ABSTRACT The greater sage-grouse (Centrocercus urophasianus; sage-grouse) has undergone range contraction and population decline because of anthropogenic land surface disturbances; yet, there is little information on the effects of mining on sage-grouse populations. In the Bighorn Basin of Montana and Wyoming, USA, bentonite mining is a growing source of surface disturbance that contributes to loss of sagebrush (Artemisia spp.) habitat. We evaluated the response of sage-grouse to active and reclaimed bentonite mining, relative to nesting, brood-rearing, adult breeding, and adult winter habitat, through resource selection and habitat-specific mortality risk analyses, based on female sage-grouse (n = 321) monitored with telemetry from 2011–2015. A greater proportion of our monitored sample was exposed to mining disturbance during winter (65%) than during other seasons (range = 25%–34%). We observed avoidance of all mining disturbance for selection of nesting habitat (n = 378 nests), adult breeding habitat (n = 1,978 locations), and adult winter habitat (n = 1,365 locations). Evidence was inconclusive for avoidance of mining for brood-rearing habitat (n = 754 locations). We also observed increased adult breeding season mortality risk (n = 62 mortality events; n = 285 female sage-grouse) associated with active mining disturbance but observed no effect on nest success (n = 207 mortality events; n = 378 nests). Evidence was inconclusive for increased mortality risk associated with broods (n = 48 mortality events; n = 157 broods) and adults during winter (n = 31 mortality events; n = 220 female sage-grouse). Stakeholders in the Bighorn Basin should be flexible and proactive to minimize the negative effects of bentonite mining on sage-grouse habitat use and demographic rates. Stakeholders should prioritize the conservation of winter habitats because of the influence of a greater proportion of the population and because of the lower regulatory priority given to winter habitat and they should strive to perfect mining reclamation to return disturbed sites back to pre-disturbance conditions to minimize long-term effects of the mines on sage-grouse. © 2019 The Wildlife Society.

KEY WORDS bentonite mining, Bighorn Basin, Centrocercus urophasianus, greater sage-grouse, habitat selection, Montana, mortality risk, reproductive success, Wyoming.

Surface disturbance of arid rangelands in western North America has been increasing because of increasing human populations, which have led to increased food and energy demands. These arid ecosystems are less resilient to abnormal and more frequent disturbances such as conversion to agriculture, energy development, increased grazing pressure, and increased fire regimes (Chambers et al. 2016, 2017). Subsequent, natural recovery from disturbance is slower than more productive systems. For example, in Utah, USA, vegetation at sites was still not recovered 90 years after cultivation (Morris et al. 2011). These arid rangelands are less resistant to invasion from non-native plants (e.g., cheatgrass [Bromus tectorum]), which influences the frequency of disturbance from fire, potentially resulting in new stable ecological states or novel ecosystems (Balch et al. 2013; Chambers et al. 2014, 2016, 2017). Anthropogenic surface disturbance increases the opportunity for plant communities to change to alternative stable states fundamentally changing the ecosystem, including the associated wildlife. For example, invasive plants can hinder the restoration of native plant communities after disturbance (Monsen 1992). Reclamation practices can be used to limit the long-term effect of anthropogenic disturbance, but they are more difficult to implement in arid rangelands (Allen 1995).

The greater sage-grouse (Centrocercus urophasianus; sage-grouse) was once commonly found across the sagebrush (Artemisia spp.) biome but has lost >40% of its historical range (Schroeder et al. 2004) and has experienced long-term population declines (0.83%/yr decline from 1965–2015; Western Association of Fish and Wildlife Agencies 2015). Since 2002, the United States Fish and Wildlife Service (USFWS) has received several petitions to list the sage-grouse under the United States Endangered Species Act.
footprint than surface coal mining, but is more expansive. In 2015, the USFWS reported that the sage-grouse was no longer warranted for listing under the ESA because of increased regulatory mechanisms designed to limit the amount and timing of land surface disturbance such as those created through the Bureau of Land Management Greater Sage-Grouse Resource Management Plans and the Wyoming Governor’s Executive Order for Greater Sage-Grouse Core Area Protection (USFWS 2015). Land surface disturbances such as agricultural development (Smith et al. 2016a), energy development (Kirol et al. 2015), residential development (Connelly et al. 2004), livestock grazing (Beck and Mitchell 2000), and fire (Lockyer et al. 2015) have contributed to habitat loss and fragmentation.

The effects of energy development, predominately extraction of oil and gas, have been cited as the leading cause of decline for sage-grouse in the eastern portion of their range (USFWS 2010). Documented negative effects from oil and gas development have included avoidance of disturbance for nesting (Lyon and Anderson 2003, Kirol et al. 2015), brood-rearing (Kirol et al. 2015), and winter (Doherty et al. 2008, Carpenter et al. 2010, Smith et al. 2014) habitat. There have also been documented lower demographic rates that have included higher adult female mortality (Holloran 2005, Holloran et al. 2010), higher nest failure (Dzialak et al. 2011), and higher chick mortality (Aldridge and Boyce 2007, Kirol et al. 2015) related to oil and gas development in sagebrush habitat. Avoidance and lower demographic rates in areas of oil and gas development were the likely contributors to observed lower lek attendance and greater lek abandonment (Holloran 2005, Walker et al. 2007, Harju et al. 2010, Hess and Beck 2012, Gregory and Beck 2014). Wind energy development, another source of energy-related disturbance that has been increasing in recent years, also displaces sage-grouse when selecting brood-rearing and adult female breeding habitat (LeBeau et al. 2017).

Mining activities are another potential source of land surface disturbance, of which little is known of their effects on sage-grouse, outside of anecdotal evidence that coal mining has displaced sage-grouse in Colorado (Braun 1998, Connelly et al. 2000). Mining within sage-grouse range has included gold, uranium, trona, coal, and bentonite. The nature of disturbance, and therefore the potential effects on sage-grouse, is not identical between mining and oil and gas development, or even among different types of mining. The actual surface area disturbed by a traditional 1-well oil or gas pad has a smaller footprint than a bentonite clay pit, but disturbance from oil and gas development can quickly become denser and more expansive across the landscape. In contrast, disturbance from bentonite mining has a smaller footprint than surface coal mining, but is more expansive. However, the duration of active mining disturbance from coal mining is likely decades longer than from bentonite mining. Even though oil and gas development may be a significant disturbance factor across the eastern sage-grouse range, it may not be the most important cause of disturbance within a localized region that may provide habitat for large populations of sage-grouse (Chambers et al. 2016).

One such region is the Bighorn Basin of Montana and Wyoming, USA, where an economically important source of surface disturbance is from bentonite clay mining. Ten of the 33 (30%) designated sage-grouse core areas in Wyoming, and over 200 leks, occur in the Bighorn Basin (Hess and Beck 2012, Big Horn Basin Sage-grouse Local Working Group 2013, State of Wyoming 2015). Bentonite clay deposits in Wyoming contain 70% of the world’s supply, and mines in the Bighorn Basin produced over 50% of Wyoming’s total bentonite production during our study (Wyoming Mining Association 2016). Bentonite extraction is carried out by shallow open-pit mining that leads to loss of sagebrush and other vegetation. Individual bentonite mines are only a few hectares in size, but disturbance can become expansive as clay extraction moves relatively quickly along clay deposits (Schuman et al. 1985, 1994). In addition, mining support activities (e.g., exploration drilling, construction and maintenance of roads, haul trucking) increase disturbance and fragment habitat around mines. To date, most bentonite mining in the Bighorn Basin has occurred in salt desert shrub communities dominated by Gardner’s saltbush (Atriplex gardneri) where clay is at or near the surface; however, mining operations will likely increase in sagebrush communities as easily accessible deposits are depleted. These mining activities may prevent or limit the ability of the sagebrush landscape in the Bighorn Basin to provide the space and resources to meet the life-history requirements of sage-grouse. Therefore, there is a need to assess whether bentonite mining affects the sage-grouse population in the Bighorn Basin. This information will help stakeholders make conservation decisions as bentonite mining expands into additional sage-grouse habitat in the Bighorn Basin and adjacent regions where bentonite deposits and sagebrush habitat overlap. Bentonite mines are reclaimed through backcasting of overburden, including top soil, from newly created adjacent mine pits, which is then seeded (Schuman et al. 1985, Wyoming Mining Association 2016). This limits the amount of top soil that must be stockpiled for long periods. Reclaimed mining disturbance may have lesser effects to sage-grouse because human activity is not present; however, reclamation of disturbed sagebrush plant communities to their pre-disturbance states is a long-term process (>30 yr; Liesenfeld 2012), so there could be lingering effects.

We evaluated resource selection and mortality risk relative to bentonite mining for the 4 most critical demographic rates and seasonal habitat requirements for sage-grouse populations: nest, brood, adult breeding, and adult winter mortality risk and habitat selection (Connelly et al. 2011, Taylor et al. 2012). We did not analyze habitat selection or mortality risk in summer because all sage-grouse moved away from areas where bentonite mining occurred, which was in lower
elevation (i.e., hotter and drier) areas, during summer to seek out more mesic sites. For each habitat requirement and demographic rate analysis, we examined 4 hypotheses: no effect from mining disturbance, effect from active mining disturbance only, effect from reclaimed mining disturbance only, and effect from all (i.e., summation of active and reclaimed mine disturbance) mining disturbance.

STUDY AREA

Our study included sage-grouse location and demographic data from 3 research sites in the Bighorn Basin of north-central Wyoming and extreme south-central Montana (Fig. 1). The landscape forming our study was approximately associated with the Carbon Sage-Grouse Core Conservation Area in Montana (State of Montana 2015), and the Shell, Hyattville, and Washakie Sage-Grouse Core Areas in Wyoming (State of Wyoming 2015). The 30-year (1981–2010) normal average annual precipitation and temperature were 35 cm and 7.1 °C, respectively (PRISM Climate Group 2016). Average precipitation and temperature during the years of our study (2011–2015) were 36 cm and 7.2 °C, respectively (PRISM Climate Group 2016). Elevations ranged from 1,180 m to 2,600 m. Plant communities were dominated by Wyoming big sagebrush (A. tridentata wyomingensis) at lower elevations and mountain big sagebrush (A. t. vaseyana) at higher elevations. Black sagebrush (A. nova) was common in localized areas at moderate elevations. Juniper (Juniperus spp.) occurred in localized areas at moderate-to-high elevations. Coniferous forest dominated elevations above sagebrush and Gardner’s saltbush dominated elevations below sagebrush. Sage-grouse winter habitat was mostly located in sagebrush at lower elevations, whereas breeding habitat occurred at a wide range of elevations (Pratt 2017). Anthropogenic disturbance was not widespread across the study area but was abundant in localized areas (Pratt 2017). Agricultural fields (row crops, hayfields, and pastures) were the most common disturbance (5.1% of study area) and were located along the major floodplains of the Bighorn Basin. Bentonite mining was present (0.2% and 0.9% of study area for active mining disturbance and reclaimed mining disturbance, respectively) in localized areas at lower elevations where sagebrush transitioned to saltbush. Land ownership included United States Bureau of Land Management (61%), private (23%), United States Forest Service (10%), and State of Wyoming or Montana (6%).

METHODS

During 2011–2015, we captured female sage-grouse by spotlighting and hoop netting (Giesen et al. 1982, Wakkinen et al. 1992) near leks during spring. We located and captured additional females during summer or winter at night-roosting locations of previously marked sage-grouse. We aged sage-grouse as yearlings or adults (Eng 1955). We marked females with very high frequency (VHF) radio-transmitters (22-g necklace-mounted VHF transmitter Model A4060, Advanced Telemetry Systems, Isanti, MN, USA), or with global positioning system (GPS) equipped platform transmitter terminals (22-g Solar Argos/GPS PTT-100 [Microwave Telemetry, Columbia, MD, USA] or Model 22 GPS PTT [North Star Science and Technology, King George, VA, USA]). We programmed GPS transmitters to acquire from 4 to 6 locations per day depending on season (Pratt et al. 2017). We located sage-grouse equipped with VHF-transmitters by triangulating on the ground from approximately 50 m away during April through August and located birds by fixed-wing aircraft (<200-m error; Dinkins et al. 2017) from September through March. We assigned locations for GPS-marked sage-grouse to season based on behavior (Pratt et al. 2017), whereas we assigned locations for VHF-marked sage-grouse based on population-average seasonal bounding dates (Pratt 2017). We rarified locations from GPS-marked sage-grouse to the sampling intensity of VHF-marked sage-grouse. We used locations from nesting females only once for the adult breeding season analysis. Average location sampling for VHF-marked sage-grouse was 1 location every 7 days, 16 days, and 26 days of exposure for broods, adults during the breeding season, and adults during winter, respectively. Very-high frequency transmitters were equipped with 8-hour mortality switches and we visited the sites of any birds with transmitters emitting mortality signals. We also confirmed mortalities for GPS-marked birds after the transmitter was consistently not moving. We visually confirmed nesting females equipped with VHF-transmitters after we relocated them in the same location on 2 occasions.

Figure 1. Approximate study area boundaries (gray outlines) for investigating greater sage-grouse response to bentonite mining (red polygons) in Bighorn Basin, USA, 2011–2015.
After observing a female sage-grouse on a nest, we monitored it every 4 days by triangulating from the nearest 2-track road until the conclusion of the nesting effort. We searched for nests from GPS-equipped females at the estimated nest location after the female left the area. We checked any GPS-equipped female that appeared to be incubating for ≥1 day for a nest (we discovered a nest in all cases except 1). We determined nest success (i.e., nests with ≥1 egg hatching) by examining egg shells after the female left the area (Sowls 1948). We defined brood success as ≥1 chick surviving to 35 days post hatch. We confirmed any female that had hatched a nest that we suspected to have lost her brood by checking her at night twice. In addition, we confirmed the presence of chicks from night roosting females at 35 days post hatch. Sage-grouse capture and monitoring were approved by University of Wyoming Animal Care and Use Committee (protocols 03142011 and 20140228JB00065) and were completed under permits from Wyoming Game and Fish Department (Chapter 33 Permit 800) and Montana Fish, Wildlife and Parks (Scientific Collector’s Permits 2013-072, 2014-037, and 2015-76).

To control for the effects of environmental landscape attributes, we developed predictor variables for habitat-specific mortality risk and resource selection modeling that were based on several climate, topographic, and vegetation characteristics important to sage-grouse in our study area, including variables used in other sage-grouse resource selection studies (Table 1; Fedy et al. 2014, Smith et al. 2016b, Walker et al. 2016). Because many of these variables were highly correlated, we used principal components analysis to combine these environmental variables into 9 independent components (number determined by inspecting scree plot), which explained 70% of the variation in our environmental variables, to use as final predictor variables. We digitized bentonite mining disturbance using the World Imagery basemap (0.3-m resolution) within ArcGIS 10.0 (Environmental Systems Research Institute 2011) and classified it into active mining (including haul roads) disturbance or reclaimed mining disturbance. Reclaimed mining disturbance were mines that had the overburden and topsoil replaced and were seeded, but vegetation had not returned to pre-disturbance conditions. We measured bentonite variables as the proportion (%) disturbed within multiple, circular spatial regions around locations with radii that started at about maximum location error (i.e., 200 m for winter locations) and systematically increased by doubling in size until the radius of circular analysis regions was 3,200 m, which was the maximum extent we thought would still capture the variability in amount of disturbance within mining areas.

To evaluate population-level second-order resource selection (i.e., selection within the range of sage-grouse in the Bighorn Basin; Johnson 1980, Manly et al. 2002) relative to bentonite mining for nesting, brood-rearing, female breeding season, and female winter season habitat, we compared use locations to randomly selected available locations that were restricted to each research site. We delineated the extents of the research sites from minimum convex polygons
model for each of their respective hypotheses. We determined the scale of measurement and the model support for each hypothesis with quasi-likelihood criteria (QIC; Pan 2001). We considered a QIC value lower than the environmental model and an estimated 95% confidence interval for the mining coefficient that did not overlap 0 demonstrated strong evidence for an effect from mining. If the QIC value was lower than the environmental model but the 95% confidence interval overlapped 0, we considered it as weaker inconclusive evidence for an effect from mining. Because we investigated multiple scales of measurement, we used 95% Bonferroni corrected confidence intervals throughout, which reduces the likelihood of committing a Type 1 error but increases the likelihood of committing a Type 2 error, especially for analyses with smaller sample sizes. For habitat selection influenced by mining, we recorded the selection coefficients for all scales of measurement to determine if there was a maximum scale where avoidance was no longer detected.

We used mixed-effects Cox proportional hazards regression, which uses the variation in exposure time to a mortality event relative to covariates (Cox 1972; coxme R package, Therneau 2015; R version 3.4.1, R Core Team 2015), to evaluate the effect of bentonite mining on mortality risk for nests, broods, and seasonal female survival during the breeding and winter seasons. The values for the mining variables were the average for each experimental unit (i.e., each nest, brood, or adult-season combination) when modeling mortality risk and when reporting descriptive statistics on the exposure to mining disturbance. For the nest mortality risk analysis, we measured variables at each nest location. For the brood mortality risk analysis, we measured variables at brood locations and averaged measurements for each individual brood. For the adult seasonal mortality risk analyses, we measured variables at the relevant seasonal locations and averaged measurements over the lifetime of each individual female for that season. Therefore, covariates were time independent and represented the average habitat use for each experimental unit. In addition to the environmental landscape attributes, we also considered weather variables (temperature, precipitation, snow depth; Liston and Elder 2006a, b) when modeling mortality. We measured these weather variables with a linear predictor (α = 0–1 by 0.05 increments; Gienapp et al. 2005) over the prior year, which allowed us to account for the appropriate timeframe over which weather influenced mortality. When selecting the final environmental model, we first determined which random effects should be included by comparing null models with all possible combinations of random effects from individual, age, transmitter type, research site, and year using Akaike’s Information Criterion corrected for small sample sizes (AICc; Burnham and Anderson 2002; AICcmodavg R package, Mazerolle 2017). We then employed variable reduction steps so there was a minimum of 10 mortality events per fixed-effect variable in the final environmental model (Harrell et al. 1984). We first selected the most predictive α-value for each weather variable and removed any non-informative variables (i.e., larger AIC, value than null model) by comparing single-variable models. We then compared all possible combinations of the remaining variables while restricting to the maximum allowed variables and selected the model with the lowest AIC, value. When selecting the model with the lowest AIC, value, we removed models from consideration with variables that demonstrated coefficient sign switching when moderately correlated variables (0.3 ≤ |r|) occurred together or if the model included variables that did not meet the proportional hazards assumption, which is represented by a slope not different from 0 for Schoenfeld residuals (Schoenfeld 1982). Finally, like resource selection modeling, we added the appropriate bentonite mining variables to the final environmental models to represent the respective hypotheses and compared model support with AICc. We report survival estimates relative to adult females marked with VHF-transmitters in our largest research site during 2014, which was the cohort from which we obtained the largest sample of observations.

RESULTS

Resource Selection

We collected data from 321 female sage-grouse captured in the Bighorn Basin during 2011–2015 (Table 2). The proportion of monitored sage-grouse that were exposed to any amount of bentonite mining disturbance within 3,200 m (i.e., ≥ 1 location with mining disturbance within our largest measurement scale) was 25% for nests, 29% for broods, 34% for adult females during the breeding season, and 65% for females during winter. For nest-site resource selection, the model that included the amount of all bentonite mining disturbance measured within 800 m was the best-supported model (Table 3). The odds of selecting a nest site decreased by half if the amount of area disturbed by mining within 800 m increased from 0 to 12% (95% CI = 7–75%; Fig. 2). The odds of selection continued to decrease by half for every increment increase of 12%. We did not observe any nests with >34% of the surrounding area within 800 m disturbed by mining (Fig. 3).

For brood-rearing resource selection, the model that included only the amount of active mining within 400 m was the best-supported model (Table 3). However, we considered this inconclusive evidence for an effect from mining because the coefficient estimate overlapped zero. We did not observe any individual brood locations with >4% of the surrounding area (within 400 m) disturbed by active mining (Fig. 3), and we did not observe any broods with an average

| Table 2. Sample sizes used for modeling habitat-specific mortality risk and resource selection for greater sage-grouse in Bighorn Basin, USA, 2011–2015. |
|---|---|---|---|---|
| Analysis | Mortality events | Locations | Broods | Sage-grouse |
| Nest | 207 | 378 | | 246 |
| Brood | 48 | 754 | 157 | 128 |
| Adult breeding | 62 | 1,978 | | 285 |
| Adult winter | 31 | 1,365 | | 220 |
active mining disturbance >2% surrounding (within 400 m) all their observed locations.

The top model explaining adult female breeding habitat use included the amount of all mining disturbance within 200 m (Table 3). The odds of selecting locations by adult females during the breeding season decreased by half if the amount of area disturbed by mining within 200 m increased from 0 to 24% (95% CI = 13–100%; Fig. 2). We did not observe any individual breeding season female locations with >51% of the surrounding area (within 200 m) disturbed by mining (Fig. 3), and we did not observe any females with an average mining disturbance >19% surrounding (within 200 m) all their observed locations.

During winter, the top model explaining adult female habitat use included all mining disturbance within 800 m (Table 3). The odds of selecting locations by adult females during winter decreased by half if the amount of area disturbed by mining within 800 m increased from 0% to 14% (95% CI = 8–50%; Fig. 2). We did not observe any individual winter season female locations with >65% of the surrounding area (within 800 m) disturbed by mining (Fig. 3), and we did not observe any females with an average mining disturbance >25% surrounding (within 800 m) all their observed locations.

We observed that avoidance of mining disturbance was equally influenced by avoidance of reclaimed mine sites as active mine sites when sage-grouse selected nesting, adult breeding, and adult winter habitat (Table 3). We also observed negative selection coefficients for mining when the amount of disturbance was measured approximately out to 2 km from sage-grouse locations (Fig. 4).

**Mortality Risk**

Our best-supported nest failure model was the environmental model; therefore, we found no evidence for increased risk of nest failure associated with bentonite mining disturbance (Table 4). Estimated nest survival to 26.5 days was 44% (95% CI = 35–53%).

For brood failure, the best-supported model included amount of active mining disturbance within 3,200 m (Table 4). However, we considered this inconclusive evidence for an effect from mining because the coefficient estimate overlapped zero. Estimated brood survival to 35 days was 69% (95% CI = 56–82%).

For the adult female breeding season mortality risk analysis, the model that included amount of active mining disturbance within 1,600 m was best supported (Table 4). The odds of mortality during the breeding season were 19 times (95% CI = 2–175) higher for females exposed to the most active mining (7%) than females with no active mining disturbance within 1,600 m (Fig. 5). Breeding season female survival to 89 days (i.e., median breeding season length; Pratt 2017) for females exposed to no active disturbance within 1,600 m was 87% (95% CI = 79–95%) and 14% (95% CI = 0–63%) for those exposed to 7% active disturbance (Fig. 6). We observed that the proportion of brood failures that were a result of the death of the brood-rearing female was higher for broods exposed to any amount of active mining disturbance (4 of 12; 33%) than for broods not exposed to mining (8 of 35; 23%), suggesting that higher female mortality could result in higher brood failure in areas with active mining.

For the adult female winter season mortality risk analysis, the model that included amount of active mining disturbance within 800 m was best supported (Table 4). However, we considered this inconclusive evidence for an effect from mining because the coefficient estimate overlapped zero. Estimated winter female survival to 127 days (i.e., median winter season length; Pratt 2017) was 92% (95% CI = 83–100%).

**DISCUSSION**

Our observations revealed that bentonite mining can have negative effects on sage-grouse populations in the Bighorn Basin through avoidance of mining surface disturbance and reduced demographic rates. We observed that sage-grouse avoided mining disturbance when selecting all their annual habitat requirements, except that we documented less evidence for avoidance by broods. We also did not investigate summer habitat use because sage-grouse selection of mesic areas naturally did not coincide with bentonite deposits and mining activity in our study area. We also observed that mining disturbance could hinder population growth by contributing to increased mortality for adult females during the breeding season and possibly for broods and adult females during winter. In general, our observations were consistent...
with impacts observed from energy development, which was cited as the leading threat to sage-grouse populations in the eastern portion of their range (USFWS 2010). We documented avoidance for nest-site selection, which was consistent with natural gas development (Lyon and Anderson 2003, Kirol et al. 2015). Sage-grouse avoid natural gas development (Kirol et al. 2015) and wind energy development (LeBeau et al. 2017) when selecting brood-rearing habitat. Adult female sage-grouse avoided mining disturbance during the breeding season, which was also the case for wind energy development (LeBeau et al. 2017), and they avoided disturbance during winter, which was also the case for oil and gas development (Doherty et al. 2008, Carpenter et al. 2010, Smith et al. 2014). One characteristic of bentonite mining that makes it different from oil and gas development and wind energy development, and potentially less intrusive, is the absence of vertical structures that may make land surface disturbance more visible. Even with this difference we documented similar avoidance behaviors.

Our results were inconclusive, but other research has documented increased brood failure risk associated with development in oil and gas producing fields (Aldridge and Boyce 2007, Kirol et al. 2015). Holloran (2005) and Holloran et al. (2010) reported increased female mortality in

Figure 2. Relative probability of selection and distribution of use and available locations for greater sage-grouse relative to amount (%) of all bentonite mining disturbance in Bighorn Basin, USA, 2011–2015. The scale of measurement is indicated in parentheses next to season. The x-axes limits represent the range of available habitat.
Pratt and Beck

We found evidence for increased female mortality near bentonite mining disturbance during the breeding season. Unlike Dzialak et al. (2011), who observed increased nest failure associated with oil and gas development, we found no evidence for increased risk associated with mining activity, similar to no observed effect from anthropogenic disturbance by Aldridge and Boyce (2007) and Kirol et al. (2015). Effects on mortality risk are inherently more difficult to detect because of smaller sample sizes, which are restricted to the number of events (i.e., deaths), and we took a more conservative approach by using Bonferroni corrected confidence intervals when estimating parameters. Also, avoidance of anthropogenic features can preclude individuals from being exposed to the feature in question, again reducing power to detect effects. Based on the number of observed mortality events (Table 2), we should have had the greatest power to detect an effect on nest mortality risk though we did not, providing evidence that mining did not have a negative effect on nest success.

We documented an avoidance response from sage-grouse to active and reclaimed mining disturbance for nesting, adult breeding, and adult winter habitat. Even though reclaimed mine sites do not have the human activity of active mine sites, sagebrush is a vital component of breeding and winter habitat by providing escape cover, nest concealment cover, and food (Connelly et al. 2011). A vegetation survey of reclaimed...
bentonite mine sites (from 10–35 years since initial seeding), in the same general area and timeframe as our study, recorded 70% of the 85 sites surveyed with <1% sagebrush cover with a maximum measured sagebrush cover of 6% (Liesenfeld 2012). Sagebrush cover measurements from a few similar, but undisturbed, adjacent sites ranged from 4–17% (Liesenfeld 2012). Reclamation of bentonite mines to pre-disturbance levels with a substantial shrub component is difficult because of inherent soil chemical and physical characteristics and climate limitations. Top soils in areas with bentonite mining are shallow and easily contaminated by saline-sodic subsoil and bentonitic material (Sieg et al. 1983, Schuman et al. 1985, Liesenfeld 2012). Sagebrush is notoriously difficult to reestablish because natural seed dispersal is limited, seed persistence in the soil is short-lived, years with favorable climatic conditions for seedling establishment are rare, and seedlings are not competitive (Shaw et al. 2005). Likelihood of success is increased with proper top soil salvage and handling to avoid contamination, using a site-specific seed source adapted to local conditions, timing seeding around precipitation events and during years with adequate precipitation, implementing practices (e.g., using micro-topography, snow fencing, fabric mulch) that retain soil moisture from precipitation, and reducing competition and herbivory (Monsen et al. 1992, Lippitt et al. 1994, Schuman et al. 1998, Schuman and Belden 2002, Musselman et al. 2014). Encouraging conditions conducive for natural recolonization, such as creating islands of sagebrush, with more intensive but more successful methods that will provide a future seed source may be the most successful reclamation practices (Longland and Bateman 2002, Liesenfeld 2012, Davies et al. 2013, McAdoo et al. 2013, Balthrop 2016).

Avoidance of mining disturbance when selecting brood-rearing habitat was less apparent. As females transition from nesting habitat to early brood-rearing habitat, the shrub component becomes less vital; however, broods do not use areas far from a sagebrush edge unless herbaceous cover is substantial enough to provide concealment cover (Hagen et al. 2007, Connelly et al. 2011). We documented a small number of brood locations from GPS-marked brood-rearing females in reclaimed mine sites.

We did not document significant negative mortality effects from reclaimed mining disturbance so effects on demographic rates appear to be influenced by active mining with areas around active mine sites likely serving as avoided sink habitat (Kiol et al. 2015). Effects on survival appear to be temporary, lasting while mines are active; however, the effects of habitat loss can be long term until the plant community returns to pre-disturbance levels. Observations on early landscape disturbances from development suggested

![Figure 4. Greater sage-grouse resource selection coefficients for all bentonite mining disturbance in Bighorn Basin, USA, 2011–2015. Negative coefficients show evidence of avoidance of mining at that scale of measurement. Error bars are 95% Bonferroni corrected confidence intervals.](image)

Table 4. Model selection statistics (K = number of parameters, ΔAICc = difference in corrected Akaike’s Information Criterion [AICc] between model and top model), scale of measurement, and mining variable coefficients for models representing hypotheses of effects from bentonite mining on greater sage-grouse demographic rates in Bighorn Basin, USA, 2011–2015.

<table>
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* Bonferroni corrected confidence interval.
that sage-grouse were displaced by disturbance and returned after the active disturbance ceased, but there was no evidence that populations would return to pre-disturbance levels (Braun 1998).

We found that the greatest proportion of our marked population was exposed to bentonite disturbance during winter when they demonstrated avoidance of disturbance up to the 1,600-m measurement scale. A greater proportion of sage-grouse were exposed to mining during winter because mining occurs where deposits are at or near the surface in low elevation sagebrush, which are used by wintering sage-grouse escaping colder summer ranges with more snow (Pratt et al. 2017). The Wyoming sage-grouse core areas were designed to protect the greatest breeding densities of sage-grouse (Doherty et al. 2011, State of Wyoming 2015) and they argue that they protect other seasonal requirements but do not explicitly incorporate other seasonal habitats if they occur separately from breeding range (the exception being designated winter concentration areas). Therefore, smaller core areas, and core areas associated with more migratory populations, are less likely to provide adequate protection for winter habitat requirements (Smith et al. 2016b, Pratt 2017). These are both characteristics of some core areas in the Bighorn Basin, so in this region it is a greater priority to incorporate winter habitat and the loss of habitat from bentonite mining in conservation decisions.

One of the most insightful pieces of information to provide to managers are the mechanisms that cause avoidance or lower demographic rates associated with anthropogenic disturbance. This information could point to possible solutions to minimize the negative effects of the ever-increasing percentage of landscapes disturbed by anthropogenic activities. Avoidance of active mining disturbance could be a result of avoidance of increasing noise (Blickley et al. 2012a) or visual human activity that sage-grouse are perceiving as a predation risk (Frid and Dill 2002). Increased mortality rates could be a result of increased predator populations associated with anthropogenic activity (Connelly et al. 2000, Hagen 2011) or an effect that makes sage-grouse more vulnerable to predation or less attentive to

**Figure 5.** Greater sage-grouse relative mortality risk and distribution of average disturbance surrounding adult females during the breeding season relative to amount (% within 1,600 m) of active bentonite mining in Bighorn Basin, USA, 2011–2015.

**Figure 6.** Greater sage-grouse estimated survival probability for adult females over 89 days during the breeding season and distribution of available locations relative to the amount (% within 1,600 m) of active bentonite mining in Bighorn Basin, USA, 2011–2015. Dashed vertical line represents the study area average disturbance amount. The x-axis limits represent the range of used habitat.
reproductive behaviors (e.g., stress; Blickley et al. 2012b). Though we did not investigate mechanisms of higher mortality risk, we did not observe any cases where mining activities were the direct cause of death. Perhaps unexpectedly, we did not document increased nest failure that could have been expected if common raven (Corvus corax) abundance increased with anthropogenic activity (Dinkins et al. 2016); however, research has suggested that established territorial pairs are likely the ravens responsible for sage-grouse nest depredations and not those associated with human activity (Bui et al. 2010).

**MANAGEMENT IMPLICATIONS**

We recommend that the bentonite industry be flexible when planning mining activities relative to the location and timing of disturbance, and that they are proactive relative to sage-grouse and sagebrush conservation. When siting a mine, the industry should be aware of potential negative effects on sage-grouse habitat quality within approximately 2 km because this was the distance from sage-grouse locations where we measured the amount of disturbance and detected avoidance behavior and increased mortality risk. Stakeholders should emphasize conservation and restoration of winter habitat in the Bighorn Basin when evaluating effects of bentonite mining on sage-grouse populations because of the tendency of mining disturbance to influence a greater proportion of the population’s habitat requirements during winter and because of the lower regulatory priority given to winter habitat. Because bentonite mining, and other sources of surface disturbance, are likely to increase, the effectiveness of sagebrush habitat restoration needs to be improved. This is a daunting challenge given that reclamation of bentonite mines to pre-disturbance vegetation characteristics suitable as sage-grouse habitat is difficult.

**ACKNOWLEDGMENTS**

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**LITERATURE CITED**


Pratt and Beck • Bentonite Mining and Sage-Grouse


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