SAGE-GROUSE CONSERVATION AND MANAGEMENT IN UTAH

A Summary of Greater Sage-grouse Research Framework for Utah's Greater Sage-grouse Conservation Strategy

1996-2018

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INTRODUCTION

The State of Utah has a long history and tradition of successful wildlife management and conservation. Utah Code Title 23 establishes and defines the State's legal wildlife management authority within the Utah Division of Wildlife Resources (UDWR). In the case of the greater sage-grouse (*Centrocercus urophasianus*; sage-grouse), significant contributions to the science, management, and conservation of the species have been achieved under state management authority (State of Utah 2013, Utah Public Land Policy Coordinating Office [PLPCO] 2018). The first strategic plan for greater sage-grouse was published in 2002 (UDWR 2002) and revised in 2009 (UDWR 2009). In 2013, the State of Utah published the "*Conservation plan for greater sage-grouse in Utah*" (State of Utah 2013). The 2013 Plan was revised in 2018 to reflect updated conservation policies such as the implementation of the Utah Compensatory Mitigation Program (PLPCO 2018). Each plan iteration has incorporated new information gained from on-going research completed on sage-grouse ecology and population responses to management actions. This narrative synthesizes the research completed in Utah and other areas that was used to frame the state strategy to guide the management and conservation of sage-grouse in Utah. These cumulative actions validate the role and impact of state management authority and voluntary conservation measures in achieving certainty in sage-grouse conservation.

The revised Utah Plan (PLPCO 2018) builds on and is a refinement of the previous plans. It seeks to protect high-quality habitat, enhance impaired habitat, and restore converted habitat for the portion of the range-wide sage-grouse population inhabiting Utah by eliminating identified species conservation threats. The Utah Plan (PLPCO 2018) was completed in accordance with the Utah Comprehensive Wildlife Conservation Strategy (UDWR 2005), Utah Local Working Group Plans (www.utahcbcp.org; Messmer et al. 2008, Messmer et al. 2011, Messmer et al. 2013, Messmer et al. 2016, Messmer et al. 2018), range wide conservation strategies and assessments (Connelly et al. 2004, Stiver et al. 2006), the Bureau of Land Management (BLM) National Sage-grouse Habitat Conservation Strategy (BLM 2004), and the U.S. Fish and Wildlife Service (USFWS) Greater Sage-grouse Conservation Objectives Final Report (COT; USFWS 2013). The Utah Plan embodies the best available science accumulated over the past 70 years and reflects the ecology of sage-grouse in Utah (Griner 1939, Dahlgren et al. 2016a). Utah's Plan recognizes the importance of sage-grouse leks, but it is **not lek-centric** in that it protects 94% of the birds and all their known seasonal habitats. The Plan includes small, peripheral populations as well as the southernmost population of sage-grouse across the range.

The Sage-grouse of Utah

In Utah, the UDWR manages sage-grouse as an upland game species as well as state sensitive species. The sage-grouse was considered a sensitive species within Utah, and a Tier II species under the Utah Comprehensive Wildlife Conservation Strategy (UDWR 2005), also referred to as the State Wildlife Action Plan.

Research conducted in the Gunnison Basin of southwestern Colorado and San Juan County in southeastern Utah confirmed that two species of sage-grouse inhabit both states. Sage-grouse populations that occur south and east of the Colorado River in Utah (Grand and San Juan counties) constitute a recently described species of sage-grouse, known as the Gunnison sage-grouse (*C. minimus*; Barber 1991, Young et al. 2000). Greater sage-grouse are located throughout the rest of the state (Dahlgren et al. 2016a).

A Gunnison Sage-grouse Conservation Plan was completed by the San Juan County Gunnison Sage-Grouse Working Group (SWOG) in 2000 (SWOG 2000). This document has been used to guide management of Gunnison sage-grouse in Utah. Therefore, Gunnison sage-grouse management and conservation strategies are not included in this narrative.

Status of Sage-grouse in Utah

Utah supports an estimated 6% of the total range-wide sage-grouse population (Western Association Fish and Wildlife Agencies [WAFWA] 2015). The populations are distributed throughout the northern, western, and central parts of Utah where they occupy a discontinuous habitat base that reflects the natural topography and geography of the Utah landscape (Dahlgren et al. 2016a).

Greater sage-grouse were thought to have been historically distributed in all 29 Utah counties. This belief is based largely on the historical distribution of sagebrush (*Artemisia* spp.), pioneer records, and museum specimens (Beck et al. 2003). Current estimates suggest that sage-grouse may occupy up to 8 million acres (3,237,490 ha) or about 41% of the historic habitats in Utah (Beck et al. 2003). The largest Utah sage-grouse populations inhabit western Box Elder County, on Blue and Diamond Mountains in Uintah County in northeastern Utah, in Rich County, and on Parker Mountain in south central Utah. Smaller populations are dispersed throughout the state. The Utah Plan encompasses over 7.5 million acres (2,832,804 ha) of the currently occupied habitat providing the best opportunity to conserve the species in the state.

The State of Utah has access to an extensive statewide database which now contains over 500,000 sage-grouse locations obtained from sage-grouse marked with very-high frequency (VHF) necklace-style radio-collars and rump-mounted global positioning system (GPS) radio-transmitters. The database is maintained by the Utah Community-Based Conservation Program (CBCP) at Utah State University (USU). The database includes seasonal habitat-use data recorded by graduate students and technicians supervised by research faculty at USU, Brigham Young University (BYU), and UDWR biologists using established range-wide protocols (Connelly et al. 2003). The Utah sage-grouse database may be most comprehensive source for local population data of its kind range-wide that directly reflect sage-grouse seasonal habitat-use and vital rates.

COMMUNITY-BASED CONSERVATION

Utah's Sage-grouse Local Working Groups

Because half of Utah's greater sage-grouse populations inhabit private lands at some time during their life cycle (UDWR 2002, 2009, State of Utah 2013, Dahlgren et al. 2016a), successful conservation will require broad support from local communities and private landowners. In 1997, USU Extension, through the CBCP, began organizing and facilitating sage-grouse local working groups (LWGs) throughout Utah (Messmer et al. 2008, Messmer et al. 2011, Messmer et al. 2013, Messmer et al. 2016, Belton et al. 2017, Messmer et al. 2018). The CBCP has enhanced coordination and communication between community-based adaptive resource management working groups, private, and public partners. To accomplish this, the CBCP facilitated the development and implementation of "seamless" plans for designated Utah geographic areas that have contributed to the conservation of sage-grouse and other wildlife species that inhabit Utah's sagebrush ecosystems and enhance the economic sustainability of local communities (Messmer et al. 2008, Belton et al. 2009). The CBCP process embraced a unique model that not only engaged LWG participants in conservation planning, but also identifying research questions, research funding, and conducting the research. As such, prior to any research being published in peer-reviewed journals, the LWGs and those most affected by conservation policies, are implementing management strategies and actions based on the research (Belton et al. 2017). Membership and participation in LWG meetings has grown steadily in Utah. The LWG sage-grouse conservation plans, previous annual reports, and meeting minutes can be accessed at www.utahcbcp.org.

There are 11 active regional LWGs in Utah. Each LWG has developed a local conservation plan that contributed to the development Utah's sage-grouse conservation strategies. The LWG plans laid the framework for the species threat analysis and conservation strategies (Messmer et al. 2008) that were incorporated into the Utah Plan (PLPCO 2018). The LWG and their plans continue provide the basis of implementation of sage-grouse conservation actions in Utah. The CBCP facilitators work closely with LWG members, state and federal, and private partners to implement the Utah Plan's goal of protecting high-quality sagebrush habitat and ameliorate the threats facing the sage-grouse while balancing the economic and social needs of the residents of Utah through a coordinated program (Messmer et al. 2008, Belton et al. 2017).

The CBCP LWGs conservation plans encompass the historical range of sage-grouse in Utah as identified in the Strategic Management Plan for Sage-grouse (Messmer et al. 2008, UDWR 2002, 2009, State of Utah 2013). The CBCP has provided long-term support to ensure the LWG administrative needs are met (Belton et al. 2017). Since inception, the CBCP has been financially supported by UDWR, USU Extension, the Jack H. Berryman Institute, private landowners, public and private natural resources management and wildlife conservation agencies and organizations. Implementation of the Utah Plan will require enhanced communication and cooperative efforts among local, state, and federal agencies, working in concert with private interests. In addition to participating as active contributors to the Utah planning process, the LWGs continue to implement their local sage-grouse conservation plans (Messmer et al. 2008, Belton et al. 2017, Messmer et al. 2016, Messmer et al. 2018).

In 2011, the CBCP developed and released an *app* based on the publication entitled "*Sage-grouse Habitat in Utah: A Guide For Landowners and Managers*" (Utah CBCP 2011). Over 5,000 copies of the publication have been distributed. The *app* "*Sage-grouse Habitat in Utah*" is free of charge and is available in Android and iOS formats. The *app* was the first of its kind, and although developed in Utah, is applicable throughout the sage-grouse range. The *app* provides managers and landowners with immediate and pertinent information about sagebrush management and sage-grouse habitat needs and can be accessed from anywhere in the field. It can assist in planning management actions to help conserve the sage-grouse population. The *app* will help landowners, federal and state partners better recognize characteristics of favorable sage-grouse habitat and assist them in developing projects to benefit species conservation across its range.

The 2013 and 2018 Utah Plans (State of Utah 2013, PLPCO 2018) endorsed and incorporated the CBCP LWG process, network, education and outreach efforts, research, and local conservation plans. The Utah Plan (PLPCO 2018) provides additional guidance and support to continue area-specific management programs focused on maintaining, improving, and restoring local sage-grouse populations and their habitats. The LWGs operate under the umbrella of the revised Utah Plan (PLPCO 2018). The scientific foundation of the 2018 Utah Plan is based on research conducted by USU, BYU, UDWR, and the U.S. Forest Service (USFS).

SAGE-GROUSE ECOLOGICAL RESEARCH IN UTAH

Connelly et al. (2011a) stated that sage-grouse conservation is achievable because sage-grouse are wide spread throughout western North America and large intact sagebrush communities still exist. The research completed and on-going in Utah provides a framework for more certainty for future sage-grouse management actions in the state as we learn more about population responses to management. However, because sage-grouse population growth rates are relatively slow compared to other gallinaceous birds (Dahlgren 2009, Taylor et al. 2012) and sagebrush systems respond over long time frames to restoration efforts, it may take several breeding cycles before management effects are noticeable (Pyke 2011, Messmer 2013).

Utah's Sage-grouse Management Areas (SGMA)

The USFWS emphasized the need to focus conservation efforts on protecting and enhancing the priority habitats as the essential mechanism for species conservation (USFWS 2013). Thus, better knowledge of sage-grouse seasonal movements is essential to conservation planning and implementation efforts. Sage-grouse seasonal habitats have been defined using three broad categories: breeding, summer, and winter. Breeding habitats consist of areas where pre-laying, lekking, nesting, and early brooding activities occur; summer habitat consist primarily of late brooding areas; and winter habitat occurs in areas where sagebrush is available above the snow throughout the winter for food and cover (Connelly et al. 2000).

Some populations are considered non-migratory, in that they use a limited geographic area to meet all their seasonal habitat requirements. Other populations are considered migratory and may move > 50 km between seasonal habitats (Connelly et al. 2000). Within Utah individual radio-marked birds within populations which could be consider non-migratory have engaged in long distant movement between seasonal habitats (Dettenmaier and Messmer 2016, Smith and

Messmer 2016, Flack 2017). These movements have included periods of habitat-use in adjacent states (Reinhart et al. 2013, Cardinal and Messmer 2016).

The Utah Plan incorporates UDWR sage-grouse lek location data and seasonal movement information obtained by two decades of research to delineate the 11 Sage-grouse Management Areas (SGMA's; PLPCO 2018). The SGMAs represent the best opportunity for high-value, focused conservation efforts for the species in Utah (State of Utah 2013, PLPCO 2018). The SGMAs reflect the biological and geographical realities of areas currently occupied by sage-grouse in Utah (Dahlgren et al. 2016a). The Utah Plan recognizes that sage-grouse populations in the Rich County area of Utah are connected to populations in eastern Idaho and western Wyoming (Dettenmaier et al. 2012, Dettenmaier and Messmer 2016, Cardinal and Messmer 2016), populations in Box Elder, Tooele, Juab, and Beaver Counties are connected to populations in southern Idaho and Nevada (Reinhart et al. 2013, Robinson and Messmer 2013), and populations in the Uintah and Daggett County areas are connected to populations in Wyoming and Colorado (Breidinger et al. 2013).

The SGMAs were delineated using known sage-grouse seasonal movements and habitat-use patterns. This approach also recognized current land uses and identified potential future uses that may conflict with species conservation (PLPCO 2018). Research indicated sage-grouse nearest lek to nesting, summer, and winter locations averaged 2.20 km (90th percentile = 5.06 km), 3.39 km (90th percentile = 8.45 km), and 3.76 km (90th percentile = 7.15 km), respectively. Seasonal movements from nest to summer, nest to winter, and summer to winter locations averaged 5.55 km (90th percentile = 13.09 km), 11.93 km (90th percentile =26.68 km), and 14.79 km (90th percentile = 30.75 km), respectively. Generally, distance from lek or seasonal ranges did not differ by age class or by sex. Successful nests were located slightly farther on average from leks than unsuccessful nests (x successful = 2.34 km, SE = 0.089, x unsuccessful = 2.04 km, SE = 0.090).

Utah's SGMAs encompass > 90 percent of Utah breeding populations and provide the greatest potential to increase sage-grouse usable space through habitat protection and active management (Dahlgren et al. 2016a). The SGMAs incorporated sage-grouse VHF radio-telemetry location data collected from 13 study areas from 1998 to 2013 to determine seasonal movements across populations. When lek to nest distance were averaged for these data, it suggested a reasonable buffer zone around leks in Utah of 3.1 mi (5.0 km). The 3.1 mi buffer distance was subsequently adopted by the Bureau of Land Management (BLM) in their 2018 Draft Resource Management Plan Amendment and Environmental Impact Statement (BLM 2018).

At the time Dahlgren et al. (2016a) was published, research in Morgan-Summit SGMA and Strawberry Valley SGMA, provided new information to better inform previous statewide lek to nest and seasonal habitat movement distance averages. Baxter et al. (2013) reported finding additional leks that were not accounted for by Dahlgren et al. (2016a) estimates of sage-grouse habitat movements. This new information given the large nest sample size (n = 204) that the Strawberry Valley SGMA contributed to the overall analysis, could reduce estimated statewide average distance sage-grouse moved from lek to nests and other seasonal habitat areas by > 50%.

Furthermore, between 2015-2016, Flack (2017) deployed 25 VHF radio-collars and 10 GPS transmitters on female sage-grouse in the Morgan-Summit SGMA. This population is one of the most productive in Utah exhibiting high nest initiation rates, hatching rates, and brood success rates despite limited habitat space and small seasonal movements. Seasonal movements from leks to nests, summer, and winter locations were smaller than other Utah populations analyzed by Dahlgren et al. (2016a). The average distance moved by female sage-grouse from lek of capture to nests was 1.2 km (SE = 0.13) while the maximum distance moved from lek of capture to summer locations was 2.4 km (SE = 0.25). The average maximum distance moved from nests to summer locations was 2.2 km (SE = 0.23). Movements from nests to summer and winter locations were also smaller suggesting that the Morgan-Summit population may also be spaced limited (Dahlgren et al. 2016a).

Sage-grouse Seasonal Movements - Range-wide Comparisons

Based on telemetry-data, Utah's SGMAs encompassed 88%, 80%, and 89% of all nest, summer, and winter locations, respectively. When weighted by the sum of maximum males counted for each lek within each study area during the years with radio-marked sage-grouse, the percentages increased to 97%, 95%, and 96% of nest, summer, and winter locations, respectively. Based on this analysis, Utah's SGMAs achieved the COT report recommendations of targeting conservation efforts in priority areas (USFWS 2013). For comparison, Fedy et al. (2012) reported that 85% of summer and 65% of winter locations are within Wyoming's core area boundaries.

The seasonal movements of Utah's sage-grouse populations reflect availability of habitat space. Populations occupying smaller isolated habitats moved shorter distances than populations occupying larger contiguous habitats (Dahlgren et al. 2016a), which are more typical of habitats in other states (Beck et al. 2003, Schroeder et al. 2004). The seasonal movement distances for Utah sage-grouse populations were generally less than those reported range-wide and reflected the localized and the naturally non-contiguous nature of many sagebrush habitats in the southern Great Basin and Colorado Plateau. Fedy et al. (2012) reported nest to summer range movement averages of 8.07 km and a 90th percentile of 19.04 km for sage-grouse populations in Wyoming. For the Utah populations studied, the same movements averaged 5.88 km and a 90th percentile of 13.65 km.

Fedy et al. (2012) reported larger maximum distances moved between seasonal locations for the Wyoming populations studied. In Utah, nest to winter and summer to winter distances were less (11.6 km and 14.8 km, respectively). Fedy et al. (2012) reported averages of 14.4 km and 17.3 km, respectively. These results validate the emphasis of the Utah Plan on habitat objectives designed to increase available and usable habitat space. Usable space may be more important than habitat quality in regulating wildlife population levels (Guthery 1997).

The Utah Plan protects habitat and associated populations of sage-grouse by implementing the strategic landscape planning principles included in the COT report. The Utah Plan designates priority areas for sage-grouse conservation (PLPCO 2108). Using a strategic landscape management approach optimizes species conservation planning benefits by considering investment tradeoffs that favors areas that are likely to yield the greatest conservation returns over areas that have limited or compromised potential to respond positively to management actions (Margules and Pressey 2000, Carvell et al. 2011). These distinctions in tradeoffs across landscapes are becoming increasingly paramount to the success of future conservation efforts in the face of limited resources (Williams et al. 2004). If the sage-grouse habitat restoration objectives in the Utah Plan are achieved (PLPCO 2018), usable space within SGMAs will increase over time benefitting the state's sage-grouse populations.

Juvenile Sage-grouse Survival

Little information has been published on mortality of juvenile sage-grouse or the level of recruitment necessary to maintain a stable population. Among western states, long-term juvenile to female ratios have varied from 1.40 to 2.96 juveniles per female in the fall. In recent years, this ratio has declined to 1.21 to 2.19 juveniles per female (Connelly and Braun 1997). It has been reported that at least 2.25 juveniles per female should be present in the fall population for stable to increasing sage-grouse populations (Connelly and Braun 1997, Connelly et al. 2000). Caudill et al. (2013), Caudill et al. (2014a), and Caudill et al. (2016a) provided new range wide insights regarding the role of juvenile sage-grouse ecology.

Sage-grouse are entirely dependent on sagebrush for food and cover during winter (Dahlgren et al. 2015a). Thus, the loss or fragmentation of important wintering areas could have a disproportionate affect on population size. To study the juvenile sage-grouse winter habitat use, Caudill et al. (2013) radio-marked and monitored 91 juvenile sage-grouse in south central Utah from 2008 to 2010 (Parker Mountain SGMA). Thirty-four individuals that survived to winter (January to March) were used to evaluate winter habitat use.

They found that juvenile sage-grouse used winter habitats characterized by 0 to 5% slopes regardless of aspect and slopes 5 to 15% with south-to-west facing aspects. The importance of high slope (5 to 15%) wintering habitats had not been previously documented in the sage-grouse literature. Most winter use was on a small proportion (3%; 2,910 ha) of available habitat. These important wintering habitats may not be readily identifiable in typical years, and consequently, due to their elevation, may be more susceptible to land management treatments focused on increasing early season livestock or big game winter forage, rendering them unsuitable for winter use by sage-grouse. Prior to implementing land management treatments in lower elevation sagebrush sites with slopes ≤5% regardless of aspect and slopes 5 to 15% south to west in aspect, managers should consider the potential effects of such treatments on the availability of suitable winter habitat to mitigate against winters with above-normal snowfall. This information has been incorporated in the Utah Plan (PLPCO 2018) and is the basis of an ongoing research effort coordinated by USU to model general and essential winter habitats.

Adult sage-grouse female and juvenile survival has been reported to influence population growth rates (Dahlgren et al. 2010b, Taylor et al. 2012, Caudill et al. 2016b). However, assessing the sensitivity of population growth rates to variability in juvenile survival has proven difficult because of limited information concerning this potentially important demographic rate. Sage-grouse survival rates are commonly assessed using necklace-type radio transmitters. Recent technological advances have increased interest in the deployment of dorsally mounted global GPS transmitters for studying sage-grouse ecology. However, the use of dorsally mounted transmitters has not been thoroughly evaluated for sage-grouse, leading to concern that birds fitted with these transmitters may experience differential mortality rates.

Caudill et al. (2014a) evaluated the effect of transmitter positioning (dorsal vs. necklace) on juvenile sage-grouse survival using a controlled experimental design with necklace-style and suture-backpack VHF transmitters. They monitored 91 juveniles captured in the Parker SGMA from 2008 to 2010. Nineteen females were equipped with backpacks, 14 males with backpacks, 39 females with necklaces, and 19 males with necklaces. They used Program MARK to analyze juvenile survival data. Although effects were only marginally significant from a statistical perspective, sex and transmitter type had biologically meaningful impacts on survival. Dorsally mounted transmitters negatively affected daily survival. Temporal variation in juvenile sage-grouse daily survival was best described by a quadratic trend in time, where daily survival was lowest in late September and was high overwinter. The low point of daily survival shifted within the season between years (27 vs. 17 Sep for 2008 and 2009, respectively). Overall (15 Aug–31 Mar) derived survival ranged 0.42–0.62 for females and 0.23–0.44 for males.

For all years pooled, the probability of death due to predation was 0.73, reported harvest was 0.16, unreported harvest was 0.09, and other undetermined factors were 0.02. They reported 0% and 6.8% crippling loss (from hunting) in 2008 and 2009, respectively. Caudill et al. (2014a) recommended the adoption of harvest management strategies that attempt to shift harvest away from juveniles and incorporate crippling rates. In addition, they recommended that future survival studies on juvenile sage-grouse should use caution if implementing dorsally mounted transmitters because of the potential for experimental bias. This has implications of studies that use rump mounted GPS radio-collars to assess sage-grouse survival rates. The use of GPS radio-collars without comparable vital rate data collected by using VHF radio-collars could bias sage-grouse survival rate estimates. Concomitantly, we continue to deploy both VHF and GPS radio transmitters in all of our on-going research.

Sage-grouse Female Reproduction Costs and Climate

Research on long-lived *iteroparous* species has shown that reproductive success may increase with age until the onset of senescence and that prior reproductive success may influence current reproductive success. These complex reproductive dynamics can complicate conservation strategies, especially for harvested species. Further complicating the matter is the fact that most studies of reproductive costs are only able to evaluate a single measure of reproductive effort.

Caudill et al. (2014b) and Caudill et al. (2016b) evaluated the effects of climatic variation and reproductive trade-offs on multiple sage-grouse reproductive vital rates. Based on over a decade of field observations obtained from sage-grouse inhabiting the Parker Mountain SGMA, they hypothesized that reproduction was influenced by previous reproductive success. They studied the reproductive activity of female sage-grouse radio-marked and monitored from 1998–2010 on the SGMA to assess effects of climate and previous reproductive success on subsequent reproductive success.

Neither nest initiation nor clutch size were affected by climatic variables or previous reproductive success. However, they found that both nest and brood success were affected by climatic variation and previous reproductive success. Nest success was highest in years with high spring snowpack, and was negatively related to previous brood success. Brood success was positively influenced by moisture in April, negatively associated with previous nest success, and positively influenced by previous brood success. Both positive and negative effects of previous reproduction on current year reproduction were reported suggesting high levels of individual heterogeneity in female reproductive output (Dahlgren et al. 2010b). Their results supported previous research in indicating that climatic variability may have significant negative impacts on reproductive rates (Guttery et al. 2013). These results support the Utah Plan objectives of increasing the sage-grouse habitat base (PLPCO 2018). Expanding the SGMA habitat base will increase the potential for increased production and recruitment in years when climatic conditions are favorable (Dahlgren et al. 2010b, Guttery et al. 2013a, Caudill et al. 2014b, Caudill et al. 2016b).

Lek Counts Track Sage-grouse Population Responses to Management

Obtaining valid population estimates is essential to understanding the effects of management and conservation strategies on population trajectories (Connelly et al. 2004). The Utah Plan proposes specific strategies to protect, maintain, improve, and enhance sage-grouse populations and habitats within the established SGMAs (PLPCO 2018). Unlike other state plans, the Utah Plan also establishes population and habitat objectives (PLPCO 2018).

Leks are the center of breeding activity for sage-grouse. Male sage-grouse begin to congregate on leks in late February/early March and perform a ritualized courtship display. Courtship displays are strongly correlated to pre and early dawn hours and quickly wane within a couple of hours following sunrise (Connelly et al. 2011b, Guttery et al. 2011). Females are attracted to leks by the male courtship displays and mating primarily occurs on the lek. Lek attendance may continue as late as early June, but typically peaks during April in Utah (UDWR 2009, Guttery et al. 2011).

As sage-grouse populations decline, the number of males attending leks may decline or the use of some leks may be discontinued. Likewise, as populations increase, male attendance may increase and/or new leks may be established or old leks reoccupied (Connelly et al. 2011b). There is little or no evidence that suggests lek habitat is limiting (Schroeder et al. 1999). Additional lek habitat can be created if needed, but does not guarantee that sage-grouse males will utilize the created lek habitat.

Count indices are often used to monitor and assess wildlife population status (Bibby et al. 1992, Pollock et al. 2002). Lek counts have been widely used as an index for sage-grouse population change and to guide management decisions (Connelly et al. 2004, UDWR 2009, Garton et al. 2011). Counts of male sage-grouse attending leks during the breeding season have also been used to estimate the breeding population size by assuming a detection probability and sex ratio. In the latter case, managers often assume a 2:1 female biased ratio. However, this sex ratio has not been validated and may result in biased population estimates. The UDWR had assumed a 75% detection rate for male sage-grouse on leks and a 2:1 female biased sex ratio (UDWR 2002, 2009).

Guttery et al. (2011) evaluated the validity of using lek-counts to estimate populations in Utah. They concluded that the standard UDWR counts which are used to monitor most sage-grouse leks may omit, on average, 2 males. Additionally, they found that only 56% of all available males were actually attending leks at any given time. Their estimates of lek attendance were similar to the findings of Walsh et al. (2004) but well below the estimates provided by Emmons and Braun (1984). Their results demonstrated that male lek attendance rates fluctuate throughout the breeding season, but typically peaked at or before sunrise. As such, they recommended that lek counts should be conducted as early as possible to obtain the most accurate counts. This may result in fewer leks being counted per morning but will provide more representative data.

Guttery et al. (2013b) also evaluated sex ratios at hatch, 42 days of age, and at harvest to determine if sex ratios were biased for sage-grouse in Utah. Sex ratios at hatch and at 42 days of age did not differ from parity. Harvest data suggested that sage-grouse may exhibit a slight female-biased sex ratio (1.458:1) in the fall. The Utah Plan has incorporated this new information into sage-grouse population estimates based on lek count data (PLPCO 2018).

The validity of lek counts for monitoring changes in population numbers remains suspect (Walsh et al. 2004, Guttery et al. 2011). However, their utility as a measure of population production has never been evaluated. Dahlgren et al. (2016b) evaluated using standard lek count protocols which followed range wide guidelines (Emmons and Braun 1984, Connelly et al. 2003) to determine if they reflected lambda. They concluded that male-based leks counts of sage-grouse can be an effective index to overall population change. These results have range wide implications as they provide a basis for states to track sage-grouse population responses to management and conservation actions.

Sagebrush and Sage-grouse Diets

Sage-grouse depend on sagebrush to complete their annual life cycle (Dahlgren et al. 2015b). The winter diet for sage-grouse consists almost entirely of sagebrush leaves, and individual birds may gain weight while foraging on sagebrush. Thacker et al. (2010) provided new insights in determining sage-grouse sagebrush winter forage preferences. The identification and protection of important winter habitats is a conservation priority. Thus, better information is needed regarding sage-grouse sagebrush winter dietary preferences for application to management. The objective of their research was to determine if chemical analysis of fecal pellets could be used to characterize winter sage-grouse diets as a substitute for more invasive methods. To conduct this research, they collected and analyzed fecal pellets and sagebrush samples from 29 different sage-grouse flock locations in the Box Elder and Parker Mountain SGMAs.

Using gas chromatography, they were able to identify crude terpene profiles that were unique to Wyoming sagebrush (*A. tridentata wyomingensis*) and black sagebrush (*A. nova*). They subsequently used the profiles to determine sagebrush composition of sage-grouse fecal pellets, to better reflect sage-grouse winter diets. This technique provided managers with a tool to determine which species or subspecies of sagebrush may be important in the winter diets of sage-grouse populations (Dahlgren et al. 2015a).

Previous studies have reported higher crude protein and lower monoterpene concentrations in the sagebrush species selected as winter forage by sage-grouse (Thacker et al. 2010). However, no studies have attempted to link female sage-grouse vital rates (i.e., nest initiation and success, egg fertility, clutch size, and adult survival) to crude protein or monoterpene concentrations of sagebrush plants browsed during pre-nesting periods. From March to May 2013, we monitored pre-nesting diets for 29 radio-marked female sage-grouse in the Box Elder Sage-grouse Management Area in northwestern Utah to determine if a relationship existed between foraging patterns and vital rates (Wing and Messmer 2016).

We randomly located radiomarked female sage-grouse ≥3 times during the study period and subsequently sampled 70 sagebrush communities where they were observed to determine which sagebrush species or subspecies were browsed and if samples collected of the browsed plants differed in nutritional quality (i.e., crude protein) and chemical composition (i.e., monoterpenes) from non-browsed plants in the areas sampled and non-browsed randomly selected plants in adjacent sagebrush communities. Seventy-three percent of these sites where radio-marked females were located consisted entirely of black sagebrush communities. Percent crude protein and total monoterpene concentration in black sagebrush and Wyoming big sagebrush did not differ between browsed, non-browsed, and non-browsed random plants. Browsed black sagebrush plants were lower in average percent crude protein ($P = 0.003$) and higher in total monoterpene concentration ($P \leq 0.001$) than browsed Wyoming big sagebrush. Apparent nest success, age of nesting females, egg fertility, clutch size ($P > 0.05$), and female monthly survival rates (CI = -0.21–0.49) for the radio-marked sage-grouse we monitored did not differ based on sagebrush crude protein and total monoterpene content. However, all of the radio-marked female sage-grouse ($n = 10$) observed in black sagebrush communities where the collected plant samples exhibited higher concentrations of an unidentified monoterpene successfully hatched nests ($P = 0.002$). All of the nests of radio-marked female sage-grouse ($n = 9$) outside these areas failed. Our results lend additional support to previous published work regarding sage-grouse preferences for black sagebrush as pre-nesting forage and suggest a potential link to nest success (Wing and Messmer 2016).

Grass Height and Sage-grouse Nest Success

For sage-grouse, the vegetation surrounding the nest has been reported to play an important role in mediating nest success by providing concealment from predators (Connelly et al. 2004). In particular, the height of grasses surrounding the nest is thought to be a driver of sage-grouse nest survival (Doherty et al. 2014). However, a growing body of the literature has found that widely used field methods can produce misleading inference on the relationship between grass height and nest success (Smith et al. 2017). Specifically, it has been demonstrated that measuring concealment following nest fate (failure or hatch) introduces a temporal bias whereby successful nests are measured later in the season, on average, than failed nests. This sampling bias can produce inference suggesting a positive effect of grass height on nest survival, though the relationship arises due to the confounding effect of plant phenology, not an effect on predation risk.

To test the generality of this finding for sage-grouse, we reanalyzed existing datasets comprising >800 sage-grouse nests from three independent studies across the range where there was a positive relationship found between grass height and nest survival, including two using methods now known to be biased. Correcting for phenology produced equivocal relationships between grass height and sage-grouse nest survival. Viewed in total, evidence for a biological effect of grass height on sage-grouse nest success across time and space is lacking. In light of these findings, we recommended a reevaluation of land management guidelines emphasizing specific grass height targets to promote nest success (Smith et al. 2017).

ACTIVE MANAGEMENT TO MITIGATE SPECIES CONSERVATION THREATS

The Utah Plan protects high-quality habitat, enhances impaired habitat, and restores converted habitat for the portion of the range-wide sage-grouse population inhabiting Utah by eliminating USFWS and State identified species conservation threats (PLPCO 2018). In addition to Utah efforts, the BLM, the USFS, and the other western states with sage-grouse populations and habitats, have initiated planning and other actions designed to mitigate the identified threats, protect important sagebrush habitats, and develop adequate regulatory mechanisms to eliminate the need for a listing under the ESA (BLM 2015, 2018). The science used to develop the Utah Plan is the basis of the BLM and USFS planning processes in the state (BLM 2015, 2018). The following are elements of Utah's active management to address sage-grouse conservation threats.

Increasing Useable Space for Sage-grouse

Sage-grouse occupied habitat in Utah largely reflects the topography and geography of Utah. The geography is characterized by mountainous terrain, separated by broad valleys in the Great Basin, and by deeply incised canyons in the Colorado Plateau (West 1983). Sage-grouse habitat may be found in intact blocks or natural fragments in the Great Basin, or in disconnected "islands" of habitat in the Colorado Plateau (Perkins 2010).

The Utah Plan emphasizes increasing usable space for sage-grouse in naturally fragmented habitat as a means of increasing both production and connectivity (PLPCO 2018). The reduction and removal of juniper (*Juniperus* spp.) and pinyon pine (*Pinus edulis*; PJ) encroachment in SGMAs where the sagebrush and herbaceous understory is relatively intact may provide the greatest potential to create and enhance sage-grouse habitat in Utah (Frey et al. 2013, Sandford et al. 2015, Cook et al. 2017, Sanford et al. 2017).

Conifer encroachment into sage-grouse habitat has been identified as a threat to sage-grouse populations (Miller et al. 2011, Baruch-Mordo et al. 2013, USFWS 2013). Research suggests sage-grouse will use areas within SGMA where PJ has been removed within a short period of time (< 1 to 3 years) post-treatment, especially if the treatment site has sagebrush remaining in the understory, mesic areas nearby, and the site is near existing sage-grouse use areas (Frey et al. 2013, Sandford et al. 2015, Cook et al. 2017). Field observations have documented a sage-grouse female successful nesting in areas where conifer removal projects were being conducted. The female nested under sagebrush in an area where the conifer canopy have been removed by a bullhog (Sandford et al. 2015). In the four years previous to the bullhog treatment, sage-grouse use had never been documented in the area during on-going habitat use studies where we were monitoring radio-marked birds.

Prioritizing Conifer Encroachment Removal Projects

There are more decisions being made now concerning sage-grouse conservation than ever before. Understanding sage-grouse populations and their ecology is critical to avoiding well intended, but mistaken, management objectives for the species (Dahlgren et al, 2016b). To encourage the creation and protection of sage-grouse habitats, the State of Utah has developed a Compensatory Mitigation Program (CMP; PLPCO 2018). The CMP is managed by the Utah Department of Natural Resources (R634-3-1, Utah State Code § 79-2-501 et. seq.,). The goals of the CMP are to increase the space available to the species and enhance habitat-use by creating corridors to offset the impacts of permanent developments in sage-grouse habitat in Utah. The CMP proposes to achieve this by providing opportunities for private landowners and others to create and market mitigation credits for increasing and protecting functional habitats. Currently, the CMP is proposing an exchange rate of 1 to 4; for every one acre of sage-grouse habitat lost through development, the developer will have to provide four replacement acres. This equation does not take into account habitat quality. The CMP desires a tool that will include habitat quality as a factor when determining mitigation credits. The Utah CBCP has partnered with the BLM and UDWR to evaluate the Habitat Treatment Prioritization Framework (HTPF) to provide CMP administrators, private landowners, and land managers with an interactive tool to optimize sage-grouse conservation benefits and the accrual of potential mitigation credits.

The scientific foundation for HTPF was reported by Sandford et al. (2017). We used VHF radio-marked sage-grouse location data from nests and broods in Resource Selection Function (RSF) analyses and incorporated vital rates (nest and brood success) into our models. They reported that grouse nest and brood site selection favored areas closer to or within conifer removal areas, and individuals with higher selection values for treatments experienced higher rates of nest and brood success.

To demonstrate the management implications of this research, we have used our best selection model for brooding habitat based known locations of radio-marked females marked. We used a 3-stage process to provide mapping (heat map) of a prioritized landscape (i.e., showing areas with the highest potential of return on investment for conifer removal projects). We modeled brood habitat under current conditions (Figure 1). We then hypothetically removed all Phase I conifer on the landscape and reran the model (Figure 2). We then calculated the relative change in probability of use by combining the two maps (Figure 3). Our results demonstrated that if conifer were removed from the red and darker yellow areas in Figure 3 treatment would result in a higher probability of providing more benefit to sage-grouse broods compared to the lighter yellow and blue areas.

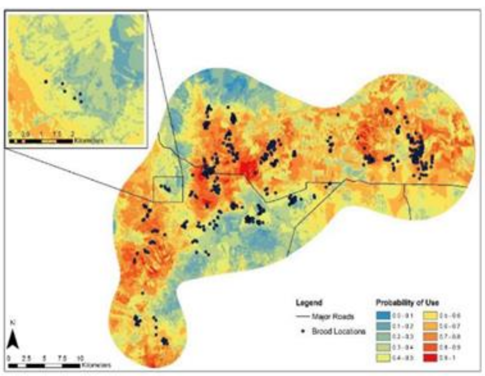


Figure 1. Current greater sage-greater (*Centrocercus urophasianus*) habitat potentials, West Box Elder Sage-grouse Management Area based on radio-telemetry studies

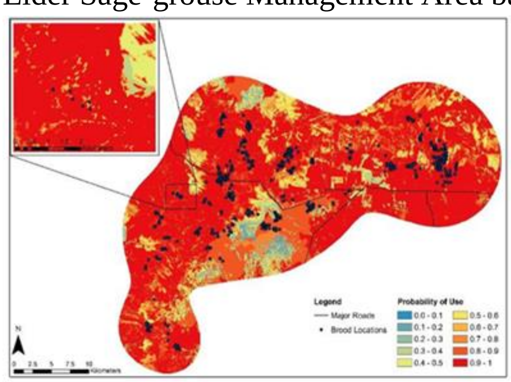


Figure 2. Greater sage-grouse (*Centrocercus urophasianus*) habitat potential with all conifers removed, West Box Elder Sage-grouse Management Area All conifers removed.

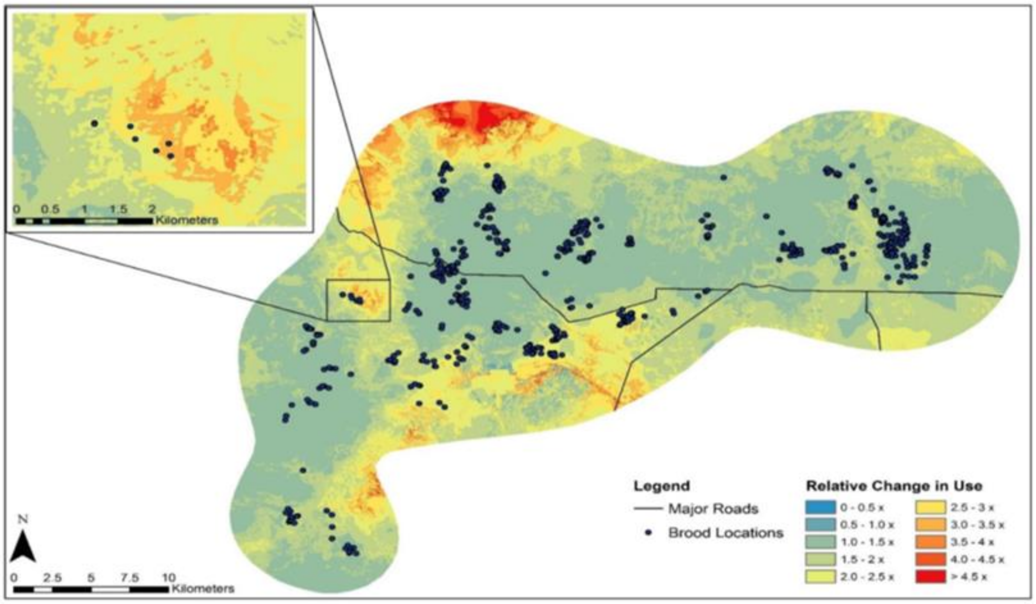


Figure 3. Benefits to greater sage-grouse (Centrocercus urophasianus) broods by removing conifers in priority areas, West Box Elder Sage-grouse Management Area.

We are evaluating the HTPF concept using conifer removal projects in the Box Elder Sage-grouse Management Area (SGMA) in West Box Elder County in northwestern Utah. This SGMA contains one of the state's largest sage-grouse population and exhibits a mix of private and public lands that are managed for multiple-uses. The first conifer removal projects were completed in the 1960's. Since then conifers have expanded, invading further into sage-grouse habitats (Sandford et al. 2017).

Future analyses will include additional data obtained from female sage-grouse radio-marked with GPS transmitters which will allow us to expand the HTPF to include multiple seasons (e.g., breeding, brooding, late summer, winter) and vital rates simultaneously. The GPS transmitters record up to nine locations a day, 24-7 allowing us remotely monitor marked birds to determine survival rates, seasonal movement patterns and overall population viability in response to management. We are also radio-marking and monitoring sage-grouse chicks to learn more about brood response to treatments. These data will allow us to better understand the entire life cycle of radio-marked sage-grouse within SGMA and the birds responses to specific habitat management treatments.

Enhancing Sage-grouse Brood-rearing Habitats

Sage-grouse have the lowest reproductive rate of any North American game bird. Thus, it is believed populations may be less able to recover from population declines as quickly as those of most other game birds (Connelly et al. 2011b). However, recovery rate may also be affected by favorable environment conditions (Guttery et al. 2013a, Caudill et al. 2014a, Caudill et al. 2016a, Caudill et al. 2016b). Research conducted on Parker Mountain SGMA has provided new knowledge regarding this relationship.

Parker Mountain is located in south-central Utah in Garfield, Piute, and Wayne counties. Parker Mountain is approximately 107,437 ha (265,584 acres) and is managed by private, state, and federal entities. The Parker Mountain Adaptive Resources Management Local Working Group (PARM) was organized in 1997 with one central goal – they wanted to "grow more grouse" to mitigate the risks of the species being listed (Messmer et al. 2008). Although concerns about declining sage-grouse populations led to the formation of PARM, the group's commitment to sustaining their community and natural resources through research and management has been the driving force keeping the group working together (PARM 2006, Messmer et al. 2014, Belton et al. 2017).

In the past decade, PARM's efforts have increased sage-grouse populations from an estimated 125 males counted on leks in 1996 to over 1,400 in 2007 (Messmer et al. 2008). The habitat work conducted to "grow more grouse" was accomplished largely with funding provided through conservation provisions of USDA's Farm Bill. The PARM has implemented a long-term adaptive resource management habitat monitoring and research program to evaluate the effects of management actions on sage-grouse and other wildlife populations. This research is part of a long-term database that has provided new insights regarding the effects of management actions on sage-grouse vital rates and ultimately recruitment in Utah and range-wide.

Increasing Chick Survival

Obtaining timely and accurate assessment of sage-grouse chick survival and recruitment is an important component of species management and conservation (Connelly et al. 2011b). Dahlgren et al. (2006) studied the effects of reducing sagebrush canopy cover to enhance forb availability for sage-grouse chicks in the Parker Mountain SGMA. Low chick survival was identified as major factor limiting recruitment (PARM 2006).

Dahlgren et al. (2006) evaluated the effects of two mechanical (Dixie harrow and Lawson aerator) treatments and one chemical (Tebuthiuron) treatment on sage-grouse use of brood-rearing habitats. To conduct this experiment, Dahlgren et al. (2006) delineated 19 40.5-ha plots that exhibited 40% mountain big sagebrush (*A. tridentata vaseyana*) canopy cover and randomly assigned 16 as treatment or controls (4 replicates each). The Tebuthiuron and Dixie-harrow-treated plots exhibited increased forb cover than the control plots post-treatment. Sage-grouse brood use was higher in Tebuthiuron than control plots and the increased use was attributed to increased herbaceous cover, particularly forbs. In all plots, sage-grouse use was greatest within 10 m of the edge of the treatments where adjacent sagebrush cover was still available. Although the treatments studied resulted in the plots achieving sage-grouse brooding-rearing habitat guidelines, they recommended caution in applying these observations at lower elevations, in areas with less annual precipitation or a different subspecies of big sagebrush.

Based on these results, PARM implemented a long-term management program where up to 500 acres (200 ha) of sage-grouse breeding habitat where sagebrush cover exceeded 40 % canopy cover were treated annually with low rate applications of Tebuthiuron. Utah State University in partnership with PARM, UDWR, BLM, and the USFS continued to monitor sage-grouse populations in response to the treatments and also evaluate the survey methodology used to determine sage-grouse response.

Dahlgren et al. (2010a) compared the effectiveness of walking, spotlight, and pointing-dog surveys to detect radio-marked and unmarked chicks within broods of radio-marked hens in Utah. Walking surveys detected 72% of marked chicks, while spotlight and pointing-dog surveys detected 100% and 96%, respectively. They found no difference between spotlight and pointing-dog counts in number of marked and unmarked chicks detected. Spotlight counts were slightly more time efficient than pointing-dog surveys. Spotlight surveys were nocturnal searches and perceived to be more technically arduous than diurnal pointing-dog surveys. They suggested pointing-dog surveys may offer greater utility in terms of area searched per unit effort and an increased ability to detect unmarked hens and broods.

Using the above techniques, Dahlgren et al. (2010b) examined factors that influenced chick survival. They radio-marked 1- to 2-day-old sage-grouse chicks in 2005–2006 on Parker Mountain and monitored their survival to 42 days. They then modeled effects of year, hatch date, chick age, brood-female age, brood-mixing, and arthropod abundance on chick survival. Their best model revealed an average survival estimate of 0.50 days to 42 days, which was the highest level ever documented range wide for the species.

Brood-mixing (chicks leaving natal brood to join with other non-natal broods) occurred in 21% (31/146) of chicks and 43% (18/42) of broods they studied. Moreover, yearling females had more chicks leave their broods than did adults. They found that survival may be higher among chicks that switch broods compared to those that stayed with their natal mother until fledging. Thus, brood-mixing may be an adaptive strategy leading to increased sage-grouse chick survival and higher productivity, especially among chicks born to yearling females. Their findings also indicated that arthropod abundance may be an important driver of chick survival, particularly during the early brood-rearing period and, therefore, sage-grouse populations may benefit from a management strategy that attempts to increase arthropod abundance via brood habitat management (Dahlgren et al. 2006).

Guttery et al. (2013a) refined this research by studying the effects of landscape scale environmental variation on sage-grouse chick survival. Effective long-term wildlife conservation planning for a species must be guided by information about population vital rates at multiple scales (Connelly et al. 2011b). Sage-grouse population growth rates appear to be particularly sensitive to hen and chick survival rates (Taylor 2012). While considerable information on female sage-grouse survival exists, there is limited information about chick survival at the population level.

Guttery et al. (2013a) analyzed sage-grouse chick survival rates from the Parker Mountain SGMA and south central Idaho across 9 years to determine what landscape variables may affect survival and ultimately recruitment. They analyzed the effects of 3 groups of related landscape scale covariates (climate, drought, and phenology of vegetation greenness). Phenology changes in vegetation greenness was measured using the Normalized Difference Vegetation Index (NDVI; Tucker 1979). The NDVI is a satellite-derived index of photosynthetic biomass, typically scaled from 0-1. It has been used to map plant phenology across climatic regimes (Stoner et al. 2016). Models with NDVI performed poorly, possibly because seasonal variation in forb and grass production was masked by sagebrush canopy. The top drought model indicated that chick survival was negatively associated with winter drought. These results suggest possible effects of climate variability on sage-grouse chick survival if winter droughts become a common occurrence.

Sagebrush Treatments

Land-use treatments that remove or reduce sagebrush canopy in areas occupied by sage-grouse are controversial given the species conservation status. In 2015, Utah Governor Gary R. Herbert signed an Executive Order (EO) that included a statement that sagebrush removal in sage-grouse habitats was highly discouraged and that future sagebrush treatment using state funding could only be justified if a net benefit to sage-grouse would be probable (PLPCO 2018). Although many studies have shown negative impacts of sagebrush treatments on sage-grouse, research completed by Utah State University on the Parker Mountain SGMA suggested positive effects for the species if the treatments occur in higher elevation late brood-rearing habitats (Dahlgren et al. 2006).

Sagebrush removal treatments completed at large scales and/or in breeding and wintering habitats are certainly not appropriate. However, in high elevation late summer brooding habitats when grouse use more open canopy areas with higher forb cover, small mosaic treatments may improve brooding habitat. Baxter et al. (2017) studied mechanical treatments of sagebrush previously implemented in Strawberry Valley SGMA in 2009. They analyzed before and after location data from radio-marked sage-grouse using the area to assess habitat selection before and after treatments. They found that sage-grouse, especially during the brooding period selected for treated areas following sagebrush canopy removal compared to pre-treatment years. This study occurred in a high elevation highly resilient mountain big sagebrush community with high average annual precipitation. Similar studies in lower elevations of Wyoming big sagebrush have not shown such positive results. This new study, along with other studies from Utah, provided the parameters and justification required by the EO for when sagebrush treatments would likely be beneficial to sage-grouse for future management decisions.

Sage-grouse and Hunting

Although hunting was not cited as a high priority threat by the USFWS (2010, 2015), stakeholders question why state wildlife agencies continue to allow sage-grouse hunting given the status of the species (Belton et al. 2009, UDWR 2009). Limited hunting of sage-grouse is currently allowed by permit only in the Box Elder, Rich-Morgan-Summit, Uintah, and Parker Mountain Emery SGMAs. These SGMAs have the largest stable populations. Hunt quotas are determined annually based on very conservative estimates, and are based on criteria found in the Utah Sage-grouse Strategic Management Plan (UDWR 2009). Decreases in population in any particular year due to natural or human caused events, will lead to a reduced number of hunting permits or cancellation of the hunt for the year.

Fees collected from hunters are typically expended only for the benefit of species that is hunted. If sage-grouse were not hunted, expenditures from that funding source for the species' benefit would cease. Sage-grouse hunting also maintains the interest of the sportsman's community by continuing a viable hunting program and allows for collecting scientific data regarding recruitment from the birds harvested (UDWR 2009, State of Utah 2013).

In 2008, the demand for sage-grouse hunting permits in Utah exceeded their availability, raising questions about why hunters choose to pursue this species. Guttery et al. (2015) hypothesized that the pending ESA listing decision increased hunter demand for permits. They surveyed randomly selected hunters who obtained permits to hunt sage-grouse in Utah in 2008-2010 (n = 838) to determine their motivations for hunting sage-grouse and determinants of hunter satisfaction. The most commonly reported reasons for hunting sage-grouse were to spend time with family, for tradition, and meat. Although the potential ESA listing was not a major motivational factor in 2009 or 2010, the percentage of respondents selecting this option did increase by 7%. Hunter awareness of the ESA listing status increased by 18% during this period. Sage-grouse hunter participation rates declined by 1.63% between 2008 and 2009 continuing a trend documented by UDWR since 2004 (UDWR, unpublished data). However, participation rates experienced an approximate 5% increase between 2009 and 2010.

Guttery et al. (2015) recommended that conservation strategies for sage-grouse must carefully weigh the social and biological implications of hunting. Because of the role of long-lived adult females in brood-mixing, and ultimately production (Dahlgren et al. 2010b), the UDWR delayed the opening of the sage-grouse hunt to reduce the harvest on adult females. This change allowed for increased amalgamation of the individual broods into larger flocks to reduce adult brood female risks to harvest (Dahlgren 2009). Guttery et al. (2015) concluded the adaptive harvest regulations adopted by UDWR that link sage-grouse hunting opportunities to annually estimated population sizes and female reproductive contributions constitute an effective and conservative harvest management strategy based on the best available science.

Translocations to Augment Declining Populations

Wildlife translocations are a common and often times successful conservation tool used to either restore extirpated or augment declining wildlife populations. Translocations have been recommended to sustain genetic diversity in declining wildlife populations, including sage-grouse. Reese and Connelly (1997) estimated that over 7,200 sage-grouse had been translocated across the range of the species. These translocations occurred in New Mexico, Oregon, Montana, Wyoming, Utah, Colorado, Idaho, and British Columbia. Since 1997, additional translocations have occurred in California, Washington, Alberta, and North Dakota.

Utah has experimented with sage-grouse translocations intended as conservation efforts to establish and/or enhance existing populations. The first documented sage-grouse translocation in Utah occurred in 1976 when 48 females and chicks were moved from the Parker Mountain SGMA to San Juan County (Reese and Connelly 1997). Utah translocation have demonstrated more success in these efforts relative to other states.

The sage-grouse populations on Wildcat and Horn Mountains (Carbon SGMA) provides an example of a successful translocation. From 1987-1990 15 males and 35 hens with juveniles were released in the area. The populations still exist with 27 strutting males observed in 2008 (Perkins 2010).

The Strawberry Valley SGMA in central Utah provided a dramatic example of the decline of sage-grouse in Utah. Griner (1939) estimated that 3,000-4,000 sage-grouse inhabited this high mountain valley in the 1930s. Bunnell (2000) estimated the Strawberry Valley SGMA population at 250-350 sage-grouse in 1999, representing a population decrease of 88-94%. Most of this decline was attributed to anthropogenic causes (roads, Strawberry Reservoir, non-native predators, and reductions in habitat quantity and quality). In total, 336 female sage-grouse were moved from Uintah Basin, Rich, Box Elder, and Parker Mountain SGMAs to the Strawberry Valley SGMA from 2003-2008.

The population in Strawberry Valley SGMA is estimated at > 500 breeding adults. This increase is attributed to the success of translocation efforts, habitat improvements, and predator control (Baxter et al. 2007, Baxter et al. 2008, Baxter et al. 2013). Characteristics common to successful sage-grouse translocations include suitable contiguous sagebrush habitats enveloped by geomorphic barriers, a residual resident population, pre-nesting releases, and active mammalian predator management (Baxter et al. 2008, Baxter et al. 2013).

Because of increasing habitat fragmentation, UDWR wildlife managers were interested in learning if translocations can be used to sustain smaller meta-populations that inhabit remote landscapes that exhibited suitable habitat but lacked geomorphic barriers. From 2009-2010, Gruber (2012) compared vital rates and behaviors of 60 translocated and 15 resident radiomarked female sage-grouse and their broods on Anthro Mountain, in the Ashley National Forest of northwest Utah. Translocated birds were released within 200 m of an active lek on Anthro Mountain. Anthro Mountain consists of 2,500 ha of suitable but non-contiguous breeding habitat ranging in elevation of 2,400-2,800 m. The sage-grouse that were translocated were captured on the Parker Mountain SGMA. The Parker birds were selected as the source population for the translocation because the population was robust and stable, ≥ 100 km from the release site, and was genetically compatible to Anthro Mountain sage-grouse (Briedinger et al. 2013). The source area also exhibited topography and elevations similar to Anthro Mountain.

Adult survival, nest success, and brood success estimates for both resident and translocated birds varied annually, but were lower than range wide averages (Gruber 2012, Gruber-Hadden et al. 2016). Adult survival was higher in 2010 than 2009 and survival differed among resident status (i.e., resident, newly translocated, and previously translocated). Nest success was higher for resident than translocated birds and was positively related to grass height. In 2009 and 2010, chick survival to day 50 was higher for chicks of resident than translocated females. Chick survival for both groups was positively related to grass cover and grass height. Area of occupancy for translocated (45 km^2) and resident females (40 km^2) overlapped by 68%.

Although adult and yearling newly translocated females had similar survival rates, Duvuvuei et al. (2017) reported adult translocated females were more likely to raise a brood in their first year in the release area. Thus, managers should consider translocating a higher ratio of adult to yearling females in future translocation efforts to see a more immediate effect on population growth in the release area. Although the translocated birds were genetically similar to the resident birds (Breidinger et al. 2013), and exhibited similar behavior patterns, the low overall vital rates for both groups suggested that managers may need to fully consider the potential interaction of vegetation structure, seasonal habitat juxtaposition, and their potential relationship to predation when planning future translocations to augment isolated and remote sage-grouse populations that occupy space limited and fragmented habitats (Duvuvuei et al. 2017)

In recent years, 10 of the 11 Utah SGMAs have shown an upward trends in the number of greater sage-grouse males counted on leks. The Sheeprock SGMA has been the notable the exception. This SGMA is located in central Utah and is comprised of 611,129 acres in Tooele and Juab Counties. Key threats to sage-grouse identified by the West Desert Adaptive Resources Management Local Working Group (WDARM) include wildfire, invasive species (annual grasses and forbs), potential loss of riparian or mesic areas, predation, habitat fragmentation, dispersed recreation, and conifer encroachment. To mitigate these threats, WDARM has implemented an aggressive habitat and predation management effort that has been augmented by translocations.

From 2016 to 2018, the UDWR, in partnership with USU, has translocated 120 birds (90 females and 30 males) from the Parker Mountain and Box Elder SGMAs to the Sheeprock SGMA to reverse the population decline in that area (Chelak and Messmer 2017, Chelak and Messmer 2018). We are monitoring translocated and resident sage-grouse to determine how they respond to habitat and predation management. We are also evaluating if habitat selection and vital rates differ for translocated and resident sage-grouse. In addition, we are studying off-highway vehicle (OHV) use patterns of recreationists in the Sheeprock to learn if current use is impacting sage-grouse habitat-use and are also surveying OHV users to determine their specific recreation needs. In 2018, we confirmed 17 nest initiations of which 14 hatched. The lek counts have increased 200% form a low of 19 males to over 60.

All translocations in Utah appear to be successful except for the San Juan County translocation where greater sage-grouse were moved into Gunnison sage-grouse habitats. Generally, it appears to take 3 years after the initial reintroductions to see a population response in terms of increased annual lek counts. This is likely because the birds often do not demonstrate similar survival and nesting success as the resident birds, and thus significantly contribute to annual production, until they make it through their first year (Duvuvuei et al. 2017).

The Strawberry Valley SGMA translocated birds have provided the best information regarding the effect of sage-grouse translocations on population genetics. This SGMA population declined from >3,000 individuals in the 1930s to ~ 150 in 1998 creating a severe genetic bottleneck. Following the translocations, BYU researchers reported significant increases in the genetic diversity of the population. This research demonstrated that translocations of sage-grouse were effective at increasing both population size and genetic diversity.

Genetic Connectivity

Because of concerns regarding the potential for increased energy development to further fragment sagebrush habitat, thus isolating sage-grouse populations and resulting, in genetic drift, inbreeding, local extinction, or rapid divergence (USFWS 2010), Breidinger et al. (2013) conducted a genetic survey of 3 remote sage-grouse populations in northeastern Utah to assess mitochondrial diversity relative to other portions of the species' range. They did not detect any unusual haplotype compositions in these populations. However, haplotype composition of the Anthro Mountain population and Strawberry Valley SGMA reference populations differed from haplotype compositions of other northeastern Utah populations. These populations are spatially separated by Desolation Canyon of the Green River. This canyon constitutes a geographic barrier to gene flow in this area, given low population densities and reduced dispersal potentials. This potential barrier will be an important consideration in future conservation efforts such as translocations. The halotype composition of the Anthro Mountain and Strawberry Valley reference populations have subsequently been altered by translocations subsequent to our sampling effort (Gruber 2012, Baxter et al. 2013).

The mitochondrial (Breidinger et al. 2013) and nuclear (Oyler-McCance 2005) data confirm that there is restricted gene flow between Utah populations west of the Green River and other adjacent populations to the north and east. State biologists have corroborated the results of these research projects using seasonal movement data of radio-collared sage-grouse.

Translocations have been used as an effective tool to reverse population declines of sage-grouse in Utah. However, Utah's successful sage-grouse translocations have complicated range-wide analyses that are currently underway to better understand the genetic connectivity of the species across its range (Cross et al. 2018, Row et al. 2018). These range-wide efforts have been driven by a need to better understand how sage-grouse populations are genetically connected both within and across state boundaries so that managers can identify and subsequently conserve critical areas that serve as hubs of genetic exchange between populations. Utah areas that were highlighted by genetic studies as key for facilitating gene flow between populations might actually be artifacts of our historical translocations. Whether these areas are hubs for genetic exchange or a translocation artifact is a question for future research. Despite this, the science has confirmed that sage-grouse translocations have been an important component of Utah's species conservation strategy.

Predation Management

Predation was identified as a population threat in several SGMAs (Messmer et al. 2008). This threat has primarily been associated with increased populations of corvids (primarily ravens) and emergence of non-native canids (Baxter et al. 2007, Baxter et al. 2013, Robinson and Messmer 2013). While predator control has not been recognized as a long-term solution to a general rangewide decline in populations of greater sage-grouse, it may be an effective tool to increase survival of specific populations (USFWS 2010, Hagen 2011, Baxter et al. 2013).

Baxter et al. (2013) studied the survival rates of sage-grouse that had been translocated to the Strawberry Valley SGMA over a 13 year period. Their objectives were to estimate seasonal and annual survival rates for resident and translocated sage-grouse and identify environmental and behavioral factors associated with survival to include mammalian predator control. They captured and radio-collared 535 individual sage-grouse (male and female, resident and translocated). Their top model of survival, which accounted for 22% of the AIC*c* weight, included 3 seasons that varied by year where rates were influenced by residency, sex, and whether a female initiated a nest. A group-level covariate for the number of canids killed each year was supported as this variable improved model fit. Annual estimates of survival for females ranged between 28% and 84% depending on year and translocation source. Survival was consistently highest during the fall–winter months with a mean monthly survival rate of 0.97 (95% CI = 0.96–0.98). They suggested managers consider enhancing nesting habitat, translocating sage-grouse, and controlling predators to improve survival rates of sage-grouse (Baxter et al. 2007, Baxter et al. 2013).

Predation is affected by habitat quality, particularly in areas where an interface exists between human disturbance and the remaining habitat (Utah Plan 2013). Many of Utah's sage-grouse populations inhabit naturally-fragmented habitats. Robinson and Messmer (2013) studied sage-grouse populations that inhabit the Sheeprock and Ibaph SGMAs in Utah's West Desert. These areas are geographically separated by the Great Salt Lake. Livestock grazing by domestic cattle was the dominate land use, and mammalian predator control for livestock protection was conducted in both SGMAs. However, corvid control was conducted only in the Sheeprock SGMA. During the study, we also documented 6 new leks that had not been previously surveyed.

Habitat structure was similar at brood-rearing and random sites for both SGMAs. They also reported higher nest and brood success and the ratio of chicks per successful brood for both populations in 2005 than 2006. Spring precipitation in 2005 was twice the 30-year average following a 5 year drought. However, chick recruitment estimates for both populations regardless of year were lower than reported in the published literature. Adult sage-grouse survival rate estimates in Sheeprock and Ibaph SGMAs were lower and higher, respectively, than published reports indicated. They believed these observations reflected difference in meso-predators communities.

Habitat Management, Arthropods, and Sage-grouse Production

Arthropods are an important component of early brood-rearing habitat (Patterson 1952). Ants (*Hymenoptera*) and beetles (*Coleoptera*) are often the most important groups of arthropods eaten by young sage-grouse (Johnson and Boyce 1990, Gregg et al. 1997, Gregg 2006). Braun et al. (1977) suggested that low-quality early brood-rearing habitat was related to declines in sage-grouse population recruitment. Thompson et al. (2006) found sage-grouse productivity was positively associated with arthropods (medium-sized *Hymenoptera* and *Coleoptera*) and herbaceous components of sagebrush habitats. Insect abundance may be related to plant diversity within sagebrush systems (especially intact sagebrush communities) but may be more highly associated with annual productivity (moisture dependent) within specific habitats (Wenninger and Inouye 2008). However, the direct relationship between insect availability and sage-grouse chick survival in a natural setting is poorly understood.

Robinson and Messmer (2013) reported that increased precipitation in 2005 in the Sheeprock and Ibaph SGMAs in Utah's West Desert contributed to the subsequent increase in forb production. They hypothesized that increased forb production translated into an increase in number and volume of arthropods collected in 2005 vs 2006. During both years of their study, the numbers and volumes of arthropods collected were also greater at brood than in random sites. Potts (1986) and Drut et al. (1994) also reported an increase in arthropod abundance with forb cover. This increase in forbs and arthropods may have contributed to the higher number of chicks per successful brood in 2005, compared to 2006 (Robinson and Messmer 2013).

Although Dahlgren et al. (2010b) reported no direct relationship between arthropods and vegetation measurements, they suggested that arthropod abundance in the immediate vicinity of broods may have influenced chick survival during the early brood-rearing period for sage-grouse inhabiting the Parker Mountain SGMA. This observation was consistent with findings for captive reared sage-grouse chicks (Johnson and Boyce 1990). Fischer et al. (1996) also found that sage-grouse broods selected specific habitat with higher abundance of *Hymenoptera* than random sites.

Sage-grouse, Livestock Grazing, and Sagebrush Treatments

Conservation of sagebrush communities remains is one of the most difficult and pressing concerns in western North America (Connelly et al. 2011c). Many of these communities are grazed by domestic livestock. Cattle grazing occurs on 87% of occupied sage-grouse range, of which 70% is managed by the BLM and USFS (Knick et al. 2011). Compared to other anthropogenic activities the impacts of livestock grazing are more diffuse across the landscape (Knick et al. 2011, Boyd et al. 2014).

The USFWS (2015) identified improper livestock grazing as a potential local conservation threat for sage-grouse because of reported negative impacts associated with reductions of herbaceous cover required for nest concealment and brood nutrition (Gregg et al. 1994, Schroeder and Baydack 2001, Holloran et al. 2005, Hagen 2011, Dahlgren et al. 2015b). However, Smith et al. (2018) reported that the methods used to sample herbaceous cover at sage-grouse nest sites, particularly grass height, were biased. This bias may have contributed to inappropriate BLM and USFS management recommendations regarding the role of grass stubble height and livestock grazing to sage-grouse nest fate. While research reported in peer-reviewed literature demonstrates the potential for negative impacts of sagebrush reduction treatments to increase livestock forage on sage-grouse habitat (Beck and Mitchell 2000), few studies have linked livestock grazing at the landscape level to vital rates for ground-nesting tetraonids such as the sage-grouse (Dettenmaier et al. 2017).

The implementation of management experiments of sufficient scale to evaluate sage-grouse responses to range management practices remains problematic. However, long-term case studies across large landscapes can provide important insights regarding sage-grouse responses to livestock grazing and related range management practices. Dahlgren et al. (2015b) analyzed 24 years of sage-grouse population data collected across 3 large landscapes in northern Utah and southwestern Wyoming to assess sage-grouse responses to corresponding land management in the Rich SGMA. During this period sage-grouse populations on Deseret Land and Livestock (DLL), a privately-owned ranch, increased compared to surrounding populations that inhabited BLM allotments as small scale sagebrush removal treatments (< 200 ha) were being conducted within a prescriptive grazing management framework (Danvir et al. 2005). The increased sage-grouse populations were maintained for nearly 15 years where after they declined to approximate levels reported in surrounding populations. The declines were attributed to prolonged, adverse winter weather conditions accompanied increased snow accumulations.

The authors attributed the DLL sage-grouse population increases to the small-scale sagebrush treatments which translated into larger broods than recorded on adjacent BLM grazing allotments. However, the small annual reductions in sagebrush may have culminated in reduced availability of sagebrush winter cover. During the winter sage-grouse use sagebrush for both food and cover, with specific use areas selected based on sagebrush type, nutrition, and availability of sagebrush above the snow (Schroeder et al. 1999, Remington and Braun 1985, Thacker et al. 2012, Frye et al. 2013). This reduced availability of winter habitat coupled with an extreme winter (e.g., 2010-2011), where cold wet conditions continue into the nesting period, may have resulted in decreased survival of adult sage-grouse and possibly nest success contributing to the corresponding decreases in lek counts over subsequent years (Moynahan et al. 2006, Anthony and Willis 2010). This case study highlights the importance of maintaining sagebrush habitats with adequate amounts of tall sagebrush for sage-grouse to use during extreme winters and nesting periods and the role of monitoring sage-grouse populations using lek and broods counts and hunter surveys to determine their response to management (Dahlgren et al. 2006, Dahlgren et al. 2010a, Dahlgren et al. 2015b, Guttery et al. 2015).

In 2011, USU initiated research on DLL and adjacent BLM and USFS livestock grazing allotments to determine if sage-grouse vital rates (i.e., nest and brood success and juvenile and adult survival) differed by study area, and if any of the observed differences were related to vegetation composition and structure (Dettenmaier and Messmer 2013, 2014, 2016).

The study sites are located in Rich County, in northeastern Utah and constitutes the southwestern portion of the Wyoming Basin Sage-grouse Management Zone II (Knick and Connelly 2011).

The DLL study area consists of 80,600 ha of private lands and 6,300 ha of federal BLM lands located in the lower elevations. The DLL has been managed as a cohesive unit under rest and deferred-rotation prescribed grazing practices since 1979. The federal allotments known as the Three Creeks (3C) consists of a 56,900 ha collection of 29 individual BLM and USFS grazing allotments and private lands managed under season-long grazing practices (see Payne 2011 for complete description of the grazing practices).

The research incorporated a Before-After Control-Impact study design where pre-treatment data collected on DLL and 3C were to be compared to data collected on the 3C allotment after it was consolidated under a HILF rest and deferred-rotation grazing system (Payne 2011). However, the 3C consolidation was delayed until the BLM National Environmental Policy Act (NEPA) process requirement could be met. The consolidation decision was signed on April 24, 2018, and it will be fully implemented in 2020.

Given that it may take several years for a sage-grouse population to respond to management actions (Dahlgren et al. 2006, Dahlgren et al. 2016a), the NEPA delay provided the partners with insights regarding the underlying mechanisms – why and how – livestock grazing may affect sage-grouse populations. Sage-grouse nest survival was higher on DLL (33%) than the 3C (17%). Our habitat analyses also revealed that four sage-grouse habitat metrics (i.e., vegetation concealment, sagebrush, perennial bunchgrass, and forb height) were greater in nesting habitats on DLL than 3C (Wallestad and Pyrah 1974, Connelly et al. 1991, Gregg et al. 1994, Coates and Delehanty 2010, Kaczor et al. 2011, Knick and Connelly 2011, Doherty et al. 2014, Dinkins et al. 2016). We detected differences in these vegetation parameters despite disparities in precipitation and stocking rates between study areas. The DLL study area received 7 cm (3 inches) less annual precipitation on average and had stocking rates ~50% greater (0.76 vs. 0.46 AUM · ha-1) than 3C.

However, our best models supported lower rabbitbrush (*Ericameria nauseosa*) cover and higher estimates of the standardized precipitation-evapotranspiration index (SPEI; Vicente-Serrano et al. 2010) as driving nest survival rates. The SPEI is a climatic drought index that combines precipitation and temperature. A higher SPEI index typically equates to greater water stress. The DLL study area exhibited less rabbitbrush cover, is on average warmer, and receives less rainfall than 3C.

Rabbitbrush occurs more frequently on degraded rangelands (Young and Evans 1974, Whisenant 1987). Beck et al. (2009) reported that increased rabbitbrush cover persisted in Wyoming sagebrush areas that had been burned 14 years previous to their study. Increased rabbitbrush has been reported in historical vegetation treatments targeted at sagebrush cover reduction within our study area (Danvir et al. 2005, Stringham 2010, Dahlgren et al. 2015b). Thus, historic sagebrush treatments and land uses coupled with other biotic or abiotic legacy effects (Ripplinger et al. 2015) may have had a greater effect on nest survival than actual grazing practices.

We included the SPEI index in our models based on the findings of Hansen et al. (2016). In their study of sage-grouse nest survival in a Wyoming population, they reported a negative correlation between the lagged SPEI index and sage-grouse nest daily survival rate (DSR) estimates. Their findings appear counterintuitive as they indicated that more xeric conditions have a positive effect on DSR. Our models also supported SPEI as a predictor of higher DSR for our populations and demonstrated the same negative relationship between nest survival and areas with higher water balances.

Studies have reported increased nest depredation for sage-grouse and other gallinaceous birds following precipitation events (Herman-Brunson et al. 2009, Webb et al. 2012). This phenomenon, referred to as the moisture-facilitated nest depredation hypothesis, has also been linked to observed increases in predation of sage-grouse chicks (Guttery et al. 2013). Our measures of SPEI represented means across a 10-month period (Sep-Jun) to encompass the most influential period of precipitation on sage-grouse habitat (Hansen et al. 2016) and were not specific to the nesting period.

Our results demonstrated the potential for grazing management practices implemented in xeric sagebrush rangeland areas to benefit sage-grouse. However, we also identified the complexities in conducting research to answer fundamental questions regarding the role of livestock grazing in managing xeric sagebrush rangeland landscapes for multiple purposes. Grazing studies implemented to evaluate the effects on wildlife and their habitats, must account for these land use legacy effects when making comparisons between studies and drawing conclusions (Ripplinger et al. 2015, Dettenmaier et al. 2017). This is particularly relevant in cold, arid systems, as shorter growing seasons and chronic water limitation increase the time required for plant communities to recover from disturbance. Ripplinger et al. (2015) suggested that the legacy effects from historical land uses and management actions in our study area may persist well beyond 50 years.

Sage-grouse and Grazing – What we know and don't know

The seasonal flush of nutrient rich vegetation that tracks the temperature-moisture optimum through time has become known as the "green wave" (van der Graaf et al. 2006, van Wijk et al. 2011). Merkle et al. (2016) found that five ungulate species indigenous to the Mountain West capitalized on this green wave by selecting patches that had high nutrient content relative to availability. Similarly, mule deer (*Odocoileus hemionus*; Stoner et al. 2016) and sage-grouse (Stoner et al. in prep.) synchronize birthing and nest initiation to match the period between the start and peak of the growing season, thereby optimizing the balance between forage predictability and quality.

The spring migration of white-fronted geese (*Anser albifrons albifons*) and bar-head geese (*A. indicus*) is also closely tied to nutrient quality of vegetation (van Wijk et al. 2011). Shariatinajafabadi et al. (2014) followed marked barnacle geese (*Branta leucopsis*) on their spring migration and found that migratory movements were correlated to forage quality. Dahlgren et al. (2016b) reported that sage-grouse broods tracked the elevational wave of succulent vegetation to minimize variation in forage quality through the brood-rearing season.

Collectively, these studies suggest that mammals and birds in seasonal environments are attuned to variation in forage quality. Herbaceous vegetation is most palatable during early growth phases between the spring flush and the peak of the growing season, becoming progressively less digestible as plants desiccate. One potential effect of herbivory by large-bodied ruminants such as cattle ("roughage eaters" Hofman 1989) is to prevent maturation of plant tissues through grazing (Turner et al. 1993). Although controversial, the literature suggests that stimulation of compensatory growth in plants is a function of the duration and intensity of grazing, given inherent edaphic and climatic conditions (Turner et al. 1993).

Holechek et al. (1982) reviewed grazing systems and concluded that wildlife could benefit from livestock grazing if adequate biomass for plant recovery is left ungrazed. The hypothesis that surgical use of livestock grazing can stimulate production and extend nutritional value of grasses has been proposed by wildlife managers and livestock producers, but remains largely untested.

To open up mature dense stands of sagebrush to promote forb and grass production in high elevation grasslands, DLL combined sagebrush treatments with a rest and deferred-rotation grazing system (Dahlgren et al. 2015b). Nesting sage-grouse depend on forbs and insects during the incubation period, and newly hatched chicks are almost entirely dependent on these same food items until ~ 6 weeks of age (Dahlgren et al. 2015a). Preliminary data suggest that the increase in forbs and grasses following range treatments provided greater forage for livestock, but may have also improved sage-grouse brooding habitat (Danvir et al. 2005). Elsewhere, Morris and Thompson (1998) noted that invertebrate densities were higher in grazed grasslands. In southcentral Utah, Dahlgren (2009) reported that forb cover could be increased by late season grazing resulting in increased use by sage-grouse. Thus, what remains to be determined, is whether the intensity and duration of grazing has facilitative or competitive relationships with sage-grouse (Monroe et al. 2017), especially during the critical brood rearing life phase.

In 2015, we began deploying GPS rump-mounted radio-transmitters on birds captured on DLL and 3C in 2015 to better describe the range of sage-grouse behavioral responses to the presence of livestock and grazing. In addition to learning more about why sage-grouse nest success is better on DLL than 3C, we want to know if brood-rearing habitat-use patterns and vital rates differ under prescribed rotational and season-long grazing practices. If so, the question becomes, can the observed differences be explained by avoidance behavior or differences in vegetation composition and structure that are the result of livestock grazing? Specifically, we want to test the hypothesis that the green wave could be facilitated, enhanced, or prolonged by managing livestock grazing. The hypothesis will be validated if radio-marked sage-grouse that select for pastures where livestock have removed standing residual vegetation creating a "green wave" on DLL are more successful than those that nest on 3C.

At the scale of the pasture, we will determine preferred habitat characteristics by measuring vegetation cover and structure at sage-grouse locations. These data will be compiled using standard techniques and compared with paired random sites (Daubenmire 1959, Robel et al, 1970, Connelly et al. 2003). To evaluate overlap in habitat selection between sage-grouse and cattle (*Bos taurus*) at the scale of the allotment, we will obtain six daily locations from GPS and 2-3 weekly locations for VHF radio-marked sage-grouse. These data will be compared to livestock location data collected from 46 GPS-collars deployed on cattle in DLL (23) and 3C (23). Cattle GPS data will be used to model the distribution of livestock and identify high-use habitats. Lastly, we will use GPS and VHF location data to create spatially-explicit models of sage-grouse vital rates, seasonal movements, and habitat use patterns relative to vegetation metrics and livestock habitat-use patterns on each site.

Primary production and plant phenological data. Both sage-grouse and cattle consume grasses and forbs during spring (Dahlgren et al. 2015a), but the question remains as to how grazing affects sage-grouse vital rates and habitat selection. Our working hypothesis is that the effects are contingent on the prevailing grazing regime. Evaluation of this hypothesis depends on the ability to monitor phenological phases of herbaceous vegetation across large extents. Here we propose to measure plant phenology at the scale of the pasture using the Normalized Difference Vegetation Index (NDVI; Tucker 1979). NDVI is a satellite-derived index of photosynthetic biomass, typically scaled from 0-1. It has been used to map plant phenology across climatic regimes (Stoner et al. 2016), track avian migration (van der Graaf et al. 2006), and to index forage quality for ungulates (Ryan et al. 2012, Garroutte et al. 2016). Indeed, recent research completed at USU confirmed that variation in sage-grouse nest initiation in Utah is explained by phenological events measured with NDVI (Stoner et al. in prep.).

To quantify differences in seasonal productivity between sites, we will use MODIS 500-m daily resolution NDVI (Stoner et al. 2016, Nagol et al. 2017). Plant phenology is rapid in systems with short growing seasons (study site mean = 50 days), and daily measures capture variation that is lost when using 8 or 16-day composites. From these data we calculated nine metrics to characterize the ‘green wave’ in response to livestock grazing. These include the start-of growing season (date and NDVI value at maximum daily rate-of-change), peak of the growing season (date and value of annual maximum NDVI), end of the growing season (date and NDVI value at maximum negative daily rate-of-change), the maximum rate-of-change during the start and end of the growing season (ΔNDVI/unit-time), and time-integrated NDVI (total season productivity).

We will use these data to study differences in green-up on each study area relative to grazing management and annual climatic conditions. Changes in the study area NDVI will be correlated with livestock stocking rates, frequency of use, rest periods, temperature, precipitation, sage-grouse nest initiation rates, nest hatch dates, brood movements, and brood success rates. We will then evaluate the relationship between observed differences in NDVI on each study area to sage-grouse vital rates and daily/seasonal movements. Development and provision of these phenological metrics began with a NASA grant to USU (Mattson et al. 2010) and has been maintained through a multi-year collaboration with the Utah BLM to develop statewide monitoring program for sage-grouse using NDVI and other satellite-derived environmental variables (Edwards et al. 2016).

Because federal grazing policies can have disproportionate impacts on rural economies (Messmer 2013), the research suggests a possible working solution to the problem of competing land uses on western ranges. If we can parameterize sage-grouse vital rates under different grazing scenarios, this may have implications for grazing policy west-wide. Completion of this project will provide definitive information regarding sage-grouse vital rates and habitat selection with respect to the presence of cattle and the effects of livestock grazing on vegetation composition and structure.

Wildfires: Using Green Stripping to Protect Sage-grouse Habitats

In the Great Basin Region of the western United States cheatgrass (*Bromus tectorum*) and other invasive vegetation species have increased the frequency of wildfires in sagebrush ecosystems exacerbating sage-grouse habitat loss. Habitat loss due to fire and replacement of (burned) native vegetation by invasive plants is the single greatest threat to sage-grouse that inhabit SGMA in Utah's Great Basin region (Messmer et al. 2008, Utah Plan 2013, PLPCO 2018). While wildfires may occur, the subsequent response to fire can have a large impact on the severity of the impacts and subsequently rehabilitation or restoration efforts (Pyke et al. 2011).

Immediate, proactive means to reduce or eliminate the spread of invasive species, particularly cheatgrass, after a wildfire, is a high priority in the Utah Plan (2013). Managers have used greenstrip firebreaks that have been planted with fire-retardant vegetation such as forage kochia (*Bassia prostrata*) to mitigate wildfire risks. However, no information has been published regarding sage-grouse potential use of kochia greenstrips as cover or forage.

Graham (2013) conducted lek surveys, measured vegetation attributes, and monitored 53 radiocollared sage-grouse from 2010-2012 on a 4,800 ha seasonal range (i.e., Badger Flat) that was greenstripped during the fall and winter of 2010 in northwestern Box Elder County, Utah, to evaluate sage-grouse potential responses in a highly fragmented landscape to the firebreak. She also described the potential effects of linear disturbances to sage-grouse nest success and mortalities. To determine sage-grouse use of kochia as winter forage they collected kochia samples and sage-grouse fecal pellets from the Badger Flat study area and the Tabby Wildlife Management Area (WMA) in north central Utah which had been greenstripped in 2004. They used microhistological techniques to analyze the relative presence of kochia and sagebrush in sage-grouse fecal pellets.

Shrub canopy cover and densities were reduced during the Badger Flat firebreak seedbed preparation. Two years post-treatment, the frequency of invasive species between treated and untreated sites were similar. Sage-grouse preferred untreated areas and used the greenstripped areas primarily as an extension of an existing lek. The number of males counted on the Badger Flat lek were stable from 2010-2014. Kochia was established and remained confined to the greenstrip seedbed. Sagebrush was the dominant plant material in the fecal pellets sampled. Pellets collected from Tabby WMA contained a greater percentage of kochia (2.7%) than pellets from Badger Flat (0.7%). This difference may be an artifact of stand longevity and thus kochia availability in the greenstrips.

Sage-grouse nests in the Badger Flat study area that were located closer to roads had higher predation rates. Also, most adult and juvenile bird mortalities (86%) were located within 450 m of a road. Road type did not affect mortality rates. These observations suggest that the greenstrip seedbed preparation, which reduces or further fragments existing sagebrush cover, may also increase sage-grouse predation risks. To mitigate these risks, managers should place greenstrip firebreaks adjacent to existing roads or disturbances. The timeframe of the study precluded an assessment of firebreak effectiveness. This information is being used to plan and implement future greenstrips in high wildfire risk areas of the Utah's SGMAs in the Great Basin.

Tall Structures and Sage-grouse

In the western U.S., electric power transmission and distribution lines (power lines) occur in sagebrush landscapes within the range of the sage-grouse. In 2005, WAFWA convened the Greater Sage-grouse Range-wide Issues Forum to engage stakeholders in the identification of strategies to address species conservation issues identified by Connelly et al. (2004). One of the issues identified by forum participants as a conservation concern was the effect of tall structures on sage-grouse. Tall structures were defined as power lines, communication towers, wind turbines, and other installations excluding livestock fencing (Stiver et al. 2006).

Connelly et al. (2004) suggested that tall structures associated with energy transmission and development (e.g. power lines, communication towers, wind turbines, and other installations) and associated operation and maintenance activities in sage-grouse habitat may impact the species through habitat avoidance and increased predation rates. The USFWS has recommended the use of various buffer distances as best management practices (BMPs) between tall structures and occupied sage-grouse habitats to mitigate the potential impacts (USFWS 2003). The sage-grouse BMPs were largely lek-centric.

In 2010 the Utah Wildlife-in-Need Foundation (UWIN) in cooperation with Rocky Mountain Power/PacifiCorp and the UDWR facilitated a public input process (i.e., focus group workshops) which included a synthesis of existing literature and contemporary federal, provincial and state tall structure siting policies in sage-grouse habitats. Focus-group participants also reviewed published information to evaluate the scientific basis for the potential impacts of tall structures on sage-grouse. The specific products published subsequent to the review included: 1) literature synthesis of existing information (published and unpublished) regarding the predicted and potential effects of tall structures on sage-grouse, 2) summary of contemporary policies regarding siting and other requirements to mitigate potential effects, 3) identification of knowledge gaps, and 4) prioritization of research needs regarding tall structures effects on sage-grouse conservation.

Focus group participants expressed concerns that the science upon which tall structure siting decisions were based was lacking. They concluded viable estimates of sage-grouse mortality resulting from power line collisions and predation were lacking. They believed a better understanding of the extent and causal factor of mortality attributed to tall structures would help state and federal agencies refine siting criteria and develop BMPs and other conservation measures to mitigate potential impacts (UWIN 2010). They also expressed concern that no research had been conducted to evaluate the effectiveness of current BMPs or buffers. They concurred that for effective BMPs to be developed, better science-based information will be needed regarding the effects of tall structures on sage-grouse reproductive success, recruitment, and survival at the population level (UWIN 2010). The USFWS (2010) acknowledged similar concerns in the sage-grouse status review.

At the time of the UWIN review there were no peer-reviewed, experimental studies reported in the scientific literature that specifically documented increased avoidance or predation on sage-grouse because of the construction, operation, and maintenance of tall structures (UWIN 2010).

A review of the scientific literature regarding sage-grouse since completion of the 2010 review produced no new published information, but recent unpublished reports have begun to address the issue (Messmer et al. 2013).

Because the science was lacking, “effective” temporal and spatial setbacks and buffers stipulations may differ by governmental agency. Manier et al. (2014) could not identify a consistent source or scientific basis for recommended BMP buffer zones.

To adequately assess the impacts of tall structures on sage-grouse, conditions before and after the activity in question must be compared (UWIN 2011). Focus groups participants identified specific questions regarding the relationship between sage-grouse and tall structures for additional study (Messmer et al. 2013). These questions included: 1) Do sage-grouse avoid tall structures and in particular what are they avoiding, 2) If sage-grouse avoid tall structures, what are the individual and population impacts and when would the impacts be manifested, 3) Will the effects be permanent, 4) Will the effects be limited to the area of disturbance, 5) What measures (BMPs) can be implemented to mitigate impacts and alleviate the negative impacts, and, 6) Will these BMPs be universally effective?

To better address stakeholder concerns, UWIN facilitated a consortium process in 2011 that engaged sage-grouse biologists, statisticians, and managers from agencies, academia, industry, and others in a process to develop a standardized research protocol for assessing the potential impacts of tall structures on sage-grouse. The protocol was subsequently endorsed by WAFWA Directors in 2011 as the standard for assessing the potential impacts of tall structures on sage-grouse (UWIN 2011).

Sage-grouse and Power Lines in Utah

Most existing utility corridors (pipelines, roads, major overhead electrical transmission lines) within Utah SGMAs are well-defined (PLPCO 2018). To address the concerns identified in the UWIN (2010, 2011) reports, we evaluated the effects of power lines on sage-grouse breeding ecology within Utah, portions of southeastern Idaho, and southwestern Wyoming from 1998-2013. Our paper reporting our results is currently under review for publication consideration.

To conduct our research, we acquired geo-referenced linear electric power distribution and transmission line (power line) locations directly from the electric utility companies PacifiCorp, Garkane Energy, Idaho Power, and Raft River Rural Electric Cooperative. These data were provided through confidentiality agreements specifically for this study. Each line in the power line database contained attributes indicating its status as a distribution line (<46 kV) or as a transmission line (>=46 kV); in total the data represent 16,493 km of transmission lines and 20,061 km of distribution lines throughout Utah, southern Idaho, and southwestern Wyoming.

Transmission lines, which deliver electric power from the source of generation to substations, were supported by taller structures (height: 18 – 40 m). These lines included linear structures that were located at lower elevations and often bisected sage-grouse habitat. In contrast, distribution lines are supported by shorter structures (height: ~ 10 m) that deliver electric power to customers (e.g., homes, businesses). Distribution lines were interspersed throughout sage-grouse habitat. All power lines evaluated were in service prior to 1998.

We restricted our analysis to power lines located in occupied sage-grouse habitat and excluded all lines that were not within 10 km of a sage-grouse lek, nest or brood location. We selected this buffer distance because it accommodated the average maximum movement distances documented for sage-grouse broods from nest sites in Utah (8.45 km) and the upper recommended conservation buffer zones reported in the literature for tall structures and linear features (8.0 km; Manier et al. 2014). Consequently, only 10% of transmission lines and 7% of distribution lines within the study area were within 10 km of these sage-grouse use habitats. This resulted in a reduced dataset of 1,698 km and 1,496 km of electric power transmission and distribution lines, and a sample of 425 nests and 2,514 unique brood locations obtained from 239 broods.

Overall, power lines negatively affected lek trends and persistence in Utah up to a distance of 2.7 and 2.8 km, respectively. Female sage-grouse were displaced by transmission lines during the nesting and brooding seasons at distances up to 1.1 and 0.8 km, respectively. Nest and brood success were also negatively affected by transmission lines up to distances of 2.6 and 1.1 km, respectively. Distribution lines did not affect sage-grouse habitat selection or reproductive fitness. Our analyses demonstrated the value of habitat quality in mitigating potential power line impacts. Conservation planners can minimize the effects of new transmission power lines by placing them in existing anthropogenic corridors and/or incorporating buffers within 2.8 km from active leks. Given the uncertainty we observed in our analyses regarding sage-grouse response to distribution lines coupled with their necessary role in providing electric power service directly to individual consumers, we recommended that buffers for these power lines be considered on a case-by-case basis. Micrositing to avoid important habitats and habitat reclamation may play important roles in reducing impacts of new power line construction.

Little information is available regarding sage-grouse responses to power lines placed in winter habitat. Hansen et al. (2016) evaluated sage-grouse habitat use before and after construction of the Sigurd-Red Butte (SRB) 345-kilovolt (kV) transmission line in winter habitat. The SRB line was constructed in the fall of 2014, and was sited parallel to a pre-existing 500-kV transmission line through salt-desert habitat on the western edge of the Bald Hills Sage-Grouse Management Area in southern Utah. They deployed GPS transmitters on 2 female and 16 male sage-grouse from 2014–2016 and compared collected locations to data independently acquired in the winter of 2011–2012 to determine if the construction of the SRB transmission line altered sage-grouse winter habitat use. Using the 2014–2016 data, they developed a resource selection function model to quantify the influence of transmission line presence on sage-grouse movements while accounting for low quality habitat (salt-desert) near the transmission line. Post-construction data were compared to the 2011–2012 data to evaluate whether RSF-predicted changes in relative probability of use were reflected in actual shifts in habitat use before and after construction. They did not detect increased avoidance by sage-grouse when comparing spatial distributions between winters. Their results suggests that immediate negative effects of new transmission line construction can be eliminated by implementing best management practices such as co-locating the transmission line in a preexisting energy corridor where impacts on habitat selection have already occurred, and siting the line in poor-quality habitat that does not fragment existing habitat.

SAGE-GROUSE HABITAT MONITERING AND ASSESSMENT

Utah Sage-grouse Habitat Guidelines

Connelly et al. (2000) published some broad sage-grouse habitat guidelines. These guidelines were developed through a synthesis of the peer-reviewed literature, and student theses, and dissertations (Connelly et al. 2000). As such, the guidelines reflected research that had been largely completed in the northern range of the species and lacked spatial representation of sage-grouse populations in the southern Great Basin and desert shrub areas within the sage-grouse distribution (Messmer 2013, Dahlgren et al. 2016a). This could be problematic for Utah, in that most of the Utah sage-grouse range falls in desert shrub areas which receive less annual precipitation than the areas that provided the data to develop the original guidelines.

They stated that the guidelines they provided may not be appropriate for universal application to range wide sage-grouse habitats and that, when available, local data should be prioritized, their guidelines were used for conservation planning purposes throughout the range of the species. To correct this problem, we combined habitat vegetation data for female sage-grouse nest and brood locations across the state of Utah from 1998-2013, with spatially continuous vegetation, climatic, and elevation data in a cluster analysis to develop Utah specific habitat guidelines. Using this approach, we identified three distinct clusters of sage-grouse breeding (i.e., nesting and early brood-rearing) and late brood-rearing habitats for the state of Utah. We named these clusters Low, Wasatch, and Parker (Figure 4). For each cluster, we subsequently identified specific vegetation characteristics, or guidelines, which managers can use to assess sage-grouse habitat conditions based on local conditions (Table 1).

We identified substantial discrepancies between our recommended guidelines and those presented in Connelly et al. (2000) that were originally adopted by the BLM in their 2015 resource management and land-use plan sage-grouse amendment (BLM 2015). In general, sage-grouse in Utah selected sites with sparser and lower vegetation conditions than Connelly et al.'s (2000) guidelines would recommend. The discrepancies were greater in the more arid Low cluster than in the higher elevation Wasatch and Parker clusters.

Moreover, Connelly et al. (2000) provided separate recommendations for drier habitats. However, none of the studies they referenced occurred in the sagebrush semi-desert shrublands of the southern Great Basin. Thus, requiring managers to implement sage-grouse habitat standards developed from vegetation communities unlike the semi-desert shrublands of the southern Great Basin will be problematic.

We demonstrated that lower sagebrush cover and shrub height to be more appropriate for the Low and Wasatch clusters for both breeding and late brood-rearing habitats than the federal plans 'desired conditions' and 'standards' would suggest for Utah. The BLM's general sagebrush guidelines for Utah by maintaining lands capable of producing sagebrush, with a minimum of 15% sagebrush canopy cover on average, consistent with site specific conditions. In contrast to the 15% guideline consistently recommended in federal plans, our very low sagebrush cover guideline of ≥ 1% in the arid Low cluster, and of only ≥ 5.4% sagebrush composition of shrub cover in the Wasatch cluster, suggests land management agencies should re-examine sage-grouse habitat standards across Utah.

Connelly et al. (2000) suggested 15-20% sagebrush cover for breeding sage-grouse in both mesic and xeric sites. This was comparable to our recommended breeding habitat guidelines of ≥ 14% sagebrush cover for the Wasatch cluster and ≥ 17% sagebrush cover for the Parker cluster. However, our sagebrush cover guideline for breeding habitat in the Low cluster was only ≥ 7%. In contrast, the USFS recommended sagebrush cover of 15-25% for breeding sage-grouse on USFS lands throughout the Utah.

For breeding sage-grouse, the BLM (2015) adopted a guideline of sagebrush height at 40-80 cm (16-32 inches) in mesic sites and 30-80 cm (12-32 inches) in xeric sites. Our recommendations were similar with respect to our Low cluster, where we recommend shrub heights ≥ 30 cm (12 inches). For the other Utah clusters, our results indicated that shorter shrub heights likely suffice: ≥ 22 cm (9 inches) in Wasatch; and ≥ 14 cm (5.5 inches) in Parker.

Although sage-grouse habitats in Utah were dominated by shrub cover of sagebrush species, other species of shrubs are also important components within these vegetation communities. For example, in the Low cluster shrub cover measured at nest and brood sites, sagebrush was less than half of the composition of all shrub species. Thus, in addition to using habitat categories consistent with Connelly et al. (2000), we provided guidelines for shrub cover and height and percent sagebrush composition of shrub cover.

Similar to the BLM and USFS, we provided specific recommendations for forb and grass cover and height. These parameters were originally one recommendation in Connelly et al. (2000). Forbs and grasses are distinct vegetation types that are measured independently in the field because they respond differently to environmental conditions, and thus can be managed separately. Thus, grass and forb characteristics should have separate recommendations, but for comparison purposes we combined forb and grass values when expedient.

For breeding sage-grouse in arid sites, habitat standards in federal plans were at least 15% combined grass-forb cover; our recommendation for combined grass-forb cover in the more arid Low cluster is ≥ 7%. The grass-forb height standard for breeding habitat was > 18 cm (7 inches) in both arid and mesic sites in federal plans. Our recommended grass height guidelines for breeding sage-grouse ranged from ≥ 9 cm (3.5 inches) in Parker to ≥ 12 cm (4.7 inches) in Wasatch to ≥ 15 cm (6 inches) in the Low cluster. Again, our guidelines differed substantially from the Connelly et al. (2000) guidelines adopted by the federal plans. Connelly et al. (2000) recommended ≥ 25% grass-forb cover in mesic sites for breeding sage-grouse; our results suggested a guideline of grass-forb ≥ 12% in Wasatch and ≥ 5% in Parker.

For brood-rearing sage-grouse Connelly et al. (2000) and the USFS recommended sagebrush canopy cover of 10-25% in both mesic and arid sites; our guidelines for late brood-rearing habitat sagebrush cover range from only ≥ 4% in the arid Low cluster to ≥ 17% in the Wasatch cluster and ≥ 16% in the Parker cluster. Connelly et al.'s (2000) sagebrush height guidelines were 40-80 cm (16-32 inches) for brood-rearing sage-grouse, whereas our guidelines suggest a shrub height of ≥ 20 cm (8 inches) in the Wasatch cluster, ≥ 11 cm (4.3 inches) in the Parker cluster, and ≥ 26 cm (10 inches) in the Low cluster. Connelly et al. (2000) recommended grass-forb cover of ≥ 15% for brood-rearing sage-grouse. Our recommendations are comparable but have slightly lower cover percentages for combined grass and forb cover: ≥ 7% in Low; ≥ 14% in Wasatch; and ≥ 8% in Parker.

We did not provide any recommendations for maximum habitat values. Based on the distribution of data from known nest and brood sites, we did not see any recorded habitat values that were so high they might be considered detrimental to sage-grouse. This does not imply that sagebrush communities are always suitable and beneficial to sage-grouse, even if certain habitat category values (e.g., sagebrush cover and height) may be too high or dense in some areas to provide optimal conditions. A manuscript reporting these results is currently under review.

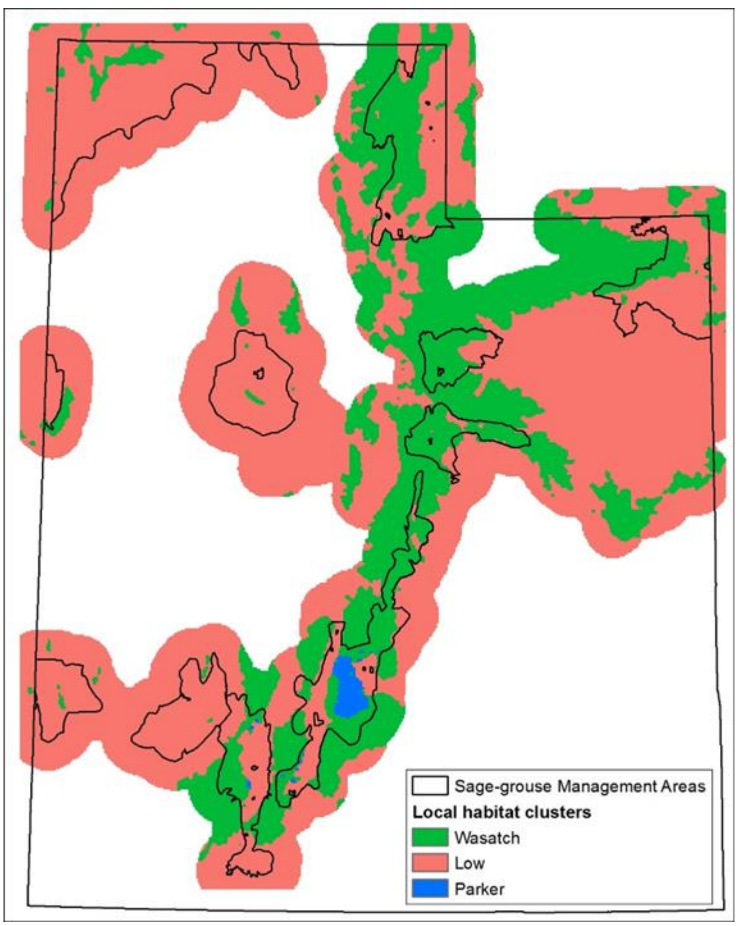


Figure 4. We identified three unique greater sage-grouse (*Centrocercus urophasianus*) habitat clusters for Utah - Low, Wasatch, and Parker.

Table. 1. For each cluster, we identified specific vegetation characteristics, or guidelines, which managers can use to assess sage-grouse habitat conditions based on local conditions. We identified substantial discrepancies between our recommended guidelines and those presented in Connelly et al. (2000) that were originally adopted by the Bureau of Land Management and the US Forest Service in their 2015 resource management and land-use plan sage-grouse amendments. In general, greater sage-grouse in Utah selected sites with sparser and lower vegetation conditions than Connelly et al.'s (2000) guidelines recommended.

	Habitat Cluster	Shrub Cover (%)	Shrub Height (cm)	Sagebrush Composition (%)	Sagebrush Cover (%)	Grass Cover (%)	Grass Height (cm)	Forb Cover (%)	Forb Height (cm)
Breeding	Wasatch	≥ 19	≥ 22	≥ 83	≥ 14	≥ 8	≥ 12	≥ 4	≥ 6
	Low	≥ 17	≥ 30	≥ 36	≥ 7	≥ 5	≥ 15	≥ 2	≥ 6
	Parker	≥ 22	≥ 14	≥ 71	≥ 17	≥ 4	≥ 9	≥ 1	≥ 5
Late Brood-Rearing	Wasatch	≥ 15	≥ 20	≥ 77	≥ 17	≥ 8	≥ 10	≥ 6	≥ 7
	Low	≥ 10	≥ 26	≥ 28	≥ 4	≥ 5	≥ 20	≥ 2	≥ 8
	Parker	≥ 19	≥ 11	≥ 7	≥ 16	≥ 6	≥ 9	≥ 2	≥ 5

Implementing Utah's Habitat Assessment Framework

Sage-grouse conservation and management is inherently complicated and uncertain. Population dynamics can be variable between populations and even year to year within a single population. Understanding how vital rates interact to effect population change and the factors that influence those changes is critical to designing appropriate management objectives. In 2016, USU Extension published a fact sheet to help decision makers create and address management objectives with the best available information and to avoid common pitfalls when it comes to this species (Dahlgren et al. 2016c).

To facilitate sage-grouse management, in 2017 we completed a process to develop better breeding, summer, and winter seasonal habitat maps for sage-grouse in Utah (Figure 5). The process is presented chronologically below, and covers technical modeling steps which included feedback from state biologists and wildlife managers.

Since the early 1990s researchers at USU and BYU have been studying sage-grouse ecology in Utah. The research involved capturing and radio-marking male and female sage-grouse with VHF necklace-style radio-collars and following them throughout the year to monitor their habitat-use patterns and survival. In the case of the females, we were also interested in nest and brood success. To determine habitat selection and if the habitat they were using affected the survival and/or production of radio-marked sage-grouse, the researchers recorded the characteristics of the habitats where the sage-grouse were re-located.

In 2016, USU developed a statewide general sage-grouse habitat map using a database of hundreds of lek locations and more than 20,000 sage-grouse VHF telemetry locations collected statewide. The VHF radio-collars transmit a radio signal that lets field personnel zero in on the location of each bird, but despite providing nearly 20,000 locations over the past 20 years, these VHF transmitters required extensive field work that was often limited to daytime hours, accessible locations, and weather-permitting conditions.

The 2016 map depicted habitat suitability on a scale from 0 to 100 at 1 km spatial resolution, based on comparing environmental (vegetation, topography, soils, climate) and anthropogenic condition (i.e., developed land cover, road density, powerline density) at active lek and VHF sage-grouse use locations versus inactive lek and random background locations statewide. Because multiple telemetry locations were often associated with a single brood-rearing or non-breeding bird, we used the median values of environmental and anthropogenic variables at these telemetry locations in the model.

We used a random forest model to create a draft sage-grouse general habitat map (Breiman 2001). Random forests is a highly accurate non-parametric classification technique that predicts the probability of an outcome (in this case, habitat vs. non-habitat) by averaging the results of many classification trees, each of which was trained on a random subset of the available data. The general habitat map was reclassified into 'habitat' and 'non-habitat' classes such that habitat areas captured 99% of all sage-grouse use locations. These general habitat areas were used to constrain preliminary predictions of seasonal habitats.

Sage-grouse radio-telemetry locations in the USU/BYU database were then classified into three seasonal habitat types based on time of year and type of use. Breeding habitat was defined as areas used by sage-grouse for lekking, nesting, and early brood-rearing, from March 1 – June 14. Summer habitat was defined as areas used by brood-rearing and non-breeding sage-grouse from June 15 – August 31. The June 15 cutoff date between breeding and summer use locations was selected based on the temporal distribution of nesting and brooding use locations (Figure 5). Winter habitat was defined as areas used by non-breeding sage-grouse from November 1 – February 29. As in the general habitat modeling approach, environmental conditions at annual brood-rearing or non-breeding locations associated with the same bird were measured as medians over the multiple locations.

We then modeled seasonal habitats using the same predictors as the general habitat model, with the addition of distance to leks due to its association with breeding habitat. We used a random forest model to estimate the suitability of general habitat areas statewide (from step 1 above) for breeding, summer, and winter use. For each seasonal use class, a suitability threshold was selected such that 85% of all seasonal use locations were captured in the resulting seasonal habitat map. This resulted in models that were neither overly restrictive nor overly liberal. To reduce the 'salt and pepper' effect of isolated or scattered habitat pixels, a 3x3 km smoothing window was applied to each of the seasonal habitat layers, assigning the majority value (habitat or non-habitat) to the center pixel.

In 2017, we presented an overview of the general and seasonal mapping methodology and preliminary maps to UDWR, BLM, and USFS and asked them for their feedback. Using their feedback we made some changes to the seasonal mapping methods. Because the breeding seasonal use model was not picking up areas around all active leks, distance to leks was dropped as a predictor variable from the seasonal habitat random forest model, and a 3 km buffer around all active leks was manually included in the breeding habitat model.

The updated seasonal sage-grouse habitat-use models were then sent back to UDWR biologists for further review. We created an ArcGIS Online webpage to share the models with biologists. The webpage allowed the biologists to provide recommended additions / deletions to areas captured by the models. Accompanying the spatial data was an 8-minute webinar communicating the modelling procedure. The biologists returned updated seasonal use models with their comments, additions, and deletions to USU researchers. Most but not all areas in the state received substantive feedback and comments from UDWR biologists.

We reviewed biologist edits and added/removed areas from the seasonal habitat-use models based on available telemetry data. We subsequently met with UDWR biologists about the areas in question to determine their status. Based input received at this meeting, it was determined that it would be preferable to have the final seasonal habitat products reflect both use and potential suitability, as opposed to only areas of known use. This decision resulted in rejecting some areas flagged for deletion by biologists, as biologist comments indicated they were conceptualizing the map as primarily a use map only. We made a number of small edits to the seasonal use layers, including several edits to include seasonal use locations not captured by preliminary models. Finally, all single, isolated habitat pixels were removed from the map (Figure 5).

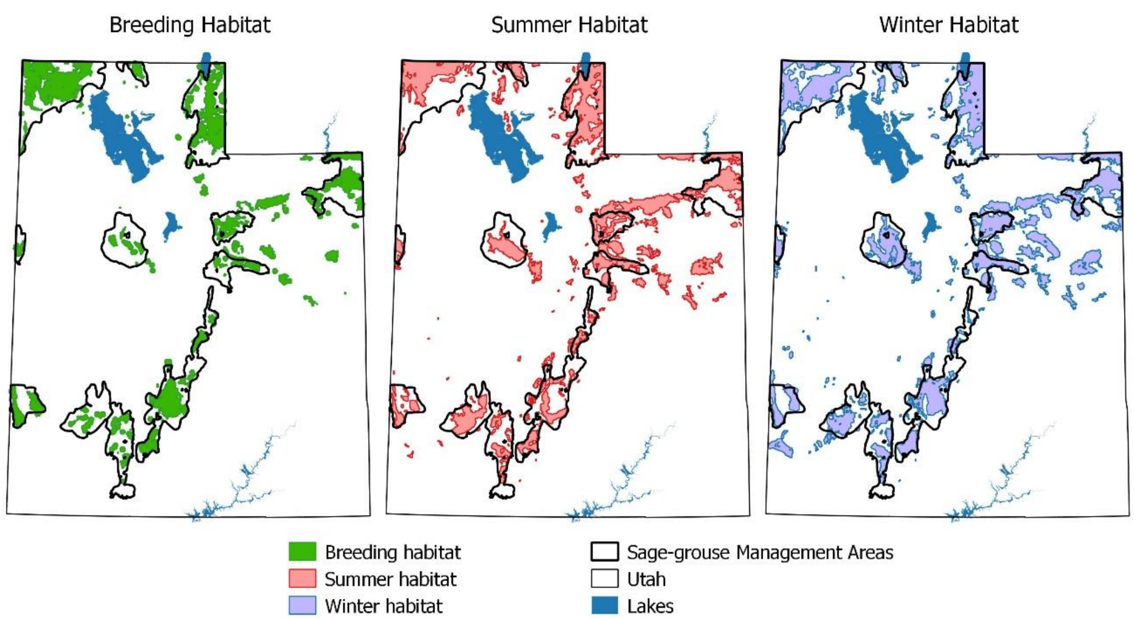
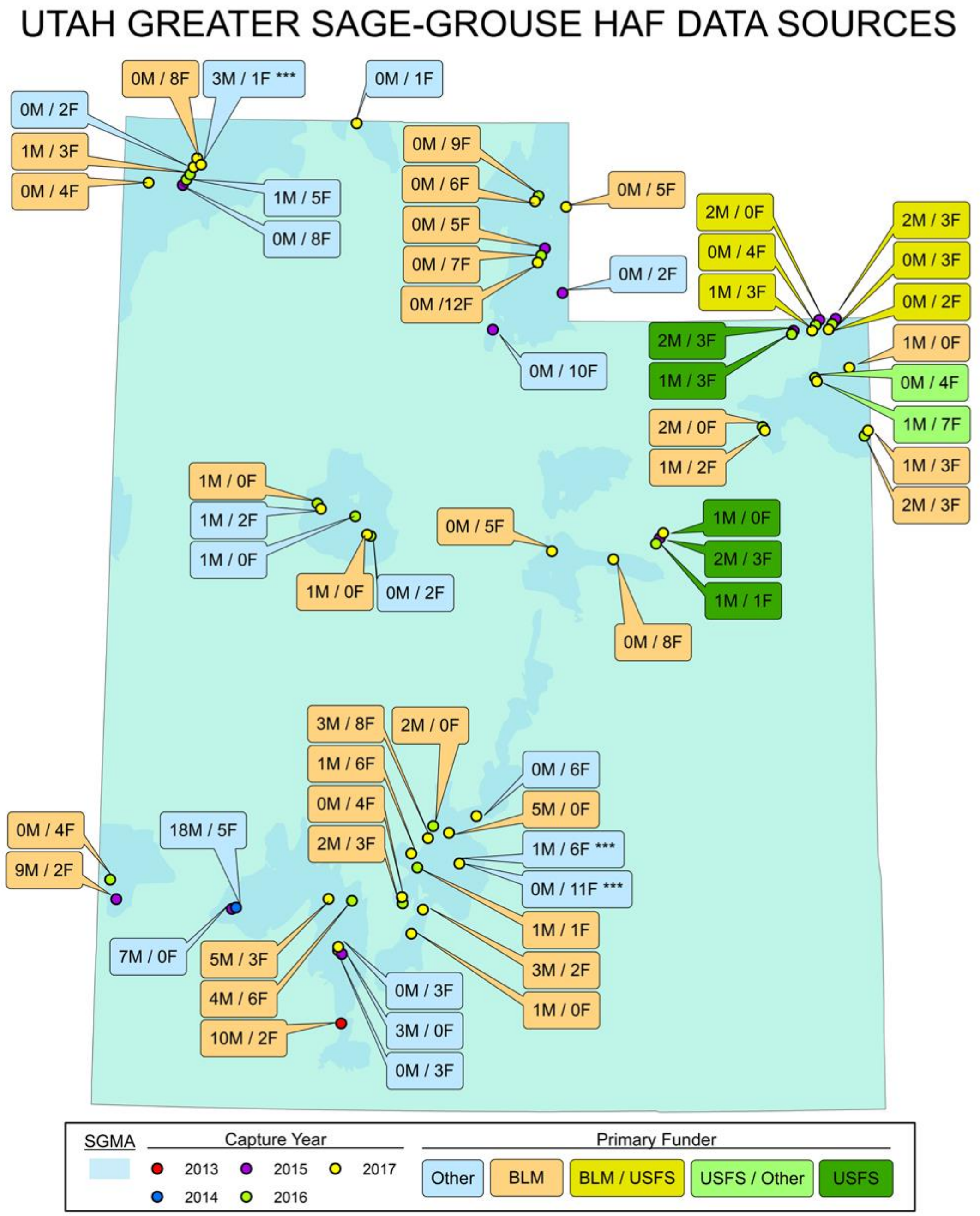


Figure 5. Greater sage-grouse (*Centrocercus urophasianus*; sage-grouse) breeding habitat was defined as areas used by sage-grouse for lekking, nesting, and early brood-rearing, from March 1 – June 14. Summer habitat was defined as areas used by brood-rearing and non-breeding sage-grouse from June 15 – August 31. The June 15 cutoff date between breeding and summer use locations was selected based on the temporal distribution of nesting and brooding use locations. Winter habitat was defined as areas used by non-breeding sage-grouse from November 1 – February 29.

These seasonal maps will be updated in 2019 using sage-grouse location data collected from over 300 GPS units we started deploying on sage-grouse in 2013 (Figure 6). By 2019, we will have over 1 million new sage-grouse locations to use in updating the existing maps. This process, known as the Sage-Grouse Habitat Assessment Framework (HAF), will ensure the conservation of sage-grouse in Utah. Completion of the HAF will identify the vegetation characteristics used by sage-grouse within the seasonal habitats.

To augment this VHF database, researchers began deploying rump-mounted GPS units on sage-grouse throughout the state in 2013 (see the front cover for a photograph of a rump-mounted GPS transmitter). We have deployed 343 GPS units spread across 9 of the 11 Sage-Grouse Management Areas in a large-scale effort to map the seasonal distribution of the species (Figure 3). Although costs of GPS units exceed those of VHF units ($4,000 vs $180), they provide multiple locations/day (5-10) throughout the year which means we will be more efficient in our field monitoring while also being provided with a greater understanding of sage-grouse winter use and night-time patterns.

Furthermore, the ability to track sage-grouse via satellites has provided us with a new appreciation for the distances these birds can migrate since birds fitted with VHF transmitters often travelled far outside of the monitoring areas of most researchers. For example, GPS technology has allowed us to follow birds that breed in the area around Henefer, Utah, to their winter range south of Lake Jordanelle; a distance greater than 35 miles and a wintering area we likely would have not considered prior to the use of GPS technology. Upon completion in 2019, the HAF seasonal habitat maps will operate as the sage-grouse distribution maps. With the state and federal agencies in Utah both using these distribution maps, we can be assured that sage-grouse management and conservation in Utah will be better suited to meet future challenges.



This map identifies the primary funding source and number of GPS rump-mounted satellitte transmitters deployed on individual sage-grouse (GRSG; n = 115 M, 228 F) in Utah. These data sources will be used to create seasonal habitat maps for GRSG as part of the Utah BLM Habitat Assesment Framework. "Other" funding designation includes Utah Public Lands Policy Coordination Office, Pacificorp, Rocky Mtn. Power, Alton Coal Mine, and private landowners. Astericks identify grouse that were translocated to Sheeprocks SGMA. Updated 8 June 2017.

Figure 6. We have deployed 343 rump-mounted global positioning satellite (GPS) transmitters on greater sage-grouse (*Centrocercus urophasianus*) in 9 of the 11 Utah Sage-Grouse Management Areas in a large-scale effort to better map the seasonal distribution of the species.

Compensating for Telemetry Bias

In the past few years, the number of GPS radio-transmitters deployed on sage-grouse throughout Utah has increased dramatically (Figure 5). Biologists deploying GPS transmitters are collecting more location from specific individuals in a population. Although we are now collecting even more data from specific individuals using GPS radio-transmitters, "the effect of telemetry bias" – remains are management concern. Because of limited resources, we can only capture and radio-mark at best > 2% of a population. So, we cannot be sure that the individuals marked are representative of the population.

To address this concern, biologist have developed mathematical habitat selection models to analyze their data. These models assume that radio-marked animal's habitat-use patterns represent selection for habitat characteristics (e.g., vegetation type, canopy cover, and distance to features, etc.) made by the rest of the population. The models then compare the habitat attributes selected by the radio-marked animals to the available habitat. The resulting differentiations (used vs. available) allow the model to predict, with probability values (i.e., values between 0 and 1), which habitat characteristics will be selected by the overall population. These models generally fall under the category of Resource Selection Functions or RSFs (Dahlgren et al. 2018).

Because, everyone may not have the expertise and/or access to the software available to model telemetry data to produce habitat selection maps (Figures 1-3), USU has initiated a process to provide this service to Utah wildlife managers for sage-grouse management. The RSF maps produced through this effort will help managers to plan and prioritize sage-grouse management projects from available telemetry data. For more information about this service, contact Terry Messmer at terry.messmer@usu.edu.

THE IMPORTANCE OF PARTNERSHIPS

The longevity, continuity, consistency, and hence accuracy of the sage-grouse database used to develop the Utah Plan (PLPCO 2018) attests to the commitment and resolve of the partners that have funded and support the research. These partners include the Utah Reclamation, Mitigation, and Conservation, UDWR, BLM, USFWS, USFS, Sportsmen for Fish and Wildlife, BYU, Western Alliance to Expand Student Opportunities, Berry Petroleum, S. J. and Jessie Quinney Foundation, USU Extension, USU Quinney College of Natural Resources, Quinney Professorship for Wildlife Conflict Management, Jack H. Berryman Institute, Enduring Resources LLC, the Parker Mountain Grazing Association, Deseret Land and Livestock, Pheasants Forever, Natural Resource Conservation Service, Idaho Fish and Game Department, Rich County Coordinated Resource Management Group, Rich County Commission, West Box Elder Coordinated Resource Management Group, Utah Department of Agriculture and Food, USDA Wildlife Services, Anadarko Petroleum, Bill Barrett Corporation, Utah Chapter of the Wildlife Society, Cooperative Sagebrush Initiative, Rocky Mountain Power, PacifiCorp, Utah Wildlife in Need Foundation, Utah Department of Natural Resources, SUFCO Mine (Canyon Fuel Company), Kerr River Pipeline, Ruby Pipeline, Utah Public Lands Policy Coordination

Office, Utah Legislature, Utah Community-Based Conservation Program, Della Ranches, Utah Conservation Districts, Grouse Creek Livestock Associations, USDA Poisonous Plants Lab, USDA Animal Research Service, and the Utah Cooperative Wildlife Management Association.

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