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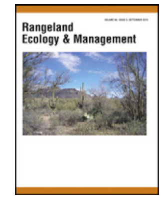

Greater Sage-Grouse and Range Management: Insights from a 25-Year Case Study in Utah and Wyoming☆

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ABSTRACT

Conservation of sagebrush (*Artemisia* spp.) systems is one of the most difficult and pressing concerns in western North America. Sagebrush obligates, such as greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse), have experienced population declines as sagebrush systems have degraded. Science-based management is crucial to improve certainty in range management practices. Although large-scale implementation of management regimens within an experimental design is difficult, long-term case studies provide opportunities to improve learning and develop and refine hypotheses. We used 25 years of data across three large landscapes in northern Utah and southwestern Wyoming to assess sage-grouse population change and corresponding land management differences in a case study design. Sage-grouse lek counts at our Deseret Land and Livestock (DLL) study site increased relative to surrounding populations in correspondence with the implementation of small-acreage sagebrush treatments designed to reduce shrub cover and increase herbaceous understory within a prescriptive grazing management framework. The higher lek counts were sustained for nearly 15 years. However, with continued sagebrush treatments and the onset of adverse winter conditions, DLL lek counts declined to levels consistent with surrounding areas. During summer, DLL sage-grouse broods used plots of small, treated sagebrush mosaics more than untreated reference sites. We hypothesize that sagebrush treatments on DLL increased availability of grasses and forbs to sage-grouse, similar to other studies, but that cumulative annual reductions in sagebrush may have reduced availability of sagebrush cover for sage-grouse seasonal needs at DLL, especially when extreme winter weather occurred.

Introduction

Increasing losses in biodiversity across the globe demand an unprecedented scale and certainty in application of conservation actions to slow declines (Waldron et al., 2013). Most imperiled are species with high vulnerability and low adaptive capacity that can only be maintained through species-specific management actions (Goble et al., 2012). Science-based management underpins conservation effectiveness, and without it, well-intentioned practitioners may implement actions that are ineffective or even detrimental to species recovery. Effectiveness of management actions can take decades to assess given inherent variability in climate and lag times that can span years to decades, particularly for species with low reproductive rates and longer life spans. Moreover, although experimental design and replication are trademarks of science-based management, replicated experiments can be difficult or even impossible to conduct on large scales. In these scenarios, case studies can offer an approach that provides reliable information and serves as a valuable precursor to hypothesis testing (Hebblewhite, 2011).

Conservation of sagebrush (*Artemisia* spp.) ecosystems is one of the most pressing issues in western North America (Knick and Connelly, 2011). Sagebrush occurs across a large portion of western North America where sagebrush communities and their associated fauna are threatened by energy development, urbanization, conversion to cropland, invasion of exotic plants and subsequent catastrophic wildfire,

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conifer encroachment, and sagebrush eradication (Naugle, 2011; Knick et al., 2013; Murphy et al., 2013). Loss and degradation of sagebrush communities have led to conservation challenges for a variety of species (Baker et al., 1976; Miller and Eddleman, 2000; Bradley, 2010). At greatest risk are obligate species found only in this ecotype (Oyler-McCance et al., 2001; Ingelfinger and Anderson, 2004; Holloran, 2005).

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) are sagebrush obligates that use this ecosystem throughout all phases of their life cycle. As with other sagebrush obligates, sage-grouse populations have declined in response to habitat loss and degradation (Garton et al., 2011). New outcome-based science is quantifying the efficacy of proactive conservation measures to stem population losses (e.g., conifer removal [Baruch-Mordo et al., 2013] and conservation easements [Copeland et al., 2013]), but examples of increasing populations as a direct result of management intervention are rare, leaving practitioners unsure of management actions that could be implemented proactively to further conservation of sage-grouse.

The detrimental impacts of sagebrush canopy removal or reduction on sagebrush obligate species across large areas are widely known (Beck et al., 2012). The efficacy of small-scale (e.g., < 200-ha mosaics) shrub removal in sage-grouse management, however, remains fiercely debated. On one hand, removal or thinning of sagebrush in small areas in mosaic patterns within sagebrush landscapes may promote growth of grasses and forbs, which could improve brood-rearing habitat and sage-grouse recruitment (e.g., Dahlgren et al., 2006). Conversely, removal of shrubs may reduce availability of sagebrush during winter, reduce nesting habitat, facilitate invasion of exotic plants, and further fragment existing sagebrush systems. Because sage-grouse are currently being considered for federal Endangered Species Act listing (Stiver, 2011), a better understanding of the response of sage-grouse to small-scale sagebrush canopy reduction with applications of mechanical, chemical, or prescribed fire is needed. Long-term case studies have been suggested as alternative options to assess the efficacy of these practices and provide important learning opportunities for practitioners (Krausman et al., 2009). To date, however, no such long-term studies exist.

In northern Utah, the 76 700-ha private Deseret Land and Livestock (DLL) ranch reported a dramatic increase in average males counted per lek between the late 1980s and early 2000s (Danvir, 2002). However, in 2010, lek counts on DLL declined to levels approximating surrounding populations. DLL employed range management practices during this period that were distinctly different from the surrounding areas in northern Utah and western Wyoming. These practices included a prescriptive grazing strategy where cattle were managed in three or four large herds and rotated through pastures for short periods of time (Danvir et al., 2005). Combined with prescriptive grazing, sagebrush treatments were conducted at small (generally < 200-ha) scales in mid- and high-elevation sagebrush communities. The surrounding areas largely consisted of U.S.D.I. Bureau of Land Management (BLM) allotments with limited inclusions of nonfederal land. These areas were managed using different grazing regimens and few sagebrush management projects. The DLL ranch provided habitat for a sage-grouse population adjacent to populations in north Rich County (RICH) and southwestern Wyoming (WWY). All three populations have been monitored using spring lek counts of male sage-grouse as an index of abundance for multiple decades.

The purpose of this case study was to document changes in sage-grouse populations over the past 25 years and begin to assess response of sage-grouse to differences in long-term, landscape-level (e.g., across multiple allotments or an entire 75 000 ha ranch) management actions. We first compared counts of breeding males (i.e., number of males per lek) between our three study areas. Next, we considered available data on brood counts and sage-grouse use of treatment areas on DLL. Although our approach lacks a true experimental design, it is a long-term retrospective case study that considers the preponderance of evidence accumulated over a 25-year period. Our intention was to use these data to provide information that begins to fill knowledge gaps and develop hypotheses that could be tested in replicated experimental designs in the future.

Study Areas

We identified three study areas for retrospective analysis that included 1) DLL located in Morgan, Rich, and Weber Counties, Utah; 2) RICH located in Rich County, Utah; and 3) WWY located in Uinta and Lincoln Counties, Wyoming (Fig. 1). Sage-grouse habitats in each study area shared similar soils, elevations, vegetation types, and weather patterns. The study areas contained two Major Land Resource Regions (MLRAs) (USDA Agriculture Handbook 296, 2006). Sage-grouse occurred on the study areas throughout MLRA 34A (Cool Central Desertic Basins and Plateaus) and in the lower elevations of MLRA 47 (Wasatch and Uinta Mountains). Occupied habitat throughout the study areas ranged in elevation from 1 950 to 2 600 m on substrate composed of shale- and sandstone-derived Aridisols and Entisols.

Sage-grouse habitat in our study areas included at least three community types based on elevation: 1) low elevations (<2000 m) were dominated by Wyoming big sagebrush *(A. tridentata wyomingensis)* or low sagebrush *(A. arbuscula)* and Douglas rabbitbrush *(Chrysothamnus viscidiflorus)*; 2) midelevation (between 2000 m and 2100 m) habitats were dominated by basin big sagebrush *(A. t. tridentata)* with inclusions of low sagebrush, often intermixed with rabbitbrush; and 3) high elevation (>2100 m) sagebrush communities were dominated by mountain big sagebrush *(A. t. vaseyana)*, with intermixed bitterbrush *(Purshia tridentata)*, serviceberry *(Amalanchier alnifolia)* or snowberry *(Symphoricarpos albus)*, and inclusions of aspen *(Populus tremuloides)* and Douglas fir *(Pseudotsuga meniziesii)* at the highest elevations. Mean annual precipitation was 25 cm at lower elevations and 55 cm at higher elevations. Irrigated, native riparian, and meadow habitats (<5% of study area) occurred along the Bear and Green River drainages.

Anthropogenic influences in each study area included livestock grazing by domestic cattle as the primary land use. During our study period we estimated active well density at 4.54 wells per 100 km^2, 1.96 wells per 100 km^2, and 2.86 wells per 100 km^2 for DLL, RICH, and WWY, respectively in 6.4-km buffers (see Walker et al., 2007) around known leks. Well spudding rates during the study period were 2.22 per 100 km^2, 0.44 per 100 km^2, and 0.76 per 100 km^2, for DLL, RICH, and WWY, respectively (Utah data from http://stage.mapserv.utah.gov/oilgasmining; Wyoming data from http://wogcc.state.wy.us). Well pad densities in all three areas were extremely low compared with density thresholds (e.g., 150 wells per 100 km^2) showing negative impacts to sage-grouse populations in other areas (Harju et al., 2010). Therefore we did not consider differences in oil and gas well densities between study areas as likely to influence sage-grouse populations.

The three study areas differed in land ownership, grazing management strategies, and frequency of sagebrush removal. The RICH study area was 158 100 ha in size, including ~ 53% publicly owned and 47% privately owned lands. The WWY study area was 407 000 ha in size, including ~64% publicly and 36% privately owned lands. The RICH and WWY study areas were primarily federally owned lands, principally controlled by the U.S. Department of Interior, Bureau of Land Management (BLM); U.S. Department of Agriculture; and U.S. Forest Service (USFS). Most of the private rangelands "checker-boarded" within the RICH and WWY areas were managed as part of BLM allotments. Allotments in the northern and southern portion of the WWY area were generally single pastures grazed May–September. The central portion of the area consisted of the Uinta-Cumberland allotment, which used a four-pasture deferred-rotation grazing plan in which pastures were grazed for 1–2 months per pasture May–October. Allotments in RICH included single pastures grazed May–September. Few pastures in RICH or WWY received growing-season rest, and cattle were generally stocked at a rate of 2.5–5 AUM $\cdot$ ha^{-1}. Conversely, DLL consisted of 76 700 ha, 93% of which was privately owned with the remaining 7% BLM inholdings. DLL practiced a prescriptive grazing strategy that emphasized

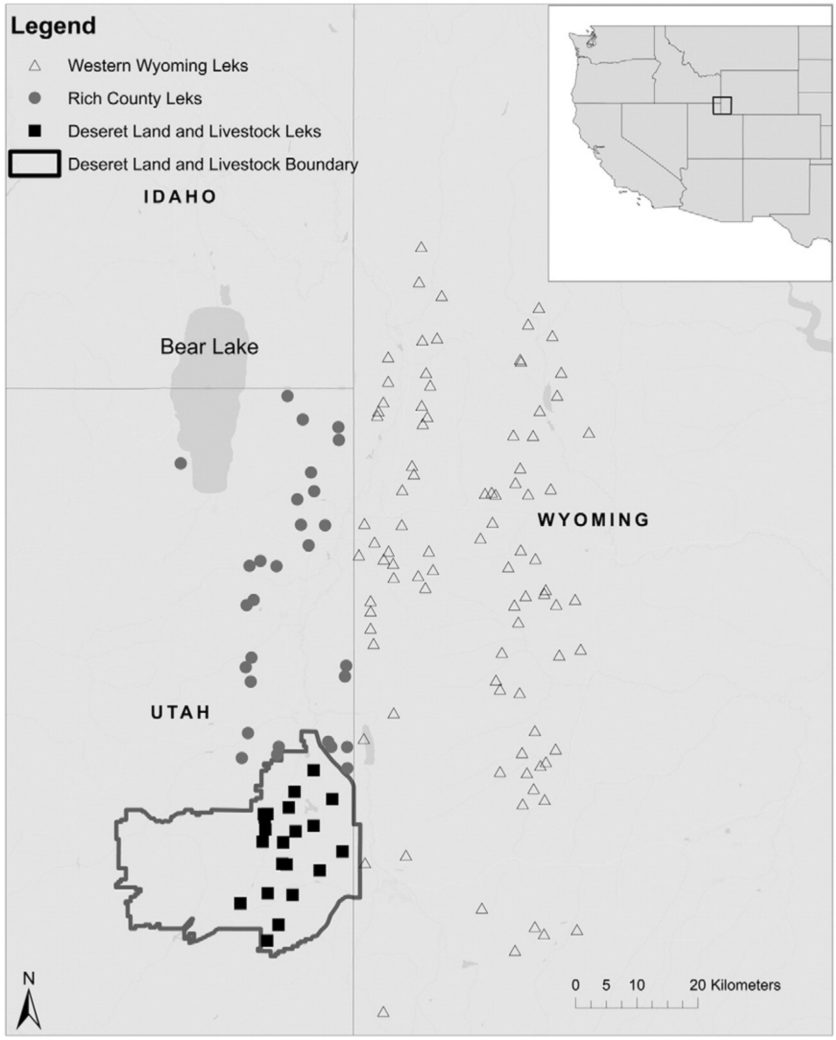

Fig. 1. Location of greater sage-grouse *(Centrocercus urophasianus)* leks across our three study areas used to assess population response of sage-grouse to differences in range management, 1989–2013. Study areas were Deseret Land and Livestock (DLL; dark squares), north Rich (RICH; filled circles), and western Wyoming (WWY; open triangles).

growing-season rest. Contrasted with the RICH and WWY areas, cattle occurred in a few large herds and pastures experienced higher stock densities, shorter grazing periods (1–2 weeks per pasture during May–September), and longer periods of rest and recovery (generally ≥ 12 months) before regrazing (Danvir et al., 2005). Up to 30% of pastures on DLL received a full year's rest annually and were not grazed during the same growing-season during subsequent use. DLL pastures were stocked at a rate of 1.2–1.6 AUM · ha^{-1} during April–November.

During our study period, sagebrush canopy control applications of Lawson aerator, disking, chain harrow, Tebuthiuron, and prescribed fire were used, primarily at DLL. The Lawson aerator is a large drum (usually filled with water for added weight) pulled behind a tractor that crushes sagebrush and impacts the soil surface. A disk is pulled behind a tractor to rip sagebrush plants out of the ground and disturb the soil surface. A chain harrow is also pulled by tractors and is a large swiveled chain with welded harrows, which rotate to rip and crush sagebrush. Tebuthiuron (i.e., Spike) is a chemical herbicide application usually applied aerially in the fall in pellet form. Seeding of forbs and grasses (both native and non-native) followed most treatments by broadcasting behind a tractor or aerially. These management actions were designed to achieve one or more of the following objectives: 1) increase herbaceous production and plant species richness by reducing plant competition with sagebrush, 2) create interspersion (complexity) of vegetative conditions, and 3) reduce fuel loads or create "green-stripping" to decrease catastrophic wild-fire risks while maintaining adequate sagebrush cover for sage-grouse and other sagebrush obligates (Aoude, 2002; Summers, 2005; Danvir et al., 2005). Treatment sizes varied (Fig. 2) but were generally < 200-ha mosaics, situated in elevations above 2 000 m in mid- (i.e., basin big sagebrush) and high-elevation (i.e., mountain big sagebrush) communities in breeding (nesting and early brooding) and late brood-rearing habitats. Treatments characteristically had meandering edges with interspersed "islands" of untreated sagebrush within treated areas (on average, 30% of treatment

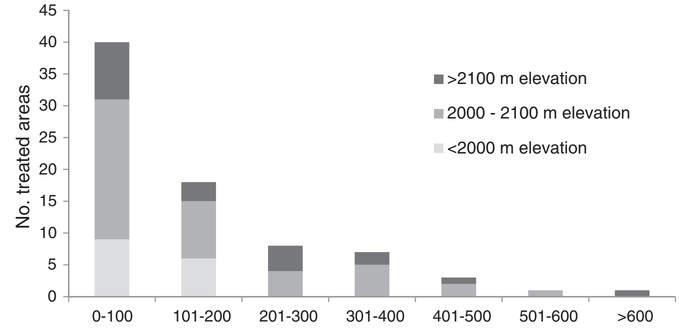

Fig. 2. Frequency of sagebrush treatments by size (ha) on Deseret Land and Livestock (DLL) ranch in northern Utah, 1989–2013.

polygons were left untreated). In addition, several relatively small (<1 610 ha) wildfires occurred at DLL in largely mid- or high-elevation sagebrush habitats during the study period (Table 1).

Between 1995 and 2008 ~ 8% of the WWY area experienced 29 500 ha of wild or prescribed fires and 1 600 ha of Tebuthiuron sagebrush treatments. Shrub cover was removed from 60–70% of impacted areas (Slater, 2003). Between 1993 and 2009 < 2% of the RICH study area experienced sagebrush removal (1 550 ha of wildfires, 1 300 ha of primarily Lawson aerator treatment). Conversely, approximately 1.5% of DLL sagebrush habitat received wildfire or a prescribed sagebrush treatment annually from 1992–2009 (Table 1) resulting in nearly 15% of total sagebrush habitat affected (Table 1).

Methods

Lek Analysis

We analyzed 25 years (1989–2013) of lek count data at DLL and compared it with adjacent areas RICH and WWY to determine if the observed trend in counts of males per lek at DLL was different from adjacent populations exposed to similar environmental conditions. We secured available lek data for these analyses from the Utah Division of Wildlife Resources (UDWR) and Wyoming Game and Fish Department (WGFD). Lek surveys were conducted each spring by UDWR, WGFD, and DLL personnel. In all study areas, each lek was counted at least three separate mornings (usually 7–10 days apart) between a half-hour before and 1.5 hours post sunrise from the first of April to early May. Generally, weather conditions were required to consist of low wind speeds and low percent cloud cover. The maximum count of the ≥ 3 samples was used as that year's lek count for a given lek. We included leks in our analysis that occurred on DLL and limited our analysis to those within ~50 km of the DLL ranch border for RICH and WWY in an effort to minimize the influence of spatial variation in climatic conditions on lek counts. Some interchange of sage-grouse between our study areas likely occurred, especially during late fall and winter periods. However, telemetry-based research on DLL suggested that most sage-grouse that attended leks on the ranch spent their entire life cycle on the property or within a couple km of the ranch boundary. Therefore, these 3 areas generally corresponded to Connelly et al.'s (2000) definition of distinct breeding populations.

Our analysis followed several steps. First, to evaluate changes in lek counts over time at DLL only, we used a Bayesian Change Point (BCP) analysis (Erdman and Emerson, 2007) in program R (RDevelopmentCoreTeam, 2008). This method partitions sequential information (in our case summed number of males at DLL for each year) into contiguous blocks such that means were assumed constant within each block but allowed to vary or change between blocks. This process is then iterated across the sequence to estimate posterior probabilities of change for each year in the time sequence. Because BCP requires consecutive numbers and in the current implementation does not allow for missing values, we were limited to data from 9 leks on DLL counted continuously since 1989 for this initial analysis. Second, to evaluate differences in mean number of males counted per lek across the three study areas we plotted mean males counted per lek across all active leks for each study area and used a generalized additive model (GAM) smoother to create a confidence band surrounding mean males per lek for study area comparison. This approach allowed for incorporation of missing values, and thus we were able to use all of the available information associated with counted leks within the study areas. We evaluated the potential use of information from 21, 29, and 91 leks at DLL, RICH, and WWY, respectively, for this analysis and used available data within our study period (1989–2013), as well as data up to 5 years previous (i.e., beginning in 1984 using Utah and Wyoming lek data referenced above) to define active leks. Third, we calculated lek persistence rates and 95% confidence intervals for each area. For lek persistence, we considered leks as active if they had two or more males counted in two or more of the 5 years surrounding our initial start date (1989) and within 5 years of our end date (2013). We considered leks inactive if they did not meet this criteria (Connelly et al., 2004) and calculated persistence rates as the proportion of leks active at the beginning of our study period that were still active at the end.

Brood Surveys

Annual estimates (1985–2009) of the number of chicks per brood on DLL were obtained by driving through multiple brooding areas across the ranch or walking through brooding areas not adjacent to a road (rare). Once established, areas searched were kept consistent year to year. We only used observations collected July 1 to August 30. Chicks per brood were compared between years before rangeland treatments (1985–1993) and in years following the initiation of rangeland treatments (1994–2009) using mean, standard error, and 95% confidence intervals.

Sage-Grouse Use of Treated Areas on DLL

From 1996–1998, we monitored sage-grouse use of five plots treated by disking or prescribed fire within the previous 4 years. In 2005, we monitored three plots treated with a Lawson aerator within the previous 5 years. All treated sagebrush areas on DLL, whether by Lawson aerator, disking, chain-harrow, or prescribed fire, were designed in a mosaic pattern creating increased edge and attempting to only remove a portion of the sagebrush cover from large contiguous areas. Plots averaged ~140 ha (range 100–200 ha). For all sampling, we paired each treatment site with a nearby (<1 km) reference site. Intact sagebrush reference sites were of similar size and delineated by field personnel based on proximity and similarity of site characteristics to treatment plots. We monitored sage-grouse use of the treatments by sampling each study plot with two to three pointing dogs followed by two to three observers mounted on horseback (1996–1998) or foot (2005). Pointing dogs searched in a quartering pattern in front of observers, sampling up to 250 m on each side of the edge of the treatment (Dahlgren et al., 2006). Surveys required approximately an hour to complete, and we did so in a circular course for each study plot. We counted and categorized grouse as adults without young, brood members (hens and chicks), and total sage-grouse. To sample the plots during the best scenting conditions for pointing dogs (Gutzwiller, 1990; Dahlgren et al., 2010, 2012), we sampled each plot two to four times during late June to mid-August (1996–1998) or late June to early July (2005) between 0700 and 1000 or 1800 and 2100 hours. When sage-grouse flushed, we marked the location with a GPS and calculated the distance to nearest treatment boundary (intact sagebrush or treatment edge). We used PROC GLIMMIX (SAS 9.2) to test for differences in mean

Table 1
Area (ha) of sagebrush canopy manipulated by treatment type on Deseret Land and Livestock in northern Utah, USA, 1993–2009.

Elevation	Type of treatment					
	Wild fire	Prescribed fire	Disked planting	Mechanical (Aerator, chain)	Tebuthiuron (spike)	Total
≤2 000 m	163	0	489	554	0	1 206
2 001–2 100 m	507	538	3 192	1 684	47	5 968
>2 100 m	1 603	853	352	413	991	4 212
					Total	11 386

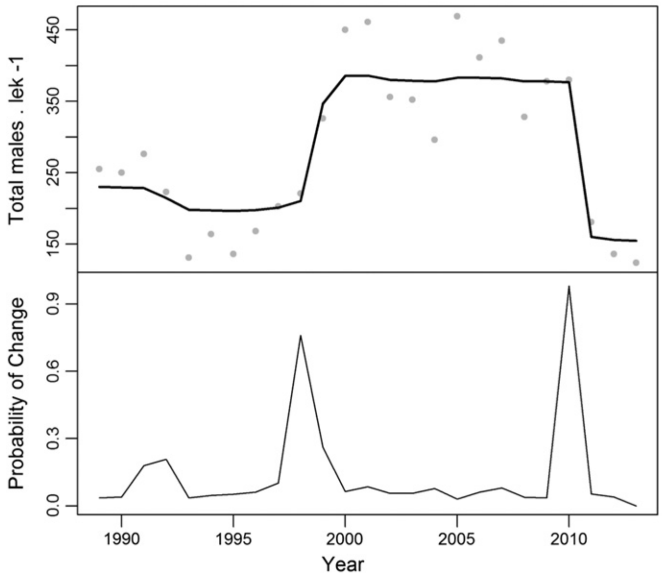

Fig. 3. Posterior means (upper frame); summed number of male sage-grouse lek (*Centrocercus urophasianus*) and probability of change (lower frame) for nine leks on Deseret Land and Livestock Ranch, northern Utah, USA 1989–2013.

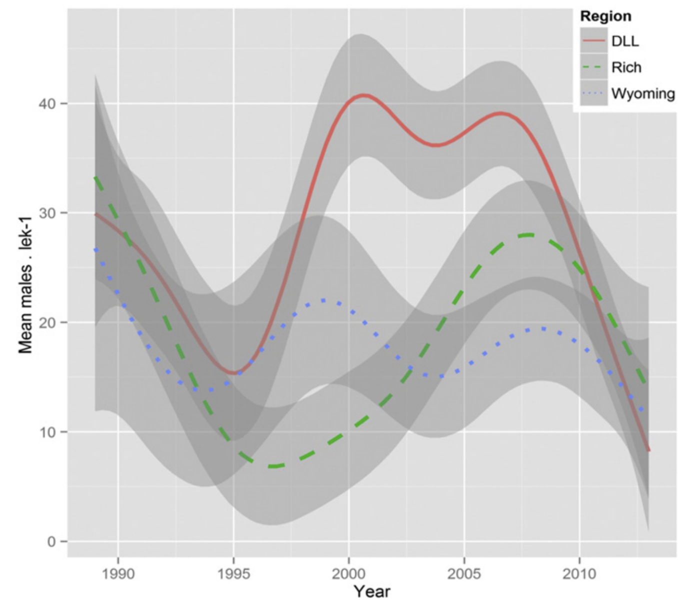

Fig. 4. Mean counts of greater sage-grouse (*Centrocercus urophasianus*) males at leks on Deseret Land and Livestock (DLL) ranch in northern Utah, Rich County (RICH), and western Wyoming (WWY), USA 1989–2013.

number of total grouse, adults, and brood members. We treated location/site of paired plots as a blocking factor to account for inherent variability among sites and more directly assess treatment effect (SAS Institute Inc. 2002–2003).

Results

Lek Data

The summed males per lek for nine leks on DLL initially decreased from > 200 (1989–1992) to < 150 during 1993 and 1995 (Fig. 3). Subsequent summed males per lek for the same nine leks increased dramatically in the late 1990s to more than 400 in 2000 and 2001. Following 2001, counts fluctuated but remained nearly double those observed during the first 10 years of the study period until 2010, when they decreased to summed males per lek (~150 males) similar to those observed during the first part of the study period. The increase in males per lek during the late 1990s and decrease in 2010 were both assigned high (~90%) posterior probabilities of change (Fig. 3). Posterior probabilities of change for all other years were < 30% (Fig. 3). Average males per lek at DLL reflected similar changes decreasing slightly to less than 25 males per lek in the early 1990s, increasing to nearly 50 between 2000 and 2009, and then decreasing drastically in 2010 (Fig. 4). The increase in counts during the middle part of our study period was not observed at the RICH or WWY study areas, and confidence bands surrounding estimated mean counts did not overlap during most of this period (Fig. 4). Conversely, substantial overlap in confidence intervals occurred during the initial and ending years of our study period (Fig. 4).

The lek persistence probability at DLL was 1.00 (95% CI: 0.92–1.0) where all ($n = 9$) of the active leks counted in 1989 were still active in 2013. During the same period, persistence probabilities were 0.80 (95% CI: 0.62–0.98; $n = 20$ leks) and 0.47 (95% CI: 0.23–0.71; $n = 17$ leks) for WWY and RICH, respectively. Confidence intervals around persistence probabilities showed DLL with a significantly higher persistence probability than the other two study areas, which overlapped considerably.

Brood Surveys

We counted 182 brood groups during pretreatment years (1985–1993; $n = 223$ hens, $n = 857$ chicks, $\bar{x}_{pre-treatment} = 3.68$, SE = 0.24, 95% CI = 3.21–4.16) compared with 365 brood groups detected in post-treatment years (1994–2009; $n = 411$ hens, $n = 1717$ chicks, $\bar{x}_{post-treatment} = 4.06$, SE = 0.26, 95% CI = 3.55–4.57).

Sage-Grouse Use of Burned and Disked Plots

Treatment plots from 1996–1998 and 2005 combined averaged more adult grouse ($\bar{x}_{treated} = 2.79$, SE = 0.62; $\bar{x}_{control} = 0.73$, SE = 0.14; F = 10.57, $P < 0.01$), brood members ($\bar{x}_{treated} = 5.80$, SE = 0.83; $\bar{x}_{control} = 0.71$, SE = 0.62; F = 24.17, $P < 0.01$), and total grouse ($\bar{x}_{treated} = 8.42$, SE = 1.16; $\bar{x}_{control} = 1.19$, SE = 0.58; F = 31.12, $P < 0.01$) counted in all treatments compared with control comparisons. Flush location data suggested that most sage-grouse (80% of both adults and broods) used areas within 60 m of a habitat edge (Table 2).

Discussion

The number of male sage-grouse counted on leks at DLL was not different from surrounding areas in the late 1980s and early 1990s. Then the DLL sage-grouse population experienced an increase and sustained higher lek count trends for nearly 15 years compared with RICH and WWY populations. By 2013, however, numbers of males on leks at DLL had returned to levels similar to the beginning of our study period and comparable with those of adjacent areas. The increase in the DLL population during the middle portion of our study period corresponded with the initiation of small-scale sagebrush treatments, but as sagebrush removal continued and adverse weather conditions occurred in winter and early spring of 2010 and 2011, the number of males on leks at DLL declined precipitously to levels similar to RICH and WWY areas.

Depending on the period evaluated, inference about the influence of DLL's management actions on sage-grouse changed from neutral (first decade) to positive (middle period) back to neutral or negative (end of study period). These changes spanned periods of increased spring precipitation (early 1990s), drought (much of the 2000s), and two extreme winters (1992–1993 and 2010–2011) providing a range of conditions for sage-grouse to respond to DLL's management actions. This suite of conditions also provided a basis from which to generate hypotheses concerning sage-grouse population response to range management actions.

Table 2
Distance to habitat edge for sage-grouse flushed during pointing dog surveys of treatment and reference plots on Deseret Land and Livestock (DLL) ranch in northern Utah, USA, 1996.

Grouse and habitat type	Distance from flush site to habitat edge				
		0–30 m	30–60 m	60–90 m	>90 m
Broods in intact sagebrush	$n =$	15	1	0	3
	[1]P(x)	0.79	0.05	–	0.16
Broods in treatment areas	$n =$	34	13	5	6
	[1]P(x)	0.59	0.22	0.09	0.10
Adults in intact sagebrush	$n =$	8	3	1	0
	[1]P(x)	0.67	0.25	0.08	0.00
Adults in treatment areas	$n =$	11	8	3	4
	[1]P(x)	0.42	0.31	0.12	0.15

[1]P(x) = proportion of broods or adult grouse.

Because sagebrush treatments on DLL increased herbaceous cover and production (Aoude, 2002; Summers, 2005) and were implemented in a mosaic pattern consisting of small annual acreage treated primarily in mid- to high-elevation sagebrush habitats (Connelly et al., 2000), we hypothesize that treatments increased availability of grasses and forbs for sage-grouse, similar to other studies (Slater, 2003; Dahlgren et al., 2006; Stringham, 2010). Treatments on DLL were applied against a backdrop of a large intact sagebrush landscape with relatively few threats from invasive plants or urban development and with prescriptive grazing during all years evaluated. We propose these herbaceous plants were able to establish and persist because the prescriptive grazing strategy employed at DLL provided periods of growing-season recovery between bouts of livestock grazing (Davies et al., 2011). Without growing-season rest, herbaceous cover may quickly disappear from treatments resulting in short-lived benefits (Davies et al., 2011).

During surveys observers and pointing dogs detected more sage-grouse, particularly broods, using treated areas (primarily edges) compared with adjacent untreated reference areas consistent with other studies (Slater, 2003; Dahlgren et al., 2006; Stringham, 2010; Thacker, 2010). We hypothesize that sage-grouse responded to increased availability of forbs and grasses by using treated areas and potentially increasing production and recruitment, particularly during favorable weather conditions during the 1990s (Guttery et al., 2013; Robinson and Messmer, 2013). Although there remains uncertainty concerning the influence of sagebrush treatments on adult and chick survival, herbaceous plants, especially forbs and associated arthropods, are linked to sage-grouse nutrition (Gregg et al., 2008) and survival (Connelly et al., 2000; Dunbar et al., 2005). Increased recruitment is important for sage-grouse population growth (Johnson and Braun, 1999; Dahlgren, 2009; Taylor et al., 2012) and low chick survival has been implicated as limiting for some populations (Connelly and Braun, 1997; Taylor et al., 2012). Additionally, increased forb availability on DLL could have facilitated increased nutrients for prelaying hens, resulting in better production through higher nest success and chick survival (Dunbar et al., 2005; Gregg et al., 2008). However, similar to Connelly et al. (2000), we emphasize that manipulating sagebrush in nesting habitat within 5 km of leks to benefit sage-grouse could be counterproductive (Coates et al., 2013). More research concerning the relationship of treatments, associated forb response, and prelaying hen use and nutrition is needed.

We further hypothesize that cumulative annual reductions in sagebrush may have reduced availability of sagebrush cover for sage-grouse seasonal needs at DLL, especially when extreme weather occurred. However, on the basis of our available data we cannot distinguish which factor, sagebrush removal or severe weather, was most influential or if an interaction of both affected the decrease in DLL's sage-grouse population. The extreme winter and spring weather of 2010 and 2011, where cold wet conditions continued through the nesting period, may have resulted in decreased nest success and survival of adult sage-grouse with corresponding decreases in number of males counted at leks over subsequent years. Sage-grouse typically use high canopy cover sagebrush to conceal nests and early broods (Connelly et al., 2000). It has been well documented that nesting habitat may be compromised if large areas of sagebrush-dominated landscapes have reduced shrub cover (Wallestad and Pyrah, 1974; Braun et al., 1977; Gregg et al., 1994; Sveum et al., 1998; Connelly et al., 2000). Lek counts in RICH and WWY, as well as other populations in Utah, showed declining trends similar to DLL from 2008–2013, although DLL's declining trend was steeper than surrounding populations (Bernales et al., 2012).

Stable populations of sage-grouse occur within large landscapes of intact sagebrush (Aldridge et al., 2008; Knick et al., 2013). We emphasize that sagebrush treatments at DLL were small (vast majority < 200 ha in size) and did not accumulate to more than 20% of the landscape over our study period. We also note with caution that large-scale treatments have not maintained or improved populations (Connelly et al., 2000) and are associated with significant population declines (Wallestad, 1975; Braun et al., 1977; Swenson et al., 1987; Beck et al., 2003). Where sage-grouse habitat is a concern, sagebrush treatment is not recommended for Wyoming big sagebrush dominated landscapes at lower elevations (Beck et al., 2009, 2012; Hess and Beck, 2012; Davies et al., 2011), especially where the potential for invasive plants occur (e.g., cheatgrass; *Bromus tectorum*; Davies et al., 2011; Knick et al., 2011; Miller et al., 2011). Treatments during our study period predominantly occurred in mid to high elevations in breeding (nest and early brooding) and summer (late brooding) habitats, not in wintering habitat at lower elevations.

Nonetheless, DLL personnel have noticed when snow levels are high, covering Wyoming big sagebrush, sage-grouse move upslope into areas of tall basin big sagebrush still available above the snow and treatments may have reduced access to food and cover during these conditions. Recent evidence from other studies suggests that extreme winter weather may also negatively influence survival rates of adult sage-grouse (Anthony and Willis, 2010; Moynahan et al., 2006). During the winter, sage-grouse use sagebrush for both food (~99 % of the diet) and cover, with specific-use areas selected on the basis of sagebrush type, nutrition, and availability of sagebrush above the snow (Remington and Braun, 1985; Schroeder et al., 1999; Thacker et al., 2012; Frye et al., 2013). Our results highlight the importance of maintaining sagebrush habitats with adequate amounts of tall sagebrush for sage-grouse to use as nesting and winter habitat. If adult survival on DLL declined during our study due to limited winter habitat, sagebrush treatments and grass plantings at lower elevations decades before (1960s) our study period might also be implicated (see Ripplinger et al., 2015).

Elements of the prescribed grazing practices at DLL may also have provided benefits to sage-grouse independent of or in concert with sagebrush treatments. In combination, these practices tend to create heterogeneity, which can be beneficial to grouse (Boyd et al., 2011). Our annual brood surveys on DLL showed higher point estimates but significant overlap in confidence intervals for chicks per brood from pretreatment to post-treatment years. The relatively high counts of chicks per brood in pretreatment years may have been an artifact of changes made in grazing practices a decade or more before the implementation of small-scale sagebrush treatments.

Regardless, we caution that our results are based on a case study relying on the preponderance of evidence from management actions implemented outside of an experimental design. More research concerning the demographic responses we have proposed herein is warranted and may be conducted where relatively stable sage-grouse populations exist. However, we can state with some certainty that the range management principles and practices used on DLL were associated with high lek persistence rates and lek counts that for nearly 15 years were higher than adjacent areas with different management practices. We believe this case study provides an initial step to quantify the influence of landscape-level management actions and relate it to population responses. Though our data do not identify mechanisms that lead to population change, they provide evidence of a correlation between management actions and indices of sage-grouse abundance. At a minimum, our data provide a starting point for future research. Given the range-wide reports of declining sage-grouse populations during our study period and the nearly ubiquitous nature of livestock grazing across sage-grouse range, it is imperative that the conservation community increase our understanding of the influence of rangeland management practices on sage-grouse populations (Connelly and Braun, 1997; Davies et al., 2011; Garton et al., 2011). Although fully designed and replicated experiments remain the standard in science, case studies such as this one can provide valuable information leading to hypothesis development and testing.

Implications

Sagebrush type, elevation, precipitation regimens, vegetative resiliency (recovery time/period), and other environmental factors must be considered when planning sagebrush treatments (Davies et al., 2011). The range management strategy employed at DLL is likely not suitable in areas where grasslands predominate (e.g., much of the eastern fringe of sage-grouse habitat) because big sagebrush cover is generally < 20% and not the primary vegetative type. If sagebrush treatments are planned, we recommend use of information on sage-grouse seasonal-use patterns for specific populations whenever possible to help in delineation of treatments in large, intact, mid- or high-elevation sagebrush communities (Dahlgren et al., 2006). To maintain sage-grouse populations, the average annual treatment rate should not exceed the sagebrush recovery rate. Furthermore, treatment patterns should be highly mosaic creating as much edge as possible. We recommend treatment widths of 120 m or less to maximize benefits to sage-grouse and suggest chemical treatment occur at low active ingredient rates where small isolated treatment patches can be created (Dahlgren et al., 2006). Prescribed fire, most appropriate in high elevation systems, can create mosaics favorable to sage-grouse use if conducted under conditions resulting in low-intensity fire (Thacker, 2010). We also encourage using grazing practices that provide adequate growing-season rest. Benefits to herbaceous cover from treatments may not persist if pastures do not receive periodic growing-season rest (Aoude, 2002; Davies et al., 2011). We strongly recommend further research be conducted to fill knowledge gaps hypothesized herein.

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