NESTING AND BROOD-REARING SUCCESS AND RESOURCE SELECTION OF GREATER SAGE-GROUSE IN NORTHWESTERN SOUTH DAKOTA

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

NESTING AND BROOD-REARING SUCCESS AND RESOURCE SELECTION OF GREATER SAGE-GROUSE IN NORTHWESTERN SOUTH DAKOTA

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Understanding population dynamics and resource selection is crucial in developing wildlife resource management plans, particularly for sensitive species. Greater sage-grouse (*Centrocercus urophasianus*) populations have declined range-wide at a rate of 2% per year from 1965 to 2003. In South Dakota, populations have generally declined. Reasons for the decline are mostly attributed to human-induced factors such as sagebrush degradation and removal, improper range management practices, oil and gas exploration, and West Nile virus infection. Sage-grouse occupy habitats at the eastern edge of their range in western South Dakota. We conducted a 2-year study to investigate the nesting and brood-rearing ecology of sage-grouse in northwestern South Dakota.

Female sage-grouse were captured and radio-marked (n = 53) on traditional display grounds. Radio-marked hens were tracked to estimate nesting effort, nest success, and associated habitats. Nest initiation was 95.9%, with an overall nest success of 45.6 ± 5.3%. Hens selected habitats with greater sagebrush canopy cover and nest bowl visual obstruction compared to random sites. Nest success models developed in Program MARK indicated taller grass structures increased nest success.

Chick survivorship to seven weeks post hatch ranged from 31 to 43% over the two year period and recruitment of chicks into the breeding population (1 March) was estimated to be between 5 and 10%. Between 12 July and 31 September, West Nile virus accounted for 7 to 21% of the mortality incurred by chicks, however WNv reduced recruitment by 2 to 4%. Sage-grouse selected brood-rearing habitats that provided increased visual obstruction and bluegrass (*Poa spp.*) cover. More herbaceous vegetation at these sites may provide increased invertebrate abundance, which is necessary in the diets of sage-grouse chicks.

Management of sage-grouse nesting habitat on the eastern edge of their range should focus on increasing levels of sagebrush density and canopy cover while maintaining cover and height of grasses. We recommend that land managers maintain maximum grass heights of 26 cm. For brood-rearing sites, managers should maintain high vegetation biomass (visual obstruction) for protective cover and increased invertebrate abundance. We recommended that land managers strive to attain >10% chick recruitment into the breeding season.

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GENERAL INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*) populations have declined range-wide at a rate of 2% per year from 1965 to 2003 (Connelly et al. 2004). These declines have been attributed to many factors, mostly human-induced (Connelly and Braun 1997). Factors for decline include, but are not limited to: sagebrush (*Artemisia spp.*) degradation and removal (Knick et al. 2003, Wisdom et al. 2005), livestock grazing (Beck and Mitchell 2000), fire (Baker 2006), construction of highways, fences, and power lines, (Braun 1998, Schroeder et al. 1999, Aldridge and Brigham 2001) oil and gas development (Lyon and Anderson 2003), and increased mortality due to West Nile virus infections (Naugle et al. 2005).

Further declines in sage-grouse populations are a concern to many stakeholders in the western United States landscape, as several petitions have been filed for sage-grouse to be listed under the Endangered Species Act (ESA) of 1973 (Connelly et al. 2004). Currently, Federal land management agencies are responsible for approximately 66% of the sagebrush landscape in the United States (Connelly et al. 2004). Federal agencies such as the Bureau of Land Management (BLM) and U.S. Forest Service (USFS) are directed by administrative policy to manage public lands for sustained multiple use under the Federal Land Policy and Management Act (1976), and Public Rangelands Improvement Act (1978). In addition, sage-grouse are a considered a sensitive species for the BLM and USFS. Listing of sage-grouse under the ESA could have major ramifications on the use and management of public lands in of the western United States (Knick et al. 2003).

It has been widely documented that sage-grouse are sagebrush obligates during winter and depend heavily upon it throughout their annual life cycle (Patterson 1952, Connelly and Braun 1997, Schroeder et al. 1999, Connelly et al. 2004, Moynahan et al. 2007). Sagebrush provides food resources, nesting cover, and protection from predators (Schroeder et al. 1999). Since the arrival of European settlers, sagebrush habitats have undergone numerous alterations and degradations (Patterson 1952). Sagebrush has been lost to tillage agricultural (Swenson et al. 1987), energy development (Braun 1998, Walker et al. 2007, Doherty et al. 2008), and urban expansion, reservoirs, and roads (Braun 1998, Aldridge and Brigham 2001). Furthermore, degradation and fragmentation of sagebrush has occurred from chemical and mechanical treatments of sagebrush, livestock grazing (Knick et al. 2003, Wisdom et al. 2005), construction of fences and powerlines (Braun 1998), and the introduction of invasive species (Knick et al. 2003).

Current guidelines for sage-grouse management (Connelly et al. 2000) are based on extensive studies in core sage-grouse range (e.g., Wyoming and Montana). These studies typically focused on varying aspects of sage-grouse ecology; particularly nesting and brood-rearing ecology. However, little research has been conducted on the eastern limit of sage-grouse distribution. Western South Dakota forms a transitional zone between the northern wheatgrass-needlegrass prairie that dominates most of the Dakotas and the big sagebrush plains of Wyoming (Johnson and Larson 1999). In South Dakota, sage-grouse are imperiled because of rarity or some factor(s) making them very vulnerable to extinction within the state (South Dakota Department of Game, Fish, and Parks 2006). Smith et al. (2004) reported steady declines in South Dakota sage-grouse

populations since 1972 that were possibly the result of sagebrush removal through cultivation and herbicides (Smith et al. 2005). No study has been conducted in western South Dakota investigating sage-grouse nesting and brood-rearing success and associated habitats.

The objectives of this study were to (1) determine and quantify nesting and brood-rearing resource selection of radio-marked sage-grouse, (2) estimate nest success and evaluate cause and timing of nest failures, and (3) estimate chick survival and recruitment. This study will complement previous and concurrent research conducted on sage-grouse in the Dakotas, thus providing regional land managers with baseline ecology of sage-grouse. Furthermore, management recommendations produced from this research will aid in resource management plans and coordination efforts to enhance sage-grouse habitats.

This thesis is designed as two chapters dealing with the nesting and brood-rearing aspects of sage-grouse in western South Dakota. It is the intent to publish these papers in the Journal of Wildlife Management (JWM) or a similar type of peer-reviewed journal. Therefore, publication style will follow JWM guidelines unless otherwise noted. This research was a team approach, including multiple authors on publications so I have substituted the pronoun "I" for "We". Data will be archived at the U.S. Forest Service Rocky Mountain Research Station, Fort Collins, CO.

STUDY AREA

The study was conducted within a 3,500-km^2 area in Butte and Harding counties, South Dakota; Crook County, Wyoming; and Carter County, Montana (44°44'N to 45°20'N, 103°15'W to 104°21'W; Figure 1). Approximately 75% of the area was privately owned and we conducted research on 40 private ranches. The remaining 25% of the study area was managed by the United States Bureau of Land Management (BLM), and State of South Dakota School and Public Lands Division (SDSPL). The area is predominately used for grazing purposes although small grain production is evident. Open-pit mining for bentonite occurs at the south end of the study site on Pierre soils (Charles Berdan, BLM, Belle Fourche, South Dakota, personal communication).

Vegetation consists of short shrubs, mostly Wyoming big sagebrush (*Artemisia tridentata spp.*) and plains silver sagebrush (*A. cana spp.*). Other shrubs include broom snakeweed (*Gutierrezia sarothrae*), greasewood (*Sarcobatus vermiculatus*), and saltbushes (*Atriplex spp.*) (Johnson and Larson 1999). Common grasses include western wheatgrass (*Pascopyrum smithii*), Junegrass (*Koeleria macrantha*), bluegrass species (*Poa spp.*), green needle-grass (*Nassella viridula*), and Japanese brome (*Bromus japonicus*). Common forbs include western yarrow (*Achillea millefolium*), common dandelion (*Taraxacum officinale*), pepperweed (*Lepidium densiflorum*), and pennycress (*Thlaspi arvense*) (Johnson and Larson 1999).

Temperatures in summer (May-August) average 20.1° C but can reach up to 43.3°C (South Dakota State Climate Office 2007). Mean annual precipitation is 35.3 cm, with a majority occurring during the months of April through July (South Dakota State

Climate Office 2007). Elevation ranges from 840 – 1225 m above sea level with nearly level to moderately steep clayey soils over clay shale (Johnson 1976).

Common predators included red fox (*Vulpes vulpes*), coyote (*Canis latrans*), bobcat (*Lynx rufus*), badger (*Taxidea taxus*), raccoon (*Procyon lotor*), golden eagle (*Aquila chrysaetos*), ferruginous hawk (*Buteo regalis*), American crow (*Corvus brachyrhynchos*), long-tailed weasel (*Mustela frenata*), and red-tailed hawks (*Buteo jamaicensis*).

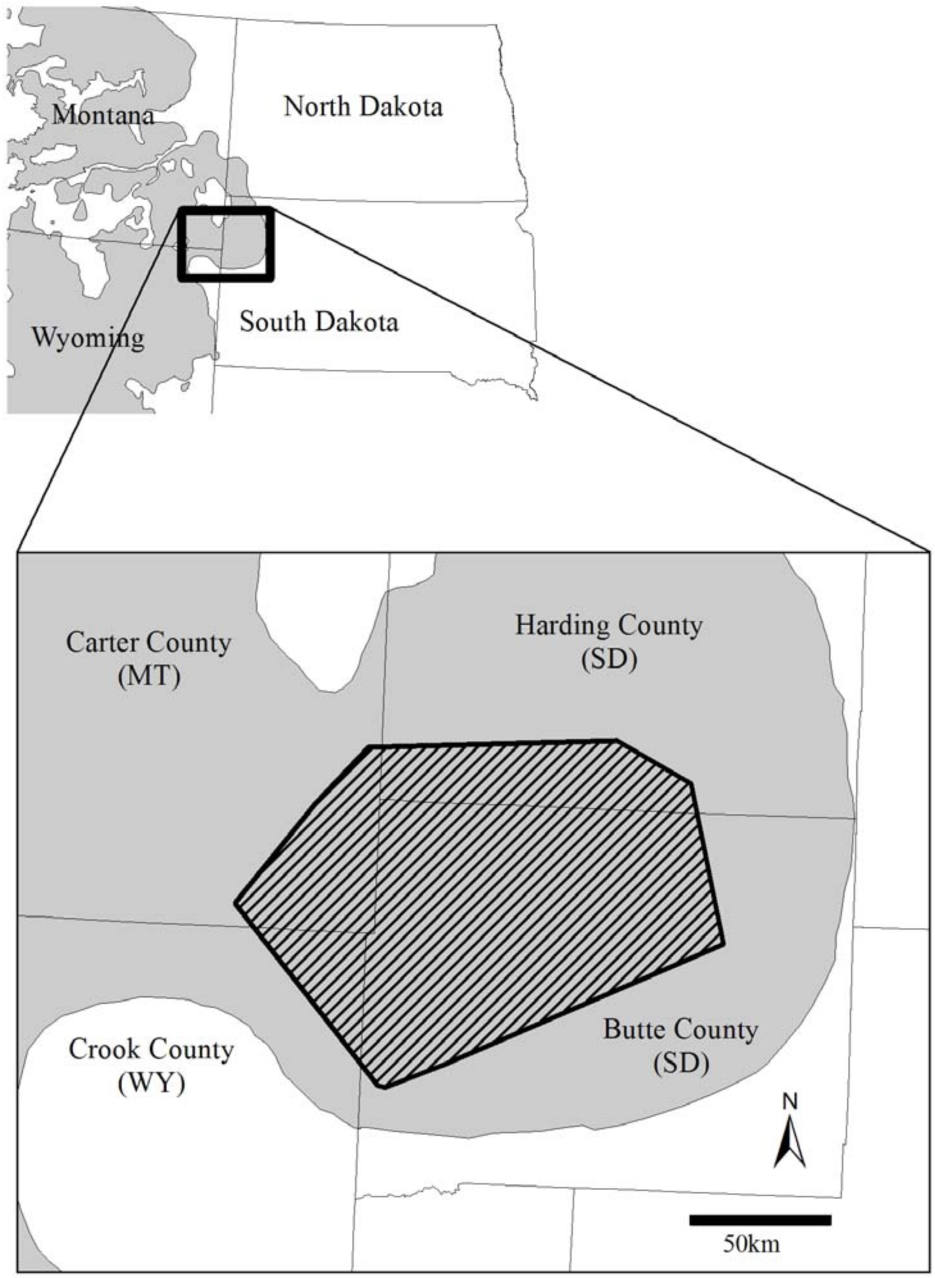

Figure 1. Study area of Butte, Carter, Crook, and Harding counties where we researched greater sage-grouse during 2006-2007. The dashed area encompasses all locations and the grayed area is current sage-grouse range (Schroeder et al. 2004).

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CHAPTER 1 – NESTING SUCCESS AND RESOURCE SELECTION OF GREATER SAGE-GROUSE IN NORTHWESTERN SOUTH DAKOTA.

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) were once distributed in parts of at least 12 states and 3 provinces, but have been extirpated from Nebraska and British Columbia (Schroeder et al. 2004). Furthermore, sage-grouse currently inhabit only 56% of their pre-settlement potential habitat (Schroeder et al. 2004) and populations have declined at an estimated rate of 2.0% per year from 1965 to 2003 (Connelly et al. 2004). Greater sage-grouse have become a sensitive species due to decreases in populations, (Aldridge and Brigham 2001, Connelly et al. 2004) and degradation of quality nesting habitat (Braun 1998, Connelly et al. 2004). Populations in South Dakota declined steadily from 1973 to 1997, and then recovered from 1997 to 2002 (Smith 2003, Connelly et al. 2004). However, in South Dakota, population indices from lek-counts were inconsistent over these time periods and meaningful assessments are lacking (Connelly et al. 2004). Nest fate and what factors determine nest success are of particular interest to biologists as it has been shown that nest success has the potential to limit population growth of sage-grouse (Schroeder 1997, Braun 1998, Schroeder et al. 1999, Dinsmore and Johnson 2005). Yet, information is lacking on the ecological requirements of nesting sage-grouse in western South Dakota. The objectives of this study were to develop an understanding on the nesting ecology, success, and resource selection of sage-grouse on the eastern edge of their range.

METHODS

Data Collection

Female Capture – We identified six active sage-grouse leks for which we had landowner cooperation for trapping. We captured female sage-grouse with large nets by spotlighting them from all-terrain vehicles between March 2006-2007 and mid-April 2006-2007 (Giesen et al. 1982). Females were weighed and equipped with a 22-g necklace-style transmitter, which were ~1.4% of mean female sage-grouse body mass and a life-expectancy of 434 days. Transmitters could be detected from approximately 2.0 to 5.0 km from the ground and were equipped with an 8-hour mortality switch. Females were classified as adults (≥2 yr old) or yearlings (<1 yr old) based upon primary wing feather characteristics (Eng 1955, Crunden 1963). The South Dakota State University Institutional Animal Care and Use Committee approved trapping and handling techniques, and study design (Approval #07-A032).

Locating and Monitoring Nests – We located radio-marked female sage-grouse twice each week during the breeding, laying, and incubation periods. In the event we could not locate an individual(s) from the ground, we searched the study-area from a fixed-wing aircraft to obtain an approximate location. Once a hen was believed to be incubating, we marked four coordinates approximately 15 m away in the four cardinal directions with a Global Positioning System (GPS) receiver (Garmin Ltd., Olathe, KS). We confirmed nest presence/absence during the subsequent visit. If a hen was present on the second visit, we flushed her to determine clutch size. This method did not cause nest abandonment as only 1 of 80 (1.3%) females abandoned their nests. Nests were checked

approximately twice each week until nest fate was determined. Nests were considered successful if ≥1 egg hatched. We documented evidence (e.g., nest bowl disturbance, eggshell remains, etc.) at the nest site to estimate predator type (i.e., mammalian or avian) (Sargeant et al. 1998). Nest distances from nearest active display ground, renests, and prior nests were calculated by Hawth's Analysis Tool (Beyer 2004) in ArcMap 9.1 (ESRI, Inc., Redlands, CA.).

Habitat Measurements – We characterized vegetation at nest sites after the fate was determined. Four, 50-m transects were established radiating in the 4 cardinal directions from the nest bowl. A modified Robel pole (Robel et al. 1970, Benkobi et al. 2000) was used to estimate visual obstruction readings (VOR) and maximum grass height at 1-m intervals from 0 m to 5m (n = 21), and at 10-m intervals out to 50 m (n = 20). We estimated sagebrush (*A. tridentata spp.* and *A. cana spp.*) density and height at 10 m intervals (n = 80) using the point-centered-quarter method (Cottam and Curtis 1956). We added four, 5-m transects, radiating in the 4 ordinal directions from the nest bowl for vegetation cover measurements. Vegetation cover was estimated using a 0.10 m^2 quadrat (Daubenmire 1959) at 1-m intervals to 5 m (n = 44) and then alternating out to 30 m (n = 52). We recorded total cover, grass cover, forb cover, shrub cover, litter cover, bare ground, and individual shrub and grass species canopy cover. In addition, we measured an equal number of random sites within a 3 km buffer of capture leks to estimate resource selection. We entered the coordinates of the random sites into a GPS and navigated to the location, then located the center over the nearest sagebrush to the coordinate.

Data Analyses

Nesting Parameters – We used the multi-response permutation procedure (MRPP; Mielke and Berry 2001) to test the null hypothesis that there were no differences among weights, clutch size, nest initiation dates, nest site fidelity, and distances to display grounds between years and between ages of females. Chi-square goodness of fit test was used to test differences of nest initiation rates between years and between ages of females. For these analyses, results were considered significant at a critical value of $\alpha \leq 0.05$.

Habitat Measurements – Maximum grass height and VOR were summarized for each of the intervals and then averages were calculated for 0 to 5 m, 1 to 5 m, 10 to 50 m, and the site level (0 to 50 m). Sagebrush density and height was estimated from a maximum likelihood estimate (Pollard 1971) and summarized for the site. Canopy coverage values were recorded to mid-point values of categories for each species, or category. These were then summarized to an average for 0 to 5 m, 1 to 5 m, 6 to 30 m, and to the site (0 to 30 m). With over 100 variables in the data set, we then screened all variables using MRPP (Mielke and Berry 2001) to identify important variables between nest and random sites and between successful and failed nests (Boyce et al. 2002). A relaxed critical value of $\alpha \leq 0.15$ was used in the screening process to reduce the risk of excluding a potentially important variable.

Resource Selection – We identified 10 habitat variables (Table 1) from the screened variables along with a year effect to investigate sage-grouse nesting habitat preferences. Variables selected included: total cover, grass cover, sagebrush cover, litter cover, mean sagebrush height, maximum grass height, and visual obstruction all at the

site level. In addition, grass height 0-5 m away from the nest bowl, visual obstruction at the nest bowl, and visual obstruction 1 m away from nest bowl were included in the data set. Year was considered a design variable in all candidate models. We used an information theoretic approach (Burnham and Anderson 2002) with nominal logistic regression to estimate the importance of various *a priori* and *post-hoc* exploratory models in SAS JMP (2005 SAS Institute Inc.). Due to a small sample size with respect to the number of parameters estimated, AIC*c* (Akaike's Information Criterion) was used being derived from our log-likelihood estimate (Burnham and Anderson 2002). Model strength was estimated using a receiver operation characteristic curve (ROC) with values between 0.7 and 0.8 considered as acceptable discrimination and values higher than 0.8 were considered excellent discrimination (Hosmer and Lemeshow 2000).

Nest Success – We used the nest survival module in program MARK (White and Burnham 1999, Dinsmore et al. 2002) to evaluate environmental and biological factors that might influence nest success. We standardized nesting dates among years by using the earliest location date for any year as the first day of the nesting season. We monitored nests over a 59-day period beginning 23 April and ending 20 June, which comprised 58 daily intervals of observations to be used in estimating daily survival rate (DSR) for the 27 day incubation period. We identified four variables from the screen process as having a potential impact on nest success which included: grass height at the site level, visual obstruction at the site level, litter cover at the site level, and 0 m forb cover (Table 2). These variables were combined with daily precipitation, daily minimum temperature, bird age, and year. We did not model nesting attempt because of a small

number of renests (*n* = 10), or days into incubation because we could not accurately measure them. Daily weather variables were obtained from the nearest daily weather station located at Nisland, South Dakota, approximately 50 km from the center of the study area (South Dakota State Climate Office 2007).

We used an information theoretic approach (Burnham and Anderson 2002) to evaluate support for models of DSR and variables. We began by developing base models which included bird age, year, and constant survival. From these base models we further explored the degree to which habitat and weather variables improved model fit. We used back-transformed estimates of DSR (Dinsmore et al. 2002) to determine effect of variables on nesting success for the best supported model. We plotted DSR versus simulated values of variables to determine the effect of variables independently from one another. We estimated standard error of DSR using the delta method (Seber 1982).

RESULTS

Nesting Parameters

Trapping and Monitoring – We captured 53 female sage-grouse (25 adults and 28 yearlings) and fitted them with transmitters during the study, 29 individuals were included both years. Adults weighed (1664 g, range: 1492 – 1912 g) more ($P < 0.01$) than yearlings (1524 g, range: 1332 – 1734 g), but there were no differences between years ($P = 0.20$). We found 80 nests (41 in 2006, and 39 in 2007) and 73 were included in nest survival analyses. Seven nests were excluded because either we did not collect vegetative measurements (*n* = 5), we felt we caused nest abandonment (*n* = 1), or were denied access to private land (*n* = 1).

Nest Initiation – Nest initiation rates (proportion of individuals initiating ≥1 nest) for all nests was 95.9% (Table 3) and did not differ between years ($P = 0.09$) or bird age ($P = 0.89$). Renest initiation rate was 28.6% (10/35) and did not differ between years ($P = 0.67$) or bird age ($P = 0.24$). Females were more likely to renest ($P = 0.02$) if their first nest was lost early into incubation with the number of first nest observation days being 7.9 ± 1.3 days for females that renested and 14.6 ± 1.8 days for females that did not renest.

Average date of nest initiation for first nests was 24 April ± 1.6 days (Table 4), with adults (≥2 years) initiating egg laying approximately 6.7 days earlier than yearlings ($P = 0.02$). No differences of nest initiation dates were detected between years for first nests ($P = 0.27$). Average hatch date for first nests was 31 May ± 1.5 days. Average renest initiation was approximately 15 days later (9 May ± 2.6 days) than first nests, with hatch date occurring 14 June ± 2.0 days. Clutch size varied between nesting attempts (first nests: 8.3 ± 0.2, renests: 6.4 ± 0.6, $P < 0.01$) (Table 4), but not between nest success ($P = 0.83$), bird age ($P = 0.98$), or year ($P = 0.10$).

Nest Location in Relation to Leks – Female sage-grouse visited multiple leks during the breeding season. One adult female in 2007 nested approximately 30.3 km from lek of capture. In 2006, successful nests were significantly closer to an active lek ($P = 0.04$) than failed nests (1.5 ± 0.3 km vs. 2.9 ± 0.5 km) (Figure 2), however there was no difference in 2007 (2.5 ± 0.5 km vs. 3.2 ± 0.7 km, $P = 0.70$), or when both years were combined (2.1 ± 0.3 km vs. 3.0 ± 0.4 km, $P = 0.13$). The distance that adults and yearlings nested to the nearest active lek did not differ significantly (2.2 ± 0.3 km vs.

3.3 ± 0.5 km, *P* = 0.08). Sixty-eight percent of nests were within 3 km of a documented active lek, and 97% of nests were within 7 km (Figure 3).

Nest site Fidelity – Mean distance between an individuals' nest in 2006 to its subsequent nest in 2007 was 1.08 ± 0.40 km (*n* = 21), but was highly variable (range: 0.07 km to 6.62 km). However, 76% of nests were within 0.70 km from a previous year's nest. There was no difference (*P* = 0.65) of nest site fidelity between adults and yearlings, or between nests that either failed or were successful the first year (*P* = 0.47). Mean distance between a failed first nest and subsequent renest was 1.85 ± 0.55 km (*n* = 10, range: 0.22 km – 5.12 km). Successful renests (0.95 ± 0.36 km, *n* = 5) were not significantly closer (*P* = 0.17) to first nests than failed renests (2.03 ± 0.91 km, *n* = 5).

Precipitation – During the months of March through June 2006, the study area received approximately 14 cm of precipitation (Figure 4). This was 33% less than the 58-year mean of 21 cm of precipitation. However, in 2007 the study area received approximately 22 cm, or 5% more precipitation than the 58-year mean for the same time period.

Resource Selection

Distributions of total cover, grass cover, grass height, visual obstruction and sagebrush height differed (*P* < 0.05) between nest sites in 2006 and 2007 (Table 1). There were also some year effects that were evident in the data for random sites, thus all logistic models included the design variable year (Table 5).

The best-approximating model (AIC*c* weight = 0.39) predicting nest sites from random sites included sagebrush canopy coverage at the site level and visual obstruction

at the nest (Table 5). Both variables positively influenced the site selected for a nest (Table 6). Increasing sagebrush cover by 5% increased the odds of use 6.1 (95% CI: 5.5 – 6.9) times. Increasing visual obstruction at the nest by 2.54 cm increased the odds of use 3.2 (95% CI: 3.0 – 3.4) times (Table 6). A second model including sagebrush canopy coverage, visual obstruction at the nest, and average grass height within 5 m was also strongly supported (AIC*c* weight = 0.35). Model discrimination (ROC values) for the top two models was excellent at 0.93 for both models. Sagebrush canopy coverage and visual obstruction at the nest had the highest summed AIC*c* weights, both achieving values of 1.0. Although the combination of sagebrush canopy coverage and visual obstruction at the nest was the strongest model, there was little evidence for a model involving them individually; visual obstruction at the nest and sagebrush canopy coverage were 11.26 and 74.54 AIC*c* units higher, respectively.

Nest Success

Most nests were located under Wyoming big sagebrush (90%) or silver sagebrush (7%). One nest was located under the side of a large boulder, and another was in a dense stand of prairie cordgrass (*Spartina pectinata*). Breeding success rates (proportion of females hatching ≥ 1 egg in a season) averaged 47.9%. Egg hatchability (proportion of eggs hatching from successful clutches) averaged 78.3%. Most of the eggs that did not hatch were infertile.

Constant nest survival rates (similar to Mayfield 1975) were 45.6 ± 5.3%, but constant survival was a poor model. Four models were within 2 AIC*c* units of the top model. The best model with an AIC*c* weight of 0.23, included grass height and litter

cover (Table 7) with a predicted nest success of 51.6 ± 6.3%. Grass height had a positive impact ($\beta = 0.15$ SE = 0.03) on nest success (Figures 5 & 6) and was present in all of the models considered. In contrast, litter cover negatively ($\beta = -0.08$ SE = 0.03) influenced nest success (Figures 6 & 7), but was also present in all of models considered.

The second-ranked model (AIC*c* weight = 0.15) included grass height, litter, daily precipitation, and a 1-day lag effect of precipitation. Although, daily precipitation had a positive influence on nest success ($\beta = 29.45$ SE = 40.35), and the 1-day lag effect negatively influenced nest success ($\beta = -1.89$ SE = 0.77), neither variable improved the top model and were only present due to being combined with grass height and litter. The third and fourth ranked models included daily precipitation, and bird age, respectively, but they were also combined with grass height and litter. Nest success varied 14.8% between years (37.7 ± 7.3% in 2006 compared to 52.5 ± 7.2% in 2007). However, adding a year affect to the top model did not improve model fit.

DISCUSSION

Nesting Parameters

Nest Initiation – Nest initiation rates for sage-grouse are generally believed to be lower compared to other prairie grouse species (Bergerud 1988). However, Schroeder et al. (1999) suggested that nesting attempts from telemetry based studies are probably under-represented in the literature, as follicular development indicated that at least 90.4% of females laid eggs the prior spring in three different studies. Our estimates of nest initiation in 2006 were probably influenced by a snow storm in late April (Figure 4) that hampered our tracking efforts during which we might have missed some nests. After the

storm we observed several "dumped" eggs suggesting that during the storm some individual females were unable to locate their nests and expelled those eggs. Nonetheless, nest initiation rates were high in this study relative to range-wide estimates (Connelly et al. 2004).

Females in our study were approximately 125 g greater than the average for 8 other studies (i.e., adults – 1525 g, yearlings – 1413 g, Schroeder et al. 1999). Heavier eastern wild turkey females (*Meleagris gallopavo silvestris*) were more likely to breed than lighter females (Porter et al. 1983), as were yearling Merriam's turkeys (*M. g. merriami*) (Hoffman et al. 1996). Sage-grouse exhibit considerable temporal variation in nest initiation rates (Moynahan et al. 2007) which may be related to nutrition during the breeding season (Hungerford 1964, Barnett and Crawford 1994).

Renest rates in sage-grouse are highly variable from 0 to 87% and are likely linked to environmental effects and habitat quality (Schroeder 1997, Moynahan et al. 2007). Low renesting rates may also be related to the relatively low productivity in these arid and semiarid environments as habitat productivity/quality has been suggested to regulate nesting and renesting in wild turkeys (Rumble and Hodorff 1993, Hoffman et al. 1996, Rumble et al. 2003). Moynahan et al. (2007) found no renest initiation for sage-grouse in dry years with little vegetative growth. Only 9.5% of hens renested in a population in North Dakota (Herman-Brunson 2007). Our observations suggest that hens that incubated nests for shorter periods were more likely to renest than hens that incubated longer. Other populations of sage-grouse on the edge of the range also showed

an inverse relation between length of incubation and renesting (Aldridge and Brigham 2001, Herman-Brunson 2007).

It has been suggested that sage-grouse nest later in more northern latitudes (Peterson 1980). South Dakota is further south than Washington and North Dakota, but had later hatch dates (Schroeder 1997, Herman-Brunson 2007), suggesting other variables (e.g., habitat, weather) may influence sage-grouse nesting chronology. Furthermore, hatch dates in South Dakota were comparable to what was reported for a northern sage-grouse population in Alberta (Aldridge and Brigham 2001)

We predicted age-specific variations in clutch size (Wallestad and Pyrah 1974, Peterson 1980, Moynahan et al. 2007) as adult females were significantly heavier than yearlings entering the breeding season. However, that was not observed in this study, or by Schroeder (1997), and Herman-Brunson (2007). Clutch size was lower for renests which was expected as female grouse expend substantial endogenous body reserves during the initial nesting attempt (Naylor and Bendell 1989).

Nest Location in Relation to Leks – Leks are the focal points of breeding and nesting conservation for non-migratory populations of sage-grouse (Connelly et al. 2000). Populations in South Dakota are believed to be non-migratory and contiguous with North Dakota and Montana populations (McCarthy and Kobriger 2005). It has been suggested that in areas with uniformly distributed habitats around leks, habitat conservation be implemented within a 3.2 km buffer (Connelly et al. 2000). However, Herman-Brunson et al. (*in review*) recommended a 5 km buffer to limit energy development and grazing

activities during the nesting period. A 5 km buffer would encompass 82% of nests in our study.

Nest site Fidelity – Sage-grouse, along with other grouse species, demonstrate fidelity in nesting areas from year to year (Fischer et al. 1993, Schroeder and Robb 2003). However, sage-grouse typically do not exhibit as strong of fidelity as other grouse, but usually 84% of nests are <3 km from a previous year's (Schroeder and Robb 2003). Seventy-six percent of nests in our study were within 0.70 km of the prior year's nest. Our results illustrate that sage-grouse in South Dakota may show more fidelity to nesting areas compared to other edge populations, which may be related to the availability of suitable nest areas around leks.

Fidelity to nesting areas may be advantageous as hens are able to maximize use of productive habitats and minimize the risk of predation (Greenwood and Harvey 1982). However, fidelity may lead to decreased productivity if sage-grouse hens occupy sink habitats (Aldridge and Boyce 2007), or it may indicate that the appropriate habitat is limited and clumped in distribution. Predators can key in on high densities of nests, increasing predation rates (e.g., Lariviére and Messier 1998). If predators are able to recognize high densities of sage-grouse nest locations due to fidelity, increased predation could occur.

Resource Selection

Sage-grouse in South Dakota selected nest sites with higher sagebrush cover and placed their nests beneath sagebrush plants with greater horizontal cover (VOR) than

random sites. In North Dakota, shrub density and nest-bowl VOR were also important predictors of sage-grouse nests (Herman-Brunson 2007).

Connelly et al. (2000) recommended 15-25% sagebrush canopy coverage for nesting sage-grouse. Meta-analysis (Hagen et al. 2007) confirmed mean sagebrush canopy coverage at sage-grouse nest sites was 21.51%. In South Dakota, sage-grouse selected the best of what was available, but that was less than the optimum. In contrast to sagebrush, grass structure in South Dakota exceeds both management recommendations (Connelly et al. 2000) and range-wide averages (Hagen et al. 2007). Western South Dakota forms a transition zone between the northern wheatgrass-needlegrass prairie that dominates most of the Dakotas and the big sagebrush plains of Wyoming (Johnson and Larson 1999). Thus, while South Dakota may have sub-optimal sagebrush cover for sage-grouse, the grass structure may be compensating the sagebrush component. However, grass structure is highly correlated with annual precipitation, and in periods of drought may not provide the necessary protection for sage-grouse nests. Poor rangeland management practices such as overgrazing will reduce grass structure which could have detrimental affects on sage-grouse populations.

Nest Success

Sage-grouse nest success varies widely across the range (Gregg 1991, Chi 2004), and is generally believed to be related to habitat conditions (Wallestad and Pyrah 1974, Connelly et al. 1991, Aldridge and Brigham 2002, Hagen et al. 2007). Our estimate of nest success was typical of other sage-grouse studies (48%, Connelly et al. 2004), despite the fact that available sagebrush canopy coverage was less than other areas. Grass height

in our study had a substantial impact on nest success (Figure 5) and probably provides the structural component necessary for nests. Successful nests in our study had taller grass structures than both failed nests and random sites, with failed nests being more comparable to random sites; this was also documented in Oregon (Gregg et al. 1994). Taller live and residual grass surrounding nests also increased nest success in Alberta (Aldridge and Brigham 2002), and was suggested to provide ample nest concealment in both sagebrush and non-sagebrush overstories in Washington (Sveum et al. 1998). Although litter cover entered our models as being an important predictive variable for nest success, the impact litter actually has on nest success is unknown. Litter could be considered as a measure of the prior year's herbaceous growth by being lower following less productive seasons, but it could also be lower after intensive grazing pressure (Hart et al. 1988, Naeth et al. 1991).

MANAGEMENT IMPLICATIONS

If sage-grouse populations continue to decrease and/or maintain sensitive status, sagebrush conservation and enhancement should be top priority for land management agencies to enable sage-grouse persistence in western South Dakota. Management for greater grass cover and height, reduced conversion to tillage agricultural, and minimizing habitat fragmentation such as energy development should be encouraged. Little information is known about the direct impacts livestock grazing has on sage-grouse habitats (Beck and Mitchell 2000) but it may be the least expensive practice to restore degraded sagebrush steppe (Braun 2006, Woodward 2006). Grazing by domestic sheep

(*Ovis aries*) has effectively controlled sagebrush (Baker et al. 1976) which could reduce sagebrush cover further in South Dakota.

Range management practices that could increase sagebrush and grass cover and height might include: rest-rotation grazing, where the rested pasture in not grazed until early July to allow for undisturbed nesting, or reduced grazing intensities and/or season of use to reduce impact on sagebrush and grass growth (Adams et al. 2004). Land managers should attempt to leave or maintain maximum grass heights ≥ 26 cm, the inflection point for 50% nest success. In addition, annual grazing utilization should not exceed 35% in order to improve rangeland conditions, particularly sagebrush cover (Holechek et al. 1999). Construction of new fences should be avoided as fences provide predator corridors, raptor perches, and pose a risk for collisions (Braun 1998). We agree with Braun (2006) and Woodward (2006) that larger pastures with fewer fences are better. Wyoming big sagebrush typically recovers from a fire in 50-120 years (Baker 2006), and because the restricted distribution and limited cover of sagebrush in South Dakota, we recommend no use of prescribed fire in areas with sagebrush.

With 75% of the study area in private ownership and the patchy network of public land; sage-grouse conservation and persistence lies in hands of private landowners. To increase sage-grouse habitats, long-term (>20 yrs) partnerships and incentives with ranchers will be imperative. This will require cooperation from state wildlife agencies, federal land management agencies, local natural resource conservation districts, and committed landowners. Forming a South Dakota sage-grouse working group may be in

order to accomplish this goal as many landowners were interested in sage-grouse conservation.

Table 1. Mean vegetation characteristics of nest sites and random sites between years for greater sage-grouse used in logistic regression models in northwestern South Dakota, USA, using MRPP (Mielke and Berry 2001), 2006-2007.

	Nest			**Random**			**Both Years**		
	2006	**2007**		**2006**	**2007**		**Nest**	**Random**	
Variable	**(*n* = 34)**	**(*n* = 39)**	**P-value**	**(*n* = 35)**	**(*n* = 39)**	**P-value**	**(*n* = 73)**	**(*n* = 74)**	**P-value**
Total Cover (%)	61.1	75.1	<0.01	55.8	66.1	<0.01	68.6	61.2	<0.01
Litter Cover (%)	7.6	7.1	0.79	6.5	6.1	0.88	7.4	6.3	0.04
Grass Cover (%)	24.2	31.4	0.01	21.1	25.8	0.21	28.1	23.6	0.01
Max Grass Hgt. (cm)	23.4	29.5	<0.01	20.4	25.0	<0.01	26.7	22.8	<0.01
Max Grass Hgt. 0-5m (cm)	25.7	30.9	0.02	20.3	24.3	0.01	28.5	22.4	<0.01
Visual Obstruction (cm)	5.5	11.1	<0.01	3.7	5.1	0.14	8.5	4.4	<0.01
Visual Obstruction 0m (cm)	20.8	29.4	<0.01	10.5	8.9	0.13	25.4	9.6	<0.01
Visual Obstruction 1m (cm)	7.3	13.7	<0.01	3.7	4.1	0.05	10.7	3.9	<0.01
Sagebrush Cover (%)	10.3	10.1	0.75	6.3	6.3	0.98	10.2	6.2	<0.01
Sagebrush Hgt. (cm)	25.8	29.7	0.04	23.8	24.0	0.97	27.9	23.9	<0.01

Table 2. Observed mean values for habitat variables between greater sage-grouse successful and failed nests used in nest success models in northwestern South Dakota, USA, using MRPP (Mielke and Berry 2001) 2006-2007.

	Successful (*n* = 33)		**Failed (*n* = 40)**		
Variable	**Mean**	**SE**	**Mean**	**SE**	**P-value**
Max Grass Hgt. (cm)	30.64	1.6	23.4	1.0	<0.01
Litter Cover (%)	6.4	0.5	8.1	0.8	0.07
Forb Cover 0 m (%)	5.3	0.8	3.9	0.6	0.09
Visual Obstruction (cm)	10.2	1.1	7.2	0.8	0.02

Table 3. Nest initiation rates of radio-marked adult and yearling greater sage-grouse in northwestern South Dakota, USA, 2006-2007.

	Ad			**Yearlings**			**Total**		
Yr	**Estimate**	**SE**	***n***	**Estimate**	**SE**	***n***	**Estimate**	**SE**	***n***
2006	90.5%	6.6	21	94.1%	5.9	17	92.1%	4.4	38
2007	100.0%	0.0	25	100.0%	0.0	10	100.0%	0.0	35
Total	95.7%	3.0	46	96.3%	3.7	27	95.9%	2.3	73

Table 4. Average clutch size and average hatch dates for first nests and renests of greater sage-grouse in northwestern South Dakota, USA, 2006-2007.

	First Nest			**Renest**		
Yr	**Initiation Date[ab]**	**Hatch Date[a]**	**Clutch Size**	**Initiation Date[ab]**	**Hatch Date[a]**	**Clutch Size**
2006	26 April ± 2.8 n = 13	3 June ± 2.6 n = 13	7.9 ± 0.3 n = 26	10 May ± 1.5 n = 2	16 June ± 1.5 n = 2	7.3 ± 0.5 n = 4
2007	21 April ± 1.7 n = 17	29 May ± 1.5 n = 17	8.5 ± 0.2 n = 30	9 May ± 4.7 n = 3	12 June ± 3.2 n = 3	5.5 ± 0.9 n = 4
Avg.	24 April ± 1.6 n = 30	31 May ± 1.5 n = 30	8.3 ± 0.2 n = 56	9 May ± 2.6 n = 5	14 June ± 2.0 n = 5	6.4 ± 0.6 n = 8

[a] Estimated only for successful nests.
[b] Estimated date of first egg laid.

Table 5. Results from logistic regression models predicting greater sage-grouse nest sites (n = 73) versus random sites (n = 74) in northwestern South Dakota, USA, 2006-2007.

Model[a]	**K**[b]	**AIC*c***	**Δ AIC*c***[c]	***wi***[d]
Sagebrush Cover + Visual Obstruction 0m	5	112.02	0.00	0.39
Sagebrush Cover + Visual Obstruction 0m + Max Grass Hgt. 0-5m	6	112.23	0.22	0.35
Sagebrush Cover+ Visual Obstruction 0m + Visual Obstruction 1m	6	113.96	1.94	0.15
Sagebrush Cover + Visual Obstruction 0m + Visual Obstruction 1m + Max Grass Hgt. 0-5m	7	114.40	2.39	0.12

[a] For ease of interpretation, year variable was excluded from model column. See Appendix 1 for full model results

[b] Number of habitat parameters plus intercept, SE, and year.

[c] Change in AIC*c* value

[d] Model weight

Table 6. Parameter Estimates, odds ratios, and corresponding confidence intervals for the best-approximating model of greater sage-grouse nests sites versus random sites in northwestern South Dakota, 2006-2007.

	Parameter			**Odds Ratio**		
Variable	**Estimate**	**Lower 95%CI**	**Upper 95%CI**	**Ratio**	**Lower 95%CI**	**Upper 95%CI**
Sagebrush Cover	0.195	0.086	0.325	1.215	1.090	1.384
Visual Obstruction 0 m	0.220	0.155	0.300	1.246	1.168	1.350

Table 7. Summary of model selection results for nest survival between year and age of greater sage-grouse in northwestern South Dakota, USA, 2006-2007.

Model [a]	**K** [b]	**AIC*c***	**Δ AIC*c***[c]	***wi***[d]
Max Grass Hgt. + Litter	3	225.79	0.00	0.23
Max Grass Hgt. + Litter + Daily Precip + Precip Lag	5	226.75	0.96	0.15
Max Grass Hgt. + Litter + Daily Precip	4	227.39	1.60	0.11
Max Grass Hgt. + Litter + Bird Age	4	227.77	1.98	0.09

[a] See appendix 2 for full model results
[b] Number of variables
[c] Change in AIC*c* value
[d] Model weight

Distance from Nearest Lek

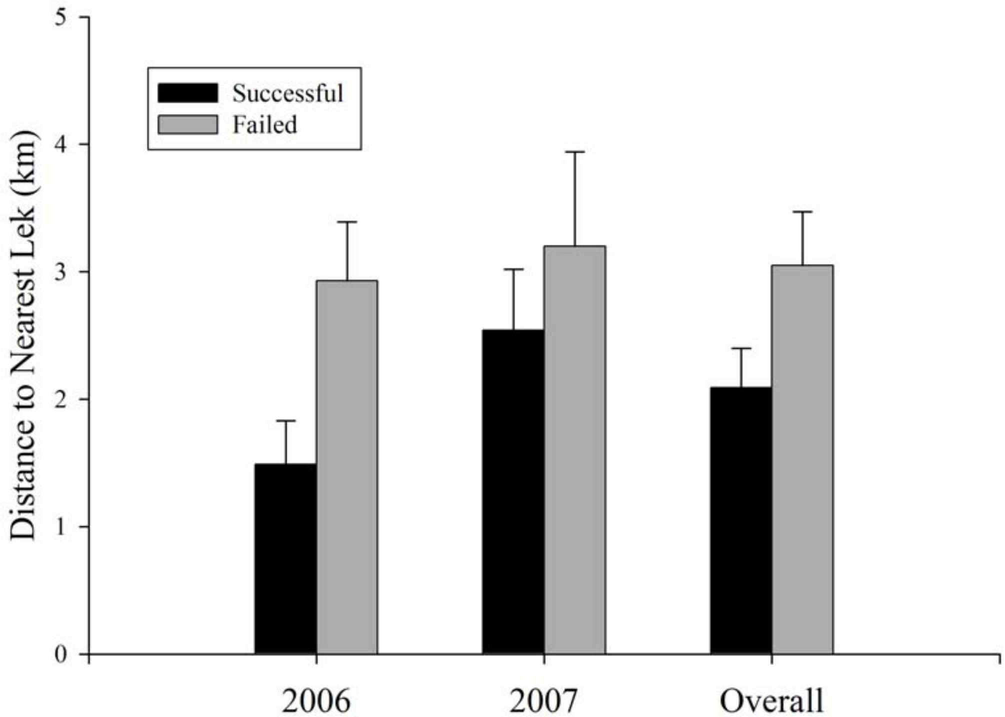

Figure 2. Mean distances plus one standard error (SE) of successful and failed greater sage-grouse nests to nearest documented active lek in northwestern South Dakota, USA, 2006-2007.

Number of Nests Within Particular Lek Buffers

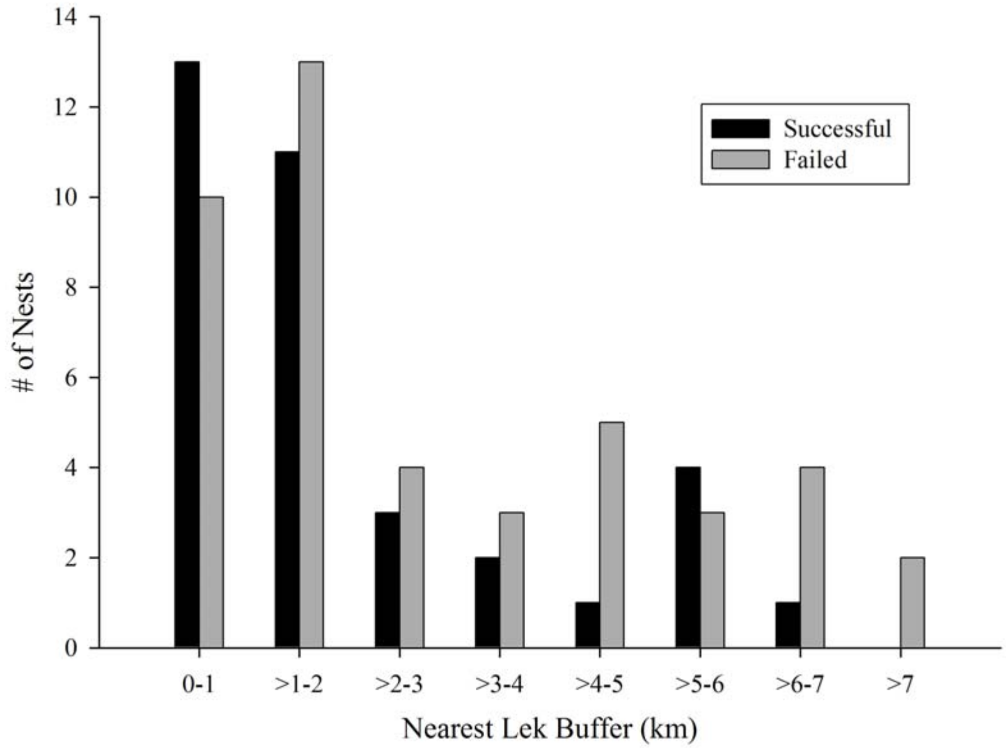

Figure 3. Distribution of successful and failed nests to nearest documented lek distances for greater sage-grouse in northwestern South Dakota, USA, 2006-2007.

Monthly Precipitation

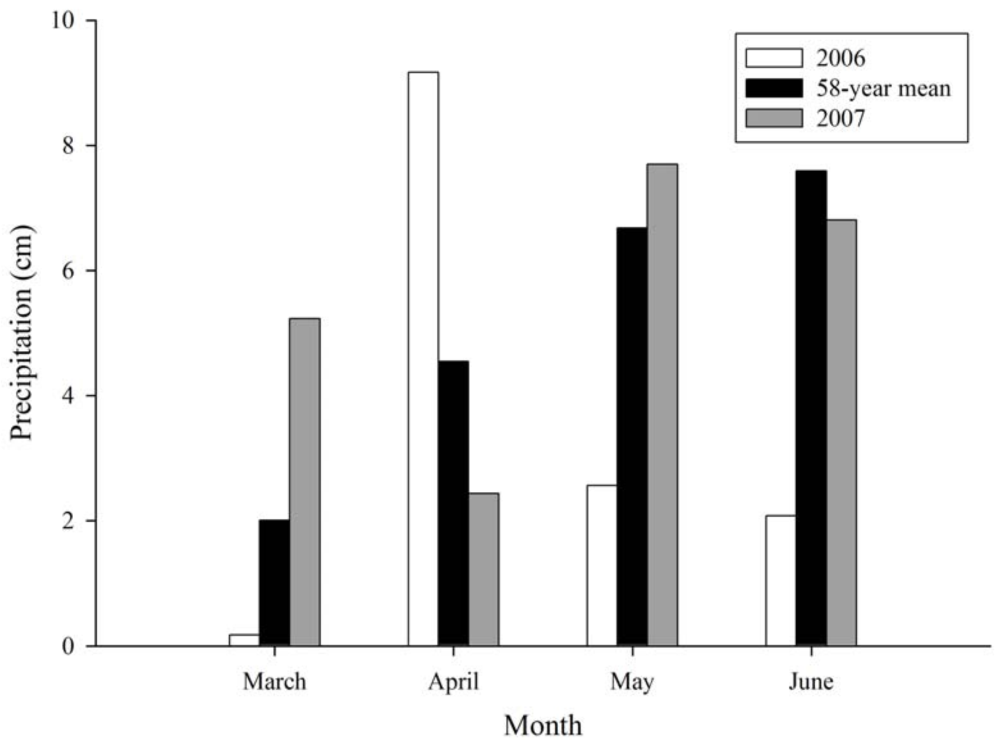

Figure 4. Monthly precipitation received during the breeding and nesting periods in 2006 – 2007 compared to the 58-year mean from the nearest daily weather station (Nisland, SD).

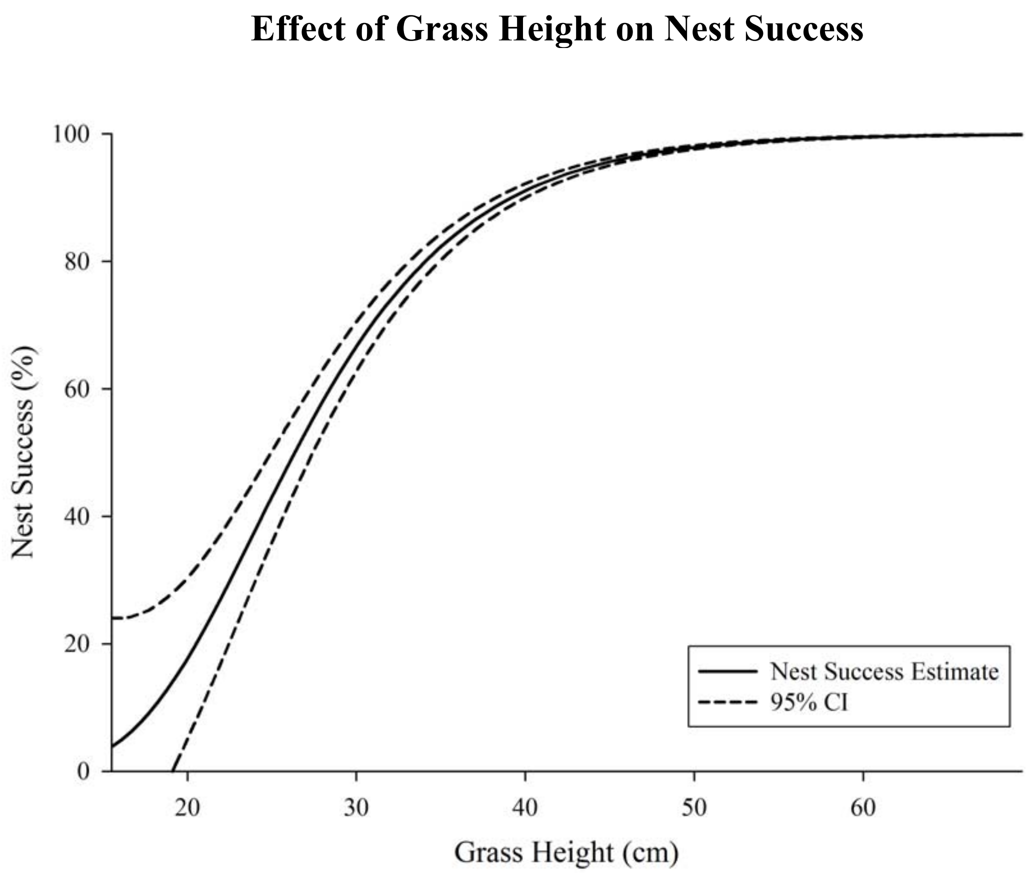

Figure 5. Effect of grass height on greater sage-grouse nest success in northwestern South Dakota, USA, 2006-2007. Nest success estimate derived from back-transformed beta estimates included in top model. Confidence intervals estimated from the delta method (Seber 1982).

Effect of Grass Height and Litter on Nest Success

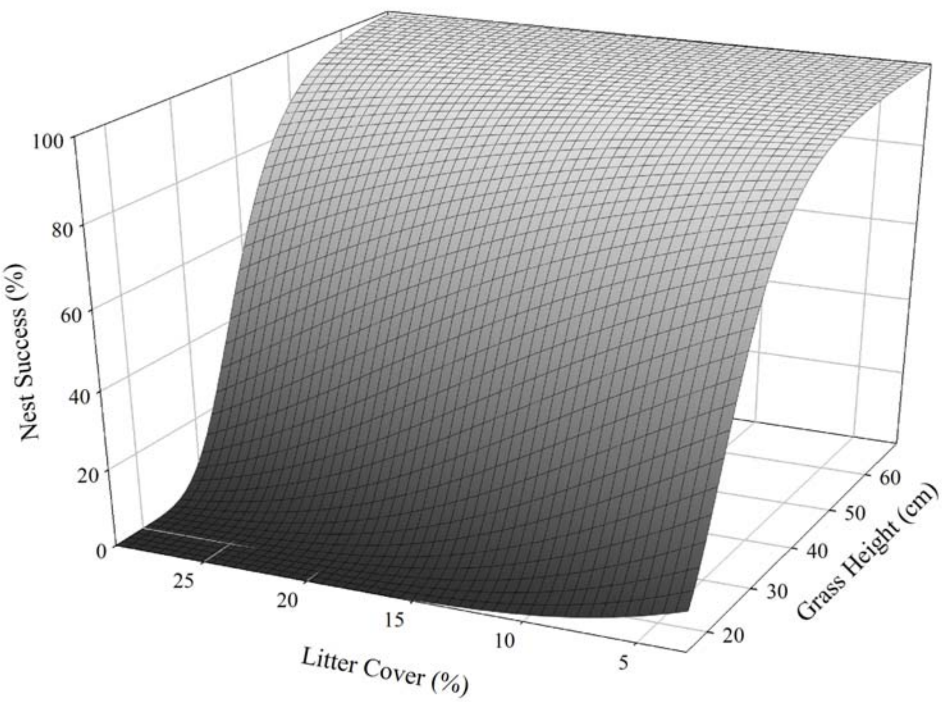

Figure 6. Effect of grass height and litter canopy coverage on greater sage-grouse nest success in northwestern South Dakota, USA, 2006-2007. Nest success estimate derived from back-transformed beta estimates included in top model.

Effect of Litter Canopy Coverage on Nest Success

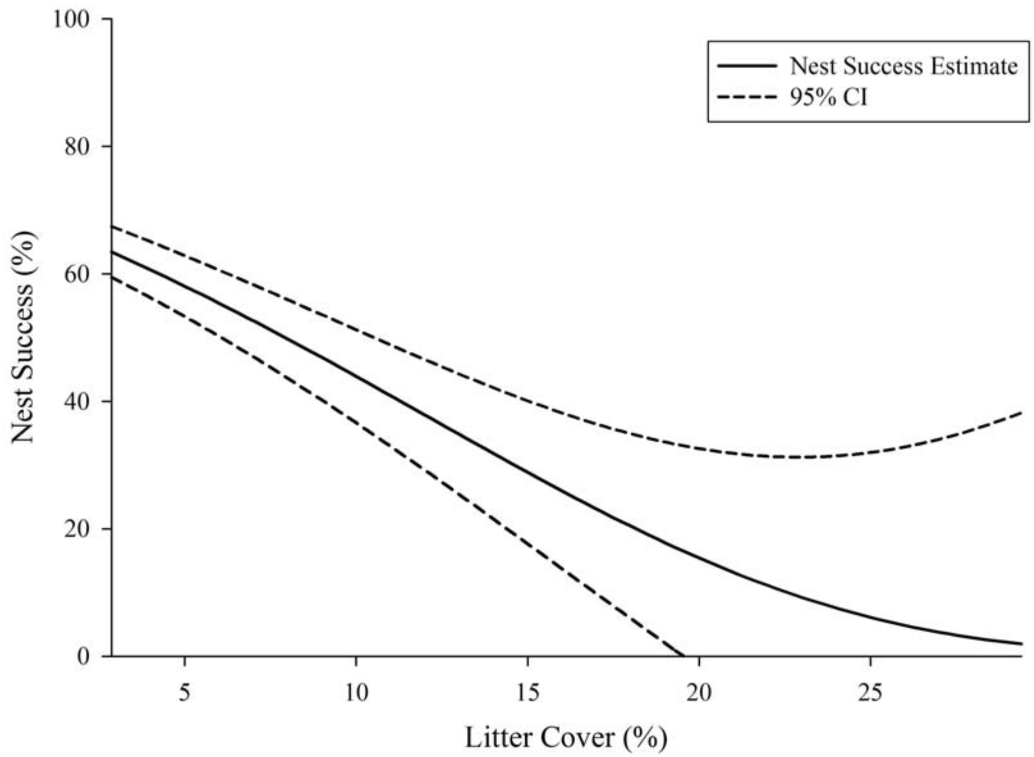

Figure 7. Effect of litter canopy coverage on greater sage-grouse nest success in northwestern South Dakota, USA, 2006-2007. Nest success estimate derived from back-transformed beta estimates included in top model. Confidence intervals estimated from the delta method (Seber 1982).

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Appendix 1. Complete results from logistic regression models predicting greater sage-grouse nest sites (*n* = 73) versus random sites (*n* = 74) in northwestern South Dakota, USA, 2006-2007.

Model[a]	K [b]	AIC*c*	Δ AIC*c*[c]	*wi*[d]
Sagebrush Cover + Visual Obstruction 0m	5	112.02	0.00	0.39
Sagebrush Cover + Visual Obstruction 0m + Max Grass Hgt. 0-5m	6	112.23	0.22	0.35
Sagebrush Cover + Visual Obstruction 0m + Visual Obstruction 1m	6	113.96	1.94	0.15
Sagebrush Cover + Visual Obstruction 0m + Visual Obstruction 1m + Max Grass Hgt. 0-5m	7	114.40	2.39	0.12
Visual Obstruction 0m	4	123.27	11.26	0.00
Visual Obstruction 0m + Max Grass Hgt. 0-5m	5	123.36	11.35	0.00
Visual Obstruction 0m + Total Cover	5	124.14	12.12	0.00
Visual Obstruction 0m + Visual Obstruction 1m	5	124.45	12.44	0.00
Visual Obstruction 0m + Max Grass Hgt.+ Sagebrush Hgt.	6	125.91	13.90	0.00
Total Cover + Max Grass Hgt. + Visual Obstruction 0m	6	125.93	13.91	0.00
Total Cover + Max Grass Hgt. + Sagebrush Hgt. + Visual Obstruction 0m	7	127.34	15.32	0.00
Visual Obstruction 1m + Sagebrush Cover	5	146.97	34.96	0.00
Visual Obstruction 1m	4	157.93	45.91	0.00
Visual Obstruction 1m + Max Grass Hgt. 0-5m	5	158.56	46.54	0.00
Sagebrush Cover + Visual Obstruction	5	162.19	50.17	0.00
Sagebrush Cover + Max Grass Hgt. 0-5m	5	166.21	54.20	0.00
Sagebrush Cover + Grass Cover	5	173.65	61.63	0.00
Sagebrush Cover + Total Cover	5	175.41	63.39	0.00
Visual Obstruction	4	176.55	64.53	0.00
Max Grass Hgt. + Sagebrush Cover	5	177.19	65.18	0.00
Total Cover + Visual Obstruction	5	178.69	66.68	0.00
Litter + Sagebrush Cover	5	180.14	68.12	0.00
Litter + Max Grass Hgt. 0-5m + Sagebrush Hgt.	6	181.63	69.62	0.00
Max Grass Hgt. 0-5m + Sagebrush Hgt.	5	182.11	70.10	0.00
Sagebrush Cover	4	186.55	74.54	0.00
Max Grass Hgt. 0-5m + Litter	5	187.00	74.99	0.00
Max Grass Hgt. 0-5m	4	187.20	75.18	0.00
Litter + Max Grass Hgt. + Sagebrush Hgt.	6	191.89	79.87	0.00
Max Grass Hgt. + Sagebrush Hgt.	5	193.07	81.06	0.00
Max Grass Hgt. + Sagebrush Hgt. + Total Cover	6	193.81	81.79	0.00
Litter + Max Grass Hgt.	5	199.64	87.63	0.00
Litter + Sagebrush Hgt.	5	199.82	87.80	0.00
Max Grass Hgt.	4	200.24	88.22	0.00
Sagebrush Hgt.	4	201.82	89.80	0.00
Total Cover	4	201.92	89.90	0.00
Grass Cover	4	206.70	94.68	0.00
Litter	4	208.96	96.94	0.00

[a] For ease of interpretation, year variable was excluded from model column.
[b] Number of habitat parameters plus intercept, SE, and year.
[c] Change in AIC*c* value
[d] Model weight

Appendix 2. Complete summary of model selection results for nest survival between year and age of greater sage-grouse in northwestern South Dakota, USA, 2006-2007.

Model	**K** [a]	**AIC*c***	**Δ AIC*c*** [c]	***wi*** [d]
Max Grass Hgt. + Litter	3	225.79	0.00	0.23
Max Grass Hgt. + Litter + Daily Precip + Precip Lag	5	226.75	0.96	0.15
Max Grass Hgt. + Litter + Daily Precip	4	227.39	1.60	0.11
Max Grass Hgt. + Litter + Bird Age	4	227.77	1.98	0.09
Max Grass Hgt. + Litter + Forb 0m	4	227.80	2.01	0.09
Year*Max Grass Hgt. + Litter	6	228.64	2.85	0.06
Max Grass Hgt.	2	228.85	3.06	0.05
Max Grass Hgt. + Litter + Forb 0m + Daily Precip	5	229.41	3.62	0.04
Max Grass Hgt. + Litter + Forb 0m+ Bird Age	5	229.79	3.99	0.03
Max Grass Hgt. + DailyPrecip + Precip Lag	4	229.96	4.17	0.03
Year + Max Grass Hgt.	3	230.15	4.36	0.03
Max Grass Hgt. + DailyPrecip	3	230.38	4.59	0.02
Max Grass Hgt. + Forb 0m	3	230.65	4.86	0.02
Max Grass Hgt. + Bird Age	3	230.78	4.99	0.02
Year*Max Grass Hgt.	4	231.18	5.39	0.02
Max Grass Hgt. + Litter + Forb 0m + DailyPrecip + MinTemp	6	231.35	5.56	0.01
Bird Age*Max Grass Hgt.	4	232.46	6.66	0.01
Year*Bird Age + Max Grass Hgt.	5	233.81	8.02	0.00
Year*Visual Obstruction + Litter	6	240.37	14.58	0.00
Year*Visual Obstruction + Litter + Forb 0m	8	240.82	15.03	0.00
Visual Obstruction + Litter	3	243.27	17.47	0.00
Visual Obstruction + Litter + Forb 0m	4	245.01	19.21	0.00
Visual Obstruction + Litter + Bird Age	4	245.11	19.32	0.00
DailyPrecip + Visual Obstruction + Litter + Forb 0m	5	246.05	20.26	0.00
Year*Visual Obstruction	4	246.35	20.56	0.00
Visual Obstruction + Litter + Forb 0m+ Bird Age	5	246.88	21.08	0.00
Daily Precip + Min Temp + Visual Obstruction + Litter + Forb 0m	6	247.27	21.48	0.00
Visual Obstruction	2	248.05	22.26	0.00
Litter	2	249.97	24.17	0.00
Year + Visual Obstruction	3	250.04	24.25	0.00
Visual Obstruction + Forb 0m	3	250.06	24.27	0.00
Visual Obstruction + Bird Age	3	250.06	24.27	0.00
Year + Litter	3	250.46	24.66	0.00
Litter + Bird Age	3	251.23	25.44	0.00
Litter + Forb 0m	3	251.49	25.70	0.00
Daily Precip + Litter + Forb 0m	4	251.91	26.12	0.00
Visual Obstruction + Forb 0m+ Bird Age	4	252.07	26.28	0.00
Year*Litter	4	252.47	26.67	0.00
Constant	1	252.71	26.92	0.00
Daily Precip	2	252.99	27.20	0.00
Year	2	253.01	27.22	0.00
Min Temp	2	253.04	27.25	0.00
Year*Forb 0m	4	253.33	27.54	0.00
Daily Precip + Precip Lag	3	253.70	27.91	0.00
Min Temp + Temp Lag	3	254.05	28.26	0.00
Year*Litter + Forb 0m	6	254.14	28.35	0.00
Daily Precip + Precip Lag + Min Temp	4	254.28	28.49	0.00
Forb 0m	2	254.36	28.57	0.00

Appendix 2. continued.

Bird Age	2	254.52	28.73	0.00
Daily Precip + Forb 0m	3	254.73	28.94	0.00
Year + Forb 0m	3	255.00	29.21	0.00
Daily Precip + Precip Lag + Min Temp + Temp Lag	5	255.06	29.27	0.00
Forb 0m + Bird Age	3	256.22	30.42	0.00
Year*Bird Age	4	256.87	31.08	0.00

[a] Number of variables
[b] Change in AIC*c* value
[c] Model weight

Appendix 3. Demographic information for all greater sage-grouse captured in northwestern South Dakota, USA, 2006-2007.

Band #	Capture Date	X[a]	Y[a]	Nearest Lek	Sex[b]	Age[c]	Weight (g)	Radio Freq.
1001	28-Mar-06	583058	4972413	Crago	F	A	1654	150.064
1002	31-Mar-06	583874	4972344	Crago	F	A	1552	150.073
1003	1-Apr-06	605131	4983015	Two Top	F	A	1618	150.083
1004	1-Apr-06	604838	4982844	Two Top	F	Y	1612	150.094
1005	1-Apr-06	604840	4983075	Two Top	F	A	1602	150.103
1006	1-Apr-06	605197	4983537	Two Top	F	A	1732	150.114
1007	1-Apr-06	605399	4982814	Two Top	F	A	1648	151.074
1008	3-Apr-06	594044	4989246	Widdoss	F	A	1586	150.133
1009	3-Apr-06	595437	4988647	Widdoss	F	Y	1734	150.145
1010	3-Apr-06	595437	4988647	Widdoss	F	Y	1464	150.155
1011	3-Apr-06	595437	4988647	Widdoss	F	Y	1482	151.085
1012	3-Apr-06	595594	4988735	Widdoss	F	A	1594	150.173
1013	3-Apr-06	595758	4988629	Widdoss	F	Y	1482	150.183
1014	3-Apr-06	595619	4988954	Widdoss	F	Y	1520	150.193
1015	4-Apr-06	623696	4994653	McFarland	F	A	1758	150.204
1016	4-Apr-06	623922	4994453	McFarland	F	Y	1556	150.214
1017	5-Apr-06	583265	4972042	Crago	F	A	1650	150.353
1018	5-Apr-06	581965	4969635	Rumph	F	Y	1520	150.363
1019	7-Apr-06	606987	5006247	County Line	F	Y	1610	150.373
1020	7-Apr-06	606596	5006738	County Line	F	A	1704	150.383
1021	7-Apr-06	606596	5006738	County Line	F	A	1626	151.014
1022	7-Apr-06	606490	5006922	County Line	F	A	1610	151.022
1023	7-Apr-06	606616	5007299	County Line	F	A	1806	151.033
1024	7-Apr-06	606053	5006751	County Line	F	A	1590	150.503
1025	7-Apr-06	605932	5006832	County Line	F	A	1642	150.703
1026	7-Apr-06	605849	5006714	County Line	F	A	1634	150.714
1027	8-Apr-06	623462	4994283	McFarland	F	A	1756	150.732
1028	8-Apr-06	623243	4995268	McFarland	F	A	1738	150.973
1029	8-Apr-06	623243	4995268	McFarland	F	Y	1470	150.764
1030	8-Apr-06	623494	4994808	McFarland	F	A	1606	150.772
1031	9-Apr-06	583034	4972327	Crago	F	Y	1472	150.785
1032	9-Apr-06	581219	4969831	Rumph	F	Y	1628	150.804
1033	9-Apr-06	581315	4969863	Rumph	F	Y	1613	150.812
1034	9-Apr-06	581512	4969966	Rumph	F	A	1636	151.333
1035	9-Apr-06	581403	4970033	Rumph	F	A	1782	151.343
1036	9-Apr-06	583487	4972092	Crago	F	Y	1544	151.353
1037	9-Apr-06	594466	4990149	Widdoss	F	A	1690	151.362
1038	10-Apr-06	605130	4983164	Two Top	F	Y	1658	151.375
1039	10-Apr-06	604967	4983102	Two Top	F	Y	1594	151.382
1040	10-Apr-06	604946	4983024	Two Top	F	Y	1480	151.393
1041	17-Jul-06	626931	4986394	Quad 7	unk	C	558	150.024
1042	17-Jul-06	626931	4986394	Quad 7	unk	C	422	151.553
1043	17-Jul-06	626931	4986394	Quad 7	unk	C	468	151.533
1044	17-Jul-06	617726	4993470	McFarland	unk	C	466	150.993
1045	17-Jul-06	617726	4993470	McFarland	unk	C	664	151.442
1046	17-Jul-06	617726	4993470	McFarland	unk	C	476	151.422
1047	18-Jul-06	602067	4986019	Widdoss	unk	C	490	150.573
1048	18-Jul-06	600432	4986227	Widdoss	unk	C	576	150.654

Appendix 3. cont.

1049	18-Jul-06	600432	4986227	Widdoss	unk	C	698	151.503
1050	18-Jul-06	600512	4987086	Widdoss	unk	C	338	151.151
1051	18-Jul-06	600512	4987086	Widdoss	unk	C	432	151.524
1052	18-Jul-06	600512	4987086	Widdoss	unk	C	600	151.245
1053	18-Jul-06	600512	4987086	Widdoss	unk	C	466	151.524
1054	18-Jul-06	596981	4987357	Widdoss	unk	C	646	151.562
1055	18-Jul-06	596981	4987357	Widdoss	unk	C	838	151.483
1056	17-Jul-06	617726	4993470	McFarland	F	A	1362	151.413
1057	18-Jul-06	596981	4987357	Widdoss	unk	C	812	151.543
1058	18-Jul-06	596981	4987357	Widdoss	unk	C	816	151.094
1059	18-Jul-06	596981	4987357	Widdoss	unk	C	644	151.533
1060	19-Jul-06	606966	4983857	Two Top	unk	C	642	151.713
1061	19-Jul-06	606966	4983857	Two Top	unk	C	628	151.453
1062	20-Jul-06	600796	4987123	Widdoss	unk	C	552	151.733
1063	31-Jul-06	599438	4991214	Widdoss	unk	C	430	150.284
1064	31-Jul-06	599438	4991214	Widdoss	unk	C	396	150.303
1065	2-Aug-06	606586	5004830	County Line	unk	C	566	151.043
1066	10-Aug-06	600069	5012561	Split Lek	unk	C	602	150.443
1067	10-Aug-06	600069	5012561	Split Lek	unk	C	494	150.524
1069	19-Jul-07	600206	4986435	Two Top	M	C	612	151.942
1070	19-Jul-07	600206	4986435	Two Top	unk	C	486	151.803
1071	19-Jul-07	600206	4986435	Two Top	unk	C	552	151.755
1072	19-Jul-07	600206	4986435	Two Top	unk	C	656	151.763
1073	19-Jul-07	600206	4986435	Two Top	unk	C	510	151.783
1074	19-Jul-07	600206	4986435	Two Top	M	C	552	151.934
1077	19-Jul-06	569728	4980943	State Line	unk	C	630	150.402
1078	19-Jul-06	569728	4980943	State Line	unk	C	500	150.127
1079	19-Jul-06	569728	4980943	State Line	unk	C	662	150.022
1080	31-Jul-06	570999	4978754	State Line	unk	C	420	150.163
1081	31-Jul-06	570999	4978754	State Line	unk	C	460	150.742
1082	20-Jul-06	600777	4987058	Widdoss	unk	C	632	N/A
1083	20-Jul-06	600777	4987058	Widdoss	unk	C	520	N/A
1084	20-Jul-06	600777	4987058	Widdoss	unk	C	584	N/A
1085	20-Jul-06	600234	4986337	Widdoss	unk	C	568	N/A
1086	20-Jul-06	600234	4986337	Widdoss	unk	C	626	N/A
1087	20-Jul-06	600234	4986337	Widdoss	unk	C	642	N/A
1088	20-Jul-06	600234	4986337	Widdoss	unk	C	640	N/A
1090	22-Aug-06	603221	4985402	Widdoss	unk	C	N/A	N/A
1092	22-Aug-06	603221	4985402	Widdoss	unk	C	N/A	N/A
1093	22-Aug-06	603221	4985402	Widdoss	unk	C	N/A	N/A
1094	22-Aug-06	603221	4985402	Widdoss	F	Y	N/A	N/A
1095	22-Aug-06	603221	4985402	Widdoss	F	C	N/A	151.123
1096	22-Aug-06	603221	4985402	Widdoss	unk	C	N/A	N/A
1097	20-Mar-07	624299	4994777	McFarland	F	Y	1566	150.984
1098	21-Mar-07	585688	4972089	Crago	F	Y	1474	150.954
1099	20-Mar-07	628371	4995961	Quad 7	F	A	N/A	N/A
1100	21-Mar-07	624274	4994608	McFarland	F	A	N/A	N/A
1101	22-Mar-07	603438	5007080	County Line	F	Y	1492	151.002
1102	22-Mar-07	585462	4970879	Crago	F	A	N/A	N/A
1103	26-Mar-07	594427	4989883	Widdoss	F	Y	1396	151.053
1104	26-Mar-07	594408	4989863	Widdoss	F	A	1684	151.064
1105	1-Apr-07	unk	unk	unk	F	unk	unk	N/A

Appendix 3. cont.

1106	1-Apr-07	unk	unk	unk	F	unk	unk	N/A
1107	1-Apr-07	unk	unk	unk	F	unk	unk	N/A
1108	1-Apr-07	unk	unk	unk	F	unk	unk	N/A
1109	23-Mar-07	605528	4982812	Two Top	F	A	N/A	N/A
1110	26-Mar-07	594255	5990427	Widdoss	F	Y	1498	151.103
1111	26-Mar-07	593709	4990683	Widdoss	F	A	1634	151.115
1112	26-Mar-07	593709	4990683	Widdoss	F	Y	1552	151.133
1119	19-Jul-07	603730	4988165	Two Top	unk	C	560	151.133
1120	19-Jul-07	603730	4988165	Two Top	unk	C	380	150.624
1121	19-Jul-07	603730	4988165	Two Top	unk	C	422	150.064
1122	19-Jul-07	606678	4984369	Two Top	unk	C	798	150.643
1123	19-Jul-07	606678	4984369	Two Top	unk	C	774	150.673
1124	19-Jul-07	606678	4984369	Two Top	unk	C	772	150.683
1125	19-Jul-07	606678	4984369	Two Top	unk	C	812	151.824
1126	23-Jul-07	580091	4970734	South Owl	unk	C	590	150.722
1127	23-Jul-07	589059	4991119	Widdoss	unk	C	532	150.793
1128	23-Jul-07	589059	4991119	Widdoss	unk	C	506	150.824
1129	23-Jul-07	589059	4991119	Widdoss	unk	C	682	150.833
1130	23-Jul-07	589059	4991119	Widdoss	unk	C	562	150.764
1131	24-Jul-07	606022	5009500	County Line	unk	C	602	150.373
1132	24-Jul-07	592056	4990220	Widdoss	unk	C	914	151.895
1133	24-Jul-07	600496	4985607	Two Top	unk	C	874	150.873
1134	2-Aug-07	608346	5002699	County Line	unk	C	966	150.883
1135	2-Aug-07	606150	5009419	County Line	unk	C	554	150.914
1136	7-Aug-07	594637	4987901	Widdoss	unk	C	566	150.923
1151	24-Oct-07	605829	5006655	County Line	M	C	2252	151.583
1152	24-Oct-07	595309	4988513	Widdoss	F	A	1500	151.393
1153	24-Oct-07	595420	4988559	Widdoss	F	A	1544	150.094
1154	24-Oct-07	605921	5006498	County Line	F	A	1496	151.363
1155	24-Oct-07	605844	5006720	County Line	F	A	1476	150.973
1501	31-Mar-06	583997	4972302	Crago	M	A	3040	151.036
1502	4-Apr-06	623572	4994708	McFarland	M	A	2920	151.194
1503	10-Apr-06	604849	4982804	Two Top	M	A	3320	151.574
1504	10-Apr-06	604701	4983175	Two Top	M	A	3216	151.585
1505	10-Apr-06	604879	4982796	Two Top	M	A	3304	151.594
1506	4-May-06	606663	5006951	County Line	M	A	3058	151.604
1507	4-May-06	606476	5006526	County Line	M	A	3048	151.614
1508	4-May-06	606663	5006951	McFarland	M	A	3022	151.962
1509	4-May-06	624042	4994699	McFarland	M	A	3094	151.973
1510	4-May-06	606508	5007060	County Line	M	A	2962	151.645
1511	5-May-06	583496	4972516	Crago	M	A	3040	151.655
1512	5-May-06	583783	4972382	Crago	M	A	3254	151.664
1513	5-May-06	581257	4969846	Rumph	M	A	2954	151.675
1514	5-May-06	594613	4989913	Widdoss	M	A	3078	151.983
1515	5-May-06	594548	4989957	Widdoss	M	A	3206	151.994
1516	5-May-06	594573	4989618	Widdoss	M	A	3044	151.036
1517	5-May-06	594437	4989670	Widdoss	M	A	3066	N/A
1518	5-May-06	594393	4989788	Widdoss	M	A	3010	N/A
1519	5-May-06	594605	4989797	Widdoss	M	A	3030	N/A
1520	20-Mar-07	624060	4994448	McFarland	M	A	3344	151.982
1522	26-Mar-07	594402	4989990	Widdoss	M	A	3140	151.803
1523	26-Mar-07	593674	4989252	Widdoss	M	Y	2378	151.813

Appendix 3. cont.

1524	26-Mar-07	594499	4989909	Widdoss	M	A	3124	151.824
1525	26-Mar-07	594409	4989727	Widdoss	M	A	3206	151.834
1526	8-May-07	606576	5006401	County Line	M	A	2932	151.843
1527	8-May-07	606581	5006401	County Line	M	Y	2302	151.854
1528	8-May-07	606648	5006757	County Line	M	A	2762	151.883
1529	8-May-07	606649	5006756	County Line	M	Y	2174	151.903
1530	10-Apr-07	583326	4972901	Crago	M	A	3234	151.914
1531	10-Apr-07	583278	4972599	Crago	M	Y	2752	151.923
1532	10-Apr-07	583280	4972594	Crago	M	Y	2550	151.934
1533	6-Apr-07	623766	4994869	McFarland	M	A	3138	151.942
1534	6-Apr-07	623813	4994912	McFarland	M	A	3046	151.956
1535	10-Apr-07	583324	4972905	Crago	M	A	2958	151.895
1536	8-May-07	632577	5029924	Squaw Creek	M	A	3230	N/A
1537	8-May-07	632419	5029864	Squaw Creek	M	A	2804	N/A
1538	8-May-07	632427	5029824	Squaw Creek	M	A	3146	N/A
1539	8-May-07	632308	5029856	Squaw Creek	M	A	3051	N/A
1540	8-May-07	632283	5029860	Squaw Creek	M	A	3190	N/A
1541	8-May-07	632251	5029908	Squaw Creek	M	A	2962	N/A
1542	8-May-07	632296	5029969	Squaw Creek	M	A	2500	N/A
1543	8-May-07	632281	5029958	Squaw Creek	M	A	2900	N/A
1544	8-May-07	632356	5029936	Squaw Creek	M	A	3190	N/A
1545	8-May-07	632099	5029946	Squaw Creek	M	A	2806	N/A
1546	8-May-07	594446	4989880	Widdoss	M	Y	2316	151.175
1547	9-May-07	605043	4982559	Two Top	M	A	2926	151.824
1548	9-May-07	583447	4972548	Crago	M	A	2828	151.895
1549	9-May-07	583149	4972598	Crago	M	Y	2310	151.914
1550	9-May-07	583115	4972531	Crago	M	A	3134	151.923
1601	16-May-06	586803	5042787	Valley Creek	M	Y	2352	N/A
1604	16-May-06	586476	5042810	Valley Creek	M	A	2874	N/A
1606	16-May-06	586717	5042928	Valley Creek	M	Y	2414	N/A
1607	16-May-06	586319	5042651	Valley Creek	M	A	2868	N/A
1608	16-May-06	586522	5042693	Valley Creek	M	A	3170	N/A
1609	16-May-06	586685	5042726	Valley Creek	M	A	3002	N/A
1610	16-May-06	586528	5042756	Valley Creek	M	A	2922	N/A
1611	16-May-06	586794	5042842	Valley Creek	M	Y	2298	N/A
1612	16-May-06	586799	5042754	Valley Creek	M	A	2864	N/A
1613	16-May-06	586671	5042868	Valley Creek	M	A	2918	N/A
1614	16-May-06	586660	5042780	Valley Creek	M	A	2738	N/A
1615	16-May-06	586597	5042715	Valley Creek	M	A	2852	N/A
1616	16-May-06	586509	5042708	Valley Creek	M	A	2990	N/A
1617	16-May-06	586433	5042659	Valley Creek	M	A	2920	N/A
1618	16-May-06	586317	5042837	Valley Creek	M	A	3034	N/A
1619	16-May-06	586459	5042861	Valley Creek	M	A	2896	N/A

[a] UTM coordinates in NAD 27, zone 13.
[b] Sex classification are: F-female, M-male, and unk-unknown.
[c] Age classification are: A-adult, Y-yearling, and C-hatch year chick.

CHAPTER 2 – BROOD-REARING SUCCESS AND RESOURCE SELECTION OF GREATER SAGE-GROUSE IN NORTHWESTERN SOUTH DAKOTA

INTRODUCTION

Knowledge of seasonal habitat selection and associated survival is important in developing management strategies for sensitive wildlife species. Concerns that greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse) populations may be declining, date back > 90 years (Hornaday 1916). In the past decade, at least seven petitions have been filed to list sage-grouse under the Endangered Species Act (ESA) of 1973 (Connelly et al. 2004). More recently, data suggest that sage-grouse populations have declined range-wide at a rate of 2.0% per year since 1965 (Connelly et al. 2004). Sage-grouse population estimates in South Dakota declined steadily from 1973 to 1997, but appeared to recover some from 1997 to 2002 (Smith 2003, Connelly et al. 2004). However, the data in South Dakota were inconsistent and firm conclusions could not be made (Connelly et al. 2004). In addition, information is lacking on the ecological requirements of sage-grouse in western South Dakota.

Initial sage-grouse brood-rearing sites are typically in close proximity of nest sites and must provide high invertebrate abundance and diversity. Invertebrates are necessary for growth, development and survival of sage-grouse chicks (Johnson and Boyce 1990). Invertebrates continue to be important in the development and survival of sage-grouse chicks >3 weeks of age (Johnson and Boyce 1990), as chicks include greater amounts of forbs in their diet after 3 weeks (Klebenow and Gray 1968). Chicks that fed in forb-rich habitats gained more weight than when they fed in forb-poor habitats (Huwer 2004) and

areas with greater forb cover may attract higher numbers of invertebrates (Jamison et al. 2002). Greater invertebrate abundance may explain why sage-grouse tend to select areas with higher forb cover (Drut et al. 1994*a*, Apa 1998, Sveum et al. 1998, Holloran 1999).

Estimates of sage-grouse chick survival are limited, and have not been based on standardized time periods, thus making comparisons among studies difficult (Beck et al. 2006). Chick survival during the first 50 days post-hatch is generally low ranging from 18 – 33% (Schroeder 1997, Aldridge and Brigham 2001). Juvenile sage-grouse survival is greater ranging from 64% to 86% for chicks 10 weeks old to about 40 weeks (Beck et al. 2006). Combined, survival from hatch to first breeding season is estimated to be about 10% (Crawford et al. 2004). To our knowledge, no study has attempted, or been able to follow sage-grouse chicks from hatch to recruitment of 1 March.

Sage-grouse in northwestern South Dakota occupy transitional habitats between the northern wheatgrass-needlegrass prairie that dominates most of the Dakotas and the big sagebrush plains of Wyoming (Johnson and Larson 1999). In South Dakota, sage-grouse are imperiled because of rarity or some factor(s) making them very vulnerable to extinction within the state (South Dakota Department of Game, Fish, and Parks 2006). The objectives of this study were to develop an understanding of brood-rearing survival, home range, and resource selection of sage-grouse in northwestern South Dakota. This information will be useful in developing conservation and management plans for sage-grouse in South Dakota and other eastern fringe populations.

METHODS

Data Collection

Female Capture – We identified six active sage-grouse leks for which we had landowner cooperation for trapping. We captured female sage-grouse with large nets by spotlighting from all-terrain vehicles between March 2006-2007 and mid-April 2006-2007 (Giesen et al. 1982). Females were weighed and equipped with a 22-g necklace-style transmitter, which were ~1.4% of mean female sage-grouse body mass and a life-expectancy of 434 days. Transmitters could be detected from approximately 2.0 to 5.0 km from the ground and were equipped with an 8-hour mortality switch. Females were classified as adults (≥2 yr old) or yearlings (≤1 yr old) based upon primary wing feather characteristics (Eng 1955, Crunden 1963). The South Dakota State University Institutional Animal Care and Use Committee approved trapping and handling techniques, and study design (Approval #07-A032).

Monitoring and Chick Capture – We located radio-marked female sage-grouse twice each week throughout the nesting season. For hens that successfully nested, we located these hens and broods twice each week. Broods were approached cautiously to minimize the possibility of flushing or scattering the brood, with most locations being acquired within 20 m of actual locations. When chicks reached approximately 3 and 5 weeks of age we flushed the brood and searched the area to obtain estimates of brood size. We recorded the site as brood failure if no chicks were present with a hen, and subsequent locations of the hen for 2 weeks showed no evidence of chicks.

At 7 weeks of age, we attempted to capture and radio-mark as many chicks in each remaining brood as possible. Aided by radio-telemetry of the female, chicks were captured at night by a 3-5 person crew using a spotlight. We counted chicks that flew off during chick capture to estimate survival to 7 weeks of age. Chicks were weighed and equipped with a 10.7 g necklace style transmitter with mortality indicator which weighed <3% of mean chick body mass at the time of capture. These transmitters had a guaranteed life-expectancy of 150 days. The South Dakota State University Institutional Animal Care and Use Committee approved all trapping and handling techniques and study design (Approval #07-A032).

We located radio-marked chicks twice each week to obtain survival estimates. Field necropsies were conducted to identify primary predators. Dead birds that yielded testable carcasses (i.e., brain, wing or leg bones, internal organs, or spinal column present) were tested for West Nile virus (WNv) infections using real-time polymerase chain reaction (Shi 2001) and immunohistochemistry (Kiupel et al. 2003).

Habitat Measurements - We characterized vegetation at sites used by females with broods about 12.6 ± 0.6 days after the location. Two 50 m transects were established in the north-south cardinal directions. A modified Robel pole (Robel et al. 1970, Benkobi et al. 2000) was used to quantify visual obstruction readings (VOR) and maximum grass height at 10 m intervals (n = 11). We estimated sagebrush (*Artemisia. tridentata spp.* and *A. cana spp.*) density and height at 10 m intervals (n = 11) using the point-centered-quarter method (Cottam and Curtis 1956). Canopy coverage was estimated using a 0.10 m^2 quadrat (Daubenmire 1959) at each 10 m interval. Four

Daubenmire frames were placed at the interval in an H-shape with each leg 1 m long, resulting in 44 quadrats per site. We recorded total cover, grass cover, forb cover, shrub cover, litter cover, bare ground, shrub species, grass species, and forb species cover. In addition, we measured an equal number of random sites during the same period. Random points were generated within a 10 km buffer of capture leks in a Geographic Information System (GIS) (ESRI, Inc. ArcMap 9.1, Redlands, CA.). Random points were not sampled if they were on a road, in a road ditch, or on private land we did not have access.

Data Analyses

Survival – We estimated apparent survival for chicks at 3, 5, and 7 weeks of age. Mean hatch date of first nests (31 May) was used as the starting point for chick survival. Broods <7 weeks old were censored from the analysis if we witnessed brood-mixing (>1 female present), or chick-adoption (more chicks present than hatched). If the female died before chicks reached 7 weeks of age, we assumed complete brood loss. For chicks that were radio-marked at 7 weeks, we used a Kaplan-Meier product-limit method (Kaplan and Meier 1958) modified for staggered entry (Pollock et al. 1989) starting at the 7-week apparent survival rate. We monitored chicks at least once each week until they were recruited into the population (1 March). We used Program CONTRAST (Hines and Sauer 1989) to test for differences between years, with a critical value of $\alpha \leq 0.05$.

Because some carcasses of chicks were not suitable for testing for WNv infections, we estimated a minimum and maximum WNv mortality rate during the peak WNv transmission period of 12 July through 31 September for chicks (Walker et al. 2007). Minimum mortality rates were based on confirmed WNv mortalities, while maximum

mortality rates were based on total mortalities minus negative cases and included mortalities where the carcass was not testable, no carcass was recovered and inconclusive tests (Walker et al. 2007).

Brood Home Range – We used the home range extension (Rodgers et al. 2007) in a Geographic Information System (GIS) (ESRI, Inc. ArcMap 9.1, Redlands, CA.) to calculate 50% and 95% adaptive kernel brood-rearing home ranges. Home ranges were estimated for broods with at least 18 locations between hatch and 31 August. If a female was monitored both years, only the home range with the most points was used to reduce dependency in our data set.

Resource Selection – All measurements were summarized to a value for the site. Sagebrush density and height was estimated from a maximum likelihood estimate (Pollard 1971). Canopy coverage values were to mid-point values of categories and summarized to an average value for the site. To reduce biologically insignificant variables, we screened canopy coverage variables and excluded any variables with canopy coverage less than 2% on sites which they were present. We then conducted a principal components analysis to distinguish important variables that captured the variation among sites. We could not discriminate between early (<5 weeks of age) and late brood sites (5 to 11 weeks of age), thus we combined early and late brood-rearing sites to test for overall habitat selection.

We identified 8 variables (Table 8) with a year effect to investigate sage-grouse brood habitat resource selection. These included: sagebrush density, visual obstruction, maximum grass height, total cover, grass cover, sagebrush cover, bluegrass (*Poa spp.*)

cover, and Japanese brome (*Bromus japanicus*) cover. Year was considered a design variable in all candidate models. We used an information theoretic approach (Burnham and Anderson 2002) with nominal logistic regression to estimate the importance of various *a priori* and *post-hoc* exploratory models in SAS JMP (2005 SAS Institute Inc.). Due to a small sample size with respect to the number of parameters estimated, AIC*c* (Akaike's Information Criterion) was used. Model predictive strength was estimated using a receiver operation characteristic curve (ROC) with values between 0.7 and 0.8 considered as acceptable discrimination and values higher than 0.8 were considered excellent discrimination (Hosmer and Lemeshow 2000).

RESULTS

Chick Survival

We monitored 10 and 14 broods in 2006 and 2007, respectively. Survival at 3 weeks post hatch was similar between years at 52%. Apparent chick survival to 7 weeks post-hatch, ranged between years from 31% in 2007 to 43% in 2006 (Table 9). Recruitment was estimated to be 9.5% (95% CI: 2.8 to 16.1%, *n* =31) in 2006 (Figure 8) and 5.1% (95% CI: 0 to 10.1%, *n* =24) in 2007 (Figure 9). There was no statistical difference between years (x^2 = 1.09, df = 1, *P* = 0.30), and combined recruitment for both years was 6.3% (95% CI: 2.7 – 9.9%, *n* = 55). Mortalities were attributed to WNv infections and predation by red foxes (*Vulpes vulpes*), coyotes (*Canis latrans*), bobcats (*Lynx rufus*), long-tailed weasels (*Mustela frenata*), and red-tailed hawks (*Buteo jamaicensis*).

Between 12 July and 31 September, WNv infection was attributed ≥ 6.5% (95% CI: 0 – 15.1%, *n* =31) of chick mortalities in 2006, but may have caused up to 71.0% (95% CI: 55.0 – 86.9%, *n* =31) of mortalities (Table 10). In 2007 the minimum WNv mortality rate was 20.8% (95% CI: 4.6 – 37.1%, *n* =24) which did not differ from 2006 (x^2 = 2.32, df = 1, *P* = 0.13). Maximum WNv mortality rate for 2007 was 62.5% (95% CI: 43.1 – 8.19%, *n* =21), which also did not differ from 2006 (x^2 = 0.42, df = 1, *P* = 0.52).

Brood-rearing Home Range

We estimated home ranges for 15 broods. Mean 50% adaptive kernel home range was 7.59 ± 2.35 km^2 and did not vary between years (x^2 = 1.498, df = 1, *P* = 0.221). Mean 95% adaptive kernel home range was 51.81 ± 16.31 km^2 and did not vary between years (x^2 = 1.279, df = 1, *P* = 0.258). The largest estimated 50 and 95% adaptive kernel home ranges were 31.39 km^2 and 201.76 km^2 (*n* = 21), respectively, while the smallest home ranges were 0.22 km^2 (*n* = 22) and 1.48 km^2, respectively.

Resource Selection

We sampled 59 and 60 brood sites and 56 and 60 random sites in mid June through August 2006 and 2007, respectively. All variables were significantly different between years for either brood or random sites, thus we applied a design variable, year, to all logistic models (Table 11). Brood-rearing sites had higher visual obstruction, taller grass heights, greater total cover, grass cover, sagebrush cover, Japanese brome cover, and bluegrass cover than random sites (Table 8). In contrast, sagebrush density was higher at random sites. The best approximating model (AIC*c* weight = 0.23) indicated

visual obstruction and bluegrass cover to be the best habitat predictors for brood-rearing sites (Table 11). The addition of other non-correlated habitat variables to the top model (sagebrush cover, sagebrush density, or Japanese brome), did not increase model fit. Model discrimination was acceptable with a ROC value of 0.73.

Both visual obstruction and bluegrass cover positively influenced brood-rearing site selection as parameter estimates were positive (Table 12), with visual obstruction having a slightly larger impact (Figure 10). Broods were 3.06 times (95% CI: 2.84– 3.34) more likely to select an area if visual obstruction increased by 2.54 cm, and 5.61 times (95% CI: 5.15 – 6.13) more likely to select an area if bluegrass cover increased by 5% canopy cover.

DISCUSSION

Survival

Survival of sage-grouse chicks to 3 to 4 weeks of age is generally low, ranging from 22 to 50% (Burkepile et al. 2002, Aldridge 2005, Gregg et al. 2007, Herman-Brunson 2007). We did not attach transmitters to sage-grouse chicks <1 week, but our estimated survival rate to 3 weeks (52%) was among the highest reported. Sage-grouse chick survival to 7 weeks (34%) in our study was higher than reported for a declining population in Alberta (Aldridge and Brigham 2001, Aldridge 2005), but similar to a stable population in Washington (Schroeder 1997). Our estimate to 7 weeks is conservative, as flush counts may underestimate chick survival (Aldridge and Brigham 2001). We feel that our 7 week survival estimate is fairly accurate as it was conducted at night when broods tend to group together, and the count was always conducted by at least

3 people. Furthermore, survival rates between flush counts and telemetry estimates for sage-grouse chicks at approximately 8 weeks of age have been documented to be similar (Aldridge 2005). Aldridge (2005) suggested that accuracy of flush counts increase as chicks become larger in size, making them easier to locate and flush.

Survival of sage-grouse chicks from 10 weeks through the following March, ranges from 64 to 86% (Beck et al. 2006). Sage-grouse chick survival to 1 January in North Dakota was 13 to 17% (Herman-Brunson 2007). However, our data suggest that chick survival to recruitment would be half that. Although seemingly low, our recruitment rate of 6% suggests that the index of recruitment by Crawford et al. (2004) was realistic. However, West Nile virus infections in 2006 decreased chick recruitment the next spring by about 2%. In 2007, WNv decreased chick recruitment by approximately 4%.

Using our estimates of nest initiation (95.9%), breeding success (47.9%), clutch size (8.0), egg hatchability (78.3%), 1:1 sex ratio, and recruitment rates of 5.1 and 9.5%, annual survival of adult hens would need to be 93 to 86% to maintain a stable population, respectively. If recruitment increased to 15 or 20%, hen survival necessary for a stable population would be lower at 78 and 71%, respectively. The latter estimate may be more reasonable for sage-grouse populations as annual female survival varies from 37 to 78% (Connelly et al. 2004). However, fluctuations of nesting parameters and recruitment could substantially alter these estimates, but chick recruitment of >10% should help maintain stable populations even in years with poor nesting success or extreme WNv infections.

Brood-rearing Home Range

Few studies have attempted to quantify brood-rearing home ranges for sage-grouse (Wallestad 1971, Connelly and Markham 1983, Drut et al. 1994*a*). However, home range estimates have ranged widely from 0.51 km^2 (Wallestad 1971) to 51.00 km^2, Drut et al. 1994*a*). Differences in home range size have been suggested to be related to forb availability with home ranges being both smaller and larger in areas with increased forb abundance (Drut et al. 1994*a*, Connelly and Markham 1983). However, forbs did not appear to be an important predictor variable in our analyses, suggesting other variables (e.g., visual obstruction, sagebrush distribution) may better explain why home range estimates in South Dakota were rather large.

Resource Selection

Visual obstruction and bluegrass cover were identified to be the best variables at predicting brood-rearing sites for sage-grouse in South Dakota. Increased visual obstruction provides protection from predators, and perhaps more importantly, greater herbaceous biomass which is correlated with greater invertebrate abundance (Healy 1985, Rumble and Anderson 1996). Invertebrates are an important component of sage-grouse chicks' diets (Johnson and Boyce 1990, Drut et al. 1994*b*). Female sage-grouse tend to move their broods from upland, nesting-type areas, to more mesic, greener areas later in the summer (Peterson 1970, Dunn and Braun 1986, Sveum et al. 1998). Adapted to a broad range of soils, bluegrass is common on sites with abundant soil moisture in South Dakota (Stubbendieck et al. 1997). Although we were not able to differentiate between early and late brood-rearing habitats, broods may be selecting areas with greater

bluegrass cover for the increased invertebrate abundance that greener areas tend to provide.

Sage-grouse brood-rearing habitats are generally linked to forb abundance (Drut et al. 1994a, Apa 1998, Sveum et al. 1998, Holloran 1999). Forbs not only provide direct food resources (Drut et al. 1994*b*), but increased invertebrate abundance (Jamison et al. 2002). We did not note a difference in forb cover between brood (7.6%) and random sites (7.1%), and it was not an important predictor in our analysis, while other studies have shown sage-grouse broods to use areas with forb cover up to 41.3% (Schoenberg 1982). In contrast, females with broods in South Dakota selected areas with higher grass cover that was greater than typically reported in the literature (Klott and Lindzey 1990, Drut et al. 1994*b*, Sveum et al. 1998, Thompson et al. 2006). Western South Dakota forms a transition zone between the northern wheatgrass-needlegrass prairie that dominates most of the Dakotas and the big sagebrush plains of Wyoming (Johnson and Larson 1999), and possesses a greater grass component compared to the shrub-steppe region (Lewis 2004). Grass structure is highly correlated with visual obstruction, which, provides increased protection from predators and invertebrate abundance. Therefore, forbs may be more important to sage-grouse brood-rearing habitat in core sagebrush areas (e.g., Columbia Basin) where there is more bareground, while grass structure may be more important for broods on the eastern edge of their range (e.g., South Dakota). In Alberta, another edge-type habitat, key brood habitat in moist areas and drainages was suggested to be limiting sage-grouse productivity (Aldridge and Brigham 2002).

MANAGEMENT IMPLICATIONS

With possible listing under the Endangered Species Act, sage-grouse conservation and preservation will be a priority for many western land management agencies. For sage-grouse brood-rearing habitat in western South Dakota and other eastern edge populations, management strategies should focus on maintaining or increasing grass structure (cover and height) which provides high visual obstruction for sage-grouse broods. In addition, managers should promote and protect greener areas during mid to late summer. These areas typically have higher production and invertebrate abundance. This may include government programs that defer or eliminate grazing and haying operations in these areas.

Domestic livestock grazing by cattle (*Bos taurus*) and sheep (*Ovis aries*) has been shown to have both positive and negative impacts on rangeland condition and health in the sagebrush ecosystem (Holechek et al. 2001) and sage-grouse habitats (Beck and Mitchell 2000). Grazing by sheep can be an effective way of reducing sagebrush (Baker et al. 1976) which could negatively affect sage-grouse productivity in South Dakota, particularly during the nesting period. High intensity cattle grazing of the herbaceous understory (grasses and forbs), may allow for greater forb and sagebrush growth (Paige and Ritter 1999) but that may also negatively influence sage-grouse productivity by decreasing plant biomass and protective cover and consequently, reduce insect abundance. However, light or moderate grazing in dense, grassy meadows increased sage-grouse use (Klebenow 1982) but overgrazing of these areas reduced sage-grouse habitat (Klebenow 1985, Oakleaf 1971) and were avoided by sage-grouse (Klebenow 1982).

WNv was an important factor for sage-grouse chick survival. Management practices to mitigate its affect on sage-grouse chick survival appear to be minimal and tied to anthropogenic water sources, particularly coal-bed natural gas ponds (Walker et al. 2007). Unless sage-grouse develop stronger immunity to this disease, their future looks uncertain. However, small increases in chick recruitment, either through increased nesting success or increased chick survival should have positive effects on sage-grouse populations.

With 75% of the study area in private ownership and the patchy network of public land; sage-grouse conservation and persistence lies in hands of private landowners. To increase sage-grouse habitats, long-term (>20 yrs) partnerships and incentives with ranchers will be imperative. This will require cooperation from state wildlife agencies, federal land management agencies, local natural resource conservation districts, and committed landowners. Forming a South Dakota sage-grouse working group may be in order to accomplish this goal, as many landowners were interested in sage-grouse conservation.

Table 8. Observed mean values for habitat variables between greater sage-grouse brood-rearing and random sites, and between years used in logistic regression in northwestern South Dakota, USA, using MRPP (Mielke and Berry 2001) 2006-2007.

	Brood			**Random**			**Both Years**		
Variable	**2006 (*n*=59)**	**2007 (*n*=60)**	**P-value**	**2006 (*n*=56)**	**2007 (*n*=60)**	**P-value**	**Brood (*n*=119)**	**Random (*n*=116)**	**P-value**
Sagebrush Density (plants/m^2)	0.3	0.5	<0.01	0.7	0.4	<0.01	0.4	0.5	0.08
Sagebrush Cover (%)	4.6	4.7	0.94	4.5	2.8	0.03	4.6	3.6	0.04
Visual Obstruction (cm)	5.4	7.1	0.12	2.3	4.7	<0.01	6.2	3.5	<0.01
Grass Height (cm)	23.3	37.5	<0.01	19.2	31.9	<0.01	30.5	25.7	<0.01
Total Cover (%)	61.3	55.6	<0.01	51.0	51.0	1.00	58.4	51.0	<0.01
Grass Cover (%)	34.4	28.3	<0.01	28.6	24.8	0.26	31.3	26.6	<0.01
Japanese Brome Cover (%)	10.4	9.9	0.66	4.9	11.4	<0.01	10.1	8.3	0.04
Bluegrass Cover (%)	5.9	2.3	<0.01	3.8	2.2	<0.01	4.0	3.0	0.08

Table 9. Apparent greater sage-grouse chick survival to 7 weeks post hatch, and recruitment as of 1 March using a Kaplan-Meier product-limit method (Kaplan and Meier 1958) modified for staggered entry (Pollock et al. 1989) in northwestern South Dakota, USA, 2006-2008. Estimated survival rates given as mean (95% CI).

Year	**3 Week Survival (Apparent)**	**5 Week Survival (Apparent)**	**7 Week Survival (Apparent)**	**Recruitment (Apparent + Kaplan-Meier)**
2006	52.4% (*n* = 42)	45.2% (*n* = 42)	42.9% (*n* = 42)	9.5% (2.8 – 16.1%, *n* = 31)
2007	52.2% (*n* = 115)	41.7% (*n* = 115)	31.3% (*n* = 115)	5.1% (0 – 10.1%, *n* = 24)
Combined	52.2% (*n* = 157)	42.7% (*n* = 157)	34.3% (*n* = 157)	6.3% (2.7 – 9.9%, *n* = 55)

Table 10. West Nile virus (WNv) mortality rates and testing for greater sage-grouse chicks during the peak WNv transmission period (12 July – 31 September) in northwestern South Dakota, USA, 2006-2007. Estimated minimum and maximum mortality given as mean (95% CI) after Walker et al. (2007).

Year	No. Monitored	No. Mortalities	No. Tested	No. Positive	No. Negative	No. Inconclusive	Minimum WNv mortality rate	Maximum WNv mortality rate
2006	31	22	10	2 (23 July - 22 Aug.)	0	8	6.5% (0 – 15.1%)	71.0% (55.0 – 86.9%)
2007	24	18	10	5 (8 Aug. – 14 Sept.)	3	2	20.8% (4.6 – 37.1%)	62.5% (43.1 – 81.9%)

Table 11. Results from logistic regression models predicting greater sage-grouse brood-rearing sites (*n* = 119) versus random sites (*n* = 116) in northwestern South Dakota, USA, 2006-2007.

Model[a]	**K** [b]	**AIC*c***	**Δ AIC*c***[c]	***wi***[d]
Visual Obstruction + Bluegrass Cover	5	303.547	0.000	0.231
Visual Obstruction + Bluegrass Cover + Sagebrush Cover	6	304.275	0.728	0.160
Visual Obstruction + Bluegrass Cover + Sage Density	6	304.455	0.908	0.146
Visual Obstruction + Bluegrass Cover + Japanese Brome Cover	6	304.798	1.251	0.123
Visual Obstruction + Bluegrass Cover + Japanese Brome Cover + Sage Density	7	305.459	1.911	0.089
Herbaceous Cover + Bluegrass Cover + Grass Height.	6	305.503	1.956	0.087

[a] For ease of interpretation, year variable was excluded from model column. See Appendix 3 for full model results
[b] Number of habitat parameters plus intercept, SE, and year.
[c] Change in AIC*c* value
[d] Model weight

Table 12. Parameter Estimates, odds ratios, and corresponding confidence intervals for the best-approximating model of greater sage-grouse brood-rearing sites versus random sites in northwestern South Dakota, 2006-2007.

	Parameter			**Odds**		
Variable	**Estimate**	**Lower 95%CI**	**Upper 95%CI**	**Ratio**	**Lower 95%CI**	**Upper 95%CI**
Visual Obstruction	0.186	0.110	0.272	1.204	1.116	1.313
Bluegrass	0.114	0.029	0.204	1.121	1.029	1.226

2006 Chick Survival
Apparent & Kaplan-Meier

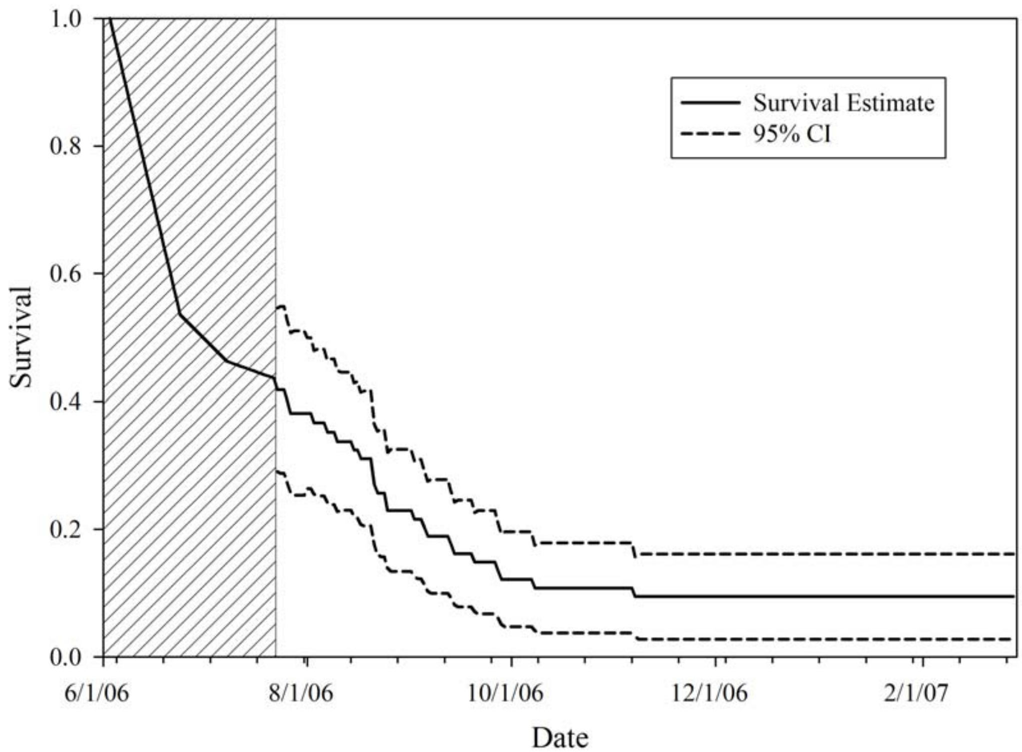

Figure 8. Greater sage-grouse apparent chick survival to 7 weeks post hatch (dashed area), and recruitment as of 1 March 2007 using a Kaplan-Meier product-limit method (Kaplan and Meier 1958) modified for staggered entry (Pollock et al. 1989) in northwestern South Dakota, USA, 2006-2007. A sample size of n = 31, was used in the Kaplan-Meier analysis.

2007 Chick Survival
Apparent & Kaplan-Meier

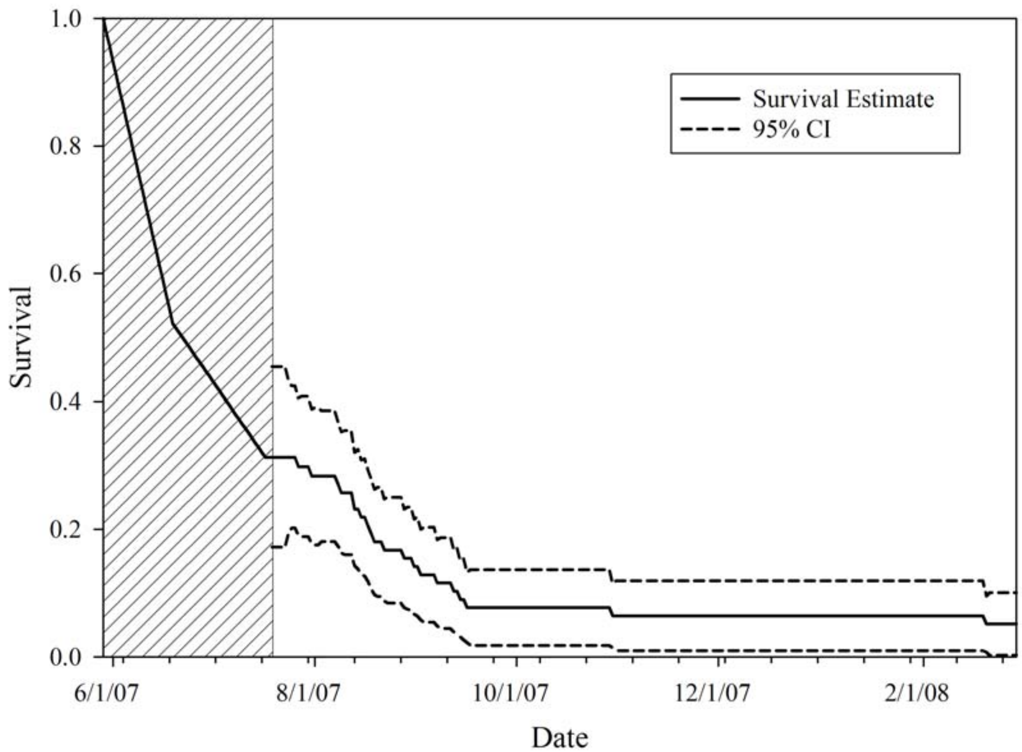

Figure 9. Greater sage-grouse apparent chick survival to 7 weeks post hatch (dashed area), and recruitment as of 1 March 2008 using a Kaplan-Meier product-limit method (Kaplan and Meier 1958) modified for staggered entry (Pollock et al. 1989) in northwestern South Dakota, USA, 2007-2008. A sample size of n = 24, was used in the Kaplan-Meier analysis.

Effect of Visual Obstruction and Bluegrass Cover On Brood-rearing Habitat Selection

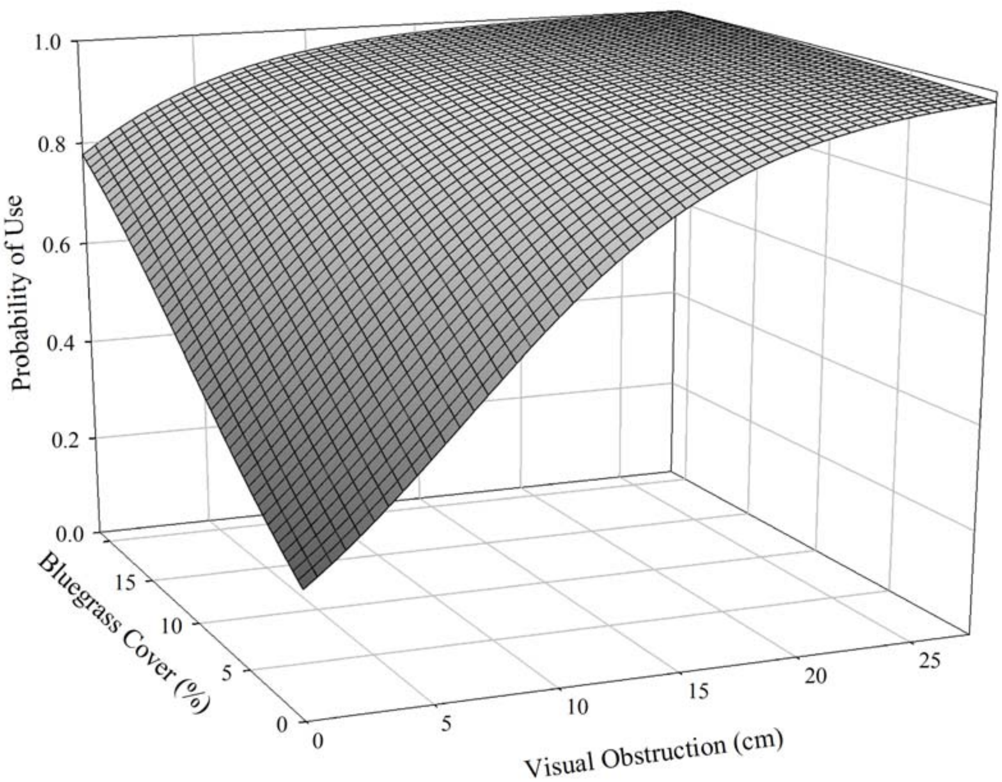

Figure 10. Effect of visual obstruction and bluegrass cover on greater sage-grouse brood-rearing habitat selection in northwestern South Dakota, USA, 2006-2007. Probability of use derived from parameter estimates in best approximated model (visual obstruction + bluegrass cover).

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Appendix 4. Complete results from logistic regression models predicting greater sage-grouse brood-rearing sites (n = 119) versus random sites (n = 116) in northwestern South Dakota, USA, 2006-2007.

Model[a]	**K**[b]	**AIC*c***	**Δ AIC*c***[c]	***wi***[d]
Visual Obstruction + Bluegrass	5	303.547	0.000	0.231
Visual Obstruction + Bluegrass + Sagebrush Cover	6	304.275	0.728	0.160
Visual Obstruction + Bluegrass + Sage Density	6	304.455	0.908	0.146
Visual Obstruction + Bluegrass + Jap. Brome	6	304.798	1.251	0.123
Visual Obstruction + Bluegrass + Jap. Brome + Sage Density	7	305.459	1.911	0.089
Total Cover + Bluegrass + Grass Hgt.	6	305.503	1.956	0.087
Grass Hgt. + Total Cover	5	307.403	3.856	0.034
Visual Obstruction + Sagebrush Cover	5	307.961	4.414	0.025
Visual Obstruction	4	308.259	4.712	0.022
Grass Hgt. + Sage Density + Bluegrass	6	308.829	5.281	0.016
Grass Hgt. + Total Cover + Sage Density	6	309.376	5.829	0.013
Visual Obstruction + Jap. Brome	5	309.416	5.869	0.012
Grass Hgt. + Bluegrass	5	309.893	6.346	0.010
Grass Hgt. + Bluegrass + Sagebrush Cover	6	310.219	6.671	0.008
Visual Obstruction + Sage Density	5	310.330	6.783	0.008
Bluegrass + Sage Density + Grass Hgt. + Jap. Brome	7	310.395	6.848	0.008
Grass Hgt. + Sagebrush Cover	5	312.905	9.358	0.002
Grass Hgt. + Grass Cover	5	313.128	9.581	0.002
Grass Hgt.	4	313.669	10.122	0.001
Sagebrush + Grass Hgt. + Jap. Brome	6	314.112	10.565	0.001
Grass Hgt. + Sagebrush Density	5	314.348	10.800	0.001
Grass Hgt. + Jap. Brome	5	315.110	11.563	0.001
Sagebrush + Total Cover	5	318.870	15.323	0.000
Total Cover + Bluegrass	5	320.013	16.465	0.000
Total Cover	4	320.699	17.152	0.000
Grass Cover + Sagebrush Cover	5	321.890	18.343	0.000
Sage Density + Total Cover	5	322.539	18.992	0.000
Grass Cover + Bluegrass	5	324.656	21.109	0.000
Grass Cover	4	326.626	23.078	0.000
Bluegrass + Sage Density	5	326.866	23.319	0.000
Bluegrass + Jap. Brome + Sage Density	6	327.142	23.595	0.000
Bluegrass + Jap. Brome	5	328.135	24.588	0.000
Sage Density + Grass Cover	5	328.447	24.900	0.000
Bluegrass	4	328.972	25.425	0.000
Sagebrush Cover + Bluegrass	5	329.056	25.509	0.000
Sagebrush Cover + Jap. Brome	5	330.167	26.620	0.000
Sagebrush Cover	4	330.739	27.191	0.000
Sage Density	4	331.620	28.073	0.000
Jap. Brome	4	331.657	28.110	0.000
Sage Density + Jap. Brome	5	332.235	28.688	0.000

[a] For ease of interpretation, year variable was excluded from model column.
[b] Number of habitat parameters plus intercept, SE, and year.
[c] Change in AIC*c* value
[d] Model weight