

**GREATER SAGE-GROUSE RESPONSE TO SEASON-LONG AND
PRESCRIBED GRAZING (NRCS CONSERVATION PRACTICE 528)
ON PAIRED STUDY SITES IN RICH COUNTY, UTAH, USA
FINAL REPORT**



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September 2016**

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FINAL REPORT

Cooperators

Bureau of Land Management

Deseret Land and Livestock

Intermountain West Joint Venture

Natural Resources Conservation Service Sage-grouse Initiative

Pheasants Forever, LLC.

Rich County Commission

Rich County Coordinated Resources Management

U.S. Fish & Wildlife Service

U.S. Forest Service

Utah Department of Agriculture and Food

Utah Division of Wildlife Resources

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Introduction

Background

The decline in greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) populations over the last half century has been mainly attributed to degradation and fragmentation of their sagebrush (*Artemisia* spp.) habitat (Connelly and Braun 1997, Knick et al. 2003, Schroeder et al. 2004, Garton et al. 2011). In 2010 the sage-grouse was listed as warranted but precluded under the Endangered Species Act (U.S. Fish and Wildlife Service 2010). In response to the 2010 U.S. Fish and Wildlife Service (USFWS) listing decision, state and federal agencies, industry, private landowners, and other stakeholders enacted concerted conservation efforts to address many of the threats to the species. These efforts led to the decision to list sage-grouse as not warranted for ESA protection (U.S. Fish and Wildlife Service 2015). Degradation and fragmentation of the sagebrush ecosystem on which the sage-grouse depends has largely been the consequence of anthropogenic activities (West 1999, West and Young 2000). Compared to many anthropogenic activities impacts of livestock grazing is spread diffusely across the landscape (Knick et al. 2011). However, those impacts encompass a larger area of the sage-grouse range than any other land use (Brussard et al. 1994, Noss 1994, Crawford et al. 2004, Knick and Connelly 2011).

Reported effects of livestock grazing on the sagebrush habitat that support sage-grouse has been mixed (Beck and Mitchell 2000). This largely results from the lack of studies designed to specifically document impacts of livestock grazing practices on sage-grouse population vital rates. Changes to sagebrush steppe vegetation communities in response to management actions are often manifested over decades (Connelly et al. 2004). Concomitantly, the prohibitive costs of meaningfully monitoring vegetation and sage-grouse population changes over extended periods of time have precluded meaningful documentation of grazing effects on sage-grouse populations (Beck and Mitchell 2000, Connelly et al. 2004).

In response to these issues the Utah Sage-grouse Strategic Management Plan (Utah Division of Wildlife Resources 2009) has identified the following research priorities regarding livestock grazing and sage-grouse:

- a) How does domestic grazing directly affect sage-grouse populations?
- b) How does domestic grazing directly or indirectly affect sage-grouse habitats (all seasonal areas)?
- c) How do water developments affect sage-grouse and their habitat (directly and indirectly)?
- d) Does domestic livestock grazing alter behavior in seasonal habitat areas (including meadows/riparian areas)?

Federal programs such as the Natural Resources Conservation Service (NRCS) Sage-Grouse Initiative (SGI) also seek cooperative engagement with private landowners and other partners in efforts to reduce threats to sage-grouse populations including those from livestock grazing. The SGI provides targeted technical and financial assistance through Farm Bill programs to assist cooperators with implementing sage-grouse conservation efforts.

The SGI focuses on implementing conservation practices on private and public lands as a means to: 1) improve sage-grouse habitat, 2) improve sage-grouse vital rates and increase population size, 3) prolong or enhance the desired effects of other land treatments, and 4) broaden land

management benefits to include other wildlife species and producers. By assisting land managers and livestock producers with range condition improvements in core sage-grouse population areas, SGI also seeks to improve sage-grouse habitat quality while ensuring the sustainability of working rangelands. An important component of the SGI is to scientifically document the effectiveness of conservation practices such as prescribed rotational grazing and its effects on sage-grouse habitat quality and populations.

Purpose

The purpose of this research was to scientifically document sage-grouse population responses to habitat and vegetation differences that may occur under prescribed grazing and season-long grazing management. This research was conducted on 2 paired study areas in Rich County, Utah, USA. General questions addressed in our research objectives include:

- 1) Are sage-grouse population vital rates affected by livestock grazing in areas managed under prescribed rotational and season-long grazing practices?
- 2) Does sage-grouse habitat structure and composition differ based on prescribed rotational or season-long grazing management practices?
- 3) Do sage-grouse seasonal habitat-use patterns differ under prescribed rotational and season-long grazing practices?

Study Area

We conducted this research on 2 study areas, Three Creeks and Deseret Land and Livestock ranch (Deseret). Three Creeks was a 569 km² collection of U.S. Bureau of Land Management (BLM) (47%) and U.S. Forest Service (USFS) (26%) grazing allotments intermixed with private (20%) and state (<7%) lands. Deseret is an 870 km² privately operated ranch (92%) with <8% of this area constituting BLM inholdings. The total study area encompassed 1,439 km² and included portions of Rich, Cache, Morgan, Weber, and Summit Counties in Utah, USA (Fig. 1). The study areas were separated by approximately 13km. Three Creeks study area consisted of 569 km² with 73% under federal ownership (47% BLM, 26% USFS), 20% private, and <7% managed by the state.

Topographically the study areas were cognate, characterized by steep canyons and wide ridges at higher elevations in the west and transitioned to open valleys along the eastern boundaries. Elevations ranged from 1,800 - 2,700 meters. Primary soil orders were comprised of Mollisols, Inceptisols, Aridisols, and Alfisols.

Annual precipitation from 1981-2010 averaged 34.8 cm in Randolph, Utah and 25.5 cm in Woodruff, Utah. These Cooperative Observer Program (COOP) weather stations represented the 2 closest to Three Creeks (1.5 km) and Deseret (13 km) respectively (Western Regional Climate Center 2016). Average temperatures were similar at both COOP weather stations and ranged from -12 - 3.5° C between November and May and 1.5 - 22.5° C between May and October.

Lower elevations were dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) intermixed with rabbitbrush (*Chrysothamnus spp.* and *Ericameria nauseosa*) and spineless horsebrush (*Tetradymia canescens*). Higher elevations were characterized by mountain big sagebrush (*A. t. vaseyana*) and incorporated other common shrubs including black sagebrush (*A. nova*), snowberry (*Symphoricarpos spp.*), and antelope bitterbrush (*Purshia tridentata*).

Common grasses included bluebunch wheatgrass (*Pseudoroegneria spicata*), western wheatgrass (*Pascopyrum smithii*), needle-and-thread (*Hesperostipa comata*), and Sandberg bluegrass (*Poa secunda*). At high elevations mountain sagebrush mixed with stands of aspen (*Populus tremuloides*) and conifers (Danvir et al. 2005). Basin big sagebrush (*A. t. tridentata*) patches were common in draws and valley bottoms across both study areas. Livestock grazing by domestic cattle was the dominant land use across both study areas.

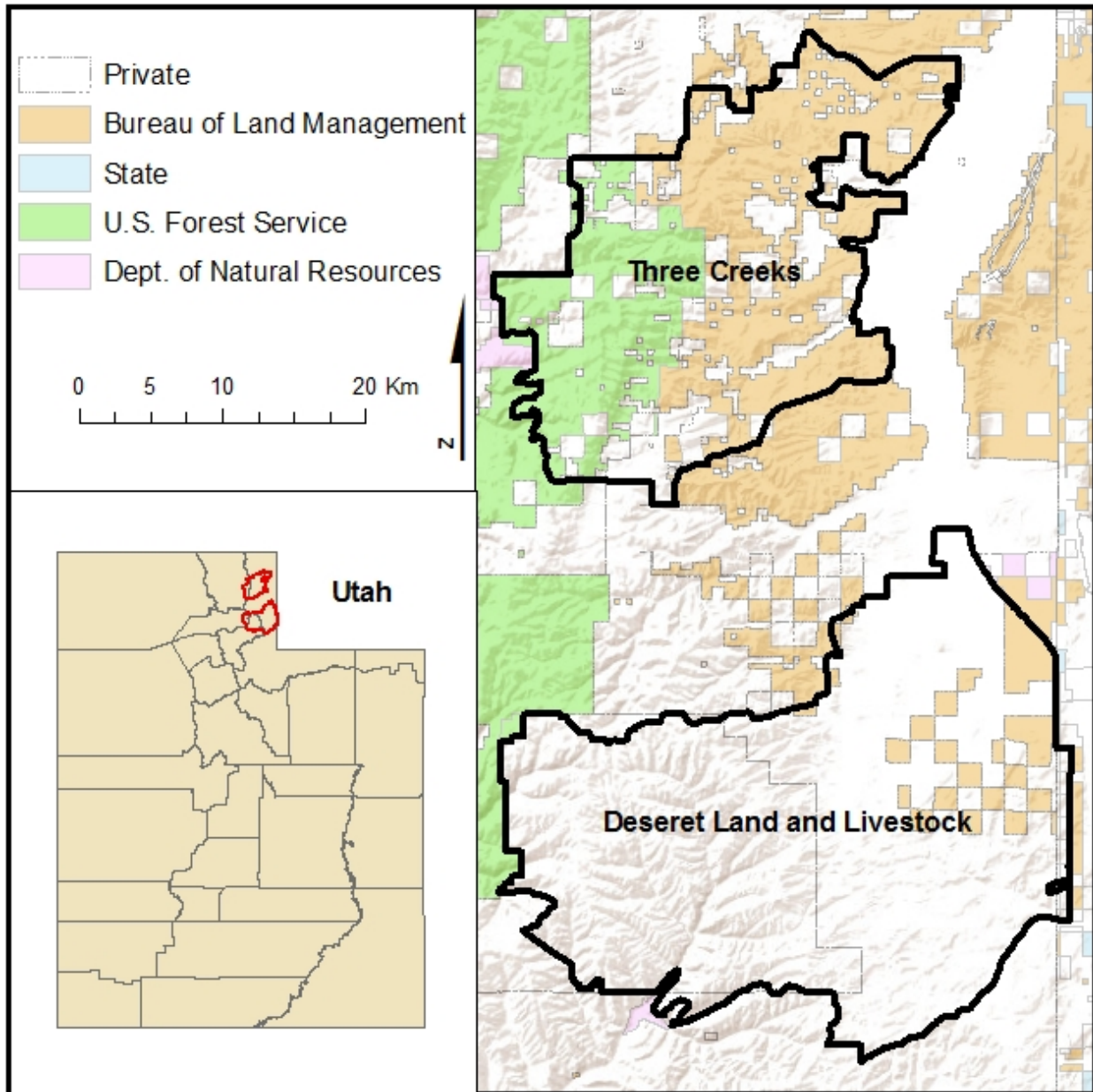


Figure 1. Study area boundaries, Rich County, Utah, USA.

Methods

Study Concepts

We originally designed the research project as a paired site study that consisted of 2 distinct phases to be implemented over a 4-year period (2012-2015). In this original research design phase 1 would have occurred in the first 2 years (2012-2013) as a comparison between the 2 grazing treatments under a paired study site design. In the first phase, Deseret would represent the treatment with Three Creeks as the research control. Phase 2 was to occur during the 2014-2015 field seasons after Three Creeks had implemented a grazing management change from season-long to rotational prescribed grazing practices. This second phase would have provided a Before-After Control-Impact (BACI) research design for Three Creeks where two years (phase 1) of pre-treatment data could be compared to two years (phase 2) of post-treatment data. However, unforeseen delays in the associated NEPA planning process postponed implementation of the new grazing system within the Three Creeks grazing allotments. This prevented the execution of phase 2 of the original research design. In response to this issue we have maintained the research project as a paired study site (phase 1) for the 4-year research period. While the strength of evidence is not as strong, this allowed us to address the research questions without the need of the BACI data.

Lek Trends

Lek counts have been used as an alternative method for obtaining indices of breeding sage-grouse males. We surveyed lek routes throughout each study area and counted the number of observed males on each lek during the spring lekking season each year. We used the maximum count from each lek to create an index to track sage-grouse population trends for each study area. We followed UDWR protocols (2009) with counts conducted from late March through mid-May. We visited leks a minimum of 3 times during the breeding season with all routes conducted on the same mornings. We counted leks between 0.5 hour before and 1.5 hours after sunrise on days of weather favorable for lekking (i.e. no precipitation or strong winds). We used binoculars from >50 m to count all observable males at the lek. Observations from this distance prevented observers from disturbing lekking activities. We estimated peak attendance using the highest male count during the breeding season for each lek.

Radio-Telemetry

Initial yearly radio-marked sage-grouse sample size objectives were 60 juvenile and adult, male and female sage-grouse at each site (40♀ and 20♂, n=120). We met this goal at the beginning of the research project in spring 2012. However, the research focus was in comparing sage-grouse vital rates between the treatments. Since most vital rates (e.g. nest and brood survival) are associated with females, we made efforts in subsequent years to increase nest and brood sample sizes by exclusively radio-marking females.

We captured female sage-grouse on and near leks throughout both study areas. To minimize capture effects on nest initiation, we concentrated captures to early spring (February-April) and concluded by the start of the nesting season (mid-April). Sage-grouse were captured at night using all-terrain vehicles, spotlights, binoculars, and long handled nets (Giesen et al. 1982, Wakkinen et al. 1992). We classified female age as either second-year (SY) or after second-year (ASY) based on wing characteristics (Eng 1955, Crunden 1963, Guttery et al. 2013). Sage-

grouse were fitted with 15–19 g necklace style radio-transmitters (Advanced Telemetry Systems, Isanti, MN, USA; Holohil Systems, Carp, Ontario, Canada) and released at point of capture. Sage-grouse capture and transmitter attachment procedures were approved under the Utah State University Institutional Animal Care and Use Committee (IACUC), permit no. 2411 and Utah Division of Wildlife Resources Certificate of Registration, permit no. 2BAND8744.

Marked females were located 2-3 times each week from April through June to determine any nest initiation attempts. Nest initiation was confirmed visually, and when possible, we used binoculars at a distance of ≥ 10 m to reduce the risk of flushing the female as nest abandonment has been problematic in other sage-grouse research (Holloran et al. 2005, Baxter et al. 2008). We monitored nesting females every 2-3 days until they were no longer detected on the nest. Once the nest was vacated we determined nest fate by visually inspecting remaining eggshells. Nests with eggshell fragments separated laterally in 2 portions with detached membranes were classified as successful (Rearden 1951). Nests with complete, crushed, punctured, shattered, or absent eggshells were classified as unsuccessful (Patterson 1952). Females with failed nests were located 1-2 times each week through the remaining nesting season to document re-nesting attempts. We located brooding females ≥ 2 /week for 50 d post hatch.

Habitat Surveys

Once nest fate was determined we measured vegetation characteristics, usually within one week, at the nest site. Each site consisted of 2 perpendicular 30m transects that intersected at the nest. We took measurements of vegetation cover and structure along each transect. We estimated the height of visual obstruction by centering a Robel pole in the nest bowl and recording the lowest decimeter mark that was $>50\%$ visible (Robel et al. 1970). Visual obstruction at the nest was calculated using the mean of 4 Robel measurements taken from a height of 1 m and a distance of 4 m from each of the cardinal directions.

Forb and grass cover was estimated using 0.1-m² quadrats (Daubenmire 1959, Bureau of Land Management 1996) placed at 3, 6, 9, 12, and 15m along each transect. We identified all forbs and grasses within the quadrat to species level and assigned them to a cover category. To reduce estimation bias between observers we used Daubenmire's class system: 1 (no cover-5%), 2 (5.1-25%), 3 (25.1-50%), 4 (50.1-75%), 5 (75.1-95%), and 6 (95.1-100%). Plants that could not be identified in the field were recorded instead by growth habit classification (forb or grass) and lifespan (annual, perennial, or biennial). We measured the heights for all species using the closest individual to a marked corner of the plot that contacted the transect line. We calculated mean height for each forb and grass species at each site.

We measured canopy foliar cover for each species if shrub using the canopy line intercept method (Canfield 1941, Bureau of Land Management 1996, Connelly et al. 2003). Because of the open nature of shrub canopies in sagebrush steppe, gaps in foliage that were <5 cm were considered continuous. The line intercept method converges on actual shrub cover at lower sample sizes when compared to Daubenmire plots (Hanley 1978). We included measurements of shrub height along each transect and calculated the mean shrub height for each species at that site. We also measured the maximum shrub width and height of the shrub(s) cluster that concealed the nest.

We surveyed sage-grouse brood habitat in both study areas using previously located brood sites. Brood locations were usually surveyed within a week of first being observed. Protocols for brood

sites were similar to those used at nest sites with 3 distinct differences. These were; 1) No measurements of visual concealment (Robel pole) were made, 2) transects were lengthened to 25 m, 3) the longer transects allowed 8 additional Daubenmire frames (n=28) at each brood site.

Habitat surveys at sage-grouse nest and brood locations are important in developing our understanding of how vegetation structure and composition effects vital rates. However, it is also important to understand the vegetation structure and composition on a broader scale to determine sage-grouse habitat selection within each study area. We addressed this issue using paired random sites generated by the command builder 'gencondrandompnts' in Geospatial Modeling Environment (GME; Beyer 2012). To ensure that generated and actual sage-grouse sites were available to similar grazing pressure, paired sites were restricted to the same pasture. We avoided sampling inappropriate sites (e.g. sites located in roads, water bodies, cliffs) by overlaying our randomly generated points with satellite imagery and censoring those from the list of available sites.

Predator surveys

Increased predation of sage-grouse is perceived as a major threat to the species by private land owners (Belton et al. 2009). Connelly et al. (Connelly et al. 2000a) found predation to be the leading cause of mortality for a sage-grouse population in SE Idaho. Range-wide, sage-grouse nest success rates and adult survival are relatively high and few studies have demonstrated a link between habitat quality, predation, and mortality rates (Hagen 2011). However, in fragmented native habitats or areas where anthropogenic activities sustain higher levels of native or invasive predator populations, predation may limit population growth (Bui et al. 2010, Coates et al. 2016). Potential risks for increased raptor and corvid predation on sage-grouse could be mitigated by maintaining or restoring sagebrush canopy cover (Coates and Delehanty 2010).

Because predator populations may change in response to changing grazing practices, continuous monitoring is important in explaining observed differences in sage-grouse vital rates. If sage-grouse nest and adult predation rates are lower in areas under prescribed grazing, this practice may constitute a Best Management Practice (BMP) for mitigating the effects of other anthropogenic disturbances (e.g., power lines, roads, oil and gas development). Because the dynamics of a predator population can impact sage-grouse populations (Schroeder and Baydack 2001), abundance and density estimates of known sage-grouse predators were incorporated into our nest survival analysis.

In the case of adult sage-grouse mortalities we examined the condition of the remains in an attempt to determine cause of death (e.g., mammal, avian, power lines, human interaction, capture myopathy, disease, etc.). In cases where bones and feathers were broken or matted (i.e., chewed), we attributed cause of death to a mammalian predator. If a mammalian predator was determined the cause, we searched the surrounding area for sign of hair, scat, tracks or evidence of a den to help identify the specific predator. If sage-grouse remains consisted of the entire carcass with feathers partially plucked, or if only the breast was consumed, we attributed the cause of death to an avian predator. Cases where mortality could not be determined were designated as unknown.

Our objective for the predator aspect of this study was to document any relative effect of prescribed and season-long grazing on sage-grouse predation rates. This information may be more important than documenting the specific predator. Changes in abundance of avian,

mammalian, and primary prey were monitored using standardized transects across both study areas (Garton et al. 2005). Monitoring trends of potential sage-grouse predators in concert with changes in vital rates in the study areas may provide data to corroborate any observed differences in vital rates between treatment and control sites.

We monitored common raven and American crow (*Corvus corvax*; *Corvus brachyrhynchos*; respectively; corvid) abundance annually from April through mid-July from specific points along a transect in Deseret and Three Creeks. Counts were restricted to days with light winds (<20 kph) and little or no precipitation (Luginbuhl et al. 2001). At each survey point, birds were counted by visually searching the area with the aid of binoculars while also listening for bird calls. Counts included all corvids and raptors detected during a 10-minute period. The species code and count was recorded along with the time, weather, behavior, and distance at time of first detection. To mitigate double counting, survey points were separated by >2 km distance and previously recorded birds were tracked prior to moving to the next survey point. We ensured that all points could be surveyed on the same morning by locating points in proximity to unimproved or low-speed gravel roads within each study area.

Spotlight surveys are a practical method for assessing relative abundance of nocturnal animals (Gese 2001). We conducted spotlight surveys to determine the relative abundance of mammalian predators of sage-grouse. Predators were counted by two observers in a vehicle driven along a 10 km transect at 16-24 km/hr while scanning the landscape with 3 million candle power spotlights. All predators were visually detected by observing for eye shine. Upon detection the vehicle was stopped and the animal was positively identified using binoculars. We recorded the mileage, time of detection, and perpendicular distance of the animal to the transect for each sighting.

Scat transects are an effective method for determining coyote abundance (Henke and Knowlton 1995). Scat transects require no special equipment and technicians can be easily trained in proper protocol. Scat transects are more effective than scent station surveys and second only to mark-recapture estimates when used to determine swift fox (*Vulpes velox*) abundance (Schauster et al. 2002). Studies have reported a high correlation ($r^2 = 0.97$) between scat deposition rates and coyote density estimates when compared to mark-recapture methods using radioisotope detection of feces (Knowlton 1984).

In 2012, to estimate coyote abundance we established 5 scat transects in each study area and surveyed each transect on 2 occasions. Our initial sampling effort was based on transect densities used by Gese and Terletzky (2009) when they estimated coyote densities across Wyoming. In a subsequent discussion with Dr. Gese regarding sampling design he recommended that a more accurate coyote density estimation could be achieved by increasing transect density and reducing sampling occasions to once per season. We implemented this change in 2013 by increasing the scat transects to 20 in each study area and only sampling on one occasion per year. The 1km scat transects were distributed across each study area. Transects were read each July and initially cleared of all scats. We surveyed each transect 14 days later to count all new scat depositions. Knowlton and Gese (1995) identified potential biases associated with scat transects. These biases include an estimated 0.7 detection probability for transects walked once and destruction of scats on heavily travelled roads. We addressed this bias by walking transects both directions which increased our detection probability. Transects were also located along unimproved two-track roads to reduce the potential destruction of scats by vehicle traffic.

Data Analysis

Annual survival of radio-marked sage-grouse was calculated using the known fate model within Program MARK (White and Burnham 1999). Sage-grouse included in survival estimates must have survived at least one week after being radio-collared to ensure that mortalities were not related to capture myopathy (Spraker et al. 1987).

Nest initiation was estimated as the proportion of females that attempted to nest divided by the total females located ≥ 3 /week within that study area during the nesting period. This frequency of location assumes that nesting attempts did not go undetected. Re-nesting effort was estimated from the proportion of females that re-nested divided by total females that survived an initial nest failure. Nests were considered successful if ≥ 1 egg successfully hatches (Connelly et al. 2003).

We used RMark 2.1.14 (Laake 2013) nest survival models in R 3.2.3 (R Development Core Team 2015) to model sage-grouse daily nest survival and estimate effects of biotic and abiotic factors on the survival rate. We defined nest success as the probability of a nest hatching $1 \geq \text{egg}$ (Schroeder 1997). We calculated overall nest survival as the product of the daily survival rate across a 37-d (laying plus incubation) exposure period (Coates and Delehanty 2010, Blomberg et al. 2015). We estimated the 95% confidence limits for overall nest survival using the delta method (Seber 1982).

We identified factors affecting nest survival rates by building 4 candidate sets of models. The 4 candidate sets tested temporal/spatial, climatic, predator, and habitat factors. We included corrected forb and grass heights in the habitat models to reduce biases associated with the comparative measurements from successful and failed nests (Gibson et al. 2016). We used univariate models for comparison within each group. Normalized Akaike weights (w_i) were calculated to evaluate the predictive power of each model (Burnham and Anderson 1998). Next, we used these weights (w_i) to gauge the weight of evidence that the selected model was the most parsimonious model for the given model set. Models from each group that outperformed the null ($\Delta AIC_c > 2$) were then used to generate a final set of “best” models. Within the final set of candidate models we included a global model containing all parameters and a null (intercept only) model for comparison (Loss and Blair 2011, Hovick et al. 2015).

We calculated brood success for each study area as the initial number of broods divided by the total broods surviving to 50-d in that study area. Dahlgren et al. (2010) documented a high rate of brood-hopping (chicks are adopted by females that are not their mother) in some populations. Chicks were not radio-marked within this study so if brood-hopping occurred, it may bias our estimates of brood success.

Coyote densities (coyotes/km²) were calculated as $4.9052 * \text{scats/km/day}$ (Gese and Terletzky 2009).

Results and Discussion

Lek Surveys

The observed number of males counted per lek was in a marked decline from 2006-2011 before the project began. From 2012-2014, the first 3 years of research, counts for both study areas were at the lowest observed levels in the previous 2 decades. This decline followed a similar reduction in precipitation for those same years. It was only in the final year of the study that increases in males count per lek were documented.

The 2015 average across both study areas was a 42% increase in males per lek compared to the previous 3 years of lek counts. However, despite this observed increase overall males/lek was still below the 10-year average (18 v. 28, Deseret; 16 v. 18, Three Creeks). Observations of lek counts in Rich County from 1960-2015 demonstrated a 10-year cyclical pattern which has been documented in other sage-grouse populations (Rich 1985, Garton et al. 2011). Given these observed population cycles we recognize that our research documents these populations at their lowest point of the cycle. This may explain why some vital rates may be relatively low compared to other published studies on sage-grouse (see Connelly et al. 2011 for review). However, we are optimistic that the increased number of males counted on leks will also be reflected in vital rates.

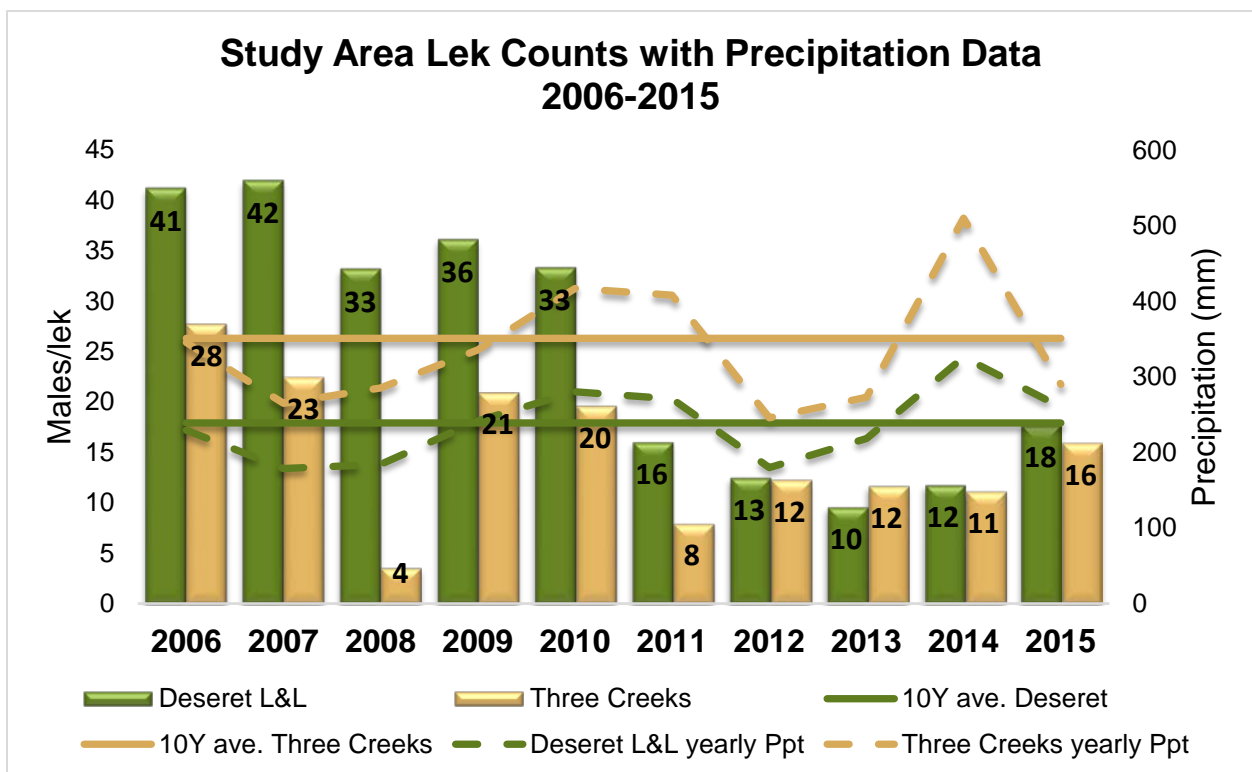


Figure 2. Project area lek counts from 2006-2015 overlaid with annual and 10-year average precipitation data for each study area. In 2015 counts were conducted for 20 leks in Deseret and 10 leks within the Three Creeks study area. Lek count data was provided by the UDWR. Climatic data was collected at GHCN stations in Woodruff and Randolph, Utah, and accessed through the Utah Climate Center website (<https://climate.usurf.usu.edu/>).

In sagebrush-steppe ecosystems, precipitation plays a large role as a driver of plant species abundance and composition. This affects sage-grouse habitat quality and ultimately sage-grouse population vital rates (Guttry et al. 2013). Thus, we have overlaid the lek counts with total annual precipitation from the closest Global Historical Climatology Network (GHCN) station for each of the study areas (Fig. 2).

Trapping and Radio-marking Efforts

We captured female sage-grouse on and near leks throughout both study areas. To minimize capture effects on nest initiation, we concentrated captures to early spring (February-April) and concluded by the start of each nesting season (mid-April). We focused capture efforts on meeting our sample size objectives of 60 radio-marked females on each site (Fig. 3). We were assisted in radio-marking efforts each year by personnel from Deseret, U.S. Wildlife Services, Utah State University, and volunteers. We attempted to trap every night with favorable weather and moonlight conditions.

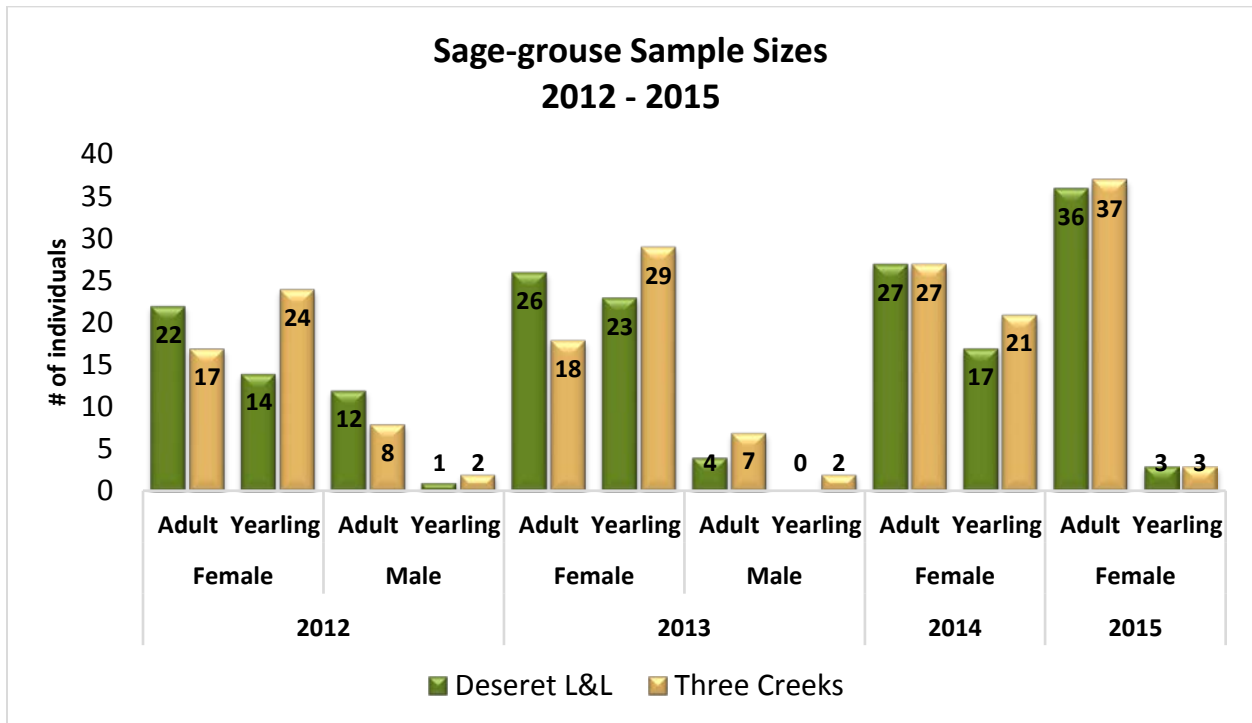


Figure 3. Initial yearly sample sizes by sex and age class for 2012-15. Totals may include sage-grouse that were missing and/or previously undetected mortalities.

Nest Initiation and Nest Survival

We calculated the start of each nesting season as the date of the first verified nest attempt each breeding season. In 2012, 2013, 2014 and 2015 the start of the nesting season occurred on 18 April, 28 April, 12 April, and 10 April respectively. Variability in the nest season start dates might be attributed to weather, the likelihood that observers detected females at date of initiation and random chance based on radio-marked individuals.

Only females located ≥ 2 /week were included in our nest initiation rate calculations to ensure a high likelihood of detecting nest initiation (Connelly et al. 2003). Unfortunately, many radio-marked females could not be consistently detected throughout the nesting season. This was likely the result of both the tendency of females from the population to disperse from early season breeding areas (Dettenmaier and Messmer 2013, 2014) as well mortalities occurring during the nesting season. We observed small annual fluctuations in initiation rates on Deseret over the study period. Three Creeks exhibited a more stable nest initiation rate (100%) during the initial 3 years of the study before dropping to 87% in 2015. Nest initiation rates for both study areas were lowest in 2015 (Fig. 4). Coincidentally, these low nest initiation rates coincided with our highest observed nest survival rates. Overall, nest initiation rates for the study were within the range of published sage-grouse studies (Taylor et al. 2012).

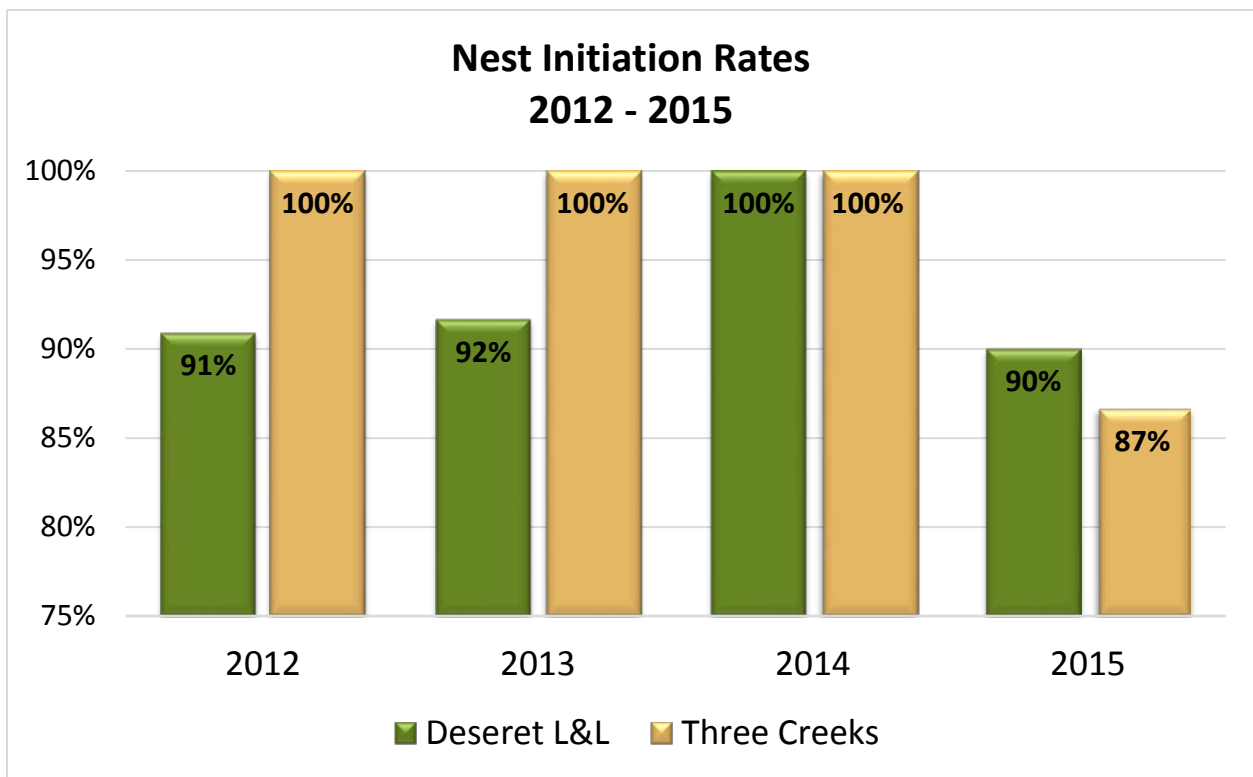


Figure 4. Nest initiation rates for Three Creeks and Deseret L&L study areas 2012-2015.

We based our nest survival analyses on 107 sage-grouse nests ($n= 28$ in 2012; $n= 22$ in 2013; $n= 35$ in 2014; $n= 22$ in 2015) monitored during the 2012-2015 breeding seasons. Nest survival on Deseret was 48.7% (95% CI: 24.5-72.8%) in 2012, 24.8% (95% CI: 3.4-46.3%) in 2013, 25.5% (95% CI: 5.9-45.2%) in 2014, 37.6% (95% CI: 11.9-63.3%) in 2015, and 32.5% (95% CI: 16-48.9%) and 17.9% (95% CI: 8.5-27.2%) across all years. Nest survival on Three Creeks was 31.2% (95% CI: 10.9-51.5%) in 2012, 10.6% (95% CI: 0-24.1%) in 2013, 11.1% (95% CI: 0.4-21.8%) in 2014, 20.6% (95% CI: 0.5-40.7%) in 2015, and 17.9% (95% CI: 8.5-27.2%) across all years. Nest survival was consistently lower on Three Creeks by an average of 15.8% across all years (Fig. 5).

There was support for nest survival models (Table 1) that included additive effects of rabbitbrush cover and the previous year’s standardized precipitation evapotranspiration index (SPEI), a measure of drought (Fig. 6). Increasing rabbitbrush cover had a negative association with nest survival while increases in the drought index contributed to increased nest survival. Rabbitbrush is an increaser on degraded rangelands and often associated with historic or currently overgrazed sites. Given this association it be intuitive that sage-grouse nest survival decreases as the amount of rabbitbrush increases. However, corresponding increases in nest survival with increases in drought appear more perplexing. Several factors could be at play here. First, sage-grouse nests are subject to a suite of predators that use combinations of visual and olfactory cues. Xeric sites may provide sage-grouse nests with additional concealment from olfactory predators. Second, Deseret exhibited a more xeric landscape than Three Creeks while simultaneously providing nesting females with taller perennial grass heights for visual concealment. This effect may further supplement the olfactory protection and increasing the overall nest survival rate. Deseret’s prescribed-rotational grazing management increases the amount of rest for each pasture which could contribute to the observed increased in perennial grass and forb height under more severe drought conditions when compared to Three Creeks. Prescribed-rotational grazing management could benefit sage-grouse range-wide by ameliorating the effects of increasing temperatures and decreasing precipitation as projected under some climate change models.

Estimates of nest survival failed to statistically demonstrate site and temporal differences. This may be attributed to small sample sizes across the study. We attribute our nest sample sizes to several factors. First, our study sites were topographically diverse and encompassing rough terrain. Each study area was comprised of large canyons and draws that obscured the VHF transmitter signals making them difficult to locate. Secondly, neither study area was large enough to completely encompass the sage- grouse population life cycles. Sage-grouse home

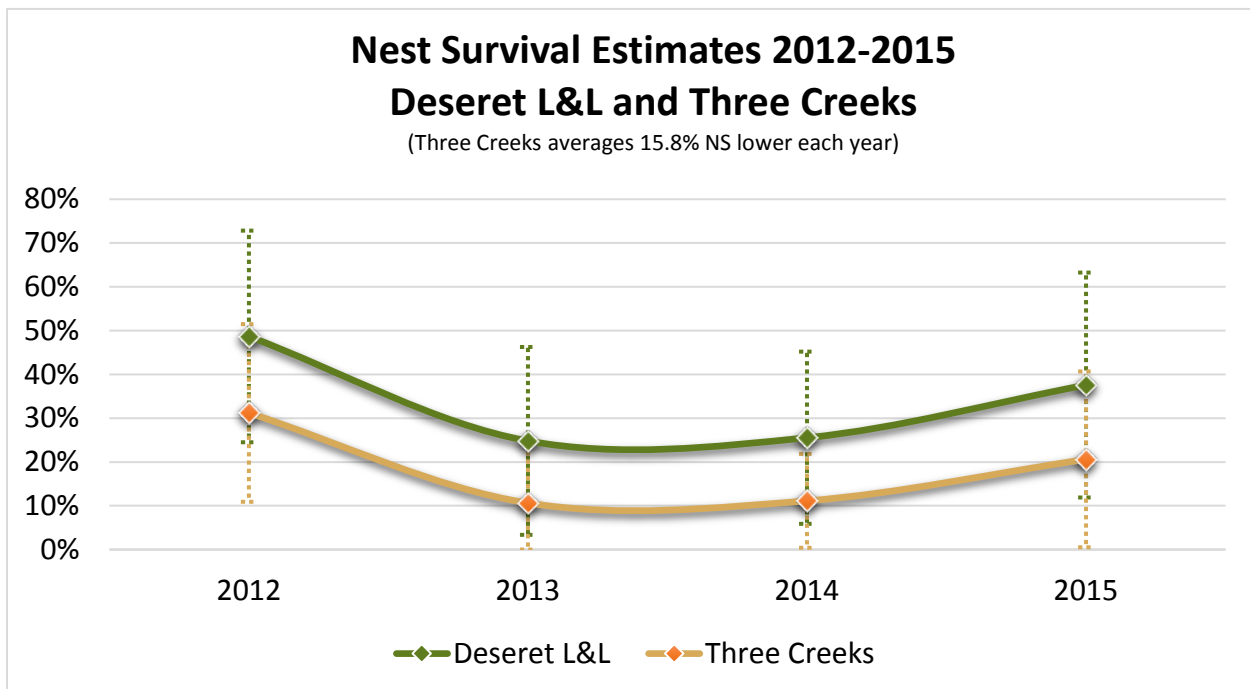


Figure 5. Estimated sage-grouse nest survival for Deseret and Three Creeks study areas, 2012-2015.

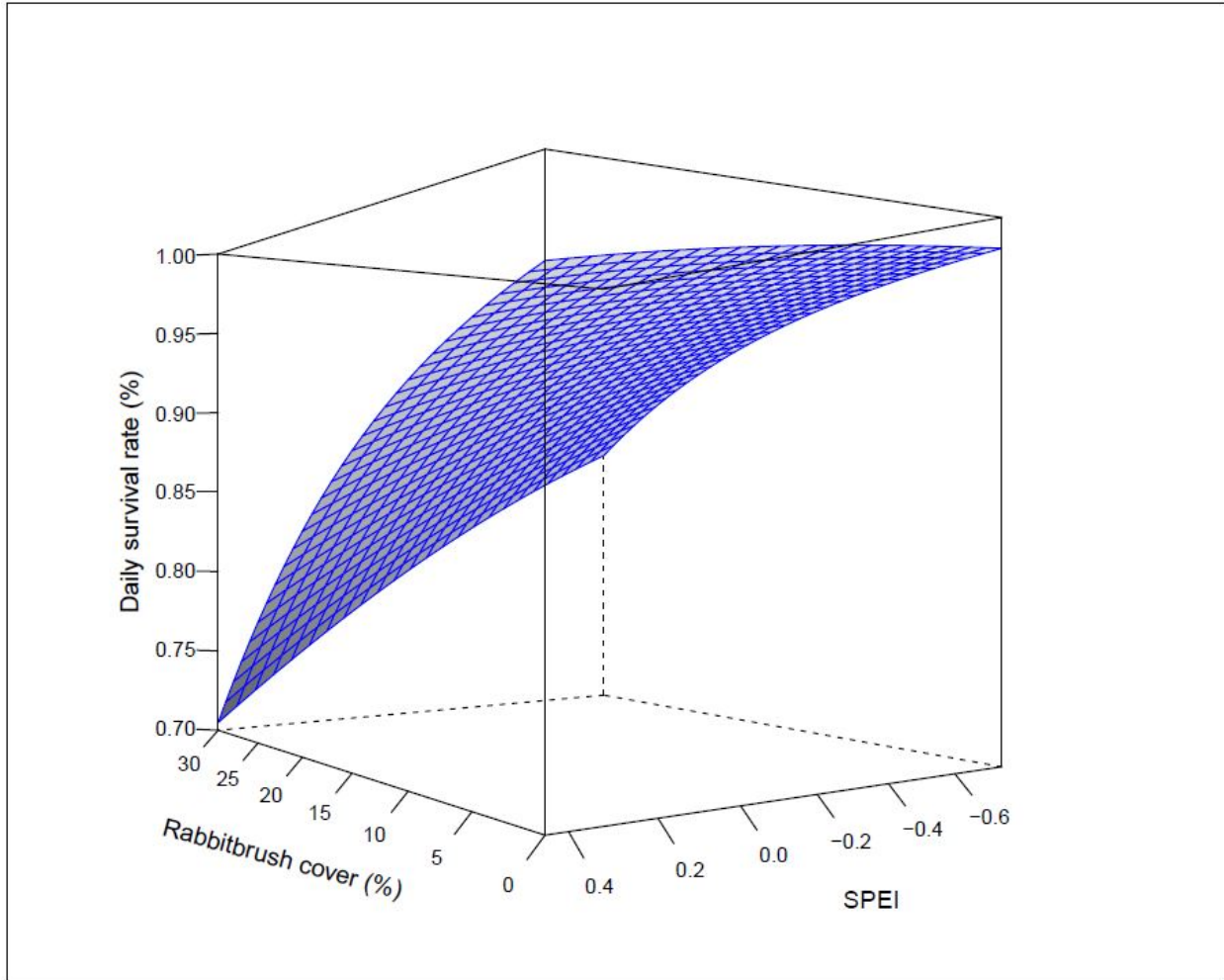
ranges may encompass >2500 km² (Schroeder et al. 1999). While both areas encompassed all seasonal habitats required for the sage-grouse life-cycle, radio-marked individuals regularly moved between study areas. However, both study areas exhibited a similar annual trends in nest survival with Three Creeks having a low mean of 16% across all years.

Table 1. Models of temporal/spatial, climate, predators, vegetation variables on greater sage-grouse nest survival in Rich County, Utah, USA, 2012-2015.

Model	ΔAIC_c^1	k ²	w ³	Deviance
<i>Temporal/Spatial models</i>				
Study area	0.00	2	0.25	408.04
Null	0.48	1	0.20	410.53
Linear trend	2.49	2	0.07	410.53
Year effects	2.63	4	0.07	406.65
Quadratic trend	4.34	3	0.03	410.37
Cubic trend	4.38	4	0.03	408.40
<i>Climatic models</i>				
SPEI w/ lag	0.00	2	0.50	405.88
Total precipitation Jan-Mar	2.35	2	0.16	408.23
SPEI current year	2.58	2	0.14	408.46
Null	2.65	1	0.13	410.53
Total precipitation Apr-Jun	3.98	2	0.07	409.85
<i>Predator models</i>				
Null	0.00	1	0.40	410.53
Coyote density 5km	1.91	2	0.15	410.44
Coyote density 10km	1.97	2	0.15	410.50
Total corvid count 5km	2.00	2	0.15	410.53
Total corvid count 10km	2.01	2	0.15	410.53
<i>Vegetation models</i>				
Forb height * Bunch grass height	0.00	4	0.33	397.54
Null	6.97	1	0.01	410.53
Bunch grass height	8.89	2	0.00	410.45
Forb height	8.97	2	0.00	410.53
<i>Best Models</i>				
Forb height * Bunch grass height + SPEI lag	0.00	5	0.58	393.72
Forb height * Bunch grass height	1.81	4	0.24	397.54
Forb height * Bunch grass height * SPEI lag	2.90	8	0.14	390.56
SPEI lag	6.12	2	0.03	405.88
Global	8.63	4	0.01	404.36
Null	8.77	1	0.01	410.53

¹ Akaike's Information Criterion adjusted for small sample sizes. Numbers are based on differences from the best approximating model within each model set.

² Number of parameters estimated.

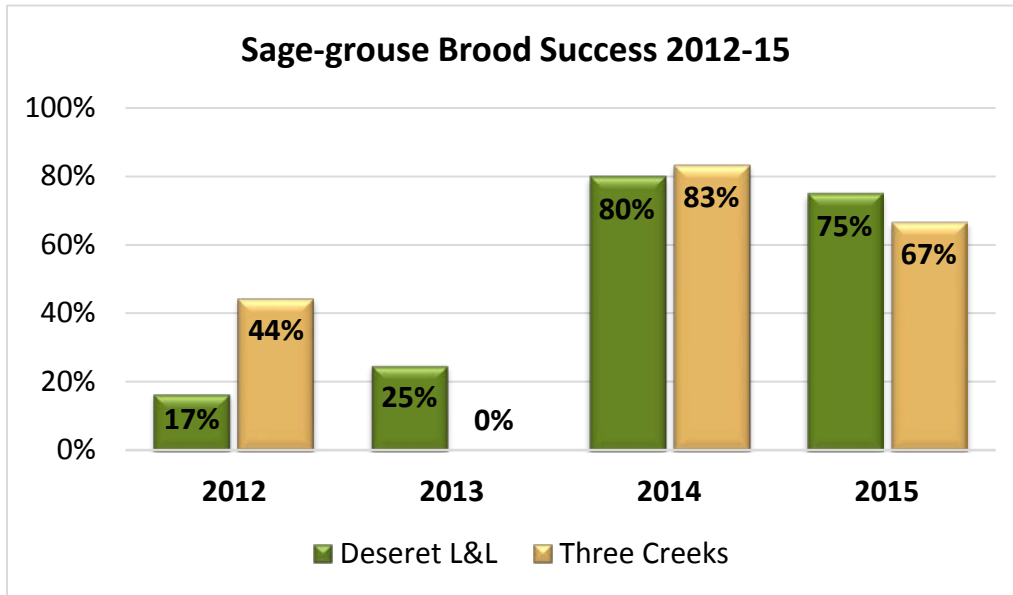


³ Akaike weight: strength of evidence given the data, normalized to sum to 1.

Figure 6. Daily nest survival rate estimates by rabbitbrush cover and the standardized precipitation evapotranspiration index (SPEI). Negative values represent drought conditions (precipitation < evapotranspiration).

Brood Success

We monitored 44 radio-marked brooding sage-grouse females across both study areas during the study period. Brood success varied widely by year and site with both study areas exhibiting the highest observed levels in 2014. This corresponded with higher lek counts the following year. Estimates ranged from 0-83% dependent on area and year. In 2013, both study areas had low brood sample sizes resulting partially from low nest survival that year (Fig. 7). Of the 4 initial broods we monitored none of them survived to independence ($\geq 50d$).



Survival

We calculated female sage-grouse survival rates each year by study area for both the spring (01 March – 31 May) and summer (01 June – 31 August) time periods. Winter survival estimates could not be accurately calculated due to our limited number of winter detections. We excluded males from estimations because of their low sample size and divergent survival rate (Connelly et al. 2000b). We combined yearling and adult age classes to increase sample size in the analysis.

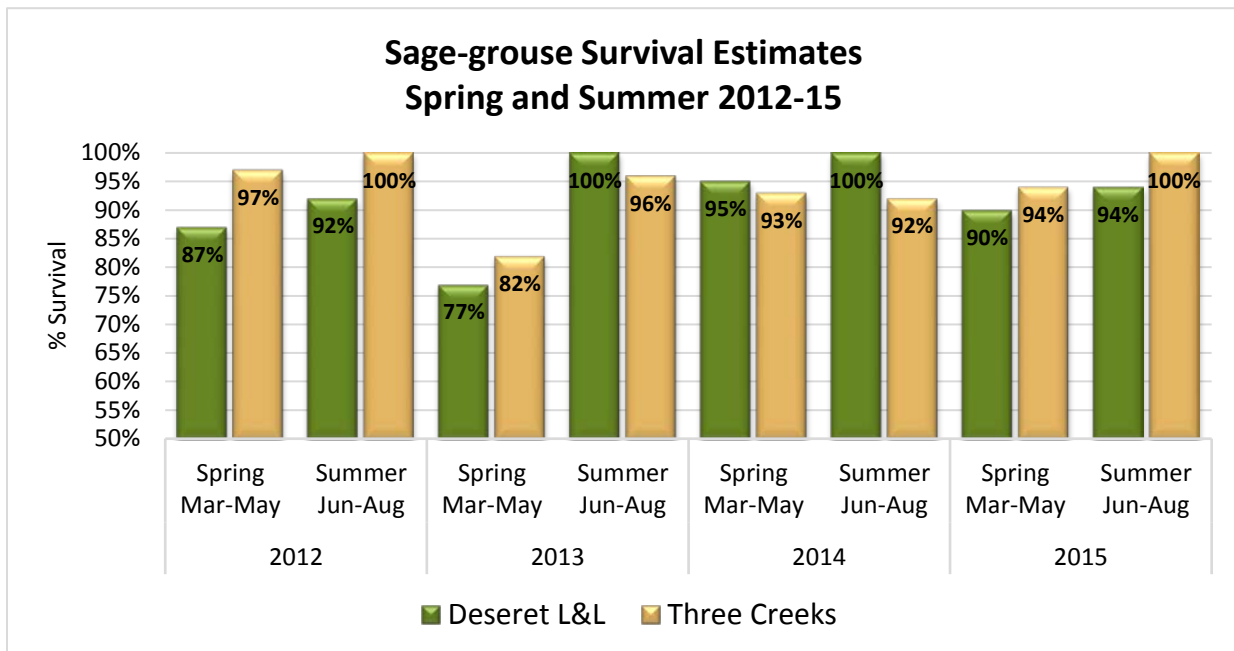


Figure 8. Estimated female sage-grouse survival for spring and summer periods, 2012-2015.

Overall, survival was high across the duration of the study with seasonal and year estimates typically $\geq 90\%$ (Fig. 8). The only marked decline was observed in the spring of 2013. We

recorded 4 females killed on the nest that spring which contributed to the lower estimated survival for that period.

Habitat

From 2012-2015 we collected habitat measurements at 107 sage-grouse nest and 199 brood sites (Table 4). These nest and brood sites were then paired with 297 randomly generated sites providing the project with 603 vegetation sample sites. For our analysis we grouped vegetation data by site type (e.g. nest or brood) and study area. We analyzed the data using a multivariate analysis of variance (MANOVA) (Anderson 2001) within the vegan package in R 3.2.3 (R Development Core Team 2015). Notable differences in habitat included a 29% increase (16.5 v. 12.8 cm; $p=0.003$) in perennial bunchgrass height and 15% increase in sagebrush height (43.9 v. 38.3 cm; $p=0.028$) at nest sites in Deseret compared to Three Creeks (Table 2-3). Deseret also had higher perennial bunchgrass heights (13 v. 11 cm; $p=0.031$) across available nesting habitat. and greater perennial bunchgrass cover in brood rearing habitat compared to Three Creeks. Brood sites on Deseret also had 36% less sagebrush cover (12.8 v. 20.5%; $p=0.001$) but 43% taller perennial grasses (18.4 v. 12.9 cm; $p=0.001$) and 49% taller forbs (8.8 cm v. 5.9 cm; $p=0.001$) (23 v. 16%; $p=0.001$). Overall, Deseret exhibited greater grass heights in every site type that we compared and was a statistically different than Three Creeks for both actual nest and brood sites. These results were congruent with our expectations that the grazing management practices on Deseret should provide for taller perennial grass heights compared to Three Creeks.

Table 2. Mean and standard deviation of vegetation percent cover and heights (cm) for greater sage-grouse nest/brood and paired (random) sites, Deseret L&L allotment, Rich County, Utah, USA, 2012-2015. Sample sizes are in parentheses.

Deseret Land & Livestock						
	Nest Actual	Nest Paired	Nest Combined	Brood Actual	Brood Paired	Brood Combined
%Cover						
Sagebrush	21.2 ± 10.1 (39)	18.6 ± 10.2 (38)	19.9 ± 10.2 (77)	12.8 ± 9.9 (100)	17 ± 12.1 (94)	14.9 ± 11.2 (194)
All Shrubs	33.9 ± 15.4 (39)	28.2 ± 10.7 (38)	31 ± 13.5 (77)	27 ± 19.9 (100)	30 ± 20.2 (94)	28.4 ± 20.1 (194)
Perennial Grasses	18.7 ± 13.8 (39)	17.6 ± 11.9 (38)	18.2 ± 12.8 (77)	26.6 ± 19.1 (100)	22.7 ± 14.4 (94)	24.7 ± 17 (194)
Forbs	15.7 ± 11.8 (39)	17 ± 17.4 (38)	13.3 ± 14.7 (77)	15.5 ± 13.9 (97)	12.1 ± 11.8 (93)	13.9 ± 13 (190)
Height (cm)						
Sagebrush	43.9 ± 12.9 (39)	38.8 ± 13.3 (38)	41.4 ± 13.2 (77)	51.1 ± 17.5 (87)	45.8 ± 19.3 (90)	48.4 ± 18.6 (177)
Perennial Grasses	16.5 ± 6 (39)	12.7 ± 4.2 (38)	13.4 ± 5.2 (77)	18.4 ± 9.6 (100)	18.9 ± 8.4 (94)	18.6 ± 9 (194)
Forbs	6.2 ± 4.2 (39)	5 ± 1.8 (38)	5.6 ± 3.3 (77)	8.8 ± 6.1 (97)	7.8 ± 4.4 (93)	8.3 ± 5.4 (190)

Table 3. Mean and standard deviation of vegetation percent cover and heights (cm) for greater sage-grouse nest/brood and paired (random) sites, Three Creeks allotment, Rich County, Utah, USA, 2012-2015. Sample sizes are in parentheses.

Three Creeks						
	Nest Actual	Nest Paired	Nest Combined	Brood Actual	Brood Paired	Brood Combined
%Cover						
Sagebrush	19.3 ± 7.6 (68)	19.5 ± 10.6 (66)	19.4 ± 9.2 (134)	20.5 ± 11.8 (99)	21.2 ± 13.6 (99)	20.8 ± 12.7 (198)
All Shrubs	28.8 ± 10.3 (68)	27.3 ± 12.1 (66)	28 ± 11.3 (134)	31.2 ± 13.6 (99)	30 ± 16.4 (99)	30.6 ± 15 (198)
Perennial Grasses	20.1 ± 10.9 (68)	22.2 ± 13 (66)	21.1 ± 12 (134)	24.1 ± 19.7 (99)	15.8 ± 10.6 (99)	20 ± 16.3 (198)
Forbs	13.1 ± 12.1 (68)	11.4 ± 8.7 (66)	12.3 ± 10.6 (134)	17 ± 12.3 (99)	13.9 ± 10.6 (99)	15.4 ± 11.6 (198)
Height (cm)						
Sagebrush	38.6 ± 11.8 (67)	35.5 ± 13.5 (65)	37 ± 12.7 (132)	41.8 ± 17.6 (96)	34 ± 16.1 (96)	37.9 ± 17.3 (192)
Perennial Grasses	12.8 ± 4.7 (67)	10.8 ± 4.2 (66)	11 ± 4.5 (133)	12.9 ± 5.1 (99)	12.2 ± 4.6 (99)	12.6 ± 4.9 (198)
Forbs	4.7 ± 2.6 (67)	4.4 ± 2.2 (65)	4.6 ± 2.4 (132)	5.9 ± 2.8 (99)	5.1 ± 2.2 (99)	5.5 ± 2.5 (198)

Table 4. Total vegetation sites sampled for each study area broken down by year and site type.

	Year	Broods Actual	Broods Paired	Nests Actual	Nests Paired
Three Creeks	2012	26	26	20	17
	2013	26	26	11	11
	2014	22	22	24	25
	2015	25	25	13	13
	Total	99	99	68	66
Deseret	2012	23	21	8	7
	2013	24	23	11	11
	2014	25	25	11	11
	2015	28	25	9	9
	Total	100	94	39	38

Predator Surveys

Estimates of coyote densities exhibited annual variation with both study areas showing similar temporal trends (Fig. 9). Coyote density estimates were lowest on Deseret (0.35/km²) in 2012 with that density doubling (0.7/km²) the following year. Estimates of density also peaked in 2013 for Three Creeks (0.61/km²) with both study areas declining through subsequent years. Human activities, particularly shooting and trapping cause a high proportion of coyote mortality (Knowlton et al. 1999) and reduced coyote populations. However, coyote populations often compensate culling efforts with increases in litter size (Connolly 1995). Removal efforts by USDA Wildlife Services throughout the county could explain some of the observed annual variation in density estimates.

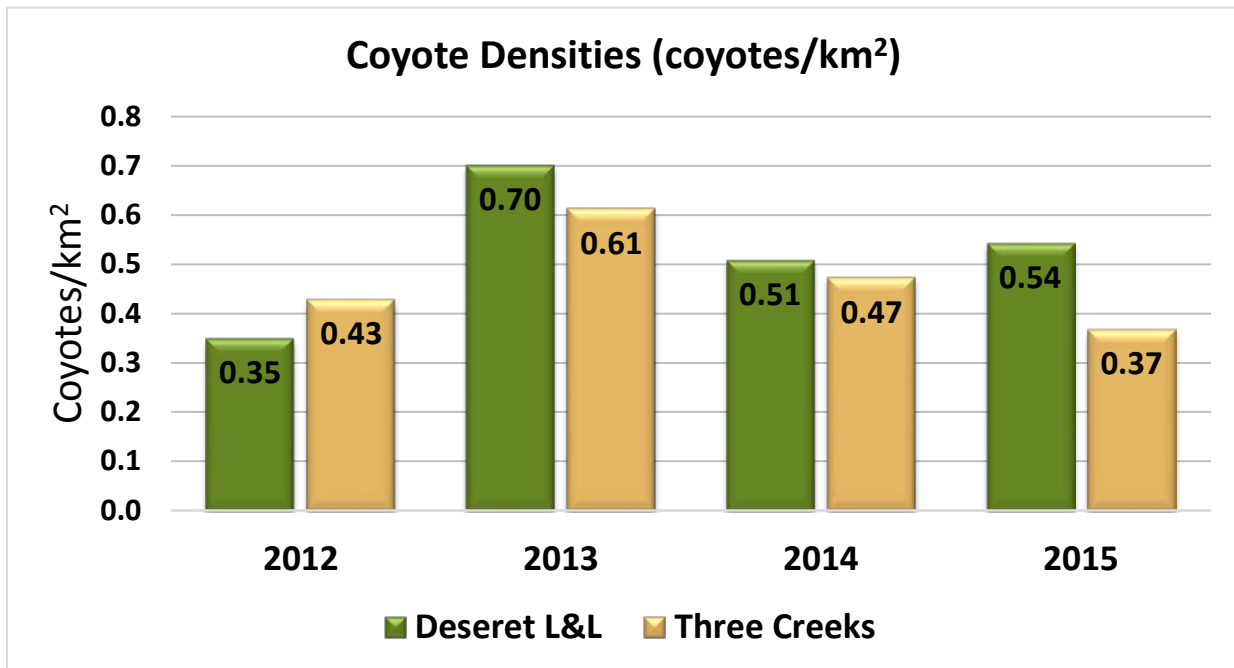


Figure 9. Comparison of estimated coyote densities between study areas for 2012-15. In 2012 5 transects within each study area were surveyed. For 2013-15 estimates, the number of transects for each study area was increased to 20.

We conducted avian predator point counts bi-weekly beginning in mid-April and continuing to late July of each year. We estimated annual corvid averages as the total number of observed corvids in each study area divided by the number of sampling days (Figure 10). To aid in our analysis, when an auditory detection was made and we could not locate the individual we applied a value of one for that detection. This prevented observations from being omitted from the calculation even when the number of individuals could not be verified.

Corvid exhibited strong annual variation in the Three Creeks study area. We attributed this largely to the detections of large groups typically associated with agricultural fields in the study area. In 2013 we didn't observe these large groups of corvids when conducting surveys which resulted in very low (1.1/day) estimations for that year. Ravens also exhibit large home-ranges encompassing 0.3-195 km² (Bruggers 1988, Linz et al. 1992) which may affect detections.

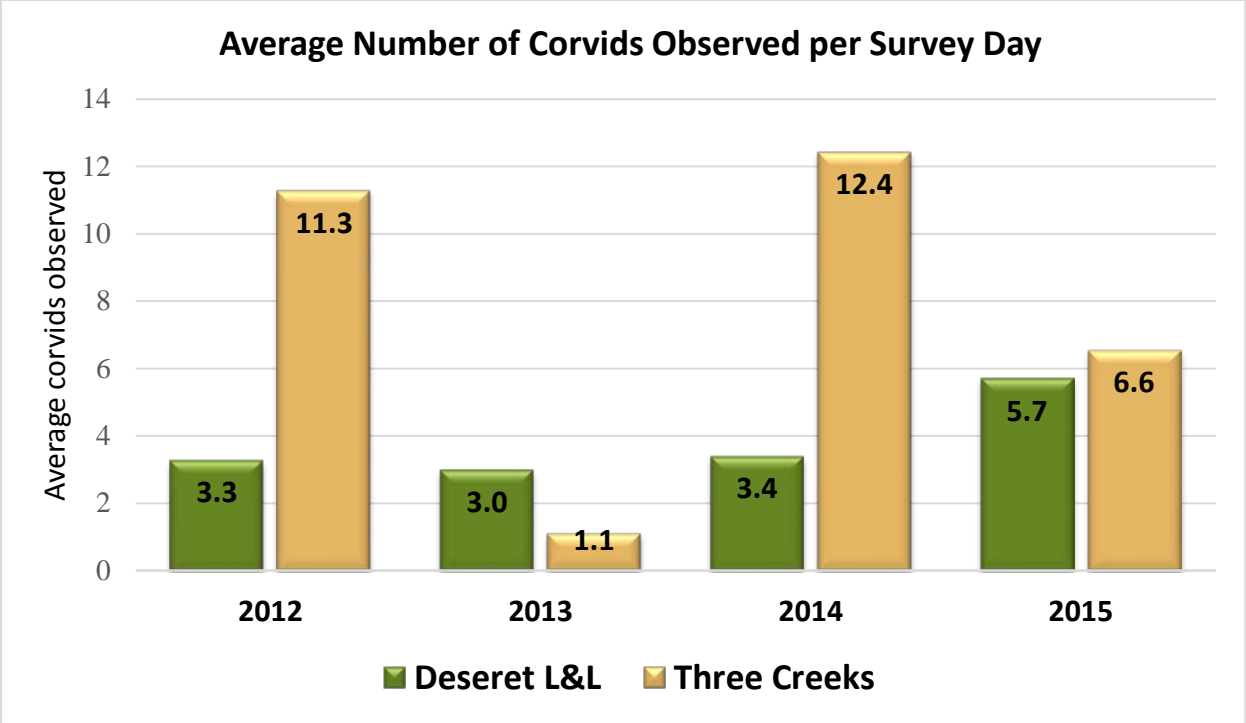


Figure 10. Average number of corvids observed per survey day in each study area in 2015.

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