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Greater Sage-Grouse Response to Sagebrush Management in Utah

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Abstract

*Greater sage-grouse (*Centrocercus urophasianus*) populations throughout much of their range have been declining. These declines have largely been attributed to the loss or deterioration of sagebrush (*Artemisia *spp.) habitat. In response government agencies such as the United States Department of Agriculture, Natural Resources Conservation Service are cost-sharing on management practices designed to improve habitat conditions for sage-grouse. Little is known regarding sage-grouse response to various sagebrush management techniques. We studied the effects of reducing sagebrush canopy cover using 2 mechanical (Dixie harrow and Lawson aerator) treatments and 1 chemical (Tebuthiuron) treatment on greater sage-grouse use of brood-rearing habitats on Parker Mountain, Utah, USA. To conduct this experiment, we identified 19 40.5-ha plots that exhibited >40% mountain big sagebrush (*A. tridentata vaseyana*) canopy cover and randomly assigned 16 as treatment or controls (4 replicates each). Tebuthiuron and Dixie-harrow-treated plots had more forb cover than did control plots (*$P = 0.01$* and 0.02, respectively) in post-treatment periods. Greater sage-grouse brood use was higher in Tebuthiuron than control plots (*$P = 0.01$*). We believe this was attributed to increased herbaceous cover, particularly forb cover. However, in all plots, sage-grouse use was greatest within 10 m of the edge of the treatments where adjacent sagebrush cover was still available. Although the treatments we studied resulted in the plots achieving sage-grouse brooding-rearing habitat guidelines, caution should be exercised in applying these observations at lower elevations, on sites with less annual precipitation, or on a different subspecies of big sagebrush. Prior to using these techniques to implement large-scale sagebrush treatments, the specific rationale for conducting them should be clearly identified. Large-scale projects using the techniques we studied would not be appropriate within sage-grouse wintering or nesting habitat.*
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Key words

2002 Farm Bill, Artemisia *spp., brood-rearing,* Centrocercus urophasianus*, Dixie harrow, greater sage-grouse, habitat management, Lawson aerator, sagebrush, Tebuthiuron, Utah.*

Greater sage-grouse (*Centrocercus urophasianus*) are sagebrush (*Artemisia* spp.) obligates that inhabit sagebrush areas throughout the western United States (Patterson 1952, Schroeder et al. 2004). Sage-grouse populations throughout much of this range have been declining (Connelly et al. 2004). These declines have largely been attributed to the loss or deterioration of sagebrush habitat (Braun et al. 1977, Connelly and Braun 1997, Braun 1998, Connelly et al. 2004). Additionally, in some sagebrush communities canopy cover has increased to such densities that it is reducing or eliminating herbaceous understory cover and diversity (West 1983). Reduced herbaceous understory cover and diversity also may impact sage-grouse productivity (Connelly et al. 2000).

Sage-grouse prefer a more open shrub canopy cover (Martin 1970, Wallestad 1971) that exhibits a high grass and forb component (~15% cover) for brood-rearing habitat (Sveum et al. 1998, Connelly et al. 2000). These areas typically provide the forb and insect abundance and diversity that are important components of brood-rearing habitat (Dunn and Braun 1986, Apa 1998). Connelly et al. (2000) and Beck and Mitchell (2000) suggested that sagebrush canopy cover should be reduced to 10–25% in brood-rearing habitats that exhibit a low grass and forb component.

The Western Association of Fish and Wildlife Agencies (WAFWA) identified a need to conduct experiments of sufficient scale to demonstrate the effect of various management practices in stabilizing and enhancing sage-grouse populations and sagebrush ecosystems (WAFWA 1999). The scientific literature clearly indicates that sage-grouse are dependent on large expanses of sagebrush-dominated landscapes. However, more information is required regarding the appropriate management techniques and scale of management activity within these areas to improve seasonal habitats for sage-grouse.

Approximately 30% of the sagebrush lands in the western United States are privately owned (Connelly et al. 2004). The greatest percentages of privately owned sagebrush lands occur in Montana, Colorado, Washington, and South Dakota. Of states containing the largest total area of sagebrush, the states with the greatest percentage in private ownership are Wyoming (38%), Oregon (27%), Nevada (17%), and Colorado (17%). The Utah Division of Wildlife Resources (UDWR) estimates that in Utah over 50% of the remaining sage-grouse populations in the state occur on private or state land (UDWR 2002). Box Elder, Garfield, Rich, Uintah, and Wayne Counties, all with an estimated

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>500 breeding sage-grouse (Beck et al. 2003), have portions of their populations that rely on nonfederal land for at least a part of their life cycle, along with many smaller populations throughout Utah.

The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) has placed a high priority on encouraging conservation practices on private lands, and other nonfederal lands, to benefit at-risk species like sage-grouse. Passage of the Farm Security and Rural Investment Act of 2002, commonly referred to as the Farm Bill, authorized programs such as the Wildlife Habitat Incentives Program (WHIP) to provide cost-share to landowners to implement conservation practices to improve wildlife habitat. With increased application of conservation practices designed to benefit wildlife on private land, there is a need for better information regarding the effects of specific conservation practices and technologies on at-risk species.

The purpose of this study was to assess the effects of 1 chemical and 2 mechanical treatments conducted to reduce mountain big sagebrush (*A. tridentata vaseyana*) canopy cover on sage-grouse use of historical brood-rearing habitat. The removal of sagebrush to increase herbaceous cover has been a common practice used to increase livestock forage (Connelly et al. 2004), but little scientific research exists regarding the effectiveness of chemical and mechanical treatments on high-elevation sagebrush communities to improve sage-grouse habitat.

Study Area

This study was conducted on Parker Mountain located in Garfield, Sevier, Piute, and Wayne counties of Utah (Fig. 1). The area consisted of ~107,478 hectares, of which 21,685 ha (20%) were managed by the United States Forest Service (USFS), 36,398 ha (34%) by Bureau of Land Management (BLM), 43,863 ha (41%) by Utah School and Institutional Trust Lands Administration (SITLA), and 5,532 ha (5%) by private landowners. Parker Mountain was a unique high-elevation sagebrush-dominated plateau at the southern edge of greater sage-grouse range. It was one of the few areas remaining in Utah with relatively stable numbers (the breeding population of sage-grouse exhibited a moving average of >500 from 1996 to 2000) of greater sage-grouse and contained some of the largest contiguous tracts of sagebrush in the state (Beck et al. 2003).

The predominant land use on Parker Mountain was domestic livestock grazing. Sheep and cattle were grazed in 5 allotments. The Parker Mountain Block allotment contained 10 pastures, of which one was deferred grazing each year until September, excepting the lowest-elevation pasture (Cyclone Knoll Co-op). Stocking densities were 1.46 ha per animal unit month (Ron Torgerson, SITLA Biologist, personal communication). Livestock grazing was initiated on the 3 lowest-elevation pastures in June. As vegetation in these pastures desiccated, livestock were sequentially herded into the 7 higher-elevation pastures. In addition to livestock, a large herd of pronghorn (*Antilocarpa americana*) grazed the mountain continuously. Parker Mountain also provided hunting opportunities, off-highway-vehicle use, camping, and other recreational activities.

Three mid-elevation pastures (2,700–2,900 m) were used by sage-grouse during late brood-rearing activities, with limited nesting and early brood-rearing use (Chi 2004). These pastures received on average 40–51 cm of precipitation annually. Most of this precipitation came in the winter in the form of snow and late-summer monsoons. During 2001–2002 precipitation was 60% below normal, with most of this occurring in late autumn.

We selected Parker Lake Pasture (PLP) to conduct this study because it constituted important sage-grouse brood-rearing areas and exhibited poor understory vegetation cover and diversity (Chi 2004). The poor vegetation diversity was believed to be impacting sage-grouse chick survival (L. Bogedahl, Division of Wildlife Resources, personal communication). We selected this pasture because grazing could be partially deferred for 2 growing seasons posttreatment without causing a major impact on livestock producers. Cattle moved through the pasture on their own throughout September to lower elevations in the autumn of 2002 and 2003. In 2004 grazing took place within PLP July to September.

The PLP contained lower-lying draws that were dominated by mountain big sagebrush with some silver sagebrush (*A. cana*) in the more mesic bottoms. Hillsides and tops were dominated by black sagebrush (*A. nova*). Common forb species included cinquefoil (*Potentilla* spp.), phlox (*Phlox* spp.), dandelion (*Taraxacum* spp.), lupine (*Lupinus* spp.), daisy (*Erigeron* spp.), penstemon (*Penstemon* spp.), and milkvetch (*Astragalus* spp.). Common grass species included wheatgrass (*Agropyron* spp.), bluegrass (*Poa* spp.), grama grass (*Bouteloua* spp.), squirreltail grass (*Hordeum* spp.), and June grass (*Koeleria* spp.). Additionally, dry land sedge (*Carex siccata*) was common in PLP. Elevation decreased gradually from north to south within PLP; however, vegetation was similar throughout.

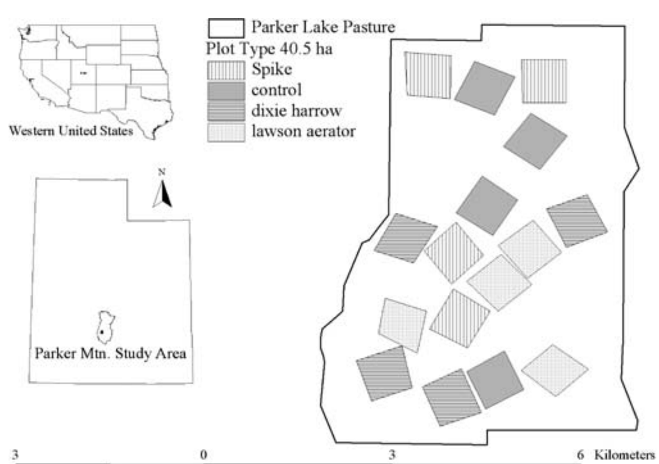

Figure 1. Parker Mountain study area and Parker Lake Pasture plots, Utah, USA, 2004.

Figure 2. Photo of Dixie harrow courtesy of United States Department of Interior Bureau of Land Management, Richfield, Utah, USA.

Methods

Vegetation Treatments

We worked with NRCS personnel to prepare a WHIP proposal to obtain the funding to conduct brush treatments. After the proposal was approved, we identified 19 40.5-ha plots that exhibited approximately 40% canopy cover within mountain big sagebrush stands and limited herbaceous understory. We estimated plot shrub canopy cover using recent fixed-wing aerial photography (1-m resolution) of the study area. From these 19 plots, we randomly selected 16 for the study (Fig. 1). We randomly assigned the plots to mechanical treatment (Dixie harrow or Lawson aerator), chemical treatment (Tebuthiuron/Spike 20P, N-(5-(1,1-dimethylethyl)-(5-^{14}C)-1,3,4-thiadiazol-2-yl)-N,N′-dimethylurea; Dow AgroSciences, Indianapolis, Indiana), or no treatment for the controls (4 replicates each).

The Dixie harrow is a spike-toothed pipe harrow that is pulled behind a large tractor (Fig. 2). The teeth of the harrow are at alternating angles, which causes it to grab and rip the sagebrush out of the ground leaving scarified bare soil. We applied a 2-way treatment. We seeded (broadcast) Dixie-harrow plots with a seed mixture provided by the DWR. However, the seed mixture failed to germinate posttreatment because of an extended drought in 2001 and 2002. This was further verified by the fact that none of the species seeded were found in the vegetation transects or other areas within the treatment during subsequent sampling activities. The Lawson aerator is a large drum aerator that is pulled behind a tractor (Fig. 3). The Lawson aerator has a crushing effect on the sagebrush. This crushing effect leaves some sagebrush plants or partial plants alive. No seeding took place with Lawson-aerator treatment.

Each plot consisted of a mix of mountain big sagebrush in the lower-lying draws and black sagebrush on the hill sides. We were only interested in treating mountain big sagebrush stands within these plots, which exceeded guidelines for brood-rearing shrub canopy cover (Connelly et al. 2000). We randomly placed 5 permanent 20-m vegetation transects within each plot. We divided plots into 100 0.41-ha squares and placed transects at a random direction at the center of each randomly chosen square in mountain big sagebrush only. We conducted pretreatment vegetation sampling for grass and forb cover within Dixie-harrow and Lawson-aerator treatments and controls in July 2000 and August 2001, while only in July 2000 for Tebuthiuron. We conducted pretreatment shrub canopy cover sampling in August 2001 in mechanical treatment and control plots and July 2000 in the Tebuthiuron and control plots.

We flagged the plots to ensure accuracy during treatment. We conducted the mechanical treatments in the autumn of 2001. We treated a total of 44 ha and 51 ha of mountain big sagebrush in Dixie-harrow and Lawson-aerator plots, respectively, which resulted in treatment of ~30% of each plot. We applied Tebuthiuron aerially in pellet form in the autumn of 2000. Because Tebuthiuron resulted in partial kill of sagebrush and the herbicide pellets were applied over the entire plot, we were not able to determine the exact percentage of sagebrush treated within each plot.

We directed contractors who did the mechanical brush treatments to conduct a mosaic pattern within flagged areas (mountain big sagebrush stands within the plots) but did not give them actual locations of vegetation transects. Thus, for Dixie-harrow and Lawson-aerator plots, post-treatment vegetation sampling included treated, untreated, and partially treated transects. We entirely covered Tebuthiuron plots with the herbicide. We conducted post-treatment vegetation sampling for all plot types in June and July of 2002, 2003, and 2004. We sampled June and July each year to determine vegetation characteristics during early and late brood-rearing.

For control and Tebuthiuron plots in 2000, we measured shrub canopy at each meter along the 20-m transect by recording whether shrub canopy occurred at 5 heights (0–20, 21–40, 41–60, 61–80, 81–100 cm) at each meter. This gave a proportion out of 100 heights of where shrub canopy occurred. We realized this was an unreliable method for shrub canopy after 2000. This only affected Tebuthiuron plots and was our only measure of pretreatment shrub

Figure 3. Photo of Lawson aerator courtesy of Utah Division of Wildlife Resources, Salt Lake City, USA.

canopy cover within Tebuthiuron plots and control during 2000. For all plots from 2001 to 2004 (all mechanical treatment, control, and post-treatment Tebuthiuron data) we measured shrub canopy using the line-intercept method (Canfield 1941). We used a variation of the point-intercept method to measure ground cover, including herbaceous cover for all sampling (Levy and Madden 1933). This variation consisted of using a pole with a nail point that was lowered to the soil surface at each meter along the 20-m transects. As the pole was lowered, we recorded which ground cover the point touched: bare ground, rock, litter, grass, or forb. Additionally, during posttreatment years (2001–2004), we used Daubenmire frames as a second method for sampling ground cover (Daubenmire 1959). We placed frames at 4-m intervals along each 20-m transect and estimated percent cover for grasses and forbs, bare ground, rock, and litter.

Parker Lake Pasture was part of the rotation grazing regime managed by SITLA. Regular grazing regimes were followed in 2000 and 2001. Livestock grazing was deferred in PLP during 2002 and 2003. Regular grazing regimes were reinstated in 2004.

Sage-Grouse Use

To determine sage-grouse use, we surveyed all the study plots in August 2003 and 2004 for the presence of sage-grouse pellets. We used a stratified-random design each year, divided each plot into thirds, and placed a transect in each third. Each transect was 636 m (across the entire plot); we placed each transect at right angles to one plot boundary so that each transect paralleled the opposite plot boundary. We slowly walked the transects and recorded pellet type (regular pellet or cecal), number of pellets or cecal droppings per cluster, distance of pellet cluster to centerline (m), estimated distance of cluster to edge of vegetation type (m), and vegetation type where we found the pellet clusters. We determined edge by a change in species of dominant shrub, or abrupt change like edge of a treated area or road. For Tebuthiuron plots we determined edge by the same criteria unless an area was closer that was considered completely treated (i.e., sagebrush plants adjacent to each other with complete defoliation). Roost piles equaled one cluster occurrence. In July 2002 we conducted a preliminary pellet persistence study. We took 10 fresh (within the hour) sage-grouse pellets and placed them in one cluster within mountain big sagebrush in a Tebuthiuron plot and reassessed them in May 2003.

We conducted bird-dog surveys, to assess sage-grouse use in general and brood use specifically, in mid to late July and early August of both 2003 and 2004. We surveyed each plot twice annually. The handler walked 4 general transects creating an "S"-shaped pattern through each plot, and the pointing dog covered the entire plot by quartering in front. It took ~1.5 hours to cover the entire plot with one dog. Both sampling times in 2003 were completed by 1 of 2 dogs. In 2004 we completed the first survey using the same 2 dogs, while we conducted the second using 16 dogs, each covering an entire plot during the same time period. We conducted this bird-dog survey in one morning from 0800–0930 hours. We did this to assess the risk of double-sampling, especially where plots were located in such close proximity (Fig. 1). Utah Chukar and Wildlife Foundation members volunteered their time and most experienced dogs for the second 2004 survey.

We classified grouse flushed during the surveys as chick, hen, male, or unknown. We counted broods as a hen with any number of chicks. If >1 hen flushed with multiple chicks, the number of broods equaled the number of hens. The survey effort was similar for all plots. The research protocols used in this study were reviewed and approved by Utah State University Institutional Animal Care and Use Committee (Approval # 942).

Data Analyses

Because of different treatment implementation schedules, we analyzed mechanical and Tebuthiuron data separately. We analyzed percent shrub, grass, and forb cover using a Before and After Control Impact (BACI) design to determine treatment effect (Smith 2002). The BACI design can be used to assess the impact of change on the environment when before and after conditions are known. We implemented the analyses using the MIXED procedure (SAS Institute, Cary, North Carolina, USA). We used combined means over pretreatment (before) and posttreatment (after) periods. Temporal changes in control plots provide a reference for the treatments. We compared the change in treatment means from before to after periods to the change in control means; thus, treatment effects are measured as deviations from control in vegetation response within treatment plots over time. When the treatment before–after interactions differed ($P \leq 0.05$) for the mechanical analysis, we compared changes in before and after means between treatments and treatments to control using pair-wise comparisons due to 3 treatment levels (Dixie harrow, Lawson aerator, and control). For the Tebuthiuron analysis, there were 2 treatment levels (Tebuthiuron and control), and pair-wise comparisons were not needed when before–after interactions occurred. We largely ignored significant period interactions because our interest was in treatment effect, not period.

For pellet counts, we calculated cluster densities and probability of detection by treatment type using program DISTANCE (Buckland et al. 2001). We compared cluster densities and probabilities of detection among treatments and between treatment and control using 2-sample z-tests. We graphed distance-to-edge pellet data in a histogram format for pellets found in untreated mountain big sagebrush or within treated mountain big sagebrush for each treatment type and control. We analyzed bird-dog survey data for year and treatment type effect for total sage-grouse and total broods flushed using an analysis of variance of a 2-way factorial in a split-plot in time design, where plot was the whole-plot unit, treatment was the whole-plot factor, repeated measurements on each plot were the subplot units, and year was the subplot factor. We made computations using the MIXED procedure (SAS Institute Inc. 2002–2003). We square-root transformed each variable

Table 1. Mean percent shrub, grass, and forb canopy cover before and after mechanical treatment, Parker Mountain, Utah, USA, 2000–2004.

Treatment	Shrub cover				Grass cover				Forb cover			
	Before		After		Before		After		Before		After	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Control	39.1	2.9	31.8	2.5	9.5	1.9	8.4	1.6	6.8	1.6	7.8	1.4
Dixie	38.2	2.9	18.8	2.5	12.6	1.9	14.5	1.6	7.6	1.6	10.7	1.4
Lawson	38.9	2.9	14.6	2.5	8.4	1.9	10.4	1.6	7.9	1.6	8.1	1.4

prior to analysis to better meet assumptions of normality and homogeneity-of-variance. We then used pair-wise comparisons to compare treatments to each other and control.

To help explain sage-grouse use patterns, we used 2003 and 2004 Daubenmire forb cover data to compare overall forb abundance and dandelion cover specifically among plots. Common dandelion (*Taraxacom officinale*) was one of the most abundant forbs found in our sampling and is one of the most important summer food items for sage-grouse (Klebenow and Gray 1968, Peterson 1970, Drut et al. 1994). Because of this we analyzed dandelion cover separately. We used the MIXED procedure to assess treatment and period effects on forb abundance and dandelion cover using an analysis of variance of a 2-way factorial in a split-plot in time design, where plot was the whole-plot unit, treatment was the whole-plot factor, repeated measurements on each plot were the subplot units, and period was the subplot factor. We log-transformed dandelion cover data to better meet assumptions of normality and homogeneity-of-variance. We set the significance level for all above tests at 0.05.

Results

Vegetation Response

Pre- and posttreatment grass, forb, and shrub canopy cover differed (Table 1). Posttreatment percent grass cover did not differ among treatments and control ($F = 2.94$, $P = 0.10$; Fig. 4). Forb cover exhibited a before–after treatment effect ($F = 5.58$, $P = 0.03$; Fig. 5). Our comparisons indicated that forb cover in the Dixie-harrow plots was higher than control and Lawson-aerator ($t = -2.41$, $P = 0.02$, and $t = 3.26$, $P = <0.01$, respectively). Forb cover in the Lawson-aerator plots did not differ from control plots ($t = 0.90$, $P = 0.37$). Posttreatment shrub cover differed by plots ($F = 5.42$, $P = 0.03$; Fig. 6). The Dixie-harrow and Lawson-aerator plots had similar shrub cover ($t = 0.92$, $P = 0.37$) but less than the controls ($t = 2.28$, $P = 0.03$, and $t = 3.20$, $P < 0.01$, respectively).

Tebuthiuron and control plot pre- and posttreatment forb and shrub canopy cover differed (Table 2). However, grass cover did not differ in response to treatment by before–after ($F = 1.03$, $P = 0.35$; Fig. 7). Forb cover increased on the Tebuthiuron plots in response to the treatment ($F = 15.91$, $P = 0.01$; Fig. 8). Shrub cover showed no statistical evidence of response to treatment by before–after ($F = 1.00$, $P = 0.36$; Fig. 9).

Sage-Grouse Response

We detected sage-grouse pellets throughout the plots, which, along with large areas of mountain big and black sagebrush, consisted of small inclusions of silver sagebrush and aspen habitat. However, we analyzed only pellet-count data recorded in black and mountain big sagebrush in treatment and control areas due to low sample sizes found in the other vegetation types. Most of the pellets found in black sagebrush were roost piles.

We found more pellet clusters in Tebuthiuron than Lawson-aerator, Dixie-harrow, or control plots (Table 3). Cluster densities for the Lawson-aerator and Dixie-harrow treatment pellet counts were higher but did not differ statistically from control (Table 3). The probability of detecting pellets differed statistically but was very similar (~25–31%) for all plots (Table 3). For the pellet-persistence preliminary study, in May 2003 only 3 of the 10 original

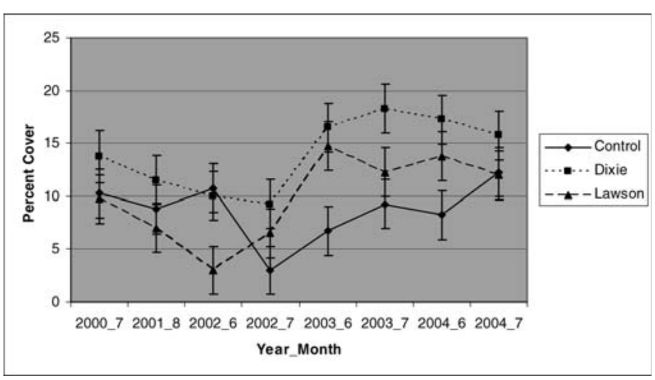

Figure 4. Grass cover response to mechanical treatment, Parker Mountain, Utah, USA, 2000–2004.

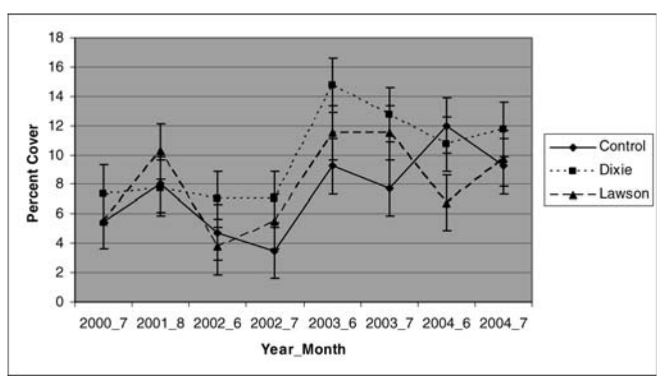

Figure 5. Forb cover response to mechanical treatment, Parker Mountain, Utah, USA, 2000–2004.

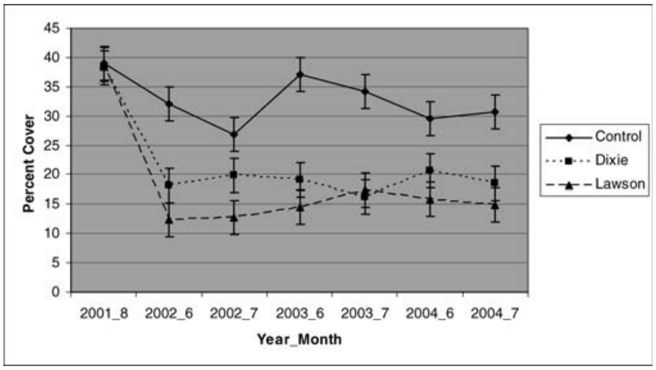

Figure 6. Shrub cover response to mechanical treatment, Parker Mountain, Utah, USA, 2001–2004.

pellets remained and were a dull gray color and losing structural integrity.

For distance-to-edge data, pellet frequency in the treated and untreated sagebrush areas of the Dixie-harrow plots drop off markedly between ~20 and 30 m. We detected pellet clusters in Lawson-aerator-treated areas out to 80 m, and we detected no marked drop-off. In the untreated sagebrush within Lawson-aerator plots, we did detect a drop-off between ~30 and 40 m. Pellet frequency in treated sagebrush in the Tebuthiuron plots declined slightly between ~40 and 50 m. In the sagebrush areas where we visually observed no treatment effect in Tebuthiuron plots, pellet frequency dropped off between ~20 and 30 m. This was similar to all of the untreated sagebrush areas within the treatment plots. In the control areas, we found most sage-grouse pellet clusters within 30 m of edges.

The number of grouse counted during bird-dog surveys reflected a treatment effect both for total grouse and broods ($F = 5.52$, $P = 0.01$; $F = 11.20$, $P < 0.01$, respectively). We counted more grouse in the Tebuthiuron than mechanical treatment or control plots (Table 4). Total numbers of flushed grouse in general and broods specifically in all treatments were higher than control, though only Tebuthiuron plots differed statistically from control (Table 4). We observed year effects for brood counts (Table 4). More broods were flushed in 2004 ($F = 6.72$, $P = 0.02$) than 2003. Total grouse counted did not differ by year ($F = 0.49$, $P = 0.50$). We averaged 3.29, 4.54, 10.50, and 0.50 grouse flushed per hour for Dixie-harrow, Lawson-aerator, Tebuthiuron, and control plots, respectively, for combined years.

For the bird-dog surveys of plots done on multiple days in 2004, we counted 120 sage-grouse. For the surveys done within the same day and time period in 2004, we counted 121 sage-grouse. Hence, we assume double-sampling did not take place while conducting bird-dog surveys on multiple days.

For total forb cover abundance in 2003 and 2004 Daubenmire data did not differ ($F = 1.99$, $P = 0.17$). Dandelion cover had a moderate ($F = 2.60$, $P = 0.10$) treatment effect with the highest percent cover in Tebuthiuron plots, though it did not meet the required alpha level ($P = 0.05$).

Discussion

Vegetation Response

Connelly et al. (2000) recommended maintaining a shrub canopy of 10–25% for brood-rearing areas. On our study area, mountain big sagebrush had become dense stands (~40% shrub cover), with limited understory vegetation. Based on our random transects, shrub canopy results indicate that areas of mountain big sagebrush within treatment plots on average achieved sagebrush canopy guidelines for sage-grouse brood-rearing habitat (Connelly et al. 2000). However, the magnitude of the reduction was less evident in the Tebuthiuron plots. We believe this could be attributed to the gradual, partial, and discontinuous sagebrush kill achieved by the low levels of Tebuthiuron we used (Clary et al. 1985). Additionally, our method of measurement changed in pretreatment to posttreatment periods, which likely impacted the analysis.

The amount of forb cover may be just as important for sage-grouse broods as shrub cover (Klebenow and Gray 1968, Drut et al. 1994, Connelly et al. 2000). The Tebuthiuron and Dixie-harrow treatments we studied increased forb cover to within the recommended guidelines provided by Connelly et al. (2000). None of the treatments showed a significant response for grass cover. We believe this could have been related to the grazing regimes and drought that followed in posttreatment years. During 2002 and 2003 PLP gates were opened in September as the cattle from higher-elevation pastures moved through PLP to lower-elevation pastures. Normal grazing regimes did not resume in PLP until July 2004, which could only have impacted the last sampling period. In addition, we frequently observed pronghorn herds and lagomorphs grazing within treatment areas prior to initiation of livestock grazing and sampling times may have impacted grass response (Chi et al. 2003).

Based on the before-to-after treatment comparisons, the Lawson aerator was less effective 2 years posttreatment at increasing herbaceous cover. We believe this is an artifact of the rocky, shallow soils found within our study plots.

Table 2. Mean percent shrub, grass, and forb canopy cover before and after Tebuthiuron treatment, Parker Mountain, Utah, USA, 2000–2004.

	Shrub cover				Grass cover				Forb cover			
	Before		After		Before		After		Before		After	
Treatment	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Control	37.5	2.8	31.8	2.5	10.3	2.2	8.4	1.0	5.5	1.2	7.8	0.6
Tebuthiuron	31.0	2.8	20.2	2.5	9.5	2.2	10.4	1.0	4.0	1.2	12.0	0.6

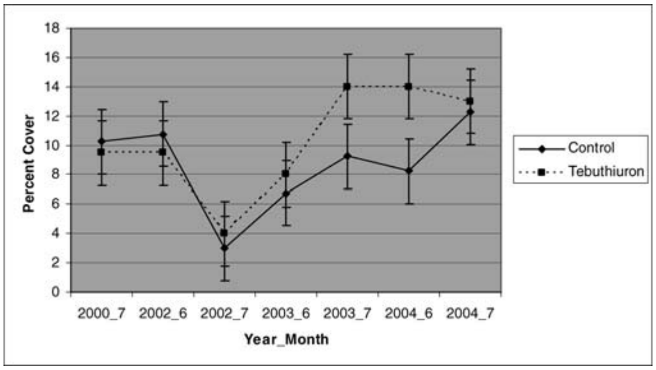

Figure 7. Grass cover response to Tebuthiuron treatment, Parker Mountain, Utah, USA, 2000–2004.

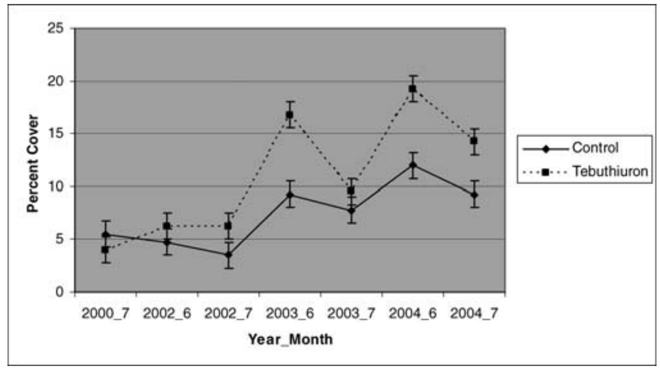

Figure 8. Forb cover response to Tebuthiuron treatment, Parker Mountain, Utah, USA, 2000–2004.

Although the Lawson aerator was effective at decreasing shrub canopy, because of the terrain it did not achieve the same level of disturbance within treated areas of the plots. In essence, the drum aerator bounced across the rocky soil, thus impeding full treatment. Without full treatment, not enough soil disturbance may have taken place, and sagebrush seedlings and other plants could have remained to compete with herbaceous plants, impeding response. The equipment also was damaged during the treatment because of the large rocks encountered.

We broadcast the seed mixture in the Dixie-harrow plots following the second treatment by the harrow. By broadcasting, the seed was most likely ineffective at penetrating the soil surface. This, combined with severe drought during the first growing season posttreatment (2002), may have caused germination failure of the seed mixture.

Sage-Grouse Response

Based on bird-dog surveys and pellet counts, sage-grouse in general, and broods specifically, preferred the Tebuthiuron plots. Bird-dog surveys were useful, in addition to pellet counts because we were able to classify most birds as chick or adult and sex most adults. Although we were not able to collect pretreatment data, the fact that the plots were randomly assigned as treatment or control and replicated validates these findings. Additionally, results from pellet counts and bird-dog surveys had very similar patterns (Tables 3,4).

Although detection probabilities for pellet-count surveys differed between treatment types, the differences were negligible. We had anticipated that the control and Tebuthiuron plots would have lower probabilities of detection because of more intact shrub canopies. Detection probability was only slightly lower because we saw most pellets within 1 or 2 m of the transect centerline for all treatment types.

Sage-grouse pellet persistence may be a source of bias for pellet data by causing a cumulative, rather than incremental, count. Additionally, season of use may be questioned with persistent pellets. However, our preliminary data suggest that decomposition in PLP removes the majority of pellets and renders the remaining pellets less detectable. The PLP (elevation 2,700–2,850 m) receives heavy snow accumulation each winter and periodic late-summer monsoonal rains, which likely aids decomposition (Epstein et al. 2002). No wintering or lekking takes place within PLP due to snow accumulation. The majority of sage-grouse use takes place in PLP during late brood-rearing and early autumn periods, with limited nesting and early brood-rearing use (Chi 2004). Therefore, the majority of detected pellets represent late-summer to early autumn use, even if some detected pellets persisted year to year.

Jarvis (1974) reported that the limiting factor of the Parker Mountain sage-grouse population was the lack of adequate food in brood habitats, except in exceptionally wet years. We believe the forb response, particularly dandelion, may be the reason broods and sage-grouse in general preferred the Tebuthiuron plots. However, the statistical validity for this assumption was not strong. This forb is highly palatable for sage-grouse (Klebenow and Gray 1968, Peterson 1970, Wallestad et al. 1975).

We believe the fact that Tebuthiuron treatments left "sagebrush skeletons" also might have contributed to the sage-grouse response we observed. These "skeletons," in addition to providing escape cover, may have served to intercept more moisture. In effect, they could have created a micro-environment by providing moisture, shade, and blocking wind, thus enhancing forb response. Also, while

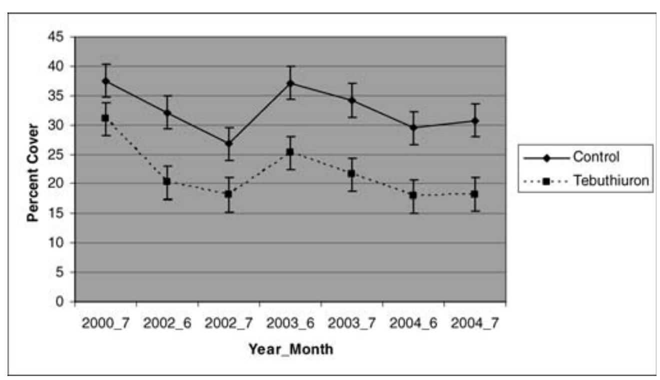

Figure 9. Shrub cover response to Tebuthiuron treatment, Parker Mountain, Utah, USA, 2000–2004.

Table 3. Greater sage-grouse pellet-count probability of detection and cluster densities, Parker Mountain, Utah, USA, 2003–2004.

Plot type	Total no. of clusters	Probability of detection P(d)[a]	Probability of detection SE[b]	Clusters Ds[c]	Clusters SE[b]
Control	135	0.255	0.0179	23.38	6.46
Dixie	225	0.274	0.0141	36.26	15.13
Lawson	207	0.312	0.0195	29.33	9.04
Tebuthiuron	433	0.248	0.0081	77.12	20.71
Comparisons		***Z* value**	***P* value**	***Z* value**	***P* value**
Control–dixie		−0.83383	0.4044	−0.783	0.4336
Control–lawson		−2.15338	0.0312	−0.536	0.5922
Control–tebuthiuron		0.356281	0.7216	−2.477	0.0132
Dixie–lawson		−1.57914	0.1144	0.393	0.6942
Dixe–tebuthiuron		1.598918	0.1098	−1.593	0.1112
Lawson–tebuthiuron		3.030964	0.0024	−2.115	0.0344

[a] P(d) = Probability of detection.
[b] SE = Standard error.
[c] Ds = Density (per acre).

providing more abundant forbs, these plots exhibited 18–25% shrub canopy cover.

Additionally, while mechanical treatments created large distinct patches or edges, the Tebuthiuron treatment resulted in a multitude of "feathered" or less distinct edges. If partial kill of sagebrush results from this treatment, distance to edge of intact sagebrush may not be as important. This partial kill resulted from the low rate of Tebuthiuron applied. Additionally, while the Lawson aerator did create distinct edges between treated and untreated areas, due to the interference by the rocky soils, more shrub canopy cover remained in treated areas of Lawson-aerator plots. Pellet count distance-to-edge data in these areas had no discernable drop-off.

We believe the distance-to-edge data reveal sage-grouse habitat preferences, even in areas not treated. Frequency data for untreated areas in all plots showed a decline in pellets after 20 m from edge and almost none after 40 m, suggesting an edge preference. If the assumption is made that sage-grouse pellet location is associated with use, then these data could be used as guidelines for future treatments of sagebrush in brood-rearing areas. However, our distance-to-edge data also may be an artifact of the shape of the sagebrush stand. Many of the PLP mountain big sagebrush stands are long and narrow (following drainages), though most exceeded widths of ~100 m. Thus, our distance-to-edge data most likely reflected sage-grouse use preference rather than the shape of the sagebrush stand.

Management Implications

We conducted relatively small (40.5-ha) treatments in known brood-rearing habitat situated in a vast expanse of contiguous sagebrush. Both mechanical treatments effectively reduced shrub canopy cover on average to within brood-rearing habitat guidelines (Connelly et al. 2000). The Dixie harrow was more effective than the Lawson-aerator treatment at improving forb cover. Based on our results, we believe the Dixie harrow and Tebuthiuron can be used to

Table 4. Total number greater sage-grouse and broods flushed during bird-dog surveys, Parker Mountain, Utah, USA, 2003 and 2004.

Treatment or year	Total grouse[a] *n*	Total grouse[a] Mean	Total grouse[a] SE[c]	Total broods[b] *n*	Total broods[b] Mean	Total broods[b] SE[c]
Control	6	0.75	0.75	1	0.13	0.13
Dixie	79	9.88	4.28	6	0.75	0.41
Lawson	109	13.63	7.85	7	0.88	0.48
Tebuthiuron	252	31.5	7.63	38	4.75	1.21
2003	205	12.81	4.54	16	1	0.42
2004	241	15.06	5.31	36	2.25	0.81
Comparisons		***t* value**	***P* value**		***t* value**	***P* value**
Control–dixie		−1.58	0.1404		−1.09	0.2962
Control–lawson		−1.85	0.0887		−1.39	0.1902
Control–tebuthiuron		−4.04	0.0017		−5.41	0.0002
Dixie–lawson		−0.27	0.7888		−0.30	0.772
Dixie–tebuthiuron		−2.46	0.0302		−4.31	0.001
Lawson–tebuthiuron		−2.18	0.0496		−4.02	0.0017

[a] Any grouse, male, hen, unknown, or chick.
[b] Broods equaled ≥1 chicks with a hen; if >1 hen was flushed with multiple chicks, broods equaled the number of hens.
[c] Standard error.

help meet sage-grouse brood-rearing habitat needs in mountain big sagebrush communities where dense (>25% shrub cover) stands of sagebrush limit the herbaceous understory. Lawson-aerator treatment was hindered by soil conditions and produced mixed results though sage-grouse still used these plots (Tables 3 and 4). The Dixie-harrow and the Lawson-aerator treatment cost US$74.00/ha including seed, and Tebuthiuron treatment cost $47.00/ha.

Sage-grouse on Parker Mountain preferred the treatment plots, especially Tebuthiuron plots, for brood-rearing and general summer use. This preference likely can be attributed to the increased availability of forbs in treated plots. However, it is important to note that sage-grouse still preferred to use the edge of the treatments where intact sagebrush cover was still available adjacent to treated areas.

Caution should be exercised in applying these observations and treatment techniques to sites with different elevations, annual precipitation, subspecies of big sagebrush, or soil substrates. It is also critical that sage-grouse seasonal use patterns of the landscape be identified and delineated prior to implementation of sagebrush treatment projects because sagebrush removal in areas where wintering or nesting habitat is a limiting factor may have devastating consequences (Connelly et al. 2000).

When applying Tebuthiuron for sage-grouse brood-rearing habitat treatment, a low rate of active ingredient that results in partial kill of sagebrush is most desirable. Soil texture and depth, sagebrush vigor, precipitation regimes, and other environmental conditions would affect the resulting percentage of sagebrush killed. Pretreatment data measuring these various factors would help guide the best application rate. Additionally, we believe distance-to-edge data from pellet counts could help guide managers to a reasonable mechanical treatment design for sage-grouse brood-rearing habitat. Based on our research, we suggest that areas treated with a Dixie harrow should not exceed widths of 60 m, with intact sagebrush widths of at least 60 m. When using the Lawson aerator, treated areas should not exceed widths of 160 m, with intact sagebrush widths of 80 m. Our Lawson-aerator plots resulted in partial kill of sagebrush plants leaving more shrub cover in treated areas than Dixie-harrow treatment. This was most likely the reason sage-grouse ventured farther into Lawson-aerator treated areas. If the soil type was deeper and less rocky, sage-grouse use patterns may have approximated the Dixie-harrow plots. Thus, future management efforts might best be conservatively kept within Dixie harrow's suggested widths. Additionally, designs maximizing edge would be most desirable.

These observations support a management strategy that creates a mosaic treatment pattern. This strategy is most desirable within late brood-rearing habitats. Rather than treat large blocks of sagebrush at a time, we suggest an alternative strategy of treating smaller patches or plots for brood-rearing activities. More sinuous treatment designs with treatment width following the above guidelines when using the Dixie harrow or Lawson aerator would create more edge habitat and may be better for sage-grouse using the area.

Our results suggest that small sagebrush treatments create resource patches that are particularly attractive to sage-grouse broods within large, contiguous brood-rearing areas dominated by mountain big sagebrush. Although additional research is needed to document the cumulative effects on a larger scale, the cautious application of small brush treatments may be a viable conservation practice for agencies like the NRCS to use for enhancing sage-grouse brood-rearing habitats.

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Literature Cited

Apa, A. D. 1998. Habitat use and movements of sympatric sage and Columbian sharp-tailed grouse in southeastern Idaho. Dissertation, University of Idaho, Moscow, USA.

Beck, J. L., and D. L. Mitchell. 2000. Influences of livestock grazing on sage grouse habitat. Wildlife Society Bulletin 28:993–1002.

Beck, J. L., D. L. Mitchell, and B. D. Maxfield. 2003. Changes in the distribution and status of sage-grouse in Utah. Western North American Naturalist 63:203–214.

Braun, C. E. 1998. Sage-grouse declines in western North America: what are the problems? Proceedings of the Western Association of State Fish and Wildlife Agencies 78:139–156.

Braun, C. E., T. Britt, and R. O. Wallestad. 1977. Guidelines for maintenance of sage grouse habitats. Wildlife Society Bulletin 5: 99–106.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University, Oxford, United Kingdom.

Canfield, R. H. 1941. Application of the line-interception method in sampling range vegetation. Journal of Forestry 39:388–394.
Chi, R. Y. 2004. Greater sage-grouse reproductive ecology and Tebuthiuron manipulation of dense big sagebrush on Parker Mountain. Thesis, Utah State University, Logan, USA.
Chi, R. Y., D. K. Dahlgren, V. L. Bagley, and T. A. Messmer. 2003. Annual report 2002: Parker Mountain Adaptive Resource Management Plan. Utah State University Extension, Logan, USA.
Clary, W. P., S. Goodrich, and B. M. Smith. 1985. Response to tebuthiuron by Utah juniper and mountain big sagebrush communities. Journal of Range Management 38:56–60.
Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biology 3/4:123–128.
Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, unpublished report, Cheyenne, Wyoming, USA.
Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28:967–985.
Daubenmire, R. F. 1959. A canopy-coverage method of vegetation analysis. Northwest Science 33:43–64.
Drut, M. S., W. H. Pyle, and J. A. Crawford. 1994. Diets and food selection of sage grouse chicks in Oregon. Journal of Range Management 47:90–93.
Dunn, P. O., and C. E. Braun. 1986. Summer habitat use by adult female and juvenile sage-grouse. Journal of Wildlife Management 50: 228–235.
Epstein, H. E., I. C. Burk, and W. K. Lauenroth. 2002. Regional patterns of decomposition and primary production rates in the US Great Plains. Ecology 83:320–327.
Jarvis, J. M. 1974. Sage grouse population studies on the Parker Mountain in south central Utah. Federal Aid in Wildlife Restoration Project W-65-R, Job c-1. Utah Department of Natural Resources, Division of Wildlife Resources, Salt Lake City, USA.
Klebenow, D. A., and G. M. Gray. 1968. The food habits of juvenile sage-grouse. Journal of Range Management 21:80–83.
Levy, E. B., and E. A. Madden. 1933. The point method for pasture analysis. New Zealand Journal of Agriculture 46:267–269.
Martin, N. S. 1970. Sagebrush control related to habitat and sage grouse occurrence. Journal of Wildlife Management 34:313–320.
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.
Schroeder, M. A., C. L. Adridge, A. D. Apa, J. R. Bohne, C. E. Braun, S. D. Bunnell, J. W. Connelly, P. A. Deibert, S. C. Gardner, M. A. Hillard, G. D. Kobriger, S. M. McAdam, C. W. McCarthy, J. J. McCarthy, D. L. Mitchell, E. V. Rickerson, and S. J. Stiver. 2004. Distribution of sage-grouse in North America. The Condor 106:363–376.
Smith, E. P. 2002. BACI design. Pages 141–148 *in* A. H. El-Shaarawi and W. W. Piegorsch, editors. Encyclopedia of environmetrics. Volume 1. John Wiley and Sons, Chichester, United Kingdom.
Sveum, C. M., W. D. Edge, and J. A. Crawford. 1998. Nesting habitat selection by sage-grouse in south-central Washington. Journal of Range Management 51:265–269.
Utah Division of Wildlife Resources. 2002. Strategic management plan for sage-grouse 2002. <http://www.wildlife.utah.gov/uplandgame/pdf/2002manplan.pdf>. Accessed 2003 Apr 14.
Wallestad, R. O. 1971. Summer movements and habitat use by sage grouse broods in central Montana. Journal of Wildlife Management 35:126–136.
Wallestad, R. O., J. G. Peterson, and R. L. Eng. 1975. Foods of adult sage-grouse in central Montana. Journal of Wildlife Management 38: 628–630.
West, N. E. 1983. Great Basin-Colorado Plateau sagebrush semi-desert and Western intermountain sagebrush steppe. Pages 331–374 *in* N. E. West, editor. Ecosystems of the world. Volume 5: temperate deserts and semi-deserts. Elsevier Science, Amsterdam, The Netherlands.
Western Association of Fish and Wildlife Agencies. 1999. Memorandum of understanding among members of the Western Association of Fish and Wildlife Agencies, Conservation and Management of Sage Grouse in North America. Appendix 1 *in* J. W. Connelly, S. T. Knick, M. A. Schroeder, and S. J. Stiver, editors. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, unpublished report, Cheyenne, Wyoming, USA.

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