communities in Idaho.

Canopy cover of Wyoming big sagebrush in southwestern Montana took longer to recover after prescribed fire than after being sprayed with 2,4-D, plowed, or roto-cut, and the Sagebrush sprayed with 2,4-D, plowed, or roto-cut exceeded cover levels in untreated Wyoming big sagebrush after 30 years (Watts & Wambolt 1996). Cover of burned Wyoming big sagebrush recovered to levels in unburned Sagebrush within 29 years after prescribed fire (Watts & Wambolt 1996). Our evidence and that of Watts and Wambolt (1996) suggest that burning Wyoming big sagebrush may restrict recovery of sufficient cover for Sage-Grouse winter habitat and nesting to three decades or more. A recent meta-analysis of Big sagebrush recovery following fire confirms our assertions (Baker 2006).

Sage-Grouse rely on forbs for reproduction and survival during nesting and brood-rearing. Forbs provide highly nutritious food to pre-laying females, which has been linked to increased Grouse productivity in years of greater forb availability (Barnett & Crawford 1994). Forbs also provide habitat for insects, and both foods are essential for chick Sage-Grouse survival and growth (Johnson & Boyce 1990) and comprise a majority of the diet of adult birds in summer (Patterson 1952; Wallestad et al. 1975). We found no difference in major forb cover between

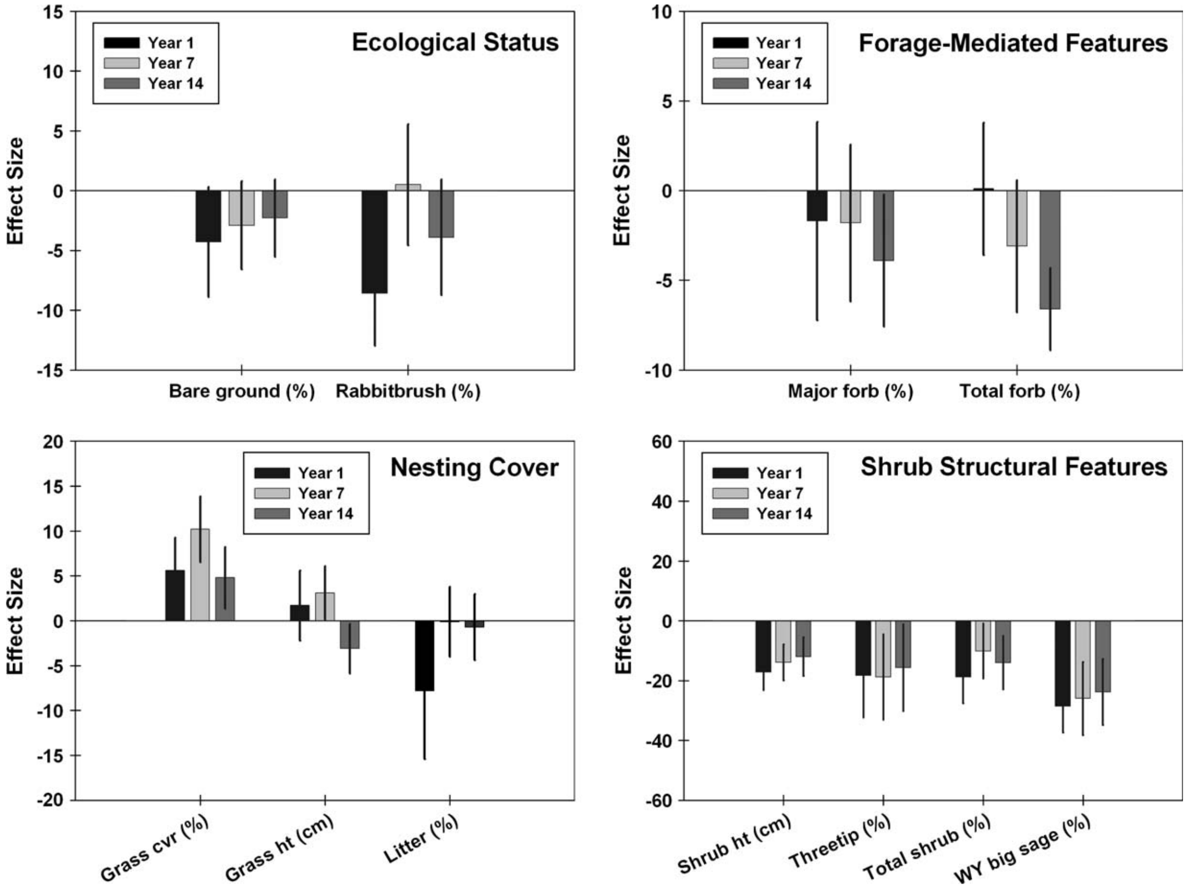

Figure 2. Effect size (±95% CI) of mean SDs in Greater Sage-Grouse habitat features in 1990 (year 1), 1996 (year 7), and 2003 (year 14) from nine transects in burned Wyoming big sagebrush, Big Desert, Idaho, U.S.A. Effect sizes were computed from habitat feature estimates in 1989 (pre-burn) and 1, 7, and 14 years postburn. Effect sizes with confidence intervals that include zeros are not considered statistically detectable from pre-burn variation in habitat features at the 0.95 probability level. Because normality was questionable, we do not have confidence in the recovery of variation for canopy cover of Threetip sagebrush (threetip), total shrubs, and Wyoming big sagebrush (WY big sage). Bare ground includes bare soil, biological soil crusts, and rock.

burned and control transects, but we detected higher rates of increase in major forb cover and forb richness in control transects than in burned transects, indicating slightly negative responses for forbs in burned Wyoming big sagebrush in our study area 14 years postburn. By comparison, Fischer et al. (1996*b*) reported similar cover of Sage-Grouse food forbs but lower abundance of *Hymenoptera* (ants) between burned and unburned habitats 4 years after burning in our study area. Because ants are important in juvenile Sage-Grouse diets (Klebenow & Gray 1968; Peterson 1970), negative effects of fire on food availability in brood-rearing habitat in Wyoming big sagebrush may be more related to insect abundance than forbs.

Conclusions

Our results indicate that prescribed fire induced quantifiable changes to wintering, nesting, and early brood-rearing Sage-Grouse habitat features 14 years after fire in Wyoming big sagebrush in the Big Desert of southeastern Idaho. Specifically, grass and litter required by Sage-Grouse for nest and brood concealment, and Rabbitbrush cover recovered relatively rapidly following fire; major forb cover was similar between burned and control sites, but the rate of increase for major forb cover and richness was greater in control transects, and structurally mediated habitat features required by Sage-Grouse for food and cover in winter and for nest and brood concealment in spring recovered slowly following fire. Consequently, any habitat alterations to Wyoming big sagebrush should be well justified and carefully planned. Herbicide (e.g., Johnson et al. 1996) or mechanical treatments to enhance vegetative features may be more appropriate than prescribed fire because they provide speedier recovery of Sagebrush (Watts & Wambolt 1996).

Implications for Practice

Our results point to several management implications that practitioners should consider relative to Wyoming big sagebrush communities recovering from fire for Greater Sage-Grouse. Because our study covered 14 years in one study area, our results must be considered accordingly.

- Herbaceous plants may recover quickly to preburn levels following fire in Wyoming big sagebrush.
- Variation in cover of Wyoming big sagebrush, Threetip sagebrush, total shrubs, and shrub height was particularly slow in recovering to preburn levels 14 years following fire in our study. This suggests that variability in shrub structure selected by Sage-Grouse in winter and during nesting may take more than 14 years to recover after fire.
- We documented important changes in habitat features in control transects over 14 years in our study area, suggesting that conservation and management of unburned areas are critical to maintain habitat features necessary for Sage-Grouse reproduction and survival. Species richness and cover of major forbs increased in control transects at greater rates than in burned transects. Wyoming big sagebrush cover slowly decreased in control transects and slowly increased in burned transects, although the rate of increase for Threetip sagebrush cover was higher in control than in burned transects. Thus, our data suggest that mature Wyoming big sagebrush communities are not likely static but undergo continual changes. Similarly, Wambolt and Payne (1986) reported a decrease in Wyoming big sagebrush cover and an increase in forbs over 18 years in a nonburned area in southwestern Montana.
- Because shrub structural characteristics required for winter cover and food and nesting and early brood-rearing cover were particularly slow in recovery in our study area, we recommend that managers avoid burning Wyoming big sagebrush but rather implement treatments that maintain Sagebrush and other shrubs when habitat manipulations are necessary (Connelly et al. 2000*b*).

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