Are Lek Disturbance Buffers Equitable for All Gunnison Sage-Grouse Populations?

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Abstract

Lek disturbance buffers can be used to identify areas that provide important seasonal habitat for Gunnison sage grouse Centrocercus minimus (hereafter GUSG), a species with declining or vulnerable populations across their range. Lek disturbance buffers define areas around leks where anthropogenic disturbance is not permitted and have been considered for potential conservation strategies across GUSG habitat. Currently there is minimal information available on the effectiveness of the size of defined lek disturbance buffers. This study focused on two GUSG populations, the smaller Crawford population and a segment of the larger Gunnison Basin population. We utilized global positioning system location data on GUSG to evaluate seasonal use within three lek disturbance buffers, then compared and contrasted results between the two populations. The Crawford GUSG population showed increased movements from breeding season to late brood-rearing season and in winter returned to a usage pattern similar to the breeding season. Comparatively, the western Gunnison Basin GUSG population showed considerable movement throughout the entire year. In addition to these differences, we noted remarkable differences in distance between active leks, home range size, and total daily distance traveled between Crawford and western Gunnison Basin populations. Lek disturbance buffers created using the standard protocol provided varying protection depending on the distance between leks and number of leks. In small populations, the disturbance buffers overlapped each other, thus producing a smaller total lek disturbance buffer area. In addition to adding to the general body of knowledge of a little-studied species, our study had two important findings: 1) the use of empirical cumulative distribution demonstrated considerable differences in lek disturbance buffer use between the Crawford and the western Gunnison Basin populations, and 2) lek disturbance buffers did not provide equal protection for all populations on the basis of their current definition and derivation. We anticipate that land managers will find our results useful and informative when developing land management plans for the conservation of GUSG. Our analysis showed that the variability between populations and species is important for managers to consider when developing conservation strategies, especially for small populations.

Keywords: Gunnison sage grouse, GPS, lek disturbance buffer

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Introduction

For many lekking species, it has been shown that habitat adjacent to areas of lekking activity are important for nesting and brood rearing (Whitfield et al. 2008; Alonso et al. 2012; Hovick et al. 2015). Further protection of these species can be provided by defining lek disturbance buffers for habitat protection. Lek disturbance buffers have been defined to encompass important seasonal habitat for greater sage grouse (GRSG) Centrocercus urophasianus (Holloran 2005; Blickley et al. 2012; Baruch-Mordo et al. 2013). Currently, there is minimal information available to evaluate the utility and effectiveness of these lek disturbance buffers for Gunnison sage grouse Centrocercus minimus, hereafter GUSG.

Before the early 1990s it was assumed that there was one species of sage grouse throughout the United States. In 2000, both the genetic uniqueness of GUSG was verified and full species recognition occurred (Banks et al. 2000; Young et al. 2000). Gunnison sage grouse is a species of special concern for all federal and state natural resource management agencies throughout its range, and was listed under the U.S. Endangered Species Act (ESA 1973, as amended) as a threatened species in 2014 (USFWS 2014). Genetic deoxyribonucleic acid sequence information from mitochondrial and nuclear genomes supports the hypothesis that there is a barrier to gene flow between GUSG and GRSG populations (Young et al. 2000). Although the GUSG range-wide conservation plan (RCP) provided information and recommendations for protection buffers for anthropogenic impacts (GSGRSC 2005), there was no basis of support from GUSG-specific data. Gunnison sage grouse currently occur in seven populations in Colorado and Utah, occupying 3,795 km² (GSGRSC 2005). The seven populations are Gunnison Basin, San Miguel Basin, Monticello–Dove Creek, Pinyon Mesa, Crawford, Cerro Summit–Cimarron–Sims Mesa, and Poncha Pass. The Gunnison Basin is considered to be the core population of the species; satellite population areas are much smaller in both habitat and population numbers.

Loss and alteration of sage-steppe habitat due to many factors have been identified as a primary reason for decline in GUSG populations. Sage grouse are dependent on sagebrush ecosystems and the availability of sagebrush habitat at relatively large spatial scales to meet their seasonal life-phase requirements. Sage-grouse populations may be affected by anthropogenic activities and structures in sagebrush ecosystems (Johnson et al. 2011; Wisdom et al. 2011). Land management agencies have attempted to reduce the negative effects of anthropogenic activities by assigning surface use designations, such as no surface occupancy or seasonal timing limitations to areas around leks (breeding grounds). However, rationale for the size of these areas has often been challenged in relation to land management agency actions for sage-grouse habitat (Connelly et al. 2000; Doherty et al. 2011; Dahlgren et al. 2016).

Lek disturbance buffers were originally developed to provide areas of relatively undisturbed habitat critical for all life stages of GRSG (Doherty et al. 2011; Fedy et al. 2012). These buffers were then adopted for use with GUSG to protect their habitat from the future effects of various threats including drought, disease, and anthropogenic influences including vegetation treatments, roads (and their use), urban development, energy development, grazing, fences, and power lines. Land management agencies have generally used three protection buffers for anthropogenic impacts to sage grouse, as described in the GUSG RCP (GSGRSC 2005): 966, 3,217 and 6,437 m. The first objective of the study was to evaluate the relationship between lek disturbance buffers and habitat use by GUSG on a seasonal basis. The second objective was to provide managers information on the utilization of lek disturbance buffers as a conservation management strategy for GUSG. The results of the study will inform the conservation strategy plan for GUSG as a protected species under the Endangered Species Act (USFWS 2014).

Study Sites

The project study area was composed of two separate areas in southwestern Colorado: Crawford and the western portion of the Gunnison Basin. The Crawford study area is approximately 48 km north and west of the western Gunnison Basin study area.

Crawford

The Crawford population (currently estimated at 148 individuals), one of the remaining GUSG populations (CPW 2016a), exists in the Green Mountain area of the Gunnison Gorge National Conservation area and Black Canyon National Park in Montrose County. Although the Crawford population is small, the persistence and growth of this population directly contributes to genetic diversity conservation of this declining species. Only observational and anecdotal information about GUSG range, movements, and seasonal habitat use existed for this population before this study. The Crawford study area for this project occurred within the upper North Fork of the Gunnison Basin, including the northernmost portion of the Black Canyon of the Gunnison National Park. The project area encompassed a 6,437-m buffer around the five known active leks within the Crawford GUSG population area. The area covered approximately 22,400 ha managed by various state, federal, and private landowners including the National Park Service (NPS) and the Bureau of Land Management (BLM) (Figure 1). The northern and eastern portions of the study area were primarily private lands and were utilized for agriculture and low-density housing development. The southern and western portions of the study area were predominantly public lands and were utilized for wildlife habitat, domestic livestock grazing, and recreation.

The Crawford study area ranges in elevation from 1,675 to 2,600 m. At the lowest elevations of the study area (1,675 to approximately 2,300 m), the vegetation was dominated by Wyoming big sagebrush Artemisia
tridentata ssp. wyomingensis on deep-soiled mesa tops, black sagebrush *Artemisia nova* occurring on shallow soils, and pinyon–juniper woodlands *Pinus edulis* and *Juniperus osteosperma* on shallow soils of the draws and canyons. From the elevations of 2,300 to 2,400 m the vegetation was dominated by mountain big sagebrush *Artemisia tridentata* ssp. *vaseyana* and Utah serviceberry *Amelanchier utahensis* on mesa tops with pinyon juniper or gamble oak *Quercus gambelii* occurring on gshallow soils and in the canyons. Above 2,300 m the vegetation was a mix of gamble oak, Utah serviceberry, and mountain big sagebrush.

**Western Gunnison Basin**

The western Gunnison basin study area was a portion of the greater Gunnison Basin GUSG population (estimated at 3,711 individuals; CPW 2016b). The Gunnison Basin population was considered the core and majority of the GUSG population and was stable to increasing. There have been several research studies on this population (Hupp and Braun 1989; Young et al. 1994; Kahn et al. 1999; Aldridge et al. 2012). The western Gunnison Basin study area was located in the Gunnison Basin to the west of the town of Gunnison extending west to Sapinero Mesa, including mesas to the north and south of Blue Mesa Reservoir. The western Gunnison Basin study area was defined by a 6,437-m buffer around the active leks within the multiple convex polygon (MCP) derived from five global positioning system platform transmitting terminals (GPS PTT) marked GUSG. The area covered approximately 69,900 ha (Figure 2) and was managed by various state, federal, and private landowners including the NPS (Curecanti National Recreation Area) and the BLM. The private lands in the study area were primarily utilized for agriculture, recreation, and low-density housing development. The NPS lands were largely covered by the Blue Mesa Reservoir and the uplands surrounding the water body have numerous developed recreation sites. The BLM public lands were utilized for wildlife habitat, domestic livestock grazing, and recreation.
The western Gunnison Basin study area ranges in elevation from 2,300 to 2,900 m. Sagebrush was the primary vegetation throughout the study area, with Mountain big sagebrush occurring on deeper soils and black sagebrush occurring on shallow soils. The highest elevations and north- and east-facing slopes were occupied by Ponderosa pine *Pinus ponderosa*, Douglas fir *Pseudotsuga menziesii*, spruce *Picea* spp., Rocky Mountain juniper *Juniperus scopulorum*, and aspen *Populus tremuloides*. Numerous drainages bisect the area with riparian communities occupied by narrowleaf cottonwood *Populus angustifolia*, Rocky Mountain juniper, gamble oak, serviceberry *Amelanchier alnifolia*, and wild rose *Rosa woodsii*. Most of the valley bottoms along major drainages had been converted to hay and pastureland (Aldridge et al. 2012).

**Methods**

We collected location data using the microwave telemetry avian backpack (Solar Argos GPS/PTT micro-wave telemetry Inc., Columbia, MD) using a rump mount technique (Figure 3). We secured the transmitter by a leg loop attachment. All transmitters weighed 22 g and did not exceed 3% of the individual’s body weight (Thirgood et al. 1995). These units attempted to collect 14 GPS locations each day, one attempt each hour from 0600 hours to 1800 hours and one location attempt at midnight. The location was telemetered directly from the collar, thus we played no role in telemetering the data to the data repository on a 5-d interval. Initially we marked five female GUSG from the western Gunnison Basin population starting in March of 2010 and collected data into January of 2013. One of these birds was able to remove its GPS unit; therefore, we ended up having four birds collect 27,827 GPS locations (Data S1, Supplemental Material). For the Crawford population we marked 12 females. One of the backpacks failed and two of the birds were depredated; thus we were left with nine marked females. This sample represents approximately 8.8% of the reported 2011–2014 average Crawford GUSG population (CPW 2016a). We collected the number of Crawford seasonal locations used in this analysis over a

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**Figure 2.** Map of the western Gunnison Basin area showing land management designations as of 2010, western Gunnison Basin overall population range, and the 4-mile lek disturbance buffer. Inset illustrates relative location of study area within Colorado.
4-y period (2011–2014), and they ranged from a minimum of 250 locations per bird per season to 4,498 locations (Data S1, Supplemental Material).

We did not use locations from a bird who had less than 250 locations in a given season within a year. For analysis purposes, we also removed clustered locations that showed no successive movement beyond the cluster. It is typical, based on prior experience, at the end of collar life to have a collection of clustered locations less than 50 m apart, indicating bird mortality or dropped collars. We did attempt to find failed collars using the last GPS location, metal detectors, and on-the-ground searches and were able to recover one collar using those methods. Thus we cannot confirm that the remaining collar failures were related to bird mortality, but were certain that the collars were no longer collecting data. For this analysis we had eight birds representing 14 bird-years for breeding season; eight birds representing 11 bird-years for the late brood-rearing season, and five birds representing 10 bird-years for the winter season from the Crawford GUSG population. For the western Gunnison Basin population we had four birds representing 9 bird-years for the breeding season; four birds representing 8 bird-years for the late brood-rearing season, and three birds representing 8 bird-years for the winter season.

For analysis purposes, we divided location data into three seasons on the basis of season descriptions in the 2005 GUSG RCP: breeding season, late brood-rearing season, and the winter season. We established these dates on the basis of expert knowledge from researchers, field biologists, and managers who have worked closely with GUSG and represent a range to be inclusive of seasonal variability (M. S. Siders, K. W. Holsinger, BLM; N. W. Seward, Colorado Parks and Wildlife, personal communication). Breeding season started on March 20 and continued through July 1 (103 d). During this time period, the birds initially spent their time around the active leks in the area, then moved off to nesting habitat and once clutches were established they moved on to early brood-rearing habitat. The late brood-rearing season started on July 2 and continued through October 15 (106 d). During late brood-rearing period the birds made a habitat use shift to more mesic habitats. The winter season occurred from October 16 through March 19 (156 d). During the winter season GUSG spent most of their time in sagebrush-dominated habitats that provide food and cover.

We determined active leks by using the RCP (page 305) definition. Colorado Parks and Wildlife in the GSGRCP (2005) defined leks for the Gunnison Basin as an open area that has been attended by two or more male sage-grouse in 2 or more of the previous 5 y. For the smaller populations outside the Gunnison Basin, an active lek was defined as an open area where one or more GUSG had been observed on more than one occasion engaging in courtship or breeding behavior in the last 5 y (GSGRCP 2005). In the western Gunnison Basin there were approximately 100 active leks. However, we used only the 11 active leks that were within the MCP of the location data collected during breeding season for analysis. For the Crawford population, the five known active leks were those used in the lek disturbance buffer analysis.

As a starting point for further analysis, we determined the mean 24-h distance between location by using individual bird data locations sorted by season and year and 24-h periods. We calculated initial home-range estimates using an MCP home-range estimation technique (Nilsen et al. 2008). In addition, we developed mean distance between leks by measuring the Euclidian distance between active leks (11) within the breeding season MCP in the Gunnison population and all five active leks in the Crawford population.

We utilized three lek disturbance buffers, with the first buffer being 966 m (referred hereafter as B1) from active leks based on GRSG studies of movements of adult males during the breeding season (GSGRSC 2005, 1–3). We utilized lek disturbance buffers developed with GRSG data because no other data were available to define lek disturbance buffers for GUSG. The 3,217-m buffer (referred hereafter as B2) from active leks is based on sage-grouse nests not being uniformly distributed within nesting habitat and some research indicating that 70–80% of nests occur within 3,217 m of an active lek (page 23 in GSGRSC 2005). The 6,437-m buffer (referred hereafter as buffer B3) from active leks is based on GRSG unpublished studies where 85% of all nests and 81% of all breeding and summer–fall seasonal locations were within 6,437 m of lek of capture (page D-3 in GSGRSC 2005). We used a geographic information system (ArcGIS® Desktop 10.5, ESRI, Redlands CA) for all spatial analysis including the delineation of the three disturbance buffers (B1, B2, and B3) defined by the distance from known active GUSG leks. For comparison of areas of protection for each of the populations, we used ArcGIS to summarize the aerial extent of each of the three lek disturbance buffers by population.

To evaluate the relationship of the disturbance buffers and GUSG seasonal activity we used GPS locational data sets from both female GUSG from the Crawford population and female GUSG from the western Gunnison...
Table 1. Gunnison sage-grouse Centrocercus minimus population data comparison representing nine marked females from the Crawford population and four females from the western Gunnison Basin population from 2010 to 2014 in western Colorado. Home-range area is defined using minimum convex polygons for seasonal location data sets representing all locations used in this analysis. We instrumented all birds with a microwave telemetry avian backpack global positioning system unit.

|                  | Crawford          | West Gunnison Basin |
|------------------|-------------------|---------------------|
|                  | Breeding | Late brood rearing | Winter   | Breeding | Late brood rearing | Winter   |
| Number of locations | 14,026   | 12,621              | 9,427    | 8,386    | 10,170              | 9,258    |
| Mean 24-h distance between locations | 729 m    | 785 m                | 531 m    | 2,391 m  | 2,278 m              | 4,327 m  |
| Home range area   | 6,174 ha  | 785 m                | 531 m    | 2,391 m  | 2,278 m              | 4,327 m  |
| Mean distance between active leks   | 1,003 m  |                      |          |          |                      |          |

Basin population. Initially, we evaluated the mean distance to active leks by season for all locations. We then did a similar evaluation using the same data set and empirical cumulative distribution functions (ECDFs). The ECDF is an estimate of an unknown cumulative distribution function (CDF), without assuming any specific parametric form (Evans et al. 2000; Millard and Nagaraj 2001). The set of quantiles that we used were 0.01 to 0.99 by increments of 0.01. Using a set of quantiles from the ECDF provided a more comprehensive description of the movements than provided by a few parametric estimates such as the mean and standard deviation, which require more assumptions (e.g., normality, homogeneity of variances, etc.) to estimate the CDF. We selected ECDF to quantify the between-bird-year variability, which addresses among-bird and among-year variations in movements. We had insufficient numbers of birds marked across all years to partition among-bird from among-year variation. The set of quantiles associated with the ECDF provided the most complete description of the data distribution with minimal assumptions and were used to describe the process of where GUSG located themselves with respect to their known leks. Averages for quantiles across bird-years within a population were estimated with quantile regression, and 95% confidence intervals on differences between averages of selected upper quantiles (0.50, 0.75, and 0.90) for the Crawford and western Gunnison Basin bird-years were estimated using Welch’s t-test for unequal variances. We performed all statistical analysis, including calculating ECDF, using Program R (version 3.1.1; R Development Core Team 2013).

**Results**

We were interested in investigating the differences and similarities between the Crawford and western Gunnison Basin GUSG populations. In general, the western Gunnison Basin population 24-h movements were greater; their home ranges were larger, and distance between leks was also greater (Table 1). For the Crawford study area the maximum number of locations collected for one bird in a year was 4,498 and for the western Gunnison Basin study area the maximum number of locations collected by one bird in a year was 3,896. There was also a difference in number of individuals marked with four females in western Gunnison and nine females in the Crawford population. We acknowledge the difference in sample size between populations but believe it provides a worthy comparison and learning opportunity, previously unavailable.

The telemetry data collected from the Crawford and western Gunnison Basin GUSG populations were non-contemporaneous in year and location; however, the compilation of these data revealed distinct differences in population spatial habitat use within each of the three lek disturbance buffers identified by B1, B2, and B3. During the breeding season, the difference between Crawford and western Gunnison Basin populations was very distinctive as evidenced by the amount of individual bird use per year captured in each buffer (Figure 4). Though some individual bird-year data from the western Gunnison Basin population mimicked the overall Crawford data, some western Gunnison Basin birds had a very different use profile, driving the average empirical cumulative distribution curve to be very different between populations. Averages of the upper quantiles of the cumulative distributions were 2,439 m (95% CI = 352–4,526 m, \( P = 0.027 \)) greater at the 50th percentile to 2,613 m (95% CI = 421–4,804 m, \( P = 0.025 \)) greater at the 90th percentile for the western Gunnison Basin population compared with the Crawford population (Figure 4). Ninety-nine percent of the western Gunnison Basin bird use was contained within buffer B3, whereas 99% of Crawford bird use was contained within buffer B2.

During the late brood-rearing period GUSG in the Crawford population moved farther away from leks than in the breeding season, with less pronounced differences between the Crawford and western Gunnison Basin populations, except for the more extreme distances found in one bird-year in the western Gunnison Basin population (Figure 5). Averages of the upper quantiles of the cumulative distributions were 1,401 m (95% CI = 789 m to 2,439 m, \( P = 0.121 \)) greater at the 50th percentile to 1,538 m (95% CI = 789 m to 2,439 m, \( P = 0.126 \)) greater at the 90th percentile for the western Gunnison Basin population compared with the Crawford population (Figure 5). During the winter season GUSG in the Crawford population remained closer to leks than GUSG in the western Gunnison Basin (Figure 6). Averages of the upper quantiles of the cumulative distributions were 2,510 m (95% CI = 1,264–3,755 m, \( P = 0.002 \)) greater at the 50th percentile to 3,216 m (95% CI = 1,264–3,755 m, \( P = 0.002 \)) greater at the 90th percentile for the western Gunnison Basin population compared with the Crawford population (Figure 6).

During the breeding season, an average of 78% of the GUSG bird-year locations was contained within B1 for the
Figure 4. Empirical cumulative distribution functions (ECDFs) for Gunnison sage grouse (GUSG) *Centrocercus minimus* population breeding season comparison for the Crawford \( (n = 14) \) and western Gunnison Basin \( (n = 9) \) populations in Colorado \( (2010–2014) \). Distance to nearest active lek shown by proportion of locations. Black ECDFs are individual bird-years and red ECDFs are averages across bird-years estimated with quantile regression. Buffer 1 (B1) represents 966-m lek disturbance buffer; buffer 2 (B2) represents 3,217-m lek disturbance buffer; buffer 3 (B3) represents 6,437-m lek disturbance buffer. We used data from nine female GUSG in the Crawford population and four female GUSG in the western Gunnison Basin population. We instrumented all birds with a microwave telemetry avian backpack global positioning system unit.

Figure 5. Empirical cumulative distribution functions (ECDFs) for Gunnison sage grouse (GUSG) *Centrocercus minimus* population late brood-rearing season comparison for the Crawford \( (n = 11) \) and western Gunnison Basin \( (n = 8) \) populations in Colorado \( (2010–2014) \). Distance to nearest active lek shown by proportion of locations. Black ECDFs are individual bird-years and red ECDFs are averages across bird-years estimated with quantile regression. Buffer 1 (B1) represents 966-m lek disturbance buffer; buffer 2 (B2) represents 3,217-m lek disturbance buffer; buffer 3 (B3) represents 6,437-m lek disturbance buffer.
Crawford population (Figure 4). However, during late brood-rearing season, this changed to only 31% within B1 (Figure 5). The Crawford population returned to a usage pattern similar to its breeding season pattern during the winter season, with the primary difference being a slight increase in individual variability. Comparatively, the western Gunnison Basin population data are 1% contained within B1 during both the breeding and the late brood-rearing season. Sixty percent of the locations were contained in B2 during breeding season and 85% in late brood-rearing season. Only the western Gunnison Basin population had individuals that utilized habitat beyond B3 during the year. The variation in seasonal locations relative to known leks was considerably greater among GUSG in the western Gunnison Basin compared with the Crawford population (Figures 4–6).

Differences in landscape use by population

The maximum distance to an active lek for any season by the Crawford population was 6,695 m and for the western Gunnison Basin birds it was 9,040 m (Data S2, Supplemental Material). Both maximum distances were collected during the late brood-rearing season. The difference in distance between leks was remarkable since the mean distance was approximately three times larger in the western Gunnison Basin population than in the Crawford population. Similarly, the home-range data differences between the populations were also substantial, with western Gunnison Basin home-range size nearly five times that of the Crawford population (Table 1). It is notable that these larger home ranges and distance between leks were associated with the larger and more robust western Gunnison Basin GUSG population.

The area protected by lek disturbance buffers varied greatly between the two populations. For comparison of protected areas, we only used active leks that were within the breeding season MCP home range as defined by our GPS location data (Data S1, Supplemental Material). This included five active leks for the Crawford population and 11 active leks for the western Gunnison Basin. For all three lek disturbance buffers, the western Gunnison Basin area of protection was 2.5 to 3 times larger than the area of protection for the Crawford population (Table 2).

Discussion

The results of this project provided an empirically based evaluation of the proportion of use by two distinct GUSG populations, captured by each of the three lek disturbance buffers described above. We found a paucity of published research evaluating the relationship between GUSG and their seasonal use within the lek disturbance buffers. However, some research existed on GRSG (Fedy et al. 2012; Coates et al. 2013) that could also be used for similar types of evaluation. Lek disturbance buffers for GUSG were developed using GRSG research results (GSGRSC 2005). However, a one-size-fits-all approach to conservation, developed from a different species (GRSG), could have very different consequences for limiting disturbance between various GUSG populations.
Table 2. Area protected by lek disturbance buffers for Gunnison sage-grouse (GUSG) *Centrocercus minimus* population for the Crawford and western Gunnison Basin populations in Colorado (2010–2014). Buffer 1 (B1) represents 966-m lek disturbance buffer; buffer 2 (B2) represents 3,217-m lek disturbance buffer; buffer 3 (B3) represents 6,437-m lek disturbance buffer.

| Population                  | Buffer | Area protected (ha) |
|-----------------------------|--------|---------------------|
| Crawford                    | B1     | 1,562               |
| Crawford                    | B2     | 8,034               |
| Crawford                    | B3     | 22,412              |
| Western Gunnison Basin      | B1     | 4,137               |
| Western Gunnison Basin      | B2     | 26,260              |
| Western Gunnison Basin      | B3     | 67,345              |

The method of evaluating seasonal use by relationship to lek disturbance buffers was a practical way to analyze GUSG usage. Leks are unique features on the landscape identifiable by aerial surveys, ground-based assessments, and modeling techniques (Ouren et al. 2014). Leks are used to guide sage-grouse habitat conservation because they are the most seasonably predictable points within an otherwise homogeneous landscape where GUSG can be observed. Thus, leks are currently used as a basis for estimating populations and predicting nesting habitat because of their concentration of use during the breeding season (Walsh et al. 2010).

Our study pointed out an important issue regarding small vs. larger populations that bears future exploration. Lek disturbance buffers created using the standard protocol provided varying protection depending on the distance between leks. The western Gunnison Basin study population had 11 active leks spaced an average of 3.3 km apart vs. the Crawford population with five active leks with an average of 1.1 km between them. Because of the difference in distance between leks, the total area protected by the lek disturbance buffers was not proportional to the number of leks. In small populations, the disturbance buffers overlapped each other, thus producing a smaller total lek disturbance buffer area and thus less habitat protection. To better protect GUSG habitat via lek disturbance buffers for the subpopulations, further consideration needs to be implemented to determine the appropriate size of lek disturbance buffers. Since there are only five known active leks in the Crawford study area and marked birds represented almost 9% of the population, it is possible that additional leks exist. In greater prairie chicken (*Tympanuchus cupido*) studies, site fidelity research has shown that lek sites are dynamic where restored landscape heterogeneity exists (65% of the lekking activity in their study moved by nearly 1 km; Hovick et. al 2015). Thus, it is possible that active GUSG lek sites could change and not be counted. An earlier peer-reviewed report (Ouren et al. 2014) identified areas throughout the GUSG-occupied habitat that had the same biophysical makeup as those areas currently classified as “active” lek sites. On the basis of the information generated by that report and lek monitoring, we identified two new potential active leks. We did not include these leks in our analysis because they had not met temporal requirements to be classified as active leks (GSGRCP 2005). Thus, utilizing currently defined lek disturbance buffers alone has the potential of excluding additional GUSG habitat. Additionally, another potential issue with lek disturbance buffers is that they are circular in design, without landscape limits that prohibit potentially large areas of non-GUSG habitat from being included. Another option would be to utilize resource selection analysis (Aldridge et al. 2012) to improve seasonal habitat mapping (i.e., identify areas of relatively high selection for each of the seasons and look at their relationship to the lek disturbance buffers). Otherwise, as populations decline, lek attendance will decline and lek buffer protection will increasingly provide less seasonal protection for GUSG. Declining seasonal protection area may exacerbate existing issues within a population and accelerate declines in populations.

Because little research has been published on GUSG, considerable gaps in knowledge exist. Studies on other lekking grouse species recommended lek disturbance buffer sizes between approximately 0.5 and 18 km (Connelly et al. 2000; Doherty et al. 2008). The width of this range indicates that there is not a clear definition of the most effective lek disturbance buffer size for GUSG. Other factors that have been shown to affect lekking grouse species include surface disturbances such as roads (Walker et al. 2007); tall vegetation (Winder et al. 2015); vegetation change (Baruch-Mordo et al. 2013); anthropogenic activities (Blickley et al. 2012); and climate variability (Cross et al. 2011). Considering the above factors specifically for GUSG could provide valuable insight to determining differences in buffer sizes for various populations. Although our findings provided strong evidence that detectable differences existed between the two populations in our study, the differences may not hold true with other subpopulations or with a larger data set.

In addition to adding to the general body of knowledge of a little-studied species, our study had two important findings: 1) the use of empirical cumulative distribution demonstrated considerable differences in lek disturbance buffer use between the Crawford and the western Gunnison Basin populations, and 2) lek disturbance buffers do not provide equal protection for all populations because of their current definition and derivation. Thus, while potentially providing conservation of habitat, lek disturbance buffers used in isolation by management could lead to missing important habitat in the conservation effort. More broadly, we anticipate that land managers will find our results useful and informative when developing land management plans for the conservation of GUSG across the seven populations.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.
Data S1. Excel spreadsheet of Gunnison sage grouse *Centrocercus minimus* attributed location data from both the Crawford and the western Gunnison Basin populations in western Colorado (2010–2014). Found at DOI: https://doi.org/10.3996/012018-JFWM-003.S1 (4.29 MB XSLX).

Data S2. Excel spreadsheet provides distance to the nearest lek in meters for all leks considered in this manuscript. Represents data collected from Gunnison sage grouse *Centrocercus minimus* from both the Crawford and the western Gunnison Basin populations in western Colorado (2010–2014). Found at DOI: https://doi.org/10.3996/012018-JFWM-003.S2 (16 KB XSLX).

Data S3. Complete metadata for S1 and S2. Represents data collected from Gunnison sage grouse *Centrocercus minimus* from both the Crawford and the western Gunnison Basin populations in western Colorado (2010–2014). Found at DOI: https://doi.org/10.3996/012018-JFWM-003.S3 (14 KB DOCX).

Reference S1. [CPW] Colorado Parks and Wildlife. 2012. 2012 Gunnison sage-grouse *Centrocercus minimus* lek count summary and population estimate for the Crawford population. Colorado Parks and Wildlife, internal report, Gunnison, CO. Found at DOI: https://doi.org/10.3996/012018-JFWM-003.S4 (1.41 MB PDF).

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