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Original Article

Burning and Mowing Wyoming Big Sagebrush: Do Treated Sites Meet Minimum Guidelines for Greater Sage-Grouse Breeding Habitats?

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ABSTRACT Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) treatments are often implemented to improve breeding habitat for greater sage-grouse (*Centrocercus urophasianus*), a species of considerable conservation concern. In 2008 and 2009, we measured vegetation structure available to sage-grouse for breeding at 19 sites that were prescribed burned during 1990–1999 and 2000–2006, 6 sites that were mowed during 2000–2006, and 25 paired, untreated reference sites in the Bighorn Basin of north-central Wyoming, USA. We compared minimum guidelines for canopy cover and height of Wyoming big sagebrush and perennial grass in arid greater sage-grouse breeding habitat (Connelly et al. 2000*b*) to measurements at our sampling sites. Sagebrush canopy cover and height at reference sites met the minimum guidelines. Sagebrush canopy cover at burned and mowed sites did not meet the minimum guideline, except for sites mowed on aridic soils measured during 2009. Burned and mowed (3 of 4 cases) sagebrush did not meet minimum height for breeding up to 19 yr and 9 yr post-treatment, respectively. Perennial grass canopy cover and height met the minimum guidelines for breeding habitat at reference, burned, and mowed sites. Burning increased grass canopy cover, but not height, compared to reference sites in 2 of 8 instances. Because burning, but not mowing, infrequently enhanced grass cover, but not height, and sagebrush structure was reduced by both practices for long periods, managers should consider how treatments may negatively affect Wyoming big sagebrush communities for sage-grouse and consider other practices, including continued nontreatment and improved livestock grazing, to increase grass cover and height.

KEY WORDS *Artemisia tridentata*, *Centrocercus urophasianus*, early brood-rearing, greater sage-grouse, habitat management, mowing, nesting, prescribed burning, Wyoming, Wyoming big sagebrush.

Habitat management for big sagebrush (*Artemisia tridentata*) has generally been conducted to restore or enhance sagebrush communities for land health (Hyder and Sneva 1956, Watts and Wambolt 1996, McDaniel et al. 2005), watershed improvement (Hibbert 1983, Wilcox 2002), increasing forage for livestock (Vale 1974), and wildlife habitat enhancement (Pyle and Crawford 1996, Wambolt et al. 2001, Crawford et al. 2004). The main objectives of treating sagebrush are to reduce conifer encroachment (Holechek et al. 2004, Davies et al. 2011*b*), decrease mature stands of sagebrush (Perryman et al. 2002), create more diverse seral stages across sagebrush landscapes (Davies et al. 2009), and increase herbaceous cover by reducing competition between the herbaceous understory and sagebrush overstory (Dahlgren et al. 2006). Past efforts to reduce big sagebrush have largely been undertaken to increase forage for livestock (Pechanec et al. 1965, Vale 1974, Beck and Mitchell 2000). However, because they change structural and functional components of wildlife habitat, treatments in big sagebrush communities have potential to influence big sagebrush–obligate species such as greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse). Furthermore, management practices such as big sagebrush reduction have contributed to habitat fragmentation and loss of sagebrush habitats used by a variety of wildlife species across the western United States (Knick et al. 2003).

Prescribed burning can be detrimental to sage-grouse populations due to loss of suitable breeding, nesting, and wintering habitat (Connelly and Braun 1997, Connelly et al. 2000*a*, Nelle et al. 2000, Wambolt et al. 2001). Quality of nesting and early brood-rearing habitat may influence sage-grouse population trends by affecting nest

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success and juvenile survival (Connelly and Braun 1997, Crawford et al. 2004, Beck et al. 2006). Structural features of perennial grasses and sagebrush, such as cover and height, are used by sage-grouse for protection from harsh weather and from predators during nesting and early brood-rearing (Gregg et al. 1994, Connelly et al. 2000*b*). In March 2010, the U.S. Fish and Wildlife Service concluded that greater sage-grouse are warranted for protection under the Endangered Species Act of 1973, but the listing was precluded at that time to other species under severe threat of extinction (U.S. Fish and Wildlife Service 2010). This listing decision identified causes of habitat loss and fragmentation, including habitat treatments, as a key reason for sage-grouse declines, and also indicated that treatments may not be beneficial to sage-grouse and that the rationale for conducting them needs further scrutiny (U.S. Fish and Wildlife Service 2010). The current distribution of sage-grouse is estimated to be 50–60% of their historic range (Schroeder et al. 2004) and little sagebrush within its extant range is undisturbed or unaltered from its condition before Euro-American settlement (Knick et al. 2003); therefore, it is imperative that we understand the influence of habitat treatments, particularly in areas used by sage-grouse for important life stages such as breeding.

Effects of prescribed fire on sagebrush communities are of particular importance as fire suppresses recovery of burned basin (*A. t. tridentata*), mountain (*A. t. vaseyana*), and Wyoming (*A. t. wyomingensis*) big sagebrush because these taxa do not resprout after fire (Pechanec et al. 1965, Tisdale and Hironaka 1981). Prescribed burning can elicit positive, short-term ($\leq$10 yr) response in the herbaceous understory in mountain big sagebrush stands, but it does not elicit short-term positive herbaceous responses in Wyoming big sagebrush or long-term (>10 yr) positive herbaceous responses in Wyoming or mountain big sagebrush (Beck et al. 2011). Wyoming big sagebrush is particularly vulnerable to fire because invasion of weedy exotics such as cheatgrass (*Bromus tectorum*) have led to increasing wildfire frequencies and subsequent loss and degradation of these important communities (Baker 2011, Davies et al. 2011*b*). Postfire recovery may take 25–100 yr in mountain big sagebrush, whereas recovery of Wyoming big sagebrush following burning is often much slower and can be highly variable (Baker 2011) and may take as long as 50–120 yr for full recovery (Baker 2006). Fire rotations in Wyoming big sagebrush range in frequency from 200 yr to 350 yr and are dependent on climate, topography, plant composition, and ecological site characteristics (Baker 2011).

Mowing and other mechanical treatments such as pipe harrowing and smooth anchor chaining in one direction to reduce density of sagebrush (Monsen et al. 2004) are seen as alternatives to prescribed burning because they leave smaller live sagebrush plants after treatment (Davies et al. 2009), leading to a rate of recovery that should be more rapid than that following burning. As compared to prescribed burning, mowing leaves residual debris used as cover by sagebrush-obligate wildlife (Dahlgren et al. 2006), reduces soil erosion (McKell 1989), and maintains the ability of sites to capture snow (Sturges 1977). Also, mowing can be easily controlled and is usually applied to smaller areas than prescribed burns. Although mowing leaves residual sagebrush plants and woody debris, it reduces Wyoming big sagebrush cover and volume for $\geq$20 yr (Davies et al. 2009). However, there is little information indicating positive or negative aspects of mowing for habitat structure used by sage-grouse for nesting or brood-rearing.

Connelly et al. (2000*b*) compiled information from existing studies from approximately 1950 to 2000 to recommend guidelines for managing and restoring sage-grouse habitats. These guidelines are frequently cited by managers as a baseline of information for sage-grouse habitats and are recommended to be adapted to local land conditions. Using the Connelly et al. (2000*b*) guidelines for arid sites, we compared canopy cover and height of Wyoming big sagebrush and perennial grasses at mowed, prescribed burned, and reference sites in the Bighorn Basin of north-central Wyoming, USA used by sage-grouse for breeding activities (lek sites, nesting, and early brood-rearing). Comparative studies such as ours are important for scientists and practitioners because they evaluate the relative value of treatments in meeting objectives. We also provide a retrospective comparison of perennial grass and Wyoming big sagebrush recovery response at 2 time scales (1990–1999 and 2000–2006) that are applicable to time horizons where treatments may have relevance to sage-grouse populations (Fedy and Doherty 2011). Comparing response variables collected at treated and nearby reference sites provided us a second way to better understand how sagebrush treatments influence key attributes of sage-grouse breeding habitat.

STUDY AREA

The Bighorn Basin encompassed 32,002 km^2 and included portions of Big Horn, Hot Springs, Park, and Washakie counties in north-central, Wyoming, USA. The Bighorn Basin was bordered by the Absoraka Mountains to the west, Beartooth and Pryor Mountains to the north, Bighorn Mountains to the east, and Bridger and Owl Creek Mountains to the south. The average valley elevation was 1,524 m (1,116 m min) and was composed of badland topography and intermittent buttes. The Bighorn Basin was semi-arid, with average annual precipitation ranging from 12.7 cm to 38.1 cm with most precipitation occurring in April and May as rain (Big Horn Basin Local Sage-Grouse Working Group 2007). Dominant land uses in the sagebrush areas between agricultural and forest lands in the Bighorn Basin included livestock grazing, limited bentonite mining, with most current extraction occurring in lower elevation saltbush desert, and oil and gas extraction.

Native flora associated with big sagebrush communities in the Bighorn Basin included perennial grasses, such as bluebunch wheatgrass (*Pseudoroegneria spicata*), blue grama (*Bouteloua gracilis*), Indian ricegrass (*Achnatherum hymenoides*), needle and thread (*Hesperostipa comata*), and western wheatgrass (*Pascopyrum smithii*); shrubs such as Wyoming and mountain big sagebrush, greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus viscidiflorus* and

Ericameria nauseosa), and spineless horsebrush (*Tetradymia canescens*); and forbs–subshrubs including buckwheat (*Eriogonum* spp.), desert parsley (*Lomatium* spp.), globemallow (*Sphaeralcea* spp.), milkvetch (*Astragalus* spp.), prairie sagewort (*A. frigida*), pussytoes (*Antennaria* spp.), sego lily (*Calochortus nuttallii*), and Western yarrow (*Achillea millefolium*). Invasive species in the Bighorn Basin included cheatgrass, Japanese brome (*B. japonicus*), Canada thistle (*Cirsium arvense*), hoary cress (*Cardaria draba*), knapweed (*Centaurea* spp.), and toadflax (*Linaria* spp.).

Since 1984, the U.S. Department of Interior-Bureau of Land Management (BLM) has conducted 156 prescribed burns (100 km^2 burned) and 55 mowing treatments (36 km^2 mowed) in big sagebrush communities to reach vegetation management objectives, including enhancing habitat conditions for sage-grouse. Because these treatments typically occurred in areas used by sage-grouse, they had potential to affect sage-grouse populations in the Bighorn Basin. In addition, 91 wildfires have burned 520 km^2 of sagebrush since 1980.

METHODS

Sampling Design

We sampled insect, soil, and vegetation parameters from May to July 2008 and 2009 along 3, 100-m transects, extending N–S, and placed within 25 treated and 25 untreated reference sites (Fig. 1) defined by combinations of soil group, age since treatment by decade (1990–1999 and 2000–2006), and treatment type. Vegetation at mowed sites was mowed to approximately 20 cm above the soil surface. We spaced transects 50 m apart starting at a randomly determined point in each treatment and reference site, no closer than 50 m from the nearest untreated edge to avoid edge effects. At sites where Wyoming big sagebrush had been mowed in strips, we placed one 100-m transect in 3 mowed strips at an average spacing of 55 m (range = 32–93 m). Functional response variables related to grouse food-forb availability were measured along the 2 outside 100-m transects, whereas insect abundance and soil quality were measured along all 3 transects at each site (Hess 2011). Vegetation structural response variables (this paper) were sampled along the middle transect at each site. To ensure that our data were comparable across years, we sampled the same sites within 1 week in 2008 and 2009. Because burning and mowing occurred irregularly across the Bighorn Basin, our sampling locations needed to reflect a spatially balanced (i.e., geographically distributed) selection of sampling sites. To ensure this, we used Program S-Draw (Western Ecosystems Technology, Incorporated, Cheyenne, WY) to select sampling sites using the Universal Transverse Mercator coordinates of each treatment site in a generalized random tessellation stratified sample.

We randomly selected 3 treated sites (burned sites, $\bar{x} = 0.4$ km^2, SE = 0.1 km^2; mowed sites, $\bar{x} = 3.0$ km^2, SE = 1.0 km^2) from each treatment combination for field sampling in May–July 2008 and repeated sampling at these sites in May–July 2009. To provide comparative sites, we randomly selected 1 untreated reference site within a geographic constraint of 0.8 km ($\bar{x} = 0.4$ km) from each randomly selected treated site. However, in some instances, we had to compromise our distance criteria to find a nontreated site (range = 0.2–1.5 km). Research in Wyoming has shown most (64%) sage-grouse nesting to occur within 5.0 km of

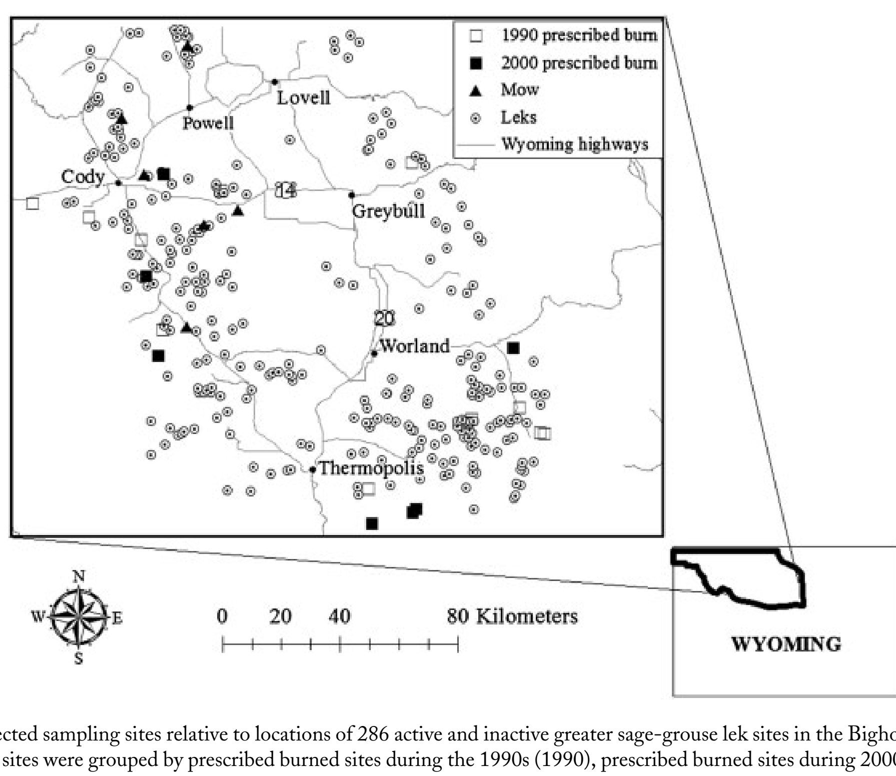

Figure 1. Randomly selected sampling sites relative to locations of 286 active and inactive greater sage-grouse lek sites in the Bighorn Basin, Wyoming, USA, 2008 and 2009. Sampled sites were grouped by prescribed burned sites during the 1990s (1990), prescribed burned sites during 2000–2006 (2000), and mowed sites (during 2000–2006).

leks in contiguous habitat (Holloran and Anderson 2005). Mean distance from treated and reference sites to nearest known sage-grouse leks in our study was 4.5 km (range = 0.2–11.8 km). Mowing treatments only occurred in the autumn, whereas burning occurred in autumn and spring. After conducting 2-sample *t*-tests (PROC TTEST; SAS Institute 2008) between treated sites for each response variable, we found no difference ($P < 0.05$) between autumn- and spring-burned sites, which permitted us to combine prescribed burned sites by soil type and decade of treatment. In addition, we collected data at 5 burned sites in mountain big sagebrush communities in 2008 and 2009, but did not include these in our analysis.

We refer to our sample site combinations as chronosequences, which are hypothetical portrayals of soil change as a function of time (Fanning and Fanning 1989). General soil groupings that comprised the soils in the Bighorn Basin were aridic, fine-textured; aridic, coarse-textured–skeletal; udic, cryic; and ustic, frigid. We based these groupings on soil temperature, moisture, and texture, which largely influenced establishment and development of big sagebrush communities in the Bighorn Basin (Young et al. 1999; L. Munn, University of Wyoming, personal communication). Much of the sage-grouse nesting and early brood-rearing activity in the Bighorn Basin was centered on areas overlying aridic, fine-textured and ustic, frigid soils, which we retained for consideration.

We excluded from consideration any untreated sites that were visibly degraded, damaged, or destroyed. Although untreated sites that were not degraded, damaged, or destroyed were also affected by past land management practices (e.g., livestock and wildlife herbivory), we assumed they represented the potential of the surrounding landscape to provide vegetation structure and ecological function, as would be expected given common grazing pressure in the Bighorn Basin. Our assumptions were supported because untreated reference sites occurred on the same soils, existed under the same climatic conditions, and were subjected to the same grazing management strategies as treated sites. Improved livestock grazing management practices have been implemented in the Bighorn Basin in the past 2 decades, leading to improved rangeland conditions—these changes have likely elicited a positive vegetative response in treated and untreated Wyoming big sagebrush communities (J. Mononi, Bureau of Land Management Cody Field Office, personal communication). Findings from our study, thus, likely reflected vegetation responses associated with improved grazing practices. However, they should not affect comparisons between mowed and prescribed burned sites or between treatment and reference sites. We assessed whether grazing had occurred at each site prior to sampling, but found minimal-to-no evidence that it had occurred. This is important to note because some cattle grazing had occurred in 2008 in grazing allotments where 4 of our sites were located prior to field sampling (J. Mononi, personal communication).

Our analysis focused on sage-grouse breeding habitat. According to Connelly et al. (2000*b*), breeding habitat contains sage-grouse lek sites, nest sites, and early brood-rearing areas. We specifically evaluated habitat characteristics for nesting and early brood-rearing (<2 weeks posthatching; Thompson et al. 2006), which occur during May through June (Connelly et al. 2000*b*, Holloran et al. 2005). In both years, we initiated data collection in late May at lower elevations and ended field sampling in late July at higher elevation sites to mimic upslope movements of adult female sage-grouse with broods (Schroeder et al. 1999).

Structural Measurements

We used a meter stick to measure droop height (cm) of grasses (Connelly et al. 2003) and shrubs (tallest leader [cm]; Connelly et al. 2003) at each 5-m location along the middle 100-m transect established at each site. To compute Wyoming big sagebrush canopy cover we first computed elliptical area of sagebrush plants (E; cm^2; Wambolt et al. 1994), as $E = \pi \times (MJ \times 0.5) \times (MN \times 0.5)$. We determined the major axis (MJ) by measuring horizontal distance across living material of each Wyoming big sagebrush plant and measured the minor axis (MN) as the maximum width of living sagebrush material perpendicular to the horizontal axis. We used the MJ and MN axes to find the area of an ellipse to compute Wyoming big sagebrush crown (cm^2) area. We recorded numbers of Wyoming big sagebrush plants rooted in a 1-m belt on the right side of each 100-m middle transect. We multiplied number of Wyoming big sagebrush per 100-m^2 belt transect by mean crown area (cm^2) of Wyoming big sagebrush to compute area covered by Wyoming big sagebrush crown. We calculated percent canopy cover as area covered by Wyoming big sagebrush crown divided by the belt area and multiplied by 100. By comparison, our approach to estimating Wyoming big sagebrush canopy cover was not statistically different (J. E. Hess and J. L. Beck, unpublished data) than the line-intercept method (Canfield 1941, Wambolt et al. 2006) that is often employed to estimate sagebrush canopy cover in sage-grouse habitat assessments (Connelly et al. 2003). At each 5-m mark along the 100-m tape, we positioned a 20-cm × 50-cm quadrat to estimate canopy cover of perennial grasses according to the following cover classes: 1 = 0–1%; 2 = 1–5%; 3 = 5–25%; 4 = 25–50%; 5 = 50–75%; 6 = 75–95%; and 7 = >95% (Daubenmire 1959).

Data Analyses

We computed means (± 1 SE) by averaging across treatment and reference sites sampled each year for each treatment combination. We compared these estimates against minimum sage-grouse breeding habitat guidelines at arid sites for canopy cover and height of sagebrush and perennial grass published in Table 3 of Connelly et al. (2000*b*). Connelly et al. (2000*b*) suggested minimum guidelines for sage-grouse breeding habitat in arid landscapes of 15% sagebrush canopy cover, 30-cm sagebrush height, 15% perennial grass canopy cover, and 18-cm perennial grass height. Canopy cover and height of perennial grass and Wyoming big sagebrush are useful to compare because they have been identified as being critical for successful sage-grouse nesting and early brood-rearing (Connelly et al. 2000*b*, Crawford et al. 2004). We tested whether estimated responses met or exceeded minimum guidelines with one-sample, one-tailed t-tests (PROC TTEST; SAS Institute 2008). We assessed normality of residuals for our one-sample t-test data with the Shapiro–Wilk statistic (PROC UNIVARIATE; SAS Institute 2008) and used natural log or inverse (1/y) transformations to achieve normality in those instances when residuals were not normally distributed. We used 2-sample t-tests to evaluate differences between reference and treated sites (PROC TTEST; SAS Institute 2008). We assessed normality of residuals with the Shapiro–Wilk statistic (PROC UNIVARIATE; SAS Institute 2008) and equality of variances with Hartley's test (Pearson and Hartley 1966). When the assumption of equal variance was not met, we conducted 2-sample t-tests using a weighted t-test (1/[square root of the variance]). We set our alpha level for all tests at 0.05 and report raw means and standard errors for all estimates.

RESULTS

During 2008 and 2009, we sampled canopy cover and height of perennial grass and Wyoming big sagebrush at 6 treatment combinations (Fig. 1): 1) mowed sites on aridic soils ($n = 3$), 2) mowed sites on ustic soils ($n = 3$), 3) sites that were prescribed burned during the 1990s on aridic soils ($n = 6$), 4) sites that were prescribed burned during the 1990s on ustic soils ($n = 6$), 5) sites that were prescribed burned during 2000–2006 on aridic soils ($n = 3$), and 6) sites that were prescribed burned during 2000–2006 on ustic soils ($n = 4$). We also sampled canopy cover and height of perennial grass and Wyoming big sagebrush at an equal number of random locations paired with each of the 25 treated sites, yielding 50 sampled sites.

Wyoming Big Sagebrush Structure

Reference sites met the minimum breeding habitat guideline for Wyoming big sagebrush canopy cover in 2008 and 2009 ($P > 0.05$; Fig. 2).The minimum sage-grouse breeding habitat guideline for Wyoming big sagebrush canopy cover was not met at any prescribed burned treatment ($P < 0.05$), but this guideline was met at sites mowed on aridic soils that were measured in 2009 ($t_2 = -1.19$, $P = 0.357$; Fig. 2). Wyoming big sagebrush canopy cover did not differ between mowed and reference sites in 2008 or 2009 ($P > 0.05$), but cover did differ between prescribed burned and reference sites in 2008 and 2009 ($P < 0.05$; Fig. 2).

Reference sites met the minimum guideline for Wyoming big sagebrush height in breeding habitat in 2008 and 2009 (Fig. 3). Wyoming big sagebrush heights did not meet the minimum breeding habitat guideline at prescribed burned sites on aridic or ustic soils or mowed sites on ustic soils in 2008 or 2009 ($P < 0.05$; Fig. 3). Wyoming big sagebrush height measured at mowed sites on aridic soils met the minimum guideline for breeding habitat in 2008 ($\bar{x} = 24.9$ cm, SE = 4.8, $t_2 = -1.23$, $P = 0.345$), but not in 2009 ($\bar{x} = 20.9$ cm, SE = 2.7, $t_2 = -3.34$, $P = 0.079$; Fig. 3). Sagebrush height at treatment sites was lower in all cases than at reference sites, except for mowed sites on aridic soils measured in our 2008 field season ($t_4 = 0.88$, $P = 0.431$) or on aridic ($t_4 = 0.34$, $P = 0.749$) or ustic ($t_4 = 1.80$, $P = 0.147$; Fig. 3) soils measured in our 2009 field season, which did not differ from reference sites.

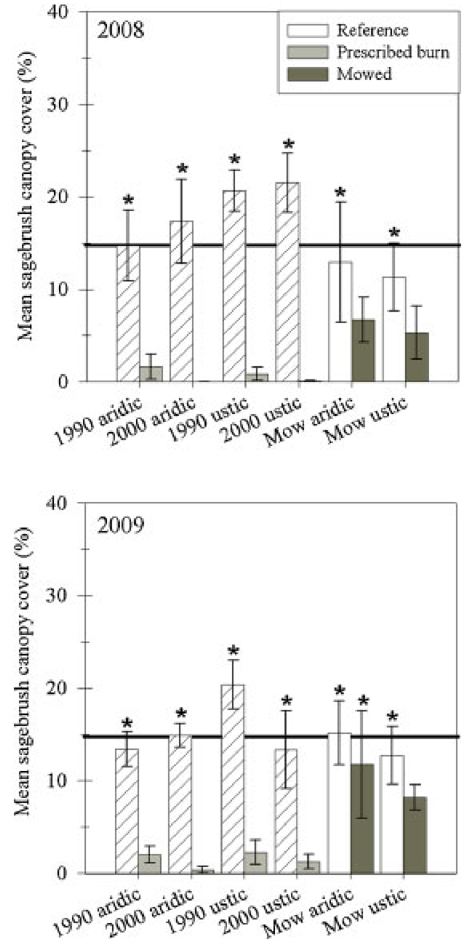

Figure 2. Mean (± 1 SE) Wyoming big sagebrush canopy cover (%) for 6 combinations of treatments in the Bighorn Basin, Wyoming, USA, 2008 and 2009. Horizontal line represents the Connelly et al. 2000*b*) recommended minimum guideline for sagebrush canopy cover (15%) for arid sage-grouse breeding habitat. Asterisk denotes the breeding guideline was met. Hashed columns indicate reference sites that were significantly different ($P < 0.05$) from treatment sites. Aridic and ustic refer to different general soil groupings where aridic were fine-textured soils in more arid climates and ustic were soils with intermediate soil moisture in cool-temperature regimes.

Perennial Grass Structure

Perennial grass canopy cover met the minimum breeding habitat guideline at mowed, prescribed burned, and reference sites in 2008 and 2009 (Fig. 4). In 2008, perennial grass canopy cover was 1.9 times higher ($t_{10} = -3.71$, $P = 0.004$) on sites prescribed burned in the 1990s on ustic soils ($\bar{x} = 31.3\%$, SE = 3.7) than at their corresponding reference sites ($\bar{x} = 16.4\%$, SE = 1.7; Fig. 4). In 2009, perennial grass canopy cover was 1.5 times higher ($t_4 = -2.69$, $P = 0.023$) on sites prescribed burned in the 1990s on ustic soils ($\bar{x} = 47.1\%$, SE = 4.4) than at their corresponding reference sites ($\bar{x} = 32.4\%$, SE = 3.3; Fig. 4). Perennial grass height met the breeding habitat guideline at mowed, prescribed burned, and reference sites in 2008 and 2009 (Fig. 5). Perennial grass heights at reference and treatment

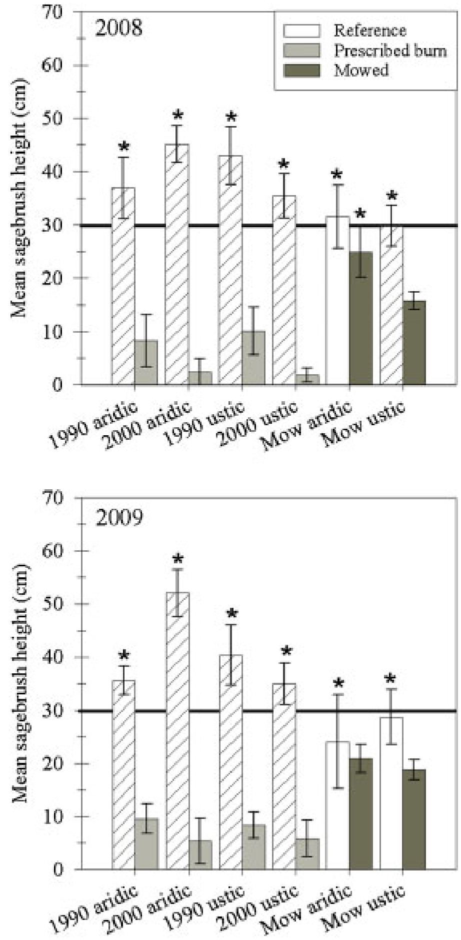

Figure 3. Mean (± 1 SE) Wyoming big sagebrush height (cm) for 6 combinations of treatments in the Bighorn Basin, Wyoming, USA, 2008 and 2009. Horizontal line represents the Connelly et al. (2000*b*) recommended minimum guideline for sagebrush height (30 cm) for arid sage-grouse breeding habitat. Asterisk denotes the breeding guideline was met. Hashed columns indicate reference sites that were significantly different ($P < 0.05$) from treatment sites. Aridic and ustic refer to different general soil groupings where aridic were fine-textured soils in more arid climates and ustic were soils with intermediate soil moisture in cool-temperature regimes.

sites did not differ for any treatment combination in 2008 or 2009 ($P > 0.05$; Fig. 5).

DISCUSSION

Connelly et al. (2000*b*) suggested that habitat treatments for sage-grouse should be designed to elicit rapid recovery while disturbing a small amount of sagebrush communities. Our study did not evaluate spatial aspects of recovery of treated sites, but we did provide a temporal perspective of recovery at prescribed burned and mowed Wyoming big sagebrush communities. Overall, we found mowing as much as 9 yr after treatment did not maintain adequate Wyoming big sagebrush canopy cover for breeding habitat minimum guidelines, except for sites mowed on aridic soils that were measured in 2009. Prescribed burning greatly reduced the canopy cover and height of Wyoming big sagebrush at our burned study sites; the sites did not recover sufficiently to meet guidelines 19 yr after treatment. Neither mowing nor prescribed burning retained adequate sagebrush height for breeding except for mowed sites on aridic soils that were measured in 2008. In addition, sagebrush height at mowed sites did not differ from sagebrush height at reference sites in 3 of 4 cases. Wyoming big sagebrush is noted for its slow recovery following treatment (Beck et al. 2009, Davies et al. 2009, Baker 2011). Our results indicate that mowing should result in more rapid recovery of Wyoming big sagebrush canopy cover and height as compared to burning. However, time for mowed communities to recover to pretreatment levels of Wyoming big sagebrush canopy cover and height needs to be further evaluated. In all cases over both years, perennial grass canopy cover and height at prescribed burned and mowed sites surpassed minimum guidelines for breeding habitat. However, the lack of differences we found in perennial grass canopy cover and height between mowed and paired reference sites suggests that mowing is not effective in increasing perennial grass structure in Wyoming big sagebrush communities. In comparison, prescribed burning did increase canopy cover, but not height, of perennial grass in 2 of 8 cases as compared to reference sites.

Connelly et al. (2000*b*) developed minimum guidelines by compiling research results across the range of sage-grouse. Therefore, comparisons to these guidelines may differ depending on geographic location. We, thus, examined 2 studies conducted in Wyoming and compared our response variables to their nest and early brood-rearing site averages. We found Holloran (1999) and Lyon (2000) nest and early brood-rearing site estimates were within the range of the Connelly et al. (2000*b*) breeding habitat guidelines, except for perennial grass canopy cover. Both studies had lower mean perennial grass canopy cover at nest sites (4.6% canopy cover from Holloran [1999]; 10.6% from Lyon [2000]) and early brood-rearing sites (5.9% canopy cover from Holloran [1999]; 14.2% canopy cover from Lyon [2000]) than the minimum Connelly et al. (2000*b*) guidelines of 15% perennial grass canopy cover. Our sites in the Bighorn Basin may be more comparable to the range-wide Connelly et al. (2000*b*) minimum guidelines due to higher perennial grass canopy cover than that reported by Holloran (1999) and Lyon (2000).

Much discussion has centered on application of the Connelly et al. (2000*b*) guidelines for sage-grouse habitat management (Bates et al. 2004). Connelly et al. (2000*b*) indicated that structural characteristics of sagebrush communities vary greatly among landscapes and they suggested that local biologists and rangeland ecologists develop height and cover requirements for local areas. However, sage-grouse are known to prefer areas with greater sagebrush canopy cover, taller grasses for nesting, and greater herbaceous canopy cover for brood-rearing than at randomly available sites throughout their range (Wallestad and Pyrah 1974, Gregg et al. 1994, Connelly et al. 2000*b*, Holloran et al. 2005). A meta-analysis evaluating findings from multiple studies showed that the Connelly et al. (2000*b*) guidelines provide a reasonable representation of structural features found at breeding locations across the range of sage-grouse (Hagen et al. 2007). If Wyoming big sagebrush characteristics in untreated communities do not meet the minimum Connelly

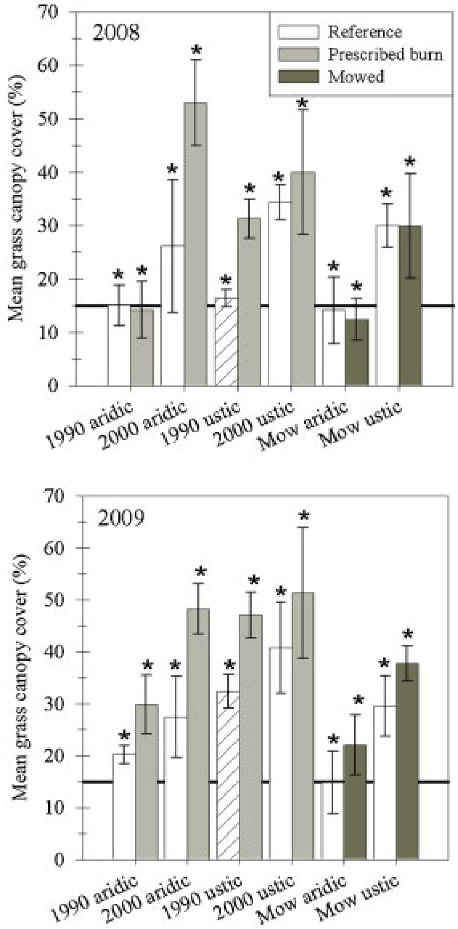

Figure 4. Mean (± 1 SE) perennial grass canopy cover (%) for 6 combinations of treatments in the Bighorn Basin, Wyoming, USA, 2008 and 2009. Horizontal line represents the Connelly et al. (2000*b*) recommended minimum guideline for perennial grass canopy cover (15%) for arid sage-grouse breeding habitat. Asterisk denotes the breeding guideline was met. Hashed columns indicate reference sites that were significantly different ($P < 0.05$) from treatment sites. Aridic and ustic refer to different general soil groupings where aridic were fine-textured soils in more arid climates and ustic were soils with intermediate soil moisture in cool-temperature regimes.

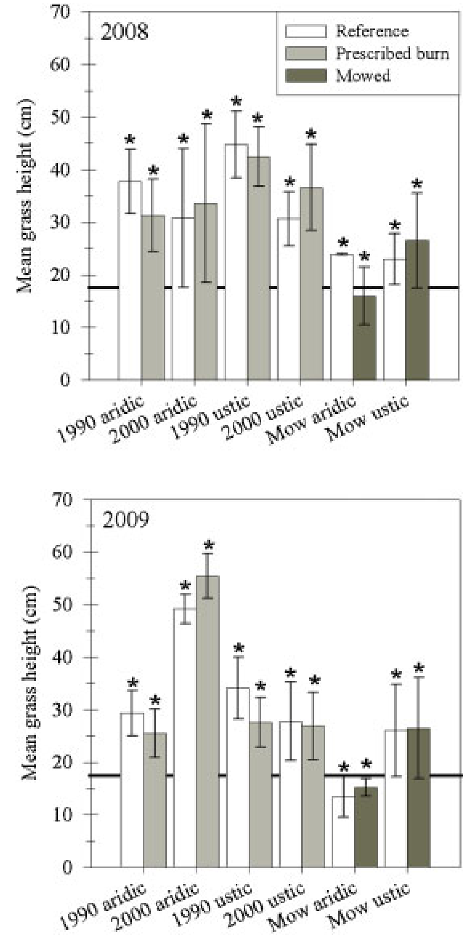

Figure 5. Mean (± 1 SE) perennial grass height (cm) for 6 combinations of treatments in the Bighorn Basin, Wyoming, USA, 2008 and 2009. Horizontal line represents the Connelly et al. (2000*b*) recommended minimum guideline for perennial grass height (18 cm) for arid sage-grouse breeding habitat. Asterisk denotes the breeding guideline was met. There were no statistical differences in perennial grass height between reference and treatment sites for any treatment combination. Aridic and ustic refer to different general soil groupings where aridic were fine-textured soils in more arid climates and ustic were soils with intermediate soil moisture in cool-temperature regimes.

et al. (2000*b*) guidelines, managers should investigate whether treatments may negatively affect sage-grouse use of those communities. In these instances, it is more appropriate to consider changes in land management practices, such as improved livestock grazing that increases perennial grass canopy cover and height for nesting and brood-rearing sage-grouse, rather than implementing sagebrush reduction treatments. Furthermore, other factors, including insect abundance and diversity, soil quality, and forb abundance and diversity, need to be examined to decide which types of treatment (or nontreatment) provide better breeding habitats for sage-grouse (Peterson 1970, Wallestad and Eng 1975, Johnson and Boyce 1990, Barnett and Crawford 1994, Hess 2011).

Enhancement of herbaceous attributes is often cited as a principal reason for treatments (Dahlgren et al. 2006). However, comparisons between values at reference and treatment sites in our study indicated that perennial grass height was not enhanced through burning or mowing. In 2008 and 2009 we determined that perennial grass canopy cover was enhanced at sites prescribed burned in the 1990s on ustic soils. Perennial grass height and canopy cover at untreated reference sites met the Connelly et al. (2000*b*) guidelines. Our findings are supported by other studies showing minimal or no improvement of structural features of sagebrush or perennial grasses following treatment in Wyoming big sagebrush communities (Wambolt and Payne 1986; Beck et al. 2009; Davies et al. 2009, 2011*a*). Our findings indicate that meeting perennial grass guidelines for canopy cover and height for sage-grouse breeding habitat were attainable by burning and mowing. However, our reference sites clearly showed that perennial grass canopy cover and height guidelines were met without mowing and burning, and treatments only resulted in an increase in perennial grass canopy cover in 2 instances at prescribed burned sites over reference sites. Moreover, Wyoming big sagebrush canopy cover and height required for sage-grouse breeding habitat was drastically reduced for long time periods at the expense of potentially increasing perennial grass structure variables. Because sagebrush is essential to maintaining native plants and limiting invasion of exotic plants in sagebrush communities (Prevéy et al. 2010, Reisner 2010), it is imperative that treatments should be limited to those that do not eliminate or greatly reduce sagebrush. By comparison, Davies et al. (2011*a*) found that mowing Wyoming big sagebrush communities with intact native understory in southeastern Oregon, USA generally did not increase biomass, cover, or density of perennial herbaceous plants, but rather, led to an increased risk for dominance by annual grasses and annual forbs as much as 3 yr after treatment, suggesting negative effects from mowing, which reduces, but does not eliminate, sagebrush.

MANAGEMENT IMPLICATIONS

Our results suggest 2 considerations for managers considering burning or mowing to enhance Wyoming big sagebrush for sage-grouse in arid habitat similar to the Bighorn Basin. First, burning never resulted in Wyoming big sagebrush of adequate height or canopy cover for recommended breeding habitat guidelines and mowing only resulted in adequate Wyoming big sagebrush height and canopy cover in 1 yr (2008 for height and 2009 for canopy cover) on sites mowed on aridic soils. Second, if Wyoming big sagebrush characteristics in untreated communities do not meet the minimum Connelly et al. (2000*b*) guidelines, managers should consider consequences of sagebrush-reduction treatments in those areas, and instead consider other practices such as grazing management to increase perennial grass cover and height (Beck and Mitchell 2000) or managing areas without treatment. Researchers have recommended caution when considering treatments at lower elevations (Davies et al. 2011*b*) and recommend conducting treatments in areas with large contiguous stands of sagebrush (Beck and Mitchell 2000, Connelly et al. 2000*b*, Dahlgren et al. 2006) and in areas where sufficient and suitable nesting habitat is left intact (DeLong et al. 1995). Because scale and size of treatments are also a factor in how treatments may affect sage-grouse, we remind habitat managers that Connelly et al. (2000*b*) recommended treating no more than 20% of breeding habitat in Wyoming big sagebrush every 30 yr and deferring additional treatments until treated areas once again provide suitable breeding habitat. Although our findings are specific to the Bighorn Basin of north-central Wyoming, we believe they are relevant to other ecologically similar Wyoming big sagebrush-dominated landscapes where prescribed burning and mowing are planned or have been used to manage nesting and early brood-rearing habitat for sage-grouse.

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