

GREATER SAGE-GROUSE AND ENERGY DEVELOPMENT IN NORTHEASTERN
UTAH: IMPLICATIONS FOR MANAGEMENT

by

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ABSTRACT

Greater Sage-grouse and Energy Development in Northeastern

Utah: Implications for Management

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Concern regarding the effect of energy development on greater sage-grouse (*Centrocercus urophasianus*) is increasing as the search for fossil fuel intensifies. Sage-grouse may be especially sensitive to energy development because they require large, diverse areas of sagebrush (*Artemisia* spp.) habitat to complete their life cycle. Additionally, the network of pipelines, roads, and wells required by energy development may fragment sagebrush habitat isolating populations and contributing to genetic drift, inbreeding, local extinction, or rapid divergence.

Seep Ridge, located in northeastern Utah, is one area where sage-grouse habitat and energy development plans overlap. Approved leases call for the construction of an additional 4,000 natural gas wells in an area currently occupied by a small sage-grouse population. This research was completed to 1) collect baseline data on the survival, reproductive success and habitat use of the Seep Ridge sage-grouse population, 2)

examine sage-grouse habitat use patterns in relation to development, and 3) describe sage-grouse mitochondrial genetic diversity in 3 northeastern Utah populations relative to other parts of the species range.

I captured and monitored 16 sage-grouse from the Seep Ridge population in 2007 and 2008. Adult mortality rate of the Seep Ridge population was high (65.2%) and recruitment was low (7.1%) compared to other sage-grouse populations in Utah. Additionally, the monitored sage-grouse used habitats located farther from wells more frequently than habitat located near wells, relative to well spacing. Current habitats occupied by this population do not meet recommended guidelines.

No unusual haplotype compositions were observed in the genetic survey of the northeastern Utah sage-grouse populations. However, differences in haplotype composition between the Anthro Mountain and Strawberry Valley populations and other northeastern grouse populations indicate there may be a barrier to gene flow in the area. I also documented that the Seep Ridge population is connected to another population inhabiting Ute Tribal land. This observation suggests that the populations inhabiting Ute Tribal land may constitute a source population to recolonize Seep Ridge during the post-energy development periods.

I recommend that mitigation measures incorporate restricting development in breeding habitat, maintaining connections between populations, and actions to reduce adult mortality on the summer range. I also recommend that biologists continue collecting genetic samples from northeastern Utah sage-grouse populations to understand population structure, divergent evolution, and inform decisions concerning translocation.

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CHAPTER 1

INTRODUCTION

BACKGROUND

Greater Sage-grouse Status

Greater sage-grouse (*Centrocercus urophasianus*) were once common in sagebrush (*Artemisia* spp.) habitat throughout the western United States. Today, the range and abundance of greater sage-grouse (hereafter sage-grouse) has been reduced because of fragmentation, degradation, and conversion of sagebrush habitat to other land uses (Braun 1998, Connelly et al. 2004).

Prior to European settlement, sage-grouse were estimated to occupy 1,200,483 km², encompassing 12 U.S. states, and 3 Canadian provinces (Schroeder et al. 2004) (Fig. 1.1). The current distribution of sage-grouse is substantially smaller. Schroeder et al. (2004) estimated that sage-grouse occupy 668,412 km², or approximately 56% of presettlement sagebrush habitat (Fig. 1.2). Sage-grouse have been extirpated from Arizona, Nebraska, New Mexico, and British Columbia (Schroeder et al. 2004).

Sage-grouse populations have declined dramatically throughout the remainder of their range (Connelly and Braun 1997, Connelly et al. 2004). Decline severity varied according to region, but ranged from 17-47% (Connelly and Braun 1997). The greatest declines occurred from the 1960s through the 1980s. Currently, most sage-grouse populations are either stable or declining at a slower rate (Connelly et al. 2004). Urbanization, natural resource development, grazing, disease, and the invasion of non-

native plants are listed as factors contributing to the decline of sage-grouse populations (Braun 1998, Connelly et al. 2004).

Hunting has been implicated by some stakeholder groups as a possible factor in the declines of local populations (Belton 2008). Sage-grouse currently are hunted in all of the western states in which they occur except Washington (Connelly et al. 2004, Christiansen 2008). Hunting is also prohibited in Saskatchewan and Alberta. Sage-grouse are a valuable game species, and early hunting in the 1800s may have decimated local populations (Patterson 1952). However, state agencies have reduced harvest quotas to reduce negative impacts on sage-grouse and hunting does not appear to be a major threat to sage-grouse conservation currently (Connelly et al. 2004).

In general, sage-grouse are sensitive to any activities that remove, degrade, or fragment the sagebrush habitat upon which they depend for sustenance and shelter (Braun 1998, Braun et al. 2002, Connelly et al. 2004). In the Intermountain West, energy development is rapidly becoming the most cited new potential threat contributing to the decline of sagebrush ecosystem integrity and sage-grouse populations (Lyon and Anderson 2003, Holloran 2005, Naugle et al. 2006a, Walker et al. 2007). Habitat fragmentation and the related disturbances associated with energy development may be especially problematic for managers attempting to maintain or recover sage-grouse populations in areas experiencing rapid growth of the industry.

Concern about sage-grouse populations has generated several petitions to list the species as threatened or endangered under the Endangered Species Act of 1973. Since 1999, 7 petitions have been filed to list the entire species or specific populations. In December 2005, the U.S. Fish and Wildlife Service (USFWS) announced that listing the

species was unwarranted. A lawsuit filed the following year resulted in a federal judge ruling in December 2007 that the USFWS must reconsider its previous decision because of procedural errors. In February 2008, the USFWS announced that the concerns expressed in the original petitions to list sage-grouse would receive additional review to determine if listing the species throughout its range or any portion of its range is warranted (USFWS 2008).

Species Description

Greater sage-grouse are the largest grouse species in North America (Schroeder et al. 1999). Males typically weigh 1.7-2.9 kg and measure 65-75 cm in length. Females are smaller, weighing on average 1.0-1.8 kg and measuring 50-60 cm in length.

Both sexes are mottled gray, brown and white, have a black belly, and a long tail. Males also have yellow combs above their eyes and short white feathers on their breast and neck. During courtship, males fan their tails, distend their chest, and expand two bright yellow air sacs on their chests, producing a popping sound (Schroeder et al. 1999).

Plumage of the male sage-grouse is distinctive; however, the more cryptic female sage-grouse may be confused with other female grouse species including blue grouse (*Dendragapus obscurus*) and sharp-tailed grouse (*Tympanuchus phasianellus*). The large size, pointed tail, and black belly patch of female sage-grouse is useful in distinguishing them from other female grouse (Schroeder et al. 1999).

The Gunnison sage-grouse (*C. minimus*) was recognized as a separate species from greater sage-grouse in 2000 (AOU Checklist Committee 2000, Young et al. 2000). The two species differ with respect to morphology (Hupp and Braun 1991), plumage,

breeding behavior (Young et al. 1994), and genetics (Kahn et al. 1999, Oyler-McCance et al. 1999). Male and female Gunnison sage-grouse weigh on average 1 kg and 400-500 g less than greater sage-grouse, respectively (Young et al. 2000). The filoplumes, specialized feathers located on the neck used in breeding displays of male Gunnison sage-grouse are wider, longer, and denser than that of greater sage-grouse. The breeding display of Gunnison sage-grouse is also comparatively slower and includes unique acoustical components (Young et al. 1994, 2000). Additionally, haplotype frequencies of Gunnison sage-grouse differed significantly from greater sage-grouse, indicating that gene flow between the two species is effectively absent (Kahn et al. 1999, Oyler-McCance et al. 1999).

Energy Development and the Sagebrush Ecosystem

In November 2000, Congress enacted the Energy Act of 2000, which requested an inventory of on-shore oil and gas reserves in the United States. Results from the inventory indicate that oil and gas resources are most concentrated in Northern Alaska and the Interior West (U.S. Departments of Interior, Agriculture, and Energy, 2008). A large portion of development within the interior west occurs within 5 geologic basins (Greater Green River Basin of southeastern Wyoming, Montana Thrust Belt, Paradox-San Juan Basin of Colorado and New Mexico, Powder River Basin of Wyoming and Montana, and the Uinta-Piceance of Colorado and Utah) (Connelly et al. 2004), all of which support sagebrush habitat and either Gunnison or greater sage-grouse populations (Knick et al. 2003, Connelly et al. 2004, Schroeder et al. 2004).

Energy development requires a large network of pipelines, roads, pump stations, well pads, buildings, and retention ponds; hence the effect of development on the sagebrush ecosystem can be substantial. Development causes direct loss of habitat via conversion of sagebrush to roads, wells pads, and other infrastructure. On average, natural gas well pads occupy approximately 0.8-3.2 ha during the drilling process (Garfield County Energy Advisory Board 2007); however, larger facilities such as pump stations may require larger pads.

Energy development also fragments sagebrush habitat (Weller et al. 2002). For example, the entire 430 km² landscape in the Big Piney-LaBarge oil and gas field in the Upper Green River Basin of Wyoming is located within 0.8 km of a road, pipeline, or other feature associated with development (Weller et al. 2002).

Additionally, energy development may facilitate the invasion of non-native plants, such as cheatgrass (*Bromus tectorum*), and the invasion of predators (Steenhof et al. 1993, Gelbard and Belnap 2003). Foxes (*Vulpes* spp.), ravens (*Corvus corax*), and raptors are more common in fragmented sagebrush landscapes. Fences, power lines, and other man-made structures provide hunting perches and nesting platforms for avian predators (Connelly et al. 2004).

Sage-grouse and Energy Development

Sage-grouse sensitivity to energy development may be heightened because they require large, diverse areas of sagebrush habitat (Braun et al. 2002, Connelly et al. 2004). Habitat availability is reduced directly, due to conversion of sagebrush habitat to roads and well pads, and indirectly, via wildlife avoidance of energy development

infrastructure (Pitman et al. 2005, Beck 2006, ALL Consulting 2007). The later may cause sage-grouse to use suboptimal habitat, which in turn may reduce vital rates.

Additionally, reduced reproductive success, and mortalities due to collisions with traffic and infrastructure may cause sage-grouse populations to decline (Lyon and Anderson 2003, Naugle et al. 2006a). Energy development may negatively affect sage-grouse throughout their life cycle.

Lek Attendance and Abandonment. —Reduced lek attendance and lek abandonment are the most frequently reported negative effect of energy development on sage-grouse (Hunt 2004, Crompton and Mitchell 2005, Holloran 2005, Beck 2006, Naugle et al. 2006a, Walker et al. 2007). Holloran (2005) found that the number of males attending leks in areas subjected to full-field natural gas development in Wyoming declined an average of 51% from the year preceding development to 2004. Comparatively, only a 3% decline was observed at undisturbed leks. An even more severe decline in male lek attendance occurred in the coal-bed natural gas fields of the Powder River Basin of Montana and Wyoming. Sage-grouse lek-count indices in gas fields declined by 82% from 2001-2005 compared to a 12% decline for leks located outside the gas fields (Walker et al. 2007). Energy development also appears to negatively affect female grouse lek attendance, although this relationship is less clear (Kaiser 2006).

Sage-grouse may also abandon disturbed leks. Lek abandonment following development has been reported in Montana, Wyoming, and Utah (Crompton and Mitchell 2005, Holloran 2005, Beck 2006, Walker et al. 2007). In the Powder River Basin, Walker et al. (2007) found that among leks active in 1997 or later, only 38% of leks located in coal-bed natural gas fields remained active by 2004-2005.

The explanation for abandonment and reduced attendance is likely complex.

Lek abandonment and reduced attendance at leks may be a function of noise disturbance, disturbance via visual obstruction, increased human activity, declining population size due to increased mortality and reduced reproductive success, or a combination of factors (Beck 2006, Walker et al. 2007). Currently, the role of these factors in reduced lek attendance and lek abandonment is unknown.

Nesting and Brood Rearing.— Females inhabiting developed areas are less likely to initiate nests. Lyon and Anderson (2003) found that nest initiation for females attending disturbed leks was 65% compared to 89% for females attending undisturbed leks.

Additionally, grouse may avoid infrastructure, reducing the availability of appropriate nesting habitat. Nesting lesser prairie-chickens (*Tympanuchus pallidicinctus* Ridgway) avoided wells (80 m) and buildings (1,000 m) (Pitman et al. 2005). Depending on well spacing requirements, avoidance of these features could drastically reduce the availability of nesting habitat.

Increased avian predation may also reduce reproductive success. Holloran (2005) found that as energy development progressed, avian nest predation increased from 13% to 40% over a 4-year period. Additionally, later hatch dates (Kaiser 2006) and reduced brood fledging success (Crompton and Mitchell 2005) can also be problematic in developed habitats.

Wintering. — Little information exists on the effect of energy development on sage-grouse wintering behavior. Sage-grouse generally have a high over-winter survival rate (reviewed in Connelly et al. 2004); however, bird densities are also highest in the winter, making them vulnerable to disturbance. Naugle et al. (2006b) and Doherty et al. (2008)

found that wintering sage-grouse avoided coal-bed natural gas wells in otherwise suitable habitat. In some areas, lack of suitable wintering habitat is the most important factor limiting population growth (Holloran and Anderson 2004); hence disturbance to wintering grouse may be an important factor in population declines.

Greater Sage-grouse Genetic Diversity:

Conservation Implications

Energy development is but one anthropogenic activity cited as contributing to sagebrush habitat loss and fragmentation. Increased fragmentation of sagebrush habitats has created islands of small sage-grouse populations (Schroeder et al. 2004). As populations become increasingly fragmented, they may suffer from the loss of genetic variability, reducing the ability of populations to respond to changing environmental conditions and increasing susceptibility to disease (Frankham 1995, Frankham et al. 1999, Reed and Frankham 2003). Additionally, genetic drift and inbreeding may reduce the likelihood of population persistence (Allendorf and Luikart 2007).

Oyler-McCance et al. (2005) conducted a range-wide genetic survey of 46 sage-grouse populations to examine the distribution of genetic variation for application to management. The survey identified 2 populations in Washington with low levels of genetic variation that may benefit from the translocation of birds from nearby populations. The survey also identified 1 population (Lyon-Mono) located near the Nevada-California border, which is sufficiently genetically distinct that it should be managed independently from other sage-grouse populations (Benedict et al. 2003, Oyler-

McCance et al. 2005). Genetic data from the study will be useful in developing cohesive management strategies that take into consideration genetic distinctiveness.

Sage-grouse Genetic Diversity in Utah

In Utah, sage-grouse are currently estimated to occupy approximately 41.4% of their pre-settlement range (Beck et al. 2003) (Fig. 1.3). The largest remaining populations are located in western Box Elder County, Rich County, the Blue and Diamond Mountains (Uintah County), and Parker Mountain (Wayne County) (Beck et al. 2003). Many small, isolated populations occur in the central and southern portion of the state (Beck et al. 2003).

The Oyler-McCance et al. (2005) range-wide genetic survey included 5 populations located in Utah (Box Elder, Wayne, Diamond, Blue Mountain, and Strawberry Valley). Microsatellite data from the survey indicated that the Strawberry Valley and Wayne populations have low amounts of gene flow due to fragmentation and isolation. The isolated populations located in central and southern Utah may also suffer from low gene flow. Genetic data may improve management of these populations by identifying populations that may benefit from translocations as well as populations that are unique, in which case translocations should not be considered.

Utah and Energy Development

Energy development in Utah has increased dramatically within the last 15 years. The majority of development occurs in the northeastern portion of the state. In 1991, 402 permits to drill were approved (Utah Division of Oil, Gas and Mining, 2007). In 2006, the number of approved permits increased to 2,062; over half of these permits were

issued in Uintah County (Fig.1.4). Uintah County was the top natural gas producer in Utah in 2005 (Utah Division of Oil, Gas and Mining, 2007) and contains the 7th largest on-shore natural gas field in the United States (Energy Information Administration, 2007).

The rapid growth rate of energy development in Uintah County is of concern because it supports substantial populations of sage-grouse (Beck et al. 2003). Sage-grouse in this area may be at a high risk for extirpation because small populations are becoming increasingly isolated and may suffer from reduced gene flow. Hence, severe population declines are possible in Uintah County where sage-grouse habitat and energy development overlap (Uintah Basin Adaptive Resource Management Local Working Group 2006).

Seep Ridge, located approximately 65 km south of Vernal, Utah, is one location in Uintah County where sage-grouse habitat and energy development plans coincide. Prospective development plans for 2 Bureau of Land Management (BLM) project areas propose to construct 4,000 natural gas wells (Bureau of Land Management 2007, 2008) in an area that is currently occupied by a small population of sage-grouse known as the Seep Ridge sage-grouse population (Fig. 1.5). Currently, little information concerning the survival, reproductive success, or habitat use of this population is known and development may already be affecting the grouse.

Research Purpose

The purpose of my research was to: 1) collect baseline data on the survival, reproductive success, and habitat use of the Seep Ridge sage-grouse population, 2)

examine sage-grouse habitat use patterns in relation to development, and 3) describe sage-grouse mitochondrial genetic diversity in northeastern Utah relative to other parts of the species range. This research will provide a basis for comparison as energy development progresses and inform management decisions. I used field data in combination with a review of pertinent literature review to develop recommendations for mitigation measures to minimize the impact of energy development on the Seep Ridge sage-grouse population.

STYLE

My thesis was written in multiple chapter format. I followed editorial guidelines outlined by the *Journal of Wildlife Management*.

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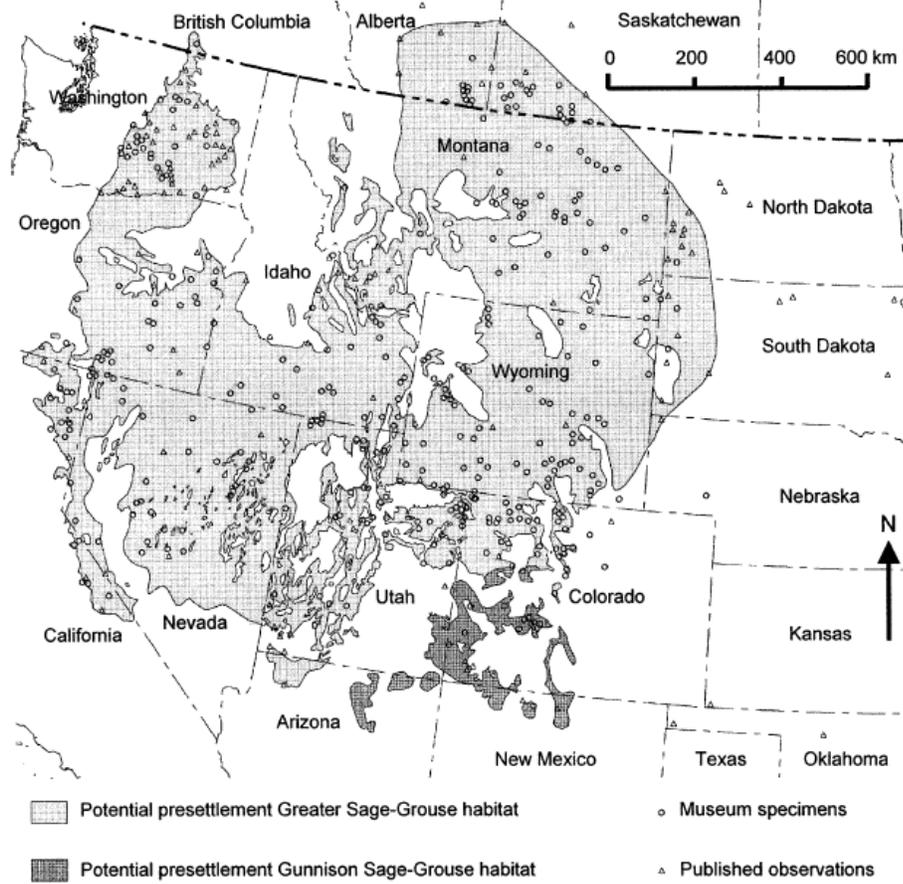


Fig. 1.1. Historic pre-settlement distribution of greater sage-grouse (*Centrocercus urophasianus*) and Gunnison sage-grouse (*C. minimus*) populations (Figure from Schroeder et al. 2004).



Fig. 1.2. Current distribution of greater sage-grouse (*Centrocercus urophasianus*) and Gunnison sage-grouse (*C. minimus*) populations (Figure from Schroeder et al. 2004).

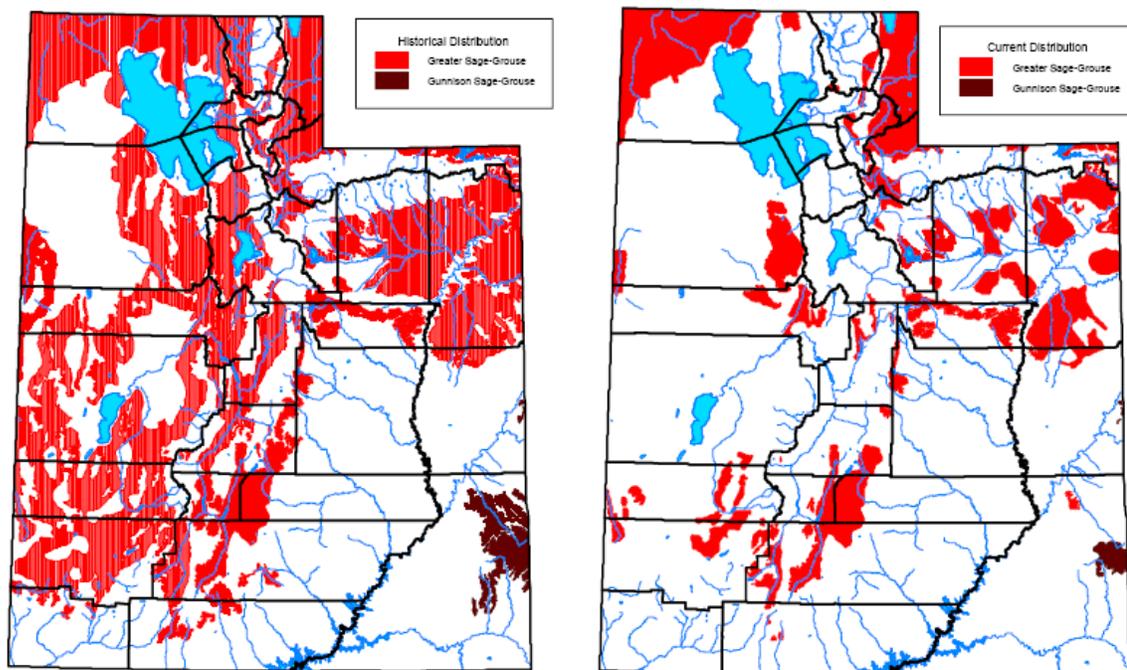


Fig. 1.3. Historic pre-settlement distribution (left) and current distribution (right) of sage-grouse (*Centrocercus* spp.) as of 2003 in Utah (Beck et al. 2003).

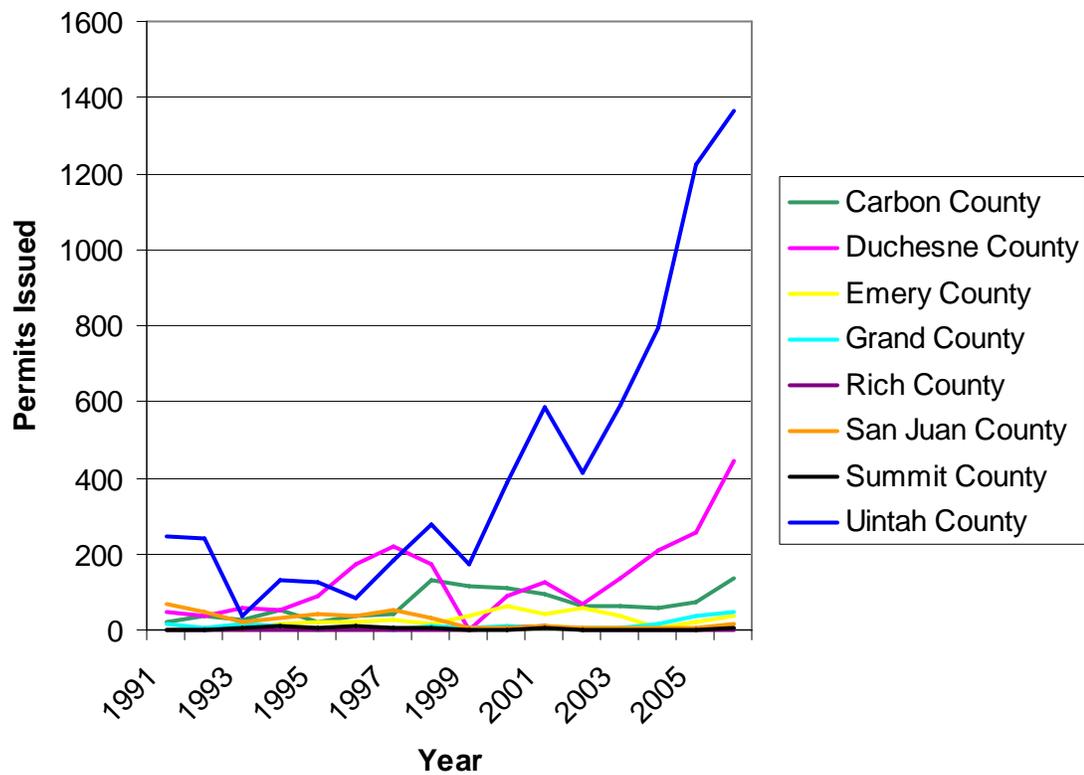
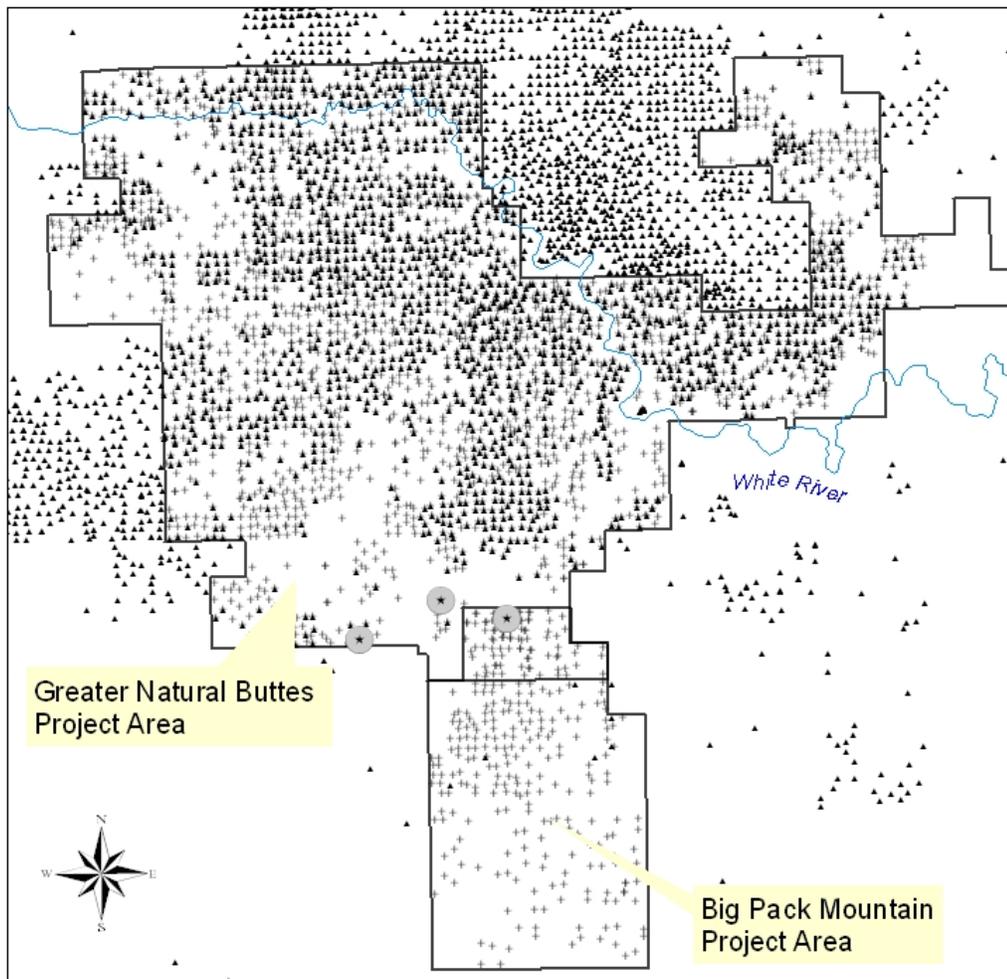


Fig. 1.4. Permits issued to drill in Utah from 1991-2006 (Utah Division of Oil, Gas and Mining data, <http://www.ogm.utah.gov/oilgas/STATISTICS/permits/1APD.htm>). Only counties issuing 10 permits in at least one year from 1991-2006 were included.



Legend

- ★ Active Leks
- ▲ Active Wells
- ⊕ Natural Gas Wells
- + Proposed Wells
- ⊕ Natural Buttes
- ⊕ Rock House
- River

Development Plans

Greater Natural Buttes: drill 3,496 wells in the 65,928 ha project area.

Big Pack Mountain: drill 664 wells in the 13,950 ha project



Fig. 1.5. Prospective energy development plans for Seep Ridge, Utah, 2008 (Utah Division of Oil, Gas, and Mining data, 2008).

CHAPTER 2

SURVIVAL, REPRODUCTIVE SUCCESS, AND HABITAT USE OF THE SEEP RIDGE GREATER SAGE-GROUSE POPULATION

ABSTRACT: Concern regarding the effect of energy development on greater sage-grouse (*Centrocercus urophasianus*) is increasing as the search for fossil fuel intensifies. One area of particular concern in Utah is Seep Ridge, located in the northeastern part of the state. Current energy leasing proposes the construction of an additional 4,000 natural gas wells in this area which is also inhabited by a small sage-grouse population. This research was conducted to obtain information about the survival, reproductive success, and habitat use of the Seep Ridge sage-grouse population relative to existing energy development. To conduct this study, I captured, radio-collared, and monitored 16 sage-grouse (3 females, 13 males) in 2007 and 2008. Prior to this study, the population was estimated to contain 200 individuals. In 2007 and 2008, I estimated that the population contained 108 and 36 individuals, respectively. Observed adult mortality rates were high (65.2%) compared to other sage-grouse populations in Utah. Most mortalities (71.4%) occurred in the late summer and early fall. Recruitment was low with only 1 of 14 (7.1%) chicks survived to 50 days of age. Sage-grouse monitored selected sites with more forb cover and habitats located farther from active wells relative to well spacing. To mitigate the impact of future oil and gas development on this population I recommend maximizing surface well pad spacing within sage-grouse seasonal ranges and restricting development in breeding habitat. Additionally, I recommend increased management actions to reduce

adult mortality rate on the summer range including WNV testing, predation management, and habitat enhancement.

INTRODUCTION

The long-term range wide decline of greater sage-grouse (*Centrocercus urophasianus*) populations presents a major challenge to natural resource managers as they attempt to balance the needs of wildlife, agriculture, and industry. Currently, greater sage-grouse (hereafter sage-grouse) occupy just over half of their estimated presettlement range (Schroeder et al. 2004) and the species has experienced dramatic declines in abundance throughout the 20th century (Connelly and Braun 1997, Connelly et al. 2004).

Urbanization, natural resource development, grazing, disease, and the invasion of non-native plants are listed as factors contributing to the decline of sage-grouse populations (Connelly et al. 2004). In general, sage-grouse are sensitive to any activities that remove, degrade, or fragment the sagebrush (*Artemisia* spp.) habitat upon which they depend for sustenance and shelter (Braun 1998, Braun et al. 2002, Connelly et al. 2004). Several organizations concerned about sage-grouse population declines have filed numerous petitions with the U.S. Fish and Wildlife (USFWS) to list the species under the Endangered Species Act. In February of 2008, the USFWS announced that due to procedural errors, it would reconsider the previous decision in 2005 not to list the species (USFWS 2008).

In the Intermountain West, the petitioners and others have identified energy development as an important new threat contributing to the decline of sagebrush ecosystem integrity and sage-grouse populations (Lyon and Anderson 2003, Holloran

2005, Doherty et al. 2008). Energy development has occurred in North America since the 1800s, however, the rate of development and exploration is increasing rapidly in response to rising demands for domestic energy (Braun et al. 2002). Energy development requires a large network of pipelines, roads, retention ponds, pump stations, and wells which fragments and degrades sagebrush communities; hence, development may be especially problematic for managers attempting to maintain or recover sage-grouse populations.

Research conducted to assess the effect of energy development on sage-grouse demonstrated that grouse occupying disturbed areas may alter their habitat use to avoid highly developed areas and exhibit increased mortality rates and reduced reproductive success (Lyon and Anderson 2003, Holloran 2005, Naugle et al. 2006, Walker et al. 2007). These negative effects may cause substantial reductions in population abundance and distribution (Holloran 2005, Walker et al. 2007). Most of this research has been conducted in areas inhabited by large populations of at least 500 individuals.

Based on increased leasing activity, the rate of energy development in Utah is expected to increase dramatically within the next 10 years (Utah Division of Oil, Gas and Mining, 2007). Seep Ridge, located in northeastern Utah, is one area where sage-grouse habitat and energy development plans are expected to overlap. Prospective development plans for 2 Bureau of Land Management (BLM) project areas propose the construction of approximately 4,000 natural gas wells (BLM 2007, 2008) in an area that is currently occupied by a small population of sage-grouse estimated to contain 200 individuals B.D. Maxfield, Utah Division of Wildlife Resources, personal communication).

Little was known about the survival, reproductive success, or habitat use of this population relative to current energy development. The goal of my research was to describe these aspects of the Seep Ridge population to assist managers in identifying measures to mitigate the effect of increased energy development on the population. The following research questions were addressed:

1. What is the current size of the Seep Ridge population?
2. Where are active leks located in the Seep Ridge study area?
3. How do the reproductive success, adult mortality rate, causes of adult mortality, and timing of mortality of the Seep Ridge population compare to other populations in Utah?
4. How do the arthropod abundance and composition at Seep Ridge brood rearing sites compare to other brood rearing sites in Utah?
5. Where are seasonal habitats located and what habitat characteristics do the Seep Ridge sage-grouse prefer to use?
6. How do the Seep Ridge sage-grouse use a disturbed landscape?

STUDY AREA

The study area was bounded to the north by the White River, to the east by the Green River, to the west by Bitter Creek, and to the south by the Book Cliffs (Fig. 2.1). The eastern portion of the study area consisted of rolling hills dominated by Wyoming big sage (*A. tridentata wyomingensis*) and scattered stands of pinyon (*Pinus edulis*) and Utah juniper (*Juniperus utahensis*). The western portion of the study area was dominated by black sage (*A. nova*) and divided by Willow Creek, a tributary to the Green River.

The Willow Creek area consisted of previously cultivated alfalfa (*Medicago* spp.) fields, greasewood (*Sarcobatus vermiculatus*), and salt cedar (*Tamarix ramosissima*). The study area was seasonally grazed by domestic sheep and cattle during the winter and spring.

Prior to this research the Utah Division of Wildlife Resources (UDWR) believed there were 3 active leks in the study area; Sand Wash Rim, East Bench 16, and Middle Bench Guzzler (Fig. 2.1). Biologists located and began monitoring these leks in 1983, 2004, and 2005, respectively. Birds strutting on the East Bench 16 lek may have previously strutted on 2 currently inactive leks: the East Bench lek (active 1983-1994; 2004) and the East Bench NE lek (active 1999-2001) (B.D. Maxfield, UDWR, unpublished data). Male attendance at these leks has declined steadily since 1983 (Fig. 2.2).

Wildlife

Common avian species observed in the study area included American kestrel (*Falco sparverius*), black-billed magpie (*Pica pica*), black-throated sparrow (*Amphispiza bilineata*), brewer's sparrow (*Spizella breweri*), common raven (*Corvus corax*), chuckar (*Alectoris chuckar*), golden eagle (*Aquila chrisaetos*), great horned owl (*Bubo virginianus*), horned lark (*Eremophila alpestris*), lark sparrow (*Chondestes grammacus*), loggerhead shrike (*Lanius ludovicianus*), mourning dove (*Zenaida macroura*), red-tailed hawk (*Buteo jamaicensis*), sage sparrow (*Amphispiza belli*), and sage thrasher (*Oreoscoptes montanus*). Biologist employed by U.S. Department of Agriculture Animal Plant Health Inspection Service (APHIS) Wildlife Services (WS)

distributed DRC-1339-treated eggs in the study area to control common raven populations.

Mammalian species observed in the study area included bison (*Bison bison*), black-tailed jackrabbit (*Lepus californicus*), coyote (*Canis latrans*), desert cottontail (*Sylvilagus auduboni*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra Americana*), white-tailed prairie dog (*Cynomys leucurus*), and wild horses. Elk, mule deer, and pronghorn were hunted during UDWR established seasons. No hunting of sage-grouse was permitted in the study area.

Energy Development

Energy development has occurred in the Seep Ridge area since the 1950s, but has begun to intensify recently (BLM 2007, 2008). Energy development plans in 2 BLM project areas, Greater Natural Buttes and Big Pack Mountain, coincide with areas occupied by Seep Ridge sage-grouse during the breeding season (Fig. 2.3). Well spacing in these project areas may range from 1 well per 16 ha to 1 well per 4 ha depending upon reservoir engineering. Well pads are expected to occupy approximately 1.8 ha.

The Greater Natural Buttes Project Area is located in the northern portion of the study area and encompasses 65,928 ha. Anadarko Petroleum Corporation proposes to construct 3,496 natural gas wells in the project area over a 10-year period (BLM 2007). Approximately 1,077 natural gas wells and 20 oil wells are currently present in the area.

The Big Pack Mountain Project Area is located directly south of the Greater Natural Buttes Project Area and encompasses 13,950 ha. Currently, the BLM is writing an Environmental Assessment evaluating Enduring Resources LLC's plan to construct

approximately 664 natural gas wells (BLM 2008). The proposal also includes plans to construct 105 km of roads and 169 km of surface gas lines.

METHODS

Lek Survey

Attendance of male and female sage-grouse was recorded at 3 known leks once a week from February to April in 2007 and 2008. A lek route was established according to guidelines as listed in *Monitoring of Greater Sage-grouse Habitats and Populations* (Connelly et al. 2003). Leks were counted in 1.5 hours and counts began 0.5 hours before sunrise. I counted sage-grouse 3 times before moving to the next lek, and recorded the highest number of males and females.

I conducted driving surveys to search for new leks in March through April in 2007 and 2008. I completed surveys from accessible roads within the study area and exited the vehicle every 1 km to scan the area with binoculars and listen for displaying sage-grouse (Connelly et al. 2003).

Capture and Marking

I located grouse by spotlighting roost sites in the study area at night and captured them with a long-handled hoop net from the back of an all terrain vehicle (Giesen et al. 1982, Wakkinen et al. 1992). Each bird was placed in a small sack to minimize stress and fitted with an ATS A4060 necklace-mounted, battery-powered radio-transmitter (Advanced Telemetry Systems, Inc., Isanti, MN). I determined the sex and age of each captured bird according to mass and plumage characteristics (Beck et al. 1975).

In 2008, I collected blood samples and additional morphological measurements. I measured the tarsus (middle toe to proximal end of tarsus), exposed culmen length and width (Pyle et al. 1987), tail length (ruler inserted between the coverts and retrices), and the lengths of primaries 10 (ruler inserted between P10 and P9), 9 (ruler inserted between P9 and P8) and 1 (ruler inserted between P1 and P2). I collected blood from clipped grouse toenails. Silver nitrate was applied to the toenail if bleeding did not stop after applying pressure with a cotton ball. Utah State University Institutional Animal Care and Use Committee approved sage-grouse handling protocols (Permit # 1332).

Tracking Sage-grouse Movements

Radio tracking took place immediately following capture. All sage-grouse were located at least once a week from April to August in 2007 and 2008. Visual locations were obtained for radio-collared birds with Telonics™ receivers (Telonics, Inc., Mesa, AZ). I located female sage-grouse incubating nests, initiating nests, or with broods 2-3 times a week.

I recorded the location of each grouse site with a global positioning system (GPS) in Universal Transverse Mercator (UTM) NAD 27 coordinates. I also recorded the sex and number of birds in the flock, habitat type, identification number of visible wells within 2.5 km, slope, aspect, and weather at each site. If a grouse was found dead, I attempted to determine the cause by examining the area for tracks, scat, and hair.

Reproductive Success

To find nests, I located female sage-grouse 2-3 times a week until the hen was observed twice under the same shrub. I used triangulation of radio-signals to estimate the nest location at increasingly closer distances by circling the probable site until the hen could be located visually. I monitored nests 3 times a week and approached hens cautiously in order to avoid nest abandonment. During nest checks, I used binoculars to obtain a visual location for each hen. I recorded coordinates for each nest after a hatch or predation event.

Productivity measures were calculated according to Schroeder (1997). I estimated clutch size by counting eggshells after the female left the nest site. I estimated the nest incubation initiation date as the midpoint between the last date that the grouse was observed off the nest and the first date the grouse was observed on the nest. I estimated the hatch date and nest failure date in the same manner. If a nest failed, I attempted to identify the predator (avian or mammalian) by examining the condition of the nest and searching the area for tracks, hair, and scat. After nest failure, I monitored the location of the hen twice a week to document re-nesting attempts. Hens with broods were located 2-3 times a week until the chicks reached 50 days old, at which point they were considered to have reached independence (Schroeder 1997).

Habitat Assessment

I used a variation of the line intercept method to estimate shrub canopy cover at all sage-grouse sites (Connelly et al. 2003). At nest sites, a 15-meter tape was stretched out in 4 directions radiating away from the nest. The first transect followed a random

bearing and additional transects were located at consecutive 90-degree intervals. At brood and adult grouse use sites, canopy cover measurements occurred along 10-meter tapes aligned in the same manner. All transects were centered as close as possible to the bird's former location.

At each transect, I measured the amount of live shrub canopy directly below the tape. Gaps larger than 5 cm were excluded from canopy cover measurements while gaps less than 5 cm were included in measurements. To estimate canopy cover, the total amount of canopy cover below the tape was summed, and then divided by the total length of the tape.

Herbaceous cover was estimated with a 20X50 cm Daubenmire frame at all sage-grouse sites (Daubenmire 1959, Connelly et al. 2003). I estimated the percent cover of grass species, forb species, litter, rock, and bare ground with the Daubenmire frame every 2.5 m along each line intercept transect. I used a Robel Pole to measure visual obstruction into brood and nest sites (Robel et al. 1970). I also recorded Robel Pole measurements out of nest sites.

In 2008, paired control sites were located a random distance (100 m, 200 m, 300 m, 400 m) and direction away from each former bird location. Vegetation attributes of each plot were recorded using the same techniques as the site it was paired to.

Arthropod Sampling

At sites used by sage-grouse chicks less than 50 days old, pit fall traps were used to collect arthropods (Morrill, 1975, Connelly et al. 2003), which are believed to be an especially important aspect of chick survival (Patterson 1952, Johnson and Boyce 1990).

Five pit fall traps were placed at each brood location. One trap was placed at the center of the former location of the brood and the remaining 4 traps were placed at the distal ends of each line intercept transects used to estimate shrub cover. Each pit fall trap was filled with a 50/50 solution of antifreeze and water and left at the site for approximately 48 hours. All arthropod samples were stored in a 70% ethyl alcohol solution. All insects were sorted by group (Hymenoptera (separated further to ants or bees and wasps), Coleoptera, Lepidoptera, Orthoptera, and Miscellaneous) and the displacement volume of each group was recorded.

Sage-grouse Habitat Use in Relation to Development

I examined habitat use patterns of individual radio-collared sage-grouse in relation to natural gas wells. I measured the distances from individual sage-grouse to wells and calculated the mean, minimum, and maximum distance each bird approached wells. Well location data were obtained from the Utah Division of Oil Gas and Mining (UDOGM) (2008).

I performed analyses at 2 scales to examine sage-grouse habitat use patterns in relation to natural gas wells. To avoid pseudoreplication, I used flock locations instead of redundant locations for individual radio-collared grouse flocking together in addition to locations for lone birds in these analyses. A flock was defined as 1 or more birds located within 15 m of one another. The flock location was recorded as the approximate center of the group of birds. Flocks ranged in size from 2 to 10 birds and consisted of both males and females.

The first analysis occurred on a broad scale encompassing grouse seasonal range use patterns. The analysis was performed within the bounds of the summer/fall grouse range (17,517 ha), winter/spring grouse range (2,961 ha), as well as the complete grouse range (29,829 ha). The boundary of these ranges was defined by constructing convex polygons around seasonal sage-grouse locations. To determine if sage-grouse flocks used habitat located far from wells more frequently, I compared the mean distance from sage-grouse flocks to the nearest well to the mean distance from random points to the nearest well. I also classified wells as active or inactive by examining UDOGM well files (2008) and compared the mean distance that sage-grouse flocks approached these 2 types of wells.

The second analysis was conducted on a smaller scale and examined sage-grouse seasonal habitat use relative to well spacing in the immediate area used by the grouse. I used Thiessen polygons, which contain only 1 point and are defined as the perpendicular bisectors between all points, to define habitat in the natural gas field located as far away from natural gas wells as possible, given current well spacing (Fig. 2.4).

Thiessen polygons are used in a diverse array of disciplines including anthropology, forestry, marketing, physics, and regional planning to define the area of influence around a point (Okabe et al. 2000). In ecology, Thiessen polygons are often used to define the area available to plants relative to neighboring plants (Mithen 1984).

A Thiessen polygon constructed around a well contained all points that were closer to that well than any other well. The location of Thiessen polygons was generally defined by natural gas wells located within 2 – 5 km of the flock. I added bird flock locations to the map of natural gas wells and Thiessen polygons and calculated the

distance from each grouse flock location to the nearest Thiessen line and to the nearest well. This analysis was also performed within the bounds of sage-grouse seasonal ranges to determine if there were any seasonal differences in habitat use patterns.

Data Analysis

Data analyses were conducted using SAS 9.1 software (SAS Institute Inc, Cary, NC). Descriptive statistics were computed for morphological characteristics, nesting success, arthropod data, vegetation characteristics at brood, nest, and adult (rooster and broodless hen) sites, and individual sage-grouse habitat use in relation to wells with the MEANS procedure. Population estimates were calculated according to methods as described by Connelly et al. (2003). Maximum male attendance was assumed to represent 75% of males; females were assumed to follow a 2:1 ratio to males.

I used matched-pair logistic regression (Breslow and Day 1980, Hosmer and Lemeshow 2000) to compare vegetation attributes (shrub cover, forb cover, grass cover, grass height, and forb height) at sites used by sage-grouse to paired control sites with the LOGISTIC procedure.

I analyzed sage-grouse movement data with ArcGIS 9.2 (ESRI, Redlands, CA) Geographic Information System (GIS) software. A Wilcoxon signed rank test, the non-parametric analog to a paired t-test, was used to compare the distance from each grouse flock location to the nearest well and the nearest Thiessen line. I used the non-parametric equivalent of the 2-sample t-test, the Wilcoxon rank-sum test, to compare the distance from sage-grouse flocks to the nearest well to random points. I also used the Wilcoxon rank-sum test to compare sage-grouse distances to active and inactive wells. All analyses

were 2-tailed and considered significant at $P \leq 0.05$. I report standard deviations (SD) with means (\bar{x}) unless otherwise stated

RESULTS

Lek Survey

Five known lek sites in the Seep Ridge study area were surveyed. Three leks were active in 2007 and 2 leks were active in 2008. I counted a maximum of 27 males and 9 males attending these leks in 2007 and 2008, respectively. From this count, I estimated that the population consisted of approximately 108 birds in 2007 and 36 birds in 2008. I did not locate any new leks in the study area during driving surveys.

Capture

I captured 16 sage-grouse near leks from 18 March – 18 April (11 in 2007, 5 in 2008). In 2007, I fitted 9 males (adults) and 2 females (adults) with radio-collars. In 2008, I fitted 4 males (2 adults, 2 juveniles) and 1 female (juvenile) with radio-collars. The average mass of adult males was 2640 ± 241 g and the average mass of juvenile males was 2400 ± 354 g. The average mass of adult females was 1690 ± 70 g and the mass of the only juvenile hen I captured weighed 1400 g (Table 2.1).

Survival

Only 2 sage-grouse were alive at the end of the study in December 2008. I attributed 1 of the mortalities to mammalian predation, 5 to avian predation, and the cause of 8 mortalities was unknown. In 2008, 1 adult male appeared to have sustained a punctured air sac during lekking, which may have caused the bird's death. Additionally,

an uncollared juvenile grouse was found dying on the side of a road in the study area.

The bird was tested for West Nile virus (WNV), but results were negative.

Most mortalities ($n = 7$) occurred in the fall from 26 September to 12 November. Of the remaining mortalities, 3 occurred in the spring, 3 occurred in the summer, and 1 occurred in the winter.

Reproductive Success

I located 3 nests in 2007 and 2008, 2 of which were successful. The unsuccessful nest was depredated on 27 April 2007, approximately 5 days after it was initiated. The condition of the nest indicated that the predator was mammalian.

The same hen initiated the successful nests on approximately 15 April 2007 and 21 April 2008. The nests hatched on 9 May 2007 and 16 May 2008. All 6 eggs hatched successfully in 2007, and all 8 eggs hatched successfully in 2008.

In 2007, the hen raised 1 of 6 (16.7%) chicks to 50 days. In 2008, none of the 8 chicks survived to 50 days. The brood was lost approximately 15 June 2008 when the chicks were 31 days old.

Arthropod Sampling

Due to the low number of broods followed throughout the study and regulations on Ute tribal land, only 7 brood sites were sampled for arthropods in 2007 and 2008. The most common groups observed in samples were the miscellaneous group (0.96 ± 1.80 mL), Hymenoptera (bees and wasps) (0.18 ± 0.19 mL), and Coleoptera (0.18 ± 0.19 mL) (Table 2.2).

Seasonal Habitat Use

Nesting. —All nests were located under sagebrush within 402 m of an active lek. Nests were located an average of 743 m from natural gas wells. The unsuccessful nest was located 329 m from a natural gas well. The average height of the nest shrub was 63.5 ± 13.4 cm (Table 2.3). The average diameter of the nest shrub was 125.0 ± 28.3 cm. The dominant forb at nest sites was western stickseed (*Lappula occidentalis*) and the dominant grass was cheatgrass (*Bromus tectorum*).

Habitat at nest sites had a mean shrub canopy cover of $14.1 \pm 3.0\%$, a mean forb cover of $5.0 \pm 4.0\%$, and a mean grass cover of $13.1 \pm 2.5\%$. The average forb height and grass height at nest sites was 5.9 ± 2.9 cm and 10.9 ± 2.8 cm, respectively. The mean visual obstruction reading into nests was 46.5 ± 26.2 cm. The mean visual obstruction reading out of nests was 30.5 ± 19.1 cm.

Brood Rearing. —Brood home range size was 16,283 km² in 2007 and 13,804 km² in 2008. Early brood rearing habitat (chicks ≤ 2 weeks old) was located near leks (Fig. 2.5). Broods used sagebrush habitat, including black sagebrush during this period. Late brood rearing habitat was located near Willow Creek (Fig. 2.5). Broods moved 12.5 km to the Willow Creek area on 13 June 2007 when the chicks were approximately 36 days old and on 2 June 2008 when the chicks were approximately 18 days old. The Willow Creek habitat used by broods during this period consisted of previously cultivated alfalfa fields that were dominated by kochia (*Kochia scoparia*) and poverty weed (*Iva axillaris*).

At brood rearing sites, the mean shrub cover was $9.1 \pm 8.3\%$, the mean forb cover was $19.2 \pm 19.0\%$, and the mean grass cover was $1.5 \pm 3.2\%$ (Table 2.3). The mean forb

and grass height at these sites was 18.1 ± 13.1 cm and 10.2 ± 13.7 cm, respectively.

The mean visual obstruction reading was 27.2 ± 31.2 cm.

Males and Broodless Hens. —Broodless hens and males remained near leks on East and Middle Bench in the spring and moved to Willow Creek and Agency Draw during the summer (Fig 2.6). The distance from the leks to Willow Creek and Agency Draw was approximately 12.5 km and 20.0 km, respectively. Movements to the summer range habitat occurred from 15 June – 2 July. In 2008, one hen traveled 28.3 km after capture to join what may be another population of sage-grouse on the Uintah and Ouray Indian Reservation (Fig. 2.7). The hen remained in this area throughout the summer. In 2007, the majority of grouse moved back to East and Middle Bench in September. However, in 2007 and 2008 males were observed using Agency Draw and Willow Creek in November.

Males and broodless hens used sites with a mean shrub cover of $13.5 \pm 6.0\%$, a mean forb cover of $4.7 \pm 8.1\%$, and a mean grass cover of $1.7 \pm 2.5\%$ (Table 2.3). The mean forb height was 9.8 ± 6.1 cm and the mean grass height was 10.8 ± 8.5 cm.

Grouse Sites Compare to Control Transects. —Forb cover was the only vegetation parameter in the model that differed at sage-grouse use and random sites ($P = 0.0376$). The odds that a sage-grouse used a site increased 1.7 times with every doubling of forb cover.

Habitat Use in Relation to Development

Individual Bird. —The average minimum distance observed between sage-grouse and natural gas wells was 670 m (Table 2.4). The smallest minimum distance observed

between a sage-grouse and a well was 168 m (4 males). The largest minimum distance observed between a grouse and a well was 6,055 m (broodless hen).

Compared to Random Points. —The mean distance from sage-grouse locations to the nearest well was less than random points at all seasonal ranges (summer/fall: 2896 ± 1877 m vs. 3624 ± 2150 m, $z = -2.0716$, $P = 0.0383$; winter/spring: 826 ± 380 m vs. 1064 ± 540 m, $z = -2.7971$, $P = 0.0052$; year-round: 2080 ± 1792 m vs. 2607 ± 1932 m, $z = -3.1893$, $P = 0.0015$).

Active vs. Inactive Wells. —Sage-grouse were located closer to active wells than inactive wells. The mean distance from sage-grouse locations to the nearest inactive well was greater than the mean distance from sage-grouse to the nearest active well in the summer/fall range and year-round population range (summer/fall: 3360 ± 1729 m vs. 1898 ± 1812 m, $z = -3.2861$, $P = .001$; year-round: 2707 ± 1848 m vs. 1274 ± 1349 m, $z = -4.8775$, $P < .0001$). In the winter range, sage-grouse mean distance to the nearest inactive well did not differ from random points (894 ± 347 m vs. 785 ± 396 m, $z = 1.2288$, $P = 0.2191$).

Thiessen Polygon Analysis. —Sage-grouse were located in habitat farther from wells (near Thiessen lines) more often than habitat located near wells (Fig. 2.8). Sage-grouse mean distance to the nearest Thiessen lines was less than the distance to the nearest well at all seasonal ranges (summer/fall: 458 ± 313 m vs. 2896 ± 1877 m, $P < 0.0001$; winter/spring 286 ± 248 m vs. 826 ± 380 m, $P < 0.0001$; year-round: 390 ± 300 m vs. 2080 ± 1792 m, $P < 0.0001$).

DISCUSSION

Lek Survey and Population Size

Lek counts indicated that the Seep Ridge sage-grouse population is declining. In 2007, I counted 27 birds attending leks and estimated that there were 108 sage-grouse in the population. In 2008, I counted only 9 birds attending leks and the population estimate decreased to 36 sage-grouse. These counts are consistent with the overall downward trend observed in the population since lek counts began in the 1980s (Utah Division of Wildlife Resources, unpublished data). Additionally, no new leks were located despite survey efforts.

Mortality and Reproductive Success

The annual mortality rate of the Seep Ridge sage-grouse population was high compared to other Utah sage-grouse populations. In Utah, annual mortality rates range from 22-85% (Bunnell 2000, Crompton and Mitchell 2005, Dahlgren 2006, Knerr 2007, Robinson 2007). The annual mortality rate of the Seep Ridge population was 63.6% in 2007 and 66.7% in 2008. Emma Park, another sage-grouse population in Utah experiencing energy development, also exhibited high mortality rates relative to other Utah sage-grouse populations (Table 2.5). Sage-grouse are a long-lived species that reproduces slowly, so the low adult survival rate of the Seep Ridge sage-grouse is cause for concern (Connelly et al. 2004).

Determining the reason for sage-grouse mortality proved difficult. Predator identification was also problematic for other researchers in Utah (Dahlgren 2006, Knerr 2007, Robinson 2007). I was able to attribute 5 mortalities to avian

predators, and 1 mortality to mammalian predation. However, I was unable to distinguish the cause of 8 sage-grouse mortalities. I was often unable to determine if the hair, scat, teeth marks, or prints I observed were that of a scavenger or the predator responsible for the mortality.

Currently, there is little consensus concerning seasonal sage-grouse mortality rates, and in Utah, seasonal mortality rates vary across populations (Crompton and Mitchell 2005, Knerr 2007, Robinson 2007). Typically, sage-grouse exhibit high winter survival rates (reviewed by Connelly et al. 2004), and the Seep Ridge sage-grouse population appears to be consistent with this observation. Most of the mortalities occurred in the fall from 26 September to 12 November. This sage-grouse population used a very small section of riparian habitat during this time period and it is possible that predators took advantage of high sage-grouse concentrations. The timing of the mortalities indicates that migrating raptors may be depredating sage-grouse and the desiccation of succulent upland forbs may also play a role.

Additionally, the timing of these mortalities suggests that WNV may be affecting the survival of Seep Ridge sage-grouse. West Nile virus reduced late-summer survival of radio collared sage-grouse by 25% in 4 populations in the western US and Canada (Naugle et al. 2004). In 2005, WNV was detected in a dead sage-grouse near Arcadia, Utah, which is located approximately 45 km northeast of the study area (B. D. Maxfield, UDWR, personal communication, 2008).

In Utah, brood success ranges from 20–66.7% (Crompton and Mitchell 2005, Knerr 2007, Robinson 2007). Only 1 of 14 (7.1%) Seep Ridge chicks observed during the study survived to 50 days of age. Reproductive success of the Seep Ridge population

was low, but the study was limited by the low number of radio collared female sage-grouse. However, given the low population size 12% of the hens in the population may have been monitored.

Arthropod Abundance and Composition

Unfortunately, low brood sample size and restrictions on Ute Tribal lands limited arthropod sampling. Arthropod sampling on tribal lands was not authorized in 2007, but was allowed in 2008. Research indicates that ants (Hymenoptera) and beetles (Coleoptera), are especially important aspects of young chick diets (Drut et al. 1994, Fischer et al. 1996). In Utah, ants and beetles also appear important aspects of chick diets (Knerr 2007, Robinson 2007), although availability of insect families likely varies according to location. Beetles were common in arthropod samples from Seep Ridge, but ant numbers were lower relative to other insect families.

Habitat Use

Seep Ridge sage-grouse are one-stage migratory, moving between 2 distinct seasonal ranges (Connelly et al. 2000). Initially, the Seep Ridge population was thought to be isolated. However, in 2008 I documented the movement of a hen from Seep Ridge to Ute tribal land. Sage-grouse are known to inhabit tribal lands, but very little is known about the status of these populations (K. Corts, Ute Tribe Fish and Wildlife, personal communication, 2008).

Nesting and brood rearing was documented near leks in areas that are currently proposed for development. Sage-grouse nests are generally located within 3.2 km of leks; therefore, when possible development should be restricted within 3.2 km of leks to

reduce negative effects of development on sage-grouse reproduction (Connelly et al. 2000). Others recommend more stringent protection measures including restricting development within 6.4 km of leks or within known seasonal ranges (Apa et al. 2008). The current lease stipulations restricting development within 0.25 miles of leks is likely inadequate for long-term sage-grouse population persistence. Additionally, drilling in the winter/spring range should occur from July to November when sage-grouse are generally absent.

Compared to recommended habitat guidelines, breeding sites contained less shrub, forb, and grass cover and brood rearing sites contained less canopy cover (Connelly et al. 2000). Additionally, the sage-grouse site use model indicated that sage-grouse selected sites with higher forb cover. This implies that providing sage-grouse with more forbs in the spring and summer ranges may be beneficial.

Development and Habitat Use Patterns

The sage-grouse habitat use and development analyses at 2 scales seem to provide contradictory results. Sage-grouse were located closer to natural gas wells than random points within seasonal ranges. Additionally, sage-grouse approached active wells more closely than inactive wells. On the other hand, the analysis with Thiessen polygons indicates that sage-grouse were located in habitat far from wells more often than habitat located near wells.

At a broad scale, the reason sage-grouse were located closer to natural gas than random points is likely related to the location of heavily developed project areas and sage-grouse site fidelity. Sage-grouse are known to display high levels of site fidelity to

seasonal habitats (Berry and Eng 1985, Fischer et al. 1993) and it is likely that Seep Ridge sage-grouse used their current seasonal ranges before energy development began. Coincidentally, highly developed natural gas fields are located directly north of areas frequently used by sage-grouse within seasonal ranges. Results from this broad scale analysis reflect sage-grouse site fidelity to probable traditional seasonal habitats in spite of imposing development.

At a smaller scale, however, the Thiessen polygon analysis implies that some aspect of energy development may be causing birds to use habitat located far from wells more often than habitat located near wells. It is important to note that sage-grouse habitat selection likely reflects a complex selection process that depends on multiple factors. Sage-grouse may select habitat based on vegetation characteristics, predation risk, site fidelity, slope, aspect, and elevation in addition to the presence of anthropogenic features. Nevertheless, the strong pattern observed in the analysis indicates that sage-grouse are avoiding some aspect of development.

Previous research demonstrates that sage-grouse avoid infrastructure associated with energy development (Holloran 2005, Aldridge and Boyce 2007) and scale may be an important aspect of habitat selection. Doherty et al. (2008) found that the addition of a variable quantifying coal bed natural gas well density improved sage-grouse habitat selection model fit by 6.66 Akaike's Information Criterion points at the 4 km² scale. Results from Seep Ridge sage-grouse habitat use analyses support findings that grouse selection within natural gas fields may be operating on a small scale similar to 4 km².

Management Implications

Mitigation efforts should focus on reducing adult mortality rates and protecting breeding habitat. To protect breeding habitat, I recommend reducing development within 3.2 km of leks and scheduling drilling only when sage-grouse are absent from the area (July – November). Efforts to reduce adult sage-grouse mortality rates should focus on habitats used by birds in the late summer and fall, when mortality rates were highest. During this time, many birds were concentrated in a small area of riparian habitat surrounded by dense greasewood stands. Providing more suitable habitat along Willow Creek by removing greasewood and increasing forb availability may increase adult survival.

However, the timing of these mortalities implies that WNV may be reducing sage-grouse populations. If this is the case, providing more forbs could attract more birds to the Willow Creek area, increasing WNV infection rates. Sage-grouse carcasses should be collected and tested for WNV when possible (Walker et al. 2004). If WNV is found to be a problem, efforts should focus on removing man-made water sources supporting breeding mosquitoes that are known to be a vector for the virus (Walker et al. 2007).

Analysis of sage-grouse habitat use in relation to natural gas wells indicates that sage-grouse have not been displaced by current development activities. However, birds used habitat located further away from natural gas wells more often than habitat located near wells, relative to well spacing nearby. As development intensifies, this preferred habitat will become less available to grouse and this could negatively affect population persistence. To reduce potential indirect habitat loss, surface well spacing should be maximized within sage-grouse seasonal ranges.

Research using Before-After/Control-Impact (BACI) designs would be a useful approach in determining sage-grouse response to features associated with development. Traffic levels, roads, types of wells, visibility of wells, and noise produced by wells are also likely involved in sage-grouse habitat use. I am not aware of any research to date that has been successful in isolating the effect of these aspects of development on sage-grouse. Additionally, use of GPS collars could provide a greater understanding of sage-grouse habitat use throughout the day and in winter when it is often difficult or impossible to follow sage-grouse movements.

If Seep Ridge sage-grouse are extirpated, conservation efforts should focus on preserving populations that could recolonize the Seep Ridge area. I recommend increasing efforts to preserve sage-grouse populations located on Ute tribal lands and the Book Cliffs.

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Table 2.1. Morphological measurements $X \pm SD$ (n) of Seep Ridge greater sage-grouse (*Centrocercus urophasianus*) in 2007 and 2008, Utah.

Age and sex	Mass (g)	Length P10 (mm)	Length P9 (mm)	Length P1 (mm)	Culmen length (mm)	Culmen width (mm)	Tail length (mm)	Tarsus length (mm)
Juvenile male	2400 \pm 354 (2)	171 \pm 13 (2)	215 \pm 16 (2)	143 \pm 6 (2)	38.0 \pm 0 (2)	14.0 \pm 0 (2)	276 \pm 49 (2)	62.5 \pm 3.5 (2)
Adult male	2640 \pm 241 (5)	176 \pm 7 (4)	222 \pm 20 (4)	152 \pm 8 (4)	39.0 \pm 1.4 (4)	18.4 \pm 0.5 (4)	226 \pm 105.2 (4)	67.6 \pm 2.1 (4)
Juvenile female	1400 \pm 0 (1)	143 \pm 0 (1)	192 \pm 0 (1)	121 \pm 0 (1)	31.0 \pm 0 (1)	19.0 \pm 0 (1)	198 \pm 0 (1)	57.0 \pm 0 (1)
Adult female	1690 \pm 70 (2)	-	-	-	-	-	-	-

Table 2.2. Arthropod volume at greater sage-grouse (*Centrocercus urophasianus*) brood rearing sites in 2007 and 2008, Utah.

Order	Mean \pm SD (mL)	Range
Hymenoptera (Ants)	0.08 \pm 0.10	0-0.30
Hymenoptera (Bees & Wasps)	0.18 \pm 0.18	0-0.40
Coleoptera	0.18 \pm 0.20	0-0.50
Lepidoptera	0.08 \pm 0.10	0-0.23
Orthoptera	0.16 \pm 0.37	0-1.00
Miscellaneous	0.96 \pm 1.80	0.05-5.00
Total Volume	1.64 \pm 1.77	0.14-5.28

Table 2.3. Vegetation characteristics at nest, brood, and adult sage-grouse (*Centrocercus urophasianus*) sites, Seep Ridge, Utah, 2007 and 2008.

	Mean Percent Cover (SD)			Height (cm) (SD)	
	Shrub	Forb	Grass	Forb	Grass
Nest	14.1 (3.0)	5.0 (4.0)	13.1 (2.5)	5.9 (2.9)	10.9 (2.8)
Brood	9.1 (8.3)	19.2 (19.0)	1.5 (3.2)	18.1 (13.1)	10.2 (13.7)
Adult	13.5 (6.0)	4.7 (8.1)	1.7 (2.5)	9.8 (6.1)	10.8 (8.5)

Table 2.4. Descriptive statistics for Seep Ridge greater sage-grouse (*Centrocercus urophasianus*) habitat use in a natural gas field, 2007-2008. The distance (m) to natural gas wells with infrastructure in place is reported for each radio-collared bird.

Bird ID	n	Minimum Distance (m)	Maximum Distance (m)	Average Distance (m)
SR929407	23	168	1274	654 ± 302
SR931207	20	168	4229	1591 ± 1397
SR937207	17	168	4511	1644 ± 1744
SR951307	24	168	4553	1379 ± 1457
SR944207	19	222	3730	1949 ± 1591
SR959508	14	224	5279	1703 ± 1912
SR983308	16	240	4846	2951 ± 2012
SR924507	14	251	1075	636 ± 292
SR912208	6	269	1345	956 ± 491
SR968307	48	357	5019	3114 ± 1823
SR979407	22	367	4406	2035 ± 1485
SR963108	5	392	2797	1027 ± 998
SR941207	19	393	3729	1143 ± 911
SR977307	20	501	3729	2087 ± 1209
SR918407	1	770	770	770 ± 0
SR971308	3	6055	6380	6205 ± 164
Average	17	670	3604	1865 ± 1112

Table 2.5. Annual mortality rates of greater sage-grouse (*Centrocercus urophasiaunus*) populations in developed and undeveloped sagebrush habitat in Utah.

Location	Energy Development	Year	Annual Mortality Rate	Reference
Emma Park	Y	2000-2005	87.5%	Crompton and Mitchell 2005
Strawberry Valley	N	1998	71.0%	Bunnell 2000
Seep Ridge	Y	2008	66.7%	
Strawberry Valley	N	1999	64.0%	Bunnell 2000
Seep Ridge	Y	2007	63.6%	
Sheeprock	N	2006	52.0%	Robinson 2007
Box Elder	N	2005	41.7%	Knerr 2007
Anthro Mountain	N	2008	39.0%	Christensen 2009, personal com.
Sheeprock	N	2005	36.8%	Robinson 2007
Deep Creek	N	2006	36.4%	Robinson 2007
Parker Mountain	N	2003	36.0%	Dahlgren 2005
Box Elder	N	2006	35.1%	Knerr 2007
Emma Park	N	2000-2005	27.0%	Crompton and Mitchell 2005
Parker Mountain	N	2004	22.0%	Dahlgren 2006
Deep Creek	N	2005	0.0%	Robinson 2007

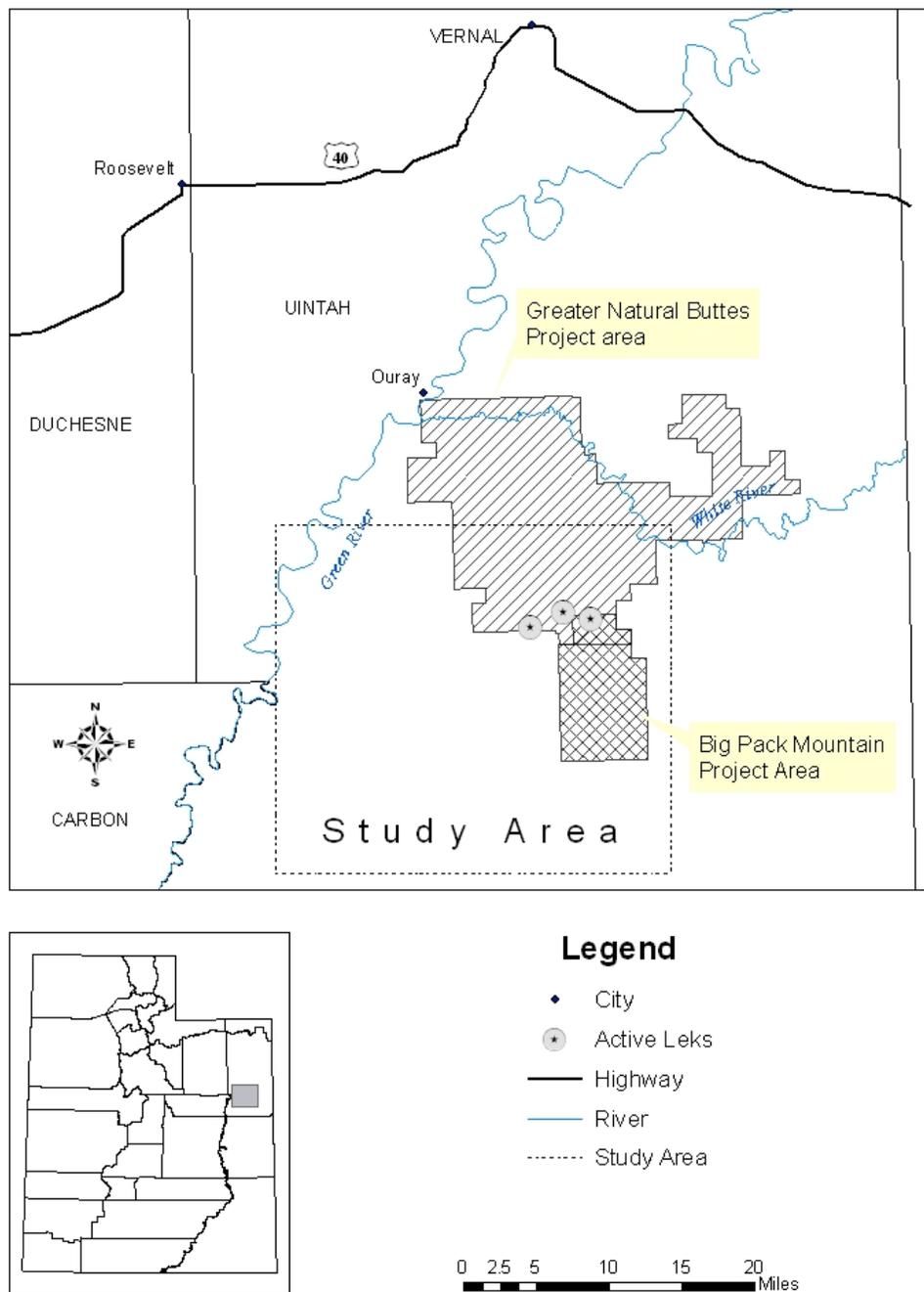


Fig. 2.1. Seep Ridge study area 2007-2008, Utah.

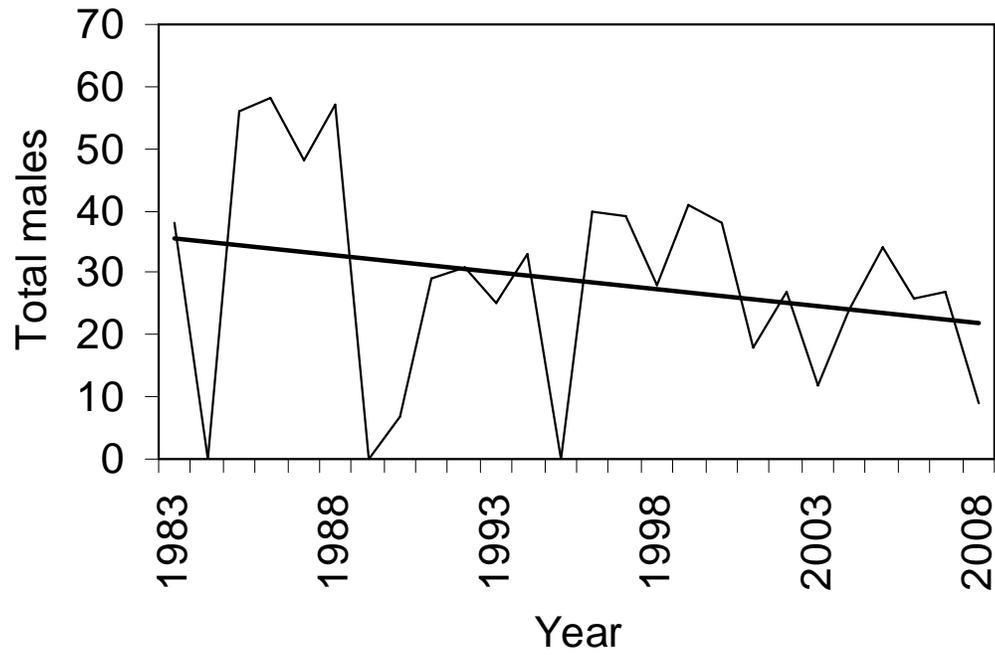


Fig. 2.2. Maximum count of male greater sage-grouse (*Centrocercus urophasianus*) attending leks in the Seep Ridge study area (Utah Division of Wildlife Resources, unpublished data). Lek counts were not conducted in 1984, 1989, or 1995.

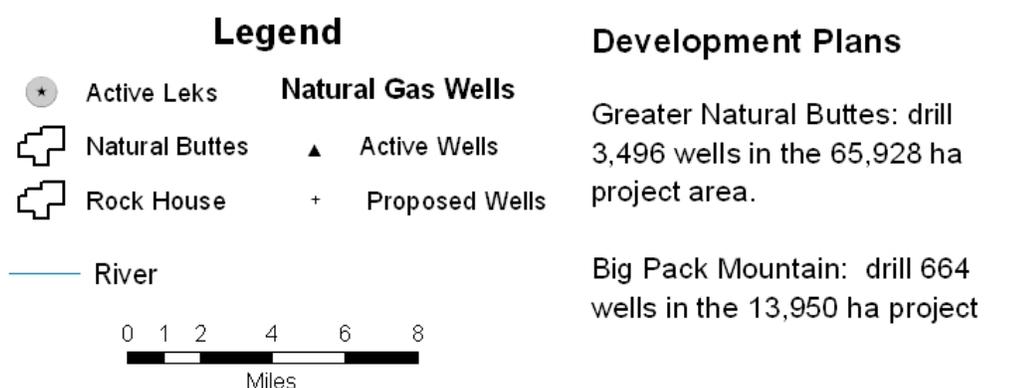
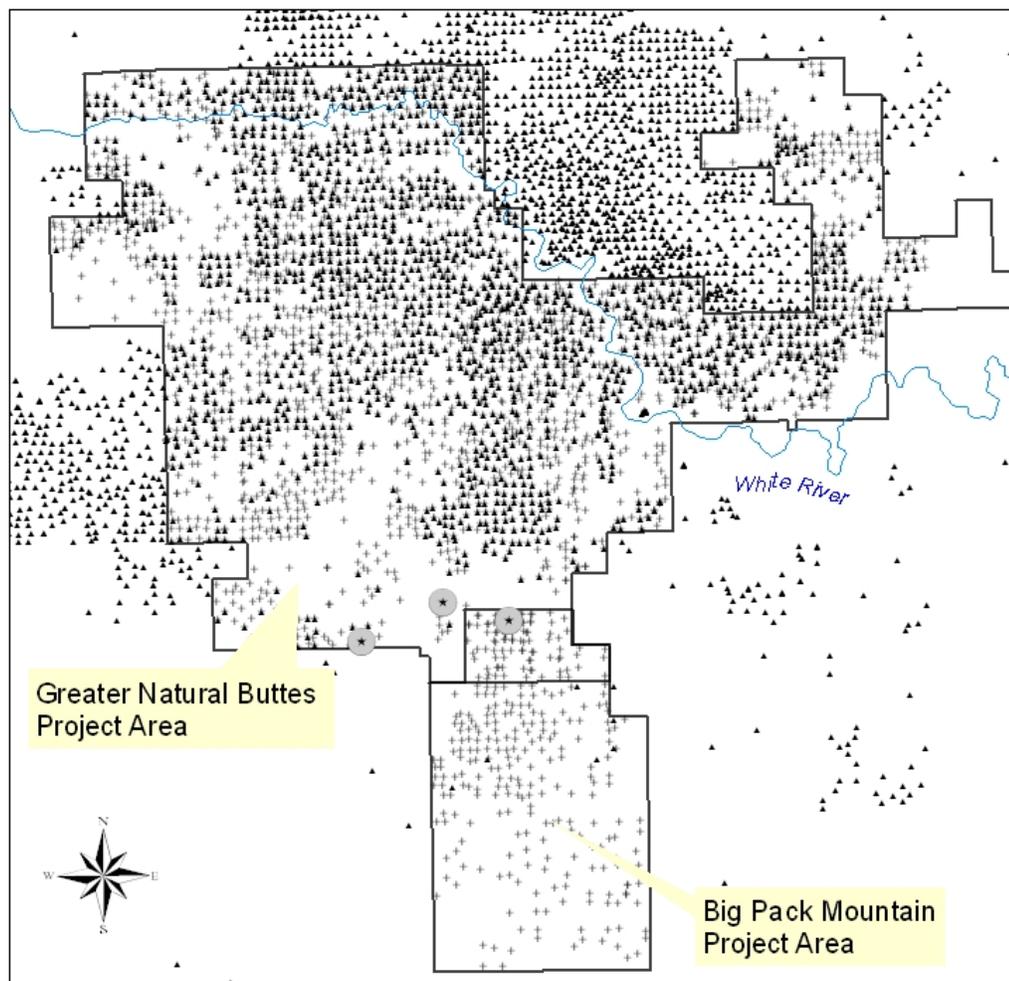


Fig. 2.3. Prospective energy development plans for Seep Ridge, Utah in relation to active sage-grouse leks (Utah Division of Oil, Gas, and Mining data, 2008).

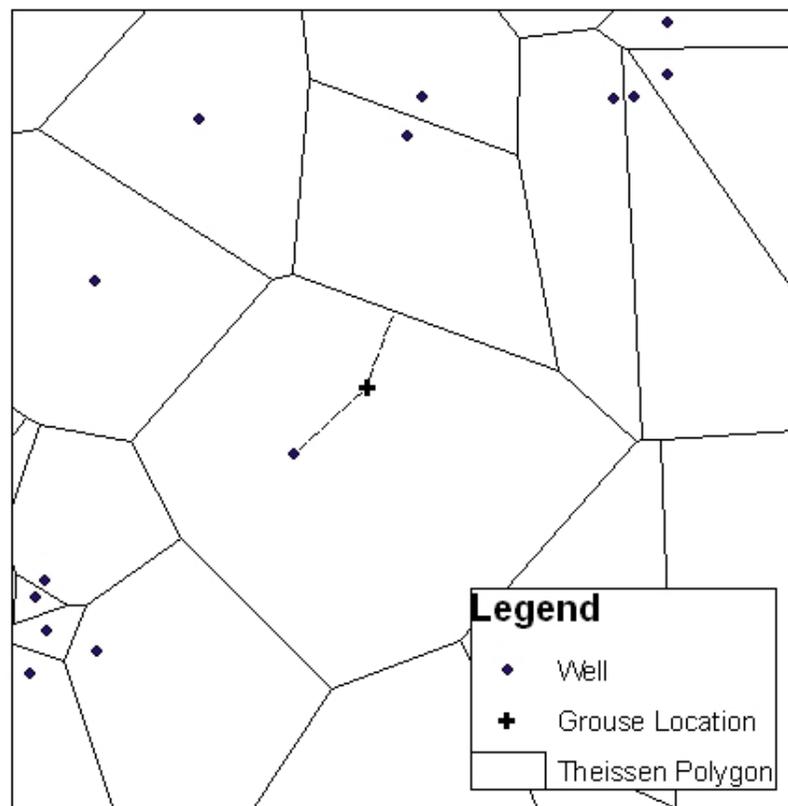


Fig. 2.4. Example of Thiessen polygons constructed around natural gas wells, 2008. The polygon boundary represents habitat located as far as possible from natural gas wells, relative to well spacing in the area.

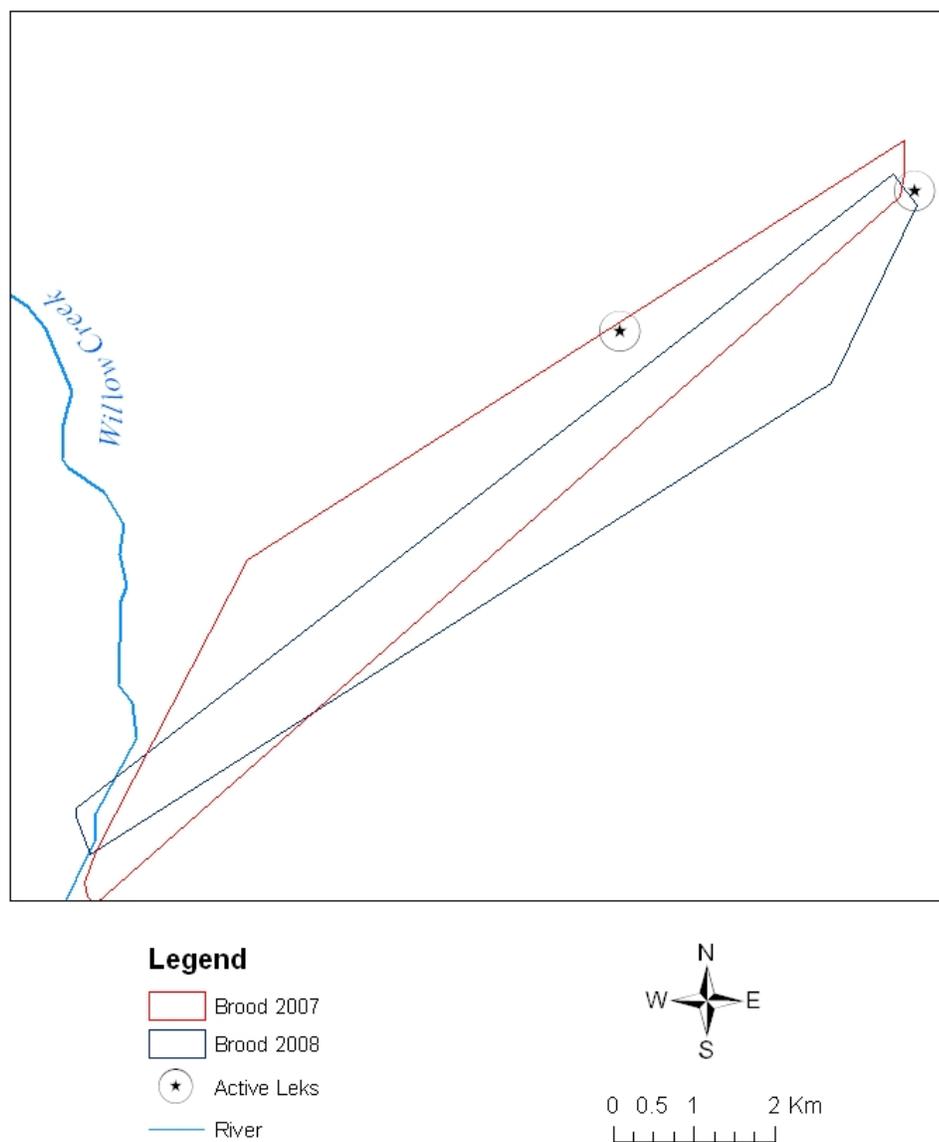


Fig. 2.5. Home ranges of greater sage-grouse (*Centrocercus urophasianus*) broods in 2007 and 2008, Utah.

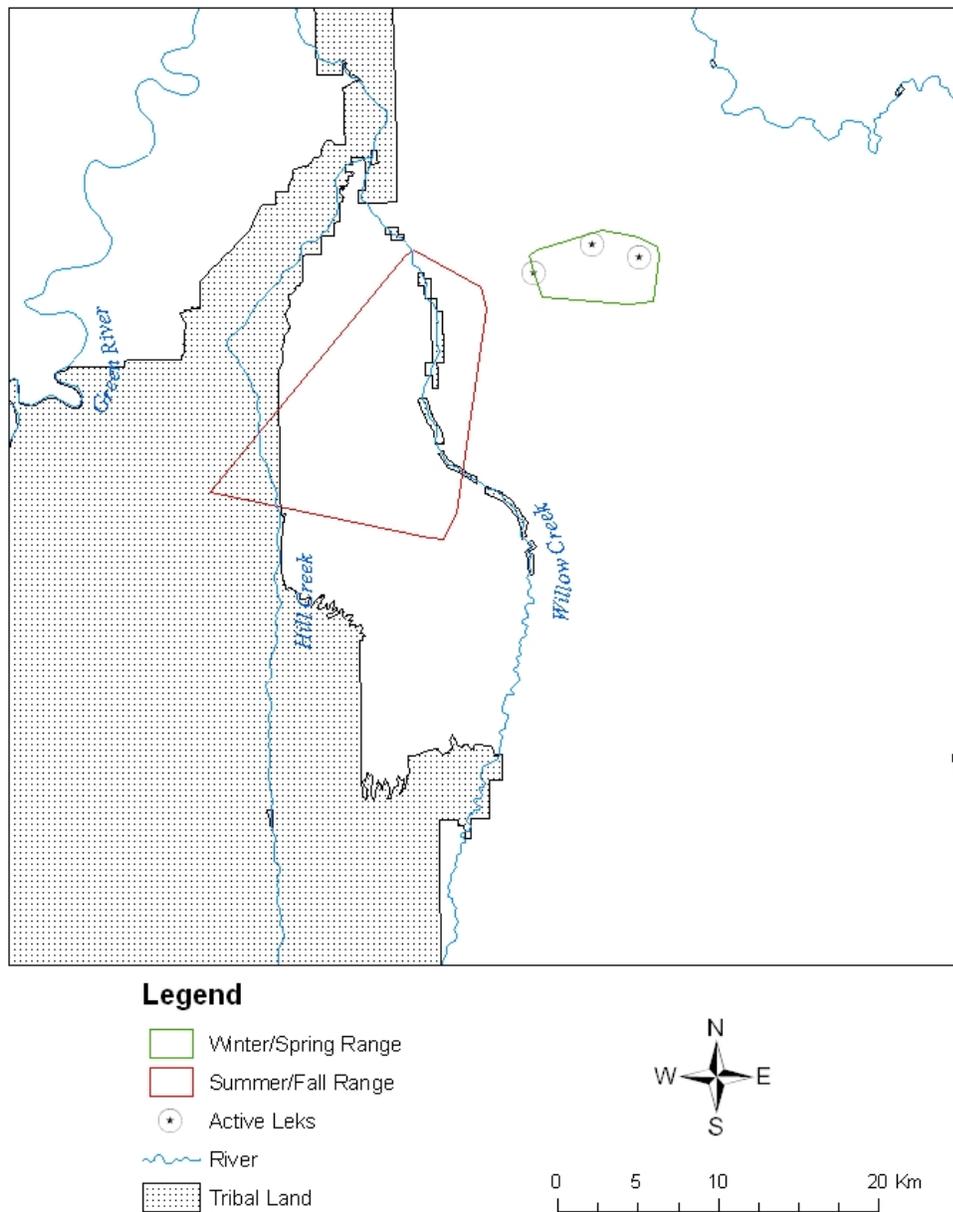


Fig. 2.6. Seasonal habitat used by Seep Ridge greater sage-grouse (*Centrocercus urophasianus*) in 2007 and 2008, Utah.

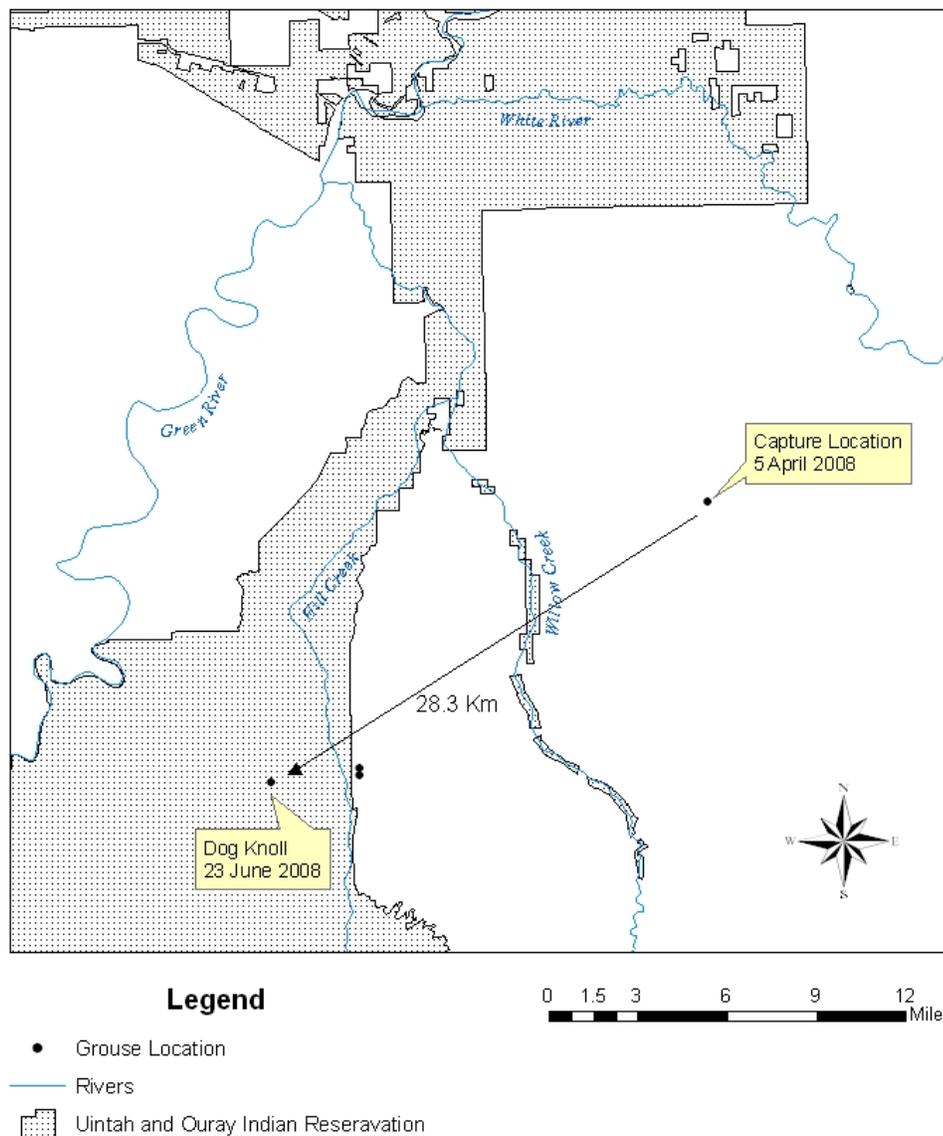


Fig. 2.7. Long distance movement of a female greater sage-grouse (*Centrocercus urophasianus*) from the capture site to Dog Knoll, which is located on the Uintah and Ouray Indian Reservation, 2008, Utah.

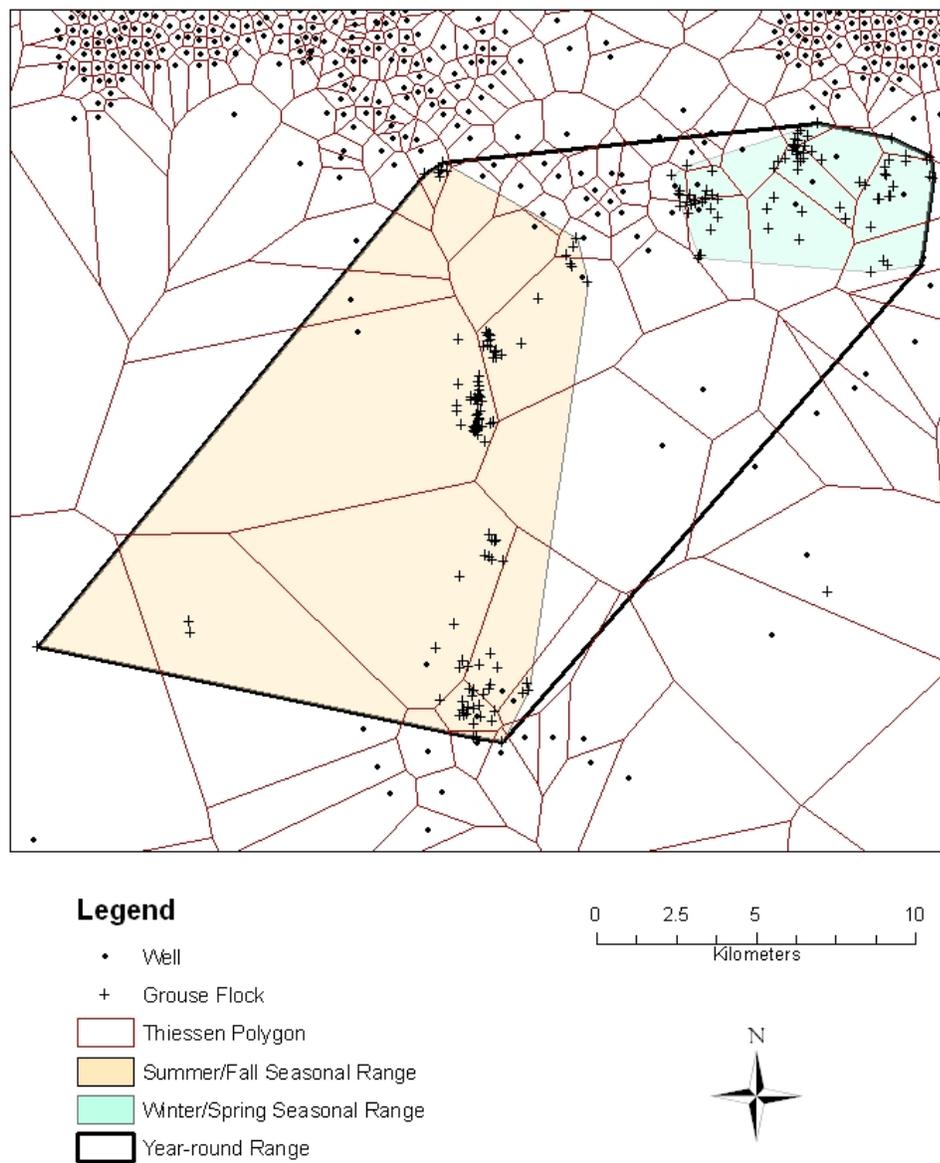


Fig. 2.8. Greater sage-grouse (*Centrocercus urophasianus*) flock locations and Thiessen polygons constructed around wells.

CHAPTER 3

THE DISTRIBUTION OF GREATER SAGE-GROUSE MITOCHONDRIAL HAPLOTYPE DIVERSITY IN NORTHEASTERN UTAH

ABSTRACT: Greater sage-grouse (*Centrocercus urophasianus*) population declines throughout the western United States have been attributed to the loss, degradation, and fragmentation of sagebrush habitats. Increased energy development may further fragment sagebrush habitat isolating sage-grouse populations and resulting in genetic drift, inbreeding, local extinction, or rapid divergence. I conducted a genetic survey of 3 small sage-grouse populations in northeastern Utah to assess mitochondrial diversity relative to other portions of the species range. I did not detect any unusual haplotype compositions in these populations, indicating that gene flow may currently be occurring and that the populations may not be as isolated as previously believed. However, differences in haplotype composition between the Anthro and Strawberry Valley populations and other northeastern Utah populations imply that there may be a barrier to gene flow in this area. I recommend that translocations between these populations do not occur until it is known that differences in haplotype proportions do not reflect potentially adaptive differences in ecology and morphology. I also recommend that biologists continue collecting samples from populations in northeastern Utah to make informed decisions concerning translocations and to provide insight into population structure and divergent evolution.

INTRODUCTION

Rangewide greater sage-grouse (*Centrocercus urophasianus*) population declines have largely been attributed to increased habitat fragmentation, resulting in small isolated populations (Connelly et al. 2004, Schroeder et al. 2004). With increasing habitat fragmentation, populations may lose genetic variability, thus reducing their ability to respond to changing environmental conditions and increasing susceptibility to disease (Frankham 1995, Frankham et al. 1999, Reed and Frankham 2003). Genetic drift and inbreeding may also reduce the likelihood of population persistence (Allendorf and Luikart 2007).

Recent population genetic studies of sage-grouse focused on assessing taxonomic relationships and describing genetic variation across their range (Kahn et al. 1999, Oyler-McCance et al. 1999, Benedict et al. 2003, Oyler-McCance et al. 2005a). Genetic data (Kahn et al. 1999, Oyler-McCance et al. 1999), in combination with morphological (Hupp and Braun 1991) and behavioral data (Young et al. 2000) led to the identification of a new grouse species, the Gunnison sage-grouse (*C. minimus*) in southwestern Colorado and southeastern Utah. Additionally, Benedict et al. (2003) did not find genetic data to support the long-questioned greater sage-grouse western subspecies delineation.

In Utah, greater sage-grouse (hereafter sage-grouse) are currently estimated to occupy 41.4% of their historic pre-settlement range (Beck et al. 2003, Fig. 3.1). Data from the Oyler-McCance et al. (2005a) range-wide survey indicated that the Strawberry Valley, UT and Parker Mountain (Wayne), UT sage-grouse populations have low amounts of gene flow due to fragmentation and isolation. These populations cluster together in analyses of microsatellite data indicating that they have similar haplotype

compositions. Additionally, the Strawberry Valley population contained low genetic diversity and showed signs of a recent bottleneck.

Small populations of sage-grouse in northeastern Utah are also likely to suffer from reduced gene flow and low genetic diversity. Rapid energy development is currently fragmenting remaining sagebrush habitat in this area (Bureau of Land Management 2007, 2008). However, no genetic data exists for northeastern Utah populations and translocations may become necessary in the future to sustain them. Additionally, sage-grouse from the Seep Ridge population in northeastern Utah appeared to be much larger physically than other Utah sage-grouse (Smith, unpublished data) and occupy atypical habitat; hence, it is important from a conservation standpoint to determine whether this population is genetically unique.

The purpose of my research was to describe the mitochondrial genetic diversity of 3 small sage-grouse populations in northeastern Utah relative to other portions of the species range. Genetic data for these populations will be helpful in informing decisions concerning translocations, identifying genetically unique populations, and locating populations that may suffer from inbreeding.

STUDY AREA

Genetic samples were collected from 3 sage-grouse populations (Anthro Mountain, Deadman Bench, and Seep Ridge) in northeastern Utah (Fig. 3.2). The Anthro Mountain population is located approximately 25 km south of Duchesne, UT. Anthro Mountain consisted of sagebrush (*Artemisia* spp.) intermixed with stands of quaking aspen (*Populus tremuloides*) at an elevation of 2,600 m. The elevation and habitat is

typical for sage-grouse (Schroeder et al. 1999, Connelley et al. 2000). In 2008, the population consisted of approximately 52 birds (R. Christensen, National Forest Service, personal communication, 2008).

The Deadman Bench population is located approximately 40 km southeast of Vernal, UT and the Seep Ridge population is located approximately 65 km south of Vernal, UT. Both sites consisted of sagebrush intermixed with some stands of pinyon (*Pinus edulis*) and Utah juniper (*Juniperus utahensis*) at an elevation of 1,750 m. The elevation is typical for sage-grouse, however, the habitat occupied by these populations appears to contain less shrub, forb, and grass cover than recommended in sage-grouse habitat guidelines (Connelly et al. 2000, B.D. Maxfield, Utah Division of Wildlife Resources, personal communication, 2008, Smith, unpublished data). In 2008, the Deadman Bench and Seep Ridge population estimates were 20 and 36 birds, respectively (B.D. Maxfield, Utah Division of Wildlife Resources, personal communication, 2008).

These 3 populations are not connected by continuous sagebrush habitat. Desert shrubland and pinyon juniper habitat may act as a barrier to dispersal between populations.

METHODS

Capture and Sample Collection

Grouse were located and trapped by spotlighting roost sites at night. Birds were captured with a long-handled hoop net from the back of an all terrain vehicle and placed in a small sack to minimize stress (Giesen et al. 1982, Wakkinen et al. 1992). Each captured bird was weighed and fitted with a necklace mounted, battery-powered radio-

transmitter. The sex and age of each captured bird was determined according to mass and plumage characteristics (Beck et al. 1975). Trappers collected blood samples from clipped grouse toenails on Nobuto blood filter strips. Silver nitrate was applied to the toenail if bleeding did not stop after applying pressure with a cotton ball. Utah State University Institutional Animal Care and Use Committee protocols were followed (IACUC Permit # 1332).

At the Seep Ridge and Deadman Bench sites, trappers measured the tarsus (middle toe to proximal end of tarsus), exposed culmen length and width (Pyle et al. 1987), tail length (ruler inserted between the coverts and retrices), and the lengths of primaries 10 (ruler inserted between P10 and P9), 9 (ruler inserted between P9 and P8) and 1 (ruler inserted between P1 and P2). Morphometric data was not collected for grouse at the Anthro Mountain site.

DNA Extraction and Amplification

DNA from blood samples was extracted, amplified, and sequenced in the Molecular Ecology laboratory at Utah State University. Utah Division of Wildlife Resources and U.S. Forest Service personnel collected and provided genetic samples from the Deadman Bench and Anthro Mountain populations, respectively.

The DNA extractions were conducted using a salting-out extraction method modified from Sunnucks and Hales (1996). Blood samples were incubated with proteinase K in 300 microliters (ul) TNES buffer (1 M Tris-HCl (pH 8.0), 0.5 M EDTA (pH 8.0), 5 M NaCl, and 10% SDS) overnight at 55°C. After incubation, 85 ul of NaCl was added followed by centrifuging at 13,500 RPM for 10 minutes to pellet the proteins.

The supernatant was pipetted into a new tube. An equal volume of cold 100% ethanol was added to the supernatant and it was spun again for another 10 minutes to pellet the DNA. The ethanol was carefully poured off, making sure the DNA pellets remained in the tube. The DNA pellets were rinsed a final time using 75% ethanol, and centrifuged for 5 minutes. The ethanol was removed again, and the pellets were dried in microvials for a few minutes before being suspended in 40 ul of 0.1X TE.

Polymerase Chain Reactions (PCRs) were performed using previously described primers 16775L (Quinn 1992) and 521H (Quinn and Wilson 1993), followed by a nested PCR with primer 418H (Quinn and Mindell 1996) to amplify a highly variable section of mitochondrial control region I (Kahn et al. 1999). Amplifications were carried out on Applied Biosystems Inc. (ABI) 2720 and 9700 thermalcyclers (Applied Biosystems, Inc., Forest City, CA) in 25 ul volumes with 200gM 2'-Deoxyadenosine 5'- Triphosphate, 2'-Deoxycytidine 5'-Triphosphate, 2'-Deoxyguanosine 5'-Triphosphate, and 2'-Deoxythymidine 5'-Triphosphate (dNTPs), 1.5mM MgCl, 1x PCR buffer, 0.3gM primers, 0.5 Units of Taq polymerase (New England Biolabs Inc., Ipswich, MA), and 50 ng DNA template. Conditions consisted of preheating to 92°C for 2 minutes followed by 30 cycles of amplification consisting of denaturing 94°C for 30 seconds, annealing 56°C for 30 seconds, and an extension at 72°C for 2 minutes. A final extension was carried out for 10 minutes at 72°C.

The quantity and quality of PCR products was assessed with electrophoresis. Two ul of PCR product was electrophoresed through a 0.7 % agarose gel in 1X TBE and 10 mg/mL ethidium bromide (EtBr) and visualized with a UV box. The PCR product

was purified using the Qiagen QIAquick PCR purification Kit (Qiagen, Spin Handbook, 2006).

Mitochondrial Sequencing

Sequencing reactions were conducted with an ABI BigDye Terminator Kit v3.1 and reaction products were separated and visualized using an ABI PRISM 3730 Genetic Analyzer. Contiguous sequences for each individual were constructed and aligned using SEQMAN and MEGALIGN software (DNASTAR Inc., Madison, WI).

Data Analysis

I used MEGA 4.0.2 (Tamura et al. 2007) software to compare sequenced haplotypes to previously described haplotypes available in Gen Bank, and to explore haplotype phylogeny. I used ArcGIS 9.2 (ESRI, Redlands, CA) Geographic Information System (GIS) software to create maps.

RESULTS

Capture

In 2008, 17 blood samples were collected from northeastern Utah sage-grouse. Seven samples were collected from the Anthro Mountain population, 7 from the Seep Ridge population, and 3 samples were collected from the Deadman Bench population. The body mass of Seep Ridge and Deadman Bench sage-grouse were within the range of previously reported masses (reviewed in Hupp and Braun 1991, Table 3.1). The tarsus length of adult male Seep Ridge grouse (67.6 ± 2.1 mm) was shorter than tarsus lengths reported for Gunnison sage-grouse, which are generally smaller than greater sage-grouse.

The tarsus length of adult male Deadman Bench grouse (71.5 ± 2.1 mm) was intermediate between Colorado greater sage-grouse and Gunnison sage-grouse. The culmen length for Seep Ridge sage-grouse was slightly shorter than values reported for Colorado greater sage-grouse.

Mitochondrial Analysis

Six mtDNA haplotypes were identified in the 17 individuals assayed (Table 3.2). Of these 6 haplotypes, 1 is newly described (Accession no XXXXXXXXX). Seep Ridge contained 4 haplotypes, Deadman Bench contained 1 haplotype, and Anthro Mountain contained 2 haplotypes (Fig. 3.3). Haplotypes from northeastern Utah fell into both of the distinct monophyletic clades (clade I and clade II) described by Kahn et al. (1999). The new haplotype (DU) was observed in the Anthro Mountain population (1 out of 7 samples) and involved a transversion of 1 base pair. This haplotype falls into clade I (data not shown) (Kahn et al. 1999, Benedict et al. 2003, Oyler-McCance et al. 2005a).

DISCUSSION

Sage-grouse haplotypes fall into 2 distinct clades that are thought to represent ancestral isolation of sage-grouse populations that occurred 85,000 years ago during the Pleistocene (Kahn et al. 1999, Benedict et al. 2003, Oyler-McCance et al. 2005a).

Interpretation of haplotype distance trees is difficult because haplotypes from these 2 clades reflect environmental conditions that no longer exist, and populations often have mixtures of haplotypes from both clades. For example, Gunnison sage-grouse share many haplotypes with greater sage-grouse including the common haplotypes A and D, but differ according to haplotype proportions (Kahn et al. 1999, Oyler-McCance et al.

2005b). For this reason, previous research has focused on the distribution of haplotypes regardless of clade when addressing population structure (Kahn et al. 1999, Benedict et al. 2003).

Two haplotypes were found in the Anthro Mountain population. The most commonly observed haplotype was DR (Clade I; n = 6 out of 7 samples), which is uncommon and previously only found in the Strawberry Valley sage-grouse population (Oyler-McCance et al. 2005a). Strawberry Valley is located approximately 100 km from Anthro Mountain and there are no obvious barriers to gene flow between the two areas. The other haplotype observed, DU (n = 1 out of 7 samples) is newly described here. This haplotype is similar to the DR haplotype (Oyler-McCance et al. 2005a) and falls into clade I. Anthro Mountain grouse did not share any haplotypes with the Seep Ridge and Deadman Bench populations.

Only 1 haplotype (B) was observed in the Deadman Bench population. Morphological measurements for Deadman grouse were within ranges reported for greater sage-grouse in Colorado with the exception of tarsus length (Hupp and Braun 1991). Deadman grouse tarsus length was intermediate between values reported for greater and Gunnison sage-grouse.

Seep Ridge contained the greatest diversity of haplotypes with 4 haplotypes observed in 7 samples (D n = 1, B n = 3, ER n = 2, Z n = 1). Haplotype B is widely distributed (Kahn et al. 1999, Benedict et al. 2003, Oyler-McCance et al. 2005a). Haplotypes D and Z are less common and usually found in Colorado (Kahn et al. 1999, Oyler-McCance et al. 2005a). The haplotype ER is rare with only one copy observed in Weston, WY (Oyler-McCance et al. 2005a).

No novel haplotypes or unusual haplotype compositions were observed in the Seep Ridge population indicating that there may be current gene flow between Seep Ridge and nearby populations located in Colorado and Utah. Additionally, with the exception of tarsus length, Seep Ridge sage-grouse morphometrics were similar to previously reported values (Hupp and Braun 1991). However, limited sample size precluded an examination of population level structure and haplotypes observed in this study may not reflect adaptive genetic evolution that has occurred more recently. Also, Seep Ridge sage-grouse occupy atypical habitat containing less shrub, forb, and grass cover than recommended in habitat guidelines (Connelly et al. 2000).

Haplotype composition of the populations indicate that the Anthro Mountain population is genetically most similar to the Strawberry Valley population, while the Seep Ridge and Deadman Bench populations are most similar to grouse from Diamond Mountain, UT, Blue Mountain, UT, and Colorado. Considering that the Seep Ridge and Anthro Mountain populations are only 80 km apart it is interesting that they do not share haplotypes. One explanation is that haplotype distributions may not reflect current movements of individuals between populations. Mitochondrial DNA is maternally inherited, so movements of male grouse between populations could go undetected. However, sage-grouse dispersal is not well understood and it is difficult to determine if this is a likely scenario (Connelly et al. 2004). Alternatively, it is possible that Desolation Canyon of the Green River has acted as a long term barrier between these populations, limiting gene flow. In northeastern Utah, ruffed grouse (*Bonasa umbellus*) only occur on the west side of the Green River and the river may limit sage-grouse

movements as well (B. D. Maxfield, Utah Division of Wildlife Resources, personal communication, 2009).

Management Implications

Results from this study do not provide evidence that the Seep Ridge population is genetically distinct. However, analysis was limited by low sample size and divergent evolution should be the subject of further study. In the future, fragmentation due to natural gas development and other anthropogenic activities may isolate the small sage-grouse populations in northeastern Utah. Artificially simulating gene flow may become a necessary aspect of management to counteract the negative effects of inbreeding and genetic drift. I recommend that biologists continue collecting genetic samples from these populations as well as additional populations from northeastern Utah to inform decisions concerning translocation and aid in developing management strategies that account for population structure and genetic distinctiveness. Specifically, analysis of microsatellites could aid in identifying populations that suffer from inbreeding.

As indicated by previous researchers, local adaptation of sage-grouse populations is likely and care should be taken to avoid outbreeding depression when considering translocations (Oyler-McCance et al. 2005a). Before conducting translocations, habitat (Connelly et al. 2000) and morphological data (Hupp and Braun 1991) could be used to assess adaptive variation. In northeastern Utah, the apparent boundary between the Anthro Mountain and Strawberry populations and other northeastern Utah populations will be important to consider during translocations. Until it is clear that these differences in mitochondrial haplotype frequencies do not reflect differences in ecology and

morphology, I recommend that translocations between these populations do not occur. However, if translocations to the Anthro Mountain or Strawberry Valley populations are necessary, I recommend that grouse are moved from the Parker Mountain population in Utah because previous population structure research has shown that these populations cluster together, indicating that they have similar haplotype compositions (Oyler-McCance et al. 2005a).

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Table 3.1. Morphological measurements $X \pm SD$ (n) of Seep Ridge and Deadman Bench greater sage-grouse (*Centrocercus urophasianus*) in 2007 and 2008, Utah.

Site	Age sex	Mass (g)	Length P10 (mm)	Length P9 (mm)	Length P1 (mm)	Culmen length (mm)	Culmen width (mm)	Tail length (mm)	Tarsus length (mm)
Seep Ridge	Juvenile male	2400 ± 354 (2)	171 ± 13 (2)	215 ± 16 (2)	143 ± 6 (2)	38.0 ± 0 (2)	14.0 ± 0 (2)	276 ± 49 (2)	62.5 ± 3.5 (2)
	Adult male	2640 ± 241 (5)	176 ± 7 (4)	222 ± 20 (4)	152 ± 8 (4)	39.0 ± 1.4 (4)	18.4 ± 0.5 (4)	226 ± 105.2 (4)	67.6 ± 2.1 (4)
	Juvenile female	1400 ± 0 (1)	143 ± 0 (1)	192 ± 0 (1)	121 ± 0 (1)	31.0 ± 0 (1)	19.0 ± 0 (1)	198 ± 0 (1)	57.0 ± 0 (1)
	Adult female	1690 ± 70 (2)	-	-	-	-	-	-	-
Deadman Bench	Adult Male	2790 ± 57 (2)	171 ± 6 (2)	219 ± 6 (2)	161 ± 15 (2)	38.5 ± 0.7 (2)	12.5 ± 2.1 (2)	308 ± 4 (2)	71.5 ± 2.1 (2)
	Adult Female	1550 ± 0 (1)	135 ± 0 (1)	180 ± 0 (1)	135 ± 0 (1)	32 ± 0 (1)	14 ± 0 (1)	110 ± 0 (1)	68.0 ± 0 (1)

Table 3.2. Observed numbers of haplotypes in northeastern Utah greater sage-grouse (*Centrocercus urophasianus*) populations. Italicized haplotypes are from clade I and bold haplotypes are from clade II (Kahn et al. 1999).

Population	Haplotype					
	<i>B</i>	<i>D</i>	<i>DR</i>	<i>DU</i>	<i>ER</i>	<i>Z</i>
Anthro Mountain	0	0	6	1	0	0
Deadman Bench	3	0	0	0	0	0
Seep Ridge	3	1	0	0	2	1

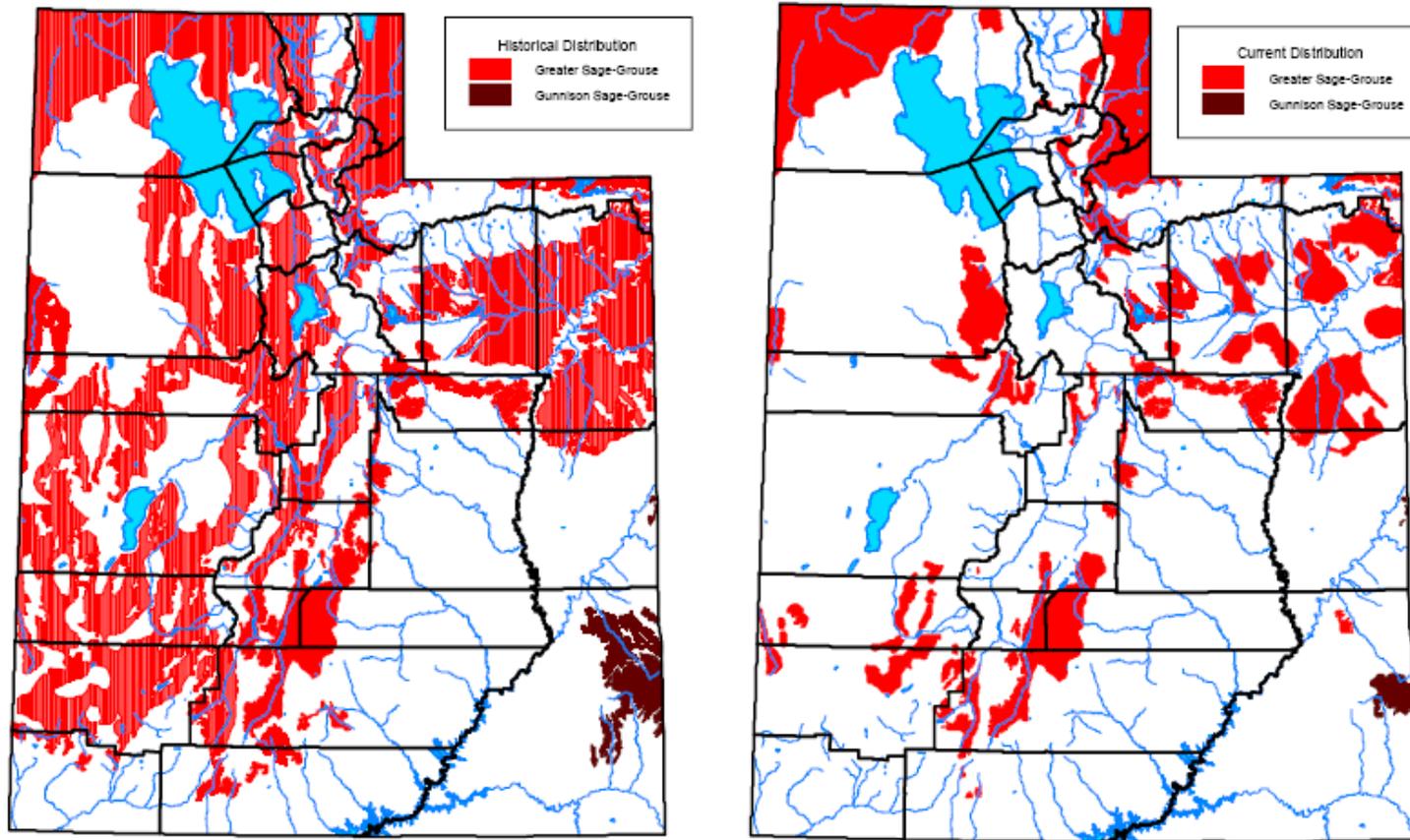


Fig. 3.1. Historic pre-settlement distribution and current distribution of sage-grouse (*Centrocercus* spp.) as of 2003 in Utah (Beck et al. 2003).

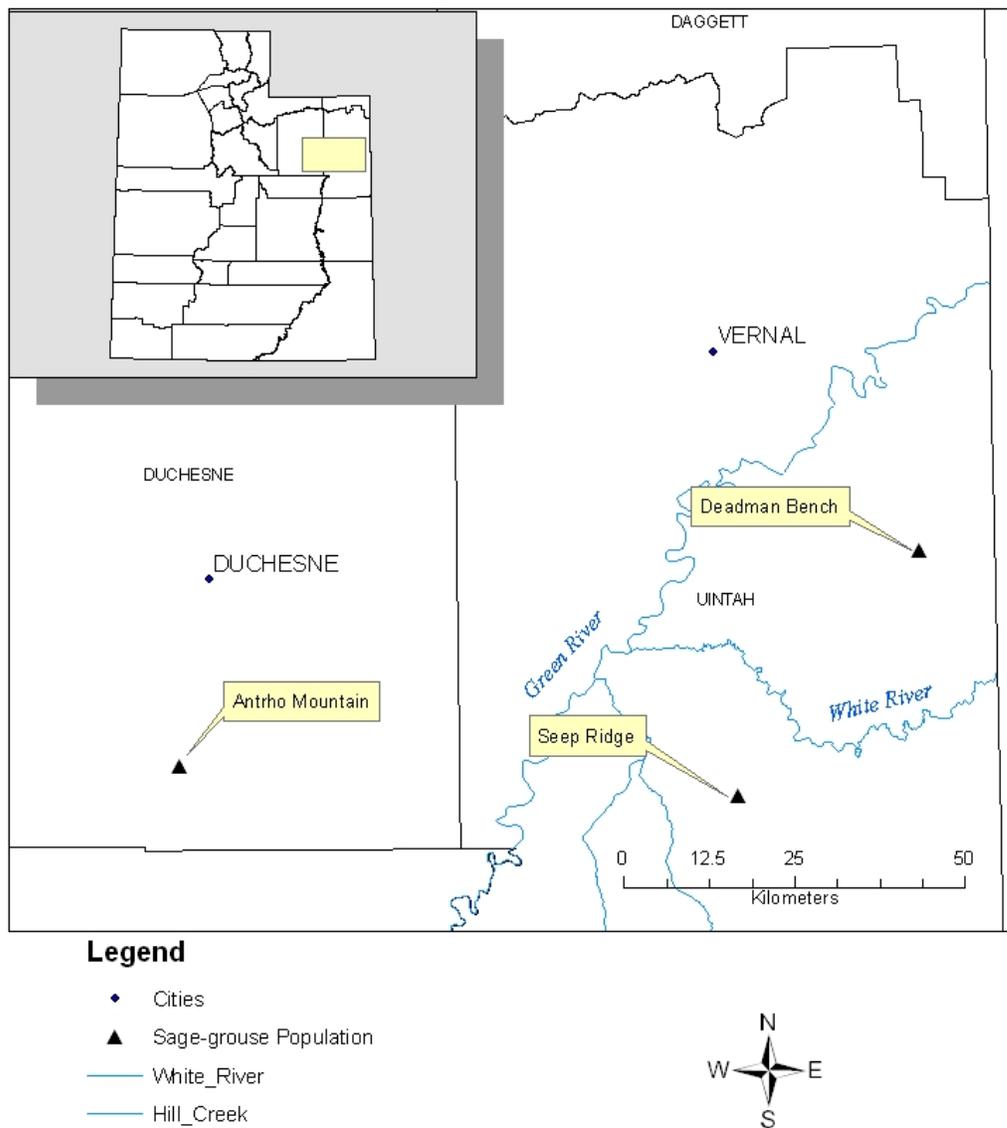
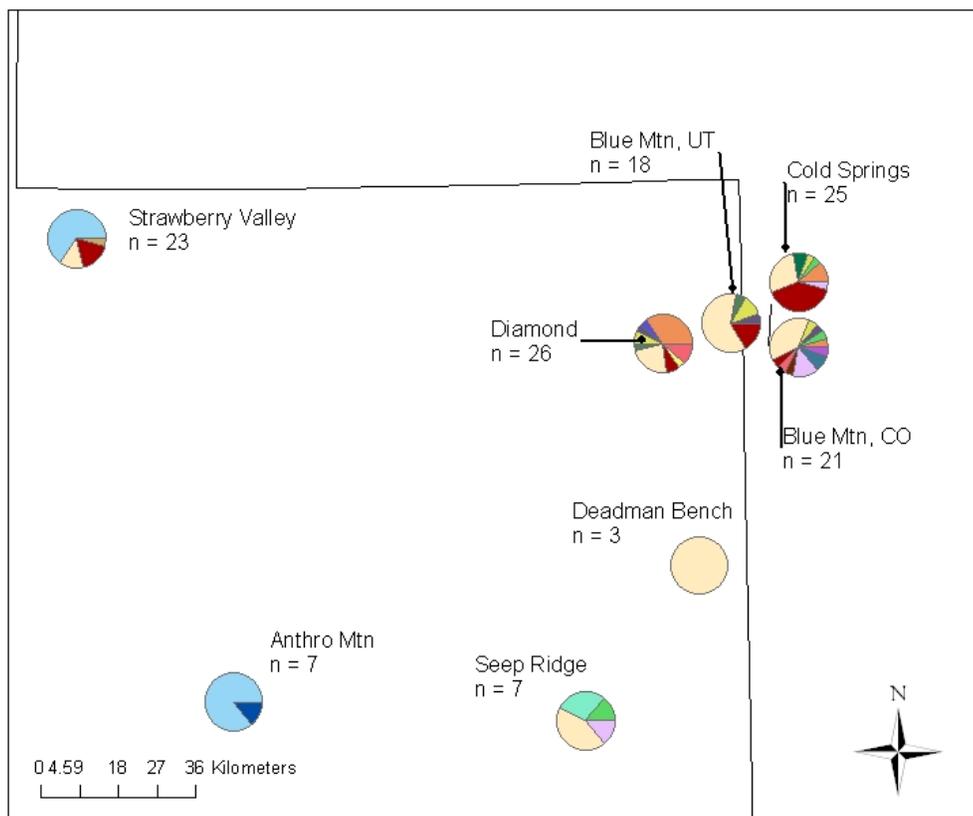


Fig. 3.2. Locations of greater sage-grouse (*Centrocercus urophasianus*) populations.



Legend

Haplotypes

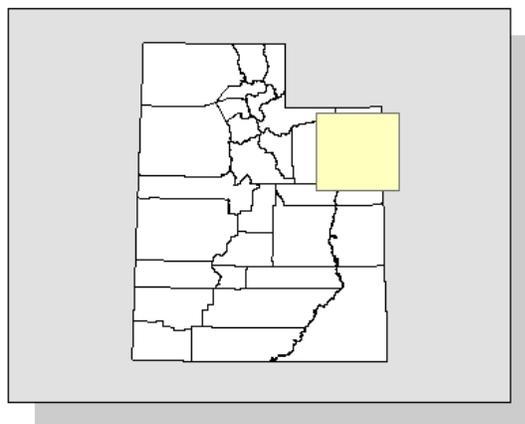
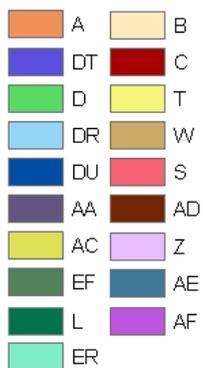


Fig. 3.3. Approximate locations of greater sage-grouse (*Centrocercus urophasianus*) populations and the proportion of haplotypes observed in each population. The newly described haplotype (DU) was found in the Anthro Mountain population. Haplotype data for Blue Mountain, UT, Diamond, UT, Strawberry, UT, Blue Mountain, CO, and Cold Springs, CO is from Oyler-McCance et al. (2005).

CHAPTER 4

CONCLUSIONS

Greater sage-grouse (*Centrocercus urophasianus*) populations have declined throughout their range over the last several decades. Public concern about these declines has prompted several organizations to file petitions with the U.S. Fish and Wildlife Service (USFWS) to list sage-grouse as threatened or endangered under the Endangered Species Act of 1973.

In the Intermountain West energy development has been identified as an emerging threat to sagebrush (*Artemisia* spp.) ecosystem integrity and the greater sage-grouse (hereafter sage-grouse) populations that depend upon sagebrush habitat for sustenance and shelter (Lyon and Anderson 2003, Holloran 2005, Walker et al. 2007). Research conducted in Wyoming and Montana demonstrated that grouse occupying areas undergoing energy development avoided highly developed habitat and exhibited increased mortality rates and reduced reproductive success (Lyon and Anderson 2003, Holloran 2005, Naugle et al. 2006, Walker et al. 2007). Energy development also may fragment sagebrush habitat, potentially isolating sage-grouse populations and thus contributing to inbreeding, genetic drift, local extinction, or rapid divergence.

In Utah, energy development has increased dramatically within the last 15 years and is progressing rapidly in the northeastern portion of the state. Development plans for leased Bureau of Land Management (BLM) lands propose the construction of approximately 4,000 additional natural gas wells in the Seep Ridge area of northeastern

Utah (BLM 2007, 2008). This habitat is occupied by a sage-grouse population estimated to consist of <200 individuals. Energy development may be especially problematic for managers attempting to sustain this sage-grouse population.

The purpose of my research was to: 1) collect baseline data on the survival, reproductive success, and habitat use of the Seep Ridge sage-grouse population, 2) examine sage-grouse habitat use patterns in relation to development, and 3) describe sage-grouse mitochondrial genetic diversity in northeastern Utah relative to other parts of the species range. The project was completed to provide a basis for comparison as development progresses, guide management decisions, and develop possible mitigation recommendations to lessen the potential effects of energy development on the Seep Ridge sage-grouse population.

During my research the Seep Ridge sage-grouse population was declining. The population estimate declined from 108 individuals in 2007 to 36 in 2008. The high mortality rates and low reproductive success I observed are probable causes for the decline. The annual mortality rate of the Seep Ridge population was 63.6% in 2007 and 66.7% in 2008. Although I was not able to identify the cause of these mortalities, I did document the timing. Most of the mortalities ($n = 7$) occurred in the fall from 26 September to 12 November. Additionally, reproductive success was low compared to other Utah sage-grouse populations. Only 1 of 14 (7.1%) chicks observed during the study survived to 50 days of age.

Seep Ridge sage-grouse are one-stage migratory, moving between 2 distinct seasonal ranges (Connelly et al. 2000). I documented nests and brood rearing in areas that are currently slated for development. Previous research indicates that sage-grouse

nests are generally located within 3.2 km of leks (Connelly et al. 2000). Connelly et al. (2000) thus recommended that development should be restricted within 3.2 km of leks to reduce potential negative effects on sage-grouse reproduction.

Habitat at breeding sites used by the Seep Ridge hens contained less shrub, forb, and grass cover than recommended in habitat guidelines and brood rearing sites contained less canopy cover (Connelly et al. 2000). However, sage-grouse hens selected sites exhibiting greater forb cover than recorded at random sites.

Analyses of sage-grouse habitat use patterns in relation to development indicated that sage-grouse have not been displaced by current development activities. However, sage-grouse used habitat located farther from natural gas wells more often than habitat located near wells, relative to well spacing within approximately 2-5 km.

I also examined sage-grouse mitochondrial genetic diversity in northeastern Utah relative to the rest of the species range (Oyler-McCance et al. 2005). Results do not provide evidence that the Seep Ridge population is genetically distinct from other populations. However, differences in haplotype composition between the Anthro and Strawberry Valley populations and other northeastern Utah populations imply that there may be a barrier to gene flow in this area. I recommend that grouse translocations do not occur between these populations until it is known that differences in haplotypes do not reflect adaptive differences in morphology and ecology. Additional samples from northeastern Utah sage-grouse populations, including grouse populations located on Ute Tribal lands and the Book Cliffs, could provide a greater understanding of population structure and divergent evolution, which would be useful when planning future translocations.

I propose that mitigation efforts to reduce the potential effect of energy development on the Seep Ridge sage-grouse population focus on reducing adult mortality, protecting breeding habitat, and maintaining connections between populations. To protect breeding habitat, I recommend restricting energy development within 3.2 km of leks and minimizing drilling activities when sage-grouse occupy habitat within the development project areas (December – June). Additionally, the high adult mortality rate in the late summer and early fall is cause for concern. Previous studies suggest that during this period, sage-grouse are more susceptible to West Nile Virus (WNV). Although none of my mortalities tested positive for WNV, I recommend testing carcasses for WNV when possible (Walker et al. 2004). The timing of high sage-grouse mortalities also corresponds to raptor migration. Providing more summer range habitat by restoring riparian habitat on the Willow Creek could mitigate the effects of seasonal predation.

In 2008, I documented the movement of a hen from Seep Ridge to what may be another population of sage-grouse on Ute Tribal land. I recommend implementing management actions designed to enhance breeding and brooding rearing habitat on both Seep Ridge and Ute Tribal land as well as maintaining corridors between these populations. Maintaining connections between populations in the area could facilitate movements of individuals between populations, reducing the possibility of inbreeding.

Energy development and the Seep Ridge sage-grouse population may successfully coexist if action is taken to protecting breeding habitat, reduce adult mortality, and maintain connections between populations. However, if the Seep Ridge population is extirpated, habitat enhancement projects could facilitate recolonization of the Seep Ridge

site from nearby populations including grouse located on the Book Cliffs and Ute Tribal property.

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