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ABSTRACT: Sage-grouse (*Centrocercus urophasianus*) range-wide population declines have induced criticism of livestock management practices in sagebrush steppe. To clarify the influences of livestock grazing management on sage-grouse nesting and early brood rearing (EB) habitats, we radio-collared 101 sage-grouse females and tracked them to seasonal habitats. Females were collared near 2 leks within close proximity of 4 livestock grazing systems near Lander, Wyoming, from 2000-2003. Systems included a high intensity spring rotational deferred (DR), a summer grazed moderate to light intensity rest rotational (SR), a spring and fall grazed moderate to light intensity rest rotational (SFR), and a rested from livestock area (NG). We measured vegetation at nest and EB sites (10-14 days post hatch) and random locations within systems. Vegetation was compared at successful versus unsuccessful nests, sage-grouse use habitats (nests and broods) versus all systems combined, and system versus system. Nests had greater total shrub canopy cover, successful nests had greater residual grass heights, and EB sites had greater total shrub cover and food forbs. All habitat use analyses indicated that the vegetation variables did influence selection and success, although the influence was weak. The SR and NG systems best influenced important sage-grouse habitat variables during the study duration, which occurred during a substantial drought. Positive influences were attributed to reduced spring grazing and low forage utilization rather than grazing system type. Additionally, we examined the influences of linear corridor presence (maintained roads, 2-tracks roads, and trails) on sage-grouse nest selection and success on an exploratory basis. Nests from 253 radio-collared females near Lander, Pinedale, and Kemmerer, Wyoming, were used. Trails were found to have negative influences on nest success at 25 m, no influence at 50 m and a positive influence at 100 m. Maintained roads and 2-tracks had positive influences on nest success at 100 m. Lander nests and randoms were used to determine nest selection. Two-track roads at 25 m and trails at 50 m increased the likelihood of nest selection, while 2-tracks at 100 m decreased selection.

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GRAZING SYSTEM AND LINEAR CORRIDOR INFLUENCES ON GREATER SAGE-GROUSE (*CENTROCERCUS UROPHASIANUS*) HABITAT SELECTION AND PRODUCTIVITY

By

Jarren Lee Kuipers

A thesis submitted to the Department of Zoology and Physiology and The Graduate School of The University of Wyoming in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

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Introduction: GRAZING SYSTEM AND LINEAR CORRIDOR INFLUENCES ON GREATER SAGE-GROUSE (CENTROCERCUS UROPHASIANUS) HABITATS AND PRODUCTIVITY

INTRODUCTION

Sage-grouse were once found in 16 western states and 3 Canadian Provinces (Aldrich 1963) wherever sagebrush was present (Klebenow 1985). Over the last century sage-grouse have been eliminated from Arizona, Kansas, Nebraska, New Mexico, Oklahoma, and British Columbia (Johnson and Braun 1999). Since the 1950s, population declines throughout the sage-grouse's range are estimated at 45 to 80%, with the greatest declines occurring since 1980 (Braun 1998). Estimated declines of 33% range-wide are suspected since 1985 (Connelly and Braun 1997).

Declines in sage-grouse populations are primarily attributed to declines in the quality and quantity of sagebrush habitats (Connelly and Braun 1997, Connelly et al. 2000). Three range-wide influences on sage-grouse habitats have been identified: fire, weather, and grazing (Connelly and Braun 1997). While nearly all of the sage-grouse's range has been grazed by livestock (Braun 1998), little direct evidence has been found linking livestock grazing to sage-grouse declines (Beck and Mitchell 2000).

Sage-grouse nesting and early brood rearing periods are the most vulnerable to livestock grazing influences (Beck and Mitchell 2000), primarily due to requirements for tall and abundant understories of residual grasses, new grasses, forbs, and litter within sagebrush habitats (Gregg et al. 1994, Heath et al. 1997 and 1998, Holloran 1999, Lyon 2000). Early brood habitats are identified as the first 10 to 14 days post hatch (Heath et al. 1997 and 1998, Holloran 1999, Lyon 2000). Long-term replicated sage-grouse and livestock grazing experiments with nongrazed controls are required to test the influences of livestock management on nesting and early brood habitats (Beck and Mitchell 2000).

Habitat fragmentation is an additional concern in sage-grouse habitats (Braun 1998). Land uses such as ranching and mineral development have led to fragmentation due to roads, fences, and powerlines (Braun 1998). The influences of these types of habitat fragmentation on sage-grouse survival and reproduction are also largely unknown.

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To address these vegetation and fragmentation issues we attempted to identify important habitat components for nest selection, nest success, and early brood habitat selection. Secondly, we compared nesting and early brood habitats with three associated rotational cattle grazing systems and a non-grazed control to determine which systems promoted sage-grouse habitats. Lastly, we examined the influences of linear corridors (maintained roads, 2-track roads, and livestock and wildlife trails) on sage-grouse nest selection and success.

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Chapter 1: REPRODUCTION, SURVIVAL, AND SEASONAL MOVEMENTS OF A GREATER SAGE-GROUSE POPULATION NEAR LANDER, WYOMING.

ABSTRACT

We estimated greater sage-grouse (*Centrocercus urophasianus*) spring and summer reproduction, adult seasonal mortality, and seasonal movements of 101 radio-collared females from 2000 to 2003. With high brood survival, nesting success was potentially limiting reproduction in this population. The fall chicks-per-hen was below recommended levels and may suggest a declining population during the study. Based on adult mortality and reproduction, we estimated average annual declines of 20% between 2000 to 2003. However, adult survival was likely underestimated, which contributed to the estimated declines. Adult female survival was lowest in the spring during the breeding season. Breeding, prenesting, and nesting mortalities accounted for 31% of the annual mortalities over 2 months. Survival rates for brooding and non-brooding hens were similar through the summer and fall. Winter survival was the highest at 91%. Movements from fall to winter habitats and winter to spring lekking habitats indicated the population was migratory, with seasonal movements of 17.4 km and 16.9 km respectively. Nests were dispersed from the nearest lek an average of 5.1 km. Only 23% of the nests were within 3 km of the nearest lek, with 24% further than 7 km. Nest success was greatest at 8 km from the nearest lek and lowest within 3 km from the nearest leks.

INTRODUCTION

Migration

Sage-grouse depend on 3 seasonal habitat types; breeding, summer, and fall/winter, to fulfill seasonal requirements for food, protection from weather, and cover from predators (Connelly et al. 2000a). Often one or more of these selected habitats are separated, influencing individual and/or population specific migration behaviors. Annual movements can be great, with a sage-grouse population in Idaho traveling 80 to 160 km (Dalke et al. 1963). Connelly et al. (2000a) categorized four types of sage grouse seasonal movements or migration patterns from the existing research: 1) no migration, all

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seasonal habitats found in the same area; 2) winter and breeding area combined with separate summer areas; 3) separate breeding, winter, and summer areas; and 4) combined summer and breeding areas and separate winter areas. Populations with no seasonal movements of >10 km are considered non-migratory (Connelly et al 2000a). Migration patterns can persist in populations because of strong annual fidelity to seasonal habitats (Fischer et al. 1993).

Productivity

Sage-grouse are long-lived with low reproductive success (Patterson 1952, Connelly et al. 1994). Annual survival estimates range from 55 to 85% for females and 37 to 54% in males (Zablan 1993, Connelly et al. 1994). Zablan (1993) reported differential mortality in yearling and adult males at 52% and 38% respectively, although not in females. Seasonal mortality differences between the sexes were found in Idaho with 52% and 46% of female mortalities found in the spring/summer and fall period respectively, opposed to 70% and 28% respectively in males (Connelly et al 2000b). Generally, the greatest mortality period of adult sage-grouse takes place during the breeding, nesting, brooding and summering periods (Connelly et al. 2000b).

Spring

Golden eagles (*Aquila chrysaetos*) are common predators of adult sage grouse during the breeding season (Patterson 1952). Ground squirrels (*Spermophilus* spp.), badgers (*Taxidea taxus*), red fox (*Vulpes vulpes*), coyotes (*Canis latrans*), bobcat (*Lynx rufus*), magpies (*Pica pica*), American ravens (*Corvis corax*), and elk (*Cervus elaphus*) have been identified as sage-grouse nest predators (Patterson 1952, Walestad and Pyrah 1974, Holloran 1999).

Spring sage-grouse habitats in Farson, Wyoming consist of breeding sites from March to early June and nesting sites from May 1 to June 4 (Patterson 1952). Sage-grouse are polygamous with hens selecting males from strutting grounds called leks, and taking on all incubation and brood rearing responsibilities (Patterson 1952).

Ellis (1985) found that sage grouse remained within 2 km of the lek while breeding and males remained closer than females. Roosters continue to use lek habitats

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throughout the spring while female use is restricted to short breeding activities (Patterson 1952).

Near Farson, Wyoming females initiated nests several days after breeding, with the first full clutches recorded between April 21-June 4 (Patterson 1952). The incubation period lasted 25 to 27 days with clutch sizes averaging 7 to 9 eggs per clutch (Patterson 1952). Nest initiation rates are generally high in sage-grouse, however, sage grouse experience the lowest nesting success of all North American grouse species (Wakkinen 1990). Renesting is generally considered uncommon in sage grouse (Patterson 1952).

In Farson, Wyoming, the first chicks hatched May 21, with the peak hatch occurring the last week in May (Patterson 1952). Hatch dates are dependent on factors influencing initiation dates, and can be altered by spring weather events (Holloran 1999). After hatch, brooding hens remain near the nest primarily in upland habitats (Connelly 1982). The first 10 to 14 days post hatch are considered the early brooding period and late brood lasts into mid-August (Heath et al. 1997 and 1998, Holloran 1999, Lyon 2000). Chicks are especially vulnerable to predation while flightless during the early brood period (Holloran 1999, Heath 1997), while the majority of broods are independent by September 1 (Patterson 1952).

Summer

Roosters and broodless hens are the first to move into mesic habitats in early to late July (Patterson 1952) while broods remain in upland habitats until forbs are desiccated (Heath 1998). Because nest success is low in sage-grouse, the summer population consists largely of barren hens (Crawford et al. 1992). With long life spans and low reproductive output, survival of barren hens may be very important for population stability (Crawford et al. 1992). Brooding hens, broodless hens, and roosters primarily remain in segregated flocks during the summer (Crawford et al. 1992). Broodless hens and roosters select a wider range of habitats than brooding hens, utilizing more open areas with less protective cover (Holloran 1999, Crawford et al. 1992).

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Fall and Winter

Fall habitats are not as fixed as other seasonal habitats, with meandering movements from summer mesic areas to upland winter habitats (Connelly et al. 1988). Weather plays a large role in determining when sage grouse leave mesic areas (Patterson 1952). Sagebrush becomes the staple forage for all sage grouse age classes in the late summer/fall as forbs decline in abundance (Patterson 1952).

Winter foraging habitats typically consist of tall dense sagebrush stands in drainages (Hupp and Braun 1989) and wind blown south and west facing slopes with less than 5% gradient (Beck 1977). Selection of slope gradients and sagebrush heights gradually changes as snow depths increase (Hupp and Braun 1989). Severe winter conditions will often restrict sage grouse to small winter habitats (Beck 1977) with similar winter roosting habitats and feeding habitats (Hubb and Braun 1989). Sage-grouse feed almost entirely on sagebrush in the winter (Patterson 1952). Even with severe winter conditions, winter mortality is lower than other seasons (Connelly et al. 2000b).

Objectives

Our objectives are to describe the adult survival, reproduction, and seasonal movements of this population near Lander and compare it to those in the literature. In addition, we will suggest if the population is migratory or nonmigratory and increasing or decreasing.

METHODS

Study Area

The study area (42°33'N, 108°29'W) was 15,525 ha and located in Southwestern Fremont County between Highway 287 and 28, 23 km southeast of Lander, Wyoming (Appendix A). It was in the foothills region of the Bridger Teton - Wind River Mountains with elevations from 1734 to 2468 m. Area drainages included the west-central regions of the Beaver Creek and Twin Creek, which empty into the Wind River. Main topographic features were Sheep Mountain on the western boundary, Schoettlin Mountain on the

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southwestern boundary, Dilabaugh Buttes and Beaver Creek on the southern boundary, and Cottonwood Divide on the western boundary.

Average annual precipitation was 34.2 cm from 1948 to the present. Precipitation is annually bimodal with months averaging > 2.5 cm during March, April, May, June, September, and October. The most precipitation takes place in April and May with an average with > 5.2 cm per month. See Table 1 for study duration precipitation.

The study area was comprised of 62% BLM and 21% state managed public lands, and 17% private lands, used for rangeland cattle production and some irrigated pastures. Vegetation on the study area was sagebrush steppe with Wyoming big sagebrush (*Artemisia tridentate ssp. wyomingensis*) the dominant shrub, intermixed with cool and warm season forbs and grasses.

Two sage-grouse lek sites were present on the study area and considered the sage-grouse population centers. Four different grazing systems were present on the study area around the leks. The three cattle grazing systems were rotational, with grazing periods from mid-May through September.

Measurements

From 2000 to 2003, female sage-grouse were captured and fitted with PVC covered wire necklace radio transmitters (Advanced Telemetry Systems Inc., Insanti, MN). Transmitters weighed 19 to 20 grams, had a battery life of 520 to 730 days, and were equipped with mortality sensors. Captures occurred in early April during peak lek attendance using spotlighting/hoop-netting techniques (Giesen et. al. 1982, Wakkinen 1990).

Sage-grouse were tracked to nesting, brooding, and summering habitats using hand-held radio-telemetry receivers and three-element Yagi antennas. Habitat use locations were marked using hand-held GPS units. Nests were located during the estimated second week of incubation and marked 5 m away using natural objects (stacked sticks, rocks, or cow pies) and a GPS location. Time spent around the nest was minimized to avoid flushing the female, drawing attention to the nest, and leaving human scent. Incubating females were checked every 2 to 3 days using radio-telemetry from >100m away. Nests were examined when the female left the area. Nests were determined

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successful when egg membranes were detached from the shell of ≥1 egg (Wallestad and Pyrah 1974). If the membranes were still attached or no eggs were found, the nest was determined unsuccessful.

Eggshell and nest condition were recorded for destroyed nests. Guard hair samples were taken from the vegetation around the nest bowl if present and later keyed to species (Moore et al. 1974). Egg and nest condition was also used to estimate the nest predator species (Sargeant et al. 1998). Positive guard hair or fresh track identification combined with egg and nest condition were labeled as confirmed specific mammalian species and confirmed mammalian nest predators. Nests with undercoat hair on the nest shrub, and eggshell and nest condition evidence were labeled as specific suspected mammalian species and confirmed mammalian nest predators. Nests with only mammalian undercoat hair and no other evidence were labeled as confirmed mammalian predators. Destroyed nests without eggs and no hair or mammalian sign were labeled as suspected non-mammalian nest predators.

Early broods were located and flushed for successfully nesting radio-collared females at 10 to 14 days post hatch. Locations were made an hour after sunrise to an hour before sunset. Summer locations took place for all hens in late June to early July and late July to early August. Fall locations on all hens took place after the sage-grouse hunting season, normally the 1st week in October. Winter locations on all hens were completed in the first 2 weeks of January. Fall and winter locations were collected using a fixed-winged airplane. Females were generally not located again until April during breeding and nest initiation periods.

Analysis

Distances between telemetry locations were measured using the GIS program ArcView 3.2 to identify the extent of movements between habitats (ESRI, Redlands, CA). Standard errors were calculated for distance means to determine precision. Primary locations (nest, early brood, late brood, early July, late July/August, fall, and winter) were examined for patterns of concentrated seasonal use and use areas in relation to other seasonal habitats and the leks.

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Annual reproductive output per female was recorded in August when chicks become independent. Nest initiation, nest success, early brood success, brood success to early July, and brood success to late July / early August were calculated by year and all totaled. Mortality dates were grouped within seasonal habitat periods to determine the seasons of greatest adult female vulnerability. Hens found alive at the end of the period, found dead during the period, and hens not found at the end of the period were calculated. All survival estimates of separate periods, combined periods, and by year were all calculated separately.

Population sustainability was estimated using an equation incorporating reproduction and survival information (Matt Holloran, University of Wyoming Cooperative Research Unit, Personal Communication). The equation used summer adult female survival (SS), winter adult female survival (WS), nest initiation rate (NI), nest success rate (NS), early brood survival rate (EBS), late brood survival rate (LB), and chicks per successful hen (CSH). Total female chick numbers (FC) were estimated to be 0.546*CSH (Swenson 1986). Winter chick survival (WCS) from October 1 to April 1 was set at 70%, based on the personal communication of Dr. Jack Connelly, Idaho Department of Fish and Game (Matt Holloran, University of Wyoming Cooperative Research Unit, Personal Communication). Female chicks produced (FCP) were estimated by taking ((NI*NS*EBS*LBS)*100)*FC. The final equations was as follows: (((SS*WS)*100)+(WCS*FCP))-100. Population sustainability was not calculated for 2001 because fall and winter locations were not obtained, making it impossible to measure summer and winter survival separately.

RESULTS

Sample Sizes

From 2000 to 2003, 101 female sage-grouse were radio-collared. Females were tracked to seasonal habitats to record reproduction rates, adult hen survival rates and seasonal movement distances. The annual availability of collared females by year was: 27 (2000), 31 (2001), 24 (2002), and 52 (2003). A total of 128 hen/years were analyzed for reproductive information including hens that survived multiple years. Not all females

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were use in annual productivity and movement analyses due to deaths and lost hens. Predator analysis of destroyed nests was completed on 42 nests. Predator type was not estimated for 10 nests due to adverse weather conditions or extended time lapse after depredation, potentially destroying predator sign.

Reproduction

Sage-grouse reproduction was tracked from breeding in April to chick fledging in August (Table 2). Nests initiation primarily took place from late April through mid-May. The average nest initiation rates for all years was 83% and ranged from 70% in 2000 to 96% in 2002. Initiation rates were likely minimums, due to potential nest destructions during laying and early incubation before nest locations.

Nest success averaged 45% and ranged from 38% in 2001 to 50% in 2002. First clutches ranged from 6 to 9 eggs. Second clutches ranged from 2 to 8 eggs. Renests were confirmed for 4 females or 8% of destroyed nests. American badgers were the most commonly confirmed nest predators at 17%. Confirmed coyotes predations ranked second at 7%. Coyotes and American badgers were both suspected in 17% more nest destructions than those confirmed. No other mammalian nest predator species was confirmed. Mammalian carnivores likely accounted for $\geq$ 79% of sage-grouse nest destructions. Twenty-one percent of the nests lacked evidence to support mammalian predation with no eggs, nest disturbance, or hair. One confirmed American raven predation (2%) matched the destroyed nests without mammalian sign. American ravens were frequently found around nesting habitats and were suspected to be important nest predators.

Early brood locations were recorded 10 to 14 days after hatch, primarily during the first 2 weeks in June. Early brood success ($\geq$ 1 chick alive) averaged 82% and ranged from 71% in 2000 to 94% in 2003. Late brood locations were recorded the last week in July and 1st week in August. Late brood success averaged 86% and ranged from 80% in 2000 to 100% in 2002. An average of 24% of all hens during the breeding season had broods in late July / early August. An average of 0.64 chicks were produced annually per breeding hen through the late brood rearing period. Chicks per potential breeding hen ranged from 0.35 chicks in 2000 to 0.88 chicks in 2002.

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Adult Survival

Annual mortality was divided into four periods, coinciding with sage-grouse seasonal habitat use; April to June (Spring; breeding/nesting/early brooding), July to September (Summer: late brooding or summering), October to December (Fall), and January to March (Winter) (Table 3). Annual periods ran from April 1 to April 1. Females were primarily trapped during the breeding peak in the first 2 weeks in April.

Average spring survival of 79% was the lowest annual period. Spring survival ranged from 84% in 2000 to 69% in 2003. Spring survival was further broken down to lekking and prenesting (81%), incubation (86%), and brooding (83%). Generally, 5% of nesting deaths occurred while foraging off the nest and 9% while on the nest. Few deaths occurred during early brooding with 3% of the total deaths, while 14% occurred after early brooding to August. Brooding hen and non-brooding hen survival estimates were idiential. Non-predation deaths (disease) accounted for 8% of deaths.

Survival rates in the summer and fall were identical. The lowest values for both periods were in 2003. The highest survival rates were in 2000 for summer at 91% and 2000 and 2002 for the fall at 94%. Few winter deaths resulted in an 87% survival rate for the January to March period, although only two years were recorded. Winter survival was not recorded for 2001 and 2003.

The percent of change in the population was estimated using reproduction and survival information for each year and all years combined (Table 4). Population declines were present in all years, with an average decline of 20%. The largest decline occurred in 2003 (24%). The smallest decline was in 2002 (12%).

Seasonal Movements

The average distance between nests and the closest leks was 5.06 km (Table 5). Average nest distances were closest to the leks in 2002 (3.95 km) and the furthest in 2001 (6.90 km). Sage-grouse capture around the leks occurred at its latest in 2002 and was suspected that some hens were captured near prenesting habitats which would influenced nest distances to the lek. Only 36% of nests were < 3 km of the leks (Table 6). Primarily, nests closer than 4 km had slightly lower success than nests further than 6 km (Table 6).

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Fewer than 4% of all nests were < 1 km from the leks. The greatest nest success rates were recorded around 8 km. Nests were widely dispersed from the leks with 24% further than 7 km from the leks. Steady to slightly declining nest success rates were present at distances > 8 km. Primary nesting areas from the leks were within the box spring drainage to the north, Schoettlin mountain to the southeast, and in the Level Meadows/Beaver Creek Drainages to the south.

Spring and summer locations for brooding and non-brood hens were analyzed separately. In 2000, non-brooding hens moved significantly further than brooding hens from the breeding period to August at 9.4 km and 3.3 km respectively. However, distances were not significantly different from August to October or for any of the other years. Primary summering areas for brood hens and non-brood hens were in the Box Creek, Wilson Draw, and Skull Gulch drainages to the north and east the leks and Level Meadows, Little Beaver, and Deep Creek drainages to the south. Most females summered to the south in higher elevation drainages.

The greatest average movements between seasonal habitats were fall to winter (17.4 km) and winter to spring (16.8 km). The greatest distance traveled between fall to winter habitats was 44.5 km and winter to the spring at 24.3 km. Fall habitats were primarily around summering habitats with some movement north to McGraw Flats around the leks, depending on snow cover. With winter snow cover, females generally moved to lower elevations north of Highway 287 and remained along the snow line when present.

DISCUSSION

Reproductive measurements from this study area from 2000 to 2003 were consistent with that found in the literature. The severe drought from 2000 to 2002 (Table 1) did not appear to reduce nest initiation, nest success, early brood survival, or late brood survival below previously found levels. Nest initiation was high and similar to that found in Rawlins and Pinedale, Wyoming (78% to 81%) (Holloran 1999, Lyon 2000). Nest initiation can be near 100% in sage-grouse (Coggins 1998) and initiation and renesting was likely higher than I reported in this study. Some nest depredation likely took place

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before nests were found. Nest success of 45% was slightly lower than the range of averages found in Wyoming (50 to 71%) (Heath 1998, Holloran 1999, Lyon 2000), although within the range found in the literature (28 to 86%) (Connelly 2000a). Our results suggest that nest success was likely the weakest reproductive period because early broods success was high (82%) compared to other studies in Wyoming (61 to 81%) (Holloran 1999, Lyon 2000). Late brood success was similar to early brood at 86%. This suggests that the chance of recruiting a chick to the population was likely good following nest success. The average fall production in this area was 0.64 chicks per hen (all hens at breeding included) and production in all years were far below the estimated 2.25 chicks per hen required to sustain a population (Connelly et al. 2000a). This is primarily attributed to the low nest success rate. We suggest that reproduction was likely insufficient to replace deaths of hens during this study.

Estimated annual adult hen survival was low (54%) but within the range found in Wyoming (50 to 85%) (Heath et al. 1997 and 1998) and other parts of the species range (40 to 85%) (Wallestad 1975, Zablan 1993, Connelly et al. 1994). Adult survival was lowest in the spring during the breeding, nesting, and early brood rearing periods (79%). Both successful and unsuccessfully reproducing females had lower survival during this period. The lekking / prenesting period accounted for 17% of all deaths, and nesting deaths accounting for 14%, being split fairly evenly between deaths on and off the nest. Considering the small amount of time spent off the nest, hen vulnerability during foraging periods appeared to be high. The breeding and nesting duration had 31% of the annual deaths during just 2 months, suggesting high vulnerability during this period. Survival rates in the summer were lowest while hens were concentrated in mesic areas in late-July through mid-August. Only one confirmed hunting mortality was identified during the 70 hen / years monitored through the hunting seasons, all years combined. Hunting on private lands was restricted in and around the study area, potentially reducing hunting access as well onto associated public lands. The winter season had high survival at 87% which was also found by Connelly et al. (2000b), suggesting that winter habitats were likely not limiting.

Using the reproduction and adult mortality information, I estimated that 20% mean annual declines occurred in the sage-grouse population in 2000, 2002, and 2003.

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Unexpectedly, the greatest mean declines occurred in 2003, during the highest precipitation year following three years of drought. More frequent non-predation deaths in 2003 accounted for much of the increase. Disease was suspected, although not confirmed in one case in 2002 and 4 cases in 2003. These deaths were found in non-nesting hens, nesting hens, and brooding hens in dry upland habitats during the late spring and early summer. All hens suffered from mild pneumonia and tested negative for the west nile virus.

Only slight declines in sage-grouse abundance were visually observed over the study period and it is likely that adult survival was greater than that recorded. We made the assumption that the detection of deaths had the same likelihood as detection of living hens, which is likely untrue. Several relocations were completed within the spring and summer periods. Deaths had to be found only once during the period to be counted while alive hens had to be located at the end of the period to register as alive and be included in the survival estimates.

Seasonal movements of $\geq$ 10 km (Connelly et al. 2000a) from fall to winter and winter to spring habitats suggest that this population is migratory with spring, summer, and fall habitats overlapping and unique winter habitats. Movements from summer habitats to winter habitats were primarily north, with spring movements returning south to the leks. The extent of the winter movements north appeared to follow snow accumulation, as was found in Idaho (Dalke et al 1963). Hens moved to lower elevations from the fall through the winter. Nesting and summer habitats were less than 10 km from the breeding habitats, although they did show two main trends, with hens remaining near the leks and some moving several kilometer to the south.

Nests on average were 5.1 km from the nearest lek, which is similar to averages in Wyoming found near Casper (4.1 km) (Holloran 1999) and Rawlins (5.5) (Heath et al. 1998), although greater than those found in Pinedale (2.9 km) (Lyon 2000). Nest success appeared highest at 8 km and stable to slightly declining at $\geq$ 8 km. Mean nest success was the lowest at $\leq$ 4 km with few hens nesting at $\leq$ 1 km, suggesting potential avoidance of nesting habitat near the leks. Significantly greater nest success further from the leks was also found near Farson, Wyoming. (Heath 1997). In 2002, several hens were captured and collared in areas near the leks, and later were found nesting near the

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location of capture. Sage-grouse capture took place later in 2002 than the other years, potentially resulting in capture of females on selected nesting habitats and reducing the average distance from leks to the nests.

MANAGEMENT IMPLICATIONS

It appears that spring was the period of greatest concern for adult hen survival during this study. We suggest that additional research focus on the quality and quantity of protective habitats around breeding and nesting areas. To increase productivity, our results we suggest that a reduction in nest destruction would have lead to greater fall productivity in this area with higher brood survival than found than in other Wyoming studies (Holloran 1999, Lyon 2000). Protection or enhancement of nesting habitats within 3.2 km of leks as is recommended in sage-grouse habitat guidelines for nonmigratory populations (Connelly et al. 2000a) would include only 32% of the nests in this study. We support suggestions by Connelly et al. (2000a) to direct protection and enhancements of nesting habitats specific to individual migratory populations. It should also be noted that sage-grouse nest success and adult survival is often attributed to vegetative cover. However, we recommend that research be extended to better understanding the roll of predator abundance, fluctuations, and distribution have on sage-grouse reproduction and survival.

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Table 1. Monthly spring and annual precipitation means (cm) compared to averages from 1948 to the present for Lander, Wyoming.

	April	May	June	Yearly
Average	5.23	6.19	2.77	33.32
1999	16.35	2.46	3.55	34.49
2000	4.34	4.34	1.67	21.85
2001	2.72	1.26	0.48	13.65
2002	3.22	4.26	0.63	20.53
2003	2.23	3.25	4.31	26.04

Table 2. Sage-grouse nest initiation, nest success and early-brood success by year near Lander, Wyoming (2000 to 2003). Potential breeding hens were the number of collared females known alive at the beginning of the lekking period. Early brood period was 10 to 14 days post hatch. The late brood period was the last week in July through the 1st week in August. Overall productivity from breeding (April 1) was included for nest success, brood success, late brood success, and chicks per breeding hen. Hens not found during the breeding season were excluded.

	2000	2001	2002	2003	Combined
Potential Breeding Hens	26	31	24	48	128
Nest Initiation	16/23 (70%)	21/27 (78%)	23/24 (96%)	36/42 (86%)	96/116 (83%)
Hen Nest Success (From Initiation and Breeding)	7/16 (44%) 7/26 (27%)	8/21 (38%) 8/30 (27%)	12/23 (50%) 12/24 (50%)	16/36 (44%) 16/48 (33%)	43/96 (45%) 43/128 (34%)
Hen Early Brood Success (From Hatch and Breeding)	5/7 (71%) 5/26 (19%)	7/9 (78%) 7/30 (23%)	9/12 (75%) 9/24 (38%)	15/16 (94%) 15/48 (31%)	36/44 (82%) 36/128 (24%)
Hen Late Brood Success (Early Brood and Breeding)	4/5 (80%) 4/26 (15%)	6/7 (88%) 6/30 (20%)	9/9 (100%) 9/24 (38%)	12/15 (80%) 12/48 (25%)	31/36 (86%) 31/128 (24%)
Total Chicks Fledged (Aug)	9 chicks	17 chicks	21 chicks	35 chicks	82 chicks
Chicks per Potential Breeding Hen	0.35 chicks	0.56 chicks	0.88 chicks	0.73 chicks	0.64 chicks

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Table 3. Estimated seasonal survival of radio-collared female sage-grouse near Lander, Wyoming from 2000 to 2003. Annual survival was estimated by dividing females found alive by females found alive or dead. Total survival was the average annual survival from 2000 to 2003. The number of hens missing from the relocation periods are provided. Missing hens were not figured into the survival estimates and it is assumed that they have an equivalent percentage of survivals and deaths as those found. Exact dates of relocations varied between years. August 1 included results from locations taken the last week in July through the first 10 days in August. In 2001, fall and winter locations were not taken. Annual and biannual periods are underlined.

	2000			2001			2002			2003			Averaged
	Deaths	Survival	Missing	Deaths	Survival	Missing	Deaths	Survival	Missing	Deaths	Survival	Missing	Survival
April – June	4	21/25 (84%)	2	6	25/31 (81%)	4	5	19/24 (79%)	2	16	36/52 (69%)	4	79%
July – Sept.	2	20/22 (91%)	1	NA	NA	NA	2	17/19 (89%)	2	6	26/32 (81%)	11	89%
April – Sept	6	20/26 (77%)	1	NA	NA	NA	7	17/24 (71%)	2	22	26/48 (54%)	11	67%
Oct. – Dec.	1	17/18 (94%)	3	NA	NA	NA	1	15/16 (94%)	1	4	18/22 (82%)	11	89%
Jan. – March	1	14/15 (93%)	5	NA	NA	NA	3	13/16 (81%)	1	NA	NA	NA	87%
Oct. – March	2	13/16 (81%)	5	NA	NA	NA	4	13/17 (77%)	1	4	18/22 (82%)*	NA	80%*
Annual	8	14/21 (67%)	5	NA	NA (NA)	NA	11	13/24 (54%)	1	26	18/44 (41%)*	NA	54%*

* contains incomplete information (winter 2003 not completed)

Table 4. Estimated annual and average sage-grouse population trends (% change) near Lander, Wyoming from 2000 to 2003. The equation (Matt Holloran, University of Wyoming Cooperative Research Unit, Personal Communication) used summer adult female survival (SS), winter adult female survival (WS), nest initiation rate (NI), nest success rate (NS), early brood survival rate (EBS), late brood survival rate (LB), and chicks per successful hen (CSH). Female survival was estimated by dividing the number found alive by the total number found at the end of the period. Female chicks were estimated as 0.546*CSH (Swenson 1986). Winter chick survival (WCS) from October 1 to April 1 was set at 70%, based on the personal communication of Dr. Jack Connelly, Idaho Department of Fish and Game (Matt Holloran, University of Wyoming Cooperative Research Unit, Personal Communication). Female chicks produced (FCP) was estimated by taking ((NI*NS*EBS*LBS)*100)*FC. Female chicks alive in the spring (FSC) was estimated by taking WCS*FCP. Annual adult hen survival (AHS) was estimated by (SS*WS)*100. Percent change in population size was estimated by (AHS+FCS)-100.

Year	SS	WS	NI	NS	EBS	LBS	CSH	FC	WCS	FCP	FSC	AHS	% Change
2000	0.77	0.81	0.70	0.44	0.71	0.80	2.25	1.23	0.70	21.49	15.04	64.60	-23
2002	0.71	0.77	0.96	0.52	0.75	1.00	2.33	1.27	0.70	47.63	33.34	51.00	-12
2003	0.54	0.82*	0.86	0.44	0.94	0.80	2.92	1.59	0.70	45.37	31.76	41.00	-24*
Average	0.67	0.80*	0.83	0.45	0.82	0.87	2.64	1.44	0.70	38.41	26.89	54.94	-20

*Incomplete information (winter 2003 not completed)

Table 5. Sage-grouse mean (M) distances (km) between seasonal habitats near Lander, Wyoming from 2000 to 2003. July, October (Oct.), and January (Jan.) locations were taken during the first 2 weeks of the month. August (Aug.) locations were taken primarily during the last week in July and 1st week in August. Breeding at the leks (Lek) and nest incubation (Nest) periods were primarily the 1st 3 weeks in March and the last week in April to 1st week in June, respectively. Nesting hens (I) initiating a nest. Early brood (EB) periods were generally from the last week in May to the 1st 3 weeks in June. Locations from lek period (April) to October were separated by brooding (B) and nonbrooding (NB) hens. All hens were combined (all) for October to lek periods (April).

Duration	2000			2001			2002			2003			All Years		
	N	M (km)	SE	N	M (km)	SE	N	M (km)	SE	N	M (km)	SE	N	M (km)	SE
Lek – Nest (I)	15	5.12	2.40	19	6.90	2.49	23	3.95	1.04	38	4.78	0.84	95	5.06	0.77
Nest – EB (B)	5	0.53	0.21	8	2.76	3.48	11	0.51	0.24	14	1.94	1.04	38	1.51	0.84
EB – July (B)	6	1.60	1.04	7	3.97	3.49	7	0.43	0.19	10	2.29	1.17	30	2.11	0.99
July – Aug. (B)	4	3.77	3.38	6	0.72	0.84	7	1.12	0.89	10	3.24	2.64	27	2.21	1.18
Lek – Aug. (B)	4	3.29	3.24	8	7.82	3.36	8	7.29	2.42	11	7.48	2.83	31	6.98	1.55
Lek – Aug. (NB)	13	9.39	2.36	14	7.44	2.05	10	9.01	3.57	18	6.96	1.89	55	8.03	1.78
Aug – Oct (B)	4	3.05	1.60	0	NA	0.00	7	5.57	3.27	8	5.79	3.04	19	5.13	1.78
Aug. – Oct (NB)	11	7.65	4.26	0	NA	0.00	7	4.38	3.29	12	3.97	1.97	30	5.41	1.95
Oct. – Jan. (All)	13	21.08	5.24	0	NA	0.00	14	11.39	5.44	17	19.45	4.15	44	17.37	3.03
Jan. – Lek (All)	16	20.83	3.27	0	NA	0.00	16	10.71	4.59	21	16.23	2.26	53	16.87	2.36

NA: Not Available

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Table 6. Distance from the lek of sage-grouse nests (% total) and nest success (% success) of sage-grouse nests near Lander, Wyoming from 2000 to 2003. Sage-grouse females were radio-collared and monitored through the nesting period. Distances were measured from the closest lek. Distance circumferences were created around an isolated 2 lek complex.

	2000	2001	2002	2003	% Success	% Total
≤ 1 km	1	2	0	1	50	4
≤ 2 km	6	4	7	5	22	23
≤ 3 km	8	5	9	12	38	36
≤ 4 km	8	5	12	18	44	45
≤ 5 km	10	7	14	21	38	55
≤ 6 km	10	9	16	24	41	62
≤ 7 km	10	14	19	30	44	76
≤ 8 km	12	15	20	34	58	84
≤ 9 km	12	15	22	37	43	91
≤ 10 km	12	15	22	37	43	91
≤ 11 km	13	17	22	38	43	95
≤ 12 km	13	17	22	38	43	95
≤ 13 km	14	18	22	38	42	97
> 13 km	15	20	22	38	42	100

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CHAPTER 2: GREATER SAGE-GROUSE NEST AND EARLY BROOD HABITATS IN RELATION TO ASSOCIATED LIVESTOCK GRAZING SYSTEMS

ABSTRACT

Livestock grazing has been implicated as one cause for range-wide sage-grouse (*Centrocercus urophasianus*) population declines. However, there is no direct evidence that livestock grazing influences sage-grouse productivity. We examined vegetation at 95 nests of radio-collard sage-grouse and 165 random plots on 4 different grazing systems in central Wyoming. Grazing systems included a high intensity 2-paddock spring deferred rotational (DR), a spring and fall grazed, 10-paddock, moderate to low intensity rest rotational (SFR), a summer grazed, 10 paddock, moderate to low duration rest rotational (SR), and a rested from livestock control (NG). Our goal was to determine what habitat components were selected by nesting, successfully nesting, and early brood rearing sage-grouse females over 4 years. Second, we examined 4 grazing systems for significant changes and trends in vegetative components important to sage-grouse over the same period. Analyses of nest selection, nest success, and early brood habitat components suggested that the habitat components tested fit the data but had only a small amount of predictive value. Selected nests had potentially greater total shrub canopy cover, residual grass heights were potentially greater at successful nests, and food forb cover was potentially greater at early brood sites. Grazing system function and forage utilization rates reflected the severe drought conditions throughout the study. Only the SR and NG systems did not increase in bare ground cover during the study. In addition, the NG system increased in residual grass height, while the SR system had no significant declines or increases in habitat variables important for sage-grouse habitats. The vegetative changes during the study were attributed to stocking rates and season of grazing rather than grazing system.

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INTRODUCTION

Range-wide breeding populations of sage-grouse (*Centrocercus urophasianus*) experienced estimated declines of 45 to 80% since the 1950s, with the greatest declines occurring since 1980 (Braun 1998). Following 1985, sage-grouse populations declined an estimated 33% range-wide (Connelly and Braun 1997). Wyoming has also experienced declines, which were indicated by a 17% reduction in rooster attendance at lek sites since 1985 (Connelly and Braun 1997).

Livestock grazing is recognized as potentially influencing sage-grouse nest and early brood success, because much, if not all, of the sage-grouse's original range has been grazed (Braun 1998). Inappropriate livestock management is thought to be one influence on historic and current sage-grouse population declines and degraded sagebrush-grassland habitats (Patterson 1952, Braun 1998, Miller et al. 1994, Beck and Mitchell 2000, Connelly et al. 2000). While poor livestock management has altered sagebrush steppe vegetation since European settlement (Miller et al. 1994), dense stands of sagebrush with sparse understories were historically present (Vale 1975). However, grazing and agricultural mismanagement further increased sagebrush densities and reduced herbaceous understories (Vale 1975).

The effects of livestock on sage-grouse and sagebrush-grassland ecosystems can be positive, negative, or neutral (Guthery 1996). Potential direct effects of livestock grazing might involve manipulation of height and cover of vegetation (Heath et al. 1998, Holloran et al. 1999), litter and fine fuels cover (Winward 1987), nutrient cycling (Willms et al. 1990), plant interspecies competition (Collins et al. 1987), soil density (Warren et al. 1986), trampling of nests (Koerth et al. 1983), and trailing (Ganskopp et al. 2000).

Indirect effects of livestock grazing (i.e. sagebrush control to increase forage) are generally better understood than direct effects and likely have had more influence on sage-grouse (Beck and Mitchell 2000). An exception to this is the indirect effects of livestock management on direct vegetation removal, which have been rarely studied. Livestock management includes direct control by humans of stocking rates, timing, and duration of grazing (Vallentine 1990). Stocking rates and grazing systems are commonly used tools to manipulate domestic livestock (Van Poolen and Lacey 1979, Holechek et al.

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1999). Stocking rates are generally defined as a function of the number of animals grazed in a particular area for a particular period of time (Society for Range Management 1998). Grazing systems dictate periods of grazing and non-grazing, or the timing and duration of grazing (Society for Range Management 1998). Stocking rates and grazing systems are often combined to determine the timing, intensity, and duration of livestock grazing in an area (Vallentine 1990). Some examples of grazing systems are deferred (delayed grazing for a purpose), rotational (systematic rotation of grazing between 2 or more paddocks per grazing period), or both combined (Society for Range Management 1998).

Beck and Mitchell (2000) suggested the nesting and early brood rearing periods may be the most vulnerable to livestock grazing influences. Sage-grouse nests are primarily found under tall sagebrush shrubs (Apa 1998, Holloran 1999) with greater percent shrub canopy cover than randomly available habitats (Wallestad and Pyrah 1974, Wakkinen 1990, Heath et al. 1997 and 1998, Sveum et al. 1998, Holloran 1999). Increased herbaceous understories of tall and abundant grasses, forbs, and litter are characteristic of nest sites (Heath et al. 1997 and 1999, Holloran 1999, Lyon 2000).

Successful nest habitats involve further increases in shrub and herbaceous vegetation. Greater shrub canopy cover, grass height, grass cover, residual grass height, and residual grass cover have been reported attributes of successful relative to unsuccessful nests (Wallestad and Pyrah 1974, Gregg 1991). Residual grasses may be important for both nest selection and success due to their availability during nest selection and incubation periods (Holloran 1999).

Early brood habitats in Wyoming consist of upland shrub-grassland habitats with reduced shrub canopy covers and bare ground with greater grass, litter, and forb cover than found in available habitats (Heath et al. 1997 and 1998, Lyon 2000). Heath et al. (1998) suggested that grazing management aimed at increasing the height and cover of grasses in early brood habitats could increase chick survival.

Few sage-grouse habitat studies have directly linked the influences of livestock management to sage-grouse productivity (Beck and Mitchell 2000). Positive effects of grazing on forb availability and palatability have been found in mesic conditions for summering sage-grouse (Neel 1980, Klebenow 1981, Evans 1986), however, no positive influences have been found in uplands. Additionally, prolonged heavy cattle use on wet meadows decrease

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sage-grouse use and reduce food forb abundance (Oakleaf 1971, Neel 1980), suggesting limitations, even in mesic areas.

Two reviews of livestock grazing systems in North American grasslands found that grazing systems had less influence on vegetative production than stocking rates (Van Poolen and Lacey 1979, Holechek et al. 1999). Forage production generally increases with a reduction from heavy to moderate and moderate to light stocking rates (Van Poolen and Lacey 1979). Contrasts between forage production of different stocking rates is even greater in dry years (Holechek et al. 1999). Heavy forage use of 50% or greater resulted in range deterioration (Holechek et al. 1999). Beck and Mitchell (2000) concluded that stocking rates and timing of grazing (particularly spring grazing) appear to be the most important influences on sage-grouse productivity.

Currently, indirect evidence is used to estimate livestock effects (Braun 1987), such as vegetative comparisons of livestock grazing system and production studies to sage-grouse seasonal habitat use studies. Unfortunately, there are no long-term replicated livestock grazing studies in the sagebrush-steppe (Holechek et al. 1999), making inferences to sage-grouse habitats difficult. With few studies available, it is important that additional replicated sage-grouse and livestock field experiments examine the effects of different grazing systems particularly on sage-grouse nest success and brood survival (Beck and Mitchell 2000). Treatment areas should have adjacent control "no grazing" areas for comparison to best determine grazing effects (Beck and Mitchell 2000). Simultaneously examining livestock grazing systems and sage-grouse seasonal habitats is a necessary step in determining any cause and effect relationship. Our primary objective was to compare sage-grouse nesting and early brood habitats to vegetation in three rotational cattle grazing systems and a rested control. We hypothesized that different stocking rates and grazing systems (differed rotational, summer grazed moderate to light intensity rest rotational, spring and fall grazed moderate to light intensity rest rotational, and rested from livestock), would influence vegetation positively or negatively for sage-grouse nesting and early brood habitats.

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METHODS

Study Area and Grazing Systems

The study area (42°33'N, 108°29'W) was 15,525 ha and located in Southwestern Fremont County between Highways 287 and 28, 23 km southeast of Lander, Wyoming. It is in the foothills region of the Bridger Teton Mountains - Wind River Range with elevations from 1734 to 2468 m. Area drainages include the west-central regions of the Beaver Creek and Twin Creek, which empty into the Wind River. Main topographic features are Sheep Mountain on the western boundary, Schoettlin Mountain on the southwestern boundary, Dilabaugh Buttes/Beaver Creek on the southern boundary, and Cottonwood Divide on the western boundary.

Average annual precipitation is 33.3 cm. Precipitation is annually bimodal with months averaging >2.54 cm March, April, May, June, September, and October. April and May receive the most precipitation on average with >5.23 cm per month. See Table 1. for study duration precipitation.

The study area was comprised of 62% BLM and 21% state managed public land, and 17% private land, used for rangeland cattle production and some irrigated pastures. Vegetation on the study area was sagebrush steppe with Wyoming big sagebrush (Artemisia tridentata wyomingensis) the dominant shrub, intermixed with cool and warm season forbs and grasses. Other common woody plants included black greasewood (Sarcobatus vermiculatus), gardner saltbrush (Atriplex gardneri), basin big sagebrush (Artemisia tridentata tridentata), Mountain big sagebrush (Artemisia tridentata vaseyana) antelope bitterbrush (Purshia tridentata), rabbitbrush (Chrysothamnus viscidiflorus), black sagebrush (Artemisia nova), and mountain snowberry (Symphoricarpos vaccinioides). Common grasses included bluebunch wheatgrass (Pseudoroegneria spicata), thickspike wheatgrass (Agropyron dasystachyum), indian ricegrass, (Oryzopsis hymenoides), needleandthread (Stipa comata), western wheatgrass (Agropyron smithii), and downy brome (Bromus tectorum). Common forbs include western yarrow (Achillea millefolium), curlycup gumweed (Grindelia squarrosa), false dandylion (Agoseris glauca), dandylion (Taraxacum officinale), tapertip hawksbeard (Crepis acuminata), arrowleaf balsamroot (Balsamorhiza sagittata), Tansymustard (Descurainia pinnata), tallcup lupine (Lupinus caudatus), and Lambert's crazyweed (Oxytropis lambertii).

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Four soil classes and 13 main soil types were present on the study area. The Patent-Forelle-Diamondville class has shallow to deep soils and commonly includes Patent, Forelle, Diamondville, and Blazon soil types. Soils are well drained with a 0 to 15% slope, elevation of 1585 to 2164 m average annual precipitation of 33 cm, and a frost-free period of 90 to 120 days. The Sinkson-Thermopolis soil class has deep to shallow soils with Sinkson and Thermopolis the primary soil types. Soils are well drained with a 3 to 60% slope, elevation of 1,676 to 2,225 m, annual precipitation of 33 cm, and a frost-free period of 90 to 120 days average. The Farlow-Duncom soil class has shallow to deep soils with Farlow, Duncom, and Sapphire the most common soil types. Soils are well drained with a 10 to 60% slope, 1,829 to 2,895 m elevation, annual precipitation of 38 cm to 51 cm, and a frost-free period of 60 to 90 days. The Handran-Midelight soil class has deep soils with Handran Channery Loam, Midelight, Irgul, and Ansel the most common soil types. Soils are well drained with 2 to 30% slope, 2,438 to 2743 m elevation, 38 to 51 cm of annual precipitation, and a frost-free season of 60 to 90 days.

Four different grazing systems were present on the study area around 2 sage-grouse leks approximately 1 km apart, considered the sage-grouse population center for the area (Appendix A). The three livestock grazing systems were rotational with 4.5 month grazing periods from mid-May through September. Rotational systems included (1) differed rotational (DR); (2) summer grazed moderate to light intensity rest rotational (SR); and (3) spring and fall grazed moderate to light intensity rest rotational (SFR). The forth system was rested from livestock (NG). Timing of rotations in the cattle grazed systems were not scripted and depended on forage availability. Livestock use was described as percent utilization of available forage during the grazing period, as annually designated by the local Bureau of Land Management. Roughly 50% of the estimated vegetation was designated annually for livestock use. Forage utilization at > 45% was termed heavy, 35% to 45% moderate, and < 35% light. Annual percent forage utilization in each grazing system for the study duration are presented in Table 2.

The SFR system covered 4953 ha and was implemented in 1993 with the current 10 paddock system completed in 1994. Average paddock size was 495 ha and ranged from 199 to 1,090 ha. Past and current management grazed for high forage utilization. Prior to 2001, the system was a rotational system with no paddocks rested for an entire

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grazing period. From 2001 to 2003, rest was incorporated into the system with the number of annually rested paddocks dependent on range conditions. One paddock was rested in 2001 and 2002, with 3 rested in 2003. Twice-over grazing (grazing the same paddock twice in a grazing period) was incorporated in 7 out of 9 years prior to the end of the study, including half of the study period. Since 1994, 27% of the paddocks were twice-over grazed annually. Most paddocks in the system were grazed in the spring or fall. Soil classes included 518 ha of Farlow-Duncom, 259 ha of Sinkson-Thermopolis and 4176 ha of Patent-Forelle-Diamondville, with elevations ranging from 1866 to 2153 m.

The SR system covered 7211 ha and was implemented in 2001 for moderate forage utilization (35 to 45%) and divided into 10 primary paddocks. Average paddock size was 753 ha, ranging from 259 to 1619 ha. Twice-over grazing was incorporated into the system briefly. Two paddocks in 2001 were twice-over grazed. Complete rest from livestock occurred in 2001 (2 paddocks), 2002 (6 paddocks), and 2003 (all paddocks). During the study, most paddocks were grazed in the summer. Traditionally, the area was used for continuous grazing throughout the grazing period at heavy utilization rates. Soil classes in the area include 907 ha of Sinkson-Thermopolis, 1813 ha of Farlow-Duncom, and 4807 ha of Patent-Forelle-Diamondville with elevations ranging from 1734 to 2468 m.

The DR system covered 2095 ha divided into 2 paddocks. The system was implemented with spring deferment alternated each year in the 2-paddock system with heavy forage utilization. Historically the system had heavy forage utilization with season-long grazing. Soil classes in the area were entirely Patent-Forelle-Diamondville with elevations of 1998-2109 m.

The NG system covered 752 ha and was last grazed by livestock in 1999 and rested thereafter. Historically, the system had season long use with heavy forage utilization (50%). Soil classes in the area consist of 130 ha of Handran-Midelight, and 820 ha of Farlow-Duncom, with elevations from 2140 to 2356 m.

Measurements

Female sage-grouse were captured and fitted with PVC covered wire necklace radio-transmitters (Advanced Telemetry Systems Inc., Insanti, MN). Transmitters

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weighed 19 to 20 grams, had a battery life of 520 to 730 days, and were equipped with mortality sensors. The females were captured in April while they attended leks using spotlighting/hoop-netting techniques (Giesen et. al. 1982, Wakkinen 1990).

Sage-grouse were tracked to nesting habitats using hand held radio-telemetry receivers and three-element Yagi antennas. Nests sites (habitats) were located within the first 2 weeks of incubation and marked 5 m away using natural objects (sticks, rock, cow pies) and a GPS location. Time spent around the nest was minimized to avoid flushing the female, drawing attention to the nest, and leaving human scent. Incubating females were checked every 2 to 3 days using radio-telemetry from >100m away. Nests were examined when the female left the area. If the egg membrane was detached from the shell of ≥ 1 egg, the nest was considered successful (Wallestad and Pyrah 1974). If the membranes were still attached or no eggs were found, the nest was deemed unsuccessful. Eggshell and nest condition were recorded for destroyed nests.

Guard hair samples were taken from the vegetation around the nest bowl if present, and later keyed to species (Moore et al. 1974). Egg and nest condition evidence was also used to estimate the nest predator species (Sargeant et al. 1998). Positive guard hair or fresh track identification combined with egg and nest condition was suggested the most reliable predictor of nest predator identification. Undercoat hair on the nest shrub with no other sign was suggested an unknown mammalian predation. Nests with no hair or mammalian sign were suggested to be non-mammalian predation. Early brood use sites (early brood habitats) were located for successfully nesting radio-collared females at 10 to 14 days post hatch. GPS locations were taken from an hour after sunrise to an hour before sunset.

Habitat characteristics recognized as important to sage-grouse nest selection, early brood habitat selection, or nest success were examined for significant changes over the study period and trends. Preexisting differences within grazing systems were beyond the scope of our data and were only of interest as to how they currently influence vegetation changes for the study duration. Vegetation measurement techniques were standardized with previously conducted sage-grouse studies in Wyoming for site comparisons (Heath et al. 1997 and 1998, Holloran 1999, Lyon 2000, Slater 2003). Vegetation measurements of randoms, nests, and broods took place after the hatch in early June. Measurements at

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sage-grouse nest and early brood habitats were compared to random habitats throughout the study area. Random number generation of easting and northings in the study area were used to select UTMs. In 2000, UTMs were generated within the grazing systems, and from 2001 to 2003 random UTMs were generated by paddock within the livestock grazed systems to ensure equal sampling of paddocks. Randoms were located in potential sage-grouse nesting habitats by selecting the closest sagebrush bush >30 cm tall from the original random UTM location.

The line-intercept method (Cainfield 1941) was used along two perpendicular 30 m transects centered on use and random locations (random habitats) to estimate percent shrub canopy cover. A meter-wide belt transect was used over transects to estimate sagebrush densities. The Daubenmire method was used to estimate the ground cover of herbaceous species, litter, and bare ground using 25 cm x 50 cm open-ended frames (Daubenmire 1959). Because of rocky soils on the study area, rock was included in bare ground estimates. Frames were placed at the center, 1 m from the center, and 2.5 m from the center for 12 frames per transect. Grass was separated into new and residual grass categories and forbs were separated in sage-grouse food forb and cover forb categories. Sage-grouse food forbs were common dandelion (*Taraxacum officinale*), curlycup gumweed (*Grindelia squarrosa*), western salsify (*Tragopogon dubius*), western yarrow (*Achillea lanulosa*), prickly lettuce (*Lactuca serriola*), cudweed (*Gnaphalium palustre*), fleabane (Asteraceae spp.), sweetclover (*Melilotus officinalis*), milkvetch (*Astragalus bisulcatus*), alfalfa (*Medicago sativa*), winterfat (*Ceratoides lanata*), fringed sagewort (*Artemisia frigida*), and aster spp. (Patterson 1952, Peterson 1970, Wallestad et. al. 1975, Barnett and Crawford 1994). All other species were classified as cover forbs.

Measured variables were percent live sagebrush canopy cover, percent dead sagebrush canopy cover, percent total shrub canopy cover, live sagebrush density per m^2, dead sagebrush density per m^2, percent food forb cover, percent cover forb cover, percent total forb cover, average forb species diversity per 0.125 m^2 (forb diversity), percent live grass cover, percent residual grass cover, percent litter cover, percent bare ground cover, average new grass height, average residual grass height, and total herbaceous cover. Percent cover was estimated separately for shrub and herbaceous variables. Average grass and residual grass heights were estimated visually.

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Twenty-five, 8 m x 8 m livestock exclosures and paired non-exclosed sites were built to supplement existing vegetation measurements in May of 2002. Exclosures consisted of 8 metal t-posts 4 meters apart and three strings of barbed wire at heights of 40, 70, and 100 cm from the ground. Exclosure sites were randomly selected in the same manner as random habitat samples. One exclosure was built in each paddock in the SR and SFR systems and five exclosures were placed in the NG system. Ten non-exclosure sites were built in the DR system, using the same randomization techniques. Exclosures were non placed in the DR system due lack of landowner participation. Sites paired with exclosures were between 50 m to 100 m from exclosures and centered on the closest sagebrush of $\geq$ 30 cm in height in an area which also visually matched the exclosure in vegetation, aspect, and slope. Paired sites were marked with 42 cm wooden stakes at the centers and at 2.5 m from the plot center along the perpendicular transects. These stakes marked the beginning of the outermost daubenmire frame placement, ensuring exact placement in subsequent measurements. Exclosures and paired sites were measured for herbaceous vegetation using aforementioned techniques in June and mid-September.

In addition to vegetation measurements, sagebrush new growth samples at nests and randoms sites were analyzed with x-ray analysis for nutritional content from 2000 to 2001. Samples were taken within 15 m of nests and random points. Nutrition comparisons between nests and random sites and successful and unsuccessful nests are found in Appendix A and B respectively.

Optimal sized arthropods (3 mm to 12 mm) were sampled at early brood sites and random sites from 2000 to 2003. Arthropods were sampled using 17 pitfall traps along the vegetation transects One pitfall trap was set at the center with traps also a 1, 2.5, 7, and 15 m from the center. Arthropod abundances were categorized into four classes; hymenoptera, coleoptera, orthoptera, and hemiptera, and the order arachnida. Total abundance (TA) and total dried mass were presented for all arthropods combined and optimal sized arthropods combined. Arthropod samples were taken at early brood sites and random sites from 2000 to 2003. Arthropod type, size, and weight categories were compared between early brood sites and individual grazing systems (Appendix C).

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Analysis

Two main questions were examined in our analyses; what habitat variables are important for sage-grouse near Lander, Wyoming, and what grazing systems appear to positively influence important sage-grouse habitat variables? Binary logistic regression with AIC model analysis was used to compare woody and herbaceous vegetation at successful vs. unsuccessful nest habitats, nests vs. available habitats, and early brood habitats vs. available habitats (Minitab Inc.).

We desired to use all combinations of variables within the models to provide an even chance for detection of importance. Sixteen variables were measured. The number of variables used was reduced to remove correlated variables and reduce the number of models necessary. Only variables with Pearson's correlation values of $r < 0.6$ were used. Variables were also selected based on importance in Wyoming studies and studies throughout the range. Variable selection was separate for sage-grouse nest success, nest selection, and early brood habitat selection analyses. Variables with multicollinearity were separated by selection of those variables that allowed for each the major habitat categories to be analyzed; shrub, new grass, residual grass, forb, and % ground cover.

Variables for the successful vs. unsuccessful nest analyses were percent total shrub canopy cover, grass height, residual grass height, percent residual grass cover, percent food forb cover and percent cover forb cover. Variables for the nests vs. available habitats were total shrub canopy cover, dead sagebrush cover, grass cover, grass height, residual grass height, and litter. Variables for early brood habitats vs. available habitats were live sagebrush cover, total shrub cover, bare ground, total forb cover, food forb cover, and grass cover. Due to large sample size differences between early brood and random habitats, equal sample sizes of randoms to early broods were selected by year using random number generation. Means, standard errors and greatest detectable difference ($\alpha \leq 0.05$) of the variables modeled was obtained for reference (Appendix D).

Maximized log-likelihoods from the regression outputs were used to calculate Akaike's Information Criterion adjusted for small sample sizes (AICc), and Akaike Weights for each model. Models with the lowest AICc values (largest Akaike's weights) represented the best models. Models were ranked by subtracting the lowest AICc value from all AICc values for simple difference values (Δ AICc). Models with a Δ AICc < 4

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were selected as the best subset of models. Models with a Δ AICc of < 2 were given special emphasis. To assess the relative importance (RI) of the variables, the Akaike's weight for each model were given to the variables in those models. The Akaike's Weights for each variable were than summed, with the most important variables having the highest Akaike's Weights. The Hosmer-Lemshow goodness-of-fits test were used to access the model's fit to the data (Hosmer and Lemeshow 1989).

To compare grazing systems to each other and related nests and early broods habitats, we calculated means and 95% confidence intervals for all sampled variables from one-way ANOVA (Minitab Inc.). Variable means for nests, early broods, and each of the grazing systems were graphed by year to analyze trends within habitats. The important variables from the models and from the literature were given special emphasis. Means, standard errors and post hoc power ($\alpha \leq 0.05$) of the variables modeled were obtained to examine the level of detection possible. Normality was determined visually using scatter plots and reported for any variable of significance.

Percent livestock forage use was compared to declines in grass heights variables from spring and fall measurements. Declines in grass heights over the winter were also examined using the same measurements. Paired t-tests at $\alpha \leq 0.05$ were used to first detect if significant declines occurred in paired and exclosures (Minitab Inc.). Mean spring to fall or fall to spring differences, standard errors, and post hoc power analyses ($\alpha \leq 0.05$) of the grass height variables were use to examine the level of detection possible. Mean differences between exclosures and paired sites were examined using the standard errors to detect significant differences. Means and standard errors are provided for all measured herbaceous variables for June to September measurements, although only grass and residual grass heights were used for comparisons.

New and residual grasses in the fall were combined for comparisons to residual grasses in the spring. To combine grass variables, new grass cover was multiplied by the average new grass height and residual grass cover by average residual grass height. The results were summed together and divided by total cover.

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RESULTS

Sample Sizes

Nest vegetation measurements were taken at 95 nests and 164 random locations in June, post-hatch. The SFR and SR grazing systems were sampled from 2000 to 2003 and totaled 50 and 54 random plots. Twenty and 24 random plots were sampled in the SFR and SR systems respectively in 2000 with 10 random plots in each subsequent year for each system. The DR and NG grazing systems were sampled from 2001 to 2003 and totaled 30 random plots each for 10 random plots a year. All 95 nests were included in the nests vs. randoms analyses. The 4 nest abandonments and 3 female fatalities off the nest during incubation were excluded from the successful vs. unsuccessful nest analysis, for 36 successful and 52 unsuccessful nests. Fifty-seven out of 95 nests measured for vegetation were found on the study area. Study area nests were distributed between the grazing systems as follows; 3 in the NG system, 17 in the SR system, 23 in the SFR system, and 13 in the DR system. Vegetation measurements were also taken at 32 early brood habitats from 2000 to 2003. Twenty-two out of 32 early brood habitats measured for vegetation were found on the study area. Distribution of early brood sites among the grazing systems were as follows; 2 in the NG system, 9 in the SR system, 7 in the SFR system, and 4 in the DR system. All random habitat locations were used in subsequent graphical displays for nests and early brood habitats comparisons while only 32 randoms were used in the early brood models.

Grazing Treatments

Estimates of forage use by livestock, forage utilization estimates by the BLM (Table 1) and ha per animal unit (Table 2), were dependent on precipitation during the study (Table 3). Estimated percent forage utilization and animal unit months harvested per acre predominantly followed the same treads, while all four years of the study had below average precipitation ranging from 41 to 78% of normal. April-May monthly precipitation was also lower than average for all months except June of 2003. Grazing management adjustments made by the participating landowners due to the drought reduced forage utilization far below normal levels.

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The average stocking density and duration of grazing (Table 4) and the categorized timing of grazing (Table 5) are also provided. The SR and SFR were grazed at moderate and light forage utilization levels for the study duration. The DR system was grazed at high forage utilization levels for all years except in 2003, reducing the utilization level to moderate. Livestock density and duration within pastures did not differ greatly between the SFR and SR systems except in 1999 before the study and in 2003 when grazing was excluded from the SR system. However, the timing of grazing was different. From 1999 to 2003, 50% of the SFR and 22% of the SR pastures were grazed before July 1, during the critical growth period for cool season bunchgrasses in the area. Due to the nature of the DR system, one of two pastures was grazed each spring and timing, duration per pasture was much longer, and stocking density was much lower than the other grazed systems.

Spring to Fall Grass Measurements

Spring and fall herbaceous measurements were used to provided a comparison of percent forage utilization or stocking rates to actual changes in herbaceous vegetation. All herbaceous variables are presented by grazing system (Tables 6 to 9). Mean differences, standard errors, and minimum detectable differences are presented in Table 10.

All grass height variables at exclosures and paired sites experienced significant declines in 2002, except residual grass heights in exclosures of the NG system. The NG system recorded little change in both residual grass categories in 2002. In 2003, residual grass heights did not decline significantly in any system except for exclosures in the SFR system.

The degree of change in grass height declines were examined between exclosures and paired sites. Only the SFR system recorded significant declines in new grass heights. However, declines were greater at paired sites in 2002 and exclosures in 2003. The only other significant declines recorded were with residual grass heights at SR and NG paired sites in 2002. Mean differences were generally lower and reversed in 2003, largely due to greater grass heights at paired sites. However, few differences in 2003 were significantly different.

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The DR system had significantly lower new and residual grass heights than all other systems, while the NG and SR systems had the tallest new grass heights. However, differences in the NG and SR system were only occasionally significantly greater than the SFR through the 2 years. Residual grass heights at exclosures and paired sites declined little in 2003.

Fall to Spring Grass Height Retention

Fall new and residual grass heights combined, were compared to spring residual grass heights for exclosures and paired sites in 2002 to 2003 (Table 11). New and residual grass heights declined significantly in all exclosures and paired sites except for paired sites in the SR system. Mean differences, standard errors, and minimum detectable differences are presented in Table 12.

The only significant difference in declines between exclosures and paired sites was found in the SR system. SR paired sites had greater declines than exclosures, while the SFR system had similar results that were nearing significance. Differences between the declines in grass heights at exclosures and paired site in the NG systems were nearly non-existent.

The lowest recorded decline in grass height was at paired sites in the DR system. Mean grass heights at the DR paired sites were also significantly the lowest of all the systems and sites in the fall and second lowest in the spring.

Nest Predator Analysis

Ten destroyed nests were not examined for predator identification, leaving 42 total nests (Table 13). American badgers (*Taxidia taxus*) were the most commonly confirmed nest predators at 17%. Confirmed coyote (*Canis latrans*) predations ranked second at 7%, with both American badger and coyote suspected in 17% additional nest destructions. No other mammalian predator species were confirmed or suspected. Mammalian carnivores accounted for $\geq$ 79% of sage-grouse nest destructions. Twenty-one percent of the nests lacked evidence to support mammalian predation, with no eggs, nest disturbance, or hair. One sage-grouse nest destruction by an American raven (*Corvus*

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corvus) was observed. No destroyed nests were found with Wyoming ground squirrel (*Spermophilus elegans*), bobcat (*Lynx rufus*), or red fox (*Vulpes vulpes*) sign.

Successful vs. Unsuccessful Nests

The best subsets analysis selected 37 out of 41 models to be of importance (Table 14). All models selected except 1 were supported with the Hosmer-Lemeshow goodness-of-fits analysis (total shrub canopy cover, residual grass height, cover forb). The summed Akiake's weights for the 36 models was 0.944 suggesting that we are 94% sure that the best model is found in this subset of models. The selected models ranged from 1 to 3 variables with no single variable alone standing out in the analysis. Akaike's Weights were low for all the models with the highest weight model having the variables total forb canopy cover and residual grass height. The variables residual grass height and total shrub canopy cover also had the highest relative importance and were found in 68% and 53% of the models at Δ AICc < 2. The variables total shrub canopy cover, residual grass height, food forb cover and cover forb cover had positive influences on nest success, grass cover had a neutral influence, and residual grass cover had a negative influence on nest success (Table 15). The mean differences in the variables tested and maximum detectable differences in a hypothesis analysis are provided for reference (Appendix E).

Nests vs. Available Habitats

The best subsets analysis selected 31 out of 62 models to be of importance (Table 16). Only one model was not supported with the Hosmer-Lemeshow goodness-of-fits analysis (total shrub canopy cover, dead sagebrush cover, grass cover, residual grass cover, litter). The summed Akiake's weights for the 30 models was 0.974 suggesting that we are 97% sure that the best model is found in this subset of models. The models ranged from 1 to 5 variables. All 31 models with total shrub canopy cover were found in the best subset of models, although all models had low Akaike's weights in single or multiple variable models. total shrub canopy cover, grass cover and litter were the most common variables at Δ AICc < 2. The model with the highest Akaike's weight included total shrub canopy cover, dead sagebrush cover, grass height, and grass cover and had a 6%

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chance of being the best model. Total shrub canopy cover, dead sagebrush cover, grass height, and litter had a positive influence and grass cover and residual grass cover had a negative influence on nest selection (Table 17). Total shrub canopy cover and grass cover had the highest influence.

Early Brood vs. Available Habitats

The best subsets analysis selected 36 out of 41 models to be of importance (Table 18). All models except 1 were supported with the Hosmer-Lemeshow goodness-of-fits analysis (total shrub canopy cover, total forb cover, food forb cover). The summed Akiake's weights for the 35 models was 0.931 suggesting that we are 93% sure that the best model is found in this subset of models. The models ranged from 1 to 3 variables. All models had low Akaike's weights in single and multiple variable models. Total shrub canopy cover and food forb cover were found in the top 4 models. The relative importance of the variables were very similar, with only food forb cover being slightly greater than the others. The analysis suggests that Live sagebrush canopy cover, total shrub canopy cover, total forb cover, and food forb cover had a positive influences and grass cover, and bare ground had a negative influences on early brood habitat selection (Table 19).

Grazing Systems

The SFR habitats were characterized by increasing GRS (Figure 4) and BG (Figure 11), declining litter (Figure 10), potentially declining total forb (Figure 7) and no significant difference or trends in total herbaceous cover (Figure 9). As with the other habitats measured in 2000, Residual grass height (Figure 1) was high in 2000 and than declined. All grazing systems experienced declines in Residual grass height and litter following the first year of drought, although the SFR habitats did rebound slightly in residual grass height from 2001 to 2002. Grass cover increased from 2000 to 2003, also suggesting an annual upward trend. Total for cover suggested a slight downward trend of all the years while no distinct trend in FFORB (Figure 5) was apparent. Food forb cover (Figure 6.) declined slightly. Bare ground increased from 2000 to 2003 and also showed a general upward-trend over the years measured. Likewise, litter cover showed a decline

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from 2001 to 2003. Total herbaceous cover remained stable through all years. Shrub cover, heights, and densities (Figures 12 to 18) showed no distinct trends.

The SR habitats were characterized by increasing grass cover and no trends or significant changes in bare ground cover, total forb cover, total herbaceous cover, and litter cover. Although, grass cover declined in 2003, it was greater than 2000 and 2001, suggesting an upward-trend. The decreasing residual grass height from 2000 was similar to all habitats measured in 2000, although significantly decreasing residual grass cover (Figure 2) was only recorded in the SR habitats from 2000 to 2001. Food forb cover showed no trends and no significant changes, while total forb cover increased from 2000 to 2001 and showed no trend in following years. Bare ground cover and total herbaceous cover were stable for all years while litter increased between 2000 and 2001, but no trend was apparent across years. The MR habitat was the only grazed habitat that appeared to have stable ground cover across the study. Total shrub canopy cover declined from 2000 to 2001 and was the only habitat to do so, while no trend was observe across years.

The DR habitats were characterized by increasing bare ground cover, potentially increasing grass cover, and potentially declining total forb cover and litter cover. The decline in residual grass variables following 2000 was consistent with the other habitats except for a significant decline in residual grass cover from 2002 to 2003. Grass cover had an increasing trend from 2001 to 2003, although not significant. Food forb cover and forb diversity (Figure 8) increased significantly from 2001 to 2002, although no trend across years was apparent. Over all the years Total forb cover was slightly declining, suggesting a possible downward-trend. Bare ground increased from 2001 to 2003 and showed a strong non-significant upward-trend due to high variability within years. Bare ground cover means more than doubled between 2001 and 2003. No trend was apparent for total herbaceous cover.

The NG habitats were characterized by increases in residual grass variables, potentially increasing new grass variables and total herbaceous cover, decreasing litter cover, and no significant changes or trends in bare ground.. Residual grass variables increased from 2001 to 2002 and were stable from 2002 to 2003. Grass cover, grass height (Figure 2), and total cover did not increase statistically between years but did show increasing trends across years. Litter cover had high variability but exhibited a rapid

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downward-trend which coinciding with Total cover and new grass upward-trends. Bare ground cover was likely the lowest of the all the habitats, showed no trends, and had high variability.

DISCUSSION

Grazing Treatments and Paired Site Sampling

Low precipitation levels for the duration of the study influenced declines in forage utilization and to some degree grazing system implementation. The number of rested paddocks increased throughout the study and the SR system was removed from grazing in 2003. However, removal of grazing in the SR system in 2003 had little impact on spring vegetation sampling that spring. Forage utilization values followed the same trends as hectares per animal unit and we suggest that forage utilization was sufficient to broadly represent livestock use.

New and residual grass heights declined in exclosures and paired sites in 2002, suggesting that non-ungulate herbivores significantly reduced grass heights without the aid of livestock. When examining the degree of difference found between exclosures and paired sites, new grass height declines were greater at paired sites in 2002, as expected. However in 2003, the greatest declines in the SR and SFR system were generally measured in exclosures. Grass heights in exclosures and paired sites were similar in 2002 when exclosures were constructed. However in 2003, exclosures were accumulating increases in grass heights allowing for greater annual losses, while grass heights at paired sites remained low, allowing for only small grass height declines. Exclosures in the DR system were not constructed for comparisons.

While the DR system (only paired sites) had the lowest reductions in grass heights for the analysis, mean grass heights were also the lowest of the study. The other systems had greater losses in grass heights, however they had more height to lose. In the NG system, the lack of significant differences between exclosures and paired sites and nearly identical means suggests that wild large ungulate use in the NG area was not detectable. This result may give some indication as to the importance of wild ungulate use in the other nearby systems as well. Our results didn't contradict forage utilization results for

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the systems, however analyses of significant difference in grass heights were not precise enough to adequately reinforce forage use estimates.

Our fall to spring grass height analyses suggest that grass heights did influence the degree of height lost during the winter. The DR system had significantly lower grass heights than all the systems as well as the lowest losses. However, areas with greater heights in the fall, still had the greatest grass heights in the spring, suggesting that tall grass in the fall are required to have tall residual grass in the spring.

Relatively low losses in the NG system in exclosures and paired sites suggests that little grass height loss occurred as a result of non-livestock herbivores in the winter. Declines occurred in paired and exclosure sites in all systems. Only the SR system had significantly greater declines at paired sites than exclosures. Grass height reductions were likely due primarily to small herbivores, snow, and wind.

Nest Destruction

Nest destruction by American badgers and coyotes was the dominantly identified source of sage-grouse nest failure during the study. Twenty-one percent of destroyed nests lacked mammalian sign, while nests lacking eggs also lacked mammalian hair. American ravens were frequently found in sage-grouse nesting habitats and one was observed destroying a sage-grouse nest, suggesting they may be important nest predators. American badgers and coyotes were previously recognized sage-grouse nest predators near Casper, Farson, and Pinedale, Wyoming, (Heath et al. 1997, Holloran 1999, Lyon 2000), although Patterson (1952) did not record coyote nest destructions.

Successful versus Unsuccessful Nests

Almost all models for the successful versus unsuccessful nest analyses were included in the best subset of models. The variables and models appeared to have a similar low strength for predicting nest success, although the goodness-of-fits tests suggest that the models did fit the data.

Greater total shrub canopy cover (32% vs. 27%) and residual grass height (7.0 cm vs. 6.7 cm) had the highest relative influences and were positive for nest success. Total shrub canopy cover was not previously recognized as important for nest success in

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Wyoming, although Gregg et al. (1994) found nest success depended on a greater canopy cover of medium height shrubs (41% at successful and 29% at unsuccessful) and cover of residual grasses over 18 cm (18% at nests and 5% at unsuccessful nests). Wallestad and Pyrah (1974) found a significant increase in shrub canopy cover of 27% at successful versus 20% at unsuccessful nests in Montana. Additionally, greater residual grass heights of 9.2 cm at successful nests versus 7.3 cm at unsuccessful nests were also found at Farson, Wyoming (Heath et al. 1997). The remaining variables appeared similar in importance and were likely not strong predictors. It is also likely that the difference in residual grass heights is not biologically significant for nest success.

Nest vs. Available Habitats

Half of the models from the logistic regression were included into the best subset of models. The variables and models appeared to have similar low strength for predicting nest success, although the goodness-of-fits tests suggest that the models did fit the data.

The relative importance results suggest that greater total shrub canopy cover (29% vs. 19%) was the most important variable for nest selection of the variables tested. Total shrub canopy cover was present in all the best subsets models. Similar results were found in Farson (30% vs. 26%) (Heath et al. 1997), Rawlins (31% vs. 22%) (Heath et al. 1998), and Casper, Wyoming (31% vs. 25%) (Holloran 1999). Sage-grouse selection for areas with greater total shrub canopy covers of 40 to 80 cm in height has also been found in Oregon (41% and 29% vs. 8%) (Gregg et al. 1994) and Montana (all nests in >15%) (Wallestad and Pyrah 1974).

Grass cover had the next highest relative importance, with a negative relationship for nest selection. The negative relationship of grass cover with nest selection is contrary to findings in other areas of Wyoming (Heath et al. 1997 and 1998, Lyon 2000), although the difference in grass cover means were small (6.9 vs. 7.7%) and likely not biologically significant, which suggests it is a potentially spurious result. Unexpectedly, litter and dead sagebrush canopy cover did not have high relative importance even through their means were significantly different. It is difficult to say if the litter means (23% vs. 17%) are biologically significant, although predictability within the regression appeared to be

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small. The importance of litter cover in Wyoming has been mixed, with a positive difference in Farson (5.7 % at nests and 1.8 % at randoms) (Heath et al. 1997) and a negative difference at Pinedale (13.8% at nests and 20.0% at randoms) (Lyon 2000). No relationships between nest selection and litter cover were found outside of Wyoming.

Early Brood vs. Available Habitats

EB habitat selection models using logistic regression had low Akaike's weights, which resulted in 36 out of 41 models being in the best subset of models. The variables and models appeared to have similar low strength for predicting nest success, although the goodness-of-fits tests suggested that the models did fit the data and improved predictability.

Total shrub canopy cover (24% vs. 22%) and food forb cover (1.7% vs. 1.2%) were found in the 4 best models and had positive influences on early brood habitat selection. Lower total shrub canopy covers at brood habitats had been previously recorded (Martin 1970, Wallestad 1971) which contradict our findings. Lyon (2000) found shrub canopy covers lower in Pinedale, Wyoming (30% at broods and 35% at random sites). Aldridge et al. (2002) found greater shrub canopy covers at early brood habitats (7% at broods and 5% at randoms), although the study location in southern Canada had little available sagebrush. It is unlikely that adequately high sagebrush canopy covers in this study area were limiting (Aldridge et al. 2002).

The greater abundance of food forb cover at early brood habitats in Lander (1.7% vs. 1.2%) was expected due to the dependence of young sage-grouse chicks on some forb species, as well as arthropods (Johnson and Boyce 1990). Food forb cover and total forb covers was in greater abundance at early brood habitats near Farson, Wyoming (9% at brood sites and 5% at randoms) (Heath et al. 1997). Svem et al. (1998) had similar results with greater food forbs abundance at brood sites versus randoms sites in big sagebrush/bunchgrass habitats in Oregon (8% vs. 2%).

Bare ground (7.9 vs. 9.2%) and grass cover (7.3% vs. 9.1%) appeared to have negative influences on early brood habitat selection. Lower bare ground was reported at Rawlins (17% at brood sites and 38% at random sites) (Heath et al. 1998) and Pinedale, Wyoming (24% at brood sites and 40% at randoms) (Lyon 2000). However, Heath et al.

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(1997) found higher grass cover near Farson, Wyoming, while Heath et al. (1998) found lower grass cover near Rawlins, Wyoming. This selection for or against grass cover is likely explained through grass cover availability at the two sites. Farson had 32% and 19% grass cover, while Rawlins had 6% and 13% at use vs. available habitats respectively (Heath et al. 1997 and 1998). Grass covers recorded near Lander were below those of available habitats near Rawlins, suggesting that a selection for grass cover would have been expected. Adequate shrub canopy covers near Lander may have reduced the need for high grass covers.

Litter cover was greater at brood sites than randoms near Farson (6% vs. 2%) (Heath et al. 1997) and Pinedale, Wyoming (20% vs. 14%). Total herbaceous cover was greater at nests than randoms at Rawlins (17% vs 8%) and Pinedale, Wyoming (25% and 9%) (Heath et al. 1998, Lyon 2000). Holloran (1999) found similar results with residual grass cover, total forb cover and vertical obstructing cover (all vertical cover) combined, being the best positive early brood habitat predictors in Bates Hole, Wyoming. Early broods in Oregon selected for the greatest availability of forbs as well as low sagebrush canopy covers (Crawford et al. 1992). Grazing management that increases the height and cover of grasses in early brood habitats is thought to increase chick survival (Heath et al. 1998).

Best Grazing Systems

Based on vegetative changes during this study, the SR and NG grazing systems appeared to be the best grazing practices for nest success, nest selection, and EB habitat selection during this study. The SR grazing system did not change significantly for residual grass height which has been shown to be of important for nest success. Residual grass height appeared to influence nest success in this study, although not greatly. The SR system did not significantly change for important habitat and range health variables such as litter cover, total herbaceous cover, and bare ground cover, even during the extensive drought. The SR was the only grazed system that did not increase significantly in bare ground cover.

Several important sage-grouse habitat variables increased in the NG system. Potential increases in cover forb cover and total forb cover may be important for nest

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success and early brood habitat selection. The NG system was also the only habitat to increase total herbaceous cover and residual grass cover. Bare ground did not change significantly while total herbaceous cover increased significantly, suggesting that soil protection is also met in this system. This system was measured following the first year of rest. It is difficult to know how much recovery, if any, occurred during this first year, although it appears that after 4 years, the area continues to be re-vegetated.

The SFR system, grazed at moderate to light levels during this study, did not improve sage-grouse nesting and early brood habitats and likely influenced the significant increase and steady increasing trend in bare ground cover over the 4 years. Because of management changes as a result of the drought, forage utilization, stocking density, and grazing duration in the SR and SFR grazing systems were similar to each other with light to moderate forage use. Season of grazing did differ in that twice as many pastures in the SFR system were grazed during the spring. The SR system was grazed with the same primary herds of cattle as the SFR, except in the summer, avoiding grazing during critical vegetation growth periods (Blaisdell et al. 1982). Twice-over grazing was also more common in the SFR system in the first 2 years of the study, which may have hindered recovery from the drought.

The DR grazing system did not alter stocking rates until 2003 and had the highest forage utilization for all years. This management likely influenced the significant increase of bare ground cover over 3 years and rapidly increasing trend in mean bare ground, which doubled over three years of sampling.

Patterson (1952) found that moderate summer grazing had no adverse effects on nesting habitats in Farson, Wyoming with 1 nest per 9 acres, although heavy grazing did reduce the quality of nest habitat, resulting in 1 nest per 23.5 acres (Patterson 1952). Near Rawlins, Wyoming, 30 to 40% annual removal of herbaceous vegetation during the growing season by cattle made no significant difference on the cover and height of residual grasses the following spring during nesting, although 50% removal resulted in significant reductions in residual grass heights (Heath et al. 1998).

Due to drought conditions, the grazing systems in this study changed extensively, making it impossible to recommend a particular system for sage-grouse nesting and early brood habitats. In addition, the all regression analyses suggested that the vegetative

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variables tested improved predictability, but only to a limited degree. However, the SR and NG habitats appeared to best mimic sage-grouse habitats and avoid significantly increasing bare ground during the extensive drought.

The change in grazing systems that we found are likely related to differences in stocking rates and season of use, rather than grazing system. Three grazing system reviews have found that stocking rates have much more influence on range health and forage productivity than grazing systems (Van Poolen and Lacey 1979, Skovlin 1987, Holechek et al. 1999). This is particularly true in arid environments (Holechek et al. 1999). Grazing systems are still an important part of livestock management, yet are not effective tools for increasing stocking rates (Taylor et al. 1993). In addition, forage utilization rates of ≥50%, frequently leads to range deterioration (Van Poolen and Lacey 1979, Skovlin 1987, Holechek et al. 1999).

Paddocks in the DR and SFR habitats were grazed more often in the spring than the other systems, even with spring deferment every other year or occasional rest. Spring grass growth in the sagebrush steppe is vital for annual forage productivity, which can be reduced with spring grazing (Blaisdell et al. 1982).

MANAGEMENT IMPLICATIONS

This study suggests that reduced forage utilization, extended periods of rest, and reduced spring grazing benefit sage-grouse nesting and early brood habitats during extensive drought periods. Grazing systems did not appear to improve sage-grouse habitats over a rested area, and may be of lesser importance to stocking rates and season of use. Focus should be placed on reducing forage utilization to 10 to 30% below maximum allowable off-take (Holechek et al. 1998a) in nesting and early brood habitats.

Reduced forage utilization can be financially feasible because the greatest financial cost to ranches is destocking (Heitschmidt et al. 1990, Holechek et al. 1998a, Torell et al. 2002). Stocking at capacity can lead to destocking every other year while stocking at moderate levels can reduce destocking to once every five years (Holechek et al. 1998a). Reduced stocking rates can be a conservation measure that restores rangeland productivity without requiring more intensive management such as fencing costs (Klipple

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and Bement 1961). Alternately, range recovery in sagebrush-steppe areas with poor to fair range health may not recover with grazing management alone (Holechek and Stephenson 1998).

Grazing of uplands often coincides with sage-grouse nesting and EB periods in the spring (Connelly et al. 2000) as well as critical growing stages for many herbaceous plants (Blaisdell et al. 1982). Spring grazing with sheep has been shown to increase sagebrush and decrease the herbaceous understories (Bork et al. 1998), while heavy fall grazing can have the opposite effect (Laycock 1967). It is typical for western ranches to use public upland ranges for spring and summer grazing to allow for hay production in the meadows for winter feed (Torell et al. 2002). In areas restricted to seasonally available use, AUMs on spring ranges are worth 5 to 10 times the amount of other seasonal ranges due to low availability of alternative forages (Torell et al 2002). Differed or rotational systems that limit consecutive spring grazing in any one paddock combined with light to moderate stocking rates, may be the best alternative, although this requires additional research.

Grazing systems are an important management tool, particularly to improve livestock distribution on ranges (Holechek et al. 2000) and protect riparian areas (Myers et al. 1995). Alternatively, the literature suggests that rotational grazing, even with periods of rest, should not be used to increase overall use (Van Poolen and Lacey 1979, Holechek et al. 2000). Claims of higher individual gains and vegetative production in short-duration rotational grazing have rarely materialized in peer reviewed literature and in fact the opposite result has been more common (Van Poolen and Lacey 1979, Skovlin 1987, Holechek et al. 1999, Holechek et al. 2000).

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Table 1. Annual percent forage use estimated by the Lander Wyoming Bureau of Land Management on 3 cattle grazing systems and one rested system (NG) from 1999 to 2003 near Lander, Wyoming. Total available forage was estimated using local soil and herbaceous plant composition information and current precipitation levels. Allowable forage use was 50% of the estimated total. Total forage use was estimated by cattle stocking rate and duration as it relates to known forage requirements per animal unit. Grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR).

	1999	2000	2001	2002	2003
SFR	40	30	23	14	19
SR	43	47	32	19	0
DR	49	47	49	46	32
NG	23	0	0	0	0

Table 2. Hectares per animal unit month over a 5.5 month grazing period for livestock on 3 cattle grazing systems and one rested system (NG) near Lander, Wyoming from 1999 to 2003. Grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR).

	1999	2000	2001	2002	2003
SFR	1.31	1.77	2.33	3.62	2.63
SR	1.76	1.34	2.12	3.55	0
DR	4.28	4.52	4.39	4.66	6.76
NG	3.72	0	0	0	0

Table 3. Monthly spring and annual precipitation means (cm) compared to averages from 1948 to 1994 for and Lander, Wyoming

	April	May	June	Yearly
Average	5.23	6.19	2.77	33.32
1999	16.35	2.46	3.55	34.49
2000	4.34	4.34	1.67	21.85
2001	2.72	1.26	0.48	13.65
2002	3.22	4.26	0.63	20.53
2003	2.23	3.25	4.31	26.04

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Table 4. Average annual stocking density and grazing duration of grazed pastures within 3 grazing systems and 1 rested system (NG) near Lander, Wyoming from 1999 to 2003. Grazing systems included differed rotational (DR), Summer grazed moderate to light intensity rest rotational (SR), spring and fall grazed moderate to light intensity rest rotational (SFR). Provided is the stocking density (density) in hectares per animal unit, grazing duration (duration), and the number of grazed pastures in the system (grazed).

		1999	2000	2001	2002	2003
SFR	density	0.99	1.54	1.07	1.25	1.4
	duration	23	22	16	15	19
	grazed	10/10	10/10	9/10	8/10	6/10
SR	density	2.25	1.2	0.83	1.43	0
	duration	21	24	22	17	0
	grazed	5/6	9/9	8/10	4/10	0/10
DR	density	10.18	10.75	10.43	11.1	14.36
	duration	71	71	71	64	64
	grazed	2/2	2/2	2/2	2/2	2/2
NG	density	2.87	0	0	0	0
	duration	94	0	0	0	0
	grazed	1/1	0/1	0/1	0/1	0/1

Table 5. Pastures grazed before July 1st on 3 cattle grazing systems and one rested system (NG) from 1999-2003 near Lander, Wyoming. Grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). Percent totals are provided for 1999 to 2003 and 2000 to 2003.

	1999	2000	2001	2002	2003	1999-2003	2000-2003
SFR	8/10	6/10	3/10	5/10	3/10	50%	43%
SR	2/6	3/9	3/10	2/10	0/10	22%	21%
DR	1/1	1/2	1/2	1/2	1/2	50%	50%
NG	1/1	0/1	0/1	0/1	0/1	20%	0%

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Table 6. Changes in herbaceous vegetation at random plots from mid-June (Spring) to mid-September (Fall) in a spring and fall grazed moderate to light intensity rest rotational grazing system (SFR) near Lander, Wyoming (2002 to 2003). Random sites consisted of 8 m x 8 m livestock exclosures (E) and paired non-exclosure sampling plots (P) with similar vegetation, aspect and slope. Ten exclosures and 10 paired sites were sampled in spring and fall of each year. Exclosures and paired sites were tested separately using paired T-tests at $\alpha = 0.05$. Livestock grazing periods were from mid-May through September. Estimated livestock forage utilization of the total forage during the grazing periods was 14% in 2002 and 19% in 2003. Herbaceous variables included average new grass height (GHT), average residual grass height (RGHT) percent new grass cover (GRS), percent residual grass cover (RGRS) percent total forb cover (TFORB), percent food forb cover (FFORB), percent cover forb cover (CFORB), forb diversity per 0.125 m (Forb Div), percent litter cover (LITT), percent bare ground cover (BG), and percent total herbaceous cover (TOCO).

	Spring 2002		Fall 2002			Spring 2003		Fall 2003		
	Mean	SE	Mean	SE	P-Value	Mean	SE	Mean	SE	P-Value
GHT (P)	10.11	0.95	7.28	0.59	0.00	9.68	0.56	9.04	0.59	0.17
GHT (E)	10.88	0.59	9.35	0.79	0.01	12.62	0.48	11.14	0.76	0.01
RGHT (P)	5.38	0.50	2.48	0.17	0.00	4.38	0.47	3.98	0.25	0.23
RGHT (E)	5.52	0.27	3.03	0.15	0.00	4.93	0.35	4.30	0.26	0.03
GRS (P)	5.73	1.04	4.79	1.01	0.22	7.21	1.60	7.44	2.13	0.85
GRS (E)	5.08	0.71	5.19	0.66	0.82	6.77	0.85	7.88	0.87	0.38
RGRS (P)	3.13	0.34	2.02	0.32	0.07	1.38	0.40	3.44	1.57	0.22
RGRS (E)	3.42	0.83	2.35	0.34	0.17	2.25	0.58	1.52	0.35	0.30
TFORB (P)	2.10	0.69	0.65	0.33	0.02	3.54	1.33	1.33	0.64	0.02
TFORB (E)	2.83	1.13	2.10	1.88	0.67	4.12	1.58	1.15	0.53	0.07
FFORB (P)	1.38	0.22	0.56	0.09	0.00	1.33	0.21	0.54	0.15	0.00
FFORB (E)	1.25	0.26	0.98	0.24	0.19	1.71	0.27	1.02	0.19	0.00
CFORB (P)	1.79	0.62	0.60	0.33	0.02	3.10	1.10	1.29	0.64	0.01
CFORB (E)	2.58	0.97	0.27	0.15	0.02	2.98	0.94	1.10	0.54	0.04
Forb D (P)	2.58	0.27	1.43	0.26	0.00	2.43	0.28	1.34	0.21	0.05
Forb D (E)	2.43	0.24	1.32	0.27	0.00	2.43	0.32	1.18	0.16	0.00
LITT (P)	19.48	1.54	23.58	3.84	0.22	18.52	3.32	23.29	2.75	0.05
LITT (E)	22.21	4.33	24.85	2.77	0.35	19.52	2.31	23.02	2.96	0.09
BG (P)	16.85	2.79	18.10	3.88	0.59	18.56	3.48	17.90	3.19	0.68
BG (E)	18.21	3.48	14.90	3.44	0.08	18.04	4.09	17.19	3.29	0.67
TOCO (P)	27.96	3.17	17.85	4.13	0.01	25.46	3.41	19.77	3.58	0.03
TOCO (E)	26.98	3.18	18.79	2.46	0.00	28.06	3.21	20.92	2.79	0.07

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Table 7. Changes in herbaceous vegetation at random plots from mid-June (Spring) to mid-September (Fall) in a summer grazed high intensity and duration rest-rotational grazing system (SR) near Lander, Wyoming (2002 to 2003). Random sites consisted of 8 m x 8 m livestock exclosures (E) and paired non-exclosure sampling plots (P) with similar vegetation, aspect and slope. Ten exclosures and 10 paired sites were sampled in spring and fall of each year. Exclosures and paired sites were tested separately using paired t-tests at $\alpha = 0.05$. Livestock grazing periods were from mid-May through September. Estimated livestock forage utilization of the total forage during the grazing periods was 19% in 2002 and 0% in 2003. Herbaceous variables included average new grass height (GHT), average residual grass height (RGHT) percent new grass cover (GRS), percent residual grass cover (RGRS) percent total forb cover (TFORB), percent food forb cover (FFORB), percent cover forb cover (CFORB), forb diversity per 0.125 m (Forb Div), percent litter cover (LITT), percent bare ground cover (BG), and percent total herbaceous cover (TOCO).

	Spring 2002		Fall 2002			Spring 2003		Fall 2003		
	Mean	SE	Mean	SE	P-Value	Mean	SE	Mean	SE	P-Value
GHT (P)	12.03	0.66	8.91	0.61	0.00	14.08	0.75	12.53	0.90	0.01
GHT (E)	13.37	1.07	11.42	0.58	0.05	15.93	1.09	13.60	0.79	0.02
RGHT (P)	5.35	0.26	3.21	0.19	0.00	5.38	0.34	5.12	0.18	0.41
RGHT (E)	5.52	0.29	3.89	0.20	0.00	6.26	0.62	6.03	0.33	0.62
GRS (P)	6.71	1.05	5.73	1.02	0.32	8.33	1.42	12.75	2.65	0.01
GRS (E)	8.54	1.07	10.13	1.31	0.16	12.56	1.52	16.10	1.61	0.05
RGRS (P)	5.81	1.88	4.40	1.06	0.23	2.35	0.45	3.63	0.50	0.08
RGRS (E)	6.17	1.39	4.81	1.22	0.17	3.33	0.49	4.81	0.65	0.15
TFORB (P)	5.65	3.59	0.75	0.38	0.17	5.33	2.95	1.52	0.74	0.17
TFORB (E)	6.40	4.17	1.02	0.55	0.18	8.54	4.50	2.17	1.29	0.10
FFORB (P)	1.81	0.73	0.71	0.18	0.13	1.19	0.30	0.52	0.14	0.03
FFORB (E)	1.44	0.48	0.44	0.19	0.03	1.19	0.37	0.48	0.17	0.02
CFORB (P)	3.42	2.02	0.54	0.28	0.14	4.13	2.30	1.62	0.83	0.23
CFORB (E)	4.83	3.00	0.98	0.54	0.16	5.40	3.41	2.17	1.29	0.17
Forb Div (P)	2.62	0.34	1.54	0.23	0.00	2.38	0.32	1.33	0.15	0.00
Forb Div (E)	2.63	0.42	1.60	0.26	0.00	2.28	0.37	1.26	0.22	0.00
LITT (P)	20.12	1.91	23.81	2.85	0.03	18.75	1.95	17.08	2.36	0.60
LITT (E)	18.35	1.87	20.35	2.49	0.40	15.08	2.86	15.29	1.80	0.92
BG (P)	9.75	3.63	11.40	4.00	0.30	10.42	3.91	10.19	4.07	0.65
BG (E)	8.73	2.47	8.35	2.46	0.74	7.25	2.52	6.46	2.42	0.29
TOCO (P)	42.48	5.90	25.29	4.16	0.00	36.15	6.83	36.44	4.65	0.94
TOCO (E)	45.06	5.44	34.35	4.72	0.00	46.71	7.22	43.69	4.49	0.40

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Table 8. Changes in herbaceous vegetation at random plots from mid-June (Spring) to mid-September (Fall) in a rested from livestock system (NG) near Lander, Wyoming (2002 to 2003). Random sites consisted of 8 m x 8 m livestock exclosures (E) and paired non-exclosure sampling plots (P) with similar vegetation, aspect and slope. Ten exclosures and 10 paired sites were sampled in spring and fall of each year. Exclosures and paired sites were tested separately using paired T-tests at $\alpha = 0.05$. Herbaceous variables included average new grass height (GHT), average residual grass height (RGHT) percent new grass cover (GRS), percent residual grass cover (RGRS) percent total forb cover (TFORB), percent food forb cover (FFORB), percent cover forb cover (CFORB), forb diversity per 0.125 m (Forb Div), percent litter cover (LITT), percent bare ground cover (BG), and percent total herbaceous cover (TOCO).

	Spring 2002		Fall 2002			Spring 2003		Fall 2003		
	Mean	SE	Mean	SE	P-Value	Mean	SE	Mean	SE	P-Value
GHT (P)	14.10	1.82	11.32	1.49	0.01	14.42	1.31	12.75	1.17	0.02
GHT (E)	12.12	1.41	9.90	1.35	0.02	13.27	1.53	11.57	1.23	0.03
RGHT (P)	5.70	0.39	4.75	0.39	0.00	6.30	0.85	5.48	0.37	0.33
RGHT (E)	5.20	0.51	5.20	0.71	1.00	6.07	0.60	5.82	0.39	0.45
GRS (P)	10.21	1.15	11.17	3.20	0.71	8.46	2.54	11.17	3.20	0.09
GRS (E)	8.42	2.53	6.54	1.42	0.27	6.25	1.83	6.96	1.33	0.46
RGRS (P)	7.29	1.11	5.50	1.11	0.02	2.33	0.35	4.71	0.68	0.00
RGRS (E)	5.21	0.58	2.96	0.74	0.06	2.04	0.50	3.88	1.09	0.12
TFORB (P)	6.83	3.15	2.67	1.32	0.18	8.00	3.92	2.92	1.06	0.17
TFORB (E)	8.75	2.94	2.21	0.85	0.04	15.38	5.98	8.08	3.65	0.08
FFORB (P)	1.04	0.49	0.21	0.09	0.14	0.17	0.04	0.58	0.14	0.02
FFORB (E)	1.08	0.57	0.46	0.22	0.38	0.67	0.29	0.58	0.20	0.85
CFORB (P)	5.42	2.81	2.62	1.33	0.36	8.00	3.92	2.75	1.02	0.16
CFORB (E)	7.12	2.03	2.13	0.88	0.02	14.58	6.01	8.00	3.68	0.13
Forb Div (P)	2.22	0.20	1.57	0.08	0.03	2.32	0.23	1.55	0.13	0.03
Forb Div (E)	2.60	0.16	1.93	0.21	0.05	2.80	0.45	1.60	0.31	0.01
LITT (P)	16.96	2.27	19.21	3.89	0.37	22.54	3.28	21.25	3.97	0.59
LITT (E)	16.42	3.81	23.50	4.95	0.05	15.54	1.80	19.13	4.17	0.32
BG (P)	7.50	4.09	8.04	4.51	0.55	9.54	5.74	8.04	6.51	0.28
BG (E)	8.08	3.26	11.04	3.64	0.14	9.25	3.47	9.25	4.34	1.00
TOCO (P)	53.38	9.28	40.63	8.14	0.01	36.25	9.97	38.71	8.29	0.39
TOCO (E)	49.58	4.82	29.88	5.33	0.00	42.08	5.29	38.88	4.56	0.30

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Table 9. Changes in herbaceous vegetation at random plots from mid-June (Spring) to mid-September (Fall) in a high intensity, spring differed rotational grazing system near Lander, Wyoming (2002 to 2003). Random plots consisted of non-exclosure sampling plots. Ten sites were sampled in spring and fall of each year. Fall and spring plots were tested using paired T-tests at $\alpha = 0.05$ Livestock grazing periods were from mid-May through September. Estimated livestock forage utilization of the total forage during the grazing periods was 46% in 2002 and 32% in 2003. Herbaceous variables included average new grass height (GHT), average residual grass height (RGHT) percent new grass cover (GRS), percent residual grass cover (RGRS) percent total forb cover (TFORB), percent food forb cover (FFORB), percent cover forb cover (CFORB), forb diversity per 0.125 m (Forb Div), percent litter cover (LITT), percent bare ground cover (BG), and percent total herbaceous cover (TOCO).

	Spring 2002		Fall 2002			Spring 2003		Fall 2003		
	Mean	SE	Mean	SE	P-Value	Mean	SE	Mean	SE	P-Value
GHT	8.68	0.25	5.45	0.41	0.00	9.00	0.60	6.39	0.40	0.00
RGHT	4.08	0.14	2.20	0.15	0.00	3.61	0.21	3.29	0.21	0.09
GRS	4.00	0.86	3.38	0.70	0.21	3.33	0.63	6.40	1.23	0.01
RGRS	2.58	0.39	1.42	0.22	0.00	0.58	0.12	2.13	0.57	0.02
TFORB	1.19	0.46	0.35	0.10	0.08	1.21	0.40	0.21	0.19	0.02
FFORB	0.92	0.21	0.44	0.19	0.00	0.94	0.21	0.60	0.20	0.18
CFORB	1.19	0.46	0.35	0.10	0.08	1.13	0.39	0.25	0.19	0.02
Forb Div	2.18	0.25	1.42	0.21	0.00	1.84	0.27	1.03	0.19	0.00
LITT	25.65	2.23	29.46	2.19	0.12	35.17	3.18	26.23	2.45	0.01
BG	16.52	2.32	18.65	2.29	0.08	17.63	2.87	18.19	1.68	0.76
TOCO	22.10	3.92	12.00	1.91	0.02	11.44	2.83	16.15	2.69	0.01

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Table 10. Mean difference, standard deviation (SD), and maximum detectable difference (Power) of the difference between new and residual grass heights in mid-June to mid-August at cattle exclosures (E) and paired non-exclosed sites (P). Sites were measured near Lander, Wyoming in 2002 and 2003. Exclosures were 8 m x 8 m squares and paired non-exclosure sites were located within 50 m to 100 m with had similar vegetation, aspect and slope. Exclosures and paired sites were tested separately using paired t-tests at $\alpha = 0.05$. Exclosures and paired sites were split into associated cattle grazing systems; differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), spring and fall grazed moderate to light intensity rest rotational (SFR), and rested from cattle (NG). New grass heights (GHT) and residual grass heights (RGHT) were measured. Ten exclosures and 10 paired sites were sampled for each system each year except the DR system which only had paired sites.

		2002			2003		
		Mean	SE	Power	Mean	SE	Power
SFR	GHT (P)	2.83	0.65	0.84	0.64	0.43	0.55
	GHT (E)	1.53	0.47	0.60	1.48	0.48	0.62
	RGHT (P)	2.90	0.48	0.62	0.41	0.32	0.41
	RGHT (E)	2.48	0.18	0.23	0.63	0.26	0.33
SR	GHT (P)	3.13	0.64	0.82	1.56	0.48	0.61
	GHT (E)	1.96	0.86	1.11	2.33	0.81	1.04
	RGHT (P)	2.14	0.21	0.27	0.27	0.31	0.39
	RGHT (E)	1.63	0.18	0.23	0.23	0.45	0.58
NG	GHT (P)	2.78	0.35	0.77	1.67	0.31	0.68
	GHT (E)	2.22	0.43	0.95	1.70	0.37	0.81
	RGHT (P)	0.95	0.06	0.13	0.82	0.52	1.14
	RGHT (E)	0.00	0.23	0.51	0.25	0.21	0.46
DR	GHT (P)	3.23	0.43	0.55	2.61	0.44	0.57
	RGHT (P)	1.88	0.17	0.22	0.32	0.17	0.22

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Table 11. Changes in residual grass heights (cm) at random plots from mid-September 2002 (Fall) to mid-June 2003 (S) in 4 grazing system near Lander, Wyoming. Residual and new grass average heights (RGHT/GHT) in the fall were compared to average residual grass heights (RGHT) in the spring. Random sites consisted of 8 m x 8 m livestock exclosures (E) and a paired non-exclosure sampling plots (P) with similar vegetation, aspect and slope. Ten exclosures and 10 paired sites were sampled in the SFR and SR systems. The DR system had 10 random sites and lacked exclosures. Exclosures and paired sites were tested separately using paired T-tests at $\alpha = 0.05$.

	RGHT/GHT Fall		RGHT Spring		
	Mean	SE	Mean	SE	P-value
SFR (E)	7.37	0.58	4.93	0.35	0.002
SFR (P)	5.89	0.59	1.18	0.47	0.033
SR (E)	9.06	0.46	6.26	0.62	0.001
SR (P)	6.46	0.66	5.38	0.34	0.092
NG (E)	8.47	1.15	6.07	0.60	0.045
NG (P)	9.12	1.16	6.30	0.85	0.010
DR (P)	4.33	0.26	3.61	0.21	0.036

Table 12. Mean difference, standard deviation (SD), and maximum detectable difference (Power) of the difference in grass heights from mid-September 2002 to mid-June 2003 for cattle exclosures (E) and paired non-exclosed sites (P) near Lander, Wyoming. Exclosures were 8 m x 8 m squares and paired non-exclosure sites were located within 50 m to 100 m with similar vegetation, aspect and slope. Exclosures and paired sites were tested separately using paired t-tests at $\alpha = 0.05$. Fall new and residual grasses were combined and compared to spring residual grass heights or covers. Exclosures and paired sites were split into grazing system types; differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), spring and fall grazed moderate to light intensity rest rotational (SFR), and rested from cattle (NG). New grass heights (GHT) and residual grass heights (RGHT) were measured. Ten exclosures and 10 paired sites were sampled each period except the NG with 5 and the DR system having only paired sites.

	Grass Height		
	Mean	SE	power
SFR(E)	2.43	0.55	0.71
SFR (P)	1.51	0.60	0.77
SR (E)	2.80	0.59	0.76
SR (P)	1.08	0.58	0.75
NG (E)	2.40	0.84	1.85
NG (P)	2.83	0.62	1.37
DR (P)	0.72	0.58	0.75

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Table 13. Nest predator identification at 42 sage-grouse nest sites near Lander, Wyoming from 2001-2003. Confirmed nest predator species had nest and egg destruction evidence with track or hair identification. Suspected nest predator species lacked conclusive hair or track identification evidence. Unknown mammalian (Unknown Mamm.) were mammalian nest destructions not identified to species. Non-mammalian carnivore nest destructions (Non-Mamm.) had punctured eggs or no eggs, no nest disturbance, no hair, and no mammalian Tracks. Predators keyed to species were American badger (*Taxidea taxus*), Coyote (*Canis latrans*), red fox (*Vulpes vulpes*), and bobcat (*Lynx rufus*).

Nest Predator	Status	# of cases	Total (%)
Badger	Confirmed	7	(16%)
	Suspected	7	(16%)
	Total	14	(33%)
Coyote	Confirmed	3	(7%)
	Suspected	7	(16%)
	Total	10	(24%)
Unknown Mamm.	Confirmed	9	(21%)
	Suspected	0	(0%)
	Total	9	(21%)
Total Mamm.	Confirmed	33	(79%)
	Suspected	0	(0%)
	Total	33	(79%)
Non-Mamm.	Confirmed	1	(2%)
	Suspected	8	(19%)
	Total	9	(21%)

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Table 14. Analysis of mean vegetation measurements at sage-grouse successful (n=36) vs. unsuccessful (n=52) nests near Lander, Wyoming from 2000 to 2003. Logistic regression was used with small sample Akaike's Infromation Criterion (AICc). Best subset of models was selected using the difference in AICc (ΔAICc) <4. Vegetative variables included total shrub canopy cover (TSCC), residual grass height (RGHT), new grass cover (GRS), residual grass cover (RGRS), food forb cover (FFORB), and cover forb cover (CFORB). Maximized Log likelyhood (-2 ln [*L*]), the number of parameters (K), AICc, ΔAICc, and Akaike's weights (*Wi*) are presented.

Model	-2 ln [*L*]	*K*	AICc	Δ AICc	*Wi*
TSCC, RGHT	56.72	3	121.477	0.000	0.059
RGHT, RGRS*	56.785	3	121.607	0.130	0.055
TSCC	57.439	2	121.610	0.133	0.055
RGHT	57.44	2	121.612	0.135	0.055
TSCC, RGHT, RGRS*	56.312	4	122.024	0.547	0.045
RGHT, GRS, RGRS*	56.532	4	122.464	0.987	0.036
TSCC, FFORB	57.296	3	122.629	1.152	0.033
TSCC, RGHT, FFORB	56.615	4	122.630	1.153	0.033
RGHT, CFORB	57.32	3	122.677	1.200	0.032
RGHT, FFORB	57.36	3	122.757	1.280	0.031
TSCC, CFORB	57.392	3	122.821	1.344	0.030
TSCC, RGHT, GRS	56.711	4	122.822	1.345	0.030
TSCC, RGRS*	57.393	3	122.823	1.346	0.030
TSCC, GRS	57.395	3	122.827	1.350	0.030
RGHT, RGRS*, FFORB	56.731	4	122.862	1.385	0.030
RGHT, RGRS*, CFORB	56.731	4	122.862	1.385	0.030
RGHT, GRS*	57.435	3	122.907	1.430	0.029
CFORB	58.369	2	123.470	1.993	0.022
FFORB	58.505	2	123.742	2.265	0.019
RGRS*	58.514	2	123.760	2.283	0.019
RGHT, FFORB, CFORB	57.229	4	123.858	2.381	0.018
TSCC, FFORB, CFORB	57.24	4	123.880	2.403	0.018
TSCC, GRS, RGRS*	57.242	4	123.884	2.407	0.018
TSCC, RGRS*, FFORB	57.257	4	123.914	2.437	0.017
TSCC, GRS, FFORB	57.26	4	123.920	2.443	0.017
GRS	58.621	2	123.974	2.497	0.017
RGHT, GRS*, CFORB	57.322	4	124.044	2.567	0.016
TSCC, GRS, CFORB	57.346	4	124.092	2.615	0.016
TSCC, RGRS*, CFORB	57.355	4	124.110	2.633	0.016
RGHT, GRS*, FFORB	57.355	4	124.110	2.633	0.016
FFORB, CFORB	58.228	3	124.493	3.016	0.013
RGRS*, CFORB	58.298	3	124.633	3.156	0.012
GRS, CFORB	58.363	3	124.763	3.286	0.011
RGRS*, FFORB	58.404	3	124.845	3.368	0.011
GRS, RGRS*	58.438	3	124.913	3.436	0.011
GRS, FFORB	57.242	3	125.047	3.570	0.010

* Negative relationship with nest success

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Table 15. Relative importance (RI) and direction (-/+) of vegetation variables for determining sage-grouse nest success at 36 successful and 52 unsuccessful nests near Lander, Wyoming (2000 to 2003). Variable relative importance was estimated by imposing Akaike's weights for each model on variables in that model and summing the weights for each variable from the representative set of models. Vegetative variables included total shrub canopy cover (TSCC), residual grass height (RGHT), new grass cover (GRS), residual grass cover (RGRS), food forb cover (FFORB), and cover forb cover (CFORB).

Variable	RI
TSCC	0.480 (+)
RGHT	0.547 (+)
GRS	0.277 (+/-)
RGRS	0.349 (-)
FFORB	0.287 (+)
CFORB	0.286 (+)

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Table 16. Analysis of mean vegetation measurements at sage-grouse nests (n=95) vs. random plots (n=164) near Lander, Wyoming from 2000 to 2003. Logistic regression was used with small sample Akaike's Infromation Criterion (AICc). Best subset of models was selected using the difference in AICc (ΔAICc) <4. Vegetative variables included total shrub canopy cover (TSCC), dead sagebrush canopy cover (DSC), new grass height (GHT), new grass cover (GRS), residual grass cover (RGRS), and litter cover (LITT). Maximized Log likelyhood (-2 ln [*L*]), the number of parameters (K), AICc, ΔAICc, and Akaike's weights (*Wi*) are presented.

Model	AIC	*K*	AICc	Δ AICc	*Wi*
TSCC, DSC, GHT, GRS*	132.056	5	273.688	0.000	0.062
TSCC, DSC, GHT, GRS*, RGRS*	131.622	6	273.967	0.279	0.054
TSCC, GHT, GRS*	132.782	4	274.010	0.322	0.053
TSCC, DSC, GHT, GRS*, LITT	131.707	6	274.137	0.449	0.050
TSCC, GHT, GRS*, RGRS*	132.306	5	274.188	0.500	0.048
TSCC, DSC, GRS*	132.881	4	274.208	0.520	0.048
TSCC, GHT, GRS*, LITT	132.344	5	274.264	0.576	0.047
TSCC, GHT, GRS*, RGRS*, LITT	131.9	6	274.523	0.835	0.041
TSCC, DSC, GRS*, LITT	132.57	5	274.716	1.028	0.037
TSCC, GRS*	133.75	3	274.833	1.145	0.035
TSCC, DSC, GRS*, RGRS*	132.649	5	274.874	1.186	0.034
TSCC, DSC, LITT	133.282	4	275.010	1.322	0.032
TSCC, GHT, RGRS*, LITT	132.743	5	275.062	1.374	0.031
TSCC, GRS*, LITT	133.343	4	275.132	1.444	0.030
TSCC, LITT	133.921	3	275.175	1.487	0.030
TSCC, DSC, RGRS*, LITT	132.82	5	275.216	1.528	0.029
TSCC, DSC, GHT, RGRS*, LITT	132.255	6	275.233	1.545	0.029
TSCC, RGRS*, LITT	133.454	3	275.354	1.666	0.027
TSCC, GRS*, RGRS*	133.495	3	275.436	1.748	0.026
TSCC, DSC, RGRS*	133.506	4	275.458	1.770	0.026
TSCC, GHT, LITT	133.535	4	275.516	1.828	0.025
TSCC, DSC, GHT, LITT	132.999	5	275.574	1.886	0.024
TSCC, DSC	134.171	3	275.675	1.987	0.023
TSCC, RGRS*	134.204	3	275.741	2.053	0.022
TSCC, GRS*, RGRS*, LITT	133.112	5	275.800	2.112	0.022
TSCC, DSC, GHT, RGRS*	133.118	5	275.812	2.124	0.021
TSCC, GHT, RGRS*	133.684	4	275.814	2.126	0.021
TSCC	134.885	2	276.007	2.319	0.019
TSCC, DSC, GHT	134.049	4	276.544	2.856	0.015
TSCC, GHT	134.691	3	276.715	3.027	0.014

* Negative relationship with nesting habitat selection

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Table 17. Relative importance (RI) and direction (-/+) of vegetation variables for determining sage-grouse nest selection at 95 nests and 164 random plots near Lander, Wyoming (2000 to 2003). Variable relative importance was estimated by imposing Akaike's weights for each model on variables in that model and summing the weights for each variable from the representative set of models. Vegetative variables included total shrub canopy cover (TSCC), dead sagebrush canopy cover (DSC), new grass height (GHT), new grass cover (GRS), residual grass cover (RGRS), and litter cover (LITT).

Variable	RI
TSCC	1.000 (+)
DSC	0.510 (+)
GHT	0.535 (+)
GRS	0.612 (-)
RGRS	0.457 (-)
LITT	0.478 (+)

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Table 18. Analysis of habitats at sage-grouse early brood habitats (n=32) and random plots (n=32) near Lander, Wyoming from 2000 to 2003. Logistic regression with small sample Akaike's Infromation Criterion (AICc) were used with the best subset of models set at (ΔAICc) <4. Variables included live sagebrush density (LIV), total shrub canopy cover (TSCC), new grass cover (GRS), total forb cover (TFORB), food forb cover (FFORB) and bare ground cover (BG). Maximized Log likelyhood (-2 ln [*L*]), the number of parameters (K), AICc, ΔAICc, and Akaike's weights (*Wi*) are presented.

Model	-2 ln [*L*]	*K*	AICc	Δ AICc	*wi*
TSCC, FFORB	40.516	3	88.479	0.000	0.062
TSCC, GRS*, FFORB	40.248	4	89.095	0.616	0.045
TSCC, FFORB, BG*	40.255	4	89.109	0.630	0.045
GRS*, FFORB, BG*	40.306	4	89.211	0.732	0.043
FFORB, BG*	40.990	3	89.427	0.948	0.039
LIV, TSCC, FFORB	40.455	4	89.509	1.030	0.037
TFORB, FFORB	41.149	3	89.745	1.266	0.033
TFORB, FFORB, BG*	40.580	4	89.759	1.280	0.033
GRS*, TFORB, BG*	40.597	4	89.793	1.314	0.032
TFORB, BG*	41.193	3	89.833	1.354	0.031
LIV, FFORB, BG*	40.668	4	89.935	1.456	0.030
LIV, TFORB, BG*	40.670	4	89.939	1.460	0.030
LIV, GRS*, BG*	40.672	4	89.943	1.464	0.030
LIV, TFORB, FFORB	40.687	4	89.973	1.494	0.029
GRS*, BG*	41.272	3	89.991	1.512	0.029
LIV, TFORB	41.370	3	90.187	1.708	0.026
BG*	41.998	2	90.313	1.835	0.025
GRS*, TFORB, FFORB	40.914	4	90.427	1.948	0.023
LIV, BG*	41.492	3	90.431	1.952	0.023
TSCC, TFORB	41.493	3	90.433	1.954	0.023
TFORB	42.074	2	90.465	1.987	0.023
TSCC, TFORB, BG*	40.986	4	90.571	2.092	0.022
FFORB	42.139	2	90.595	2.117	0.021
TSCC, GRS*, BG*	41.009	4	90.617	2.138	0.021
TSCC, BG*	41.628	3	90.703	2.224	0.020
LIV, TSCC, TFORB	41.080	4	90.759	2.280	0.020
LIV, GRS*, TFORB	41.093	4	90.785	2.306	0.020
LIV, FFORB	41.734	3	90.915	2.436	0.018
TSCC, GRS*, TFORB	41.271	4	91.141	2.662	0.016
LIV, TSCC, BG*	41.295	4	91.189	2.710	0.016
GRS*, TFORB	41.888	3	91.223	2.744	0.016
GRS*, FFORB	41.909	3	91.265	2.786	0.015
LIV, GRS*, FFORB	41.430	4	91.459	2.980	0.014
TSCC	42.833	2	91.983	3.505	0.011
LIV, TSCC	42.502	3	92.451	3.972	0.008

* Negative relationship with early brood habitat selection

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Table 19. Relative importance (RI) and direction (-/+) of vegetation variables for determining sage-grouse early brood habitats vs. available habitats near Lander, Wyoming (2000 to 2003). Thirty-two early brood and 32 random sites were sampled. Variable relative importance was estimated by imposing Akaike's weights for each model on variables in that model and summing the weights for each variable from the representative set of models. Vegetative variables included total shrub canopy cover (TSCC), dead sagebrush canopy cover (DSC), new grass height (GHT), new grass cover (GRS), residual grass cover (RGRS), and litter cover(LITT).

Variable	RI
LIV	0.316 (+)
TSCC	0.406 (+)
GRS	0.324 (-)
TFORB	0.422 (+)
FFORB	0.533 (+)
BG	0.468 (-)

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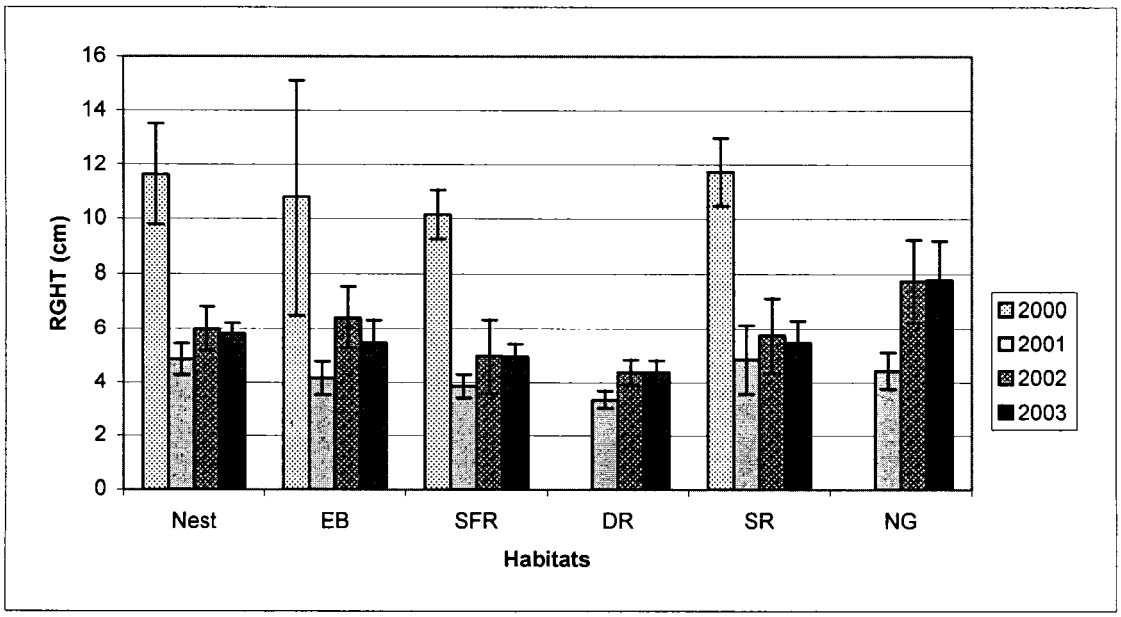
Figure 1. Mean residual grass heights (RGHT) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	11.65	2.34	3.57
	2001	20	4.85	0.83	1.11
	2002	22	5.99	1.21	1.54
	2003	37	5.80	0.83	0.8
Broods	2000	4	10.79	2.72	12.15
	2001	8	4.16	0.55	1.3
	2002	9	6.41	1.08	2.36
	2003	11	5.48	0.89	1.71
SFR	2000	20	10.17	1.28	1.73
	2001	10	3.85	0.44	0.89
	2002	10	4.97	1.39	2.83
	2003	10	4.95	0.48	0.98
DR	2001	10	3.35	0.32	0.64
	2002	10	4.36	0.47	0.96
	2003	10	4.37	0.44	0.9
SR	2000	24	11.73	1.95	2.37
	2001	10	4.86	1.28	2.6
	2002	10	5.73	1.39	2.82
	2003	10	5.48	0.83	1.68
NG	2001	10	4.43	0.68	1.38
	2002	10	7.75	1.50	3.04
	2003	10	7.78	1.42	2.88

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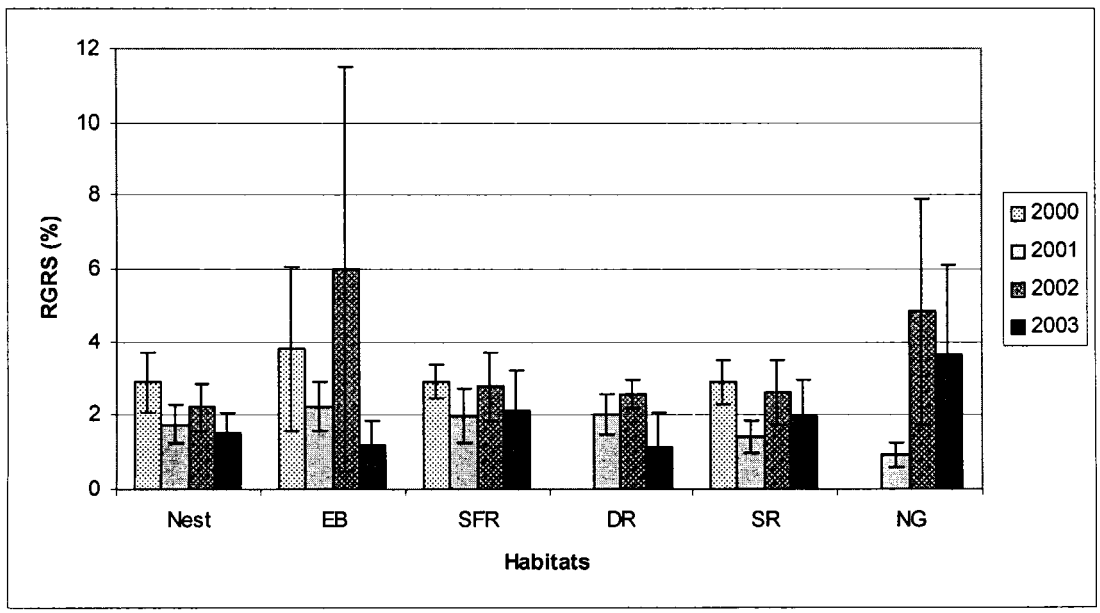
Figure 2. Mean residual grass cover (RGRS) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	2.87	1.00	2.11
	2001	20	1.76	0.71	0.96
	2002	22	2.22	0.92	1.18
	2003	37	1.55	0.97	0.94
Broods	2000	4	3.80	1.41	6.31
	2001	8	2.24	0.60	1.41
	2002	9	6.00	5.25	11.43
	2003	11	1.17	0.69	1.32
SFR	2000	20	2.91	0.64	0.86
	2001	10	1.98	0.73	1.48
	2002	10	2.79	0.92	1.86
	2003	10	2.10	1.14	2.31
DR	2001	10	2.02	0.43	0.88
	2002	10	2.56	0.56	1.13
	2003	10	1.17	0.38	0.77
SR	2000	24	2.88	0.93	1.13
	2001	10	1.44	0.43	0.88
	2002	10	2.63	0.87	1.78
	2003	10	1.96	1.00	2.04
NG	2001	10	0.94	0.33	0.67
	2002	10	4.83	3.08	6.25
	2003	10	3.67	2.43	4.94

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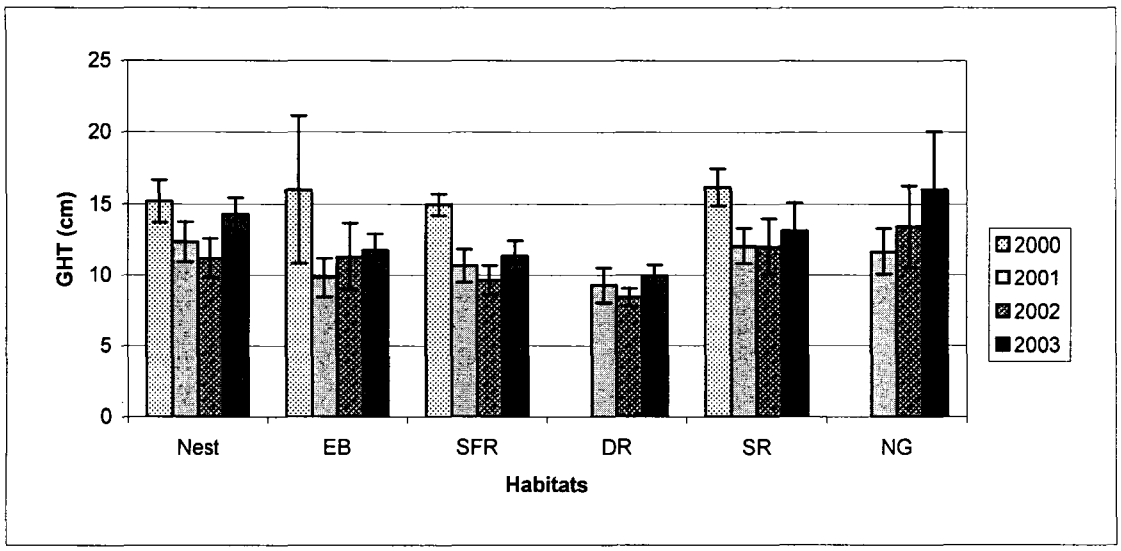
Figure 3. Mean new grass heights (GHT) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	15.19	1.88	2.87
	2001	20	12.33	1.99	2.67
	2002	22	11.21	2.00	2.55
	2003	37	14.33	2.15	2.07
Broods	2000	4	15.98	3.25	14.55
	2001	8	9.80	1.24	2.92
	2002	9	11.32	2.23	4.86
	2003	11	11.80	1.17	2.24
SFR	2000	20	14.97	1.05	1.41
	2001	10	10.68	1.19	2.42
	2002	10	9.63	1.03	2.1
	2003	10	11.38	1.04	2.11
DR	2001	10	9.28	1.24	2.51
	2002	10	8.43	0.59	1.2
	2003	10	9.93	0.76	1.54
SR	2000	24	16.16	1.97	2.39
	2001	10	12.07	1.27	2.58
	2002	10	12.03	1.95	3.96
	2003	10	13.14	1.95	3.96
NG	2001	10	11.68	1.60	3.25
	2002	10	13.42	2.86	5.82
	2003	10	16.03	3.99	8.11

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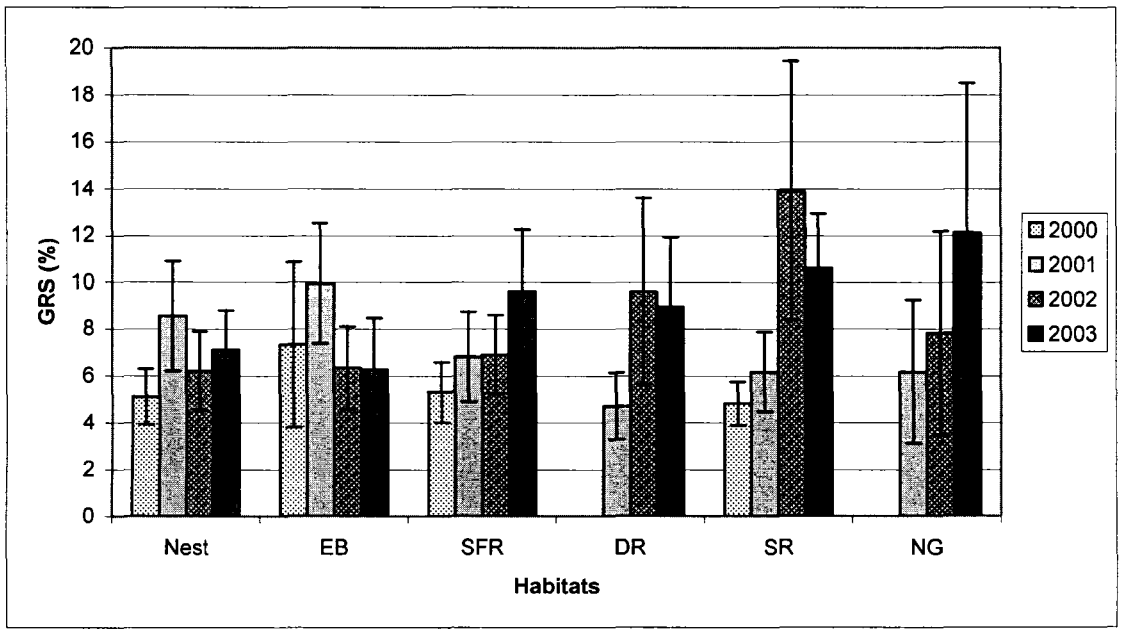
Figure 4. Mean new grass cover (GRS) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	5.12	1.50	2.3
	2001	20	8.55	3.32	4.46
	2002	22	6.21	2.49	3.17
	2003	37	7.11	3.24	3.12
Broods	2000	4	7.34	2.22	9.94
	2001	8	9.95	2.28	5.4
	2002	9	6.34	1.68	3.66
	2003	11	6.27	2.30	4.4
SFR	2000	20	5.31	1.80	2.42
	2001	10	6.81	1.92	3.89
	2002	10	6.90	1.66	3.38
	2003	10	9.65	2.59	5.27
DR	2001	10	4.71	1.42	2.89
	2002	10	9.63	3.98	8.09
	2003	10	8.96	2.98	6.05
SR	2000	24	4.82	1.45	1.76
	2001	10	6.17	1.69	3.43
	2002	10	13.92	5.54	11.25
	2003	10	10.63	2.31	4.69
NG	2001	10	6.17	3.05	6.2
	2002	10	7.81	4.36	8.87
	2003	10	12.15	6.38	12.96

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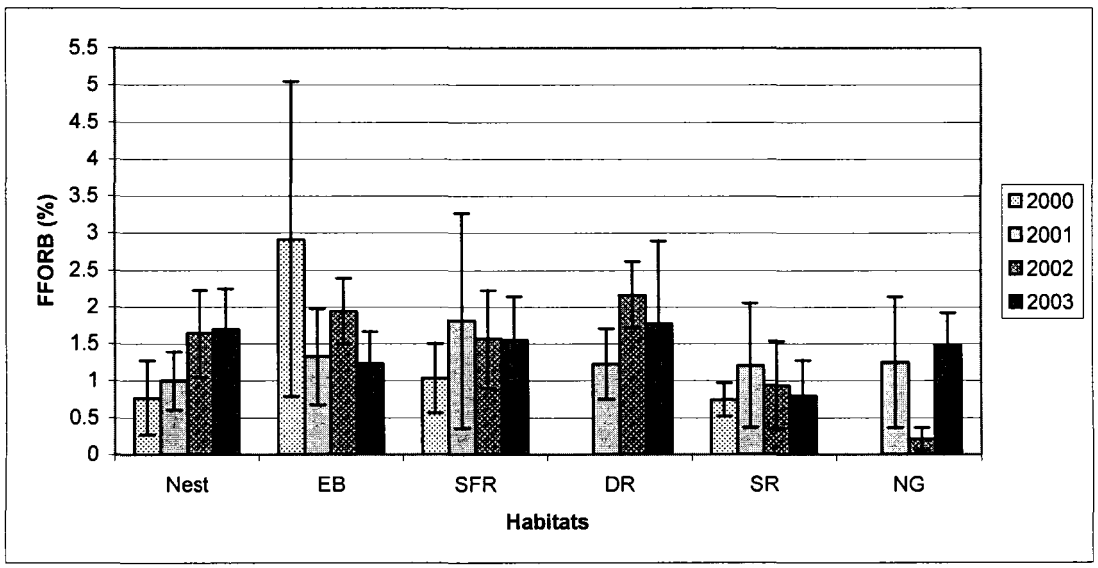
Figure 5. Mean food forb cover (FFORB) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	0.77	0.64	0.97
	2001	20	1.00	0.56	0.75
	2002	22	1.64	0.88	1.12
	2003	37	1.70	1.08	1.04
Broods	2000	4	2.92	1.35	6.02
	2001	8	1.33	0.58	1.37
	2002	9	1.94	0.42	0.92
	2003	11	1.23	0.45	0.85
SFR	2000	20	1.03	0.66	0.89
	2001	10	1.81	1.46	2.96
	2002	10	1.56	0.67	1.36
	2003	10	1.54	0.60	1.23
DR	2001	10	1.23	0.47	0.97
	2002	10	2.17	0.45	0.91
	2003	10	1.77	1.13	2.30
SR	2000	24	0.75	0.35	0.43
	2001	10	1.21	0.84	1.71
	2002	10	0.94	0.59	1.20
	2003	10	0.79	0.49	0.99
NG	2001	10	1.25	0.89	1.81
	2002	10	0.21	0.15	0.31
	2003	10	1.48	0.44	0.90

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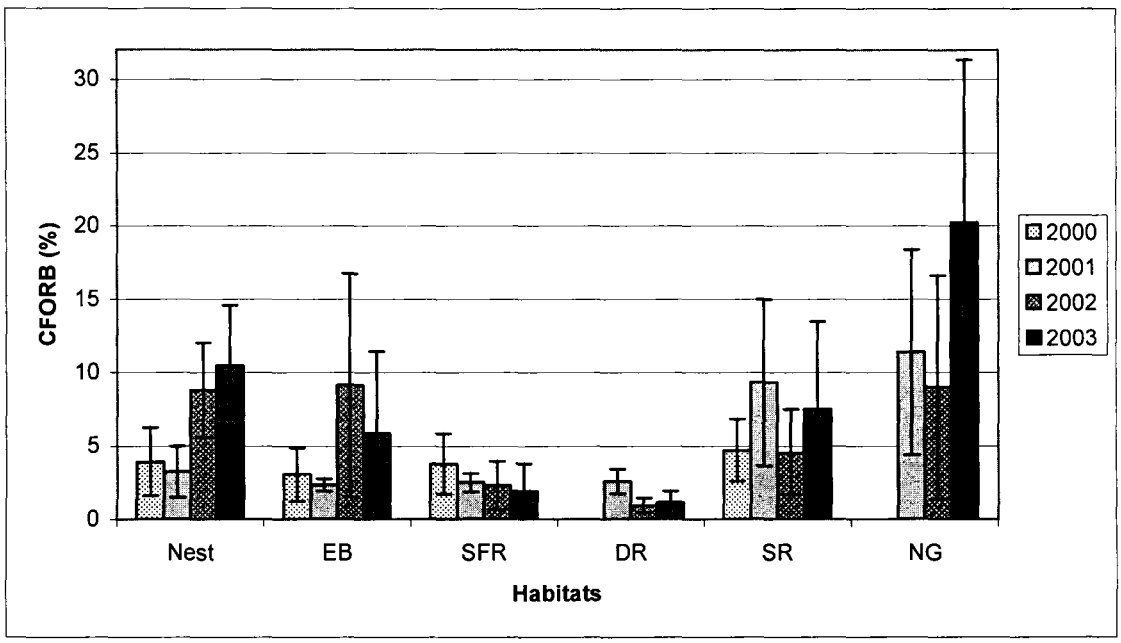
Figure 6. Mean cover forb cover (CFORB) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	3.93	2.94	4.49
	2001	20	3.26	2.48	3.34
	2002	22	8.80	4.77	6.08
	2003	37	10.46	7.99	7.69
Broods	2000	4	3.07	1.17	5.21
	2001	8	2.34	0.38	0.89
	2002	9	9.12	7.22	15.74
	2003	11	5.89	5.82	11.13
SFR	2000	20	3.79	2.90	3.90
	2001	10	2.54	0.64	1.29
	2002	10	2.33	1.64	3.33
	2003	10	1.98	1.83	3.72
DR	2001	10	2.63	0.84	1.70
	2002	10	0.96	0.49	0.99
	2003	10	1.17	0.80	1.62
SR	2000	24	4.73	3.25	3.95
	2001	10	9.33	5.66	11.51
	2002	10	4.58	2.88	5.86
	2003	10	7.48	6.06	12.31
NG	2001	10	11.42	7.00	14.24
	2002	10	9.02	7.60	15.45
	2003	10	20.25	11.06	22.48

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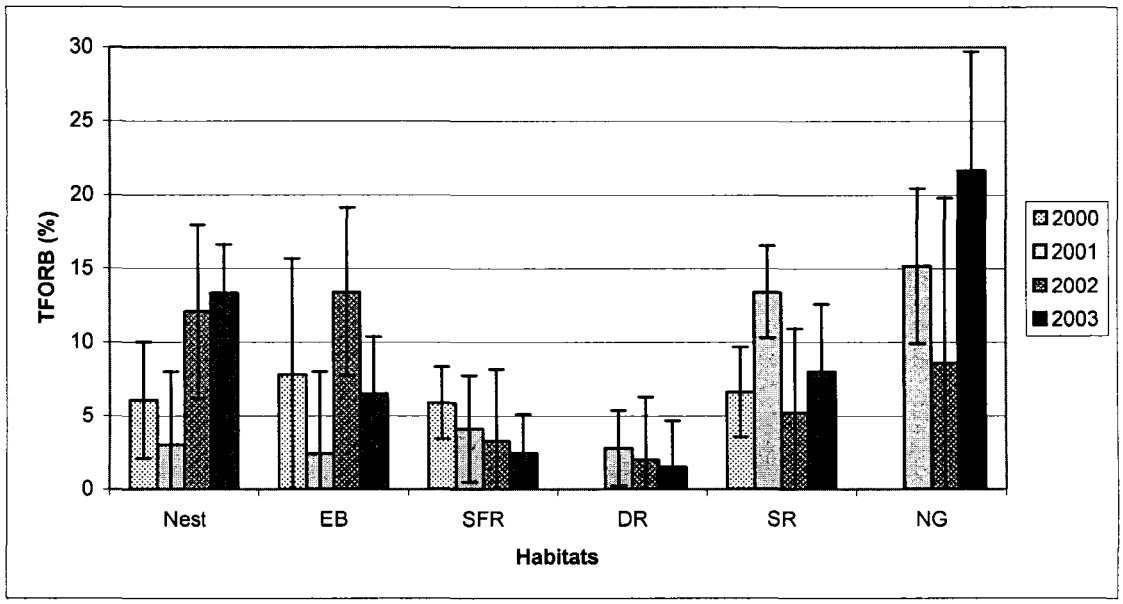
Figure 7. Mean total forb cover (TFORB) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	6.06	4.80	7.33
	2001	20	3.05	2.68	3.61
	2002	22	12.06	6.46	8.24
	2003	37	13.33	8.73	8.41
Broods	2000	4	7.81	3.58	16.01
	2001	8	2.42	2.20	5.21
	2002	9	13.43	9.23	20.11
	2003	11	6.52	6.20	11.86
SFR	2000	20	5.91	3.60	4.83
	2001	10	4.10	3.32	6.76
	2002	10	3.29	2.20	4.48
	2003	10	2.46	1.82	3.7
DR	2001	10	2.79	1.91	3.89
	2002	10	2.00	0.99	2.02
	2003	10	1.48	1.35	2.74
SR	2000	24	6.62	4.26	5.18
	2001	10	13.42	8.97	18.23
	2002	10	5.19	3.57	7.26
	2003	10	8.02	6.32	12.86
NG	2001	10	15.19	8.67	17.63
	2002	10	8.60	7.65	15.55
	2003	10	21.63	10.70	21.75

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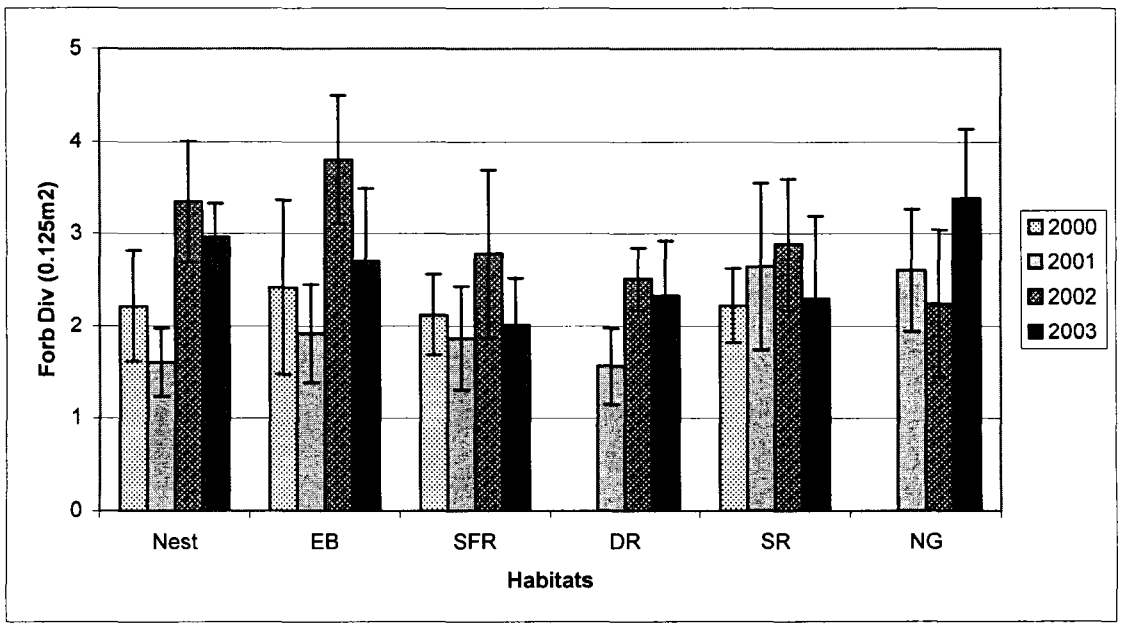
Figure 8. Mean forb diversity (Forb Div) per 0.125 m² at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	2.21	0.76	1.16
	2001	20	1.60	0.52	0.7
	2002	22	3.35	0.98	1.25
	2003	37	2.96	0.71	0.68
Broods	2000	4	2.42	0.60	2.67
	2001	8	1.92	0.48	1.13
	2002	9	3.81	0.66	1.44
	2003	11	2.70	0.83	1.59
SFR	2000	20	2.12	0.61	0.3
	2001	10	1.87	0.56	1.13
	2002	10	2.78	0.91	1.85
	2003	10	2.02	0.50	1.01
DR	2001	10	1.56	0.42	0.85
	2002	10	2.51	0.34	0.68
	2003	10	2.33	0.59	1.2
SR	2000	24	2.22	0.62	0.75
	2001	10	2.64	0.91	1.85
	2002	10	2.88	0.71	1.45
	2003	10	2.29	0.90	1.83
NG	2001	10	2.60	0.66	1.35
	2002	10	2.24	0.80	1.63
	2003	10	3.38	0.75	1.53

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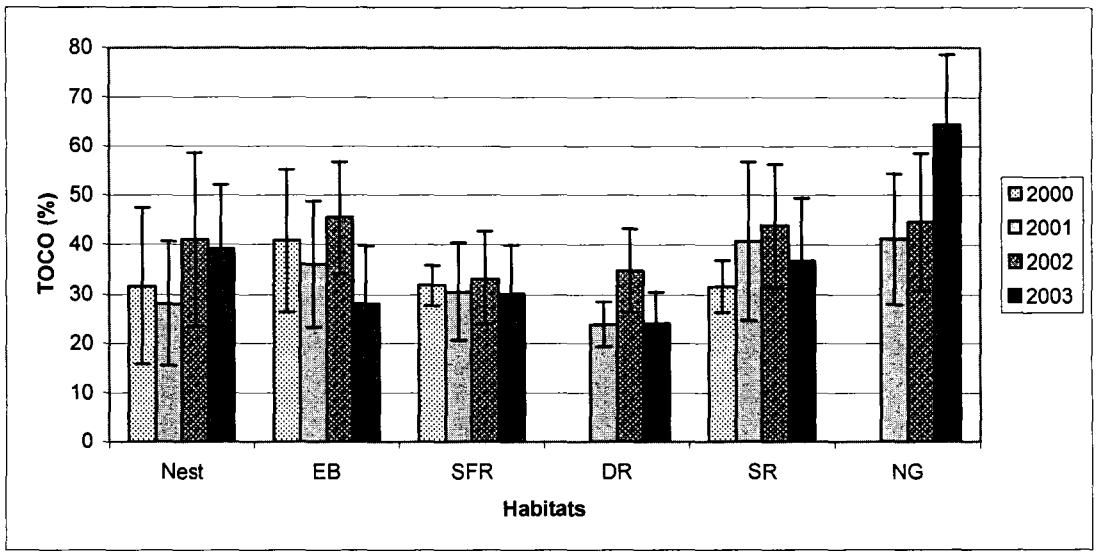
Figure 9. Mean total herbaceous cover (TOCO) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured.



	Year	N	Mean	SE	Power
Nests	2000	16	31.55	8.41	12.83
	2001	20	28.09	7.48	10.06
	2002	22	41.07	12.16	15.5
	2003	37	39.15	13.28	12.79
Broods	2000	4	40.83	9.05	40.45
	2001	8	36.07	11.38	26.94
	2002	9	45.53	10.66	23.25
	2003	11	28.07	12.12	23.18
SFR	2000	20	31.85	5.75	7.73
	2001	10	30.50	9.90	20.12
	2002	10	33.31	9.30	18.91
	2003	10	30.21	9.71	19.74
DR	2001	10	23.94	4.59	9.34
	2002	10	34.83	8.35	16.99
	2003	10	24.13	6.38	12.96
SR	2000	24	31.67	8.15	9.9
	2001	10	40.73	15.99	32.52
	2002	10	43.88	12.45	25.32
	2003	10	36.85	12.46	25.33
NG	2001	10	41.15	13.19	26.82
	2002	10	44.69	13.92	28.3
	2003	10	64.31	14.24	28.95

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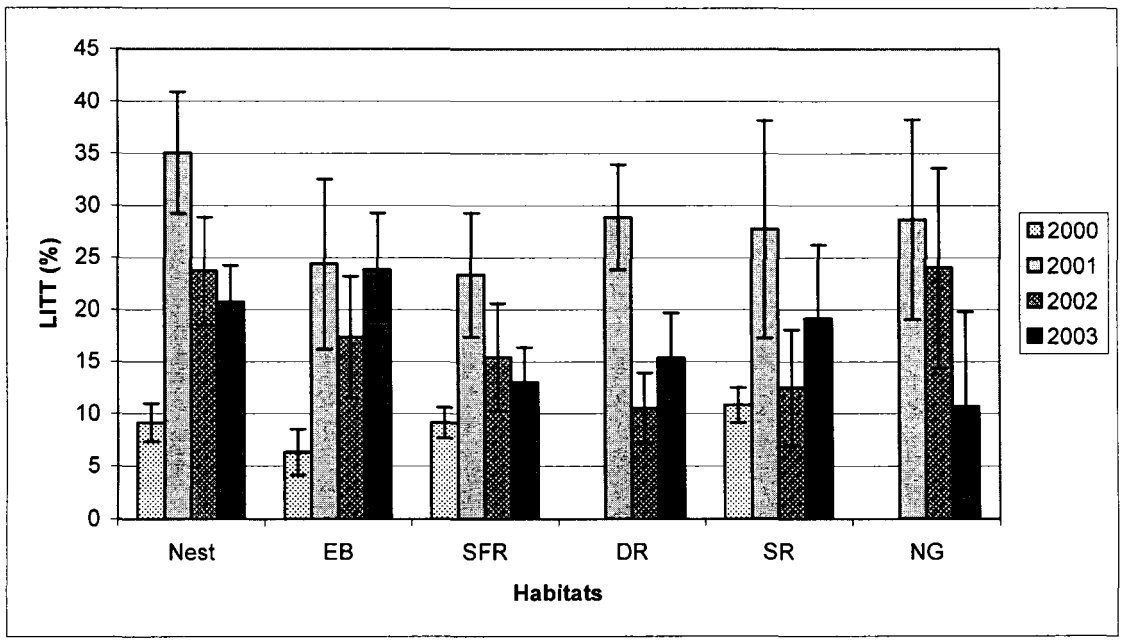
Figure 10. Mean litter cover (LITT) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	9.15	2.32	3.54
	2001	20	35.06	8.27	11.12
	2002	22	23.69	7.64	9.73
	2003	37	20.73	6.75	6.50
Broods	2000	4	6.30	1.37	6.15
	2001	8	24.38	7.31	17.31
	2002	9	17.36	5.52	12.03
	2003	11	23.81	5.75	11.00
SFR	2000	20	9.14	2.10	2.82
	2001	10	23.33	5.96	12.12
	2002	10	15.42	5.15	10.47
	2003	10	13.00	3.41	6.93
DR	2001	10	28.88	5.08	10.33
	2002	10	10.56	3.34	6.80
	2003	10	15.40	4.31	8.76
SR	2000	24	10.86	2.56	3.11
	2001	10	27.71	10.44	21.23
	2002	10	12.52	5.58	11.35
	2003	10	19.23	6.92	14.06
NG	2001	10	28.67	9.59	19.49
	2002	10	24.00	9.59	19.51
	2003	10	10.73	9.07	18.44

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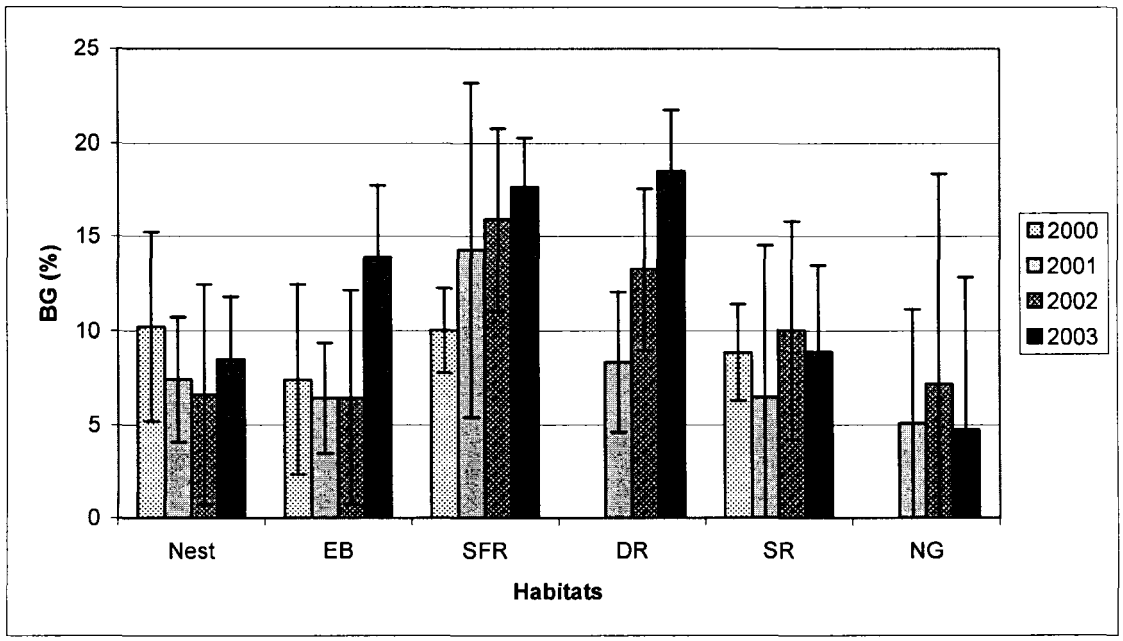
Figure 11. Mean bare ground (BG) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	10.22	6.36	9.71
	2001	20	7.43	4.71	6.33
	2002	22	6.61	5.51	7.03
	2003	37	8.50	6.04	5.82
Broods	2000	4	7.40	3.20	14.3
	2001	8	6.43	2.62	6.21
	2002	9	6.44	3.26	7.1
	2003	11	13.88	7.22	13.81
SFR	2000	20	10.02	3.17	4.26
	2001	10	14.31	8.89	18.07
	2002	10	15.92	5.69	11.56
	2003	10	17.65	7.03	14.29
DR	2001	10	8.33	3.70	7.52
	2002	10	13.27	4.64	9.44
	2003	10	18.54	5.39	10.95
SR	2000	24	8.85	3.95	4.8
	2001	10	6.50	8.03	16.32
	2002	10	10.02	5.03	10.22
	2003	10	8.90	3.35	6.81
NG	2001	10	5.08	6.04	12.28
	2002	10	7.19	5.78	11.75
	2003	10	4.75	4.35	8.85

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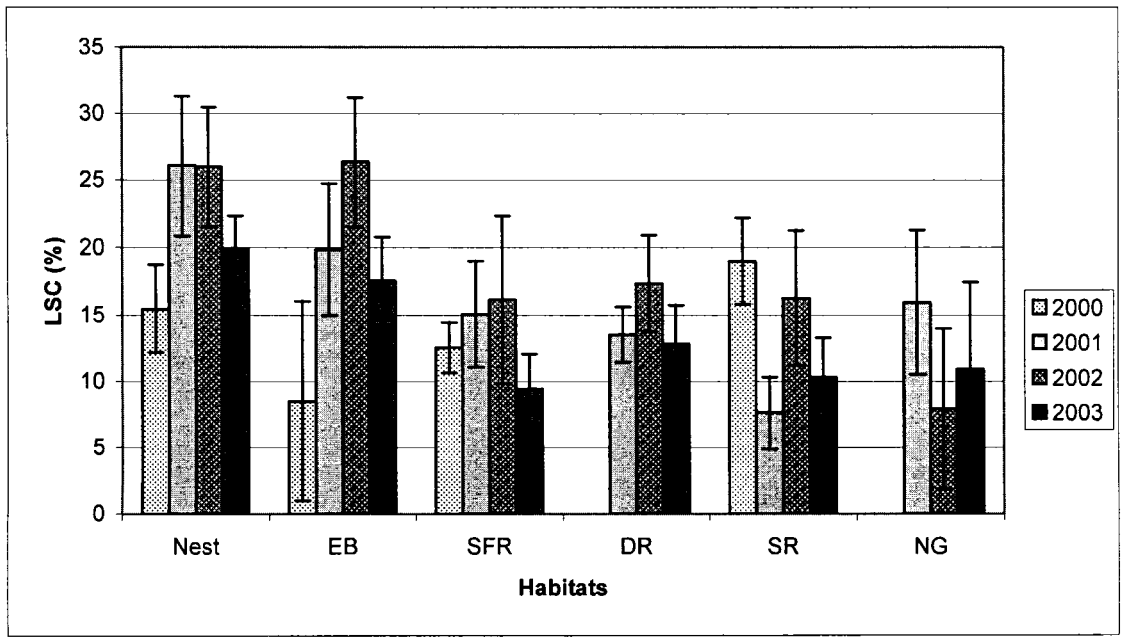
Table 12. Mean live sagebrush cover (LSC) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	15.43	4.16	6.35
	2001	20	26.08	7.37	9.91
	2002	22	25.99	6.66	8.49
	2003	37	19.95	4.62	4.45
Broods	2000	4	8.46	4.75	21.23
	2001	8	19.86	4.36	10.32
	2002	9	26.35	4.62	10.06
	2003	11	17.53	3.41	6.52
SFR	2000	20	12.53	2.70	3.63
	2001	10	15.05	3.99	8.11
	2002	10	16.11	6.29	12.78
	2003	10	9.45	2.57	5.23
DR	2001	10	13.52	2.06	4.19
	2002	10	17.35	3.59	7.31
	2003	10	12.81	2.89	5.88
SR	2000	24	18.99	4.97	6.04
	2001	10	7.60	2.72	5.53
	2002	10	16.24	5.03	10.22
	2003	10	10.29	2.95	6.01
NG	2001	10	15.90	5.40	10.97
	2002	10	7.88	6.06	12.32
	2003	10	10.90	6.50	13.23

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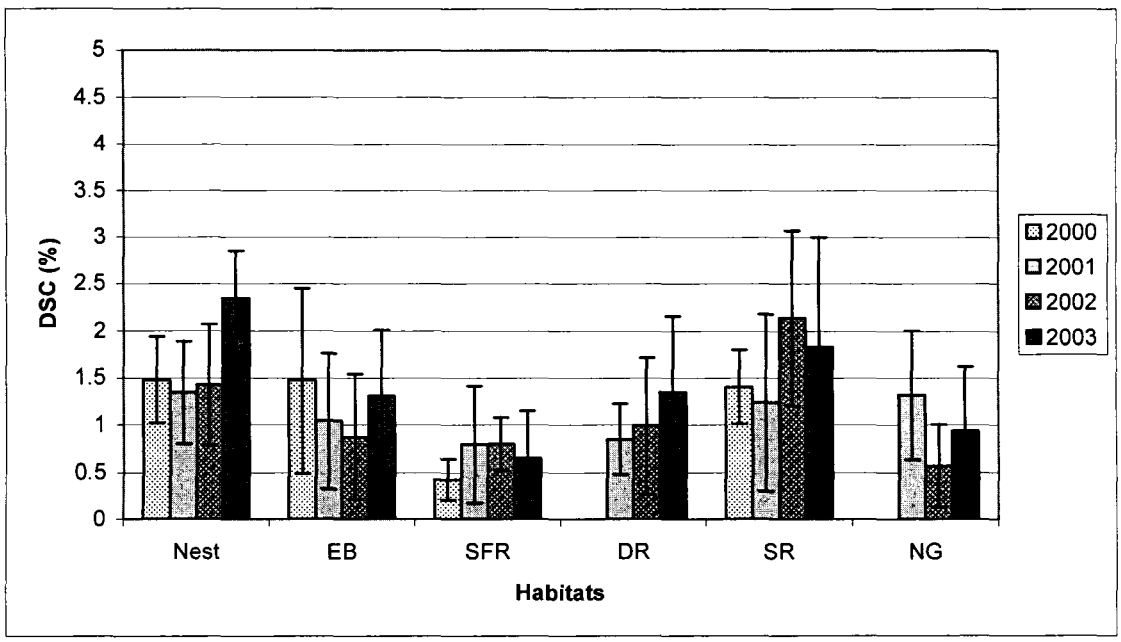
Figure 13. Mean dead sagebrush cover (DSC) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	1.48	0.59	0.9
	2001	20	1.34	0.77	1.04
	2002	22	1.43	0.95	1.22
	2003	37	2.34	0.98	0.94
Broods	2000	4	1.48	0.62	2.77
	2001	8	1.05	0.64	1.51
	2002	9	0.88	0.63	1.36
	2003	11	1.31	0.74	1.41
SFR	2000	20	0.43	0.30	0.41
	2001	10	0.79	0.62	1.26
	2002	10	0.80	0.28	0.56
	2003	10	0.65	0.50	1.01
DR	2001	10	0.85	0.37	0.75
	2002	10	0.99	0.72	1.47
	2003	10	1.35	0.81	1.65
SR	2000	24	1.40	0.61	0.74
	2001	10	1.24	0.94	1.95
	2002	10	2.14	0.94	1.9
	2003	10	1.84	1.17	2.38
NG	2001	10	1.32	0.68	1.39
	2002	10	0.57	0.44	0.89
	2003	10	0.94	0.68	1.39

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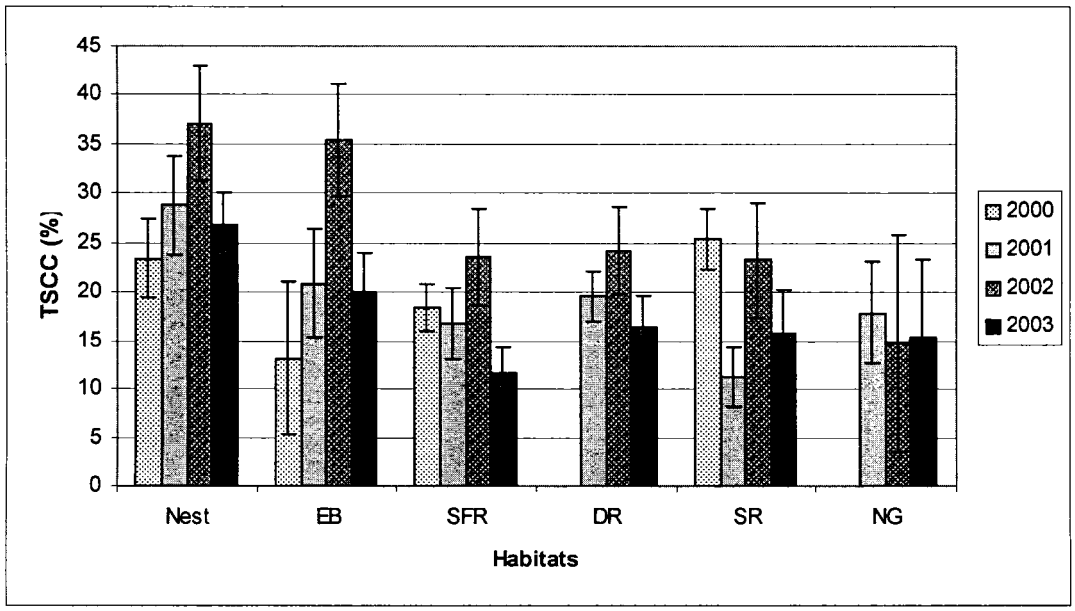
Figure 14. Mean total shrub canopy cover (TSCC) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. The three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	23.42	5.01	7.65
	2001	20	28.74	6.98	9.39
	2002	22	37.11	8.69	11.08
	2003	37	26.74	6.29	6.06
Broods	2000	4	13.13	4.99	22.29
	2001	8	20.90	4.97	11.76
	2002	9	35.42	5.39	11.76
	2003	11	20.03	4.04	7.73
SFR	2000	20	18.49	3.48	4.67
	2001	10	16.74	3.63	7.38
	2002	10	23.54	4.86	9.88
	2003	10	11.76	2.63	5.36
DR	2001	10	19.55	2.57	5.24
	2002	10	24.24	4.30	8.75
	2003	10	16.42	3.19	6.49
SR	2000	24	25.36	4.73	5.75
	2001	10	11.24	3.12	6.33
	2002	10	23.23	5.78	11.75
	2003	10	15.68	4.57	9.3
NG	2001	10	17.85	5.23	10.64
	2002	10	14.64	11.20	22.78
	2003	10	15.31	8.09	16.44

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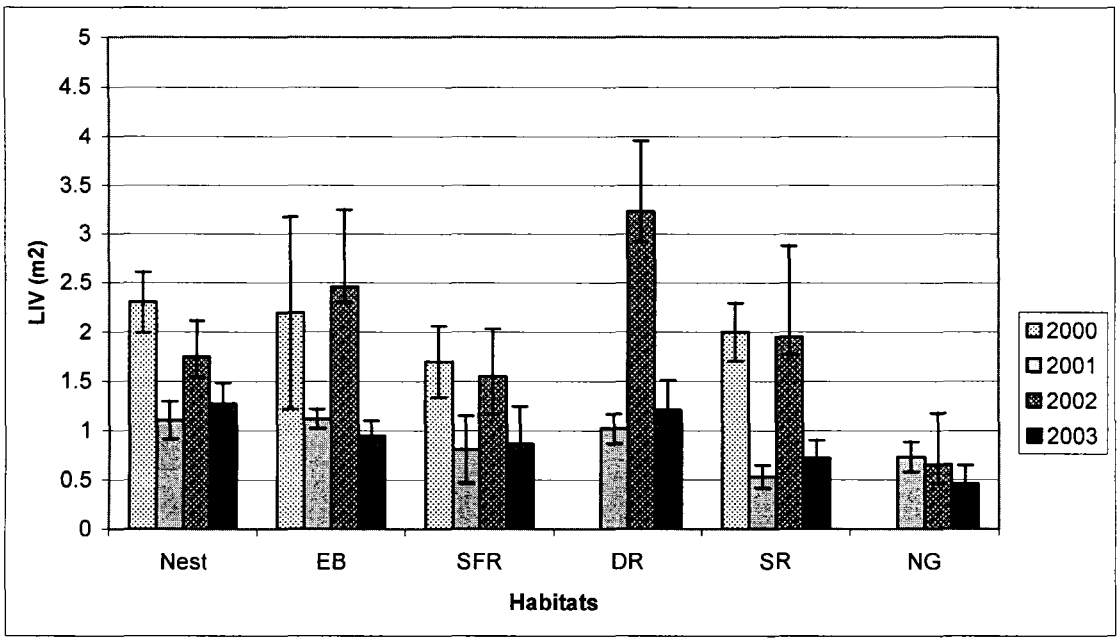
Figure 16. Mean live sagebrush density (LIV) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	2.30	0.39	0.59
	2001	20	1.11	0.27	0.36
	2002	22	1.75	0.55	0.70
	2003	37	1.28	0.39	0.38
Broods	2000	4	2.20	0.62	2.77
	2001	8	1.12	0.09	0.21
	2002	9	2.46	0.75	1.62
	2003	11	0.95	0.16	0.31
SFR	2000	20	1.70	0.51	0.69
	2001	10	0.81	0.34	0.69
	2002	10	1.55	0.48	0.98
	2003	10	0.87	0.38	0.78
DR	2001	10	1.02	0.15	0.31
	2002	10	3.23	0.73	1.48
	2003	10	1.21	0.31	0.62
SR	2000	24	2.00	0.46	0.61
	2001	10	0.53	0.11	0.23
	2002	10	1.95	0.93	1.86
	2003	10	0.73	0.18	0.36
NG	2001	10	0.73	0.15	0.31
	2002	10	0.65	0.53	1.08
	2003	10	0.46	0.19	0.39

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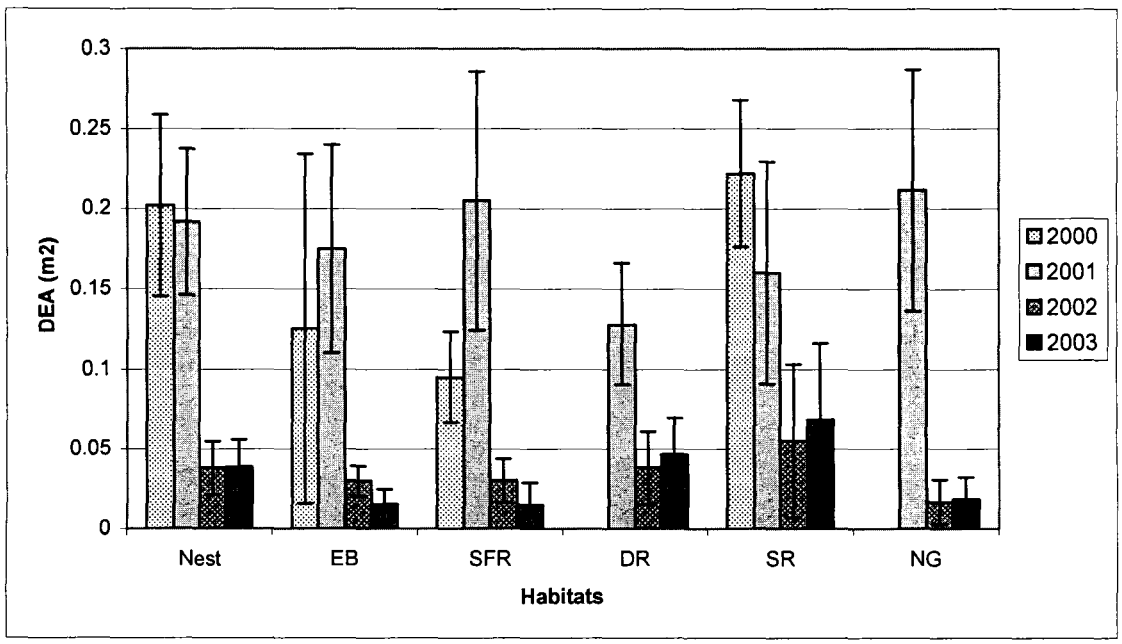
Figure 17. Mean dead sagebrush density (DEA) at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	0.20	0.07	0.11
	2001	20	0.19	0.06	0.09
	2002	22	0.04	0.02	0.03
	2003	37	0.04	0.03	0.03
Broods	2000	4	0.13	0.07	0.31
	2001	8	0.18	0.06	0.14
	2002	9	0.03	0.01	0.02
	2003	11	0.02	0.01	0.02
SFR	2000	20	0.10	0.04	0.05
	2001	10	0.21	0.08	0.17
	2002	10	0.03	0.02	0.03
	2003	10	0.02	0.01	0.03
DR	2001	10	0.13	0.04	0.08
	2002	10	0.04	0.02	0.04
	2003	10	0.05	0.02	0.05
SR	2000	24	0.22	0.07	0.09
	2001	10	0.16	0.07	0.14
	2002	10	0.06	0.02	0.04
	2003	10	0.07	0.05	0.1
NG	2001	10	0.21	0.08	0.14
	2002	10	0.02	0.01	0.03
	2003	10	0.02	0.01	0.03

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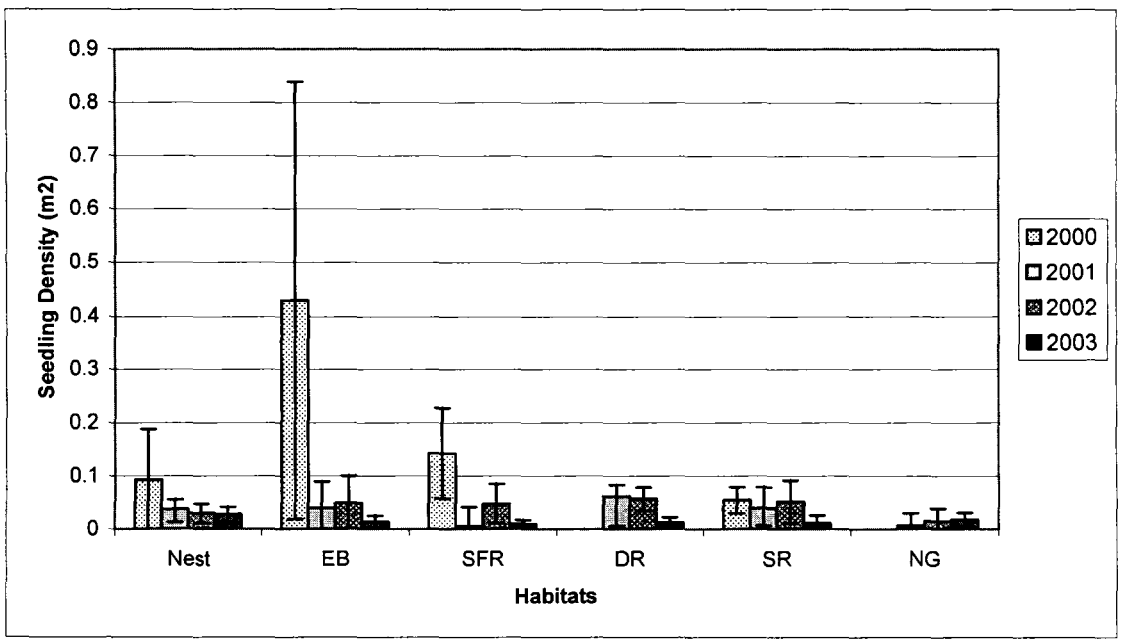
Figure 18. Mean seedling density at radio collared sage-grouse nest and early brood (EB) habitats, and random locations within 4 associated grazing systems near Lander, Wyoming from 2000 to 2001. Means, standard errors at α=0.05 (SE), sample sizes, and smallest detectable difference (Power) are found in the table below. Three cattle grazing systems included differed rotational (DR), summer grazed moderate to light intensity rest rotational (SR), and spring and fall grazed moderate to light intensity rest rotational (SFR). A rested from domestic grazing control (NG) was also measured. Error bars denote 95% confidence intervals.



	Year	N	Mean	SE	Power
Nests	2000	16	0.09	0.12	0.1827
	2001	20	0.04	0.03	0.046
	2002	22	0.03	0.03	0.0357
	2003	37	0.03	0.03	0.0259
Broods	2000	4	0.43	0.26	1.16
	2001	8	0.04	0.05	0.11
	2002	9	0.05	0.05	0.1
	2003	11	0.01	0.01	0.02
SFR	2000	20	0.14	0.12	0.16
	2001	10	0.01	0.01	0.02
	2002	10	0.05	0.04	0.08
	2003	10	0.01	0.01	0.02
DR	2001	10	0.06	0.06	0.11
	2002	10	0.06	0.02	0.04
	2003	10	0.01	0.01	0.02
SR	2000	24	0.05	0.04	0.05
	2001	10	0.04	0.03	0.06
	2002	10	0.05	0.04	0.08
	2003	10	0.01	0.01	0.03
NG	2001	10	0.01	0.01	0.015
	2002	10	0.02	0.02	0.05
	2003	10	0.02	0.01	0.03

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Chapter 3: ANALYSIS OF LINEAR CORRIDORS (ROADS AND LIVESTOCK/WILDLIFE TRAILS) IN RELATION TO SAGE GROUSE NEST SUCCESS AND SELECTION

ABSTRACT

Linear corridors have been implicated to reduce nest success of ground nesting birds by aiding nest predator movements. We examined 253 sage-grouse nests in Wyoming to determine if the presence of livestock and wildlife trails, 2-track roads, and maintained roads increased nest destruction rates. Our method provided for exploratory analyses. We found that trail presence within 25 m increased nest destruction rates. Trail presence at 50 m had no affect, while trail presence at 100 m increased nest success. Similarly, 2-track and maintained roads increased nest success at 100 m as well. Livestock trails my be important nest predator corridors which may increase or decrease the likelihood nest failure, depending on the distance from the nest. However, roads might increase nest success by causing predator avoidance. Two-track roads at 25 m and trails at 50 m increased the likelihood of sage-grouse nest selection while 2-tracks at 100 m decreased the likelihood. Roads may provide desirable microsite habitats for nesting sage-grouse such as increased forb or insect availability or reduced predator abundance. However, road were a rare feature within 100m of nests and may be selected only when available. Our results suggested that roads did not reduce sage-grouse nest success and future sage-grouse productivity studies should consider the potential for artificially high nest success near roads.

INTRODUCTION

Predation rates of on nests of ground nesting birds are often attributed to man-made disturbances which fragment, degrade, or eliminate nesting habitats, improving success of nest predators (Lidicker 1999). High sage-grouse (*Centrocercus urophasianus*) nest destruction rates are a concern for population viability in some areas (Gregg et al. 1994, Connelly et al. 2000). Population viability of sage-grouse is a concern because estimated breeding populations range-wide have declined from 45 to 80% since the 1950's, with the greatest declines occurring since 1980 (Braun 1998). Analysis of sage

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grouse nest success has been directed primarily at vegetative habitat quality and quantity (Wallstad and Pyrah 1974, Connelly et al. 1991, Fischer 1994, Delong et al. 1995, Aldridge and Brigham 2002, Slater 2003). Still, our understanding of how predators find ground-nests is poor (Keppie and Herzog 1978, Greenwood et al. 1999), limiting our ability to identify habitat deficiencies.

Linear corridors such as roads or trails influence predator behavior though improving access and foraging efficiency (Thurber et al 1994), or roads may deter predators (Clevenger et al. 2001). The later relationship is likely dependant on the nature of human/predator interactions in an area and the level of human presence (Thurber et al. 1994). Common ravens (*Corvus corax*), which are frequent sage-grouse nest predators, have shown both selection for road corridors with little human avoidance (Knight and Kawashima 1993), and aversion to human presence (White and Tanner-White 1988). Gray wolves in Alaska have also shown an attraction to roads with low human use for movement corridors, but an aversion to roads with high human use (Thurber et al. 1994).

Corridors can increase predation of species requiring contiguous habitats by increasing penetration into and throughout contiguous habitats and "spilling over" into surrounding habitats to capitalize on new or underutilized prey sources (Lidicker 1999). Interior habitats are thought to decrease predator success by reducing mobility because of dense vegetation, which dilutes foraging effectiveness (Phillips et al. 2003). An aversion to interior grassland areas was found in red fox (*Vulpes vulpes*), while waterfowl nest success was concurrently highest in interior grassland habitats (Phillips et al. 2003). Winter et al. (2000) found that mammalian nest destruction of Dickcissels *(Spiza americana)* and Henslow's Sparrows *(Ammodramus henslowii)* increased significantly in interior grassland habitats in a woodland/grassland habitat.

For most generalist predators, eggs and occasionally incubating birds make up a small percentage of the total diet (Greenwood et al. 1999). Because nests are often dispersed over large areas, it would be difficult for generalist predators to prey exclusively on ground nests (Greenwood et al. 1999). Predator foraging behavior studies have found increased nest destructions correlated with increased primary food sources within nesting habitats, such as lagomorph abundance attracting red fox (Yanes and Suarez 1996), or arthropod abundance attracting striped skunks (*Mephitis mephitis*)

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(Greenwood et al. 1999, Vickery et al. 1992). This suggests ground-nests are most often located by chance by the predator while foraging for primary food sources (Greenwood et al. 1999, Vickery et al. 1992, Yanes and Suarez 1996). If nest destruction is predominantly a result of chance, then alterations to contiguous nesting habitats that improve predator access or foraging efficiency for primary prey should be examined in nest destruction studies.

Few studies have shown if the presence of roads throughout contiguous habitats improve or reduce nest predator foraging movements and correspondingly increase or decrease ground-nest destruction. Cowardin et al. (1985) found that predation of duck nests along roads was significantly higher than other available habitats. Nest success along roads may be lower due to parallel travel corridors frequently found along roads such as tree lines, fences, and trails (Bergin et al. 1997). Roads themselves may also be used by predators for traveling (Bennett 1991). It was theorized that the gravel road right-of-ways utilized by nesting ducks in North Dakota did not receive enough vehicle traffic to detour predators, encouraging increased predation (Cowardin et al. 1985). In Georgia and Florida, nest destruction rates of artificial freshwater turtle nests were lowest near roads (Hamilton and Franz 2002) suggesting potential predator aversion. Roads also appeared to have positive effects on dickcissel *(Spiza Americana)* nest success in Missouri, although the affect was not significant (Winter et al. 2000).

The potential effects of cattle/livestock trail densities on predator behavior or prey vulnerability has not been previously examined. Although unproven, Braun (1998) suggested that fences with paralleling trails increased sage-grouse predation. Trails are developed and used by livestock and wildlife to aid movements to limiting resources such as water, minerals, protective cover, and forage (Ganskopp et al. 2000). Trails form when the ground disturbance from frequent traveling is greater than the vegetations' ability to recover (Walker and Heitschmidt 1986). However, little evidence is available correlating livestock use and management to trail densities. Walker and Heitschmidt (1986) found that increased livestock densities within a cell rotational grazing system developed greater trail densities than three other grazing systems with lower stocking densities. Stocking density was suggested to be the cause of increased trailing due to intense hoof

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action resulting in bare ground and the slow recolonization of bare ground by vegetation in the area (Walker and Heitschmidt 1986).

Our objectives were to determine if livestock/wildlife trails, 2-track roads, and maintained roads influenced sage-grouse nest success and selection, and to determine the distances to linear corridors where nesting success probabilities were influenced.

METHODS

Study Areas

This study took place on 3 areas of Wyoming. Sage-grouse nests were measured near Pinedale (2001 to 2003), Kemmerer (2001 to 2002), and Lander, WY (2001 to 2003) for a successful nest versus unsuccessful nest analyses. Random plots were measured near Lander (2001 to 2003) for comparison with Lander nest characteristics for use vs. available analyses. All three areas were in sagebrush steppe habitats with Wyoming big sagebrush (*Artemesia. tridentata wyomingensis*) the dominant shrub. Grasses and forbs were a mix of annuals and perennials and warm and cool season. In addition to livestock grazing, all three areas were grazed seasonally by antelope (*Antilocapra americana*), moose (*Alces alces*), elk (*Cervus elaphus*), and mule deer (*Odocioleus hemionus*).

The Lander study area (42°33'N, 108°29'W) is 15,535 ha and located in Southwestern Fremont County between Highway 287 and 28. It is considered part the foothills region of the Bridger Teton - Wind River Mountains with elevations from 1,676 to 2,520 m. The area was grazed by cattle from the late spring through early fall with some areas permanently rested from cattle grazing. Cattle grazing systems used were a rested from livestock grazing system (NG), a differed rotational system (DR), a moderate intensity and duration rest rotational system (SR), and a high intensity and low duration rest rotational system (SFR). Rest rotational systems rotate livestock through multiple paddocks throughout the grazing period with a percentage of paddocks rested each year for the whole grazing period. A differed rotational system rotates livestock between multiple paddocks with the purpose of allowing some paddocks rest for part of the grazing period for a particular season each year. In this instance spring grazing is avoided periodically to allow for grass reproduction. No organized predator control was done on the study area.

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The Pinedale study area included, the Mesa (42°45'N, 109°55'W) 30,400 ha and the Jonah Field (42°33'N, 109°40'W) with 53,420 ha. The Mesa and most of the Jonah Field areas are located primarily West of Hwy 191, with the Mesa directly South of Pinedale and the Jonah Field between Pinedale and Farson, in central Sublette County, Wyoming. Both areas were Southeast of the Bridger Teton - Wind River Mountains. Elevations in the area range from 2,140 to 2,300 m. Natural gas production was the primary use of the two areas with short-term spring cattle grazing. The two areas were heavily developed for natural gas extraction. No organized predator control was done during the study period.

Kemmerer had two separate study areas, Collette Creek (45°53'N, 110°54'W) with 55,000 ha and Salt Creek with 13,000 ha. The Collette Creek area was 30 km west of Kemmerer, Wyoming and south of Hwy 30 in southwestern Lincoln County. The area was to the west of Fossil Ridge. The Salt Creek area was 15 km east of Woodruff, Utah. It was south of Hwy 30 and east of Hwy 16 in southwestern Lincoln County and northwestern Uinta County. The area was south of the Sawtooth Mountains and part of the Bear River Drainage. Both areas ranged from 1,895 to 2,514 m in elevation. Both areas were used for natural gas extraction and livestock grazing. Collette Creek had sheep grazing in the spring and fall of 2001 to 2002 and cattle grazing in the fall of 2001 and the spring of 2002, using a 4 paddock rotational grazing system. Salt Creek cattle grazed in the spring of 2001 and fall of 2002. Organized predator control took place mid-February to June 1 on Collette Creek before and during the study. Salt Creek had no organized predator control.

Capture and Monitoring

Sage-grouse hens were captured in March and April of 2000 to 2003 using spotlighting and hoop-netting techniques around leks (Giesen et al. 1982, Wakkinen 1990), and stationary cannon nets (Codah Enterprises, Inc., Mesa, Arizona). Hens were fitted with a 19 to 20 gram PVC coated necklace radio collars with a battery life expectancy of 520 to 730 days and mortality indicators (Advanced Telemetry Systems Inc., Insanti, MN). Hens were aged to yearling or adult based on outer primary feather wear (Eng 1955) and released.

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Sage-grouse were tracked to nesting habitats using hand held radio-telemetry receivers and three-element Yagi antennas. Nests sites were identified at the start of incubation and marked at 5 m from the nest using stacked cow chips or rocks and a GPS location. Time spent around the nest was minimized to avoid flushing the hen, drawing attention to the nest, and leaving human scent. Incubating hens were checked every 2 to 3 days using radio-telemetry from >100m away. Nests were examined when the hen left the area. If the egg membrane was detached from the shell of ≥1 egg, the nest was considered successful (Wallestad and Pyrah 1974).

If the membranes were still attached or no eggs were found, the nest was deemed unsuccessful. Eggshell and nest condition were recorded for destroyed nests. Guard hair samples were taken from the vegetation around the nest bowl, if present, and later examined (Moore et al. 1974), along with egg and nest condition to estimate the nest predator species (Sargeant et al. 1998). Positive guard hair or fresh track identification combined with egg and nest condition was suggested the most reliable predictor to confirm nest predator identification. Undercoat hair at nest sites with no other sign was suggested an unknown mammalian predation. All nests with destroyed egg present also had undercoat hair. Destroyed nests lacking definitive evidence but with undercoat hair and egg shell present were keyed to suspected mammalian nest predator species using egg shell characteristics (Sargent et al. 1998). Nests with no hair or mammalian sign were suggested a non-mammalian predation. The few known avian predations were included in the non-mammalian group. All destroyed nests examined were labeled either confirmed mammalian or non-mammalian nest destructions. Mammalian nest destruction were further labeled by confirmed species, suspected species, or unknown.

Measurements and Random Plot Selection

The methods for measuring linear corridor presence were developed for the purpose of this study. Circumferences were examined at 100, 50, 25, 12.5, 6, 3, and 1.5m radii from the nests and random points at the Lander area and nest sites at the Pinedale and Kemmerer areas. Distances from the random point or nest were determined using GPS points and tape measurements. A corridor that intersected the circumference constituted the presence of that corridor type at that radii distance. The number of times a

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corridor type crossed a circumference was recorded as an estimate of abundance. More circumferences were measured closer to improve our chance of identifying distance changes in corridor effects if sample sizes were sufficient, assuming that corridor influences are most likely closer to the nest.

Linear corridors were broken into livestock/wildlife trails, two-track roads, and maintained roads. Trail and two-track roads were identified based on percent bare ground (Walker and Heitschmidt 1996) measured using the daubenmire method (Daubenmire 1959). Three daubenmire frames were taken at two-track and trail hits, with 1 measurement at the point were the apparent corridor crossed the circumference and 1 at 5 m along the corridor in each direction. Trails were measured in the center of the trail while 2-tracks and maintained roads were measured in the tire track or depression closest to the center point. Only the closest track was identified as the corridor. If the trail or track edge crossed the circumference it was measured for that circumference. To qualify, trails and 2-tracks had to have 2 out of 3 measurements of $\geq$ 25% bare ground, to visually extend for $\geq$ 5 m in both directions, and be visually $\geq$ 30 m in total length. Trail and 2-track requirements were made to eliminate false trails in areas with abundant bare ground or rock and short branching trails. Maintained roads were graveled and graded with no vegetation growing in the road center.

Random plots near Lander were evenly distributed between associated grazing systems using randomly generated UTMs (Excel 2000) within the perimeters of the paddocks (Appendix A). Ten random locations were measured for each system each year. One random location was generated for each paddock each year for the 10 paddock SR and SFR systems, five annually per paddock for the two paddock DR system and 10 per paddock for the 1 paddock NG system. The closest sagebrush bush (*Artemesia spp.*) of $\geq$ 30 cm was used. Grazing systems were located around or near the two trapped sage-grouse leks, which were considered to be the population's center. Grazing systems were not evenly distributed from the leks with the closest edge or the furthest system at 3.2 km and furthest outer boundary at 14.4 km.

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Analysis

We found that presence/absence and abundance data were highly correlated at Pearson's correlation values < 0.6 (Minitab Inc.). As a result, presence/absence data were used solely for our analyses. Binary logistic regression was used to compare corridors at successful versus unsuccessful nests with Lander, Kemmerer, and Pinedale areas combined and use versus available plots near Lander (Minitab Inc.). Maximized log-likelihoods from the regression outputs were used to calculate Akaike's Information Criterion adjusted for small sample sizes (AICc), and Akaike Weights (*wi*) for each model. The largest Akaike's Weights and the smallest AICc values represented the best models. Models were ranked by subtracting the lowest AICc value from all AICc values for simple difference values (Δ AICc). Models with a Δ AICc < 4 were selected as the best subset of models. Models with a Δ AICc < 2 were given special emphasis. To assess the relative importance (RI) of the variables, the Akaike's weight for each model were given to the variables in those models. The Akaike's Weights for each variable were summed. The most important variables had the highest summed Akaike's Weights.

Acceptable variables had Pearson's correlation values of < 0.6, which left trail presence at 25, 50, and 100m, 2-track presence at 25 and 100m, and maintained road presence at 100m. Two-track presence at 50m and trail presence at 12m were excluded due to correlation. Variables present on fewer than 5% of the plots were also excluded due to limited prediction value, resulting from small sample sizes.

One to 4 variable models of all combinations of acceptable variables were used to examine plot differences. The successful vs. unsuccessful analysis used 7 variables in 56 models. Three indicator variables were used to account for site variation. Because 91 percent of measured nests did not have maintained road within 100m, we examined 30 models using the same methods and variables except MR. The nests vs. random plots analyses used 6 variables in 30 models. Maintained roads were rare near the Lander area and not included in the analysis.

Means, standard errors and post hoc power ($\alpha \leq 0.05$) of the variables modeled were calculated to examine the level of detection possible as a reference.

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RESULTS

Sample Sizes

All corridor variables were measured at 263 nests from three study sites. Ten nests had unusable success information due to hen predation off the nest during incubation or nest abandonment, resulting in 253 nests for the nest success analysis (149 unsuccessful; 104 successful) Unsuccessful and successful nests were distributed between study areas as follows: Lander (39/32), Kemmerer (51/23), and Pinedale (59/49).

Predator Analysis

American badgers (*Taxidia taxus*) were the most commonly confirmed (10%) and suspected (36%) nest predators (Table 1). Coyotes (*Canis latrans*) (6%) were confirmed almost as often as American badger, although it was suspected far less at non-confirmed nests (6%). Predation by red fox and bobcat (*Lynx rufus*) was rarely confirmed or suspected. Mammalian carnivores accounted for at least 83% of sage-grouse nest destruction for these areas combined. Seventeen percent of the nests did not have evidence to support mammalian carnivore predation. Avian nest destruction was suspected in all these cases and likely accounted for much of the non-mammalian carnivore predation.

Successful vs. Unsuccessful Nests

The best subsets analysis selected 16 of 56 models as important (Table 2). The summed Akiake's weights for the 16 models was 0.697 suggesting that we are 70% sure that the best model was in the subset of models. The selected models ranged from 3 to 4 variables with no one variable or model standing out alone in the analysis. Akaike's Weights were low for all the models with the highest weight model having the variables 25Trl, 100Trl, 100Trk, and 100MR. The three variables 25Trl, 100Trl, and 100MR were found in all three models with Δ AICc < 2. Maintained roads were present in 15 of the 16 top models and appeared to be a highly influential variable. The analysis suggests that presence of all the variables had a positive direction of influence on nest success except 25Trl and 50Trl (Table 3). The direction of influence for 50Trl was negative in 16 of the 24 models. Generally the models including 50Trl in the best subset models were

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indicated a negative interaction with this variable and nest success. The variables with the highest influence were 25Trl, 100Trl, 100Trk, and 100MR (Table 3).

Maintained roads were found at 100 m for only 9 percent of the nests from all sites combined. Because maintained roads were so common in the subset of models, we ran a second analysis using the same dataset to better examine the influences of the other variables excluding maintained roads. Twelve of the 30 models without maintained roads had a Δ AICc ≤ 4 (Table 4). The summed Akiake's weights for the 12 models was 0.756, suggesting that we are roughly 76% sure that the best model was in the subset of models. The 12 selected models ranged from 2 to 4 variables with no one variable or model standing out alone in the analysis. Variable importance appeared similar, with 25Trl, 100Trl, and 100Trk found in the three models with Δ AICc < 2. 100Trl was the most common variable in the subset and also had the heaviest Akaike's Weight followed by 100Trk and 25Trl (Table 3). Directions of influence for the variables stayed the same as the first subset. The mean differences in the variables tested and maximum detectable differences are provided for reference (Appendix E).

Nest Use vs. Availability

The best subsets analysis selected 5 of 30 models (Table 6). The summed Akiake's weights for the 5 models was 0.893 suggesting that we are 89% sure that the best model was in the subset of models. The models ranged from 3 to 4 variables with no one variable or model standing out alone in the analysis. Akaike's Weights were fair for the 3 models with a Δ AICc ≤ 2, suggesting that the best model is likely in this subset. The model with the heaviest Akaike's weight included 50Trl, 25Trk, and 100Trk. Variables 25Trk and 100Trk were found in all five models. The analysis suggests that presence of all the variables had a positive influence on nest selection except 100Trl and 100Trk (Table 6). The direction of influence for 100Trk was positive in all models in the best subset and 87% of the 15 models where it was present. The variables with the highest RI were 50Trl, 25Trk, and 100Trk. The mean differences in the variables tested and maximum detectable differences are provided for reference (Appendix E).

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DISCUSSION

Measurements and Methods

We feel that our method of measuring along circumferences around nest and random plots was the most complete way to determine distance categories for corridors, for use in logistic regression models. However, this method did have drawbacks. The regression analysis requires that the same data set be used for all models in order to make inferences, such a relative importance, in relation the same corridor type at a different distance or a different corridor type. As a result, randoms and nest sites could not be examined separately when corridors crossed both outer and inner circles. Inevitably, the influence of a corridor at the outer distances is influenced by corridors present at closer distances when present. It is suspected that this would result in the influences of some variables not being detected. However, due to our large sample sizes for nests, we feel that our method still adequately capture the influences of the variables measured. Due to this caveat our results should be view as exploratory research.

Nest Predators

Mid-sized mammalian carnivores were the most important sage-grouse nest predators for all of the study areas. The 2 primary mammalian nest predators in order of importance were American badgers and coyotes. Although we did not identify avian predations as a significant source of nest destruction, common ravens (*Corvus corax*), American crows (*Corvus brachyrhynchos*), and magpies (*Pica pica*) were likely the most important avian nest predators.

Nest Success

Our data suggests that the presence or absence of roads and livestock/wildlife trails influenced sage-grouse nest success. Almost all models for the successful versus unsuccessful nest analyses were included in the best subset of models. The variables and models appeared to have a similar low strength for predicting nest success, although the goodness-of-fits tests suggest that the models did fit the data and improve predictability.

Important predictors for nest success were trail absence at 25 m, trail presence at 100 m, and 2-track or maintained gravel road presence at 100 m. If trails are attractive to

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sage-grouse nest predators for traveling and/or foraging, it seems feasible that trails closer to nests would increase nest destruction probabilities, and trails further away would draw predators away. Trail presence at 50 m had little influence on nest success which suggests that 50 m may be a threshold distance, with trails closer having negative effects and further having positive effects. The use of trails by mammalian carnivores, particularly canids, is abundant in the popular trapping literature, although only alluded too in the scientific literature. This is likely because microsite habitat selection of American badgers and coyotes is difficult to obtain due to their crepuscular and nocturnal foraging habits, aversion to humans, and mobility.

Two-tracks and maintained gravel roads may represent an aversion to sage-grouse nest predators. It is legal to hunt and trap many sage-grouse nest predators in Wyoming such as badgers, coyotes, red fox, bobcat, and crows. It is likely that hunting or trapping occurs to some degree in each of the study areas, providing sufficient stimulus to avoid human travel corridors. The activities of hunters, trappers, and poachers is often elevated in areas with high road density (Bennett 1991). The relative importance and presence of road variables in the top models suggests that maintained roads have a stronger effect than 2-tracks, further suggesting that levels of human use may be directly related to increased nest success probabilities at 100 m.

All two-tracks of various qualities were grouped together for this analysis and it is likely that they represent a wide range of effects depending on the physical structure and amount of human use. Influences were generally small for 2-track presence within 25 m of the nest. If lightly used 2-tracks act as predator travel corridors and heavily used 2-tracks act as an aversion, two-tracks at 100 m could improve success either by drawing predators away from nests to the road or pushing them far away from the road when nests are close. This scenario depends on the assumptions that predators use and avoid roads and that aversion distance effects could be greater than attraction.

Nest Selection

Nest selection near Lander was positively influenced by trail presence at 50 m and 2-track presence at 25 m, and negatively influenced by 2-tracks at 100 m. The absence of 2-tracks at 100 m appears to be conflicting, although it likely suggests that 2-tracks are

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present more often at random sites than nest sites. It may be that when 2-tracks are present at nests, they are closer.

Sage-grouse nests are found in areas with high shrub canopy covers and heights (Heath et al. 1998, Holloran 1999, Aldridge and Brigham 2002), which are commonly found in more mesic topographic depressions such as valleys, saddles, and draws. These areas might also concentrate trail and 2-track development. Topographical least-effort pathways dictate cattle trail formation (Ganskopp et al. 2000). Determining if nesting sage-grouse select for livestock/wildlife trails and 2-tracks or areas associated with these corridors will require further investigation.

Trails and roads could constitute a shrub canopy opening that improves the availability of forage and decreases the amount of time hens forage during incubation. It is suggested that narrow openings in sagebrush canopy cover due to disturbances may improve the production of forbs eaten by sage-grouse (Braun 1998). Holloran (1999) found that the availability of food forbs tended to be greater at successful nests and hens at successful nests tended to spend less time foraging during incubation. It is may be that nest site selection and nest success near roads is related to microsite forage availability.

MANAGEMENT IMPLICATIONS

Our results suggests that sage-grouse nest success was not reduced due to 2-track and maintained gravel roads, and may have been increased, especially near maintained roads. Also, sage-grouse nest success may be adversely affected by livestock trailing, particularly within 25 m. Livestock management has been shown to influence trail densities (Walker and Heitschmidt 1986) and increases in trail densities might reduce nest success. Livestock and wildlife management efforts that focus on allowing sufficient recovery of vegetation, may increase nesting success by reducing trail abundance.

The development of roads is a major sage-grouse management concern though out the species range, especially where associated with mineral development (Braun 1998). Mineral development areas with higher road densities have been found to influence breeding and nesting behavior in sage-grouse (Lyon 2000). Our data suggests that roads at the levels studied at our three study areas during the study duration, were not reducing sage-grouse nest success. Because this is the first in-depth study to look at

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maintained road, 2-track, and livestock trail influences on nest success, further research must be done before broader conclusion can be made. Future sage-grouse research in high road or trail density areas should take into consideration the potential for corridor influences on nest success.

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Table 1. Nest predator identification at 167 Sage-grouse nest sites near Lander (Land), Kemmerer (Kemm), and Pinedale (Pine), Wyoming from 2001 to 2003. Confirmed (Conf.) nest predator species had nest and egg destruction evidence with track or hair identification. Suspected nest predator species (Susp.) lacked conclusive hair or track identification evidence. Unknown mammalian carnivores (Unknown Mamm.) were mammalian carnivore nest destructions not identified to species. Non-mammalian carnivore nest destructions (Non-Mamm.) had punctured eggs or no eggs, no nest disturbance, no hair, and no mammalian Tracks. Predators keyed to species were American badger (*Taxidea taxus*), Coyote (*Canis latrans*), red fox (*Vulpes vulpes*), and bobcat (*Lynx rufus*).

		Land.	Kemm.	Pine.	Total (%)
Badger	Confirmed	7	4	5	16 (10)
	Suspected	7	14	39	60 (36)
	Total	14	18	44	76 (46)
Coyote	Confirmed	3	5	2	10 (6)
	Suspected	7	0	3	10 (6)
	Total	10	5	5	20 (12)
Red Fox	Confirmed	0	1	0	1 (1)
	Suspected	0	0	2	2 (1)
	Total	0	1	2	3 (2)
Bobcat	Confirmed	0	1	2	3 (2)
	Suspected	0	0	0	0 (0)
	Total	0	1	2	3 (2)
Unknown Mamm.	Confirmed	9	22	5	36 (0)
	Suspected	0	0	0	0 (0)
	Total	9	22	5	36 (21)
Total Mamm.	Confirmed	31	46	58	138 (83)
	Suspected	0	0	0	0 (0)
	Total	31	46	58	138 (83)
Non-Mamm.	Confirmed	0	0	0	0 (0)
	Suspected	9	4	16	29 (17)
	Total	9	4	16	29 (17)

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Table 2. Analysis of linear corridor presence at sage-grouse successful (n=104) vs. unsuccessful (n=149) nests near Lander, Kemmerer, and Pinedale, Wyoming from 2001 to 2003. Logistic regression was used with small sample Akaike's Infromation Criterion (AICc). The best subset of models was selected using difference in AICc (ΔAICc) <4. Corridor variables include livestock/wildlife trail presence (Trl) at 25, 50, and 100m from the nest, 2-track road presence (Trk) at 25 and 100m from the nest, and gravel maintained road presence (MR) at 100m from the nest. Maximized Log likelyhood (-2 ln [*L*]), the number of parameters (K), AICc, ΔAICc, and Akaike's weights (*Wi*) are presented.

Model	-2 ln [*L*]	*K*	AICc	ΔAICc	*Wi*
25Trl*, 100Trl, 100Trk, 100MR	325.006	5	332.463	0.000	0.157
25Trl*, 100Trl, 25Trk, 100MR	326.614	5	334.071	1.608	0.070
25Trl*, 100Trl, 100MR	327.74	4	334.081	1.618	0.070
100Trl, 100Trk, 100MR	328.372	4	334.713	2.250	0.051
50Trl*, 100Trl, 100Trk, 100MR	327.582	5	335.039	2.576	0.043
25Trl*, 50Trl*, 100Trl, 100MR	327.736	5	335.193	2.730	0.040
25Trl*, 100Trk, 100MR	329.214	4	335.555	3.092	0.033
100Trl, 25Trk, 100Trk, 100MR	328.188	5	335.645	3.182	0.032
100Trk, 100MR	330.472	3	335.715	3.252	0.031
25Trl*,100Trl,100Trk	329.57	4	335.911	3.448	0.028
100Trl, 25Trk,100MR	329.658	4	335.999	3.536	0.027
25Trl*, 50Trl, 100Trk, 100MR	328.66	5	336.117	3.654	0.025
100Trl, 100MR	330.992	3	336.235	3.772	0.024
25Trl*, 25Trk, 100Trk, 100MR	328.884	5	336.341	3.878	0.023
25Trl*, 25Trk, 100MR	330.006	4	336.347	3.884	0.022
25Trk, 100Trk, 100MR	330.118	4	336.459	3.996	0.021

* Variables with negative relationships to nest success

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Table 3. Relative importance (RI) and direction (-/+) of linear corridor variables for determining sage-grouse nest success at 104 successful and 149 unsuccessful nests near Lander, Kemmerer, and Pinedale,Wyoming (2001 to 2003). Variable relative importance was estimated by imposing Akaike's weights for each model on variables in that model and summing the weights for each variable from the representative set of models. Corridor variables include livestock/wildlife trail presence (Trl) at 25, 50, and 100m from the nest, 2-track road presence (Trk) at 25 and 100m from the nest, and gravel maintained road presence (MR) at 100m from the nest.

	With MR	Without MR
Variable	RI	RI
25Trl	0.593 (-)	0.686 (-)
50Trl	0.287 (-/+)	0.364 (-/+)
100Trl	0.675 (+)	0.796 (+)
25Trk	0.335 (+)	0.373 (+)
100Trk	0.552 (+)	0.698 (+)
100MR	0.848 (+)	

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Table 4. Analysis of linear corridor presence at sage-grouse successful (n=104) vs. unsuccessful (n=149) nests near Lander, Kemmerer, and Pinedale, Wyoming from 2001 to 2003. Logistic regression was used with small sample Akaike's Infromation Criterion (AICc). The best subset of models was selected using difference in AICc (ΔAICc) <4. Corridor variables include livestock/wildlife trail presence (Trl) at 25, 50, and 100m from the nest, 2-track road presence (Trk) at 25 and 100m from the nest. Maximized Log likelyhood (-2 ln [*L*]), the number of parameters (K), AICc, ΔAICc, and Akaike's weights (*Wi*) are presented.

Model	-2 ln [*L*]	*K*	AICc	Δ AICc	*wi*
25Trl*, 100Trl, 100Trk	329.57	4	335.91	0	0.184
25Trl*, 50Trl*, 100Trl,100Trk	332.80	5	337.02	1.11	0.106
25Trl*,100Trl, 25Trk, 100Trk	329.56	5	337.02	1.11	0.106
25Trl*,100Trl	329.56	3	338.27	2.36	0.057
100Trl, 100Trk	333.02	3	338.42	2.51	0.053
25Trl*, 100Trl, 25Trk,	333.18	4	338.43	2.52	0.052
25Trl*, 50Trl*, 100Trl, 100Trk	332.09	5	338.57	2.66	0.049
25Trl*, 50Trl, 100Trl,	332.23	4	339.35	3.44	0.033
100Trl, 25Trk, 100Trk	333.01	4	339.47	3.56	0.031
25Trl*, 50Trl*, 100Trl, 25Trk	333.13	5	339.54	3.63	0.030
50Trl*, 100Trl, 50Trk, 100Trk	332.08	5	339.67	3.76	0.028
25Trl*, 100Trk	332.21	3	339.75	3.84	0.027

* Variables with negative relationships to nest success

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Table 5. Analysis of linear corridor presence at sage-grouse nests (n=71) vs. available sites (n=120) nests near Lander, Kemmerer, and Pinedale, Wyoming, from 2001 to 2003. Logistic regression was used with small sample Akaike's Infromation Criterion (AICc). The best subset of models was selected using difference in AICc (ΔAICc) <4. Corridor variables include livestock/wildlife trail presence (Trl) at 25, 50, and 100m from the nest, and 2-track road presence (Trk) at 25 and 100m from the nest. Maximized Log likelyhood (-2 ln [*L*]), the number of parameters (K), AICc, ΔAICc, and Akaike's weights (*Wi*) are presented.

Model	-2 ln [*L*]	*K*	AICc	Δ AICc	*Wi*
50Trl, 25Trk, 100Trk*	233.044	4	239.205	0.000	0.341
25Trl, 50Trl, 25Trk, 100Trk*	232.586	5	239.829	0.624	0.250
50Trl, 100Trl, 25Trk, 100Trk*	233.014	4	240.257	1.052	0.202
25Trl, 100Trl, 25Trk, 100Trk*	235.756	5	242.999	3.794	0.051
25Trl, 25Trk, 100Trk*	236.952	4	243.113	3.908	0.048

* Variables with negative relationships to nest success

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Table 6. Relative importance (RI) and direction (-/+) of linear corridor variables for comparing sage-grouse nests (n=71) vs. available sites (n=120) near Lander, Kemmerer, and Pinedale,Wyoming (2001 to 2003). Variable relative importance was estimated by imposing Akaike's weights for each model on variables in that model and summing the weights for each variable from the representative set of models. Corridor variables include livestock/wildlife trail presence (Trl) at 25, 50, and 100m from the nest, and 2-track road presence (Trk) at 25 and 100m from the nest.

Variable	RI
25Trl	0.388 (+)
50Trl	0.859 (+)
100Trl	0.307 (+/-)
25Trk	0.984 (+)
100Trk	0.931 (-)

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CHAPTER 4. GRAZING SYSTEM AND LINEAR CORRIDOR INFLUENCES ON SAGE-GROUSE NESTING AND EARLY BROOD HABITATS: PROJECT SUMMARY

Sage-grouse (*Centrocercus urophasianus*) populations have declined an estimated 45 to 80% range-wide since the 1950's (Braun 1998), with estimated declines of 33% range-wide since 1985 (Connelly and Braun 1997). Declines in sage-grouse populations are primarily attributed to declines in the quality and quantity of sagebrush habitats (Connelly and Braun 1997, Connelly et al. 2000). While nearly all of the sage-grouse's range has been grazed by livestock (Braun 1998), nesting and early brood habitats are thought to be the most vulnerable to grazing influences. Additionally, fragmentation of sage-grouse habitats due to ranching and mineral development is another concern for sage-grouse population sustainability (Braun 1998). Little direct evidence has been found linking livestock grazing to sage-grouse declines (Beck and Mitchell 2000), and few studies have been done on livestock grazing influences or habitat fragmentation influences.

Our first set of objectives were to determine if reproduction was sufficient to offset adult mortality in a sage-grouse population near Lander, Wyoming. In addition, we wanted to determined important seasonal movements and habitats that influenced sage-grouse productivity. Our second set of objectives were to determine habitat components selected by nesting, successfully nesting, and early brood rearing sage-grouse females. Using the important habitat components, we examined 4 grazing systems for significant changes and trends in vegetative components important to sage-grouse seasonal use over the same periods. As a related objective we wanted to determine if forage use over the grazing periods directly related to reduced grass cover, and if grass cover in the fall related to grass cover in the spring.

To accomplish the first two sets of objectives we radio-collared 101 sage-grouse hens from 2 leks and tracked them to seasonal habitats while monitoring reproduction from April to August and adult mortality year-long. Sage-grouse were monitored from 2000 to 2003. We examined vegetation at 95 nests, 32 early brood sites, and 165 random plots on 4 different grazing systems surrounding the 2 study area leks. Grazing systems included a high intensity spring rotational deferred, a summer grazed moderate to light

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intensity rest rotational (SR), a spring and fall grazed moderate to light intensity rest rotational (SFR), and a rested from livestock control (NG). The 4 grazing systems were compared for significant changes and trends in vegetative components important to sage-grouse seasonal habitats.

We found that brood survival was high, indicating that nest success was potentially limiting reproduction in this population near Lander. Fall chicks-per-hen was far below recommended levels and suggested that the population had been declining during the study. Using both mortality and reproduction, we estimated average annual declines of 20% from 2000, 2002, and 2003. Adult female survival was lowest in the spring during the breeding season, while breeding, prenesting, and nesting deaths accounted for 31% of the annual deaths over 2 months. Survival rates for brooding and non-brooding hens were similar during the summer. Summer and fall survival rates were identical, with winter survival the highest at 91%.

Movements between seasonal habitats indicate that the population was migratory, with mean distances of 17.37 km to winter habitats and 16.87 km to the leks in the spring. Nest distances from the leks averaged 5.08 km away, with only 23% of the nests within 3 km of the leks and 24% further than 7 km. The greatest nest success occurred around 8 km from the leks with the lowest at ≤ 3 km.

Analyses of nest selection, nest success, and early brood habitats suggested that the habitat variables measured had little strength for predicting success. However, the variables did fit the data and improved predictability. The most important habitat components were total shrub canopy cover for nest selection and success, and early brood, residual grass height for nest success, and food forb cover for early brood habitat selection. Due to drought conditions, grazing system and forage utilization rates changed throughout the study. The rested and the SR systems best influenced sage-grouse habitat components. Only the SR and NG systems did not have increased bare ground cover during the study. In addition the NG system increased residual grass height. The SR system had no significant declines or increases in habitat variables important for sage-grouse habitats. The vegetative changes during the study were attributed to stocking rates and season of grazing rather than grazing system.

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Our third set of objectives were to determine if the presence of livestock/wildlife trails, 2-track roads, and maintained roads increased nest destruction rates. To accomplish these objectives we examined 253 sage-grouse nests from radio-collared females near three areas in Wyoming (Lander, Pinedale, and Kemmerer). From 2001 to 2003 we attempted to determine if the presence of livestock/wildlife trails, 2-track roads, and maintained roads at selected distance from the nests influenced sage-grouse nest destruction rates.

Linear corridor analyses at the three study sites found increased nest destruction rates when trail presence was within 25 m. Trail presence at 50 m had no effect, while presence at 100 m increased nest success rates. Two-track and maintained roads increased nest success rates at 100 m, potentially through predator aversion. For nest selection, 2-track roads at 25 m and trails at 50 m increased the likelihood of a sage-grouse nest selection while 2-tracks at 100m decreased that likelihood. Habitat or topographic features may increase this concentration of trails and roads near nest habitats or roads may provide desirable micosite habitats for foraging, influencing selection. Our results suggested that roads do not reduce sage-grouse nest success. Future sage-grouse productivity studies in high road density areas should consider the potential for artificially high nest success due to the influences of roads.

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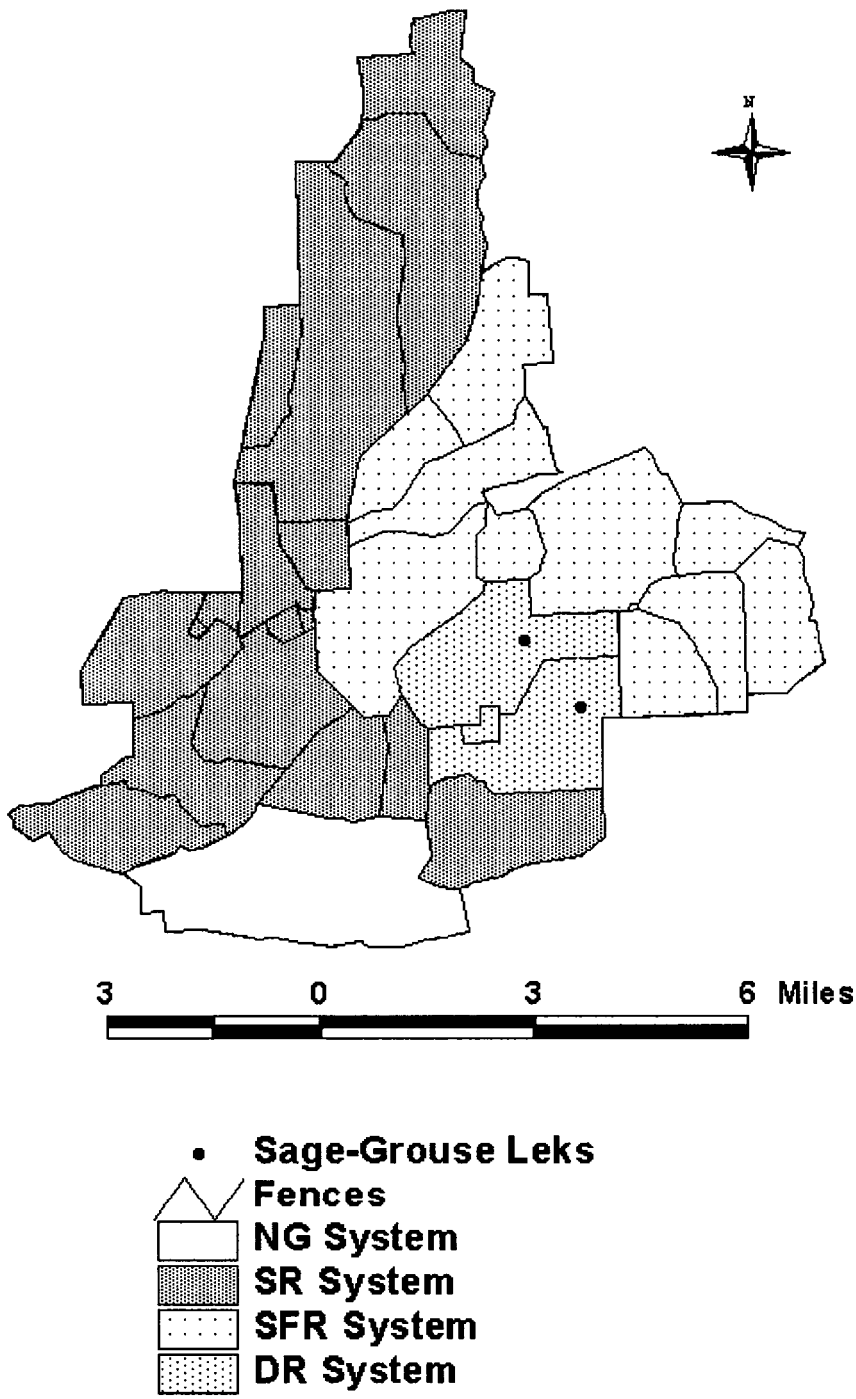
APPENDICES

Appendix A. Study area grazing systems near Lander, Wyoming from 2000 to 2003. Grazing systems included high intensity spring differed (DR), summer grazed moderate to light intensity rest rotational (SR), spring and fall grazed moderate to light intensity rest rotational (SFR), and rest from grazing (NG). Sage-grouse lek sites are included.



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Appendix B. Sagebrush new growth nutrition at radio-collared sage-grouse nests and random sites near Lander, Wyoming from 2001 to 2002. Sagebrush was collected within 15 m of samping points and examined using x-ray analysis. Nutrition variables were tested using 2-sample T-tests, with equal variances not assumed. Significance was set at $\alpha = 0.05$, with significant P-values bolded. Means, standard errors, and P-values are provided. Variables were expressed as percent of the total or parts-per-million (PPM). Acid detergent fiber was abbreviated to ADF.

	Nests		Randoms		
	Mean	SE	Mean	SE	P-Value
Sodium %	0.09	0.03	0.10	0.02	0.44
Phosphorus %	0.24	0.02	0.23	0.01	0.54
Clorine %	0.22	0.02	0.21	0.02	0.56
Calcium %	0.61	0.03	0.60	0.04	0.49
ADF %	28.27	1.16	29.16	1.08	0.27
Total Carbon %	54.06	0.89	53.58	0.76	0.42
Total Nitrogen %	2.54	0.15	2.81	0.13	**0.01**
Crude Protein %	15.83	0.94	17.48	0.84	**0.01**
Fat %	8.84	0.92	9.03	0.62	0.73
Magnesium %	0.12	0.01	0.13	0.01	0.59
Sulfer %	0.14	0.01	0.14	0.00	0.55
Potassium %	1.83	0.07	1.99	0.31	0.29
Iron PPM	101.40	22.65	108.50	21.00	0.65
Copper PPM	8.15	0.76	8.90	0.57	0.12
Zinc PPM	22.64	3.24	20.89	1.55	0.34

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Appendix C. Sagebrush new growth nutrition at radio-collared sage-grouse successful and unsuccessful nests near Lander, Wyoming from 2001 to 2002. Sagebrush was collected within 15 m of samping points and examined using x-ray analysis. Nutrition variables were tested using 2-sample T-tests with equal variances not assumed. Significance was set at $\alpha = 0.05$, with significant P-values bolded. Means, standard errors, and P-values are provided. Variables were expressed as percents of the total or parts-per-million (PPM). Acid detergent fiber was abbreviated to ADF.

	Successful		Unsuccessful		
	Mean	SE	Mean	SE	P-Value
Sodium %	0.09	0.05	0.08	0.03	0.77
Phosphorus %	0.24	0.03	0.24	0.02	0.71
Clorine %	0.21	0.04	0.22	0.02	0.59
Calcium %	0.57	0.03	0.63	0.04	**0.03**
ADF %	28.67	1.44	28.07	1.59	0.58
Total Carbon %	53.39	1.71	54.38	1.03	0.33
Total Nitrogen %	2.65	0.24	2.49	0.19	0.31
Crude Protein %	16.43	1.56	15.55	1.18	0.38
Fat %	8.89	1.62	8.80	1.14	0.92
Magnesium %	0.12	0.01	0.13	0.02	0.33
Sulfer %	0.14	0.01	0.14	0.01	0.55
Potassium %	1.88	0.14	1.78	0.06	0.25
Iron PPM	105.30	46.04	98.60	23.46	0.80
Copper PPM	8.30	1.62	8.05	0.70	0.78
Zinc PPM	23.40	5.75	22.11	4.01	0.72

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Appendix D. Optimal size (O) (3mm to 12mm) arthropods sampled at sage-grouse (*Centrocercus urophasianus*) early brood (EB) habitats (< 2 weeks old) and 4 grazing system habitats near Lander, Wyoming from 2000 to 2003. Arthropods were sampled using 17 pitfall traps along 2 parallel transects intersecting on the closest sagebrush bush of > 30 cm at EB locations and randoms points. One pitfall trap was set at the center with traps also a 1, 2.5, 7, and 15 m from the center. Data are presented by habitat type and year (00-03). Grazing systems included a high intensity differed rotational (DR), a summer grazed moderate to light intensity rest rotational (SR), a spring and fall grazed moderate to light intensity rest rotational (SFR), and a rested from livestock grazing system (NG). Arthropod abundances were categorized into four classes; hymenoptera (Hymenop), coleoptera (Coleop), orthoptera (Orthop), and hemiptera (Hemip), and the order arachnida (Arach). Total abundance (TA) and total dried mass (TM) are presented for all arthropods combined and optimal sized arthropods combined. Means and standard deviations at the 95% confidence level are provided. Yearly sample sizes for EB, SFR, DR, SR, and NG habitats in order were 5, 10, 0, 10, and 0 for 2000, 8, 8, 8, 7, and 6 for 2001, 11, 10, 8, 9, and 0 for 2002, and 10, 10, 10, 10,and 9 for 2003.

	Hymenop (O)		Coleop (O)		Orthop (O)		Hemip (O)		Arach (O)		TA (O)		TA (A)		TM (O)		TM (A)	
EB 00	491.2	395.6	70.0	63.8	3.2	2.5	4.2	4.4	24.2	8.8	595.8	415.46	869.8	453.92	2.1	1.38	5.0	3.77
EB 01	473.0	471.5	38.1	17.8	1.1	0.9	1.3	1.5	14.3	3.6	537.0	468.10	607.3	478.15	1.2	0.58	2.6	1.27
EB 02	267.9	232.0	46.0	17.3	0.4	0.4	0.4	0.4	13.5	5.6	330.5	241.69	445.2	225.83	1.5	0.64	3.2	1.15
EB 03	67.6	54.5	49.5	24.9	0.3	0.4	0.6	0.4	14.8	5.7	137.0	69.57	212.6	61.35	1.0	0.59	2.3	1.01
SFR 00	259.1	167.7	165.4	131.7	2.3	1.9	5.2	2.1	28.2	9.9	464.0	202.89	811.9	247.10	2.3	0.96	4.7	1.13
SFR 01	801.9	473.4	87.1	38.7	4.6	4.5	5.4	3.2	29.4	7.9	941.1	480.83	1098.9	485.71	2.0	0.80	4.3	1.38
SFR 02	91.8	79.3	50.7	27.3	2.3	3.1	0.6	0.8	11.7	3.4	159.9	79.18	282.0	105.11	1.2	0.55	3.5	0.81
SFR 03	156.7	129.6	57.3	25.5	1.2	1.0	0.0	0.0	23.7	4.0	242.8	116.94	338.1	102.14	1.1	0.21	3.2	0.58
DR 01	462.6	362.3	57.9	20.3	1.9	1.3	5.1	4.8	15.5	4.1	549.9	360.27	696.6	351.64	1.1	0.40	2.3	0.61
DR 02	462.0	520.6	169.0	103.9	3.5	4.3	1.0	2.0	19.0	25.5	657.9	643.68	737.6	658.81	5.1	3.65	9.1	4.24
DR 03	114.5	90.9	51.2	24.7	0.5	0.5	0.0	0.0	18.0	2.8	187.5	81.84	260.8	78.87	1.0	0.33	4.6	1.12
SR 00	153.7	95.1	70.3	37.1	2.0	0.9	4.2	2.1	49.7	16.5	288.9	90.88	634.1	198.84	1.8	0.69	3.6	1.24
SR 01	204.1	152.8	39.6	15.9	1.7	0.8	1.4	0.6	26.6	11.4	283.1	146.27	369.4	155.95	1.0	0.21	3.6	1.45
SR 02	115.4	145.9	35.4	23.0	0.4	0.5	0.1	0.2	15.8	5.6	169.6	149.20	305.1	163.13	1.0	0.61	3.2	1.67
SR 03	163.1	176.1	46.2	24.4	0.5	0.8	0.8	0.8	10.9	5.5	228.2	171.02	300.8	160.83	1.2	0.76	3.3	1.47
NG 01	1232.8	567.3	65.2	22.0	1.5	1.7	4.5	3.8	55.7	20.0	1364.2	593.18	1523.8	621.93	2.6	0.96	6.3	1.23
NG 03	426.9	313.1	94.4	43.9	0.6	0.7	0.1	0.2	34.0	13.1	566.9	300.47	643.2	278.53	4.6	2.38	6.3	2.57

Appendix E. Means (M), standard errors (SE) at α=0.05, and post hoc minimum detectable differences (P) at α=0.05 for sage-grouse habitat variables collected near Lander, Wyoming from 2000 to 2003. Habitats measured were successful nests (Succ Nest), unsuccessful nests (Unsucc Nest), all nests (Nest), associated random sites (Random), early brood use sites (Early Brood), and a subset of random sites (Brd Random) used for comparison with Early Brood. Measured variables includes total shrub canopy cover (TSCC), dead sagebrush cover (DSC), live sagebrush density (LIV), new grass cover (GRS), new grass height (GHT), residual grass cover (RGRS), residual grass height (RGHT), food forb cover (FFORB), cover forb cover (CFORB), total forb cover (TFORB), litter cover (LITTER), and bare ground cover (BG).

		Succ Nest N=36	Unsucc Nest N=52	Nest N=95	Random N=164	Early Brood N=32	Brd Random N=32
TSCC (% cover)	M	31.83	26.82	29.00	18.86	23.72	21.79
	SE	4.96	2.53	2.41	1.44	3.76	3.53
	P	9.19	4.66	4.38	2.62	6.99	6.57
DSC (% cover)	M	1.78	1.66	1.78	1.07	1.14	1.26
	SE	0.47	0.38	0.30	0.17	0.36	0.42
	P	0.87	0.70	0.54	0.31	0.68	0.78
LIV (% cover)	M	1.40	1.53	1.52	1.34	1.57	1.43
	SE	0.21	0.19	0.16	0.16	0.34	0.31
	P	0.39	0.36	0.29	0.28	0.64	0.58
GRS (cm)	M	7.01	6.94	6.87	7.72	7.34	9.08
	SE	1.44	1.32	0.95	0.84	1.26	2.29
	P	2.67	2.43	1.72	1.53	2.34	4.27
GHT (cm)	M	14.27	12.72	13.33	12.50	11.69	13.79
	SE	1.14	0.99	0.72	0.57	1.18	1.69
	P	2.11	1.82	1.31	1.03	2.19	3.14
RGRS (cm)	M	1.92	2.10	1.97	2.50	3.13	2.81
	SE	0.38	0.49	0.31	0.32	1.69	0.82
	P	0.71	0.90	0.57	0.58	3.14	1.53
RGHT (cm)	M	6.93	6.65	6.63	6.60	6.07	7.11
	SE	0.90	0.95	0.63	0.50	0.96	1.26
	P	1.67	1.73	1.14	0.90	1.78	2.35
FFORB (% cover)	M	1.49	1.27	1.38	1.20	1.67	1.22
	SE	0.55	0.36	0.29	0.18	0.39	0.40
	P	1.03	0.65	0.53	0.33	0.73	0.75
CFORB (% cover)	M	8.77	6.93	7.46	5.85	5.56	7.62
	SE	3.48	2.53	1.95	1.34	2.93	3.71
	P	6.45	4.64	3.55	2.44	5.45	6.90
TFORB (% cover)	M	11.24	9.08	9.65	7.27	7.60	9.41
	SE	3.84	3.20	2.31	1.52	3.69	4.17
	P	7.12	5.88	4.22	2.76	6.87	7.76
LITTER (% cover)	M	24.21	21.20	22.48	16.78	19.95	15.01
	SE	4.35	3.84	2.74	1.80	3.76	3.40
	P	8.07	7.05	4.99	3.27	7.00	6.33
BG (% cover)	M	5.56	9.11	8.13	10.27	9.12	7.90
	SE	2.19	2.77	1.84	1.42	2.91	2.46
	P	4.05	5.09	3.36	2.58	5.40	4.57

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Appendix F. Mean distances (M) of linear corridors from successful, unsuccessful sage grouse nests near Lander, Kemmerer, and Pinedale, Wyoming and sage-grouse nest sites and random sites near Lander, Wyoming from 2001 to 2003. Linear corridors measured were livestock wildlife trails (Trl) at 25, 50, and 100 m, 2-track roads (Trk) at 25 and 50 m, and maintained gravel roads (MR) at 100 m. Sample sizes (N) and the minimum and maximum range of detection or power (P) are provided.

		Successful N=104	Unsuccessful N=149	Nest N=72	Random N=120
25Trl	M	0.35	0.41	0.44	0.27
	P	0.17, 0.56	0.26, 0.57	0.21, 0.68	0.12, 0.46
50Trl	M	0.61	0.60	0.71	0.49
	P	0.40, 0.80	0.42, 0.78	0.46, 0.90	0.30, 0.68
100Trl	M	0.85	0.76	0.83	0.71
	P	0.67, 0.96	0.60, 0.90	0.60, 0.97	0.52, 0.87
25Trk	M	0.13	0.09	0.15	0.05
	P	0.03, 0.30	0.02, 0.20	0.03, 0.37	NA, 0.18
100Trk	M	0.45	0.36	0.22	0.27
	P	0.26, 0.65	0.21, 0.53	0.06, 0.46	0.12, 0.46
100MR	M	0.13	0.04	0.03	0.00
	P	0.03, 0.30	NA, 0.15	NA, 0.18	NA, NA

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