GREATER SAGE-GROUSE RESEARCH IN WYOMING: AN OVERVIEW OF STUDIES CONDUCTED BY THE WYOMING COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT BETWEEN 1994 AND 2005

(Appendix C in Holloran PhD Dissertation Dec 2005)

Matthew J. Holloran, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Box 3166 University Station, Laramie, WY, 82071, USA.
holloran@uwyo.edu; 307 766 5415 (voice); 307 766 5400 (fax).

Stanley H. Anderson, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Box 3166 University Station, Laramie, WY, 82071, USA.

ABSTRACT

Greater sage-grouse (*Centrocercus urophasianus*) populations have been declining throughout Wyoming since the 1960s. Game and land managers, sportsmen organizations, and Wyoming citizens have been concerned over the plight of the sage-grouse for over a half-century, but this concern has escalated within the last decade. In 1994, the first of a series of 10 research projects on greater sage-grouse in Wyoming was initiated; the Wyoming Cooperative Research Unit was responsible for conducting these studies. The projects have focused on a wide array of objectives, including greater sage-grouse microsite and landscape scale seasonal habitat use and the identification of limiting seasonal habitats, the effects of mineral extraction activity on greater sage-grouse populations, greater sage-grouse seasonal use of habitats manipulated by fire, livestock grazing management system influences on greater sage-grouse productivity, and the response of greater sage-grouse populations to predator control programs. This report is a synopsis of the results from the research conducted by the Wyoming Cooperative Research Unit on greater sage-grouse since 1994. Detailed information pertaining to methods and site-specific results are found in the original job completion reports (Wyoming Game and Fish Department, Cheyenne, WY, USA) and theses (University of Wyoming, Laramie, WY, USA).

ACKNOWLEDGMENTS

Financial support was provided by the Wyoming Game and Fish Department, Bureau of Land Management, U.S. Department of Energy, Ultra Petroleum, Yellowstone-to-Yukon Initiative, EnCana Oil and Gas Inc., Shell Rocky Mountain Production LLC, Animal Damage Management Board, National Park Service, and Cowboy 3-Shot Sage-Grouse Foundation. We thank the following landowners for access: Bates Creek Cattle Company, Bousman Ranch, Carney Ranch, Ferris Mountain Ranch, Garrott Ranch, Julian Sheep Company, Little Sandy Grazing Association, Luther Ranch, Miles Cattle Company, Miller Estate, Red Bluff Ranch, Reed Ranch, Ruby Ranch, Sealy/Sawyer Ranch, Sommers Ranch, Stone Ranch, Mayo Ranch, Luman Ranch, Carney Ranch, Pope Cattle Company, and the Three-quarter Circle Ranch. Field assistance and technical support were provided by K. D. Downs, M. B. Hicks, R. A. Holloran, B. K. Holtby, M. A. Kaemingk, Mr. and Mrs. T. W. Malmberg, T. E. McCollum, R. C. Powell, C. M. Sazama, M. S. Stotts, C. G. Taber, K. M. Thompson, Mr. and Mrs. N. A. Tratnik, C. T. Weibel, G. L. Wilson, and J. A. Wyllie. We thank T. D. Moore (Wyoming Game and Fish Department) for laboratory analysis of hair and scat samples. Telemetry flights and lek surveys were conducted with the assistance of Cheney Flying Service (Casper, WY), France Flying Service (Rawlins, WY), and Mountain Air Research (Driggs, ID). Although I have specifically recognized those who were hired to assist with these projects, the people and organizations that voluntarily assisted with these projects would take volumes to list in their entirety; to all those with the Wyoming Game and Fish Department, Bureau of Land Management, National Park Service, Wyoming Cooperative Research Unit, and interested citizens, I personally want you to know that your assistance was sincerely appreciated.

TABLE OF CONTENTS

INTRODUCTION

The sage-grouse (*Centrocercus* spp.) is North America's largest grouse, and is a species uniquely adapted to and dependent on sagebrush (*Artemisia* spp.) for survival. Sage-grouse are renowned for their spectacular breeding displays, and have inspired Native Americans, naturalists, behavioral ecologists, photographers, and hunters throughout history (Schroeder et al. 1999). Recently, greater sage-grouse (*Centrocercus urophasianus*) entered the American spotlight because of the potential for listing under the Endangered Species Act (ESA). If the species were listed as nationally threatened, the management of millions of acres of sagebrush dominated land would be affected, with dramatic implications for the grazing, mining, farming, recreation, and other activities occurring on those lands (Johnsgard 2002). In January 2005, the U.S. Fish and Wildlife Service (USFWS) announced a not warranted 12-month finding for 3 petitions to list the greater sage-grouse as threatened or endangered throughout its current range. Although the best available scientific information suggested to the USFWS that greater sage-grouse were not currently warranted for protection under the ESA, concern for the species has remained high. Sage-grouse population maintenance requires a recognition of the intrinsic value of sagebrush dominated landscapes and the development of a comprehensive approach to sagebrush habitat conservation that involves commitments and partnerships between state, federal and tribal governments, academia, industry, private organizations, and landowners; "only through this concerted effort and commitment can we afford to be optimistic about the future of sagebrush ecosystems and their avifauna" (Knick et al. 2003:627).

Substantial areas in Wyoming, especially the southwestern portions of the state, are currently considered greater sage-grouse breeding population strongholds (Figure 1); compared to other states harboring sage-grouse populations, Wyoming currently has the highest percentage (67%) of potential sagebrush vegetation still in sagebrush habitats (Connelly et al. 2004). Braun (1998) estimated that in the spring of 1998, only Wyoming, Montana and Oregon contained greater sage-grouse (hereafter, "sage-grouse" refers to greater sage-grouse unless specifically indicated) populations of more than 20,000 birds. Additionally, Connelly et al. (2004) suggested that Wyoming currently represents a "key sage-grouse state." However, evidence suggests that sage-grouse populations in Wyoming have been declining over the last half of the 20^{th} century.

Since 1965, sage-grouse breeding populations, as estimated through changes in the number of males occupying leks statewide, have declined by 5.2% annually and the average number of males per lek has declined 49% (Connelly et al. 2004). Between 1975-79 and 1990-94, Wyoming's statewide sage-grouse harvest declined 55%. Additionally, the number of harvested birds per hunter day (an index that accounts for hunter effort and participation) declined 52% between 1975-79 and 1995-99 (harvest and birds/day value comparisons made between the indicated 5-year period means; Wyoming

Game and Fish Department harvest reports 1979-99, Cheyenne, WY, USA). Examples of relatively localized sage-grouse population changes in Wyoming during the latter half of the 20th century are common. From 1994-96, the Wyoming Cooperative Research Unit (University of Wyoming; WyCOOP) conducted a sage-grouse study in western Wyoming on the same study location as a portion of Robert Patterson's landmark study that culminated in his book *The Sage Grouse in Wyoming* (1952). When Patterson began his work on the Dry Sandy-Pacific Creek study area (northeast of Farson, WY) in 1949, he knew of 22 leks used during the breeding season by 1167 strutting males. In 1994, 5 leks comprising 210 males (Heath et al. 1997) were known to exist on the same study area, a decline of 77% in the number of active leks and 82% in the number of strutting males over 45 years. In the southeastern part of the state, the average total number of males strutting on 3 lek complexes (i.e., a group of closely spaced leks where inter-lek movements during a breeding season potentially occur) declined 46% between 1968-69 and 2000-01; additionally, average lek size, defined as the number of males per known lek within the complexes, declined 91% over the same time period (Bob Lanka, Wyoming Game and Fish Department Laramie Region, personal communication). Prior to the 1950s, Patterson (1952) estimated that 500 individual sage-grouse were resident in the Jackson Hole area (a relatively isolated population residing within and around Grand Teton National Park and the National Elk Refuge). In 2002-03, populations were conservatively estimated at less than 182 individuals, 64% below pre-1950 estimates. Additionally, the number of male sage-grouse counted on leks in the Jackson Hole area declined 76% over a 12-year period between 1990-91 and 2002-03 (Holloran and Anderson 2004). Although Wyoming wildlife and land managers have suspected that statewide sage-grouse populations have been declining for many decades, the identification of specific cause(s) for the declines have remained elusive.

Given the importance of Wyoming's sage-grouse populations and habitats, statewide declining populations, and the inability to identify specific reasons for the declines, game and land management agencies in the state initiated several studies beginning in 1994; the WyCOOP was responsible for conducting these studies. The general focus of these studies was to identify limiting seasonal habitats and investigate the potential effects of specific management actions on sage-grouse populations. Results from research projects conducted by the WyCOOP have played a pivotal role in the state's sage-grouse management goals, and were used extensively during the writing of the statewide Wyoming Greater Sage-grouse Conservation Plan (http://gf.state.wy.us/wildlife/wildlife_management/sagegrouse). These projects have resulted in 3 job completion reports, 4 masters' theses, and a dissertation; additionally, 2 students are currently working on their masters' projects at the University of Wyoming. The following report consists of a synopsis of the sage-grouse studies conducted by the

WyCOOP since 1994. I have organized the report around objectives investigated by the studies instead of around each study, thus the sections are focused on specific topics and not on specific study areas within the state. Each section consists of a brief literature review pertaining to the topic, followed by a discussion of the general findings from the Wyoming studies. For more detailed information pertaining to specific results and methods, consult the original job completion reports (Wyoming Game and Fish Department, Cheyenne, WY, USA) or theses (University of Wyoming, Laramie, WY, USA).

HISTORICAL SAGE-GROUSE INFORMATION

Sage-grouse were historically distributed throughout the intermountain and northwestern states and southern regions of 3 Canadian provinces (Schroeder et al. 2004). Pre-settlement distributions included western Nebraska and the Dakotas, all of Montana, Idaho, Wyoming, Nevada and Utah, northwestern New Mexico, northern Arizona, western Colorado, portions of eastern California, Oregon and Washington, and southern British Columbia, Alberta, and Saskatchewan. In Wyoming, greater sage-grouse were historically found in all 23 counties (Patterson 1952). The original range of sage-grouse closely followed that of the historical distribution of big sagebrush (*Artemesia tridentata* sub-spp.), and was not continuous throughout the previously outlined area due to the presence of other habitat types (i.e, forested mountains; Patterson 1952).

The only information relating to the historical abundance of sage-grouse throughout the intermountain west and Wyoming comes from early anecdotal reports, which suggest that the bird was abundant throughout its range. Lewis and Clark were the first Europeans to encounter the species: "I [Lewis] saw a flock of the mountain cock, or a large species of heath hen [*Tympanuchus cupido cupido*] with a long pointed tail which the Indians informed us were common in the Rocky Mountains…" (Moulton 1987). John C. Fremont mentioned that the Crow Indians had named the upper Green River after the sage-grouse, and reported that the birds were "very abundant" in 1843; and in 1874, Elliott Coues suggested that sage-grouse were generally well known to early western explorers (Patterson 1952). Patterson and Cram (1949) indicated that old-time residents in Wyoming typically recalled historic sage-grouse numbers using expressions such as "flocks that blackened the sky" and "rode for miles horseback without being out of sight of birds." McDowell (1956) reported that in Goshen County, Wyoming, he interviewed an old-time resident who said that before eastern parts of the state (the area around Torrington, WY) were settled to farms and ranches, sage-grouse were so numerous that people gathered the eggs during the laying season for table use. One of the more interesting accounts is given by Dr. George B. Grinnell, relating his experience in central Wyoming (near Bates Hole south of Casper, WY) during the fall of 1886: "The number of grouse which flew over the camp reminded me of the old time flights of Passenger Pigeons [*Ectopisties migratorius*] that I used to see when I was a boy. I have no means whatever of estimating the number of birds which I saw, but there must have been thousands of them" (Patterson 1952: after Bent 1932).

It is commonly believed that the sage-grouse began to decline over much of its range during the late 1890s and early 1900s, and continued to decline until the late 1930s (Griner 1939, Patterson 1952, Autenrieth 1981). In the mid-1910s, Hornaday (1916) wrote: "the fact is beyond controversy that unless something on a very broad scale is immediately done, they [sage-grouse] are doomed to early extinction" and demanded that western lawmakers take action to save the species. Similarly, William L. Simpson believed that under protections present in the early 1900s, the "sage hen will be practically extinct" in a decade (Hornaday 1916). Simpson further indicated that he "was over a large portion of the Shoshone Reservation [in central Wyoming] this last year [mid-1910s], and saw only a few [sage-grouse] where there used to be thousands" (Hornaday 1916). Fuller and Bole (1930) suggested that the "stately sage grouse must either radically change its attitude towards man, or face ultimate extermination…local hunters admit that the birds are ever on the decline, and are certainly far less plentiful now [late 1920s] than in 1914." Perhaps Girard (1937) best captured the current mood of the day when he commented that the "impending fate [of the sage-grouse] is extinction and has become so apparent within recent years that the time for words has passed and need for immediate action is imperative."

By the late 1930s, continued concern for the species by conservationists and increasing concern by sportsmen and managers led to widespread hunting season restrictions and closures; by 1937, only Montana had a regular open hunting season (Griner 1939). In 1937, the Wyoming Game and Fish Department issued the following statement concerning sage-grouse hunting in Wyoming (Anonymous 1937): "The commission regrets the necessity of having to take this action [hunting season closure]. However, in view of the rapid depletion of this magnificent game bird, its extinction in many parts of its former range, and the conditions found in all parts of the State, some drastic action becomes necessary if we are to save this fine game bird." Wyoming's sage-grouse hunting season was closed between 1937 and 1948 (Patterson 1952), similar to most states where the restrictions imposed on hunting initiated in the 1930s continued into the 1950s (Braun 1998).

Open hunting seasons in 7 states in the early 1950s coincided with an apparent widespread upward turn in sage-grouse population trends beginning in the late 1940s (Patterson 1952). In 1949, Patterson (1952) counted over 3241 males on 49 study leks in central Wyoming, and had one study lek where he estimated over 400 strutting cocks. Additionally, during the 1947-48 aerial census of wintering pronghorn (*Antilocapra americana*), crews reported concentrations of sage-grouse flocks containing from “several hundred to several thousand birds” in Johnson, Natrona, Sweetwater, Carbon and Fremont counties, WY (Patterson 1952). However, it is generally believed that sage-grouse populations entered a second period of decline within a few years of this temporary reprieve.

Current sage-grouse breeding populations throughout western North America are approximately two to three times lower than those during the late 1960s, and populations declined on average 2% annually from 1965 to 2003 (Connelly et al. 2004). In 2000, greater sage-grouse occupied 56% of their pre-European settlement distribution (Schroeder et al. 2004). Connelly and Braun (1997) reported that long-term population declines prior to 1994 in states historically supporting the largest sage-grouse populations (Colorado, Idaho, Montana, Oregon, Wyoming) averaged 30%; in states and Canadian provinces historically supporting smaller populations, breeding populations declined by an average of 37%. Although harvest and lek count estimations should not be interpreted as absolute, they suggest that sage-grouse populations throughout North American have been trending downward at least since the late 1960s.

FACTORS POTENTIALLY CONTRIBUTING TO HISTORIC POPULATION CHANGES

The list of potential factors contributing to sage-grouse range-wide declines essentially includes every imaginable human caused impact on the species and its habitats. Braun (1998) grouped the factors into 3 main categories: habitat loss, habitat degradation, and habitat fragmentation. Habitat loss includes agricultural conversion, energy and mineral development, and the building of towns, ranches, roads and reservoirs. Habitat degradation can result from sagebrush treatments (mechanical, chemical and fire), grazing, and the introduction of exotic plant species. And habitat fragmentation, defined as a process during which large expanses of habitat are transformed into a number of smaller patches (Fahrig 2003), is commonly caused by fences, power lines, roads, sagebrush treatments, as well as the presence of habitat loss factors previously outlined. Other factors such as hunting, predation, and drought have also been implicated (Braun 1998). The relative importance of these individual factors most likely has varied over the range of the sage-grouse as well as through time.

The factors most commonly implicated in the early declines between the 1900s and 1930s are excessive harvest, overgrazing, and agricultural development (Girard 1937, Rasmussen and Griner 1938, Patterson 1952). The first regulations providing protection for sage-grouse from hunting were established around the turn of the century; early protective measures were largely concerned with the establishment of closed seasons and not bag limits (Patterson 1952). An early account of a lone hunter in Wyoming harvesting 100 birds a day (Patterson 1952: after Burnett 1905) serves to illustrate the level of pressure populations may have experienced during the early 1900s. Even when states began to expand hunting regulations, early opening dates, extended season length, high bag limits, and lack of enforcement acted to afford little real protection to the species (Hornaday 1916, Patterson 1952). The early decline of the sage-grouse also coincided with a period of intensive livestock grazing and agricultural development and settlement that likely fragmented and degraded the quality of sagebrush habitats (Griner 1939, Patterson 1952). Rangelands supporting the greatest numbers of sage-grouse were often those with the most productive soils; because of the soil conditions, these areas were commonly the first to be developed. Additionally, the drought of the 1930's likely further degraded sagebrush dominated areas and compounded the negative effects of poor quality habitats on sage-grouse populations (Patterson 1952).

Population recoveries in the late 1940s and 1950s were likely a result of improved range conditions; however, potential improvements in all 3 factors suggested as responsible for the early declines occurred during this period. Widespread hunting season closures, range improvement as the result of the Taylor Grazing Act of 1934 (Patterson 1952), and range reversion resulting from land abandonment after the drought and depression of the 1930s (Wallestad 1975) were probably responsible for the temporary range-wide increase in sage-grouse populations.

The beginning of the second period of decline could have been in response to increased sagebrush treatment. Aerial application of herbicides (primarily 2,4-D) and mechanical treatments gained popularity during the 1950s and resulted in the widespread eradication of sagebrush that continued into the 1960s (Wallestad 1975). Although the intensity of sagebrush treatment programs declined in the late 1960s, these programs in combination with renewed agricultural development during this period resulted in the degradation, alteration, and loss of substantial portions of the sagebrush dominated rangelands (Braun et al. 1976, Klebenow 1969).

It is more difficult to determine a single factor or group of factors responsible for sage-grouse population declines in recent decades and into the present. Braun (1998) suggests that a complexity of factors related to human caused habitat changes is responsible. Each population is likely subjected to habitat degradation arising from the long-term consequences of historic use of sagebrush habitats that may be influencing current conditions plus unique circumstances compounding the negative influence of suboptimal habitats. Although range-management techniques have improved over the last half of the 20^{th} century, providing or managing sagebrush habitats for pre-settlement conditions is likely impossible as many key elements may no longer exist (Connelly et al. 2004). Connelly et al. (2004) estimated that approximately 47% (>234,700 km^2) of the area within the western United States that potentially could be dominated by sagebrush was either in agricultural, urban, or industrial areas or in unsuitable habitats in 2003 (i.e., exotic grassland, burn, juniper woodland, etc.).

STUDY AREAS and OBJECTIVES by STUDY (FIGURE 1)

1. FARSON

Heath, B. J., R. Straw, S. H. Anderson, and J. Lawson. 1997. Sage grouse productivity, survival, and seasonal habitat use near Farson, Wyoming. Job Completion Report, Wyoming Game and Fish Department, Cheyenne, WY, USA.

The Farson study area was selected primarily because of the existence of historical population and vegetation data collected by Patterson (1952) during the late 1940s and early 1950s. The area supported some of the highest sage-grouse densities in the state, and had contiguous sagebrush cover that had not been drastically altered within the last 30 to 40 years. The primary objectives established for the study were to identify seasonal habitat components that limit sage-grouse productivity and decrease survival.

The study area was located approximately 30 km northeast of Farson, Wyoming in portions of Sweetwater, Sublette, and Fremont Counties. Annual precipitation averaged between 20 cm in the southwestern portions of the study area to 35 cm in the northeast, and was approximately 119% of normal during the study years (1994-96). Topography of the area was characterized by flat plains interrupted by rolling hills, ridges, and drainages. Overstory vegetation was dominated by Wyoming big sagebrush (*A. t. wyomingensis*), with mountain big sagebrush (*A. t. vaseyana*), basin big sagebrush (*A. t. tridentata*), black sagebrush (*A. nova*), low sagebrush (*A. arbuscula*), greasewood (*Sarcobatus vermiculatus*), and rabbitbrush (*Chrysothamnus* spp.) interspersed throughout.

2. RAWLINS

Heath, B. J., R. Straw, S. H. Anderson, J. Lawson, and M. J. Holloran. 1998. Sage-grouse productivity, survival, and seasonal habitat use among three ranches with different livestock grazing, predator control, and harvest management practices. Job Completion Report, Wyoming Game and Fish Department, Cheyenne, WY, USA.

The sagebrush steppe communities adjacent to Rawlins, Wyoming historically supported abundant sage-grouse populations. However, population declines within the area prompted local residents, especially members of a local sportsmen's organization (Cowboy 3-shot Sage Grouse Foundation), to voice concern. In response to these concerns, the Wyoming Game and Fish Department initiated the Rawlins sage-grouse study. The overriding objectives of the study were to evaluate differences in sage-grouse productivity, habitat selection, and survival on 3 ranches with distinct grazing management, predator control, and harvest levels and provide insight into how these management strategies effected sage-grouse populations.

The study area was located approximately 25 km northeast of Rawlins, Wyoming in portions of Carbon County. Annual precipitation averaged 25 cm, and was approximately 104% of normal during the study years (1997-98). Topography of the area was generally flat to gently rolling hills with a predominantly Wyoming big sagebrush overstory. The foothills of the Ferris Mountains in the northern end of the study area were dominated by sand dunes with predominantly a silver sagebrush (*A. cana* spp.) and rabbitbrush overstory.

Grazing management between the 3 ranches differed in terms of livestock and level of use. One ranch grazed both cattle and sheep, and rotated pastures after a specific number of use-days; the other 2 ranches grazed cattle, and rotated pastures after 30% or 40% of the herbaceous vegetation was removed. Predator control differences were primarily between the cattle-sheep and cattle-only ranches. The ranch raising sheep employed a federal predator control program aimed primarily at coyote (*Canis latrans*) control; the other 2 ranches had no organized predator control programs, but allowed recreational predator hunting. Sage-grouse hunting opportunities between the 3 ranches ranged from unrestricted access to no hunting allowed.

3. CASPER

Holloran, M. J. 1999. Sage grouse (Centrocercus urophasianus) seasonal habitat use near Casper, Wyoming. MS Thesis, University of Wyoming, Laramie, WY, USA.

The final project concentrating primarily on sage-grouse seasonal habitat selection was conducted in an area with personal significance for people in the Wyoming Game and Fish Department. The primary objectives established for this study were to determine habitat conditions that were selected by sage-grouse and that influenced sage-grouse productivity and survival. Another objective of this study was to evaluate late-incubation chronology and identify nest predators using remote sensing cameras.

The study area was located approximately 35 km south of Casper, Wyoming in portions of Natrona County. Annual precipitation averaged 28 cm, and was approximately 125% of normal during the study years (1997-98). Topography was generally flat to gently rolling hills with predominantly north and south aspects. The vegetation overstory was dominated by Wyoming big sagebrush, with silver sagebrush, Wyoming threetip sagebrush (*A. tripartita*), black sagebrush, and rabbitbrush dispersed throughout the study area.

4. PINEDALE

Lyon, A. G. 2000. The potential effects of natural gas development on sage grouse near Pinedale, Wyoming. MS Thesis, University of Wyoming, Laramie, WY, USA.

The emphasis of the studies changed from habitat selection to the investigation of specific land-use effects on sage-grouse beginning with this first of several Pinedale studies. The primary objective of the study was to quantify the potential effects of natural gas development activity on male and female sage-grouse seasonal habitat selection.

The study area was situated approximately 5 km south of Pinedale, Wyoming on an area locally known as the Mesa in Sublette County; the Mesa was situated within the Pinedale Anticline Project Area (PAPA) natural gas field. Annual precipitation averaged 30 cm, and was approximately 112% of normal during the study years (1998-99). Topographically, the Mesa was relatively flat with a series of north/south-running draws circumventing the southern and northern portions of the study area. Overstory vegetation was dominated by Wyoming big sagebrush.

The first natural gas well was drilled in the PAPA in 1939; however, only 23 additional wells were drilled in the project area prior to 1997. In May, 1998, the BLM approved limited exploratory drilling of 45 wells prior to completion of the Environmental Impact Statement (EIS); the EIS was being drafted during this study and was not completed until after the conclusion of the study. Therefore, the primary gas related disturbance during the years of the study was traffic related, and the results pertained primarily to the influence traffic had on breeding male and female sage-grouse.

5. KEMMERER

Slater, S. J. 2003. Sage-grouse (Centrocercus urophasianus) use of different-aged burns and the effects of coyote control in southwestern Wyoming. MS Thesis, University of Wyoming, Laramie, WY, USA.

The lack of agreement among land management personnel as to the appropriate role of prescribed fire in Wyoming's sage-grouse habitats necessitated the Kemmerer study. The primary objectives of the study were to document seasonal sage-grouse use, and describe the vegetation and insect characteristics of burned areas compared to the overall landscape. An additional objective for this study was to determine the effect a coyote control program had on sage-grouse productivity and survival and on predator species composition.

The study area was situated approximately 30 km west of Kemmerer, Wyoming in Lincoln County. Annual precipitation averaged 26 cm, and was approximately 50% of normal during the study years (2000-02). Topography varied throughout the area with ridges, basins and draws as common features. Overstory vegetation was dominated by Wyoming and mountain big sagebrush, with low, basin big, and black sagebrush, serviceberry (*Amelanchier alnifolia*), rabbitbrush, and snowberry (*Symphoricarpos* spp.) interspersed throughout the study area.

Four different burns ranging in age from 2 to 26 years were present within the study area; between approximately 20 and 80% of the shrub overstory was removed by fire from these burns. Intensive coyote control by aerial gunning and other means was performed within the study area during the study to protect domestic sheep. A control area (located approximately 25 km south of the main study area) with no organized predator control was established for comparison purposes.

6. JACKSON

Holloran, M. J., and S. H. Anderson. 2004. Greater sage-grouse seasonal habitat selection and survival in Jackson Hole, Wyoming. Job Completion Report, Wyoming Game and Fish Department, Cheyenne, WY, USA.

A relatively unique, isolated population of sage-grouse in the Jackson Hole valley has experienced substantial declines since the early 1990s; the population is currently approximately 65% below sustainable (Connelly et al. 2000b) levels. Because of the recreational importance of this population (situated within and around Grand Teton National Park), the Jackson study was initiated to investigate possible reasons for the declines. The primary objectives of this study were to document sage-grouse seasonal habitat selection and survival, identify the limiting seasonal range(s), and quantify the habitat conditions associated with sustainable and increasing productivity.

The study area was situated primarily within Grand Teton National Park and the National Elk Refuge approximately 10 km north of Jackson, Wyoming in Teton County. Annual precipitation averaged 51 cm, and was between 77 and 111% of normal during the study years (1999-2002). Topography varied substantially throughout the study area, with relatively flat valley floors traversing quickly into generally east and west facing foothills. Overstory vegetation was dominated by mountain and Wyoming big sagebrush, with basin big, low and tall threetip (*A. tripartita tripartita*) sagebrush interspersed throughout. A substantial antelope bitterbrush (*Purshia tridentata*) community covered portions of the study area. Additionally, the sagebrush dominated areas were interspersed with pockets of aspen (*Populus tremuloides*), conifer (*Pinus, Pseudotsuga, Picea* spp.), and cottonwood (*Populus angustifolia*), predominantly on northern and northwestern aspects and along watercourses.

7. LANDER

Kuipers, J. L. 2004. Grazing system and linear corridor influences on greater sage-grouse (Centrocercus urophasianus) habitat selection and productivity. MS Thesis, University of Wyoming, Laramie, WY, USA.

One of the primary questions facing western land management agencies is the potential influence of livestock grazing on sagebrush dominated habitats and sage-grouse populations; the Lander study tackled this subject. The primary objectives of the study were to describe the response of sagebrush dominated ecosystems to livestock grazing under 4 different grazing schemes, and to describe sage-grouse habitat use, productivity and survival relative to these grazing systems. An additional objective was to determine the influence linear corridors (i.e., livestock trails, roads, fence lines) had on sage-grouse nest success probabilities.

The study area was situated approximately 25 km southeast of Lander, Wyoming in Fremont County. Annual precipitation averaged 34 cm, and was approximately 68% of normal during the study years (2000-03). Topography consisted of several relatively flat benches stepping upwards in elevation into the foothills of the Wind River Mountains. A series of north-south running draws were prominent features throughout the study area. Overstory vegetation was dominated by Wyoming big sagebrush, with patches of snowberry, aspen, and conifer (*Juniperus osteosperma, J. scopulorum*) interspersed throughout the study area.

Three different livestock (cattle) gazing systems were present on the study area; a 4th area was included as a non-livestock grazed control. The 3 grazing systems were rotational with 4.5 month grazing periods from mid-May through September. Rotation systems included: (1) differed rotational (spring deferment alternated annually in a 2 paddock system with >45% forage utilization); (2) summer grazed rest rotational [livestock rotation between a 10 paddock system, paddocks grazed primarily during the summer, complete rest from livestock in 2 to 10 paddocks annually during the study, 1 paddock twice-over grazed (same paddock grazed twice in a grazing season) during the study, and 35 to 45% forage utilization]; and (3) spring and fall grazed rest rotational (rotation between a 10 paddock system, paddocks grazing primarily during spring and fall, complete rest from livestock in 1 to 3 paddocks annually during the study, 27% of the paddocks twice-over grazed during the study, and 35 to 45% forage utilization).

8. PINEDALE

Holloran, M. J. In Preparation. Greater sage-grouse (Centrocercus urophasianus) population response to natural gas field development in western Wyoming. PhD Dissertation, University of Wyoming, Laramie, WY, USA.

The amount of sagebrush dominated lands potentially influenced by natural gas and oil development has increased dramatically in recent years; however, limited information exists as to the response of sage-grouse to this development. The second Pinedale study was initiated as a continuation of Lyon's (2000) research outlined above. The primary objective of the study was to quantify the potential effects of natural gas development activity on sage-grouse populations and seasonal habitat selection.

The study area was expanded approximately 35 km south and east from the original concentration of areas on the Mesa. Annual precipitation was approximately 87% of normal during the study years (2000-04). Overstory vegetation within the expanded portions of the study area was also dominated by Wyoming big sagebrush, with rabbitbrush, greasewood and saltbush (*Atriplex* spp.) interspersed throughout.

The final EIS for the PAPA was approved in July 2000. Full development of the PAPA is expected to continue for the next 10 to 15 years. The BLM's record of decision approved construction of 700 producing wells with minimum densities of 1 well per 16 ha (equivalent to 16 wells per section), 645 km of pipeline, and 445 km of road. According to information supplied by the Wyoming Oil and Gas Conservation Commission (Casper, WY, USA), between 1998 and 2004 approximately 340 natural gas wells were drilling on the PAPA; if surrounding areas are included, approximately 780 wells became active during the study (i.e., including the substantial development occurring within the Jonah natural gas fields situated south of the PAPA).

SEASONAL HABITAT SELECTION

NESTING HABITAT SELECTION

Sage-grouse females retire into the vicinity of their nest location within a few days of being bred, and remain relatively sedentary until they nest (Patterson 1952). No concealment strategies are attempted at the nest except that afforded by natural cover and the hen's cryptic plumage coloration pattern (Rassmussen and Griner 1938). Egg laying takes 7 to 10 days, incubation lasts 25 to 29 days, and average clutch sizes are between 6.5 and 9.1 eggs (Patterson 1952, Schroeder et al. 1999). Reproductive effort (nesting propensity) estimates in sage-grouse range from 68 to 93% (Connelly et al. 1993, Schroeder 1997). However, research on follicular development indicates that between 91 and 98% of females breed annually (Braun 1979). The differences may hinge on the nutritional status of pre-laying hens, as a higher nutrient composite diet (sagebrush and forbs) results in increased nesting effort and clutch sizes (Barnett and Crawford 1994). See Table 1 for nesting propensity estimates from throughout Wyoming. Re-nesting rates <25% are typically reported (Patterson 1952, Eng 1963, Hulet 1983, Connelly et al. 1993, Sveum et al. 1998b); however, Schroeder (1997) reported re-nesting rates >80% in Washington. Reduced male lek attendance and infertility (caused by reductions in testis development) are associated with the timing of rebreeding attempts, suggesting that limitations to re-nesting are imposed by the male (Eng 1963). Sage-grouse are relatively long lived tetraonids, thus re-nesting is not necessarily beneficial after weighing the benefits and costs of the increased parental investment in a second clutch (Bergerud 1988).

Sage-grouse nesting habitat is often a broad area between winter and summer range (Klebenow 1969). Average distances between nests and nearest known leks vary from 1.1 to 6.2 km (Autenrieth 1981, Wakkinen et al. 1992, Fischer 1994), but distance from lek of female capture to nest may be >80 km (Lyon 2000). Protection of sage-grouse nesting habitat within 3.2 km of occupied leks has been a standard management recommendation since the 1970s (Braun et al. 1977, Connelly et al. 2000b); however, research in fragmented (Aldridge and Brigham 2001, Schroeder and Robb 2003) and contiguous (Bradbury et al. 1989, Wakkinen et al. 1992) habitats suggest these recommendations may offer limited or unsubstantiated protection to nesting areas. Using data collected throughout Wyoming, Holloran and Anderson (2005) investigated the spatial relationship between lek location and nest distributions. The authors concluded that nest distributions were related to lek location within 5 km of the lek, but cautioned that, because of increased nest success probabilities for dispersing individuals (i.e., females nesting >5 km from a lek), nesting habitats situated beyond the 5 km lek buffer could be important for population viability.

Most sage-grouse nests are located under sagebrush plants (Girard 1937, Patterson 1952, Rothenmaier 1979). In southeastern Idaho, however, Connelly et al. (1991) reported that 21% of sage-grouse hens nested under shrub species (rabbitbrush, snowberry, and bitterbrush) other than sagebrush, but hatching success for non-sagebrush nests was 22% compared to 53% for sagebrush nests. In California, Wyoming big sagebrush and mixed shrub communities were used for nesting in proportion to their availability (Popham and Gutierrez 2003). A congregation of several individual shrubs of different heights and decadence stages are normally selected as nest sites (Pyrah 1970). To reduce conspicuousness, it is advantageous for sage-grouse hens to choose patches with uniform sagebrush heights and sizes if these plants meet nesting requirements (Wakkinen 1990).

Distances between consecutive-year nests (individual females followed through consecutive nesting seasons) suggest female fidelity to specific nesting areas. Fischer et al. (1993), in Idaho, reported that distances between sage-grouse nests in consecutive years represented 3.5% of median annual movements, suggesting fidelity for specific nesting areas. In Wyoming, the probability that observed consecutive-year nest spacing occurred randomly was between 1.2 and 2.6%, suggesting nesting site-area fidelity for consecutive year nesting females (Holloran and Anderson 2005). Additionally, although sample sizes were low (n = 3), yearling females nested in the same general area as their mother (Lyon 2000), suggesting fidelity for a specific area could carry over to subsequent generations.

Selection of specific habitat features within a landscape by nesting sage-grouse has been extensively documented. Connelly et al. (2000b) suggested that sagebrush nesting habitat should range between 15 and 25% canopy cover. Females preferentially selected areas with sagebrush 36 to >63.5 cm tall and with canopies 15 to >50% for nesting in Utah (Rasmussen and Griner 1938). Rothenmaier (1979) reported that mean sagebrush canopy cover was 21.6% and average sagebrush height was 30.6 cm at nests in southeastern Wyoming. In western Wyoming, 83% of nests were under bushes between 25 and 51 cm tall (average nest bush height 35.6 cm; Patterson 1952). In central Montana, all nests were located in areas with >15% sagebrush canopy cover (Wallestad and Pyrah 1974). And, in northeastern California, sage-grouse avoided low sagebrush for nesting and used big sagebrush and mixed shrub cover in proportion to their availability (Popham 2000).

In southeastern Idaho, nests within a threetip sagebrush vegetation type were found in areas with increased big sagebrush density, basal area of grasses, and threetip sagebrush canopy cover relative to random plots within the same habitat type; overall, total shrub canopy cover was greater at nests relative to random locations (Klebenow 1969). In southeastern Idaho, Wakkinen (1990) reported that nests had taller grasses compared to random locations. Adding a year of data to Wakkinen's (1990) study, Fischer (1994) indicated that nests had increased nest bush total area, increased ground obstructing cover (from 5 m), increased lateral obstructing cover (from 2.5 m), and increased total shrub canopy cover relative to random sites. In southcentral Washington, nests were consistently located in areas with increased shrub cover and taller shrubs compared to randomly-selected sites (Sveum et al. 1998b). The cover of short (<18 cm) grasses and bare ground were consistently lower, and vertical cover height (obstructing cover from 4 m) and litter cover were consistently greater at nests relative to available sites (Sveum et al. 1998b). Nests were located in areas with taller average sagebrush relative to random plots in central Montana (Wallestad and Pyrah 1974). And, in southern Canada, nests were located in areas with increased sagebrush canopy cover and sagebrush density compared to random locations (Aldridge and Brigham 2002).

Combining vegetation data collected at sage-grouse nest sites from 7 different areas in central and southwestern Wyoming between 1994 and 2002 (studies mentioned below), Holloran et al. (2005) reported that a combination of increased total shrub canopy cover, sagebrush height, and residual grass cover and height were important determinants of sage-grouse selected nesting habitat relative to available nesting habitat. Nests near Casper, Rawlins, Farson, and Jackson, Wyoming had increased total shrub canopy cover relative to available nesting habitats. Live sagebrush heights were taller at nests compared to random locations in Casper, Pinedale, Jackson, and Kemmerer. Additional shrub variable differences reported in Wyoming included increased live sagebrush and dead sagebrush density at nests compared to available habitat. Herbaceous differences at nests relative to random plots included: taller live and residual grasses, increased live and residual grass cover, increased total herbaceous cover, increased non-food forb and total forb cover, and decreased bare ground.

Consistently throughout the range of studied sage-grouse populations, nests were located under larger sagebrush bushes with more obstructing cover relative to within patch characteristics. Selected nesting habitat had more sagebrush canopy cover and taller sagebrush compared to available habitats. Other relatively consistent differences included: increased sagebrush density, taller live and residual grasses, increased live and residual grass cover, and decreased bare ground at selected nesting sites compared to randomly-selected sites (Klebenow 1969, Wallestad and Pyrah 1974, Wakkinen 1990, Fischer 1994, Sveum et al. 1998b, Aldridge and Brigham 2002, Holloran et al. 2005).

NESTING SUCCESS

Nesting success in sage-grouse ranges from 15 to 86% (Schroeder et al. 1999); apparent nest success within Wyoming varied from 6 to 79% (Table 1). In Utah, nesting success was highest in areas with sagebrush >46 cm tall, with canopies >50%, and "where a good understory of grasses and weeds were present;" the presence of a good herbaceous understory interspersed throughout sagebrush stands increased the probability of a successful hatch relative to sagebrush stands of equal density without the understory (Rasmussen and Griner 1938). Sagebrush canopy cover was greater at successful vs. unsuccessful sage-grouse nests in Montana (Wallestad and Pyrah 1974). Sveum et al. (1998b) reported that successful nests in Washington had increased residual herbaceous cover compared to unsuccessful nests. In Oregon, tall (>18 cm) residual grass cover and medium height (40 to 80 cm) shrub cover were greater at successful vs. unsuccessful nests (Crawford et al. 1992, Gregg et al. 1994), and a combination of shrub and herbaceous screening cover were important for nest success in Idaho (Connelly et al. 1991). Successful nests in southern Canada had taller grasses, taller palatable forbs, and decreased grass cover relative to unsuccessful nests (Aldridge and Brigham 2002). In California, percent rock cover, total shrub height, and visual obstruction were greater at successful than unsuccessful nest sites (Popham 2000). Hausleitner (2003) reported that successful nests in northwestern Colorado had increased average forb and grass cover and taller grasses compared to unsuccessful nests.

Successful artificial sage-grouse nests consistently (variable included in ≥2 logistic regression models) had more forb and total sagebrush canopy cover, taller grasses, and decreased numbers of sagebrush plants within 0.5 m compared to unsuccessful artificial nests (Watters et al. 2002). DeLong et al. (1995) reported that a combination of greater amounts of tall (>18 cm) grass and medium height (40 to 80 cm) shrub cover at artificial sage-grouse nests in southeastern Oregon increased the probability of success.

Heath et al. (1996) maintained that the chance of a sagebrush nest successfully hatching will increase 30% if it is within herbaceous vegetation exhibiting 20% canopy cover and heights of 15 to 30 cm. The residual herbaceous component is important during the initial stages of incubation because nests are initiated prior to the growing season for most grasses and forbs (Crawford et al. 1992, Heath et al. 1996).

Barnett and Crawford (1994) suggest that consumption of forbs during the pre-laying period may affect reproductive success by improving nutritional status of hens. Braun (1981) reported that less than 50% of yearling hens were successful, whereas at least 50% of the adult hens were successful in Colorado, and adult hens in Montana experienced higher nest success than yearlings (Wallestad and Pyrah 1974). However, no significant differences in nest success between different age groups were reported in Idaho and Washington (Connelly et al. 1993, Schroeder 1997).

Batterson and Morse (1948), after extensive nest studies concluded that “the greatest single limiting factor of sage-grouse is nest predation by ravens (*Corvus corax*);” 51% nest success was realized on raven control areas compared to 6% on uncontrolled areas. Conversely, Patterson (1952) reported that 42% of sage-grouse nest predation in Wyoming was due to Richardson’s and thirteen-lined ground squirrels (*Spermophilus* spp.). Interestingly, the percentage of bird and eggshell fragments in most coyote (*Canis latrans*) prey base studies ranges from 2 to 5%, suggesting minimal impact (Johnson and Hansen 1979, Reichel 1991, Heath et al. 1996). Common ravens, black-billed magpies (*Pica pica*), ground squirrels, red foxes (*Vulpes vulpes*) and badgers (*Taxidea taxus*) are reported as predominant sage-grouse nest predators (Patterson 1952, Autenrieth 1981, Connelly et al. 1991, Heath et al. 1996).

Data from 7 different areas in central, western, and southwestern Wyoming combined suggested that a combination of increased residual grass cover and height were the best determinants of successful compared to unsuccessful sage-grouse nests (Holloran et al. 2005). Successful nests had taller residual grasses, and increased residual grass and forb cover relative to unsuccessful nests near Farson, Wyoming. In Casper, food-forb cover tended to be higher at successful nests relative to unsuccessful nests. Nests destroyed by avian predators near Kemmerer, Wyoming consistently had decreased overhead cover (live sagebrush and total shrub canopy cover) and increased lateral cover (herbaceous cover and height) relative to nests in general and mammalian destroyed nests. Successful nests in Jackson had increased live and residual grass height and residual grass cover compared to unsuccessful nests.

Vegetation consistently higher at successful compared to unsuccessful sage-grouse nests throughout the range of studied populations included: live and residual grass height, residual vegetative cover, forb cover and visual obstruction (Wakkinen 1990, Gregg et al. 1994, Sveum et al. 1998b, Popham 2000, Aldridge and Brigham 2002, Hausleitner 2003, Holloran et al. 2005). These observations suggest that sage-grouse nesting success is influenced predominantly by the herbaceous understory; this conclusion, given that sage-grouse nesting success varies annually (Connelly et al. 2000b) while the sagebrush overstory does not change dramatically between years, seems sensible.

EARLY BROOD-REARING HABITAT SELECTION and SUCCESS

I consider early brood-rearing the time broods remain within the sagebrush dominated uplands associated with nesting locations; the amount of time broods spend in these habitats varies annually and throughout the range of the species. A key factor associated with sage-grouse productivity is brood-rearing habitat availability (Crawford et al. 1992). Low chick recruitment has been proposed as a factor limiting sage-grouse population stability (Connelly and Braun 1997), and most chick mortality occurs prior to the flight stage (2 to 3 weeks) when decreased mobility increases vulnerability to predation and starvation (Patterson 1952, Autenrieth 1981). Sage-grouse chicks require protein-rich foods, including insects and forbs, for survival (1 to 10 days post-hatch) and optimal development (10 to 45 days post-hatch; Johnson and Boyce 1990). Sage-grouse productivity in Oregon was higher in areas where chick diets consisted of 80% forbs and insects compared to where chicks ate primarily (65%) sagebrush (Drut et al. 1994a).

Sage-grouse chicks are precocial and move immediately following hatch to search for food (Patterson 1952); early brood-rearing areas occur in upland sagebrush habitats relatively close to nest sites (Connelly 1982, Berry and Eng 1985). Early brood-rearing areas (between 2 weeks post-hatch and prior to July 8) were located between 1.6 and 3.2 km of the nest near Rawlins (Heath et al. 1998), and between 0.2 and 5.0 km of the nest during the first 4 weeks post-hatch near Pinedale, Wyoming (Lyon 2000). In Kemmerer, 80% of early brood locations were within 1.5 km of the nest (Slater 2003). During June and July in central Montana, brood use areas averaged 86 ha and there were no apparent movements that indicated a daily use of free water (Wallestad 1971).

Brood-use sites within big sagebrush dominated habitat type in southeastern Idaho had decreased big sagebrush density and canopy cover, and increased percent frequency of yarrow (*Achillea lanulosa*), lupine (*Lupinus caudatus*), dandelion (*Taraxacum officinale*) and salsify (*Tragopogon dubius*) compared to random locations within the same habitat type (mean brood ages between 1 to 8 weeks; Klebenow 1969). Conversely, early brood-rearing (hatch through 7 weeks) locations had increased sagebrush cover compared to random locations in southern Canada (Aldridge and Brigham 2002). Total forb and food forb cover were higher, and residual herbaceous cover and height were lower at early brooding areas relative to random locations in south-central Washington (Sveum et al. 1998a).

Dead sagebrush density was higher at early brood-rearing (habitat use prior to July 8) compared to random locations near Farson, Wyoming. Near Rawlins, early brood use areas had increased sagebrush height, increased live grass and total herbaceous cover, and decreased effective vegetation height (Robel pole read from 10m) compared to random locations. A combination of increased residual grass and total forb cover, and decreased effective vegetation height were the best predictors of selected early brood-rearing (between 2 and 4 weeks post-hatch) compared to available habitats near Casper. Early brood-rearing locations had decreased live sagebrush and total shrub canopy cover, increased residual grass and total herbaceous cover, and food-forb cover tended to be higher, relative to available habitats. Near Pinedale, early brood-rearing (through 4 weeks post-hatch) locations had decreased live sagebrush density, live sagebrush and total shrub canopy cover, and bare ground and increased total herbaceous cover compared to available habitat. And, in Jackson, brooding females (hatch through 2 weeks post-hatch) selected areas with increased total shrub canopy cover and sagebrush height, food forb cover and forb diversity, and decreased live and residual grass cover. Chick survival during brooding stages in Wyoming is presented in Table 1.

Thompson et al. (*in review*) combined early brood-rearing (hatch through 2 weeks post-hatch) data collected from 3 sites in central and southwestern Wyoming between 1999 and 2003, and found that during the early brood-rearing period, broods used sites within or near dense (average 20% canopy cover) sagebrush cover, and increased productivity was positively associated with abundance of insects and herbaceous cover. Females with broods were found in areas with greater sagebrush canopy and grass cover, but lower numbers of invertebrates compared to random areas. However, the number of juveniles per female (estimated from wing barrel collections during fall harvest) was positively associated with the abundance of Hymenoptera and grass cover, and the proportion of females with confirmed chicks 14 days post-hatch was positively related to Coleoptera abundance and total herbaceous cover.

LATE BROOD-REARING HABITAT SELECTION and SUCCESS

Sage-grouse broods remain in sagebrush habitats until range desiccation induces them to move to riparian habitats still supporting succulent vegetation (Peterson 1970, Wallestad 1971, Neel 1980, Fisher et al. 1997). However, brooding females may remain in upland habitats if suitable microsite conditions (i.e., swales, ditches, springs) are found (Wallestad 1971). Stand structure and food availability are characteristics most frequently associated with habitat selection by brooding hens during the summer (Klebenow 1969, Autenrieth 1981, Aldridge and Brigham 2002). Chick diets during the summer consist of primarily forbs and insects (Klebenow and Grey 1968, Drut et al. 1994b), while sagebrush stands provide escape and thermal cover (Peterson 1970, Wallestad 1971, Crawford et al. 1992).

Open water has been suggested as a limiting factor for summering sage-grouse. Autenrieth et al. (1982) inferred that water was important to sage-grouse, and Patterson (1952) suggested that water markedly affected the species' summer distribution. However, movements to agricultural lands or high elevation summer range are probably in response to lack of succulent forbs in an area rather then a lack of free water (Connelly and Doughty 1989). It has been suggested that grouse do not commonly use water developments even during relatively dry years, but instead obtain moisture from consuming succulent vegetation (Connelly 1982, Connelly and Doughty 1989). Moreover, water developments tend to attract other animals and thus may serve as a predator "sink" for grouse (Connelly and Doughty 1989). Free water reservoirs can, however, provide islands of succulent vegetation (Wallestad 1971) and this use of water developments may be enhanced by placing them along migration routes or close to summer range (Connelly and Doughty 1989).

In Farson, Wyoming, visual obstruction (from 10 m), food forb, total forb, and litter cover were higher, and grass cover was lower at selected late brood-rearing locations compared to available summering habitats (i.e., areas potentially suitable for summering grouse, or areas with succulent herbaceous vegetation throughout the summer). Near Casper, brooding females selected areas with increased food forb cover and decreased residual grass cover relative to available summering areas. Late-brooding females in the Pinedale area selected locations with increased total shrub canopy cover, and in Jackson, used summer habitats were in areas with proportionally increased food forb cover (relative to total cover) compared to available summering habitats. No differences were detected between used and available late brooding locations near Rawlins.

In areas where riparian habitats were limiting, drought conditions concentrated birds, resulting in increased predation rates and increased adult hen fall mortality. Fall mortality was caused by hunting and predation, the majority of which occurred during September. In 1994, 62% of the annual mortality occurred during September, presumably because drought conditions concentrated birds on riparian areas. Results from Casper in 1998 and Pinedale in 2004 indicated that sage-grouse preferred to remain within sagebrush dominated habitats throughout the summer, and resorted to concentrating on riparian corridors only after upland forb desiccation. This information suggests that riparian area (and associated succulent vegetation) distribution and extent could be important to sage-grouse survival.

WINTER HABITAT SELECTION

Sage-grouse may travel many kilometers or only short distances between seasonal ranges (Eng and Schladweiler 1972); migratory populations often travel 80 to 160 km (50 to 100 miles) to winter ranges (Patterson 1952), while sedentary populations merely increase flock size and move from meadows into sagebrush during the winter (Autenrieth 1981). A precipitation event (usually snow) or a drop in the temperature initiates migration, which begins in late August (in advance of snow accumulation) and continues until December (Dalke et al. 1960, Berry and Eng 1985, Connelly et al. 1988). Winter habitat is probably the most limiting seasonal habitat (Patterson 1952, Beck 1977), with sage-grouse over a broad summering area congregating on smaller, traditional wintering grounds (Beck 1977, Berry and Eng 1985).

Selection of wintering habitats by sage-grouse is influenced by snow depth and hardness, topography (i.e., elevation, slope, and aspect), and vegetation height and density (Batterson and Morse 1948, Gill 1965, Greer 1990, Schroeder et al. 1999). The primary requirement of wintering sage-grouse is sagebrush exposure above the snow (Patterson 1952, Hupp and Braun 1989, Schroeder et al. 1999, Connelly et al. 2000b, Crawford et al. 2004). During the winter, sage-grouse could be restricted to <10% of the sagebrush dominated lands in any given area (Beck 1977). Sage-grouse populations will utilize critical winter habitat once every 8 to 10 years, these locations providing food and thermal protection when increased snow pack has covered most surrounding areas (Heath et al. 1996). Winter ranges are characterized by large expanses of dense sagebrush (>20% sagebrush canopy cover) on land with south to west-facing slopes of <5% gradient (Eng and Schladweiler 1972, Beck 1977). Robertson (1991) reported that sage-grouse in Idaho selected areas with increased Wyoming big sagebrush canopy cover and average height compared to available habitats during the winter.

During severe winters, flat area usage diminishes after snow pack exceeds 30 cm, and drainages and steeper southwest facing slopes are used (Autenrieth 1981, Hupp and Braun 1989). Drainages are sheltered from the wind and contain taller sagebrush stands, snow drifts (used for roosting to escape extreme cold), and closed shrub canopies, which combined provide food and reduce thermoregulatory costs (Hupp and Braun 1989, Homer et al. 1993, Heath et al. 1996). Because sagebrush exposure is critical for feeding, wind scoured ridge-tops provide suitable foraging areas until wind velocities exceeding 15 to 25 kph force grouse off these areas (Eng and Schladweiler 1972, Beck 1977). Sage-grouse distribution during the winter is primarily a reflection of sagebrush exposure and topographic categories (slope and aspect).

Sage-grouse feed during almost all weather conditions and subsist on a diet consisting solely of sagebrush during the winter (Patterson 1952, Beck 1977). Remington and Braun (1985) contend that sage-grouse selectively feed on Wyoming big sagebrush due to its relatively high crude protein (nitrogen) content and reduced monoterpene levels compared to other big sagebrush sub-species. But, Welch et al. (1991), comparing food selection by captured wild birds, found that sage-grouse prefer mountain big sagebrush. However, because of the high elevation requirements for mountain big sagebrush growth, this shrub is typically covered by snow during the winter, and not available. Sage-grouse express preference while selecting both foraging plants and sites, but are capable of shifting their eating habits when either sagebrush quantity or quality becomes limiting (Remington and Braun 1985, Welch et al. 1991). Again, sage-grouse distribution is affected by sagebrush exposure rather than differences in nutritional quality of forage (Hupp and Braun 1989).

In Wyoming, the Jackson area has the best possibility of sage-grouse limiting winter habitats; based on the correlation between winter precipitation and changes in the number of males occupying leks, winter habitat could be limiting this population. In Jackson, sage-grouse selected areas with increased sagebrush canopy cover and height, and decreased sagebrush density relative to available sagebrush dominated areas. Additionally, 89% of wintering locations were on southern or western aspects, and 98% of the selected winter sites were on slopes <10%.

SEASONAL ADULT SURVIVAL

Zablan et al. (2003), using band-recovery data from over 6,000 banding individuals in Colorado, estimated 59% annual survival for adult females, 78% for yearling females, 37% for adult males, and 63% for yearling males. In Wyoming, 67% annual survival for females and 59% for males was estimated from over 3,000 banded individuals (Schroeder et al. 1999 after June 1963). Moynahan (2004) investigated factors influencing monthly survival of female sage-grouse in Montana, and reported that breeding status (nesting or non-nesting), environmental condition, and exposure to hunting resulted in variable seasonal survival probabilities. Environmentally, severe winter weather (heavy snow and extreme cold) and the emergence of West Nile virus (Naugle et al. 2004) reduced sage-grouse survival during an annual winter and fall period, respectively, whereas drought conditions (throughout the year) resulted in increased annual survival (Moynahan 2004).

In Farson, survival from April through October (period length due to battery life of radio-transmitters) varied seasonally and annually; survival ranged from 50% to 80%. During the Farson study, 49% of the females that nested successfully survived from May through October, with 60% of the mortalities occurring in September; only 22% of brooding females survived September 1994. Heath et al. (1997) suggested that drought conditions during 1994 resulted in birds concentrating on limited available summering habitat, facilitating prey search for both hunters and natural predators. Regardless, because of the apparent susceptibility of brooding females during an early September hunting season (although harvest was not identified specifically as the primary source of mortality), the Wyoming Game and Fish Department shifted the sage-grouse season opener from September 1 to the 2^{nd} weekend in the month throughout Wyoming in 1995.

Female sage-grouse survival from April to October in Rawlins averaged 73%, with no apparent seasonal variability. In Jackson, female summer (April through August) and winter (September through March) survival averaged 88% and 83% respectively; however, the Jackson study was conducted during 4 years of below normal winter precipitation. Changes in long-term lek counts correlated well with winter precipitation levels, suggesting that reported winter survival probabilities were higher than typically experienced in the Jackson Hole area. Seasonal survival in Lander ranged from 69 to 94%, with the lowest survival occurring during April through June (average 79%). However, there was no apparent variability in spring survival during breeding (April 81%), nesting (May 86%), or brooding (June 83%) periods. Female annual survival (April through March) in Kemmerer ranged from 54 to 80%; the greatest proportion of mortalities occurred during April and September.

LIVESTOCK GRAZING

Livestock grazing and its potential effect on sagebrush-dominated ecosystems is one of the most contentious and argued issues underlying the management and use of these habitats (Connelly et al. 2004). Domestic livestock have grazed over most sage-grouse occupied habitats, and this use is typically repetitive with annual or biennial grazing periods of varying timing and length (Braun 1998). Scientific evidence suggests that livestock grazing did not increase sagebrush distributions (Peterson 1995), but reduced the herbaceous understory and increased sagebrush densities (Vale 1975, Tisdale and Hironaka 1981). Some argue that sagebrush steppe ecosystems within the intermountain west (and their associated plant communities) did not evolve with heavy wild ungulate grazing as did the grasslands of central North America, and conclude historic and present livestock utilization has probably resulted in vegetative changes (Mack and Thompson 1982, Miller et al. 1994) and declines in species richness (Reynolds and Trost 1980). Part of this reasoning is that grazing by large ungulates results in the permanent loss of cryptogamic crusts (non-vascular plants of algae, lichens, mosses and diatoms; Pieper 1994) through trampling (Mack and Thompson 1982). Mack and Thompson (1982) maintain that if the crusts represent a component in the evolutionary process of plant establishment throughout the intermountain west, than large ungulates could not have been present, even at low densities.

However, paleoecological records support that the intermountain west evolved with large ungulate grazing (Burkhardt 1995). At the time of the Pleistocene Ice Age (2.5 million years ago), the flora was essentially the same as modern flora, including sagebrush, grass and forb species (as indicated by pollen core samples; Tidewell et al. 1972, Barnosky et al. 1987). There is evidence to support abundant, widespread bison herds within the intermountain west prior to the 1800s (Schroedl 1973, Agenbroad 1978, Butler 1978), and that there was an ecological void (relatively small numbers of large ungulates) when the first Europeans arrived in the area (Burkhardt 1995). Savory (1988) argues that historic movement and grazing patterns were different from recent patterns due to predator influences resulting in tightly packed ungulate herds (a theory supported in part by changes in elk movement patterns when wolves were reintroduced into Yellowstone National Park).

Johnson (1987), comparing 56 photographs taken in Wyoming in 1870 with present day photographs, reported that the ecological change has been relatively small, and the overall impression was one of stability (as cited in Bennett 1992). Additionally, a study examining the vegetative differences between grazed and exclosed plots (excluded from grazing for 31 years, on average) throughout the intermountain west found no landscape scale differences in: (1) native or exotic species richness, (2) species diversity, (3) species evenness, and (4) cover of grasses, forbs, and shrubs

(Stohlgren et al. 1999). However, Pieper (1994) maintains that removing livestock from rangelands grazed from the early 1900's is unlikely to return ecosystems to their pristine conditions; and Connelly et al. (2004) contend that our previous history of livestock grazing has influenced soils and plant composition which continue to influence current patterns and processes.

There is little scientific data linking grazing practices to sage-grouse population levels (Connelly and Braun 1997). However, comparing sage-grouse seasonal habitat requirements (outlined above) to studies investigating the response of the habitat to livestock grazing can provide suggestions. Short-term rotational grazing patterns (vs. continuous grazing patterns) benefit native grass and forb production (Derner et al. 1994), which are key habitat features associated with hatching success and hen pre-laying nutrition. However, heavy spring and spring-fall grazing are detrimental to upland herbaceous understories essential for sage-grouse nesting success, whereas fall utilization is neither detrimental nor advantageous (Mueggler 1950, Laycock 1979, Owens and Norton 1990). Insect diversity and density are positively correlated with herbaceous density and diversity (Hull et al. 1996, Jamison et al. 2002), thus spring or spring-fall grazing could also negatively impact young chick survival. Stocking rate appears to be the variable impacting residual grass stubble height (important during the initial stages of nest incubation), with high stocking rates reducing heights (Owens and Norton 1990, Derner et al. 1994). Conversely, spring grazing at high stocking rates is potentially beneficial on sage-grouse winter range, while heavy fall utilization is detrimental (because of differing impacts to sagebrush densities; Wright 1970, Owens and Norton 1990, Angell 1997). Holloran et al. (2005) reported that reducing the amount of residual grass in sagebrush habitats could negatively impact the quantity and quality of sage-grouse nesting habitat, and suggested annual grazing in nesting habitat, regardless of the timing, could negatively impact the following year's nesting success. The importance of annual and seasonal range monitoring and subsequent removal of livestock as utilization reaches capacity cannot be over-emphasized (Holechek 1996, Thurow and Taylor 1999).

Livestock distribution patterns (which are directly linked with water availability) and impacts to riparian habitats primarily influence sage-grouse late brood-rearing and summering habitats. The transition zones or ecotones between types (upland sagebrush and wet meadow) provide food forbs with associated protective cover and are important areas for sage-grouse broods (Klebenow 1982). However, meadows that are heavily invaded by sagebrush and heavy vegetation on ungrazed meadows are not utilized by sage-grouse (Oakleaf 1971, Klebenow 1982). High stocking rates in areas with limited water resource availability are detrimental to forage productivity surrounding water sources (Hall and Bryant 1995, Dobkin et al. 1998). Summer grazing on riparian habitats also appears to concentrate livestock on riparian corridors, resulting in decreased low vegetative growth (typically the forb communities essential in sage-grouse summer diets) and the extent of the hyporheic zone (reducing the lateral extent of succulent vegetation associated with the riparian corridor). However, sage-grouse use grazed instead of ungrazed meadows where protective cover conditions are otherwise equal (Neel 1980). Grazing increases the quality of the forb resource (by interrupting and delaying maturation) and increases accessibility to low-growing food forbs (by producing patchy small openings) sought by sage-grouse (Neel 1980, Evans 1996). Bryant (1982) suggests that stocking pastures containing riparian zones with cow/calf pairs (vs. yearlings) during the cooler part of the grazing season will decrease adverse livestock impacts to the riparian habitats. Additionally, Neel (1980) maintains that rest-rotation grazing can beneficially impact sage-grouse summering habitat if moderate stocking levels are maintained, and rest is afforded a given meadow every 3 years.

The Lander, Wyoming study was primarily focused on the potential effects of livestock grazing management practices on sage-grouse productivity (Kuipers 2004). The study suggested that reduced forage utilization, extended periods of rest, and reduced spring grazing could provide conditions suitable for sage-grouse nesting and early brooding during periods of extensive drought (precipitation 68% of normal during study). Grazing system (based on rotation period) appeared to be less important than stocking rates and season of use. Herbaceous cover and height estimates were consistently lower in livestock grazed relative to non-grazed pastures; residual and live grass height and cover and forb cover were lower in deferred (essentially season long grazing) compared to rotation systems, and grass and forb cover were lower in spring – fall grazed compared to summer grazed rotation systems. Interestingly, bare ground doubled during the time of the study in pastures grazed season long. Shrub components did not appear to be influenced by grazing system. Kuipers (2004) concluded that pastures grazed during the summer and the non-grazed control pastures best mimicked suitable sage-grouse nesting and early brood-rearing habitat during an extensive drought.

The Rawlins study compared 3 ranches with differing grazing management schemes; a non-grazed control was not available for this study (Heath et al. 1998). Live grass height appeared to be least impacted by rotating cattle after 30 instead of 40% forage utilization. Average live and residual grass heights were shorter on the sheep and cattle ranch with >50% utilization compared to the cattle only ranches with <40% utilization. Shrub and herbaceous cover variables did not differ between ranches. Heath et al. (1998) concluded that ranches where the only grazing management difference was 30 compared to 40% forage utilization did not differ in terms of nesting and early brood-rearing habitat condition, but that >50% utilization reduced nesting and brooding habitat quality.

SAGEBRUSH MANIPULATION

The current consensus (although highly speculative) is that historic sagebrush-steppe ecosystems were a mosaic of successional shrub age classes created and maintained by fire regimes ranging in frequency from 10-110 years (Klebenow 1972, Wright et al. 1979, Winward 1991). Selective (patchy) fires appear to have been normal in most sagebrush shrublands, while larger fires at lower frequencies occurred in other areas, depending on the climate, topography, plant composition, and aridity of the site (Paige and Ritter 1999). However, after a review of the ecological literature pertaining to sagebrush ecosystems, Tisdale and Hironaka (1981) concluded that because most sagebrush species are sensitive to fire and that early explorers found sagebrush abundant throughout the region, fire must have been historically infrequent.

During most of the 20th century, the sagebrush habitat management consent was that fire should be used to control shrubs (sagebrush) to increase productivity, nutritional quality, and forage availability for livestock (Harniss and Murray 1973, Bunting 1989). Presently, the landscape goal for sagebrush systems in Wyoming is to promote a mosaic of shrub age classes and canopy covers across large, contiguous stands; prescribed fire has been identified as a management option to accomplish this goal (Kilpatrick 2000, Wyoming Interagency Vegetation Committee 2002). However, Lommasson (1948), after studying sagebrush stands for 31 years (1915-45) in Montana, concluded that sagebrush will continue to reproduce and maintain itself indefinitely under natural conditions; over time, sites favorable for sagebrush growth will eventually become (and be maintained in) a multi-aged stand.

Burning results in the greatest reduction of sagebrush cover and has the most protracted effect on sagebrush when compared to other treatments (Watts and Wambolt 1996). Since most species of big sagebrush can only recover by seed, burning significantly lengthens the time required for re-establishment (Vale 1974, Braun 1987). Recovery from a burn to a 20% sagebrush canopy exceeds 35-40 years in Wyoming big sagebrush habitat types, 25 years in basin big sagebrush types, and 15-25 years in mountain big sagebrush sites (Harniss and Murray 1973, Wright and Bailey 1982, Bunting et al. 1987, Winward 1991, Watts and Wambolt 1996). Additionally, Watts and Wambolt (1996) reported that Wyoming big sagebrush canopy cover had reestablished at levels below original levels 30 years post-burn, which indicates that historic wildfires had to have been infrequent for current sagebrush canopies (in untreated sagebrush) to be maintained. Although sagebrush in a burn in Idaho was approaching pre-burn density 30 years post-burn, the majority of the plants in the burned plots were less than 6 inches tall (Harniss and Murray 1973), indicating that the plant community was far from a climax community. However, these fire recovery intervals were estimated from plant recovery evidence. Combining fire-scar data with these recovery estimates, Baker (*in press*) reported that the best available estimates of fire rotation (i.e., the average interval in which fire would impact each point in a landscape) are 100 to 240 years in Wyoming big sagebrush and 70 to 200 years in mountain big sagebrush. The author went on to conclude that fire suppression likely has had little effect in most sagebrush communities, and that the reintroduction of fire into these systems is currently not a restoration need (Baker *in press*).

The overall effect of sagebrush treatments on sage-grouse populations is largely dependent on the vegetative response, the status of the population, and the type of habitat treated. Increasing sage-grouse populations and populations below their potential carrying capacity do not appear to be adversely affected by the treatment of sagebrush (Wallestad 1975, Martin 1990). However, neither do they show a positive response through an increase in relative abundance (Wallestad 1975, Martin 1990, Fischer et al. 1996). In contrast, Connelly et al. (1994) found that a declining population declined to a much greater extent in treated areas relative to untreated areas. Destruction of wintering and nesting habitat is believed to have the greatest potential to reduce the total capacity of an area to support a sage-grouse population (Wallestad 1975, Connelly and Braun 1997).

Relatively large treatment areas typically result in sage-grouse declines (Klebenow 1970). A >20% sagebrush crown reduction on >350 ha treatment blocks caused a reduction in the number of cocks on adjacent strutting grounds in Montana (Martin 1970, Wallestad 1975). Connelly et al. (2000a) reported that the negative effects of a 57% sagebrush crown removal project on a sage-grouse breeding population (estimated by lek counts) included: (1) increased loss of leks; (2) increased decline in average cock lek attendance; and (3) increased decline in the mean number of cocks per lek when comparing treatment to control areas in Idaho (findings applicable to low precipitation zones dominated by Wyoming big sagebrush). In Montana, sage-grouse use of a treatment area (2,4-D spray strips) was restricted almost exclusively to remnant sagebrush patches (Martin 1970). And, the loss of a relatively large portion of wintering sagebrush dominated habitat to plowing resulted in a substantial decline (73%) in the number of strutting male sage-grouse on adjacent leks in Montana (Swenson et al. 1987).

There is almost no justification for removing sagebrush in areas where winter cover for sage-grouse is limited (Klebenow 1972). Sagebrush removal on winter range can significantly reduce the availability of tall sagebrush that provides critical cover and food, especially during severe winters (Schneegas 1967, Robertson 1991). In Idaho, the removal of 60% of the sagebrush cover (in a mosaic pattern) resulted in a significant decline in the use of these sites for winter range (34 and 42% of locations pre- versus 6% post-burn; Connelly et al. 1994).

There is disagreement regarding the result of sagebrush removal on the breeding activities of sage-grouse. Some researchers have reported a significant decrease in lek attendance by cocks

(Wallestad 1975, Connelly et al. 1994), whereas others have found no clear effect (Gates 1983, Martin 1990, Benson et al. 1991, Fischer 1994). Shrub removal reduced the availability of cover surrounding leks (breeding adults avoided manipulated areas for feeding, loafing, and roosting; Martin 1990), and birds migrated from altered breeding grounds earlier than normal in Idaho (Fischer et al. 1997). However, in areas with limited suitable lekking grounds, sagebrush removal could be an effective tool to create open areas for breeding, provided there is sagebrush nearby for escape and feeding (Dalke et al. 1960, Connelly et al. 1981, Phillips et al. 1986).

Nesting habitat is especially susceptible to burning because of relatively high fuel loads characteristic of this habitat (Connelly et al. 1994). Sage-grouse restrict their nesting use of manipulated areas to remaining patches of live sagebrush (Connelly et al. 1994, Fischer 1994). Although some research has found similar nesting densities and success between burned and unburned areas (Klebenow 1970, Fischer 1994), large reductions in the amount of available nesting habitat will reduce the capacity of an area, and result in the clustering of nests within the remaining sagebrush patches and increasing predatory pressure (Niemuth and Boyce 1995). In addition, coyotes (*Canis latrans*) are reportedly able to increase following sagebrush treatment (Wright 1974), and habitat fragmentation and the creation of edges may reduce the difficulty of foraging by predators (Burger et al. 1994, Braun 1998). However, lower nest predation rates may occur in recovering treated sagebrush as the sagebrush treatment reduces the long-term density of larger mammalian prey (rabbits; *Lepus* and *Sylvilagus* spp. and ground squirrels; *Spermophilus* spp.) and subsequently reduces predator densities (Ritchie et al. 1994).

The inability of sagebrush removal treatments to consistently increase forbs or insects limits their utility as a tool for sage-grouse brood-rearing habitat management (Gates 1983, Martin 1990, Connelly et al. 1994, Nelle 1998). Klebenow (1970) reported that broods did not use treated areas for 2 years post-treatment. Additionally, Connelly et al. (1994) reported that the abundance and biomass of ants was reduced the 2nd and 3rd years post-treatment in southeastern Idaho (Fischer et al. 1996); grasshopper densities were reduced by 60% the first year after a prescribed burn in Arizona (Bock and Bock 1991); and 6 years after a big sagebrush wildfire in southeastern Washington, half of the ground dwelling beetle species were less abundant on burned sites, and overall beetle abundance was reduced by 20% (Rickard 1970). In contrast, the abundance of ants and beetles on the Upper Snake River Plain in Idaho was significantly greater in a 1-year old burn, but had returned to unburned levels 3 to 5 years post-burn (Nelle et al. 2000).

Relative to unburned control sites, burning in sagebrush habitats near Kemmerer, Wyoming, resulted in reduced sagebrush and total shrub cover, increased common burn shrub (i.e., rabbitbrush in particular) cover, and did not stimulate herbaceous production during drought conditions (precipitation 50% of normal during study; Slater 2003). However, sage-grouse did not avoid burned habitats for nesting providing that adequate structural cover (shrub overstory cover) within the burns existed, and nesting within burned areas (relative to outside burns) did not negatively influence the probability of a successful hatch. Although burning did not improve relative (to non-burned habitats) forb or herbaceous cover or insect numbers, females nesting within a burn moved shorter distances from nests to early brooding sites, suggesting that burning created areas attractive for brood-rearing. General grouse burn-use observations (throughout spring and summer periods) suggested birds feed and loaf in both burned and unburned portions of the burns, with locations concentrated relatively close (within 60 m) to the interface between these two habitats. Slater (2003) concluded by cautioning that drought likely played a significant role in shaping the findings reported in the study, and that low nest success (average 24% during study) and productivity (average 0.3 chicks fledged in August per female), although probably impacted by the drought, suggested that burning could influence sage-grouse beyond the spatial scale of the burn itself.

MINERAL EXTRACTION ACTIVITIES

The magnitude of energy development impacts on wildlife resources throughout North America is relatively unknown. Generally, gregarious species (i.e., sage-grouse during the breeding season) are more severely affected by a disturbance than are solitary species, and hunted species will exhibit a greater avoidance of road-related disturbances than will their unhunted conspecifics (PRISM Environmental Management Consultants 1982). Potential impacts of mineral extraction development to sage-grouse include: (1) direct habitat loss from well, road, pipeline, and transmission line construction, (2) the replacement of mature plant and animal communities with lower successional stages of plants and associated fauna, (3) increased human activity causing avoidance and displacement, (4) pumping noise causing displacement and reducing breeding efficiency, (5) increased legal and illegal harvest (it has been estimated that game violations increase by 3 times in remote areas undergoing intensive development; Bay 1989), (6) direct mortality associated with evaporation ponds and associated diseases (Naugle et al. 2004), and (7) reduced water tables resulting in herbaceous vegetation loss (USDI BLM 1979, Schoenburg and Braun 1982, Braun 1986, Braun 1987, TRC Mariah Associates Inc. 1997, Connelly et al. 2004). Sage-grouse leks within 0.4 km of coalbed methane (CBM) wells in northern Wyoming had significantly fewer males per lek and lower annual rates of population growth compared to leks situated >0.4 km from a CBM well (Braun et al. 2002). The extirpation of 3 lek complexes within 0.2 km of oil field infrastructure in Alberta, Canada, was associated with the arrival of oil field-related disturbance sources (Braun et al. 2002, Aldridge and Brigham 2003). Additionally, the number of displaying males on 2 leks within 2 km of active coal mines in northern Colorado declined by approximately 94% over a 5-year period following an increase in mining activity (Braun 1986, Remington and Braun 1991).

Roads constructed for mineral exploration and production may result in the development of permanent travel routes, improved public access, increased long-term traffic related disturbance to previously inaccessible regions, indirect noise impacts (to leks ≤1 km from the road; Braun 1998), and direct mortality (USDI BLM 1979, PRISM Environmental Management Consultants 1982, Braun 1998). Generally, road effect-distances (the distance from a road at which a population density decrease is detected) are positively correlated with increased traffic density and speed, and are more severe in years when wildlife population sizes are low (Forman and Alexander 1998). However, Ingelfinger (2001), studying the potential effects of road disturbance on sagebrush steppe passerines along the Pinedale Anticline, reported that sagebrush obligate bird densities were reduced within 100 m of a road, regardless of traffic volumes. The author suggested that habitat edge avoidance or changes in passerine species composition along the roads (i.e., increased horned lark abundance) explained sagebrush obligate declines (Ingelfinger 2001). The upgrade of haul roads associated with surface coal mining activity in North Park, Colorado resulted in one sage-grouse lek (50 m from a road) becoming inactive, and an 83% reduction in the number of displaying cocks on another lek (500 m from a road) within 3 years post-upgrade (Braun 1986, Remington and Braun 1991). Additionally, patch occupancy probabilities of Gunnison sage-grouse (*Centrocercus minimus*) in Colorado were positively correlated with distance to roads, suggesting avoidance (Oyler-McCance 1999).

Although transmission line construction does not cause direct habitat loss, sage-grouse avoidance of vertical structure, due to altered raptor distributions and raptor species composition within relatively flat landscapes, results in habitat exclusion (≤1 km wide band centered on power lines; USDI BLM 1979, Braun 1998). The construction of transmission line structures located within 200 m of an active sage-grouse lek and between the lek and cock day use areas in northeastern Utah resulted in a 72% decline in the mean number of strutting cocks and an alteration in daily dispersal patterns during the breeding season within 2 years (Ellis 1985). The frequency of raptor-sage-grouse interactions during the breeding season increased 65%, and golden eagle (*Aquila chrysaetos*) interactions increased 47% between pre- and post-transmission line construction (Ellis 1985). Transmission lines constructed in southeastern Colorado significantly increased: (1) raptor density within 400 m of the towers, and (2) overall raptor populations in the total census area; although the towers represented <2% of the available perches, 81% of all perched raptors recorded were on them (Stahlecker 1978).

The effects of noise on wildlife include: (1) masking signals that influence courtship, grouping, escape, etc., and (2) direct effects on behavioral and physiological processes (Bromley 1985 after Memphis State University 1971). Masking vocal communication of birds, especially sounds that may mask acoustic cues necessary for reproduction, may be the most negative influence of noise (Reijnen et al. 1995). Gibson and Bradbury (1985) reported that male sage-grouse mating success was more closely related to individual differences in strut display effort and sound characteristics (i.e., lek attendance, strut display rate, and the temporal and frequency characteristics of the whistle emitted towards the end of the strut display) than to territorial or morphological characteristics. Gibson (1989) further indicated that the acoustic component of the strut display alone (produced by hidden audio speakers situated on a lek) was attractive to females. Although it is unknown if unnatural noises associated with anthropogenic activity (i.e., gas and oil development operations, traffic) disrupt females' ability to evaluate males' displays, it seems reasonable that noises within the range of those emitted by sage-grouse males (within the frequency bands 300-1200 Hz; Dantzker et al. 1999) could mask courtship acoustics and influence breeding behavior and lek attendance.

Sage-grouse populations apparently decline in response to mineral development activity; however, establishing causality has remained elusive. Remington and Braun (1991) theorized that regional distributions rather than numbers of breeding sage-grouse were altered by coal mining activity in Colorado. This displacement theory is additionally supported by several studies: greater sage-grouse in Alberta, Canada avoided nesting in areas with increased levels of human development (i.e., roads, well sites, urban habitats, cropland), and females with chicks avoided areas with high densities of visible oil wells (Aldridge 2005); lesser prairie-chickens (*Tympanuchus pallidicinctus*) in Kansas selected habitats removed from anthropogenic features (Hagen 2003); and Gunnison sage-grouse in Colorado avoided roads (Oyler-McCance 1999). Potential negative effects to population levels also have been suggested: Aldridge (2005) reported that greater sage-grouse chick survival decreased as well densities within 1 km of brooding locations increased in Canada, and Hagen (2003) suggested that a lesser prairie-chicken population impacted by anthropogenic activity in Kansas had lower nest success and female survival probabilities compared to a non-impacted population.

Sage-grouse response to natural gas field development has been studied in the Pinedale area since 1998. The first 2 years (1998-99) of the study were concentrated on the northern end of the Pinedale Anticline Project Area (the Mesa), and were primarily investigating the reaction of female sage-grouse breeding on road-disturbed compared to undisturbed leks (Lyon 2000, Lyon and Anderson 2003). Females breeding on disturbed leks initiated nests less frequently (65%) than undisturbed individuals (89%); additionally, for females that were followed for consecutive nesting seasons, 56%

breeding on disturbed leks initiated nests both years compared to 82% of the females breeding on undisturbed leks. Females disturbed during the breeding season moved on average twice as far from the lek to nest compared to undisturbed females (4.1 vs. 2.1 km, respectively); 26% of the disturbed females nested within 3 km of the lek compared to 91% of the undisturbed females. For those females that nested, hatching success and early brood-rearing brood survival probabilities did not differ between disturbed and undisturbed females. Lyon (2000) also reported that sage-grouse breeding and summering throughout the entire upper Green River region (including areas extending north of Pinedale approximately 70 km to Green River Lakes) were concentrating on the Mesa and areas approximately 15 km south of the New Fork River during the winter.

The second phase of the Pinedale study incorporated data from Lyon's (2000) study, expanded the study area to include the entire Pinedale Anticline Project Area, and continued to investigate the response of sage-grouse populations to the development of a natural gas field (Holloran *in preparation*). Because the EIS was completed in 2000, we were able to investigate all aspects of gas development versus concentrating on road related disturbance impacts. Over the long-term, sage-grouse in the Pinedale area apparently were excluded from breeding within or near the development boundaries of a natural gas field. Declines in the number of displaying males were positively correlated with decreased lek-to-gas field-related disturbance source (i.e., active drilling rig, producing well pad, main haul road) distances, increased traffic volumes within 3 km of leks, and increased potential for greater noise intensity at leks. The results suggested that well densities exceeding 1 well per 283 ha within 3 km of a lek negatively influence male lek attendance, and rates of lek attendance decline increased on leks located relatively centrally within the developing gas field (i.e., producing wells occupying ≥3 directional quadrates around the lek). Adult male displacement and minimal juvenile male recruitment could be contributing to declines in the number of breeding males on impacted leks. Additionally, predatory species' responses to gas field development could be responsible for decreased male survival probabilities on leks situated on the edges of the developing field and could be extending the gas field's range-of-influence.

Female nest site selection results suggested that site-tenacious adult females did not disperse in response to increased levels of gas development within selected nesting locations; however, subsequent generations apparently avoided gas field infrastructure during the nesting period. Additionally, portions of the yearling female breeding cohort apparently avoided breeding on leks situated relatively near the developing field. Population growth differences between impacted and non-impacted populations of individuals suggest that natural gas related impacts negatively influenced female greater sage-grouse population growth. In general, most of the variability in population growth differences between treatment and control populations was explained by lower annual survival (especially of adult females) buffered to some extent by higher productivity in treatment populations. Interestingly, disturbed female annual survival was primarily influenced during the early brooding and summering stages, after and not during actual gas development impact (individuals were primarily subjected to natural gas activity during the breeding and nesting seasons). Because treatment and control individuals summered in generally the same areas (and these areas were not situated close to the developing gas field), this suggests that individuals subjected to gas development activity during the spring were reacting hormonally and that the hormonal reaction was predisposing them to predation during the summer (most birds that died were killed by predators vs. dying from other causes). Holloran (*in preparation*) concluded that regional sage-grouse population levels as well as population distribution were negatively influenced by the development of a natural gas field.

PREDATOR CONTROL

Predation is commonly believed to have played an important role in shaping nearly every aspect of avian life history. Mortality due to predation can be high, particularly during early life stages (Cote and Sutherland 1997). The loss of nests to predators is the most damaging to sage-grouse populations, as production of young and recruitment may be affected (Braun 1998). However, although predation could play a role in reducing sage-grouse production, the quality of breeding habitat is believed to be an overriding factor controlling the importance of predation (Connelly et al. 1994, Braun 1998).

Despite the number of factors influencing predation rates, there is little doubt that the majority of unsuccessful nests are lost to predation (Patterson 1952, Gregg et al. 1994, Heath et al. 1997, Holloran 1999). Throughout Wyoming, >95% of 246 failed nests were attributed to predators (Holloran et al. 2005). Additionally, studies in Oregon report a high incidence of chick predation during the early brood-rearing period (Willis et al. 1993). Ravens and various hawks are known to take young grouse during this stage (Girard 1937, Patterson 1952). Also, preliminary findings in Idaho suggest that a significant portion of young chick loss results from red fox predation (J. W. Connelly, Idaho Department of Fish and Game, personal communication).

Vegetation consistently higher at successful compared to unsuccessful sage-grouse nests throughout the range of studied populations included live and residual grass height, residual vegetative cover, forb cover and visual obstruction (Wakkinen 1990, Gregg et al. 1994, Sveum et al. 1998b, Popham 2000, Aldridge and Brigham 2002, Hausleitner 2003, Holloran et al. 2005). Other studies on ground nest predation suggest that the penetrability of vegetation surrounding nests, as influenced by spatial heterogeneity, may be more important than concealment at the nest (Bowman and Harris 1980, Schranck 1972, Crabtree et al. 1989). Additionally, high nest densities due to habitat fragmentation or the lack of quality nesting habitat, habitat size, and the presence of edges, fencerows, or trails may increase predation rates by reducing foraging difficulty for predators (Mankin and Warner 1992, Burger et al. 1994, Niemuth and Boyce 1995, Braun 1998, Holloran and Anderson 2005).

The density and distribution of predators is also likely to affect nest predation rates. Nest and brood predation, as influenced by changes in coyote and raven abundance in particular, have been identified by some researchers as an important factor limiting annual productivity (Batterson and Morse 1948, Willis et al. 1993). High predator densities may also cause some predators to increase their use of foods that are normally of less importance. The alternative prey hypothesis predicts that predators shift their diet from usual prey sources to alternative prey sources during times of primary prey scarcity (Angelstam et al. 1984, Lindstrom et al. 1986). High predator densities, overall or relative to preferred prey sources, may result in increased consumption of normally unimportant food sources. Nest losses of black grouse were low (11%) in a small rodent peak years and high (78%) in a small rodent crash years (Angelstam et al. 1984).

Due to its effect on bird populations and the difficulty of controlling other factors, predation is often seen as an important source of mortality that can be reduced if necessary (Cote and Sutherland 1997). Predator control is currently conducted in many areas used by sage-grouse to reduce predation on livestock that share these ranges. Predation is generally of greatest concern to sheep and various studies have documented the significant impact of predators on these range animals (Tigner and Larson 1977, McAdoo and Klebenow 1978, Scrivner et al. 1985). In a review of 20 studies on the effectiveness of predator removal in protecting bird populations, it was found that removal can reduce early mortality, but that it may not increase the breeding bird population to any great extent (Cote and Sutherland 1997). The effectiveness of predator control appears to be influenced by the status of the target population. Stable and increasing populations appear to respond positively to predator removal, while declining populations are likely to continue declining (Cote and Sutherland 1997).

Commonly cited mammalian sage-grouse and nest predators, namely red foxes, coyotes, bobcats (*Felis rufus*), and badgers, have a great overlap of diets (Patterson 1952, Voigt and Earle 1983, Major and Sherburne 1987, Dibello et al. 1990). As a result, resource competition likely exists and the failure to remove all predator species may simply allow the remaining species to increase in their absence. Using trapping as an index to population, Robinson (1961) found that a decrease in coyote numbers over a 20-year period corresponded to an increase of bobcat, badger, skunk (*Mephitis mephitis*), and other carnivores. Other species interactions must be considered as well. Studies of red fox/coyote interactions have shown that red foxes strongly avoid the territories of coyotes. Because coyotes generally have much larger home ranges, their presence may seriously limit the fox population of an area (Voigt and Earle 1983, Major and Sherburne 1987, Sargeant et al. 1987, Harrison et al. 1989). As coyote control became more effective during the 1930s and 1940s, the number of coyotes in farmland areas was reduced and red fox populations began to expand, with red fox becoming more numerous relative to recorded history beginning in the late 1940's (Sargeant et al. 1987). Predator removal is generally focused on the coyote because it is responsible for the vast majority of sheep predator kills (Tigner and Larson 1977, Taylor et al. 1979). However, it may not be an important sage-grouse nest predator (Patterson 1952). Diet studies of the coyote indicate that birds as a whole contribute <7% of the yearly dry weight consumed (Johnson and Hansen 1979, Reichel 1991). In contrast, the red fox is known to be a significant predator of ground nesting ducks and eggs (Sargeant 1972).

In Casper, remote-sensing cameras were placed at 33 sage-grouse nests to identify nest predators (Holloran 1999, Holloran and Anderson 2003). Four of the monitored nests were unsuccessful; an elk (*Cervus elaphus*), badger, and black-billed magpie were directly responsible for 3 of the 4 losses, and repeated disturbance by cattle caused the 4th female to abandon. Interestingly, Patterson (1952) reported that most sage-grouse nest loss in Wyoming was attributable to ground squirrels; however, both thirteen-lined and Richardson's ground squirrels were documented at sage-grouse nests in Casper, yet none of these nests were destroyed. The probability of a successful hatch was negatively related to the amount of time females spent away from the nest during incubation-feeding times, and food forb cover tended to be higher at successful compared to unsuccessful nests. This suggests that forb cover within dense sagebrush patches could reduce the amount of time a female remains off the nest during incubation and result in increased nest success probabilities.

Comparing ranches with different predator control management (intensive vs. recreational predator control) near Rawlins, Heath et al. (1998) reported that control measures could potentially have counteracted some of the effect of substandard nesting habitat (primarily in terms of short residual grass heights on the sheep and cattle ranch). However, predator control did not influence brooding period chick or adult annual survival. Heath et al. (1998) concluded that predator control had limited value to sage-grouse populations.

In Kemmerer, Slater (2003) compared predator density and species composition and sage-grouse productivity in 2 areas, 1 with extensive coyote control and 1 with limited recreational predator control. The results suggested that the coyote control program decreased coyote abundance, but that badger abundance was increased in the coyote control area (although a direct link between decreased coyote and increased badger abundance was not established). However, nest success and brood survival did not differ between the 2 areas, suggesting reduced coyote abundance and coyote control did not benefit sage-grouse populations.

An interesting theory pertaining to nest depredation probabilities and the presence of potential predator travel corridors (i.e., trails) was investigated in Lander (Kuipers 2004). In terms of trail configuration within 100 m of sage-grouse nests, important predictors of nest success were trail absence within 25 m, and trail presence at 100 m. Kuipers (2004) theorized that if trails represented attractive travel paths for predators, trail presence close to a nest would increase nest detection probabilities, whereas trails farther away would act to draw predators away from a nest and increase hatching probabilities.

FUTURE SAGE-GROUSE RESEARCH in WYOMING

Although the WyCOOP has recently been involved in numerous research projects investigating questions from general sage-grouse seasonal habitat use and survival to specific aspects of sagebrush habitat management and how they influence sage-grouse biology, several questions that surfaced as a result of those projects remain uninvestigated. The WyCoop currently is addressing 3 of these questions.

Results from the first 2 Pinedale studies suggest that sage-grouse leks situated relatively near extractive mineral developments ultimately become unoccupied. However, indications from these studies are that adult birds are reluctant to disperse from a disturbance, both during the breeding and nesting/early brood-rearing seasons. During the initial phases of the study, birds were captured from leks along the Pinedale Anticline that were either being impacted by gas development, or had the potential to be impacted in the future. This resulted in one of two possible scenarios for the sample population. (1) If a lek was being impacted during the year in question, all the birds using that lek during that year were willing to disregard the potential impact, and our entire sample consisted of these individuals. Thus, we do not know if the sample population was representative of the population as a whole, or consisted solely of individuals able to ignore the presence of gas field activity (presumably adults, which is supported by data collected by Braun 1986). Or, (2) if a lek was impacted one year following initial capture of individuals from that lek (i.e., a pre- vs. post-treatment type of comparison), all the collared individuals returning would be adult birds, and less willing to disperse. Therefore, the first 2 phases of the Pinedale study may not have accurately documented the response of the yearling population to natural gas field development. A scenario where limited yearling recruitment was occurring on leks within gas fields could result in the gradual declines to extinction witnessed at highly impacted leks on the Pinedale Anticline. Thus, a major question remains: “Are juvenile (i.e., yearling) sage-grouse that would normally be using a lek disturbed by gas development using the impacted lek, moving to another lek, or not breeding?" By radio-equipping juvenile sage-grouse in the fall, and tracking those individuals through the following breeding season, the potential influence of natural gas development on the yearling cohort is currently being investigated by the WyCOOP.

The scale of the landscape used by sage-grouse changes throughout seasons and differs between populations. Site area fidelity [established for nesting habitat (Berry and Eng 1985, Fischer et al. 1993, Holloran and Anderson 2005) and surmised for other seasonal habitats (Berry and Eng 1985)] suggests that the "landscape" for an individual hen during different life-history stages is relatively small. The overall landscape requirements for an individual are the conglomeration of these seasonal habitats combined with the necessary migration corridors (the length of these corridors will be different between and within populations). Thus, the landscape question becomes one of seasonal habitat requirements on a relatively small scale, the juxtapositional requirements of those seasonal habitats, and the habitats required to move between those seasonal ranges. The majority of the published research has been concerned with describing microsite selection within seasonal habitats and microsite adequacy of those selected habitats (i.e., use vs. available and successful vs. unsuccessful studies). Little information is available on gross selection parameters within seasonal ranges (i.e., distance to edge, sagebrush patch size requirements, spatial extent of nesting habitat required), juxtapostional requirements between seasonal ranges (i.e., distances between nesting and brooding habitats and the relationship between distances moved and productivity, summer habitat dispersion and adult/chick survival), or the habitat requirements of transitional ranges (i.e., habitat use and requirements during migration). The other 2 questions currently being investigated by the WyCOOP are concerned with gross seasonal habitat selection and habitat use during the spring and fall transition periods. Seasonal locations from the studies conducted by the WyCOOP since 1994 are being used to quantify habitat selection at the scale of the landscape, essentially investigating the question: "Are sage-grouse females selecting seasonal habitats based on landscape features beyond the spatial scale of microsite habitat conditions?" Additionally, radio-equipped birds from migratory and sedentary populations in the Lander area are being used to investigate transitional-range habitat use, and to investigate survival and productivity differences between migratory and non-migratory individuals.

Additional sage-grouse research is being conducted in Wyoming by personnel from other universities. In the northern part of the state (from the Sheridan region south to Gillette), research investigating the potential effects of coal bed methane (CBM) development on sage-grouse distributions and population growth is being conducted by the University of Montana. Sage-grouse population level impacts of West Nile virus (WNv) outbreaks and the potential influence CBM evaporation ponds have on WNv prevalence are also being investigated (Dr. David E. Naugle, University of Montana, Missoula, MT, USA). In the Pinedale and Lander areas, a project aimed at experimentally determining the behavioral response of breeding sage-grouse to noise associated with natural gas development activity is being conducted by the University of California, Davis (Dr. Gail L. Patricelli, University of California Davis, Davis, CA, USA). Wyoming is currently at the forefront of research investigating the impacts certain land-use management practices have on sage-grouse populations, especially the potential effects of resource extraction activity. The concern over sage-grouse is not likely to dissipate in the near future; the need for continued research and modifications to land-use practices remains high.

LITERATURE CITED

Agenbroad, L. D. 1978. Buffalo jump complexes in Owyhee County, Idaho. Plains Anthropologist 23:313-321.

Aldridge, C. L. 2005. Identifying habitats for persistence of greater sage-grouse (*Centrocercus urophasianus*) in Alberta, Canada. PhD Dissertation, University of Alberta, Edmonton, Alberta, Canada.

Aldridge, C. L., and R. M. Brigham. 2001. Nesting and reproductive activities of Greater Sage-Grouse in a declining northern fringe population. Condor 103:537-543.

Aldridge, C. L., and R. M. Brigham. 2002. Sage-grouse nesting and brood habitat use in southern Canada. Journal Wildlife Management 66:433-444.

Aldridge, C. L., and R. M. Brigham. 2003. Distribution, abundance, and status of the greater sage-grouse, *Centrocercus urophasianus*, in Canada. Canadian Field-Naturalist 117:25-34.

Angell, R. F. 1997. Crested wheatgrass and shrub response to continuous or rotational grazing. Journal Range Management 50:160-164.

Angelstam, P., E. Lindstrom, and P. Widen. 1984. Role of predation in short-term population fluctuations of some birds and mammals in Fennoscandia. Oecologia 62:199-208.

Anonymous. 1937. Sage hen season closed. Wyoming Wildlife 2.

Autenrieth, R. E. 1981. Sage grouse management in Idaho. Wildlife Bulletin 9, Idaho Department of Fish and Game, Boise, ID, USA.

Autenrieth, R., W. Molini, and C. Braun (eds.). 1982. Sage grouse management practices. Western States Sage Grouse Committee Technical Bulletin Number 1. Twin Falls, ID, USA.

Baker, W. L. *In Press*. Fire and restoration of sagebrush ecosystems. Wildlife Society Bulletin 00:000-000.

Barnett, J. K., and J. A. Crawford. 1994. Pre-laying nutrition of sage grouse hens in Oregon. Journal Range Management 47:114-118.

Barnosky, C. W., P. M. Anderson, and P. J. Bartleim. 1987. The northwestern U. S. during deglaciation: vegetational history and paleoclimate implications. Geology of North America Volume K3, North America and adjacent oceans during the last deglaciation. The Geological Society of America, Boulder, CO, USA.

Batterson, W. M., and W. B. Morse. 1948. Oregon sage grouse. Oregon Fauna Series 1, Oregon Game Commission, Portland, OR, USA.

Bay, K. G. 1989. Writing the rules of progress: a look at oil and gas development in the midwest. Proceedings of the 43rd Midwest Fish and Wildlife Conference, Wichita, KS, USA.

Beck, T. D. I. 1977. Sage grouse flock characteristics and habitat selection in winter. Journal Wildlife Management 41:18-26.

Bennett, L. E. 1992. Soil conservation service (SCS) brush project: final report. Wyoming Fish and Wildlife Research Unit, University of Wyoming, Laramie, WY, USA.

Benson, L. A., C. E. Braun, and W. C. Leininger. 1991. Sage grouse response to burning in the big sagebrush type. Proceedings: Issues and Technology in the Management of Impacted Western Wildlife, Thorne Ecological Institute 5:97-104.

Bergerud, A. T. 1988. Survival and breeding strategies of grouse. Pages 473-577 *in* A. T. Bergerud and M. W. Gratson, (eds.). Adaptive Strategies and population ecology on northern grouse. University of Minnesota Press, Minneapolis, MN, USA.

Berry, J. D., and R. L. Eng. 1985. Interseasonal movements and fidelity to seasonal use areas by female sage grouse. Journal Wildlife Management 49:237-240.

Bock, C. E. and J. H. Bock. 1991. Response of grasshoppers (Orthoptera: Acrididae) to wildfire in a southeastern Arizona grassland. American Midland Naturalist 125:162-167.

Bowman, G. B., and L. D. Harris. 1980. Effect of spatial heterogeneity on ground-nest predation. Journal Wildlife Management 44:806-813.

Bradbury, J. W., R. M. Gibson, C. E. McCarthy, and S. L. Vehrencamp. 1989. Dispersion of displaying male sage grouse II: the role of female dispersion. Behavioral Ecology and Sociobiology 24:15-24.

Braun, C. E. 1979. Evolution of the effects of changes in hunting regulations on sage grouse populations. Game Research Report, Project W-37-R-32. Job 9a., Colorado Division of Wildlife, Denver, CO, USA.

Braun, C. E. 1981. Vulnerability and population characteristics of sage grouse in Moffat County. Final Report, Federal Aid Project W-37-R-34, Work Plan 3, Job 11. Colorado Division of Wildlife, Denver, CO, USA.

Braun, C. E. 1986. Changes in sage grouse lek counts with advent of surface coal mining. Proceedings: Issues and Technology in the Management of Impacted Western Wildlife, Thorne Ecological Institute 2:227-231.

Braun, C. E. 1987. Current issues in sage grouse management. Proceedings of the Western Association of State Fish and Wildlife Agencies 67:134-144.

Braun, C. E. 1998. Sage grouse declines in western North America: what are the problems? Proceedings of the Western Association of State Fish and Wildlife Agencies 78:139-156.

Braun, C. E., M. F. Baker, R. L. Eng, J. S. Gashwiler, and M. H. Schroeder. 1976. Conservation committee report on effects of alteration of sagebrush communities on the associated avifauna. Wilson Bulletin 88:165-171.

Braun, C. E., T. E. Britt, and R. O. Wallestad. 1977. Guidelines for maintenance of sage grouse habitats. Wildlife Society Bulletin 5:99-106.

Braun, C. E., O. O. Oedekoven, and C. L. Aldridge. 2002. Oil and gas development in western North America: effects on sagebrush steppe avifauna with particular emphasis on sage grouse. Transactions North American Wildlife and Natural Resources Conference 67:337-349.

Bromley, M. 1985. Wildlife management implications of petroleum exploration and development in wildland environments. U.S. Department of Agriculture, Forest Service, Intermountain Research Station General Technical Report INT-191. Ogden, UT, USA.

Bryant, L. D. 1982. Response of livestock to riparian zone exclusion. Journal Range Management 35:780-785.

Bunting, S. C. 1989. Forest site preparation and range improvement. Pages 103-106 *in* D. M. Baumgartner, D. W. Breuer, B. A. Zamora, L. F. Neuenschwander, and R. H. Wakimoto (eds.). Proceedings: Prescribed fire in the intermountain region symposium.

Bunting, S. C., B. M. Kilgore, and C. L. Bushey. 1987. Guidelines for prescribed burning in sagebrush-grass rangelands in the northern Great Basin. U.S. Department of Agriculture, General Technical Report. INT-231, Forest Service Intermountain Research Station. Ogden, UT, USA.

Burger, L. D., L. W. Burger, Jr., and J. Faaborg. 1994. Effects of prairie fragmentation on predation of artificial nests. Journal Wildlife Management 58:249-254.

Burkhardt, J. W. 1995. Herbivory in the intermountain west: an overview of evolutionary history, historic cultural impacts and lessons from the past. Pacific Northwest Range Short Course, Boise, ID, USA.

Butler, R. B. 1978. Bison hunting in the desert west before 1800: the paleoecological potential and the archaeological reality. Plains Anthropologist 23:106-112.

Connelly, J. W. 1982. An ecological study of sage grouse in southeastern Idaho. PhD Dissertation, Washington State University, Pullman, WA, USA.

Connelly, J. W., W. J. Arthur, and O. D. Markham. 1981. Sage grouse leks on recently disturbed sites. Journal Range Management 52:153-154.

Connelly, J. W., H. W. Browers, and R. J. Gates. 1988. Seasonal movements of sage grouse in southeastern Idaho. Journal Wildlife Management 52:116-122.

Connelly, J. W., and L. A. Doughty. 1989. Sage grouse use of wildlife water developments in southeastern Idaho. Pages 167-172 *in* G. K. Tsukamoto and S. J. Striver (eds.). Wildlife water development: a proceedings of the wildlife water development symposium.

Connelly, J. W., W. L. Wakkinen, A. D. Apa, and K. P. Reese. 1991. Sage grouse use of nest sites in southeastern Idaho. Journal Wildlife Management 55:521-524.

Connelly, J. W., W. L. Wakkinen, A. D. Apa, K. P. Reese, and J. W. Fischer. 1993. Re-nesting by sage grouse in southeastern Idaho. Condor 94:1041-1043.

Connelly, J. W., K. P. Reese, W. L. Wakkinen, M. D. Robertson, and J. W. Fischer. 1994. Sage grouse ecology report. Job Completion Report W-160-R-19 Subproject 9, Idaho Department of Fish and Game, Boise, ID, USA.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse (*Centrocercus urophasianus*) populations in western North America. Wildlife Biology 3:229-234.

Connelly, J. W., K. P. Reese, R. A. Fischer, and W. L. Wakkinen. 2000a. Response of sage grouse breeding population to fire in southeastern Idaho. Wildlife Society Bulletin 28:90-95.

Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000b. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28:1-19.

Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, WY, USA.

Cote, I. M., and W. J. Sutherland. 1997. The effectiveness of removing predators to protect bird populations. Conservation Biology 11:395-405.

Crabtree, R. L., L. S. Broome, and M. L. Wolfe. 1989. Effects of habitat characteristics on gadwall nest predation and nest-site selection. Journal Wildlife Management 53:129-137.

Crawford, J. A., M. A. Gregg, M. S. Drut, and A. K. DeLong. 1992. Habitat use by female sage grouse during the breeding season in Oregon. Final Report. Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR, USA.

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Witson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Ecology and management of sage-grouse and sage-grouse habitat. Journal Range Management 57:2-19.

Dalke, P. D., D. B. Pyrah, D. C. Stanton, J. E. Crawford, and E. F. Schlatterer. 1960. Seasonal movements and breeding behavior of sage grouse in Idaho. Transactions of North American Wildlife and Natural Resource Conference 25:396-407.

Dantzker, M. S., G. B. Deane, and J. W. Bradbury. 1999. Directional acoustic radiation in the strut display of male sage grouse *Centrocercus urophasianus*. Journal Environmental Biology 202:2893-2909.

DeLong, A. K., J. A. Crawford, and D. C. DeLong. 1995. Relationship between vegetational structure and predation of artificial sage grouse nests. Journal Wildlife Management 59:88-92.

Derner, J. D., R. L. Gillen, F. T. McCollum, and K. W. Tate. 1994. Little bluestem tiller defoliation patterns under continuous and rotational grazing. Journal Range Management 47:220-225.

Dibello, F. J., S. M. Arthur, and W. B. Krohn. 1990. Food habits of sympatric coyotes, *Canis latrans*, red foxes, *Vulpes vulpes*, and bobcats, *Lynx rufus*, in Maine. Canadian Field Naturalist 104:403-408.

Dobkin, D. S., A. C. Rich, and W. H. Pyle. 1998. Habitat and avifaunal recovery from livestock grazing in a riparian meadow system of the northwest Great Basin. Conservation Biology 12:209-221.

Drut, M. S., J. A. Crawford, and M. A. Gregg. 1994a. Brood habitat use by sage grouse in Oregon. Great Basin Naturalist 54:170-176.

Drut, M. S., W. H. Pyle, and J. A. Crawford. 1994b. Diets and food selection of sage grouse chicks in Oregon. Journal Range Management 47:90-93.

Ellis, K. L. 1985. Distribution and habitat selection of breeding male sage grouse in northeastern Utah. MS Thesis, Brigham Young University, Provo, UT, USA.

Eng, R. L. 1963. Observations on the breeding biology of male sage grouse. Journal Wildlife Management 27:841-846.

Eng, R. L., and P. Schladweiler. 1972. Sage grouse winter movements and habitat use in central

Montana. Journal Wildlife Management 36:141-146.

Evans, C. C. 1986. The relationship of cattle grazing to sage-grouse use of meadow habitat on the Sheldon National Wildlife Refuge. MS Thesis, University of Nevada, Reno, NV, USA.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Review Ecology, Evolution, and Systematics 34:487-515.

Fischer, R. A. 1994. The effects of prescribed fire on the ecology of migratory sage grouse in southeastern Idaho. PhD Dissertation, University of Idaho, Moscow, ID, USA.

Fischer, R. A., A. D. Apa, W. L. Wakkinen, and K. P. Reese. 1993. Nesting-area fidelity of sage grouse in southeastern Idaho. Condor 95:1038-1041.

Fischer, R. A., K. P. Reese, and J. W. Connelly. 1996. An investigation of fire effects within xeric sage grouse brood habitat. Journal Range Management 49:194-198.

Fischer, R. A., W. L. Wakkinen, K. P. Reese, and J. W. Connelly. 1997. Effects of prescribed fire on movements of female sage grouse from breeding to summer ranges. Wilson Bulletin 109:82-91.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems 29:207-231.

Fuller, A. B., and B. P. Bole, Jr. 1930. Centrocercus urophasianus (Bonaparte). Sage grouse. Observations on some Wyoming Birds, Cleveland Museum Natural History Science Publication 1:37-80.

Gates, R. J. 1983. Sage grouse, lagomorph, and pronghorn use of a sagebrush grassland burn site on the Idaho National Engineering Laboratory. MS Thesis, Montana State University, Bozeman, MT, USA.

Gibson, R. M. 1989. Field playback of male display attracts females in lek breeding sage grouse. Behavioral Ecology and Sociobiology 24:439-443.

Gibson, R. M. and J. W. Bradbury. 1985. Sexual selection in lekking sage grouse: phenotypic correlates of male mating success. Behavioral Ecology and Sociobiology 18:177-123.

Gill, R. B. 1965. Distribution and abundance of a population of sage grouse in North Park, Colorado. MS Thesis, Colorado State University, Fort Collins, CO, USA.

Girard, G. L. 1937. Life history, habits, and food of the sage grouse *Centrocercus urophasianus* Bonaparte. University of Wyoming Publication 3. University of Wyoming, Laramie, WY, USA.

Greer, R. 1990. Sage grouse habitat requirements and development. Habitat Extension Bulletin Number 31. Habitat Extension Services, Wyoming Game and Fish Department, Laramie, WY, USA.

Gregg, M. A., J. A. Crawford, M. S. Drut, and A. K. DeLong. 1994. Vegetational cover and predation of sage grouse nests in Oregon. Journal Wildlife Management 58:162-166.

Griner, L. A. 1939. A study of the sage grouse (*Centrocercus urophasianus*), with special reference to the life history, habitat requirements, and numbers and distribution. MS Thesis, Utah State Agricultural College, Logan, UT, USA.

Hagen, C. A. 2003. A demographic analysis of Lesser Prairie-Chicken populations in southwestern Kansas: survival, population viability, and habitat use. PhD Dissertation, Kansas State University, Manhattan, KS, USA.

Hall, F. C., and L. Bryant. 1995. Herbacious stubble height as a warning of impending cattle grazing damage to riparian areas. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-362. Portland, OR, USA.

Harniss, R. O. and R. B. Murray. 1973. 30 years of vegetal change following burning of sagebrush-grass range. Journal Range Management 26:322-325.

Harrison, D. J., J. A. Bissonette, and J. A. Sherburne. 1989. Spatial relationships between coyotes and red foxes in eastern Maine. Journal Wildlife Management 53:181-185.

Hausleitner, D. 2003. Population dynamics, habitat use and movements of greater sage-grouse in Moffat County, Colorado. MS Thesis, University of Idaho, Moscow, ID, USA.

Heath, B., R. Straw, S. Anderson, and J. Lawson. 1996. Proceedings of sage grouse workshop. Pinedale, WY, USA.

Heath, B. J., R. Straw, S. H. Anderson, and J. Lawson. 1997. Sage grouse productivity, survival, and seasonal habitat use near Farson, Wyoming. Job Completion Report. Wyoming Game and Fish Department, Cheyenne, WY, USA.

Heath, B. J., R. Straw, S. H. Anderson, J. Lawson, and M. J. Holloran. 1998. Sage-grouse productivity, survival, and seasonal habitat use among three ranches with different livestock grazing, predator control, and harvest management practices. Job Completion Report. Wyoming Game and Fish Department, Cheyenne, WY, USA.

Holechek, J. L. 1996. Drought in New Mexico: prospects and management. Rangelands 18:225-227.

Holloran, M. J. 1999. Sage grouse (*Centrocercus urophasianus*) seasonal habitat use near Casper, Wyoming. MS Thesis, University of Wyoming, Laramie, WY, USA.

Holloran, M. J., and S. H. Anderson. 2003. Direct identification of Northern sage-grouse, *Centrocercus urophasianus*, nest predators using remote sensing cameras. Canadian Field-Naturalist 117:308-310.

Holloran, M. J., and S. H. Anderson. 2004. Greater sage-grouse seasonal habitat selection and survival in Jackson Hole, Wyoming. Job Completion Report, Wyoming Game and Fish Department, Cheyenne, WY, USA.

Holloran, M. J., and S. H. Anderson. 2005. Spatial distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats. Condor 107:742-752.

Holloran, M. J., B. J. Heath, A. G. Lyon, S. J. Slater, J. L. Kuipers, and S. H. Anderson. 2005. Greater sage-grouse nesting habitat selection and success in Wyoming. Journal Wildlife Management 69:638-649.

Holloran, M. J. In Preparation. Greater sage-grouse (*Centrocercus urophasianus*) population response to natural gas field development in western Wyoming. PhD Dissertation, University of Wyoming, Laramie, WY, USA.

Homer, C. G., T. C. Edwards, Jr., R. D. Ramsey, and K. P. Reese. 1993. Use of remote sensing methods in modeling sage grouse winter habitat. Journal Wildlife Management 57:78-84.

Hornaday, W. T. 1916. Save the sage grouse from extinction, a demand from civilization to the western states. New York Zoological Park Bulletin 5:179-219.

Hulet, B. V. 1983. Selected responses of sage-grouse to prescribed fire, predation and grazing by domestic sheep in southeastern Idaho. MS Thesis, Brigham Young University, Provo, UT, USA.

Hull, S. D., R. J. Robel, and K. E. Kemp. 1996. Summer avian abundance, invertebrate biomass, and forbs in Kansas CRP. Prairie Naturalist 28:1-12.

Hupp, J. W., and C. E. Braun. 1989. Topographic distribution of sage grouse foraging in winter. Journal Wildlife Management 53:823-829.

Ingelfinger, F. M. 2001. The effects of natural gas development on sagebrush steppe passerines in Sublette County, Wyoming. MS Thesis, University of Wyoming, Laramie, WY, USA.

Jamison, B.E., R.J. Robel, J.S. Pontius, and R.D. Applegate. 2002. Invertebrate biomass: associations with lesser prairie-chicken habitat use and sand sagebrush density in southwestern Kansas. Wildlife Society Bulletin 30:517-526.

Johnsgard, P. A. 2002. Grassland grouse and their conservation. Smithsonian Institution Press, Washington D.C., USA.

Johnson, K. L. 1987. Sagebrush over time: a photographic study of vegetation change in Wyoming 1870-1986. Agricultural Experimental Station Publication 50, University of Wyoming, Laramie, WY, USA.

Johnson, G.D. and M. S. Boyce. 1990. Feeding trials with insects in the diet of sage grouse chicks.

Journal Wildlife Management 54:89-91.

Johnson, M. K. and R. M. Hansen. 1979. Coyote food habits on the Idaho National Engineering Laboratory. Journal Wildlife Management 43:951-956.

Kilpatrick, S. 2000. Using prescribed fire to manage sagebrush communities in occupied sage grouse habitats of Wyoming. 22nd Western States Sage and Columbian Sharp-tailed Grouse Symposium, Redmond, OR, USA.

Klebenow, D. A. 1969. Sage grouse nesting and brood habitat in Idaho. Journal Wildlife Management 33:649-662.

Klebenow, D. A. 1970. Sage grouse vs. sagebrush control in Idaho. Journal Range Management 23:396-400.

Klebenow, D. A. 1972. The habitat requirements of sage grouse and the role of fire in management. Tall Timbers Fire Ecology Conference 12:305-315.

Klebenow, D. A. 1982. Livestock grazing interactions with sage grouse. Pages 113-123 *in* J. M. Peck and P. D. Dalke (eds.). Wildlife-Livestock Relationships Symposium: Proceedings 10, Coeur d'Alene, ID, USA.

Klebenow, D. A., and G. M. Gray. 1968. Food habits of juvenile sage grouse. Journal Range Management 21:80-83.

Knick, S. T., D. S. Dobkin, J. T. Rotenberry, M. A. Schroeder, W. M. Vander Haegen, and C. van Riper III. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. Condor 105:611-634.

Kuipers, J. L. 2004. Grazing system and linear corridor influences on greater sage-grouse (*Centrocercus urophasianus*) habitat selection and productivity. MS Thesis, University of Wyoming, Laramie, WY, USA.

Laycock, W. A. 1979. Management of sagebrush. Rangelands 1:207-210.

Lindstrom, E., P. Angelstam, P. Widen, and H. Andren. 1986. Do predators synchronize vole and grouse fluctuations? An experiment. Oikos 48:121-124.

Lommasson, T. 1948. Succession in sagebrush. Journal Range Management 1:19-21.

Lyon, A. G. 2000. The potential effects of natural gas development on sage grouse near Pinedale, Wyoming. MS Thesis, University of Wyoming, Laramie, WY, USA.

Lyon, A. G., and S. H. Anderson. 2003. Potential gas development impacts on sage grouse nest initiation and movement. Wildlife Society Bulletin 31:486-491.

Mack, R. N., and J. N. Thompson. 1982. Evolution in steppe with few large, hooved mammals. American Naturalist 119:757-773.

Major, J. T. and J. A. Sherburne. 1987. Interspecific relationships of coyotes, bobcats, and red foxes in western Maine. Journal Wildlife Management 51:606-616.

Mankin, P. L., and R. E. Warner. 1992. Vulnerability of ground nests to predation on an agricultural habitat island in east-central Illinois. American Midland Naturalist 128:281-291.

Martin, N. S. 1970. Sagebrush control related to habitat and sage grouse occurrence. Journal Wildlife Management 34:313-320.

Martin, R. C. 1990. Sage grouse responses to wildfires in spring and summer habitats. MS Thesis, University of Idaho, Moscow, ID, USA.

McAdoo, J. K., and D. A. Klebenow. 1978. Predation on range sheep with no predator control. Journal Range Management 31:111-114.

McDowell, K. 1956. The proud strutter. Wyoming Wildlife 20:4-7.

Miller, R. F., T. J. Svejcar, and N. E. West. 1994. Implications of livestock grazing in the intermountain sagebrush region: plant composition. Pages 101-146 *in* M. Vavra, W. A. Laycock, and R. D. Pieper (eds.). Ecological Implications of livestock herbivory in the west. Society for Range Management, Denver, CO, USA.

Moulton, G. E. (ed.). 1987. Journals of the Lewis and Clark Expedition. Volume 4. University of Nebraska Press, Lincoln, NE, USA.

Moynahan, B. J. 2004. Landscape-scale factors affecting population dynamics of greater sage-grouse (*Centrocercus urophasianus*) in north-central Montana, 2001-2004. PhD Dissertation, University of Montana, Missoula, MT, USA.

Mueggler, W. F. 1950. Effects of spring and fall grazing by sheep on vegetation of the upper snake river plains. Journal Range Management 3:308-315.

Naugle, D. E., C. L. Aldridge, B. L. Walker, T. E. Cornish, B. J. Moynahan, M. J. Holloran, K. Brown, G. D. Johnson, E. T. Schmidtmann, R. T. Mayer, C. Y. Dato, M. R. Matchett, T. J. Christiansen, W. E. Cook, T. Creekmore, R. D. Falise, E. T. Rinkes, and M. S. Boyce. 2004. West Nile virus: pending crisis for greater sage-grouse. Ecology Letters 7:704-713.

Neel, L. A. 1980. Sage grouse response to grazing management in Nevada. MS Thesis, University of Nevada, Reno, NV, USA.

Nelle, P. J. 1998. The long-term effects of fire on sage grouse nesting and brood –rearing habitats on the Upper Snake River Plain. MS Thesis, University of Idaho, Moscow, ID, USA.

Nelle, P. J., K. P. Reese, and J. W. Connelly. 2000. Long-term effect of fire on sage grouse nesting and brood-rearing habitats in the Upper Snake River Plain. Journal Range Management 53-586-591.

Niemuth, N. D., and M. S. Boyce. 1995. Spatial and temporal patterns of predation of simulated sage grouse nests at high and low nest densities: an experimental study. Canadian Journal Zoology 73:819-825.

Oakleaf, R. J. 1971. The relationship of sage grouse to upland meadows in Nevada. Job Final Report, Federal Aid Project W-48-2, Nevada Department of Fish and Game, Reno, NV, USA.

Owens, M. K., and B. E. Norton. 1990. Survival of juvenile basin big sagebrush under different grazing regimes. Journal Range Management 43:132-135.

Oyler-McCance, S. J. 1999. Genetic and habitat factors underlying conservation strategies for Gunnison sage-grouse. PhD Dissertation, Colorado State University, Fort Collins, CO, USA.

Paige, C., and S. A. Ritter. 1999. Birds in a sagebrush sea: managing sagebrush habitats for bird communities. Partners in Flight Western Working Group, Boise, ID, USA.

Patterson, R. L. 1952. The sage grouse in Wyoming. Wyoming Game and Fish Commission and Sage Books. Denver, CO, USA.

Patterson, R. L., and D. Cram. 1949. Sage grouse in the west. Wyoming Wildlife 8:10-13.

Peterson, J. G. 1970. The food habits and summer distribution of juvenile sage grouse in central Montana. Journal Wildlife Management 34:147-155.

Peterson, J. G. 1995. Ecological implications of sagebrush manipulation. Wildlife Management Division Montana Fish, Wildlife, and Parks, Federal Aid in Wildlife Restoration Project W-101-R-2, Helena, MT, USA.

Phillips, R. L., D. E. Biggins and A. B. Hoag. 1986. Coal surface mining and selected wildlife-a ten year study near Decker, Montana. Proceedings, Issues and Technology in the Management of Impacted Western Wildlife. Thorne Ecological Institute 2:235-244.

Pieper, R. 1994. Ecological implications of livestock grazing. Pages 177-211 *in* M. Vavra, W. A. Laycock, and R. D. Pieper (eds.). Ecological Implications of livestock herbivory in the west. Society for Range Management, Denver, CO, USA.

Popham, G. P. 2000. Sage grouse nesting habitat in northeastern California. MS Thesis, Humboldt State University, Arcata, CA, USA.

Popham, G. P. and R. J. Gutierrez. 2003. Greater sage-grouse *Centrocercus urophasianus* nesting success and habitat use in northeastern California. Wildlife Biology 9:327-334.

PRISM Environmental Management Consultants. 1982. A review of petroleum industry operations and other land use activities affecting wildlife. The Canadian Petroleum Association, Calgary, Alberta, Canada.

Pyrah, D. B. 1970. Sage grouse habitat research in central Montana. *In* E. F. Schlatterer and D.B. Pyrah (eds.). Ecological effects of chemical and mechanical sagebrush control. Montana Fish and Game Department Completion Report, Project W-105-R-4:293-300, Helena, MT, USA.

Rassmussen, D. I., and L. A. Griner. 1938. Life history and management studies of the sage grouse in Utah, with special reference to nesting and feeding habits. Transactions of the North American Wildlife and Natural Resources Conference 3:852-864.

Reichel, J. D. 1991. Relationships among coyote food habits, prey populations, and habitat use. Northwest Science 65(3):133-137.

Reijnen, R., R. Foppen, C. ter Braak, and J. Thissen. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. Journal Applied Ecology 32:187-202.

Remington, T. E., and C. E. Braun. 1985. Sage grouse food selection in winter, North Park, Colorado. Journal Wildlife Management 49:1055-1061.

Remington, T. E. and C. E. Braun. 1991. How surface coal mining affects sage grouse, North Park, Colorado. Proceedings, Issues and Technology in the Management of Impacted Western Wildlife. Thorne Ecological Institute 5:128-132.

Reynolds, R. T., and C. H. Trost. 1980. The response of native vertebrate populations to crested wheatgrass planting and grazing by sheep. Journal Range Management 33:122-125.

Rickard, W. H. 1970. Ground dwelling beetles in burned and unburned vegetation. Journal Range Management 23:293-294.

Ritchie, M. E., M. L. Wolfe, and R. Danvir. 1994. Predation of artificial sage grouse nests in treated and untreated sagebrush. Great Basin Naturalist 54:122-129.

Robertson, M. D. 1991. Winter ecology of migratory sage grouse and associated effects of prescribed fire in southern Idaho. MS Thesis, University of Idaho, Moscow, ID, USA.

Robinson, W. B. 1961. Population changes of carnivores in some coyote-control areas. Journal Mammalogy 42:510-515.

Rothenmaier, D. 1979. Sage grouse reproductive ecology: breeding season movements, strutting ground attendance and site characteristics, and nesting. MS Thesis, University of Wyoming, Laramie, WY, USA.

Sargeant, A. B. 1972. Red fox spatial characteristics in relation to waterfowl predation. Journal Wildlife Management 36:225-236.

Sargeant, A. B., M. A. Sovada, and R. J. Greenwood. 1987. Responses to three prairie ground squirrel species, *Spermophilus franklinii, S. richardsonii, and S. tridecemlineatus*, to duck eggs. Canadian Field-Naturalist 101:95-97.

Savory, A. 1988. Holistic resource management. Island Press. Washington D. C., USA.

Schneegas, E. R. 1967. Sage grouse and sagebrush control. Transactions North American Wildlife and Natural Resource Conference 32:270-274.

Schoenburg, T. J., and C. E. Braun. 1982. Potential impacts of strip mining on sage grouse movements and habitat use. Job Completion Report. Federal Aid Project W-37-R-35, Work Plan 3, Job 12, Colorado Division of Wildlife, Denver, CO, USA.

Schranck, B. W. 1972. Waterfowl nest cover and some predation relationships. Journal Wildlife Management 36:182-186.

Schroeder, M. A. 1997. Unusually high reproductive effort by sage grouse in a fragmented habitat in north-central Washington. Condor 9:378-385.

Schroeder, M. A., J. R. Young, and C. E. Braun. 1999. Sage grouse (*Centrocercus urophasianus*). Pages 1-28 *in* A. Poole and F. Gill, editors. The birds of North America, No. 425. The Birds of North America, Philadelphia, PA, USA.

Schroeder, M. A., and L. A. Robb. 2003. Fidelity of greater sage-grouse *Centrocercus urophasianus* to breeding areas in a fragmented landscape. Wildlife Biology 9:291-299.

Schroeder, M. A., C. L. Aldridge, A. D. Apa, J. R. Bohne, C. E. Braun, S. D. Bunnell, J. W. Connelly, P. A. Deibert, S. C. Gardner, M. A. Hilliard, G. D. Kobriger, S. M. McAdam, C. W. McCarthy, J. J. McCarthy, D. L. Mitchell, E. V. Rickerson, and S. J. Stiver. 2004. Distribution of Sage-grouse in North America. Condor 106:363-376.

Schroedl, G. F. 1973. The archeological occurrence of bison in the Southern Plateau. Washington State University Lab of Anthropology, Report of Investigation 51, Pullman, WA, USA.

Scrivner, J. H., W. E. Howard, A. H. Murphy, and J. R. Hays. 1985. Sheep losses to predators on a California range, 1973-1983. Journal Range Management 38:418-421.

Slater, S. J. 2003. Sage-grouse (*Centrocercus urophasianus*) use of different-aged burns and the effects of coyote control in southwestern Wyoming. MS Thesis, University of Wyoming, Laramie, WY, USA.

Stahlecker, D. W. 1978. Effect of a new transmission line on wintering prairie raptors. Condor 80:444-446.

Stohlgren, T. J., L. D. Schell, and B. Vanden Heuvel. 1999. How grazing and soil quality affect native and exotic plant diversity in Rocky Mountain grasslands. Ecological Applications 9:45-64.

Sveum, C. M., J. A. Crawford, and D. Edge. 1998a. Use and selection of brood-rearing habitat by sage grouse in south-central Washington. Great Basin Naturalist 58: 344-351.

Sveum, C. M., W. D. Edge, and J. A. Crawford. 1998b. Nesting habitat selection by sage grouse in south-central Washington. Journal Range Management 51:265-269.

Swenson, J. E., C. A. Simmons, and C. D. Eustace. 1987. Decrease of sage grouse *Centrocercus urophasianus* after ploughing of sagebrush steppe. Biological Conservation 41:125-132.

Taylor, R. G., J. R. Workman, and J. E. Bowns. 1979. The economics of sheep predation in southwestern Utah. Journal Range Management 32:317-321.

Thompson, K. M., M. J. Holloran, S. J. Slater, J. L. Kuipers, and S. H. Anderson. *In Review*. Greater sage-grouse early brood-rearing habitat use and productivity in Wyoming. Western North American Naturalist 00:000-000.

Thurow, T. L. and C. A. Taylor. 1999. Viewpoint: the role of drought in range management. Journal Range Management 52:413-419.

Tidewell, W. D., S. R. Rashforth, and D. Simper. 1972. Evolution of floras in the intermountain region. Volume 1 *in* A. Cronquist, A. H. Cronquist, H. H. Holmgren, and J. L. Reveal (eds.). Intermountain flora, Hafner Publishing Company, New York, NY, USA.

Tigner, J. R. and G. E. Larson. 1977. Sheep losses on selected ranches in southern Wyoming. Journal Range Management 30:244-252.

Tisdale, E. W., and M. Hironaka. 1981. The sagebrush-grass region: a review of the ecological literature. Idaho Forest, Wildlife and Range Experiment Station Bulletin 33, Moscow, ID, USA.

TRC Mariah Associates Inc. 1997. Environmental impact statement for the Jonah Field II natural gas development project, Sublette County, Wyoming. Draft Wildlife Technical Report, Laramie, WY, USA.

United States Department of Interior Bureau of Land Management. 1979. Kemmerer resource area oil and gas leasing environmental assessment record. Bureau of Land Management, Rock Springs District, WY, USA.

Vale, T. R. 1974. Sagebrush conversion projects: an element of contemporary environmental change in the western United States. Biological Conservation 6:274-284.

Vale, T. R. 1975. Presettlement vegetation in the sagebrush-grass area of the intermountain west. Journal Range Management 28:32-36.

Voigt, D.R. and B.D. Earle. 1983. Avoidance of coyotes by red fox families. Journal Wildlife Management 47:852-857.

Wakkinen, W. L. 1990. Nest site characteristics and spring-summer movements of migratory sage grouse in southeastern Idaho. MS Thesis, University of Idaho, Moscow, ID, USA.

Wakkinen, W. L., K. P. Reese, and J. W. Connelly. 1992. Sage grouse nest locations in relation to leks. Journal Wildlife Management 56:381-383.

Wallestad, R. O. 1971. Summer movements and habitat use by sage grouse broods in central Montana. Journal Wildlife Management 35:129-136.

Wallestad, R. O. 1975. Life history and habitat requirements of sage grouse in central Montana. Montana Fish and Game Department Technical Bulletin, Helena, MT, USA.

Wallestad, R. O., and D. B. Pyrah. 1974. Movement and nesting of sage grouse hens in central Montana. Journal Wildlife Management 38:630-633.

Watters, M. E., T. L. McLash, C. L. Aldridge, and R. M. Brigham. 2002. The effect of vegetation structure on predation of artificial greater sage-grouse nests. Ecoscience 9:314-319.

Watts, M. J., and C. L. Wambolt. 1996. Long-term recovery of Wyoming big sagebrush after four treatments. Journal Environmental Management 46:95-102.

Welch, B. L., F. J. Wagstaff, and J. A. Robertson. 1991. Preference of wintering sage grouse for big sagebrush. Journal Range Management 44:462-465.

Willis, M. J., G. P. Keister, Jr., D. A. Immell, D. M. Jones, R. M. Powell, and K. R. Durbin. 1993. Sage grouse in Oregon. Wildlife Research Report 15, Oregon Department of Fish and Wildlife, Portland, OR, USA.

Winward, A. H. 1991. A renewed commitment to management of sagebrush grasslands. Agricultural Experiment Station Special Report 880. Oregon State University, Corvallis, OR, USA.

Wright, H. A. 1970. Responses of big sagebrush and three-tip sagebrush to season of clipping. Journal Range Management 23:20-22.

Wright, H. A. 1974. Range burning. Journal Range Management 27:5-11.

Wright, H. A., and A. W. Bailey. 1982. Fire ecology: United States and southern Canada. Wiley and Sons, New York, NY, USA.

Wright, H. A., L. F. Nuenschwander, and C. M. Britton. 1979. The role and use of fire in sagebrush grass and pinyon juniper plant communities. A state-of-the-art review, U.S. Department of Agriculture, Forest Service, General Technical Report INT-58.

Wyoming Interagency Vegetation Committee. 2002. Wyoming guidelines for managing sagebrush communities with emphasis on fire management. Wyoming Game and Fish Department and Wyoming Bureau of Land Management, Cheyenne, WY, USA.

Zablan, M. A., C. E. Braun, and G. C. White. 2003. Estimation of greater sage-grouse survival in North Park, Colorado. Journal Wildlife Management 67:144-154.

Table 1: Productivity estimates for greater sage-grouse populations studied by the Wyoming Cooperative Research Unit in central and western Wyoming, 1994-2004. Nesting propensity is the apparent number of potential females documented incubating, nesting success is the apparent probability of hatching ≥1 egg, and brood success is the apparent number of successfully nesting females fledging ≥1 chick the last 2 weeks in August.

Study Area	Year	n[a]	Nesting Propensity	Nesting Success	Brooding Success	Chicks per Female[b]
Farson	1994	29	24/29 (83%)	9/24 (38%)	4/9 (44%)	8/29 (0.28)
	1995	41	33/37 (89%)	9/36 (25%)	8/9 (89%)	24/37 (0.65)
	1996	25	21/24 (88%)	11/23 (48%)	10/11 (91%)	38/24 (1.58)
Rawlins	1996	24	19/23 (83%)	15/19 (79%)	11/15 (73%)	38/23 (1.65)
	1997	32	21/30 (70%)	15/23 (65%)	6/15 (40%)	24/30 (0.80)
Casper	1997	40	32/38 (84%)	16/31 (52%)	11/16 (69%)	41/38 (1.08)
	1998	55	50/54 (93%)	29/43 (67%)	16/29 (55%)	57/54 (1.06)
Pinedale	1998	41	28/31 (90%)	14/32 (44%)	10/13 (77%)	27/31 (0.87)
	1999	40	26/33 (79%)	12/27 (44%)	3/10 (30%)	10/33 (0.30)
	2000	37	17/23 (74%)	7/16 (44%)	5/7 (71%)	17/23 (0.74)
	2001	46	27/32 (84%)	10/27 (37%)	6/8 (75%)	13/32 (0.41)
	2002	76	51/60 (85%)	21/52 (40%)	14/20 (70%)	33/60 (0.55)
	2003	91	54/64 (84%)	24/53 (45%)	12/20 (60%)	37/64 (0.58)
	2004	97	59/77 (77%)	36/57 (63%)	25/33 (76%)	62/77 (0.81)
Kemmerer	2000	27	16/25 (64%)	1/17 (6%)	1/1 (100%)	1/25 (0.04)
	2001	45	29/38 (76%)	10/30 (33%)	5/10 (50%)	11/38 (0.29)
	2002	57	42/48 (88%)	13/50 (26%)	9/13 (69%)	26/48 (0.54)
Jackson	1999	9	7/8 (88%)	4/7 (57%)	3/4 (75%)	7/8 (0.88)
	2000	14	11/13 (85%)	5/11 (45%)	1/4 (25%)	0
	2001	20	13/17 (76%)	6/15 (40%)	4/6 (67%)	11/17 (0.65)
	2002	10	9/10 (90%)	4/10 (40%)	3/4 (75%)	8/10 (0.80)
Lander	2000	26	16/23 (70%)	7/16 (44%)	4/7 (57%)	9/23 (0.39)
	2001	31	21/27 (78%)	8/21 (38%)	6/9 (67%)	17/27 (0.63)
	2002	24	23/24 (96%)	12/23 (52%)	9/12 (75%)	21/14 (0.88)
	2003	48	36/42 (86%)	16/36 (44%)	12/16 (75%)	35/42 (0.83)

[a] Potential breeding females (i.e., number of females alive the first 2 weeks in April).

[b] Number of chicks fledged (last 2 weeks August) divided by the total number of females that could have produced a chick (i.e., number of potentially nesting females).

Figure 1: Study area locations for greater sage-grouse research projects conducted by the Wyoming Cooperative Research Unit, 1994-2005. Consult the text for study area description corresponding to numbers present on map. Inset map (Connelly et al. 2004) outlines sage-grouse breeding population strongholds as of 2003; the darkest shades represent the greatest densities of males / km^2.