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Response of greater sage-grouse to surface coal mining and habitat conservation in association with the mine

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Abstract: Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) is a sagebrush-obligate species that has experienced species-wide declines in population density and distribution. Sage-grouse habitats support human-related needs including domestic livestock grazing, urban development, and energy extraction. The U.S. Fish and Wildlife Service identified energy extraction as a range-wide sage-grouse conservation threat. Mining has been of specific concern because of observed sage-grouse population declines and impaired habitat within close proximity to the activity. Mining may be particularly problematic for small, isolated sage-grouse populations. In southwestern Utah, proactive habitat improvements and predator management have been implemented to mitigate the potential effects of surface mining on the southernmost population of sage-grouse in the United States. We evaluated sage-grouse lek attendance trends before (1991–2010) and during (2011–2016) mining on a lek located near the mine (Sink Valley lek) to assess population responses to coal mining and related mitigation activities. Changes in lek trends have been demonstrated as a valid metric to assess the effects of conservation actions on sage-grouse populations. We used a paired *t*-test to compare differences in male lek attendance before and during mining and analysis of variance to determine if sage-grouse densities and distance to mining changed during the mining period. We recorded bird coordinate location and the number of birds observed at each sighting location along 10 transects within the study site area. Differences in location from mining was tested using Analysis of Variance with $\alpha < 0.5$. There was no difference in the number of males attending the Sink Valley lek before and during mining. Population cycles were consistent over the time period sampled. With the exception of 2013, which had an unusually high number of sage-grouse found within the Sink Valley area, there were no differences in the number of birds observed at each sighting location in relation to the mine center ($P = 0.37$), the coal crushing facility ($P = 0.34$), and the mine boundary ($P = 0.24$). Coupled with ongoing mitigation activities including habitat restoration, pinyon-juniper (*Pinus edulis, Juniperus osteosperma*) removal, aggressive predator control, pre-mining acclimation to human influences, and removal of pinyon-juniper woodlands, surface coal mining had no negative effect on population cycles in the Alton/Sink Valley area.

Key words: *Centrocercus urophasianus*, coal mining, greater sage-grouse, habitat restoration, lek, population cycles, reclamation

Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) have experienced population declines range-wide, due primarily to environmental factors that affect reproduction and survival (Connelly and Braun 1997, Dahlgren et al. 2016*b*). Because sage-grouse rely on sagebrush habitats for year-round habitat needs, anthropogenic developments and large-scale transformations have been reported to decrease suitable sagebrush habitats, alter ecosystem processes, decrease biodiversity, and fragment historic wildlife habitats (Knick et al. 2003, Schroeder et al. 2005, Davies et al. 2011, Miller et al. 2011, Chambers et al. 2014).

Energy demands across western North America (renewable and nonrenewable) have resulted in the extraction of natural resources and exploration of new energy sources within sagebrush ecosystems. The U.S. Fish and Wildlife Service (USFWS) has identified energy development as a range-wide species conservation threat (USFWS 2015). Mining

Figure 1. Three male sage-grouse strutting on a lek located approximately 2.2 km from a coal crushing facility (shown in background) and 0.5 km from the nearest mining activity. Birds are lekking on a juniper removal treatment site.

and oil and gas extraction modify sage-grouse behavior and fragment sagebrush habitats to the detriment of sagebrush-obligate and facultative plant and animal species (Connelly et al. 2000, Lyon and Anderson 2003, Holloran et al. 2005, Naugle et al. 2011). While energy extraction practices vary, sage-grouse response to disturbance was related to the intensity of the energy extraction activity, rather than the specific activity type; responses included changes in lekking behavior and lek attendance (Holloran 2005). Similarly, Braun et al. (2002) found that leks located within 200 m of oil and coal mining activities (roads, well sites) in southeastern Alberta resulted in lower lek attendance.

One of the major concerns for sage-grouse above mining impacts is surface disturbance, habitat loss, and noise pollution (Dahlgren et al. 2016*b*). The most effective way to mitigate these impacts is through habitat management and improvement. Dahlgren et al. (2016*a*) found that Utah sage-grouse populations are primarily limited by space. The removal of pinyon-juniper (*Pinus edulis* Engelm.; *Juniperus osteosperma* [Torr.] Little) woodlands (PJ) has been found to significantly increase sagebrush habitat availability. Utah's Greater Sage-grouse Conservation Strategy recognized the potential for mining to impact local sage-grouse populations (UDWR 2013). The plan recommended the implementation of mitigation activities to include creating habitat and predation management to abate these potential impacts. Dahlgren et al. (2016*b*,*c*) recommended habitat restoration projects with the removal of conifers that have encroached into historical sage-grouse habitat as an effective strategy with the potential for immediate populations benefits. Frey et al. (2013) reported immediate sage-grouse use of areas where conifers have been removed.

Increased predation by corvids, particularly common ravens (*Corvus corax*) and mesopredators, have impacted sage-grouse populations throughout some of Utah's sage-grouse management area (UDWR 2013, Baxter et al. 2013), especially in areas associated with human activities (Coates and Delehanty 2004, Bui et al. 2010). Anthropogenic activities, such as resource extraction, transmission lines, and urban development increase food and perching substrates for ravens, resulting in increased raven populations around these areas (Kristan et al. 2004, Messmer et al. 2013). Furthermore, loss of habitat can increase predation on sage-grouse nests by increasing the ability of predators to detect nests and observe hen activity (Coates and Delehanty 2010, Baxter et al. 2013).

Habitat management and predator control can result in stable or even improving sage-grouse populations (Boyd et al. 2011, Baxter et

Table 1. Total land disturbed during coal mining at the Coal Hollow Mine in southwestern Utah.

Year	Hectares disturbed	Hectares reclaimed
2010	70.8	0.0
2011	8.5	0.0
2012	9.7	0.0
2013	21.9	5.5
2014	23.5	24.3
2015	4.0	11.8
Total	138.4	41.6

al. 2013, Dahlgren et al. 2015, Dahlgren et al. 2016*b*). Research in southern Utah determined that sagebrush treatments (mechanical and chemical) created habitat that increased sage-grouse use both within and adjacent to treated areas (Dahlgren et al. 2006, Frey et al. 2013). Baxter et al. (2013) found that enhancing habitat and controlling predators improved sage-grouse survival in Strawberry Valley, Utah. Frey et al. (2013) reported that pinyon-juniper mastication increased sage-grouse habitat and expanded sage-grouse distribution where treatments occurred. One source of possible restoration effort may be in off-site mitigation or habitat restoration within mined landscapes. In areas where the increase in tree density has fragmented or decreased habitat availability, mitigation practices may be used to restore these areas. In areas where sage-grouse habitat has been highly fragmented or deteriorated, it is possible that the benefits of mitigating mining activities may offset the negative impacts to this resource use (UDWR 2013, Dahlgren et al. 2016*c*). The purpose of this study was to determine how mining activities in concert with habitat management and mitigation strategies affect sage-grouse population cycles.

Study area

The sage-grouse population in the Alton/Sink Valley is the southernmost extent of the species (Dahlgren et al. 2016*a*), adjacent to and south of the town of Alton, Utah (37°26′20″ N 112°20′ W). Average annual precipitation is approximately 43.2 cm, delivered generally in 2 annual wet periods. During winter, cyclic storms bring precipitation as snowfall, and in summertime, storms originating from convection air masses from the Gulf of Mexico or the Pacific Ocean provide rainfall to the region. Of the 2 annual wet cycles, summer rainfall is most reliable and consistent. Monthly average minimum temperatures range from a low of -9.4°C during January to a high of 28.1°C in July. The study area covers approximately 1,575 ha, comprised of both private and public land ownership. The vegetation is dominated by black sagebrush (*A. nova* A. Nelson) that supports a diversity of plant communities including sagebrush grasslands, Gambel oak (*Quercus gambelii* Nutt.) woodlands, seep and spring fed wet meadows, pastures used for livestock grazing, and alfalfa fields. Much of this area has been heavily encroached by pinyon pine (*Pinus edulis* Engelm.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) woodlands, reducing and fragmenting available and suitable sagebrush habitats (Frey et al. 2013, Dahlgren et al. 2016*b*, Dahlgren et al. 2016*c*).

The habitat occupied by the Sink Valley sage-grouse population has been influenced by human-related impacts and ecological succession pathways (Frey et al. 2013). In addition to providing year-round sage-grouse habitat, this region also supports human development and activity including alfalfa farming, pasture for livestock grazing, residential homes and seasonal cabins, and a network of maintained gravel county roads and unimproved dirt roads that transects the habitat use area (UDWR 2013). Pinyon-juniper (PJ) has expanded into much of the landscape, including tree encroachment into extensive regions that would have once been sagebrush grasslands (Frey et al. 2013). Additionally, PJ woodlands have experienced infill where they have outcompeted sagebrush and other shrub and herbaceous species. This PJ invasion has constricted suitable sage-grouse nesting, brood-rearing, and winter habitat throughout the Alton and Sink Valley (UDWR 2013).

Prior to mining, a relatively small population of sage-grouse have occupied the region that surrounds the Sink Valley lek (UDWR 2013). The study area is part of the Pangutich Sage-grouse Management Area (SGMA), which consists of 245,729 ha. The Panguitch SGMA is one of 11 SGMAs that occur within the state of Utah, serving as high priority habitat for sage-grouse management and conservation. The occurrence of a coal mine within an SGMA has been of significant importance regarding the relationship between surface coal mining and sage-grouse conservation in the state. It has provided the state of Utah a unique opportunity to assess sage-grouse population patterns in association with disturbance related to surface mining activities (UDWR 2013). The Utah Division of Wildlife Resources (UDWR) conducts annual lek counts of the Sink Valley sage-grouse population. UDWR biologists monitor each lek in the region multiple times per year, recording the total number of strutting males observed at dawn. Lek count data used in this study were provided by the UDWR Cedar City office.

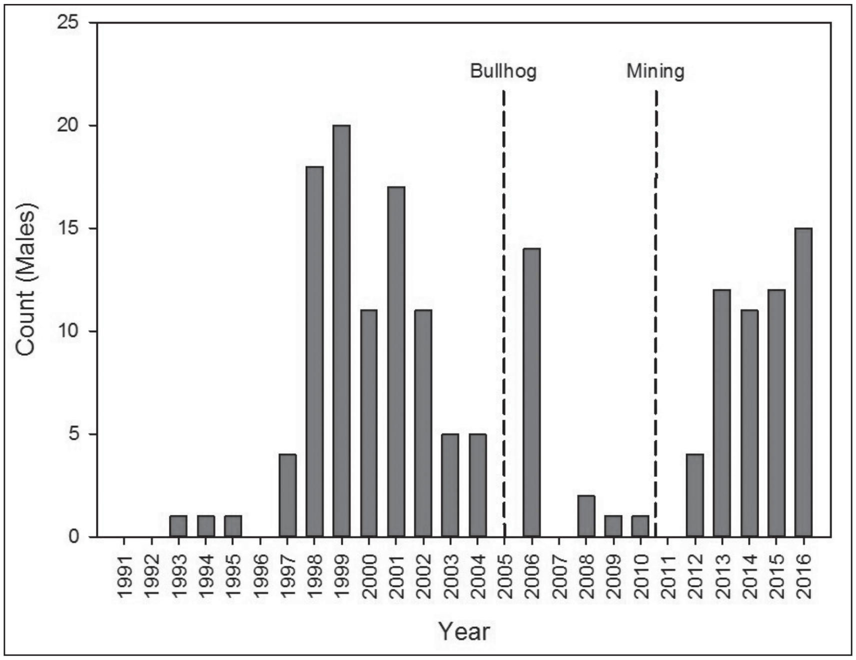

Figure 2. Male lek attendance between 1991 and 2016 at the Sink Valley lek located in southwestern Utah. In 2006, a bullhog mastication project was completed to remove encroached pinyon-juniper woodlands and enhance sage-grouse habitat within the region. Coal mining began in fall 2010.

During the breeding season, an average of 6.0 ± 1.6 male birds attended the lek prior to mining activity (1991–2009; UDWR unpublished data; Figure 1). This ranged from no birds in 5 non-consecutive years to a maximum of 20 birds in 1999. Between 1998 and 2006, male lek attendance was highest with 11.2 ± 2.3 males attending the lek annually (based on highest count on a single day). During a period of low lek attendance (2007–2011), an average 3.4 ± 1.9 males were observed. In 2012, a new lek was identified approximately 0.8 km southwest of the historic lek. Lek count data, however, cycle on a period of 9–12 years (UDWR unpublished data), which is a similar pattern observed in the Sink Valley lek data.

The original lek was located along a fenced wet meadow pasture within the valley bottom of the study area (Sink Valley). This site was dominated primarily by pasture grasses (*Poa pratensis*, *Phleum pratense*, *Dactylis glomerata*). Prior to mining, male counts at the original lek dropped to low numbers, including no birds observed. Between 2013–2014, the original lek was mined for coal and then reseeded in 2015 using a mix of native and introduced grasses and forbs. In 2012, males were observed strutting on the new lek area, located 0.8 km southwest of the original lek. This lek was positioned on the top of a ridgeline adjacent to and overlooking the sagebrush field where the highest bird counts and number of observation had occurred. The new lek occurred within a previously bull-hogged area, consisting of scattered shrubs (*Artemisia nova*), perennial grasses (i.e., *Elymus trachycaulus*, *Poa pratensis, Elymus elymoides*), and forbs (i.e., *Melilotus officinalis*). Reclamation of the original lek was assessed with mean values and the coefficient of determination.

Surface coal mining operations

Land ownership within the mining area is approximately 65% federal (Bureau of Land Management) and 35% private ownership. Private lands are used primarily for livestock production (pasture) and 2 ranch homes and stock yards. Mining operations began in 2010 with coal extracted from shallow coal beds. Since then, 138.4 ha have been mined (Table 1). Initially, topsoil and subsoil were stockpiled or live-hauled for later use in habitat reclamation. Mining operations employed standard, open-pit methods using truck/loader type equipment

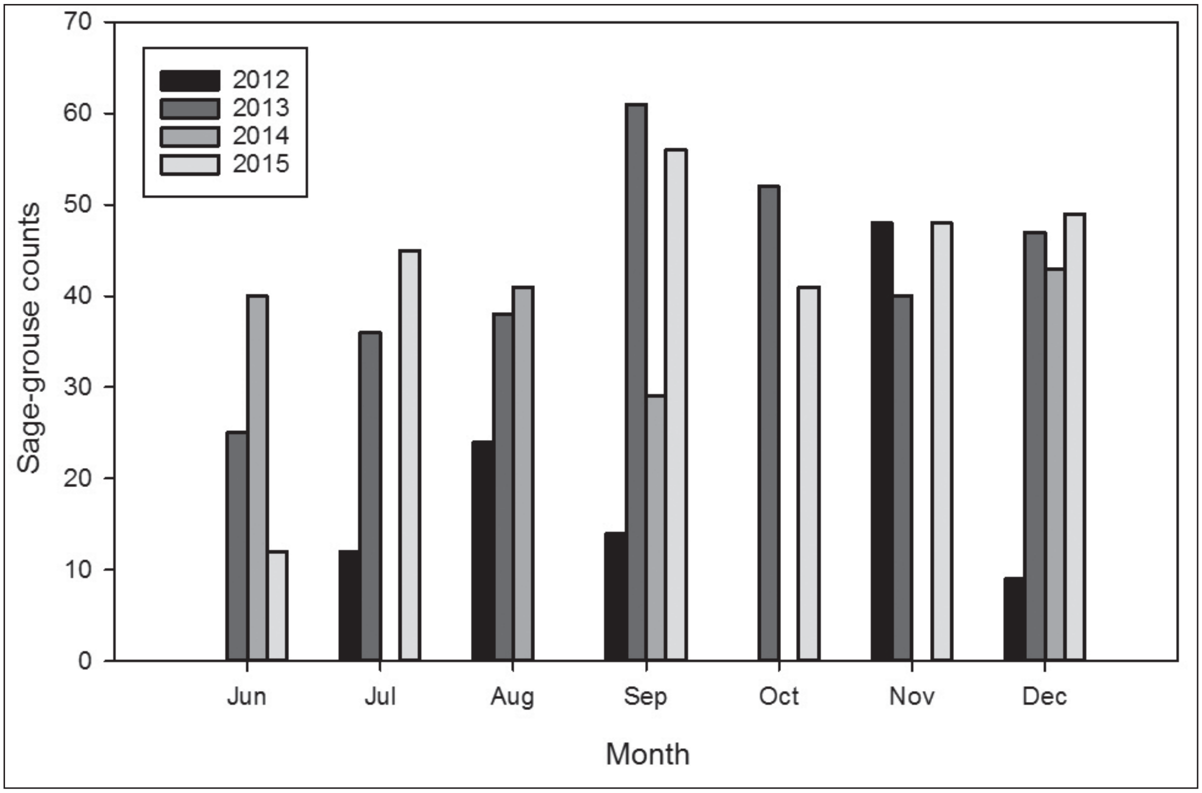

Figure 3. Sage-grouse counts during late brood-rearing and winter months within the mining region. All observations occurred <2 km from the center of the mine. No data were due to periods that did not have a survey conducted.

to remove overburden and recover the coal. Mining advanced across the property in successive cuts approximately 76.2 m in width and 243.8–396.2 m in length, with the previous pit being filled to approximate original contour from the current excavation. Extracted coal is transported from open pits to a coal crushing facility where trucks are filled and the coal is hauled from the mine site at a rate of up to 6 trucks per hour. Daily mining activity levels have been variable (4–6 days per week, 10–24 hours per day). Prior to mining, sagebrush habitats located east and south of the mine were excluded from the mining permit because these were identified as critical sage-grouse nesting and brood-rearing habitats. Throughout the mining period, sage-grouse have continued to lek at a new site located 2.2 km south of the coal crushing facility, 0.8 km from the historic lek, and ranging 0.25–0.5 km from the nearest edge of the mine footprint.

Habitat reclamation, vegetation improvements, and predator control

As part of their mitigation, the mining company reduced all tree canopy cover within the primary habitat areas to increase available sagebrush habitat both inside the mining footprint and throughout mapped sage-grouse habitat in Sink Valley and Alton. Pinyon-juniper woodlands were reduced both before and during mining by both tree cutting and mastication with a bullhog shredder. This was conducted to expand sagebrush grassland habitat that could eventually provide the structure required by sage-grouse for breeding, brood-rearing, and winter use. In 2006, PJ woodlands were thinned by mastication with the intent to increase suitable sagebrush habitat. In 2015, the same areas were treated by clearing trees not removed in 2006, providing more suitable habitat conditions for nesting and brood-rearing. In addition to reducing tree canopy cover, the mining company conducted shrubland habitat treatments to improve existing sagebrush-steppe habitats. Habitat improvements included the reduction of rubber rabbitbrush (*Ericameria nauseosa*) by treating shrubs with the herbicide Tordon 22k® and an increase in sagebrush density, cover, and vigor.

To reduce the impact of common ravens on nest and chick predation, USDA Wildlife

Services (USDA-WS) distributed hard-boiled eggs treated with DRC 1339, an avicide used to control corvid species (Spencer 2002). Eggs were placed along roadsides near the mine, within sage-grouse habitat areas, and at the feedlot located at the north end of town that provides a consistent food source and generates high raven concentrations. Each year (2012–2015) an average of 1,344 (SD = 144) eggs were distributed throughout the area, resulting in an estimated removal of 122–672 ravens from the area (Coates et al. 2007). Wildlife Services removed coyotes (*Canis latrans*) using bait traps placed along fencelines and near dens as well as ground and aerial shooting. From 2012 to 2015, an average of 17.8 (SD = 1.3) animals were removed annually. Both raven and coyote removals were aimed at lessening the degree of predation on chicks, young of the year, and adult sage-grouse.

Methods

Sage-grouse response to mining activity and restoration

To determine how sage-grouse responded to mining activities and the reclamation and restoration activities, we analyzed annual lek count data, relative to both pre- and post-mining activity (Dahlgren et al. 2016*b*, Dahlgren et al. 2016*c*). Dahlgren et al. (2016*b*) found that male-based lek counts of sage-grouse are an effective index to overall population change. These data provide insight into population dynamics at sites where the annual lifecycle is undetermined and to be used to examine population dynamics at greater spatio-temporal scales. Furthermore, perturbation analyses such as this long-term demographic analysis is needed to enhance scientific rigor for prioritization of the most cost-effective species conservation and management actions (Akçakaya and Raphael 1998, Cooch et al. 2001, Baxter et al. 2008).

Within the study area, which extends 1.7 km to the south of the mine footprint, 0.7 km to the west, 0.6 km to the north, and 1.1 km to the east, there is 1 lek (Sink Valley Lek). We used the lek count data provided by the UDWR (unpublished data), determined from the highest count recorded following multiple lek visits during the breeding season. For this study, lek counts recorded before and during mining were compared using a 2-way Kruskal-Wallace non-parametric test of variances with $\alpha < 0.5$. Because lek counts were highly variable during pre-mining years, potentially due to typical population cycles (Dahlgren et al. 2016*b*), data were analyzed across all years and for years with >1 bird per lek count in the case that birds were present but not detected.

We recorded the coordinate location of all sage-grouse observed within the mine area between June and January during 2012 to 2016 to detect sage-grouse habitat use and to determine shifting patterns in the distance birds were observed from mining activities. Observations were not conducted during the nesting and early brood-rearing periods (February through May) to prevent any disruption to breeding hens or young chicks. Observations were conducted during morning hours at the beginning of each month. We searched for birds along 10 established transect lines within sagebrush and meadow habitats surrounding the mine/lek area each month. Transect lines ranged between 0.3 and 0.75 km in length and were located in habitat patches that we determined from past studies and observations were the most likely to provide habitat for sage-grouse. The same survey lines were followed each year. The coordinate locations for each sage-grouse observation were recorded using Global Positioning System (GPS) or aerial photographs. The researcher also recorded the time of day, weather conditions, habitat type, number of birds observed, and age/sex when discernable. To avoid repeat counts of the same birds along the transect line. We also took note of the direction flushed birds moved.

To determine the correlation of sage-grouse sightings to mining activity, we used ArcGIS (ESRI 2011) to analyze the locations with spatial information. We calculated the minimum Euclidian distance from each bird/flock sighting and measured the 1) center of the mine, 2) center of the coal crushing facility, and 3) closest area within the mine footprint (boundary). We divided bird sightings into 3 categories (near, mid, far) to compare differences in bird use patterns across years. Bird observations near the center of the mine (0–800 m) were in close proximity to roads, high traffic, and long-term mining activity compared to mid (800–1,500 m) and far (>1,500 m), which included birds with low to no visual or auditory mine-related

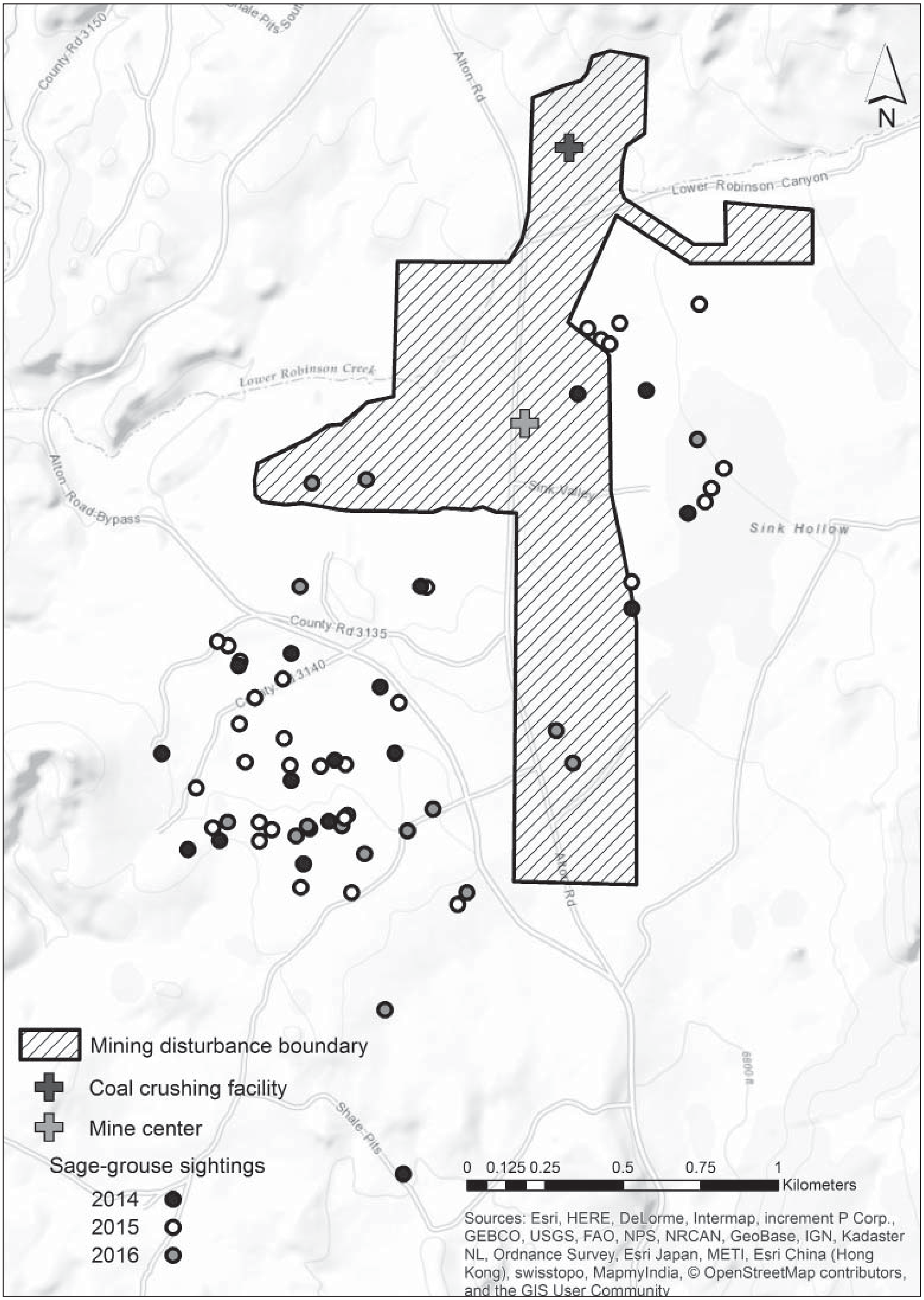

Figure 4. Location of sage-grouse habitat use (sightings) 4–6 years since the start of coal mining (Fall 2010). Bird sightings were recorded during ground surveys conducted monthly. The coal crushing facility represents stationary mining while the center of the mine site has high traffic patterns and transitional mining activity.

influences. The coal crushing facility was located at the north end of the mine footprint, adjacent to a PJ woodland and more distant from suitable sage-grouse habitat. Birds located near the coal crushing facility (0–1,500 m) had long-term mining activity, high traffic, with higher occurrence of people outside of vehicles compared to mid (1,500–2,300 m) and far (>2,300 m) distances. The mine footprint is located substantially closer to most of the intact sagebrush habitats, with closer proximity to bird observations compared to the mine center and coal crushing facility. Sage-grouse sighted near the footprint (0–400 m) included short- and long-term mining activity with less consistent traffic and human activity compared to mid (400–850 m) and far (>850 m) distances. We used Analysis of Variance (SAS® 2013) with $\alpha < 0.5$ to detect significant differences among distances and years, including an assessment of interactions between distances and years.

Results

Sage-grouse response to mining activity and restoration

When considering all lek count years, there was no difference in male lek attendance before and during mining ($T = 1.10$, df = 24, $P = 0.28$) with 5.6 ± 1.5 and 9.0 ± 2.7 birds observed, respectively (Figure 2). There was similarly no difference in lek counts before and during mining when >1 male was observed ($T = 1.31$, df = 14, $P = 0.98$) with 10.8 ± 2.6 and 10.7 ± 1.7 males observed, respectively. Bird sightings were recorded on average 1.2 ± 0.1 km from the center of the mine, 2.0 ± 0.1 km from the coal crushing facility, and 0.5 ± 0.03 km from the mine footprint. A total of 68.8% of all bird observations were located in the sagebrush-steppe habitat southwest of the mine footprint. Sage-grouse occurrence in this region was year-round. Sage-grouse were observed 9.8% of the time in the wet meadow area east of the mine. Observations occurred primarily from early to late brood-rearing periods. Considering all years combined, there was no intersection between year and location ($F = 1.15$, df = 61, $P = 0.34$) for sage-grouse counts. When testing for main effects, there were differences in bird numbers averaged across all locations among years ($F = 7.53$, $P < 0.001$). This was due to an unusually high number of birds in 2013 (31.3 ± 3.8) compared to 2012, 2014, and 2015 with 10.7 ± 3.4, 9.7 ± 3.2, and 10.2 ± 2.3 birds, respectively (Figure 3). When 2013 was removed from the analysis, there were no differences in the number of birds counted by year ($F = 0.03$, $P = 0.97$).

We detected no significant interactions between year and distance the mine center ($F = 1.09$, $P = 0.37$), the crushing facility ($F = 1.15$, $P = 0.34$), and the boundary ($F = 1.36$, $P = 0.25$). Considering main effects, the distance of birds from mining activity was different across years, with more birds in the mid-range in 2013 compared to the same year in both near and far ($P < 0.001$ for all distances). Similar to count data, an unusually high number of sage-grouse were observed in the region during 2013. With 2013 excluded from the analysis, there were no differences in bird sightings by year for the mine center ($F = 0.53$, $P = 0.66$), the coal crushing facility ($F = 0.60$, $P = 0.62$), and the mine boundary ($F = 0.62$, $P = 0.61$; Figure 4). During our flush surveys, an average of 6.6 ± 3.8 ($\bar{x}$ ± SD) chicks were observed with a hen during both early and late brood rearing periods across all survey years. Hens with chicks were observed during early brood-rearing periods in sagebrush habitats and during late brood-rearing periods in wet meadow habitats approximately 0.59 km and 0.36 km from the active mine site, respectively. Between 2013–2015, an average of 4.8 chicks were observed adjacent to the mine site, primarily within the wet meadow area east of the mining activity. Chicks were observed 0.08 km from the mine footprint. Since completing reclamation on the historic lek, 12 males have been observed displaying in this location following 5 years of no activity. This area is located 1.9 km from the coal crushing facility and 0.7 km from active mining activity (Figure 5).

Discussion

Sage-grouse occupied the same general habitat area during breeding and non-breeding periods for the duration of the study. While others have found that sage-grouse are less likely to use habitat within 4 km of energy extraction activity (oil, gas) compared to undisturbed areas (Lyon and Anderson 2003, Doherty et al. 2006, Naugle et al. 2006), the birds occupying our study site were observed within 2 km of the center of the mine throughout the duration of the study period. Before mining, this sage-grouse population was in close

Figure 5. Sage-grouse at the reclaimed historic lek following 5 years with no sightings and 2 years with 1 male attending only.

proximity to human-related activities including frequent vehicle traffic, farming and ranching operations, and urban development. Mining equipment and facilities may have provided a similar set of conditions to pre-mining that would create a similar behavioral response. In contrast to this study, Naugle et al. (2006) characterize declining trends in sage-grouse lek attendance relative to natural gas mining activities (permanent wells, power lines, and roads). They observed 516 leks from 1990–2005 and found that overall populations declined with extensive natural gas development (>40% within 3.2 km). They also attribute avoidance behavior to agricultural practices.

It is possible that site and habitat fidelity have played a large role in the location of the grouse in proximity to the mine. There are large patches of suitable habitat >1 km from the mine that are not frequently used by sage-grouse, which suggests that sage-grouse are not so limited in habitat that they are required to use sub-optimal habitat rather than leave the area entirely. We acknowledge that using an area near mining activity does not necessarily indicate that sage-grouse are thriving alongside such activity. However, we suggest that the restoration and habitat mitigation efforts that were initiated during the onset of mining activity, coupled with the reclamation of habitat as mining activity moved across the landscape, worked to maintain the existing sage-grouse population.

Lek counts did not decline as a result of the mining activity; the lek moved (resulting in low lek attendance counts until the UDWR found the new location) but remained stable. According to Dahlgren et al. (2016*c*), population cycles are typical for sage-grouse lek attendance, a pattern detectable at the Sink Valley Lek. Subsequently, attendance by male sage-grouse may not signify successful recruitment. Although this study did assess movement data, there was no data indicating recruitment success in Alton/Sink Valley prior to mining; therefore, we did not attempt to make the comparison of recruitment before and during mining. However, during our monthly observation surveys, we consistently observed hens and chicks, which may indicate that recruitment was occurring within the study area. Additionally, a recent study designed to monitor hens with GPS radio-telemetry repeatedly identified young hens within the study area, supporting the hypothesis that sage-grouse are successfully rearing brood in the area during the mining activity. Sage-grouse recruitment within 2 km of the mine is potentially increased with a combination of consistent and aggressive predator control, which was conducted as mitigation and increased habitat availability (i.e., PJ mastication, sagebrush treatments).

Management implications

Effective sage-grouse conservation practices are needed that reduce impacts while sustaining energy development demands. Increasing habitat suitability and availability while reducing threats from predators may contribute to sustainable and stable sage-grouse populations. The impacts of energy development on sage-grouse populations and sagebrush habitats has been a concern for land managers. Applying practices that minimize these impacts are needed. Because we did not evaluate the direct influence of predator control on sage-grouse survival, this aspect of management was not included in this study. However, extensive raven and coyote control was implemented to reduce predator threats to eggs, chicks, and adult sage-grouse. This effort may be an important factor in sustaining sage-grouse populations.

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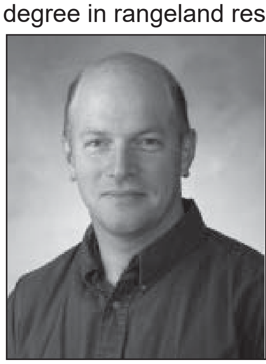

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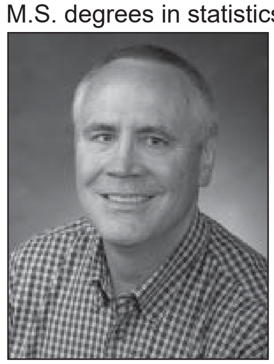

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