GREATER SAGE-GROUSE (*Centrocercus urophasianus*) HABITAT IN CENTRAL MONTANA

by

Jennifer Kristy Woodward

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APPROVAL

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Jennifer Kristy Woodward

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the Division of Graduate Education.

Dr. Carl Wambolt

Approved for the Department of Animal and Range Science

Dr. Brett Olson

Approved for the Division of Graduate Education

Dr. Carl A. Fox

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ABSTRACT

Greater sage-grouse (*Centrocercus urophasianus)* habitat was studied in central Montana primarily on Wyoming big sagebrush *(Artemisia tridentata wyomingensis*) dominated rangeland. The primary objective was to compare shrub and herbaceous parameters within (use, random or non-use) and between seasonal habitats (nest, brood, winter).

Nesting occurred in areas with greater total shrub cover (15v13%) and height (28v26 cm), and taller live (12v11 cm) and residual grass (9v8 cm) than randomly available. The shrubs under which hens nested were taller (50v44 cm) and more productive (61v51 g) than random shrubs. Due to increased precipitation in 2005, total herbaceous (18v13%), grass (15v12%), and forb cover (7v3%), and live grass height (13v10 cm) were greater in 2005 than 2004.

Brood and paired random sites were similar for all parameters. There was greater shrub height (29v25 cm), total herbaceous cover (19v16%), forb cover (15v13%), and live grass height (17v11cm) in 2005 than 2004. Shrub density (1.5v1.1/m^2) and residual grass height (9v5 cm) were greater in 2004.

Both winters were mild as no month had > 20 cm total snowfall. Shrub height was greater at winter non-use sites than use sites in 2005 (36v32 cm), but similar in 2004 (27v27 cm). Shrub height was different between years. Despite mild winters, shrub cover (12v10%) and density (1.2v0.8/m^2) were greater at winter use sites than non-use sites although residual grass height (19v18 cm) and cover (13v14%) were similar. Winter use sites had less shrub cover than nest sites (12v15%). The nest and brood habitat and winter and brood habitat had similar shrub cover, density, and height.

Herbaceous vegetation was more important during nesting and brood rearing than in winter. Some portions of grouse habitat may benefit from management for greater herbaceous cover, but never at the sake of less sagebrush. Sagebrush cover from 5 to 36% was the most consistent component of sage-grouse habitat. The differences between cover for nesting (15%), brood (14%), and winter (12%) were small. Therefore, any manipulation attempting to improve one seasonal habitat would impact the others.

CHAPTER 1

INTRODUCTION

Justification

As early as 1913, extinction of the sage-grouse (*Centrocercus spp*.) was predicted (Braun 1998). It is estimated that the overall distribution of sage-grouse has decreased by 50% since European settlement (Braun 1998). The historical distribution of greater sage-grouse (*C. urophasianus*) included 12 states and 3 Canadian provinces; currently sage-grouse have been extirpated from British Columbia and Nebraska (Schroeder et al. 2006).

Sage-grouse decline is most often attributed to a loss of habitat. Sage-grouse are sagebrush obligates, dependent on sagebrush for food, thermal cover, and hiding cover (Patterson 1952, Eng and Schladweiler 1972, Wallestad 1975). The quality (presence of adequate cover and forages) and abundance of sage-grouse habitat has been declining over the last 50 years despite recognition of habitat importance (Swenson et al. 1987, Braun 1998, Connelly et al. 2000). Loss, fragmentation, and degradation of sagebrush grassland habitats have been attributed to invasive plant species, fire, conversion to cropland, removal of sagebrush hypothesized to increase livestock grazing capacity, and to a lesser extent grazing, housing developments, mining and energy developments (Braun 1998, Knick 1999, Connelly et al. 2000, Wambolt et al. 2002). Montana currently supports 11 million ha of sage-grouse habitat (Montana Sage-grouse Work Group 2002) although it is estimated 50% of the original habitat has been lost (C. L. Wambolt personal communication, March, 2005).

Relatively few studies have assessed sage-grouse habitat in Montana (Martin 1970, Peterson 1970, Eng and Schladweiler 1972, Pyrah 1972, Wallestad and Pyrah 1974, Wallestad 1975, Moynahan 2004, Lane 2005). Additional information on sage-grouse habitat in central Montana would assist land managers in making decisions that benefit sage-grouse habitat (J. W. Connelly personal communication, March 2005, J. A. Newell personal communication, February 2005). Sage-grouse habitat is quite variable due to variations in weather (especially snow depth), sagebrush taxa present, habitat types, landscape patterns available, and topography of habitat (Eng and Schladweiler 1972, Wallestad 1975, Beck 1977, Remington and Braun 1985, Hupp and Braun 1989, Schroeder et al. 1999, Connelly et al. 2000). Few studies have had the opportunity to investigate nesting, brood rearing and winter habitats required by a common sage-grouse population.

The primary objectives of this study were to compare: 1) shrub and residual grass parameters between winter use and non-use sites; 2) shrub and herbaceous parameters between nest and random sites; 3) shrub and herbaceous parameters between brood and random sites; and 4) shrub and herbaceous parameters between seasonal habitats (nest, brood, and winter), 2 study sites (ie. counties), and 2 years.

The secondary objectives of the study were to compare shrub and herbaceous parameters between: 1) successful and failed nests, 2) adult and yearling hen nests 3) brood sites at 1 and 4 weeks old, and to 4) determine if sage-grouse were using soil types in equal proportion to availability during the winter.

CHAPTER 2

LITERATURE REVIEW

Winter Habitat

Sage-grouse are completely dependant upon sagebrush for both cover and food throughout winter (Table 1) (Patterson 1952, Eng and Schladweiler 1972, Wallestad 1975). Big sagebrush was found to be the only food in crops of birds from December to February in central Montana (Wallestad 1975). Sage-grouse prefer taller, more robust, exposed sagebrush in the winter (Connelly et al. 2000) because it provides food, thermal and escape cover in even the most severe winters.

Sage-grouse may choose micro sites in order to increase thermal efficiency. Sage-grouse cooled to 10°C in a Plexiglas chamber showed an increase in metabolic rate for male and female sage-grouse at 12% and 21% respectively (Sherfy and Perkins 1994). Wind also increased metabolic rate when temperatures dropped below 0°C (Sherfy and Perkins 1995). Sage-grouse may gain weight over the winter (Remington and Braun 1988), therefore, an increase in metabolic rate may have little negative impact on grouse if they have full access to food. Under thermal neutral conditions female sage-grouse have been estimated to be able to survive 4 days and males 6 days without food (Remington and Braun 1988, Sherfy and Perkins 1994).

After a severe storm, need for conservation of thermal energy, and use of thermal neutral micro-sites, may be higher if sagebrush is not available for foraging (Sherfy and Perkins 1994). Grouse have been cited for exhibiting behavior that suggests they are

increasing their thermal efficiency. When wind speeds exceeded 10-15mph it was noted that birds moved off flat ridges and onto level areas protected by step terrain (Eng and Schladweiler 1972). Grouse may also make small “snow caves” to avoid weather (Beck 1977).

Sagebrush canopy cover and density have been positively correlated with amount of use by sage-grouse in winter (Eng and Schladweiler 1972, Connelly 1982, Robertson 1991). During the winter in southeast Idaho 53% of sage-grouse were found in areas with canopy cover >20%. Eighty-nine percent of observations were made in areas with canopy cover >10% (Connelly 1982). Eng and Schladweiler (1972) observed 82% of 60 sage-grouse observations were in sagebrush with >20% cover in central Montana. Female flocks of sage-grouse have been found to use denser sagebrush stands than male grouse in North Park, Colorado (Beck 1977).

Managing for multiple heights, 25-80 cm above the snow, allows grouse access to food and cover under all snow conditions (Connelly et al. 2000, Crawford et. al 2004). Sage-grouse used drainages when snow depths were >30 cm in the Gunnison Basin of Colorado, because these areas had the greatest shrub height. In addition southwest slopes had the greatest shrub height above the snow and accounted for 42% of use locations (Hupp and Braun 1989).

With high snowfall, sage-grouse can be restricted to areas that have either been wind swept, received greater amounts of solar radiation, or have taller sagebrush (Beck 1977, Connelly 1982, Hupp and Braun 1989, Robertson 1991). When snow was 26% greater than average in North Park, Colorado grouse were concentrated in smaller

foraging areas. The small foraging areas were <10% of sagebrush winter habitat (Beck 1977). In central Montana, birds were restricted to 7% of their normal winter range when snow exceeded 12 inches (Wallestad 1975). Robertson (1991) only found detectable selection preference for sage-grouse habitat during the most severe winter of his study in southeast Idaho. When the winters were not severe sage-grouse used all available sagebrush habitats, suggesting an abundance of suitable habitat (Robertson 1991).

Sage-grouse use of various topographic sites is driven by availability of the habitat type, availability of sagebrush, and the microclimate associated with the site (Beck 1977, Eng and Schladweiler 1977, Hupp and Braun 1989). In North Park, Colorado flocks were typically found on southwest slopes with < 5% gradient. Wind kept southwest slopes clear of snow while depositing it on northeast slopes, making sagebrush on southwest slopes accessible in areas with sagebrush <10 cm tall (Beck 1977). In central Montana birds were nearly always found on gentle terrain with less than a 5% slope (Wallestad 1975). In the Gunnison Basin of Colorado, when snow depth exceeded 30 cm sage-grouse used drainages that were sheltered from wind and contained sagebrush with canopy cover and height greater than all other topographic categories. Feeding took place on high flat sites in only 2% of observations, while it comprised 13% of the study area. Sagebrush plants on high flats were shorter and snow depth was greater than other available sites, therefore snow often covered the shrubs (Hupp and Braun 1989).

Nest Habitat

Nesting habitat was comprehensively reviewed by Connelly et al. (2000). Throughout sagebrush types in the west sage-grouse nested in sagebrush stands with

15%-38% shrub canopy cover, 4%-51% herbaceous cover, and 15-34 cm grass heights (Table 1). Hens typically nested under sagebrush with average nest shrub heights between 29 -80 cm (Connelly et al. 2000). Greater residual grass height at nests is important because nests are often initiated before new grass growth (Sveum et al. 1998, Holloran 2005).

Habitat quality has been positively correlated with reproductive success. Sage-grouse nesting under sagebrush had greater success than hens nesting in other shrub cover types (Connelly et al. 1991). However Sveum et al. (1998) found hens that nested under non-shrub cover types (tall grass and residual herbaceous material) were equally successful to hens that nested under sagebrush. Successful nests had greater shrub height, residual cover, and canopy cover than unsuccessful nests (Wallestad 1975, Sveum et al. 1998). In addition adult hens have ≥ success than yearling hens (Schroeder et al. 1999). Nest success in Oregon increased in years with greater grass cover and nest initiation and re-nesting rates also increased in years where forb cover was greater (Coggins 1998). Annual nest success rates have been positively correlated to the preceding year's spring precipitation (Holloran 2005).

Brood Rearing Habitat

Succulent forbs and insects have been considered the key components in brood habitat (Table 1) (Klebenow 1968, Peterson 1970, Wallestad 1975, Connelly et al. 2000). As plants mature through the summer broods may move to moist areas that support succulent vegetation (Wallestad 1975). Broods used less dense sagebrush than was available in Idaho (Klebenow 1969). In Montana broods were found in less dense

sagebrush than adults, most of this difference was attributed to broods with chicks <6 weeks of age (Martin 1970). Sage-grouse moved out of sagebrush grassland habitat types and into grassland and greasewood habitat types in north central Montana as the summer progressed (Peterson 1970). During the first 12 weeks following hatching , 76% of a chicks diet was vegetable matter and 24% insect matter, with only traces of sagebrush found in grouse less than 10 weeks old (Peterson 1970). Chick survival has the potential to be increased with habitat quality, but difficulty in obtaining precise chick counts hinders corroboration of survival and habitat quality (Coggins 1998, Moynhan 2004). Moynahan (2004) found brood survival to be highest in a year with a dense cover of sweet clover (*Melilotus officinalis* (L.) Lam.).

Seasonal Habitats

Seasonal habitat changes for sage-grouse are driven by availability of food and changing needs for thermal and hiding cover (Table 1). Connelly et al. (2000) recommended breeding habitats with 15%-25% canopy cover of sagebrush, with an average herbaceous height >18cm, including 15% and 10% canopy cover for grass and forbs respectively. Winter habitat sagebrush canopy cover is recommended to range between 10%-30% with heights between 25-35 cm (Connelly et al. 2000).

In eastern Montana, wintering, nesting, and brood rearing habitats are closely interspersed, yet distinctive (Eng and Schladweiler 1972, Wallestad 1975). In north central Montana broods preferred relatively open sagebrush stands compared to the rest of the year (Wallestad 1975). Wallestad (1975) also found sage-grouse used the same areas for both nesting and winter habitat.

Loss of large dense stands of sagebrush in areas where specific habitat types are limiting may have negative impacts on sage-grouse. After disturbance by fire sagebrush can take >30 years to re-establish to pre–burn conditions (Wambolt 2001a). In central Montana 30% of an area known to be sage-grouse winter habitat was plowed, leaving 84% of the total sagebrush steppe unplowed. This was followed by a 73% reduction in male attendance on leks (Swenson et al.1987). In north central Montana reduction in

sage-grouse populations were proportional to the amount and severity of sagebrush reduction projects (Pyrah 1972). Habitat management should protect stands of tall sagebrush from burning, plowing, herbicide application and other sagebrush destructive practices (Connelly et al. 2000). Adequate habitat for each season is necessary for stable sage-grouse populations (Connelly et al. 2000). Sage-grouse winter habitat is often limited to small areas when snow depths are high (Beck 1977, Hupp and Braun 1989). Sage-grouse prefer taller, more robust, exposed sagebrush in the winter (Connelly et al. 2000). Identifying and protecting areas of winter habitat suitable for a variety of snow depths may be critical to survival (Moynahan 2004).

Sage-grouse have relatively low reproductive rates for game birds, annual reproductive success (the percentage of hens who produce >1 egg) ranged from 15-70% throughout the range of the sage-grouse (Wallestad 1975, Gregg 1991, Schroeder 1997, Sveum et al. 1998, Schroeder et al. 1999). Survival of juveniles, from egg until fall, ranges from 15%- 69% (Wallestad 1975, Schroeder 1997, Aldridge 2001, Moynahan 2004). Reproductive success has been increased with increased habitat quality (Coggins

Table 1. Sage-grouse habitat needs by season modified and adapted from Wambolt et al.(2002).

		Winter	Spring	Summer	Fall
Habitat need		December – Early March	March - Early June	June - September	September - December
Sagebrush	Forage	Almost 100% of diet	50% - 70% of diet; insects (ants, beetles) and forbs also important	Males and adult females without chicks	All age classes are consuming - can be up to 90% of diet
	Cover	Canopy provides cover relative to height of snow; cover and feed behavior changes based on snow;	Very important; nesting cover; protective cover; height and under-story mix important	Canopy cover is important;	Canopy cover is very important
Herbaceous cover	Forage		Need mix of grasses and forbs	Forbs are important to hens and chicks; need a composite of species;	Forbs are decreasing in dietary importance
	Cover		Tall grass and large forbs	Tall grass and large forbs	
Location		Normally lower elevations; aspect matters, south- or west-facing slopes make difference	Larger than winter/ summer; habitat size is quite variable	Hens with chicks go to mesic areas (meadows, farm fields, etc.); longer, narrower areas better	Most mobile time of year; dispersed out of uplands; moving back into winter ranges
Importance		Very critical [some believe most critical]	Many believe most critical time; 70 - 80% of chick mortality occurs in first 3 weeks	Generally not limiting habitat	Juveniles are foraging as adults; birds pretty secure this time of year

1998). Identifying, protecting and or improving nest and brood habitat has the potential to increase reproductive rates and survival rates (Coggins 1998, Moynahan 2004).

CHAPTER 3

METHODS

Study Site Description

This study was conducted in central Montana with 1 location in Musselshell county and another in Golden Valley county, 25 km north and 32 km west of Roundup (lat 46°26'57.96"N, long 108°32'35.45"W), respectively. The majority of the study took place within a 5 km buffer around each of the 5 capture leks in each county (study lek buffer) (Figs. 1 and 2). The area within these buffers will be discussed for site descriptions. This area is primarily privately owned (75%), with some land managed by the Bureau of Land Management (16%), and the remaining by the state (5%). Approximately 80% of the area was sagebrush-steppe, with 1% grasslands, 1% ponderosa pine, and 15% agriculture (Sika 2006). Eighty-nine percent of the area within 5 km of the capture leks is used for beef and sheep production.

The weather station in Roundup receives an annual mean precipitation of 12.3 inches. The peak precipitation falls in May and June (36%). During the growing season (April-September) the area receives 75% of the annual average precipitation. The extreme temperatures range from -52°F in the winter to 111°F in the summer (Western Regional Climate Center 2005). The frost free period is 105-135 days in length.

The study area is made up of shale lowlands separated by sandstone ridges containing several undrained basins (USDA 2003). Parent materials of soils include

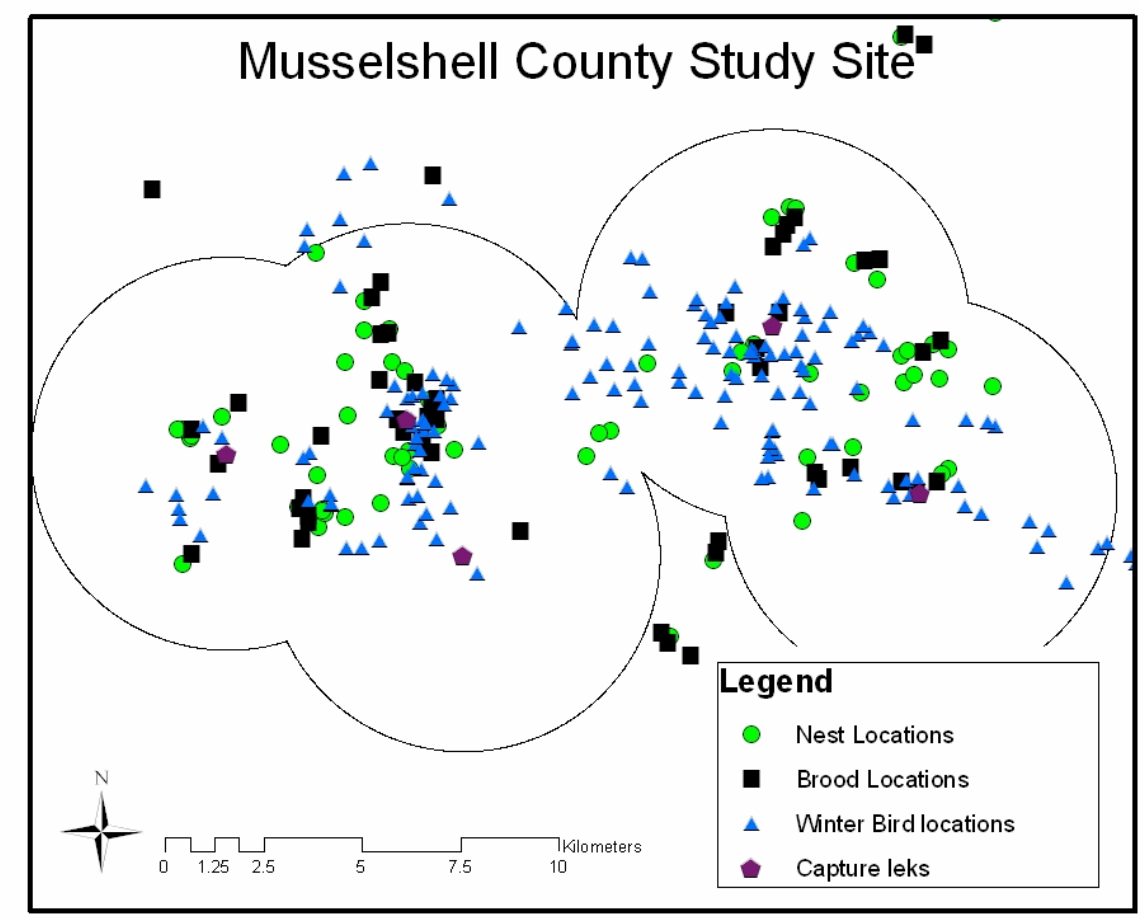

Figure 1. Musselshell county study site including all nest, brood and winter locations sampled within the study site from 2003-2006. The capture leks are the leks from which birds were captured from 2003 to 2005.

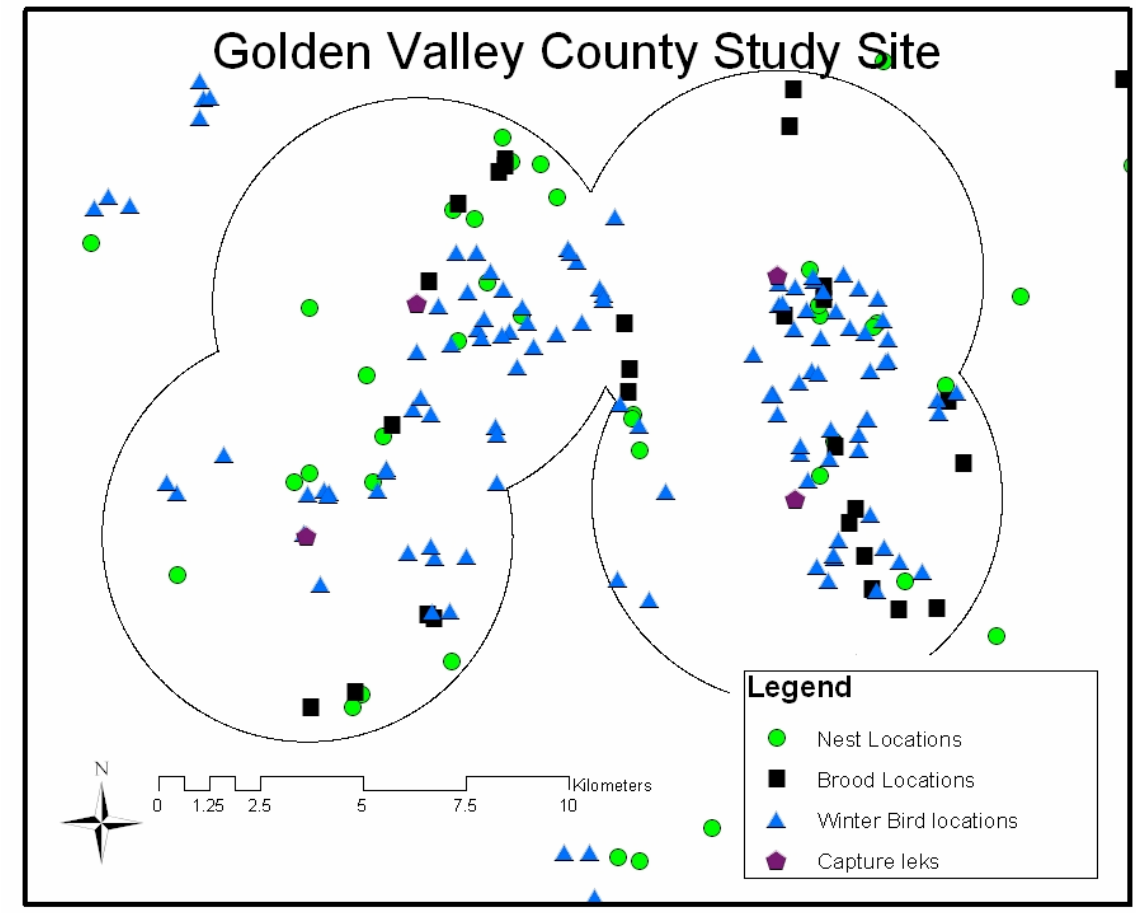

Figure 2. Golden Valley county study site including all nest, brood and winter locations sampled within the study site from 2003-2006. The capture leks are the leks from which birds were captured from 2003 to 2005.

Table 2. Description of soil series used by sage-grouse during the winter of 2005 including depth to parent material, parent material, ecological sites associated with the series, common map unit symbols on study site representing series, percent clay, electric conductivity, and pH of soil.

Soil Series	Depth (in)	Parent Material	Ecological sites (10-14 in. ppt. zone)	Map Unit Symbols (MUSYM) representing common soil series on study site	Clay (%)[a]	EC (mmhos/ cm)[ad]	pH[a]
Abor	20-40	Residuum, Shale	Clayey, Clayey-Steep	60C, 60D, 68C, 460E	40-55	0-4	7.4-8.4
Cabbart	10-20	SC[a] Sedimentary Beds	Shallow	95E, 181D, 181E,	18-27	0-4	7.4-9.0
Crago	>60	Alluvium	Silty-Limy	95E, 96E, 181D,	15-27		7.4-8.4
Creed	>60	Alluvium	Claypan	23A, 23B, 23C, 64A	20-27		6.1-8.4
Delpoint	20-40	SC Sedimentary Beds	Silty, Silty-Steep	181D, 189C, 84D	18-27		6.6-8.4
Gerdrum	>60	Alluvium	Claypan, Dense Clay	22B, 23A, 23B, 64A	20-27		6.6-7.8
Hinterland	10-20	Hard Sandstone	Shallow	50B, 50C, 50D	20-27		6.6-7.8
Kobase	>60	Alluvium	Clayey	140B, 140C, 40C	27-40	0-2	6.6-8.4
Lost River	>60	Alluvium	Saline Lowland	7A, 7B	40-55	2-8	7.4-9.4
Marvan	>60	Alluvium	Clayey	23A, 23B, 23C, 64A	40-60	0-4	7.4-8.4
Megonot	20-40	Residuum	Clayey	140C, 67D, 68C, 230E	35-40		6.6-7.8
Neldore	10-20	SC Shale Residuum	Shallow Clay, Dense Clay	60D, 68C, 69C, 460E	40-60	0-4	5.6-8.4
Nobe	>60	Alluvium	Saline Upland	22B	27-40[b]	4-8[b]	6.6-8.4[b]
Orinoco	20-40	SC Shale Residuum	Clayey, Clayey-Steep	140B, 69C	30-40		7.4-8.4
Rentsac	10-20	Sandstone Residuum	Shallow	189C, 89C	7-18		6.6-8.4
Tanna	20-40	SC Sedimentary Beds	Clayey	153C	20-27		6.6-7.8
Twilight	20-40	SC Sandy Sedimentary Beds	Sandy	32D	5-20		6.1-7.8
Vanda	>60	Alluvium	Dense Clay	22B, 23A, 23B, 64A	40-60	2-8	7.9-9.6
Volberg	10-20	SC Shale Residuum	Coarse Clay	60B, 60C, 60D, 61D	40-50	0-4	4.5-6.5
Yamacall	>60	Alluvium	Silty, Clayey	230E	18-35		6.6-8.4
Yawdim	10-20	SC Shale Residuum	Shallow Clay	41B, 60C, 60D, 68C	27-50		6.6-7.8
Zatoville	>60	Alluvium	Clayey	68C, 460E	30-40	0-2	7.4-9.0

[a] SC = Semi-consolidated [b] All values are for A horizon [c] denotes value from E horizon

[d] The calcium carbonate equivalent is the acid neutralizing capacity of a material expressed as weight percentage of calcium carbonate.

[e] Electric conductivity is the extent which water conducts electricity, which is proportional to the concentration of dissolved salts present and is used as an estimate of total dissolved salts in soil water expressed in millimhos/centimeter (mmhos/cm).

semiconsolidated sandy sedimentary beds, shale residuum, and semiconsolidated loamy sedimentary beds. Some soil types acquired salts and sodium. The stream valleys are chiefly alkali flats (Gieseker 1938). Soils used by sage-grouse are described in Table 2. Elevation ranges from 826 m – 1495 m.

The study sites consist of the Wyoming big sagebrush (*Artemisia tridentata* Nutt ssp. *wyomingensis* Beetle & Young) habitat type, native and introduced grasslands, and agricultural lands. The dominant shrub is Wyoming big sagebrush, with plains silver sage (*A. cana* Pursh *cana*) and greasewood (*Sarcobatus vermicultatus* (Hook.)Torr.) occurring generally in lowlands. Western wheatgrass *(Agropyron smithii* (Rydb.)A. Löve), thickspike wheatgrass (*A. dasystachyum* (Hook.) Scribn. & J.G. Sm), Sandberg's bluegrass (*Poa secunda* J. Persl) and blue grama (*Bouteloua gracilis (*Wild. ex Kunth) Lag. Ex Griffiths) are the dominant grasses, threadleaf sedge (*Carex filifolia* Nutt), needle-and-thread (*Stipa comata* Trin. & Rupr.), green needlegrass (*S. viridula* Trin.) are also common. The most abundant forbs were American vetch (*Vicea Americana* Muhl.ex Willd.), scarlet globe mallow (*Spaeralcea coccinea* (Nutt.) Rydb.), and small seed false flax (*Camelina microcarpa* Andrz. ex DC). Agricultural land was made up of various wheatgrasses (*Agropyron spp*. Gaertn.) including crested wheatgrass (*A. cristatum* (L.) Gaertn.), as well as alfalfa (*Medicago sativa* L.), and wheat (*Triticum aestivum* L.).

The study area supported abundant breeding populations of non-migratory sage-grouse (Sika 2006). Average peak attendance ranged from 1 to 67 males among 28 leks from 1996- 2006 (Appendix D).

Sampling Methods

Winter Use Site Determination.

Over a 3 year period (2003-2005) sage-grouse were captured on or near leks during breeding season (22 March - 14 April) at night with a spotlight and a long handled net, or rocket net. Captured birds were fitted with a radio transmitter. Twelve birds transmitted signals during the winter of 2003-2004, 71 birds during the winter of 2004-2005, and 52 birds during the winter 2005-2006.

Between December and early March radio collared hen winter locations were determined. A truck mounted receiver antenna determined general locations and a hand held directional antenna was used to precisely locate sage-grouse. Birds were flushed and a geographic position system (GPS) was used to record exact location of tracks and fresh sage-grouse droppings.

Site descriptions, number of males and females, snow depth, and weather data were recorded at all winter locations. Snow depth was measured every 2 m, along a 10 m transect in each of the 4 cardinal directions away from the bird location (n = 20). Temperature, wind, cloud cover, and presence or absence of precipitation was estimated without the use of weather equipment.

During the winter of 2005-2006 residual grass height and residual grass canopy cover measurements were each taken every 1 m, north and south along a 10 m transect (n = 10). Residual grass height was recorded as the tallest portion of the grass plant,

either vegetative or inflorescence, that was closest to the outside right corner of the 20 x 50 cm quadrat that was used to measure residual cover.

Sage-grouse Winter Use Sites

Winter bird locations were relocated with GPS during June and July 2004, 2005 and 2006 vegetation parameters were sampled. When sage-grouse droppings were present at the GPS location they were used as the center point for the sampling transects.

All 52 winter use locations from the winter of 2003-2004 were sampled during the summer of 2004. Ninety-seven of the 257 bird locations collected during the winter of 2004-2005 were sampled. In the 2005-2006 winter, 254 bird locations were collected, and 144 of those sites were sampled. All of the 511 winter flush locations collected from 2004-2006 were visited. Most sites not sampled were those located within 400 m of a previously sampled location and having the same soil map unit and vegetation characteristics. In 2005 some sites were not sampled because of a lack of time.

Using the computer software ArcGIS 9® the soil map unit (soil type) of each bird location was determined before conducting summer sampling. Soil map units are made up of multiple soil series typically found together. Soil map unit polygons drawn on aerial photographs by soil scientists of the Natural Resource Conservation Service (NRCS) were used within ArcGIS 9® (Montana Natural Resource Information Systems 2005). Soils maps were consulted in the field and soil map units of each site recorded. Changes in plant communities were used to define changes in soil map units. All winter use sites were measured within 1 soil map unit. When a bird location occurred on the edge of 2 soil types, 2 sets of 3-30 m transects were sampled, 1 in each soil map unit. At

most of the relocated use sites winter droppings were used as the center point for the newly established transect lines. All soil map unit designations from the 2004-2005 winter were confirmed in the field by Brian Kloster, soil scientist for the NRCS in Roundup. Out of the 131 soil map unit designations I made in the field in 2004-2005, 89% of them were determined to be correct. I was solely responsible for naming the soil map units at winter sites that were sampled in 2005-2006.

Sage-grouse Winter Non-Use Sites

Sage-grouse non-use sites were established during the summer of 2005 and the winter of 2005-2006. Random points were placed on a map created in ArcGIS 9® within areas that were not known to be used heavily during winter. An analysis was completed in ArcGIS 9® to determine how many bird locations fell within each soil map unit. Random points were placed within soil map units with the same map unit symbol as use sites but without use. Random points were placed in soil map unit polygons that were a minimum of 300 m from known collared sage-grouse use during the winters of 2003-04 and 2004-05 (example: if winter bird locations were found in soil map unit 23A at least 1 random point was placed in a 23A polygon). No random points were placed within 300 m of an actual winter bird location. Arial photographs were assessed and random points were not placed in agricultural areas (both cropland and seeded grasslands).

A GPS unit was used to locate non-use sampling sites. An area of 1200 m^2 was delineated around each GPS location for sampling. This area was searched thoroughly for winter droppings. All droppings were considered possible winter droppings unless they had insect remains. If droppings were located the site was dropped from my analysis. At

locations with no indication of winter use, 3-30 m transects duplicating those in use sites were sampled. Non-use areas from the winter of 2005-2006 were sampled for residual grass height and canopy cover at the initial visit to the site during the winter.

Measurements were taken every meter, 5 times north along the transect and 5 times south (n = 10). The use of GPS allowed me to revisit the sites during summer 2006 and sample the sites with the same methodology as winter use sites. Non-use sites without shrubs were not sampled. Sampling sites were moved into shrub habitats if they were within 300 m of original random point. Sage-grouse rely on shrubs in the winter (Patterson 1952, Connelly et al. 2000, Crawford et al. 2004), thus, sampling shrub-less sites would have inflated the results by showing non-use sites with exceptionally low average canopy cover and densities.

Winter Habitat Use and Non-use Measurements

Habitat measurements for both use and non-use sites were collected along 3-30 m transects spaced 30 m apart oriented north to south. The first transect was centered over the GPS location of either the winter use or non-use site. The second and third transects were 30 m to each side and parallel to the first transect. Transects were occasionally moved closer together or rotated in order to sample only 1 soil type.

Line intercept sampling was used to estimate shrub canopy cover, and height along 3-30 m transects (Canfield 1941, Connelly et al. 2003). Shrub cover followed the recommended procedure of Wambolt et al. (2006), with gaps in shrubs >3 cm (0.1 ft) excluded. Line intercepts were separated into live and dead crown, if both were present within the same 3 cm, the component >50% was recorded. Shrub height was measured

every 2 m on the nearest shrub with an average crown >15 cm in diameter (n = 15/transect). Shrub height was measured at the tallest average portion of the crown (ie. avoiding single tall branches). No shrub height was recorded if none occurred within 10 m of the transect.

Belt transects were used to estimate shrub density (Connelly et al. 2003). All shrubs within 1 m of either side of the 3-30 m transect lines were recorded for a total of 3-60 m^2 belt transects. Shrubs whose main stem had rose from the ground within the belt transect were counted. Younger shrubs, those with an average crown diameter of ≤15 cm were recorded separately. This was done because big sagebrush plants smaller than this diameter cannot be considered established (Wambolt and Sherwood 1999).

Due to the evergreen nature of sagebrush, shrub attributes vary minimally from winter to summer (Wambolt pers. comm. 2005). Greasewood is deciduous, thus measurements in the summer do not precisely measure cover furnished during the winter but should be proportional among different greasewood sites.

Topographic features of slope, aspect and location within the landscape were determined at each site (Hupp and Braun 1989). Aspect was the compass direction in degrees, the site was oriented towards. The percent slope was estimated from below the site to the center of the site using a clinometer. Detailed written descriptions of topography were also recorded.

Soil Descriptions of Winter Use and Non-use Sites

During the fall of 2005 all soil map units, from 97 winter use sites and 30 non-use sites sampled during the summer of 2005, were confirmed by a NRCS soil scientist. Soil

depth, pH, and percent clay were all recorded and used to determine the soil series and map unit. Depth to parent material was measured using a truck mounted auger to remove a soil core. Soil pH was measured with the colorimetric method using Lamotte indicator dyes. Percent clay was determined using a ribbon test. Because soil maps are made on a large scale (1:250,000), the soil map units were confirmed in the field using the soils series determination.

Nest Sites

The nest and brood rearing habitat portion of this study continued research initiated by Lane (2005) in order to investigate year effects. The methods, measurements, and analyses are precisely after Lane (2005) and are outlined below. My analyses included data from Lane (2005) for nest and brood habitat.

"Sagebrush canopy cover, density, and height, nest shrub height, nest shrub productivity, forb, grass, herbaceous, ….grass height, and residual height were measured. Sagebrush canopy cover was measured using the line-intercept method (Canfield 1941, Klebenow 1969, Gregg 1991), and was considered more precise than other methods (Connelly et al. 2003). Line-intercepts were measured on 2 perpendicular 30 m N-S and E-W transects, with the nest located at the center (15 m) of each line. True north was used to orient the lines at each site. Gaps in the canopy that were greater than 3 cm were recorded, and the amount of live versus dead canopy cover was noted. The 2 transects were averaged for analysis at each nest site.

Two 30 m by 2 m belt transects were measured along each N-S, E-W line to measure sagebrush density (number of shrubs / m^2) around the nest site. Large plots such

as belt transects were useful to measure density on large plants (Gurevitch et al. 2002). The 2 belt transects for each site were averaged to obtain an estimate of sagebrush density per nest site. Belt transects were determined by holding a 1 m measuring stick and walking the length of the tape on both sides. All live and dead sagebrush with a crown diameter ≥15 cm were counted. Sagebrush with crown diameters <15 cm were considered immature and were not large enough to provide cover for sage-grouse."

"Average shrub height around the nest site was estimated by measuring the nearest shrub to the line-intercept at 3 m intervals within 15 m of the nest shrub for a total of 10 shrub height measurements per line. Height of the nest shrub was also measured. Nest shrub productivity was calculated to determine if grouse were selecting nest shrubs based upon the parameter. Nest shrub productivity was calculated by measuring the nest shrub's major axis, followed by a perpendicular minor axis, and 2–45° crown width measurements, and is reported in grams of available winter forage (Wambolt et al. 1994)." Average crown diameter was the average of the major axis, minor axis, and 2 measurements at 45° to the major-minor axes intersection.

"Herbaceous understory cover and composition were measured using 20 x 50 cm quadrats (Daubenmire 1959). Connelly et al. (2003) considered these quadrats to be very precise and repeatable. The same N–S, E–W transects used for line-intercepts and belt transects were used for the herbaceous measurements. Quadrats were placed at 3, 6, 9, 12, and 15 m from nest shrub for a total of 20 at each nest site. Total herbaceous, forb, and grass cover were measured by this method. Vegetative droop height of living grass was also recorded at each quadrat. Residual grass cover and height were also measured."

"There were no differences between Daubenmire plots at 3, 6, 9, 12, and 15 m from the nest, therefore cover and height data from all quadrats were averaged for statistical analyses. Nests were considered successful if shell membranes were detached from the shell (Wallestad 1975). This only required one egg to hatch. Hens with worn outermost primaries were considered adults (Wallestad 1975)."

Random Sites

"Random sites were paired with nest sites within the same habitat to test if sage-grouse hens were randomly selecting shrub or herbaceous characteristics for nesting. This paired design addressed the following question. Once a sage-grouse hen selects a stand of sagebrush in which to nest, are there specific habitat parameters she selects within that stand? The paired random design examines sage-grouse nest selection on a relatively small scale, and is useful to detect within-stand habitat parameter preferences of nesting sage-grouse.

Shrub and herbaceous characteristics of random sites were measured using the same methods as nest sites. Random sites were measured on the same or next day as their paired nest sites. At each nest site a random compass direction and distance (between 30 and 1000 m) were chosen using random number tables. The tallest sagebrush $\geq$ 35 cm nearest the end of the random distance was selected as the random nest shrub. If the habitat encountered at the random site was not sagebrush (i.e. road, uniform agricultural field, etc.), the closest sagebrush stand in the same direction was selected and, using the milliseconds indicator on a stopwatch, a random distance from 15 to 100 m was determined to locate sampling sites."

Brood Sites

"Hens with broods were tracked throughout the brood-rearing season. Shrub and herbaceous parameters at brood sites were measured using the same methods as nest sites. In Roundup, paired random sites were located for brood sites using the same methods described for paired random sites for nests (Lane 2005)." Brood locations were located and measured at 1 and 4 weeks after hatch.

Statistical Analyses

Seasonal Habitat Analyses

An analysis of variance (ANOVA) was conducted using the GLM version of SAS® 9.0 to determine if sage-grouse habitat differed by season (nest, brood, random, winter, or winter non-use), year (2004 and 2005) or county (Golden Valley and Musselshell counties). Nest, brood, and random sites were compared for total herbaceous, grass, and forb cover, and live and residual grass height. Nest, brood, random, winter use and winter non-use sites were compared for total shrub canopy cover, total shrub density, and shrub height. The experimental unit was each bird location, or one sampled site. Effects in the model were compared with least squares means. Because data were unbalanced a Tukey-Kramer test was used to separate least squares means (Kramer 1959). The linear model included all main effects (season, year, county) and all possible interactions. When interaction terms were not significant reduced models were fitted to the data. Least squares means are presented where no interactions were determined. Least

squares means for the interactive terms are reported when interactions were significant. Differences were considered significant at $P \leq 0.05$.

Vegetative parameters were analyzed for 648 sites measured in 2004 and 2005. Thirty-four sites in 2004 had insufficient species information for density and cover therefore only shrub density and cover were analyzed. Sites with 0% shrub cover were omitted from the analyses. Included in the analysis were 22 sites where greasewood contributed >50% of total canopy cover, and 4 sites where silver sage contributed >50% total canopy cover. The remaining 626 sites (97%) sampled had >50% shrub cover composed of Wyoming big sagebrush. Wyoming big sagebrush, silver sagebrush, and greasewood sites were analyzed together as one shrub cover type in the ANOVA. Measurements of total shrub parameters were similar to sagebrush parameters except where noted. Over 90% of total shrub cover was from Wyoming big sagebrush.

Soil Analyses

A Chi square analysis (Neu et al. 1974, Byers et al. 1984) was used to test the hypothesis that sage-grouse use soil types in equal proportion to their availability. The percentages of each soil map unit within the study area and the number of sage-grouse winter locations within each soil map unit were calculated (Neu et al. 1974) on ArcGIS 9® using the query function. The number of grouse locations in each soil map unit was divided by the number of grouse locations collected providing percent use of each soil type. The percent use of each soil map unit was compared to the available percentage of each soil map unit to show preference or avoidance in the statistical program R®. Bonferroni confidence intervals were constructed, when the expected proportion of usage

did not fall within in the interval it was concluded that the expected and actual use were significantly different (Neu et al. 1974, Byers et al. 1984). A family of Bonferroni confidence intervals with an alpha of .05 insures that 95% of the samples would lead to a family of estimates where all confidence intervals are correct (Neter et al. 1996).

T-test Analyses

The vegetation parameters shrub cover, density, and height, forb, grass and , herbaceous cover, live and residual grass height, nest shrub height, and nest shrub productivity were compared between successful and failed nest sites, yearling and adult hen nest sites, and 1st week and 4th week brood sites, using 2-independent sample *t*-tests or Wilcoxon-Mann-Whitney tests. These variables were first tested for normality using the Shapiro-Wilk test (Shapiro and Wilk 1965). If $P \leq 0.05$ with this test, the variable was considered to have a non-normal distribution and a nonparametric test was used. Paired *t*-tests were used to compare sites for normally distributed variables, and Wilcoxon signed ranks tests were used for variables with non-normal distributions. Only sites in the sagebrush habitat type had a sufficient sample size to be analyzed. Differences were considered significant at $P \leq 0.05$. All data were analyzed using SAS® version 9.

Residual grass height and cover from the 2005-2006 winter were also analyzed with either 2-independent sample *t*-tests or Wilcoxon-Mann-Whitney tests depending on normality. These data could not be added to the ANOVA because of differences in sampling methodology. Means are reported for *t*-tests used to determine differences between successful and unsuccessful hens, adult and juvenile hens, 1st and 4th week brood sites, residual grass height and cover for winter use and non-use sites.

CHAPTER 4

RESULTS

Nest Habitat

The ANOVA for nesting habitat included 49 nest and paired random sites in 2004, and 50 nest and paired random sites in 2005. Total shrub and sagebrush parameters were similar with the exception of cover for seasonal habitat (ie. nest vs. random) and height for seasonal habitat and year (Tables 3 and 4). There was an interaction ($P > 0.01$) between year and seasonal habitat for nest shrub average cover crown diameter (Fig. 3). Crown diameter of the shrub the hen nested under (hereafter referred to as the "nest shrub") was greater than random sites paired with nests in 2004. However in 2005 nest shrub crown diameter was similar to paired random sites.

Shrub parameters offering hiding cover were greater at nest sites than that available randomly. Nest sites had greater shrub cover (14.9%) and height (28.0 cm) than paired random sites (13.0% and 26.0 cm, respectively) (Table 3). Shrub density was similar at nest (1.4 shrubs/m^2) and random sites (1.3 shrubs/m^2). The shrub the hens nested under were taller at 49.8 cm, and had greater productivity with 60.8 g available forage than random shrubs (43.7 cm, and 50.6 g, respectively) (Table 5).

Grass heights were greater at nest sites than random sites but herbaceous cover was similar at these sites. The live and residual grass heights at nest sites were greater at 12.1 cm and 8.7 cm respectively; than random sites at 11.1 cm and 7.9 cm respectively

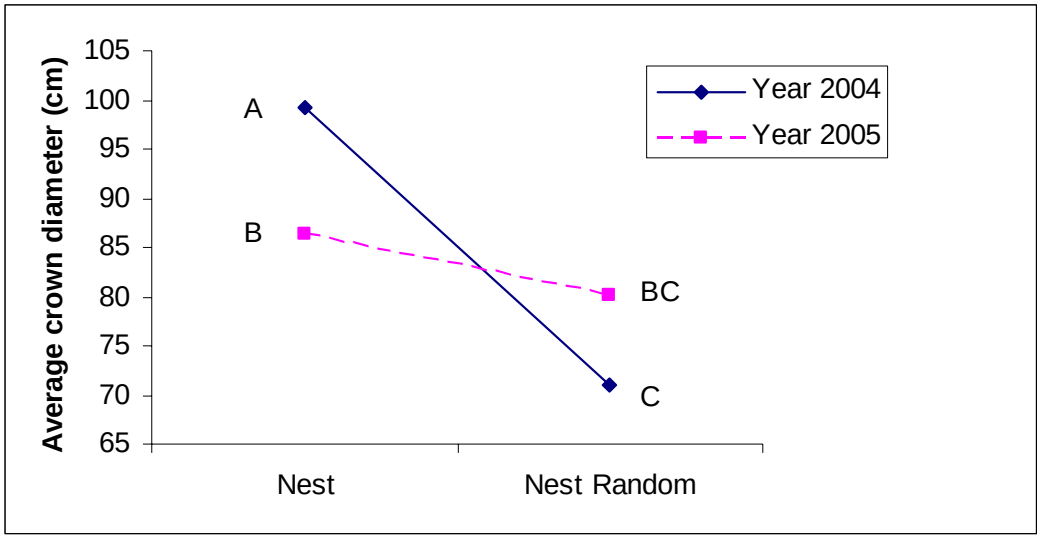

Figure 3. Interaction between year and seasonal habitat for average crown diameter of the nest shrub for nest and paired random sites in 2004 and 2005 in Golden Valley and Musselshell counties. Means differ ($P \leq 0.05$) between sites when followed by a different letter.

Table 3. Shrub cover, density and height least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at nest and paired random sites during 2004 and 2005 in Musselshell and Golden Valley counties.

	Shrub cover (%)			Shrub density (no./m^2)			Shrub height (cm)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Nest	14.9	0.63	0.03	1.4	0.07	0.27	28.0	0.72	0.05
Paired Random	13.0	0.63		1.3	0.07		26.0	0.72	
2004	14.3	0.64	0.45	1.3	0.07	0.84	26.0	0.72	0.05
2005	13.6	0.63		1.3	0.07		28.0	0.72	
Golden Valley	13.9	0.71	0.86	1.4	0.07	0.02	25.4	0.80	0.02
Musselshell	14.0	0.57		1.2	0.06		28.6	0.65	

Table 4. Sagebrush cover, density, and height least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at nest and paired random sites during 2004 and 2005 in Musselshell and Golden Valley counties.

	Sagebrush cover (%)			Sagebrush density (no./m^2)			Sagebrush height (cm)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Nest	14.6	0.66	0.06	1.4	0.07	0.21	27.1	0.66	0.15
Paired Random	12.9	0.66		1.3	0.07		25.8	0.66	
2004	14.3	0.67	0.21	1.4	0.07	0.71	26.0	0.66	0.29
2005	13.2	0.65		1.3	0.07		26.9	0.66	
Golden Valley	13.7	0.74	0.92	1.5	0.08	0.02	24.5	0.74	0.00
Musselshell	13.8	0.59		1.2	0.06		28.4	0.60	

Table 5. Nest shrub height and productivity least squares mean, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at nest and paired random sites during 2004 and 2005 in Musselshell and Golden Valley counties.

	Nest shrub height (cm)			Nest shrub productivity (g avail. forage)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Nest	49.8	1.21	0.00	60.8	1.87	0.00
Paired Random	43.7	1.22		50.6	1.88	
2004	44.9	1.21	0.03	53.4	1.87	0.08
2005	48.5	1.22		58.0	1.87	
Golden Valley	45.8	1.35	0.28	53.0	2.08	0.05
Musselshell	47.7	1.09		58.4	1.69	

Table 6. Live and residual grass vegetative height least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at nest and paired random sites during 2004 and 2005 in Musselshell and Golden Valley counties.

	Grass height (cm)			Residual grass height (cm)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Nest	12.1	0.33	0.03	8.7	0.29	0.04
Paired Random	11.1	0.33		7.9	0.28	
2004	10.1	0.33	0.00	9.7	0.29	0.00
2005	13.1	0.33		6.9	0.28	
Golden Valley	11.5	0.36	0.88	8.8	0.31	0.01
Musselshell	11.6	0.29		7.8	0.26	

Table 7. Total herbaceous, grass and forb cover least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at nest and paired random sites during 2004 and 2005 in Musselshell and Golden Valley counties.

	Herbaceous cover (%)			Grass cover (%)			Forb cover (%)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Nest	15.5	0.61	0.65	13.4	0.57	0.50	5.5	0.38	0.23
Paired Random	15.1	0.60		12.8	0.57		4.9	0.38	
2004	12.9	0.60	0.00	11.8	0.57	0.00	3.0	0.38	0.00
2005	17.7	0.61		14.5	0.57		7.4	0.38	
Golden Valley	13.3	0.68	0.00	11.5	0.64	0.00	4.4	0.43	0.01
Musselshell	17.3	0.54		14.7	0.50		5.9	0.34	

Table 8. Means for shrub parameters for successful and unsuccessful nests, adult and yearling nests and 1st and 4th week brood locations in Golden Valley and Musselshell counties in 2005.

	Total shrub cover (%)	Sage-brush cover (%)	Total shrub density (no./m^2)	Sage-brush density (no./m^2)	Sage-brush height (cm)	Total shrub height (cm)	Nest Shrub height (cm)	Productivity (g. avail forage)
Successful nests	16.5	16.1	1.2	1.3	30.4A[1]	31.1	50.3	60.1
Unsuccessful nests	13.1	13.3	1.5	1.5	26.9B	27.0	50.1	60.4
Adult nests	15.0	14.8	1.4	1.4	27.7	28.8	49.8	60.0
Yearling nests	15.4	14.8	1.5	1.4	30.3	30.8	52.2	64.9
1st week brood	12.5	12.4	1.4	1.3	26.6	26.7	N/A	N/A
4th week brood	14.4	13.0	1.0	1.0	26.4	27.3	N/A	N/A

[1]Means differ ($P \leq 0.05$) between sites when followed by a different letter.

(Table 6). There were no differences in herbaceous, grass or forb cover for nest (15.5%, 13.4%, and 5.5%) and paired random sites (15.1%, 12.8%, and 4.9%) (Table 7).

There were differences between years for nest herbaceous and shrub parameters. Herbaceous, forb, grass cover, and live grass height were all greater in 2005 than 2004.

Residual grass height was greater in 2004 than 2005. The height of the shrub the hen nested under was greater in 2005 than 2004.

Herbaceous, forb and grass cover were all greater in Musselshell county than Golden Valley county. Residual grass height and shrub density was greater in Golden Valley than Musselshell county. Musselshell county had greater nest shrub productivity, and average shrub height than Golden Valley county.

Only nests in sagebrush cover types were included in t-tests used to compare 2005 successful and unsuccessful nests and yearling and adult nests. Successful nests had greater sagebrush height than unsuccessful nests in 2005 (Table 8). There was no difference between adult and juvenile nest sites (Tables 8 and 9).

Brood Habitat

There were 26 and 37 brood and 35 and 38 random sites, respectively, for 2004 and 2005 analyzed together. There was no difference between 1st and 4th week brood locations so all locations were combined (Tables 8 and 9). Shrub parameters responded similarly to sagebrush except for sagebrush height comparisons between counties (Tables 10 and 11). There were no interactions for any of the variables in the brood ANOVA.

Brood sites were not different in shrub cover (13.7%), density (1.4 shrubs/m^2), or shrub height (27.9 cm) compared to random sites (12.9%, 1.2 shrubs/m^2, and 26.3 cm, respectively) (Table 10). Live and residual grass height were also the same for brood (13.9 cm and 7.5 cm) and paired random sites (13.7 cm and 7.2 cm) (Table 12).There was

Table 9. Herbaceous parameters for successful and unsuccessful nests, adult and yearling nests and 1st and 4th week brood locations in Golden Valley and Musselshell counties in 2005.

	Total herbaceous cover (%)	Grass cover (%)	Forb cover (%)	Grass height (cm)	Residual height (cm)
Successful nest	18.0[1]	15.0	7.7	14.6	7.9
Unsuccessful nests	19.0	14.9	8.8	13.2	6.6
Adult nests	18.0	14.5	7.8	14.0	7.6
Yearling nests	20.9	17.7	9.8	12.9	5.8
1st week brood	12.3	15.2	11.6	15.0	6.4
4th week brood	20.1	15.4	10.1	17.9	4.3

[1]Means differ ($P \leq 0.05$) between sites when followed by a different letter.

no difference in total herbaceous, grass or forb cover for brood (18.4 %, 14.5%, and 7.6%) and random sites (16.5%, 13.1%, and 7.1%) (Table 13).

Brood sites were different between years. There was greater shrub density in 2004 than 2005. Shrubs were taller in 2005 than 2004. Total herbaceous cover, forb cover, and live grass height were greater in 2005 than 2004. Residual grass height was greater in 2004 than 2005.

For brood and paired random sites there was no difference between the 2 study counties for shrub parameters but herbaceous parameters were different. Total herbaceous cover, and grass cover were greater in Musselshell county than Golden Valley county. Residual grass height was greater in Golden Valley county than Musselshell county.

Table 10. Shrub cover, density, and height least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at brood and paired random sites during 2004 and 2005 in Musselshell and Golden Valley counties.

	Shrub cover (%)			Shrub density (no./ m^2)			Shrub height (cm)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Brood	13.7	1.01	0.54	1.4	0.10	0.32	27.9	0.96	0.23
Paired Random	12.9	0.95		1.2	0.09		26.3	0.88	
2004	13.9	1.03	0.40	1.5	0.10	0.01	25.1	0.97	0.00
2005	12.8	0.91		1.1	0.09		29.1	0.86	
Golden Valley	13.4	1.15	0.93	1.4	0.11	0.50	26.0	1.10	0.10
Musselshell	13.3	0.80		1.3	0.08		28.1	0.76	

Table 11. Sagebrush cover, density, and height least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at brood and paired random sites during 2004 and 2005 in Musselshell and Golden Valley counties.

	Sagebrush cover (%)			Sagebrush density (no./m^2)			Sagebrush height (cm)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Brood	13.6	1.02	0.90	1.4	0.11	0.43	27.1	0.98	0.09
Paired Random	13.4	1.03		1.3	0.10		24.9	0.90	
2004	14.8	1.19	0.09	1.6	0.11	0.00	23.9	1.00	0.00
2005	12.2	0.93		1.1	0.09		28.1	0.88	
Golden Valley	13.9	1.21	0.64	1.4	0.12	0.22	24.4	1.12	0.02
Musselshell	13.1	0.90		1.3	0.09		27.6	0.78	

Table 12. Residual and live grass vegetative height least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at brood and paired random sites during 2004 and 2005 in Musselshell and Golden Valley counties.

	Grass height (cm)			Residual grass height (cm)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Brood	13.9	0.52	0.72	7.5	0.42	0.66
Paired Random	13.7	0.48		7.2	0.39	
2004	11.2	0.53	0.00	9.3	0.43	0.00
2005	16.5	0.47		5.4	0.38	
Golden Valley	14.3	0.60	0.22	8.0	0.48	0.04
Musselshell	13.4	0.41		6.8	0.33	

Table 13. Herbaceous, grass and forb cover least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at brood and paired random sites during 2004 and 2005 in Musselshell and Golden Valley counties.

	Herbaceous cover (%)			Grass cover (%)			Forb cover (%)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Brood	18.4	1.14	0.20	14.5	0.92	0.23	7.6	0.59	0.46
Paired Random	16.5	1.02		13.1	0.82		7.1	0.53	
2004	15.5	1.11	0.01	13.0	0.90	0.17	4.5	0.59	0.00
2005	19.4	1.04		14.6	0.84		10.2	0.56	
Golden Valley	15.8	1.27	0.04	12.1	1.03	0.01	6.9	0.67	0.23
Musselshell	19.1	0.90		15.4	0.73		7.9	0.47	

Winter Habitat

This analysis included 100 use sites and 31 non-use sites in 2004, and 146 use sites and 39 non-use sites in 2005. There were 52 winter use locations mostly from Musselshell county sampled in 2003 that were not included in this analysis because there were no non-use sites sampled for that year. The 2003 summary statistics are found in Appendix A, Table 27. Total shrub cover responded similarly to sagebrush for all parameters except with shrub cover comparison between counties (Tables 14 and 15).

Shrub height had a significant ($P > 0.02$) seasonal habitat by year interaction (Fig. 4). Winter use and non-use in 2004 had similar heights. In 2005 winter non-use sites had greater shrub height than use sites. Shrub height for winter use sites was greater in 2005, than 2004. An interaction between year and seasonal habitat ($P > 0.00$) for sagebrush height responded in the same way as shrub height (Fig. 5).

Winter use sites were different from non-use sites. Winter use sites had greater shrub cover (12.2%) and density (1.2 shrubs/m^2) than winter non-use sites (10.1% and

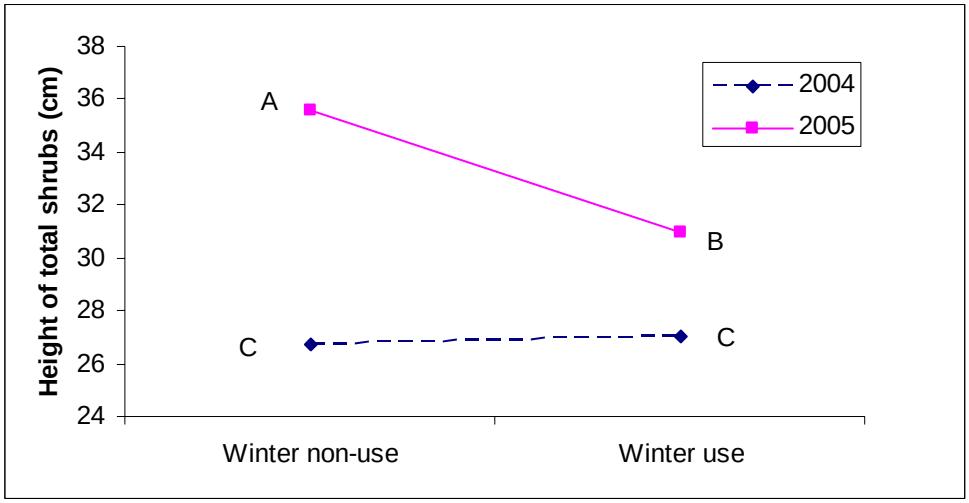

Figure 4. Interaction for year and seasonal habitat for shrub height for winter use and non-use sites in Musselshell and Golden Valley counties from 2004-2005. Means differ ($P \leq 0.05$) between sites when followed by a different letter.

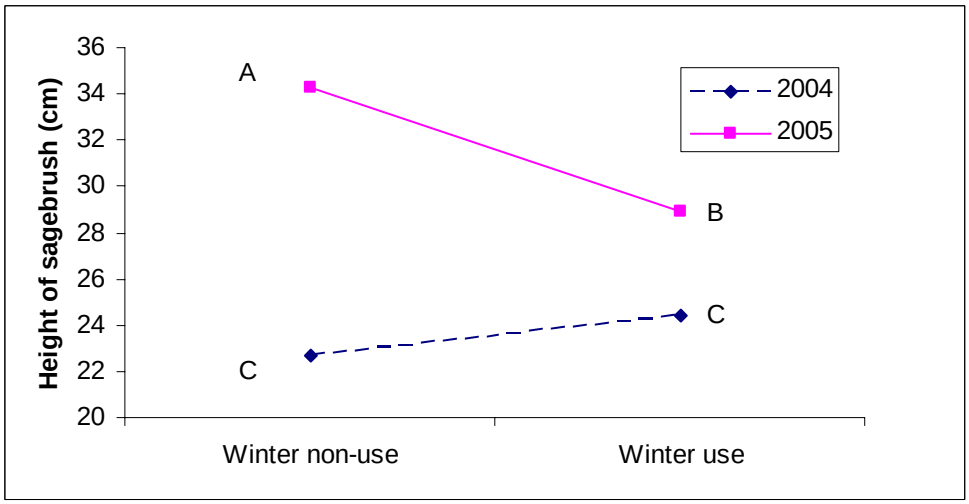

Figure 5. Interaction for year and seasonal habitat for sagebrush height for winter use and non-use sites in Musselshell and Golden Valley counties from 2004-2005. Means differ ($P \leq 0.05$) between sites when followed by a different letter.

Table 14. Shrub cover and density least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) for winter use and non-use sites in 2004 and 2005 in Musselshell and Golden Valley counties.

	Shrub cover (%)			Shrub density (no./m^2)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Winter non-use	10.1	0.6	0	0.8	0.07	0
Winter use	12.2	0.33		1.2	0.03	
2004	12.5	0.48	0	1.1	0.05	0
2005	9.8	0.42		0.9	0.05	
Golden Valley	11.9	0.45	0.01	1	0.05	0.49
Musselshell	10.4	0.45		1.1	0.05	

Table 15. Sagebrush cover and density least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) for winter use and non-use sites in 2004 and 2005 in Musselshell and Golden Valley counties.

	Sagebrush cover (%)			Sagebrush density (no/m^2)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Winter non-use	9.1	0.74	0.02	0.7	0.07	0.00
Winter use	10.9	0.37		1.1	0.04	
2004	11.1	0.54	0.00	1.1	0.05	0.00
2005	8.8	0.48		0.8	0.05	
Golden Valley	10.5	0.50	0.09	0.9	0.05	0.32
Musselshell	9.4	0.05		1.0	0.05	

Table 16. Greasewood cover and density least squares means, standard error, and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) for winter use and non-use sites in 2004 and 2005 in Musselshell and Golden Valley counties.

	Greasewood cover (%)			Greasewood density (no./m2)		
Main effects	LSMEAN	SE	*P* > *F*	LSMEAN	SE	*P* > *F*
Winter non-use	1.0	0.27	0.56	0.1	0.02	0.50
Winter use	1.2	0.16		0.1	0.01	
2004	1.3	0.23	0.08	0.1	0.02	0.29
2005	0.8	0.20		0.1	0.02	
Golden Valley	1.3	0.22	0.14	0.1	0.02	0.09
Musselshell	0.9	0.22		0.1	0.02	

Table 17. Means for residual grass height (vegetative and inflorescence) and residual grass cover at winter use and non-use sites for 2006 in Golden Valley and Musselshell counties. There were no significant differences.

	n	Grass height (cm)	*n*	Residual grass cover (%)
Winter non-use	31	18.0	30	14.4
Winter use	272	18.5	166	12.6

0.8 shrubs/m^2) (Table 14). There were no differences among the main effects for any of the greasewood parameters (Table 16).

There were differences for main effects year and county. Shrub cover and density were greater in 2004 than 2005. Golden Valley county had greater shrub canopy cover than Musselshell county.

Residual grass height and cover were collected at winter use and non-use sites during the 2005-2006 winter and were analyzed with a *t*-test. There were no differences between residual grass height and cover for use and non-use sites (Table 17).

Soils

In the Golden Valley study site, 4, 114, and 163 bird locations were recorded during the winters 2003-2004 (2003), 2004-2005 (2004), and 2005-2006 (2005), respectively. In Musselshell county study site 49, 100, and 151 bird winter locations were recorded in 2003, 2004, and 2005, respectively (Figs. 6 and 7). All bird locations were used in the analysis of use versus availability. The sample size in 2003 was not large enough to analyze separately, therefore 2003 locations were combined into the overall analysis for all 3 winters.

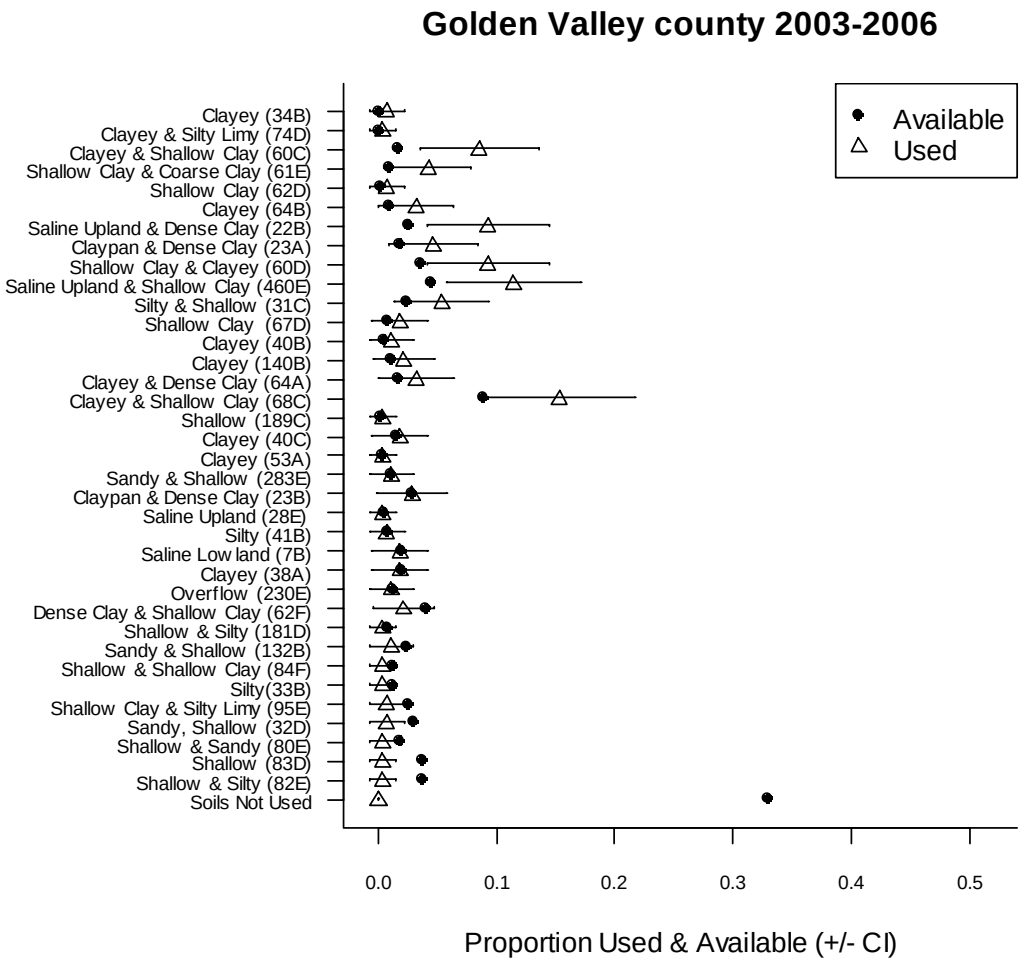

Figure 6. Proportion of use versus availability of soils (ecological site and map unit symbol) and bonferroni confidence interval for sage-grouse locations collected during the winters of 2003-2005 in Golden Valley county.

During winter 2004, soil MUSYM's 60C and 22B were used in greater proportion than that which was available in Golden Valley (Appendix B). Soil MUSYM 68C was used more than available during the winter of 2005 (Appendix B). When all bird locations during winters 2003, 2004, and 2005 were combined; 60C, 22B, and 460E were all used in greater proportion than was available (Fig. 6).

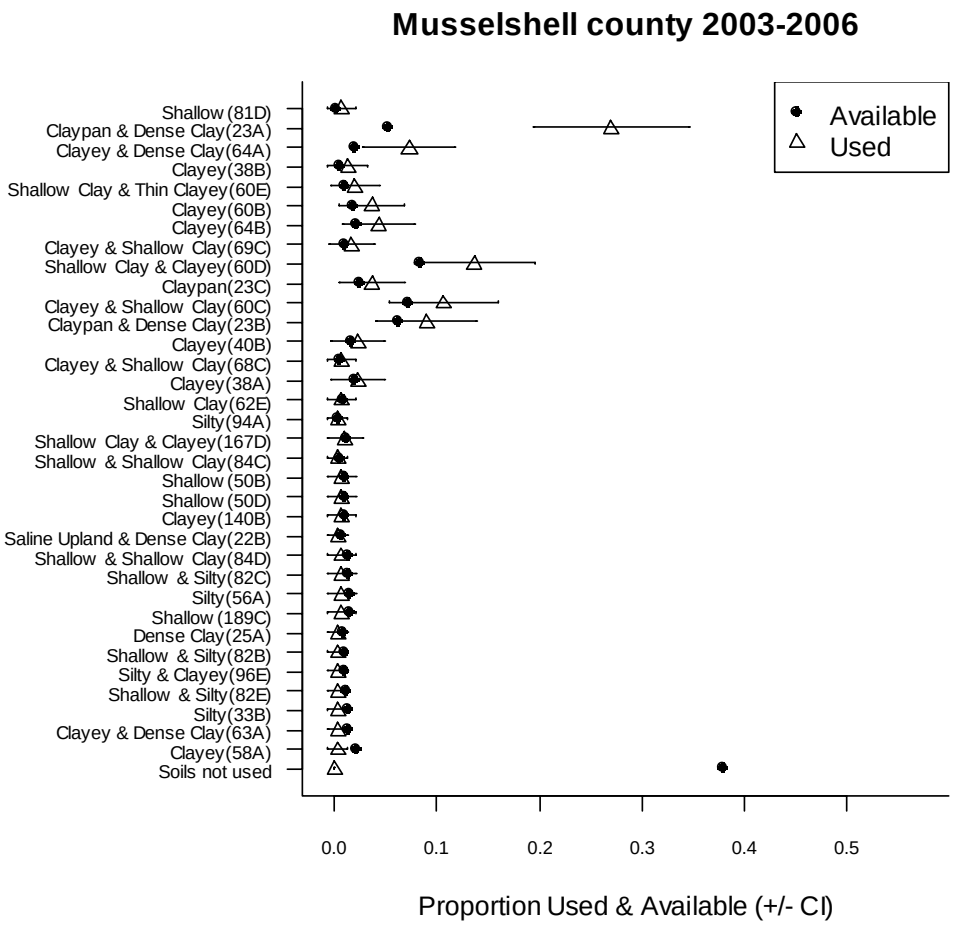

Figure 7. Proportion of use versus availability of soils (ecological site and map unit symbol) and bonferroni confidence interval for sage-grouse locations collected during the winters of 2003-2005 in Musselshell county.

In Musselshell county during the winter of 2004, MUSYM 23A was used more than available (Appendix B). During 2005, 64A and 23A were used more than available (Appendix B). When all 3 winters were combined, 23A and 64A were both used more than available (Fig. 7).

Table 18. Total shrub cover, density, and height least squares means, standard error and P value of the F statistic for main effects (seasonal habitat, year, and county) for all uses (brood, nest, and winter) in 2004 and 2005 in Golden Valley and Musselshell counties.

	Shrub cover (%)			Shrub density (no/m^2)			Shrub height (cm)		
Main effects	LS MEAN	SE	*P* > f	LS MEAN	SE	*P* > f	LS MEAN	SE	*P* > f
Brood	14.0AB	0.75	0.01	1.4A	0.08	0.19	28.3A	1.00	0.70
Nest	15.1A	0.61		1.4A	0.06		28.4A	0.79	
Winter use	12.1B	0.36		1.2A	0.04		29.0A	0.50	
Year 2004	14.7A	0.47	0.01	1.4A	0.05	0.00	26.8B	0.64	0.01
Year 2005	12.7B	0.42		1.2B	0.05		30.4A	0.57	
Golden Valley	14.3A	0.48	0.03	1.4A	0.05	0.31	28.7A	0.64	0.73
Musselshell	13.1B	0.41		1.3B	0.04		28.4A	0.57	

[1]Means differ ($P \leq 0.05$) between sites when followed by a different letter.

Seasonal Habitat Comparisons

This analysis included 61 brood sites, 99 nest sites and 246 winter use sites. Total shrub cover responded similarly to sagebrush except for the density comparison between seasonal uses, and cover and height in comparison of counties (Tables 18 and 19). There were no interactions between dependant variables.

Cover was the only shrub parameter that differed between seasonal habitats. Winter use sites had lower shrub cover, 12.1%, than nest sites 15.1% (Table 18). Shrub cover was similar between nest and brood sites as well as between winter use and brood sites. Shrub density and height were similar for brood, nest, and winter sites, ranging from 1.2-1.4 shrubs/m^2 and 28.3 - 29.0 cm respectively. Greasewood cover and density did not differ for brood (0.9%, 0.04/m^2), nest (0.8%, 0.03/m^2), or winter sites (1.1%, 0.08/m^2) (Table 20).

Table 19. Sagebrush cover, density, and height least squares means, standard error and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) for all uses (brood, nest, and winter) in 2004 and 2005 in Golden Valley and Musselshell counties.

	Sagebrush cover (%)			Sagebrush density (no/m^2)			Sagebrush height (cm)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Brood	13.6A[1]	0.84	0.00	1.3AB	0.09	0.01	27.5A	0.91	0.68
Nest	14.8A	0.64		1.4A	0.07		27.4A	0.71	
Winter use	10.9B	0.40		1.2B	0.04		26.8A	0.45	
2004	14.1A	0.48	0.00	1.4A	0.06	0.00	25.5B	0.58	0.00
2005	12.0B	0.70		1.2B	0.05		29.0A	0.51	
Golden Valley	13.5A	0.53	0.16	1.3A	0.06	0.52	26.5B	0.59	0.04
Musselshell	12.6A	0.46		1.3A	0.05		27.9A	0.50	

[1]Means differ ($P \leq 0.05$) between sites when followed by a different letter.

Table 20. Greasewood cover and density height least squares means, standard error and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) for all uses (brood, nest, and winter) in 2004 and 2005 in Golden Valley and Musselshell counties.

	Greasewood cover (%)			Greasewood density no/m^2)		
Main effects	LSMEAN	SE	*P* > *F*	LSMEAN	SE	*P* > *F*
Brood	0.9A[1]	0.44	0.69	0.04A	0.03	0.15
Nest	0.8A	0.39		0.03A	0.03	
Winter use	1.2A	0.16		0.08A	0.01	
2004	1.2A	0.34	0.21	0.06A	0.02	0.65
2005	0.8A	0.19		0.05A	0.01	
Golden Valley	1.2A	0.28	0.07	0.07A	0.02	0.04
Musselshell	0.7A	0.72		0.03B	0.02	

[1]Means differ ($P \leq 0.05$) between sites when followed by a different letter.

Table 21. Residual and live grass height least squares means, standard error and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at brood and nest sites in 2004 and 2005 in Golden Valley and Musselshell counties.

	Grass height (cm)			Residual grass height (cm)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Brood	14.1	0.48	0.00	7.4	0.44	0.02
Nest	12.2	0.37		8.7	0.35	
2004	11.0	0.44	0.00	9.7	0.41	0.00
2005	15.2	0.40		6.5	0.37	
Golden Valley	13.6	0.48	0.16	8.6	0.45	0.04
Musselshell	12.7	0.37		7.5	0.34	

Table 22. Total herbaceous, grass and forb cover least squares means, standard error and *P* value of the *F* statistic for main effects (seasonal habitat, year, and county) at nest and brood sites in 2004 and 2005 in Musselshell and Golden Valley counties.

	Herbaceous cover (%)			Grass cover (%)			Forb cover (%)		
Main effects	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*	LS MEAN	SE	*P* > *F*
Brood	18.4	1.08	0.04	14.5	0.89	0.30	7.6	0.61	0.01
Nest	15.6	0.84		13.4	0.69		5.6	0.48	
2004	14.9	0.97	0.00	13.2	0.80	0.21	3.8	0.55	0.00
2005	19.1	0.93		14.6	0.77		9.4	0.53	
Golden Valley	15.2	1.11	0.01	12.2	0.92	0.00	6.3	0.63	0.40
Musselshell	18.7	0.82		15.6	0.67		6.9	0.46	

Herbaceous parameters differed between nest and brood sites. Grass height was greater at brood sites (14.1 cm) than nest sites (12.2 cm) (Table 21). Residual grass height was greater at nest sites (8.7 cm) than brood sites (7.4 cm). Brood sites had greater herbaceous cover (18.4%) and forb cover (7.6%) than nest sites (15.6% and 5.6%) (Table 22).

There were significant differences for the main effects year and county. Total shrub cover, density and height were greater in 2004 than 2005. Grass height, herbaceous cover and forb cover were greatest in 2005. Residual grass height was greater in 2004. Total shrub cover and greasewood density were greater in Golden Valley than Musselshell county. Residual grass height was greater in Golden Valley county than Musselshell county, but herbaceous and grass cover were greater in Musselshell county.

CHAPTER 5

DISCUSSION

Nest Habitat

The importance of herbaceous and shrub cover for nest concealment has been demonstrated in previous studies (Connelly et al. 2000, Sveum et al. 1998). Holloran et al. (2005) identified total shrub canopy cover sagebrush height, residual grass cover, and residual grass height as important determinants of nesting habitat. When total shrub cover, residual grass height, or residual grass cover increased by 10%, the probability of a nest increased by 31.3% (Holloran et. al. 2005). I also found sage-grouse nested in areas with greater total shrub cover and height, and taller live and residual grass than was randomly available. I measured nests within 7 days of nest hatch, but the hen chose the nest site and began laying ~36 days before hatch. Therefore residual grass height and shrub cover were likely more important in nest site selection than the current year's growth.

The shrub under which the hen nested was taller and had greater productivity than random shrubs in both years. Nest shrub average crown diameter was greater at nest sites than paired random sites in 2004. This suggests that hens selected nest shrubs that would provide adequate hiding cover. In southeastern Idaho grouse nested under taller shrubs with greater area and more cover (Wakkinen 1990). In general sage-grouse nests were under shrubs with larger canopies, more ground and canopy cover, as well as within

Table 23. Weather including precipitation and temperature during nesting and brood rearing (March-July) from weather station (# 247220) in Roundup, MT (National Oceanic and Atmospheric Administration 2006).

		MAR	APR	MAY	JUN	JUL
2004	Sum precipitation (in)	0.1	0.6	1.7	2.1	1.1
2004	Monthly mean temperature (°F)	44.8	50.5	54.8	61.0	72.4
2005	Sum precipitation (in)	0.6	3.6	2.4	5.6	0.5
2005	Monthly mean temperature (°F)	40.5	47.3	54.2	53.7	73.5

stands with greater shrub cover than randomly available (Sveum et al. 1998, Holloran 1999, Connelly et al. 2000).

Due to increased precipitation in 2005, total herbaceous, forb, and grass cover and live grass height were greater in 2005 than 2004 (Table 23). Sika (2006) found some support for increased nest success in 2005 on the same study area. Coggins (1998) found nest success for sage-grouse increased in years with greater residual tall grass cover. Haustliner (2003) considered grass height to be a limiting factor for nest success during drought years. Annual nest success rates have been positively correlated with the preceding year's precipitation (Holloran 2005). Therefore an increase in nest success may have been realized in the spring of 2006, unfortunately that was not measured in this study.

Because multiple years preceding 2005 were dry, residual grass height (grass left over from 2004) was shorter in 2005 than 2004. Drought stress can reduce plant stature, and change plant species composition (Archer and Smeins 1991). Prolonged drought leads to reduced amounts of forage (Archer and Smeins 1991). With sustained grazing pressure the number of grazed plants increases, decreasing the average herbaceous plant height.

There was a greater number of re-nests (ie. 2nd and 3rd nest attempts) in 2005 than 2004. Because there were more re-nests, more nest measurements were taken later in the season after more of the growing season had passed. Differences in vegetation cover between years may have been caused by the increase in re-nests measured in 2005. Re-nests were more successful (56%) than first nests (32%) (Sika 2006). This was likely because of the increase in herbaceous cover. Although there was a higher proportion of successful nests in 2004, there was greater hen success in 2005 (success in raising a brood out of all of the females beginning the study) (Sika 2006). Moynahan (2004) and Sika (2006) found that nesting probability increased when habitat condition was improved.

Herbaceous cover associated with nest sites may have provided scent, visual, and physical barriers to predators (DeLong et al. 1995). Nest shrub height and productivity were greater in 2005 than 2004 (nest shrub productivity $P = 0.08$), while residual grass was lower in 2005 than 2004. More hens in 2004 selected nest sites before live herbaceous vegetation contributed to cover. Residual grass height was taller at nest sites than random sites. Therefore, they might have selected sites with greater residual grass height to increase hiding cover on the nest. Because residual grass height was lower in 2005 than 2004, hens may have needed to select sites with greater shrub cover to compensate for the lack of residual grass height.

Total herbaceous, grass, and forb cover, nest shrub productivity, and average shrub height were greater in Musselshell county than Golden Valley county. Nest shrub productivity and average shrub height were both greater at nest sites than randomly

available. If hens in Golden Valley were not able to select equally suitable habitat as hens in Musselshell county, they might have been at a reproductive disadvantage. Sika (2006) detected a slightly higher nest survival in Musselshell county but estimates were too imprecise to very confident of the exact level variation. Golden Valley county had greater shrub density and greater residual grass height than Musselshell. Hens appeared to be selecting nest sites with greater residual cover. Hens in Golden Valley county could have compensated for less herbaceous material, and shorter shrubs with less productivity by choosing nest sites with greater residual grass cover. Land management and or potentially different weather conditions may have contributed to differences between counties. Weather data was only available at the Roundup weather station which is between the two study sites, but I suspect Musselshell county may have received more precipitation.

I learned that successful nests had taller sagebrush plants surrounding the nest than unsuccessful nests. In south-central Washington, successful nests had greater residual cover and height than unsuccessful nests (Sveum et. al 1998). In central Montana Wallestad and Pyrah (1974) found successful nests to be located in sagebrush stands with greater than average shrub cover compared to unsuccessful nests.

Over the course of this study out of 182 nests, 91% of nests were located under sagebrush, 3% were under greasewood, and 6% were located in either seeded grasslands, or alfalfa fields (Sika 2006). Wallestad and Pyrah (1974) found all 41 of the nests sampled to be under sagebrush in the Yellow-water triangle of central Montana. In Wyoming, 92% of 300 nests were under sagebrush (Patterson 1952).

In summary, herbaceous cover either from herbaceous vegetation or shrubs was greater at nest sites than paired random sites. Herbaceous cover increased substantially from 2004 to 2005 increasing cover on nests as well as allowing for greater numbers of re-nests. The positive effects of increased herbaceous vegetation may also have carried on to brood rearing.

Brood Habitat

I found no differences between brood and paired random sites for any of the herbaceous or shrub parameters measured. Klebenow (1969) did not find a statistical difference between brood and random sites in Idaho. A meta-analysis of 7 sage-grouse studies throughout the west found areas used by broods < 6 weeks of age had greater forb and grass cover, taller grass, and less sagebrush cover than random sites (Hagen et al. in press).

There was greater shrub height, total herbaceous cover, forb cover, and live grass height in 2005 than 2004. Shrub density and residual grass height were greater in 2004 than 2005. Because there was no difference between brood and paired random sites, hens may have been selecting sites on a larger scale than we sampled. Broods in southern Oregon and southern Idaho used areas with the greatest forb cover (Klebenow 1969, Drut 1994a). Forbs, insects, and sagebrush are the primary food sources for young chicks (Drut 1994b, Peterson 1970). Forb cover increased 2.5 fold from 2004 to 2005 due to increased precipitation across my study area (Table 23). As forb cover increased, broods may have been able to forage in a variety of cover types in 2005. The added herbaceous

cover may have added a component making chicks less visible in a variety of cover types. Coggin's (1998) brood use was equitably distributed between cover types in wet years more than dry years because of the greater availability of forbs.

Increased food availability and cover have the potential to increase survival of chicks (Crawford 1998). On my study area there was 71% brood survival in 2004, and 84% in 2005 (brood survival is the survival of at least one chick to 30 days of age) (Sika 2006). Increased grass height, total herbaceous cover and forb cover, likely increased survival of chicks.

Due to unfavorable precipitation and a lack of forbs, the food source for chicks could have been comprised more of sagebrush than forbs in 2004. This could be why sagebrush density was higher in 2004 than 2005. Drut (1994a) found chick diets in Oregon to correspond directly to the availability of primary foods. Forbs and invertebrates constituted >75% of the diet at Hart Mountain, while sagebrush composed 65% of the mass consumed by chicks at Jackass Creek. Peterson (1970) in central Montana and Klebenow (1968) in Idaho found young grouse to eat mostly forbs and insects and very little sagebrush until they were ≥10 weeks old. Total forb cover has been positively correlated with potentially preferred invertebrate (medium length Hymenoptera and Coleoptera) abundances (Thompson et al. 2006). When forb cover was low in 2004 on my study area, invertebrate abundances may have also been low.

In 2004 most of my measurements were taken at 1st and 2nd week brood locations in late may and early June. Wallestad (1975) in central Montana found broods to use canopy covers between 10-25% in June and move into more mesic areas to follow the

green forbs in July and August. Chicks <2 weeks in age were found in areas with greater sagebrush cover than surrounding areas in Wyoming (Thompson et al. 2006).

Brood locations collected in 2005 were 1st and 4th week brood locations distributed from late June until the end of July. There was no statistical difference between 1st and 4th week locations in 2005, although 1st week locations did appear to have greater shrub density than 4th week locations (1.4 shrubs/m^2 vs. 1.0 shrub/m^2). Due to the small number of 4th week brood locations in 2004, differences between 1st, 2nd and 4th week locations could not be determined. The differences in brood ages between years may have led to differences in vegetation means between years such as greater shrub density in 2004 than 2005 (1.5 shrubs/m^2 vs. 1.1 shrub/m^2).

Though total herbaceous cover and grass cover were greater in Musselshell county, residual grass height was greater in Golden Valley county. Because total herbaceous cover was higher in Musselshell county, chicks may have benefited from greater hiding cover and greater foraging potential. Residual grass may have provided more hiding cover in Golden Valley county. Sika (2006) found brood survival to be slightly higher in Golden Valley county but estimates were to imprecise to allow much confidence in the exact level of variation between the 2 counties.

In summary brood sites were not different from random sites. Differences in herbaceous cover between years may have allowed for greater chick production. Musselshell county had more herbaceous cover, potentially offering more hiding cover for chicks.

Winter Habitat

I believe shrub height was greater at non-use sites than use sites in 2005 because approximately 20 non-use sites had relatively large shrubs and low density. There was no difference in height between use and non-use sites in 2004. Most winter studies have found height of sagebrush to be an important determinant of sage-grouse habitat because sagebrush availability above the snow pack has been determined to be critical for sage-grouse survival (Wallestad 1975, Beck 1977, Robertson 1991). Snow never completely covered sagebrush during the 2 years of this study (Table 24). Both winters were relatively mild with low snowfall and warm temperatures. In a study in the Yellow-Water Triangle of Montana, <15 miles north of my Musselshell study site, Wallestad (1975) found sage-grouse restricted to 7% of their available range when snow depths exceeded 12 inches. This occurred in 3 of the 7 winters of his study (Wallestad 1975). It is not known where grouse in my study area will go under harsh winter conditions.

Regardless of my sampling occurring over a period of mild winters, shrub cover and density were greater at winter use sites than non-use sites. This is similar to findings in Idaho sage-grouse winter habitats (Robertson 1991). During the winter sage-grouse were almost completely reliant on sagebrush as a food and cover source (Patterson 1952, Wallestad 1975). Sage-grouse were able to maintain or gain weight during the winter (Patterson 1952, Remington and Braun 1988) because of their nutritious diet (Wambolt 2004) of abundant sagebrush.

Shrub density and cover were greater in 2004 than 2005. Winter weather conditions were similar for both years. In the fall of 2005, 827 acres of important winter habitat in Musselshell county were chisel-plowed, effectively removing all sagebrush from the site. While it appeared that birds had plenty of similar habitats available they were still found in the chisel-plowed area and in adjacent habitat that appeared less than ideal. The 10 sites immediately surrounding the newly plowed area during the 2005 winter had a shrub canopy cover of 7.2% and a density of 0.86 shrubs/m^2. I found sage-grouse returned to wintering grounds year after year as did Berry and Eng (1985). Swenson (1987) in south-central Montana found grouse populations to decline by 73% after 30% of a known sage-grouse winter habitat was plowed. On my study area, lek numbers increased the following year (MTFWP unpublished data), possibly due to the wet productive spring before. Although less than 30% of my winter range was plowed declines in population numbers could occur in the future if the study area received harsh winter conditions.

Sika (2006) found monthly winter survival to be lower in the 2005 winter than the 2004 winter. Because reproductive effort was higher in 2005, Sika (2006) attributed the decline in survival to trade-offs between survival and reproductive effort. The differences in habitat between the 2 years (decreased density and cover in 2005) could be a cause or an effect of decreased survival in 2005. It is possible that grouse choose habitats that were less suitable causing mortality. It is also possible that grouse chose habitats to mitigate high mortality, for example they may have used habitats with less density and cover in order to be able to visualize and avoid predators.

Golden Valley county had greater total shrub canopy cover than Musselshell county, but the difference was only 1.5% or 12% more. Golden Valley and Musselshell counties had similar sagebrush cover. Though the difference is small, grouse in Golden Valley county may have had more hiding and thermal cover than grouse in Musselshell county. The large newly plowed area in Musselshell county could have influenced these differences.

Residual grass height and cover were similar at use and non-use sites. Because grass heights measured for residual grass height in the winter of 2005-2006 included inflorescences the heights are not comparable with nest and brood residual grass heights were vegetative droop heights were measured. Sage-grouse did not appear to be selecting areas with residual grass cover in the winter. To my knowledge, no other study has addressed the importance of herbaceous cover in the winter. Selection for areas with greater herbaceous cover seems to be restricted to nesting and brood rearing activities when predator avoidance involves hiding.

Patterson (1952) noted birds used large flocks for predator avoidance during cold, and or snowy conditions. I also observed larger flocks on my study site when weather was cold. Flock sizes ranged from 1 to > 150 birds during the two winters (Table 25). I noticed flocks flushed when the observer was at a further distance in the winter than was the case during nesting and brood rearing season. This suggests grouse would use cover for hiding from predators in nesting and brood rearing, but in the winter sage-grouse relied on one another to acknowledge predators and quickly leave the area. During warm weather periods on my study area flocks dispersed. Beck (1977) in North Park Colorado

noted larger flocks the second winter of his study and attributed this to greater production the spring before and milder conditions during the second winter.

Water may be limiting during the winter in my study area. On multiple occasions grouse were found on the only patch of snow available within miles. The study area was dry and windy for much of the winter. Autenrieth (1981) found grouse to need free water when forbs were desiccated in the summer. Some grouse locations may have been influenced more by distance to water than food and cover.

Sage-grouse winter locations were closely related to lek locations with 82% of locations within 3 km of an active lek in 2004 and 71% in 2005 (Table 26). Nearly all locations were within 5 km of an active lek, 99% in 2004, and 94% in 2005. Use was distributed through out approximately 25% of each lek complex (the area within overlapping 5 km radii around trapped leks (Figs. 1 and 2). This was different from other studies that found winter range to be limited to 1-15% of year-long range (Beck 1977, Wallestad 1975, Swenson et al. 1987). Another Study in central Montana where snow depths were not limiting found grouse to be using 53% of their study area (Eng and Schladweiler 1972).

In summary, winter use sites had greater shrub cover and density than non-use sites because of sage-grouse reliance on sagebrush as food source and cover. Differences between habitats in 2004 and 2005 cannot be attributed to weather conditions. Sage-grouse used similar location on the landscape in 2004 and 2005. Residual grass cover and height was not important at winter use sites.

Table 24. Maximum, minimum, and average temperature, total precipitation, and total snow depth from January to December in 2004-2006 at station 247220 in Roundup, MT (National Oceanic and Atmospheric Administration 2006).

Year	Month	Average maximum Temp. °F	Average minimum Temp. °F	Average Temp. °F	Total Precip.(in)	Total Snow (in)
2004	Jan	33	12	22.5	0.4	7.5
2004	Feb	43	19	31	0.26	0.5
2004	March	60	30	45	0.11	0.5
2004	December	46	21	33.5	0.39	4.2
2005	Jan	33	11	22	0.26	6.5
2005	Feb	49	19	34	Trace	Trace
2005	March	54	27	40.5	0.63	6.4
2005	December	36	18	27	0.33	4.5
2006	Jan	47	28	37.5	0.02	0
2006	Feb	42	16	29	0.22	1.4
2006	March	47	22	34.5	1.55	8

Table 25. Number and percent of flocks with number of birds per flock.

	2004		2005	
Number of birds/ flock	# of flocks	% of flocks	# of flocks	% of flocks
100-150	3	2	41	11
50-99	20	9	70	18
25-49	28	13	70	18
24-1	167	76	202	52

Table 26. Percent of winter bird locations within distance of nearest lek during winters 2004-2006.

Year	Distance to nearest lek (km)	# of Bird Locations	Percent
2004-2005	1	66	28.6
	2	136	58.9
	3	190	82.3
	4	201	87.0
	5	229	99.1
		Total 231	
2005-2006	1	46	12.8
	2	137	38.3
	3	254	70.9
	4	295	82.4
	5	338	94.4
		Total 358	

Soils

Preferred soils in Golden Valley county were 60C, 22B, 68C, 60D, and 460E. The preferred soils in Musselshell county were 23A, and 64A in addition 60C and 60D were often used.

Soil MUSYM's (think of map unit symbols as soil types) 22B, 23A, and 64A are all greasewood bottom cover types that have relatively low sagebrush canopy cover compared to other soils on the study area. The texture of these soils varied among silty clay, silty clay loam, and loam. These soils were salt and sodium affected within 76 cm, depths were >152 cm and slopes ranged form 0-5% (USDA 2003). Two of the 246 winter use sites sample had no sagebrush canopy cover; both of these sites were in greasewood bottoms. It is worth noting that 22B was used in greater proportion than availability despite sagebrush cover as low as 4.2% and 2.7% for greasewood (Table 27).

I believe the large amount of greasewood bottom use by grouse was one reason for the relatively low sagebrush cover at winter use sites. There were 171 sites with no greasewood cover, they averaged 12.7% shrub and sagebrush cover. The 78 sites that had any greasewood cover at all had an average sagebrush cover of 6.1% and a shrub cover of 9.8%.

There are several reasons why grouse may have been using greasewood bottoms. Greasewood bottoms represented the riparian areas in our study site, having the most water on the landscape. Grouse may have needed free water due to the dry, windy winter conditions. Greasewood bottoms also had annual pepperweed (*Lepidium densiflorum* and

L. perfoliatum) cover when soils were moist and temperatures were warm during the winter. Pepperweed was found in droppings and at use sites during a 3 day period in January 2006. Additionally soils in these saline bottoms may have provided a nutrient grouse needed either via soil minerals or plant material.

MUSYM's 460E, 68C, 60C and 60D had silty clay and silty clay loam soil textures, and there was little to no salinity or sodicity within 30 in of the surface of these soils. Slopes ranged from 2-15% and soil depth form 10-40 in (USDA 2003). These 4 soil types had 12-13% canopy cover of Wyoming big sagebrush. Soils 68C and 460E received most shrub cover from sagebrush, but may have had a small greasewood component as well. In eastern Montana, Wyoming big sagebrush occupies upland soils typically vertisols or alluvial soils with clay or silt (Morris et al. 1976). In other regions Wyoming big sagebrush may be found on finer textured soils than those on our study site (Welch 2005).

Sagebrush habitats in my study area have commonly been converted for agricultural production of either dryland wheat or seeded grasslands. The Golden Valley study site had approximately 5,429 acres (6% of the area within the study lek buffer) that were in agricultural production (not rangeland). In Golden Valley 60C was the most commonly converted MUSYM, and 21% of the total area plowed in Golden Valley was 60C. MUSYM 60D was the 16th most converted soils type and comprised 2% of the area plowed in Golden Valley. In Golden Valley county 23A was the 25th most converted soil and was 1% of the area plowed. Approximately 65% of the area converted to agriculture in Golden Valley had potential to be sage-grouse habitat (ie. 65% of the area converted to

agriculture was on a soil type where I have had at least 1 sage-grouse winter location). Sage-grouse used 24 % of the area within the lek complex, when the area was calculated by taking the sum of the area of all soil polygons used during the 2 winters.

The Musselshell county study site had approximately 13,292 acres in agricultural production (not rangeland). In Musselshell county 23A ranked as the 4th most converted soil type and made up 5% of the converted soils. MUSYM 60C was the 13th most converted soil type and comprised 2% of the total area in agriculture in Musselshell county. Finally, 60D ranked 25th for soil types plowed in Musselshell county and was 1% of the total area under cultivation. Approximately 62% of the area converted to agriculture in Musselshell county had potential to be sage-grouse habitat (ie. 62% of the area converted to agriculture was on a soil type where I have had at least 1 sage-grouse winter location). Sage-grouse used 19% of the area within the lek complex, when the area was calculated by taking the sum of the area of all soil polygons used during the 2 winters.

This method of determining soils that sage-grouse used more than was available is applicable across sage-grouse range. Soils maps are available for the majority of the west. This method can be used to identify potential sites for sagebrush restoration and potential sage-grouse habitat for improvements or protection.

Table 27. Cover, density, and height of sagebrush, silver sagebrush, and greasewood averaged over all sites sampled during the study (nest, brood, winter and random sites) for soil MUSYM's that were used often by grouse in the winter.

			Cover (%)				Density (no./m^2)			Height (cm)		
Soil MUSYM	# Winter Bird locations	Sites Measured	Sagebrush	Silver sage	Grease-wood	Total shrub	Sagebrush	Silver sage	Grease-wood	Sagebrush	Silver sage	Grease-wood
22B	27	19	4.2	0.0	2.7	7.6	0.59	0.01	0.34	25.9	18.0	40.2
23A	99	63	6.9	0.1	1.6	9.8	0.79	0.01	0.23	25.1	23.0	34.8
23B	39	46	7.7	0.0	2.7	10.9	0.73	0.05	0.24	30.2	21.3	42.6
23C	11	20	10.8	0.0	0.8	11.6	1.01	0.00	0.21	30.9	0.0	46.7
38A	5	15	9.6	0.0	1.0	10.7	0.74	0.03	0.15	30.8	0.0	45.9
460E	32	28	12.6	0.0	0.5	13.2	1.27	0.00	0.04	28.7	46.2	47.5
50D	2	15	11.0	0.0	0.1	11.1	0.80	0.00	0.03	33.8	0.0	65.8
60B	12	19	12.5	0.0	0.0	12.5	1.32	0.00	0.03	25.7	0.0	0.0
60C	60	57	12.1	0.0	0.1	12.2	1.37	0.00	0.01	25.4	0.0	32.4
60D	66	102	13.2	0.1	0.1	13.4	1.37	0.01	0.05	27.1	24.3	54.3
62F	6	15	8.2	0.0	0.5	9.7	0.65	0.00	0.03	28.4	0.0	58.8
64A	8	23	9.0	0.0	1.9	11.6	1.17	0.00	0.14	23.1	0.0	38.7
64B	22	24	10.7	0.0	0.1	12.0	1.02	0.02	0.10	23.4	27.5	48.3
68C	45	50	11.5	0.0	0.1	11.6	1.02	0.01	0.02	28.1	25.0	60.2
82E	1	16	14.6	0.3	0.0	14.9	1.14	0.02	0.04	32.3	16.9	13.5
95E	2	17	9.4	0.0	0.0	9.5	1.22	0.00	0.01	25.4	0.0	0.0

Table 28. Count and percent of each habitat use site (nest, brood and winter) from both years (2004-2005) sampled within 6 cover ranges from 0.3% - 36.7% shrub cover.

Shrub cover (%)	Number of use sites in each cover range	Percent of sites in cover range (%)
0.3- 5.0	34	8
5.1- 10.0	109	26
10.1- 15.0	148	35
15.1- 20.0	75	18
20.1- 25.0	37	9
25.1 -36.7	14	3

Seasonal Habitat Comparisons

Winter use sites had less shrub cover than nest sites seemingly in conflict with Wallestad (1975) who found nest and winter habitats to be synonymous in central Montana. I believe our winter sites were low in cover, height, and density compared to other studies because snow depth was not great enough during this study to influence grouse distribution. Wallestad's (1975) study included 3 of 7 winters which were above average in snow accumulation. If our study had occurred in similar winters it is likely that the winter habitat could have been similar to nesting habitat.

Other studies have found brood sites to have less shrub cover than random sites and nest sites to have greater shrub cover than random sites (Hagen et al. in press); however I found the 2 habitats (nest and brood) to be similar in my study area. I removed all non-shrub habitats from my analysis in order to compare shrub habitats; if this had not been done the average cover of shrubs at brood sites would have been lower. As forbs desiccate, grouse often moved to more mesic sites in other studies (Connelly et al. 2000). Birds in my study were non-migratory with movements typically less than 10 km between seasonal habitats, therefore, nesting and brood rearing routinely took place within close proximity to each other.

Logically, because of the growing season, brood sites had greater grass height than nest sites and nest sites had greater residual grass height than brood sites. Total herbaceous cover and forb cover were greater at brood sites, but grass cover was similar

at nest and brood sites. Residual grass height was lower at brood sites because residual grass was continually degrading as the season progressed.

Wallestad (1975) analyzed sage-grouse production over 10 years and found that rain during the laying season resulted in poor production due to a late hatch, but spring rainfall increased production overall. The spring of 2005 was rainy during the laying period in early May and until the end of June. More nests failed in 2005 than 2004, but the hens were able to re-nest, and re-nests were more successful (Sika 2006). The continuing rain may have enabled the green up period to last long enough to promote chick survival. Due to increased precipitation, total herbaceous, grass and forb cover were greater in 2005 than 2004 (grass cover $P > 0.05$). The proportion of hens that successfully raised a brood to 30 days of age increased from 28% in 2004 to 43% in 2005 (Sika 2006). Lek counts increased between 30-50% from 2005 to 2006 (MTFWP unpublished data) verifying high recruitment from the 2005 breeding season. Moynahan (2004) observed greater re-nesting in a year when 1st nest survival was low to moderate and habitat conditions were favorable.

Because there were 2 to 4 times more winter sites than nest and brood sites in the shrub analyses the differences between years and counties were largely influenced by the winter use sites. Shrub height was greater in 2005 than 2004. Shrub height may have increased from 2004 to 2005 due to the increased precipitation in the summer of 2005 (Table 23).

It is difficult to draw any conclusions as to why shrub cover and density were greater in 2004 than 2005 on all seasonal habitats. It is unlikely that shrub cover or

density on the study sites changed from one year to another because mature plants encountered in this study are relatively stable in these traits (C. L. Wambolt pers. comm. 2005).

The Golden Valley county study area had greater greasewood density and residual grass height than Musselshell county. Taller residual grass height at nest locations may have provided a reproductive advantage to hens in Golden Valley county (why discussed in nest section). Greater greasewood density in Golden Valley indicates that birds were selecting greasewood bottom cover types more than in Musselshell county (why discussed in soils section).

Differences between nest, brood and winter sites were relatively minimal except nest sites had great shrub cover than winter sites. These habitat types were interspersed across the landscape. Approximately 79% of all habitats used had shrub canopy cover ranging from 5-20% and 35% of the use sites had 10-15% shrub cover (Table 28). Habitat attributes on my study site were different from other studies.

Comparison of Habitat Parameters to Other Studies

Sage-grouse habitats vary widely due to different environmental conditions especially precipitation regimes, and alteration by humans. A variety of measurement techniques are used to evaluate habitats and, the variation in results obtained by different methodology can create problems if adapted for management recommendations (Wambolt et al. 2006). Because a number of habitat components in this study seemed to

differ from other studies, I will compare the means of sage-grouse seasonal habitats in my study area (averaged over both years and both counties) to others.

My nesting habitat had less shrub cover and height than other studies; brood habitat had similar cover, but lower shrub heights than other studies. Nesting habitats were characterized by 14.8% sagebrush cover and a sagebrush height of 27.4 cm in my study area (Table 19). Other studies report sagebrush cover values at nests between 19% and 38% and sagebrush height values from 31-79 cm (Connelly et al. 2000, Hagen et al. in press). Brood sagebrush cover was 13.6%, and height of shrubs was 27.5 cm on average on my study site. Seven sage-grouse brood habitats had sagebrush canopy cover ranging from 11% to 23% for hen with chicks <6 weeks old (Hagen et al. in press).

Winter habitat cover and height at my study site was at the bottom end of ranges reported by others. Winter habitat had an average sagebrush cover of 10.9%, and sagebrush height of 26.8 cm. Eng and Schladweiler (1972) in central Montana found 82% of winter locations in sagebrush canopy cover >20% and all heights averaged 25.4 cm. Robertson (1991) reported an average sagebrush cover of 15% and an average height of 46 cm on winter sites in Idaho. Sagebrush cover was >10% at 89% of winter locations in central Idaho, and habitats with sagebrush cover from 11-30% and with sagebrush heights under 40 cm were considered most important for winter (Connelly 1982).

I only included live cover in my cover estimate. Whether others used live and dead cover combined is generally unreported. On average, including dead cover increased our cover value by 3%. When common variations in the Canfield (1941) method were applied to the same line intercept, statistically different canopy cover

estimates were reported (Wambolt et al. 2006). The method I used on this study was the most conservative of the 3 methods tested by Wambolt et al. (2006). Connelly et al. (2003) recommended using a line intercept method to measure canopy cover and to exclude gaps greater than 5 cm in sage-grouse habitats; our method would be more conservative than this one. Connelly et al. (2000) recommended breeding habitat that had between 15-25% canopy cover, my averages were at or below this recommendation.

I measured shrub height at the tallest average portion of the crown (ie. avoiding single tall branches). This only allows inclusion of height that is providing cover, and may not be comparable to studies where the tallest portion of the shrub was measured. Finally, Wyoming big sagebrush tends to grow shorter and have less cover than other big sagebrush sub-species, so I would have expected cover and heights to be lower than studies of other sub-species. Vegetation sampling methods must be further standardized in order to compare sage-grouse habitats.

Herbaceous vegetation at my nest sites was similar to others in respect to cover, but lower with respect to height. Average live grass height at nest sites was 13.1 cm in 2005 and 10.1 cm in 2004 and residual grass height was 6.9 cm and 9.7 cm, respectively (Table 6). Live grass heights at nest sites, reported by Connelly et al. (2000) in a comprehensive review of sage-grouse habitat, ranged from 15 cm to 30 cm. A look at 24 studies done all over the range of sage-grouse found live grass heights to range from 13 cm to 107 cm at nest sites (Hagen et al. in press). Total herbaceous cover at my nest sites was 17.7% and 12.9%, grass cover was 14.5% and 11.8%, and forb cover was 7.4% and

3.0% in 2005 and 2004 respectively (Table 5). Hagen et al. (in press) showed grass cover to range from 3% to 58% and forb cover to range from 2% to 21%.

I found brood site herbaceous cover that was similar to other studies, but grass heights were lower. Live grass height was 16.5 cm and 11.2 cm and residual grass height was 5.4 cm and 9.3 cm in 2005 and 2004 at my brood sites (Table 12). Total herbaceous cover at my brood sites was 19.4% and 15.5%, grass cover was 14.6% and 13.0% and forb cover was 10.2% and 4.5% in 2005 and 2004, respectively (Table 13). Hagen et al. (in press) compared 7 brood habitats and found live grass heights ranging from 14 cm to 23 cm. Total grass cover on the same sites ranged from 5% to 50% and forb cover from 3% to 22% respectively.

My herbaceous cover measurements were within the range of other studies completed, but our heights were either lower or at the bottom end of the range and well under the recommended grass height of >18 cm (Connelly et al. 2000). The height I collected at nest and brood sites was the vegetative droop height. Seed stalks are typically much taller and if included increase the grass height significantly. This is the reason I had excluded the residual grass heights collected at winter sites from comparisons with nest and brood sites. Again, very few of the other studies provide information on what portion of the grass plant was measured. Connelly et al. (2003) recommended measuring the "droop height" of the grass, but does not specifically state whether to include the seed head or not. Short grass species like blue grama (*Bouteloua gracilis*) contributed to lower grass height in my area, but provided relatively high cover values. Blue grama would not contribute a substantial amount of hiding cover due to its short stature.

CHAPTER 6

MANAGEMENT IMPLICATIONS

I sampled 246 winter use sites, 99 nest sites and 61 brood sites from 2004-2005. Sage-grouse habitats should be managed to include sagebrush, forbs, and grass. Herbaceous vegetation was more important during nesting and brood rearing than during the winter. Therefore, some portions of grouse habitat may benefit from management for greater herbaceous cover, but never at the sake of sagebrush. This may be accomplished through changes in grazing management, or through inter-seeding. Sagebrush was the dominant cover type at 97% of my sites. Sagebrush cover from 10% to 30% was the most consistent component of sage-grouse habitat.

Improved livestock grazing management is the least expensive practice to restore degraded sagebrush steppe (Braun 2006) and the most important because it often treats the cause of degradation. The majority of my study area was grazed by livestock (beef cattle and sheep). Increases in chick production were realized in 2005 because of increased precipitation resulting in an increase in herbaceous cover. If herbaceous cover could be increased through time regardless of precipitation, production could potentially be increased markedly. Practices that increase the amount of rest a pasture receives may be useful to restore fair and poor condition range, hence, increasing herbaceous cover for grouse (Adams et al. 2004).

Reductions in stocking rates (or grazing intensity) in over-grazed areas have the greatest potential to increase herbaceous cover. Braun (2006) recommends 25-30%

utilization for livestock on public land that needs improvement. Holechek et al. (2005) recommended utilization from 30-35% to improve rangeland vegetation. Higher utilization levels would be appropriate where herbaceous cover was currently optimal. Connelly et al. (2000) recommended breeding habitat cover values >15% for grasses and >10% for forbs and grass heights >18cm. Because the average grass and forb cover at my study site was similar to what was recommended by Connelly et al. (2000), and because there was high variation in grazing pressure, I assume that some portions of my study site would benefit much more from improved grazing management than others. Decreasing intensity of grazing (stocking rate) will likely have the greatest benefit followed by changing timing of grazing, and changing frequency of grazing (Braun 2006).

Changing the timing of livestock grazing also has the potential to promote herbaceous growth possibly benefiting sage-grouse production. Hens selected nest sites with taller live and residual grass height. Grazing during nesting would decrease grass height at the nest sites, while grazing late in the growing season or during the winter would impact the residual grass height during the following nesting season. The optimal time for grazing important nesting and brood rearing areas would be at the end of July until mid September. Broods would be more mobile at this time, avoiding the possibilities of trampling. In most years forbs would be senescing by this time and less important for sage-grouse production. Adams et al. (2004) found typical deferral of grazing used by producers in Alberta (waiting until May 15-June 15 to graze) reduced conflicts of grouse and livestock during breeding and much of the nesting period during their life cycle. Deferral of grazing can be beneficial to forage plants allowing them to re-

accumulate stored energy reserves, while promoting the full growth potential of range plants (Adam et al. 2004). Deferral requires alternate forage sources for livestock. Identifying critical pastures to implement this change in timing of grazing is a possibility if the change is on a small portion of each landowners pasture system.

Sage-grouse occupied sites with a large variety of ecological conditions (ecological conditions are determined by comparing vegetation currently on the site to the vegetation potential for the site). Nearly all pastures were ≥640 acres in size. I believe this offered grouse the opportunity to select desired herbaceous cover and forbs for foraging from a variety of ecological conditions. Braun (2006) agrees that larger pastures with fewer fences are better. Adams et al. (2004) recommended grazing in light intensities to produce mosaics in vegetation and increase herbaceous production that is beneficial to nesting and brood rearing sage-grouse. They believe that patchy grazing increases the availability of forbs and stimulates their growth in uplands.

Another means for increasing herbaceous cover would be seeding desirable plant species. Using a rangeland drill is a good technique for planting forbs (Autenrieth 1981). I would recommend forb species at my study area include salsify (*Tragopogon dubius*), dandelion (*Taraxacum officinnale*), yarrow (*Achillea millefolium*), fringed sage (*Artemisia frigida*), American vetch (*Vicea americana*) and yellow sweet clover. These forb species have been shown to be grouse food sources in previous studies (Peterson 1970, Drut et al. 1994). Native grasses that do not out-compete forbs and shrubs should be used (Beck and Mitchell 2000). On my study area this would include western wheatgrass, thickspike wheatgrass, needle and thread grass, and green needlegrass. Soil

type and precipitation should be considered when choosing seed, state and federal resource agencies can often help with this (Beck and Mitchell 2000).

Habitat loss, chiefly removal of sagebrush in order to plant crops or increase forage production for livestock, in my opinion is the most important habitat threat in our area. During the 2 years of this study approximately 1,100 acres of sagebrush were removed from the study area. Another 3,000 acres was removed 3.5 km north the Golden Valley study site. Because the majority of the study area and a large percent of sage-grouse habitat in Montana is on private land, the only way to maintain quality habitat is to work with the landowners.

There is considerable evidence in Montana that additional herbaceous cover for livestock foraging is not always realized following sagebrush control (Wambolt 2001a, 2001b). Unpublished data from 155 sites on my study area indicated no relationship between sagebrush cover and herbaceous cover ($R^2_a = 0.00$, $P = 1.0$, $n = 155$). More research is needed to determine if and or when sagebrush removal is beneficial for livestock production. If removal is not an economically efficient means to improve forage quantity this information needs to be distributed to producers.

Sagebrush should not be removed to improve sage-grouse habitat unless it exceeds 30% cover (Braun 2006). Among the 700 sites I sampled only 9 had a shrub canopy cover >30%. Therefore, it is unlikely to benefit sage-grouse to remove sagebrush from any portion of my study area. If private landowners are set on removing sagebrush to increase forage I would recommend a technique that would not damage forb cover and would be patchy across the landscape. Braun (2006) recommends brush beating in strips not to

exceed 25% of the width of the untreated strips, and to treat no more than 20-30% of the area every 10-15 years. Land should be rested from grazing following brush beating or other mechanical treatment for sagebrush.

More research is needed to assess the direct impacts of grazing management techniques on sage-grouse productivity. Specifically a variety of grazing intensities, and durations should be compared. Development of a guide similar to "Beneficial grazing management for Sage-grouse and Ecology of silver sagebrush in southeastern Alberta" by Adams et al. (2004), for different sage-grouse habitats would be extremely useful. Finally, the amount of contiguous sagebrush habitat necessary to sustain healthy sage-grouse populations needs to be determined.

Much of the discussion surrounding management effects on sage-grouse habitat are only applicable to public land. Most of this study area (79%) is privately owned. Livestock producers in central Montana are making a living off of the land and happen to be supporting healthy sage-grouse populations. Efforts should be made to encourage sustainable sagebrush habitats that benefit the producers and the birds. Although habitat degradation is a serious problem throughout sagebrush habitats the largest threat these birds face at this time is the complete removal of sagebrush habitats.

The differences between percent sagebrush cover used for nesting (15%), brood rearing (14%), and winter (12%) are minimal. Additionally all seasonal cover types required by sage-grouse are distributed throughout the study area. Thus, any manipulation targeted at one habitat would impact all 3 seasonally important habitats and be detrimental for sage-grouse on a year-around basis.

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APPENDICES

APPENDIX A:

WINTER 2003 SUMMARY STATISTICS

Table 29. Mean shrub parameters from 52 winter use sites collected in the winter of 2003-2004, not used in over-all analyses.

Shrub Parameter	Value
Sagebrush live cover	13.9 %
Sagebrush live and dead cover	17.2 %
Live total shrub cover	14.6 %
Live greasewood cover	0.6 %
Sagebrush density	1.2. /m^2
Total shrub density	1.2 /m^2
Greasewood density	0.04 /m^2
Sagebrush height	38.1 cm
Shrub height	38.5 cm
Greasewood height	6.8 cm

APPENDIX B:

SOIL USE VS. AVAILABILITY

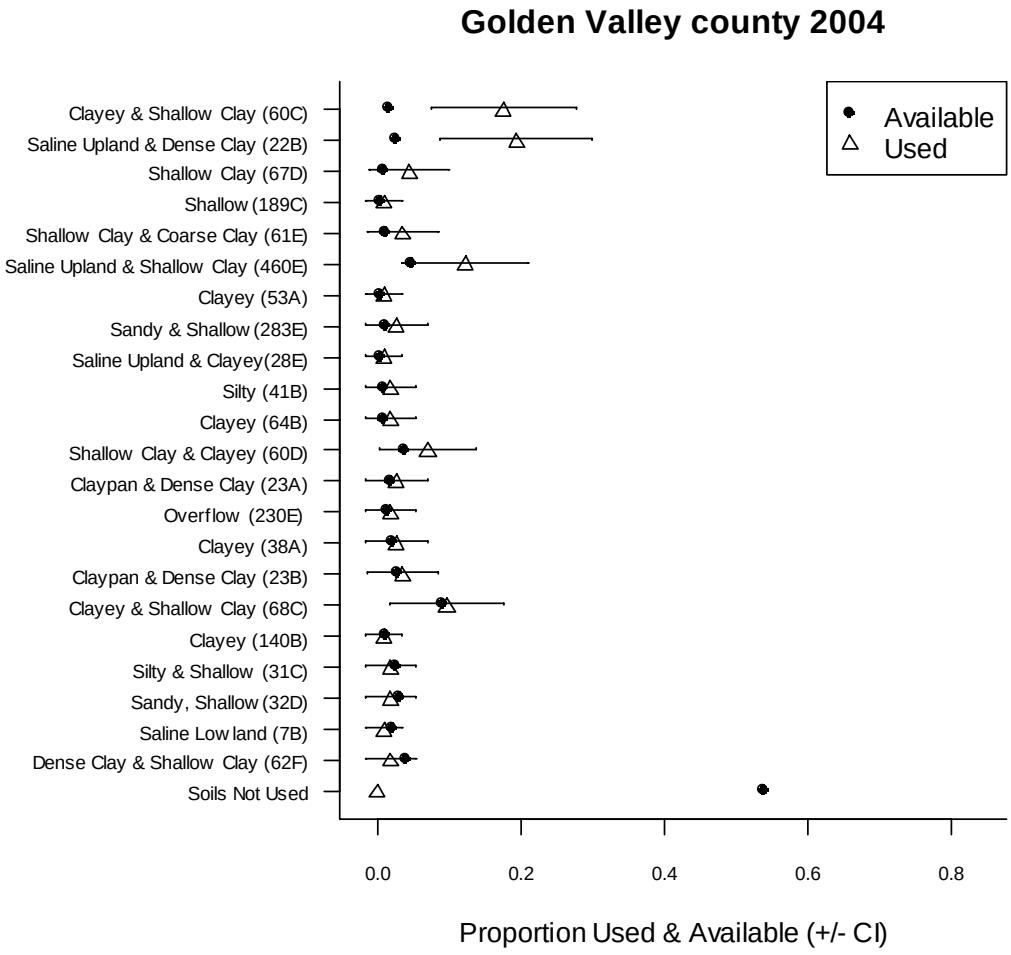

Figure 8. Proportion of use versus availability of soils (ecological site and map unit symbol) and bonferroni confidence interval for sage-grouse locations collected during the winter of 2004-2005 in Golden Valley county.

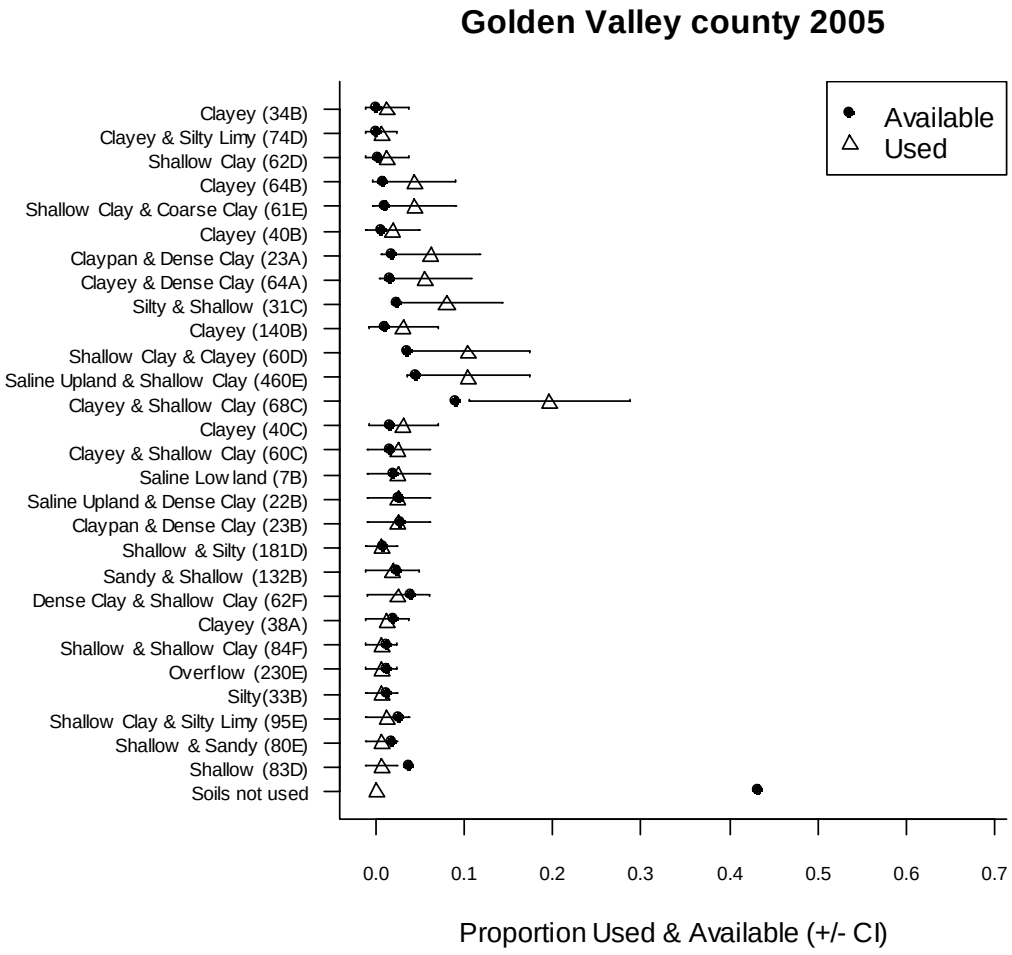

Figure 9. Proportion of use versus availability of soils (ecological site and map unit symbol) and bonferroni confidence interval for sage-grouse locations collected during the winter of 2005-2006 in Golden Valley county.

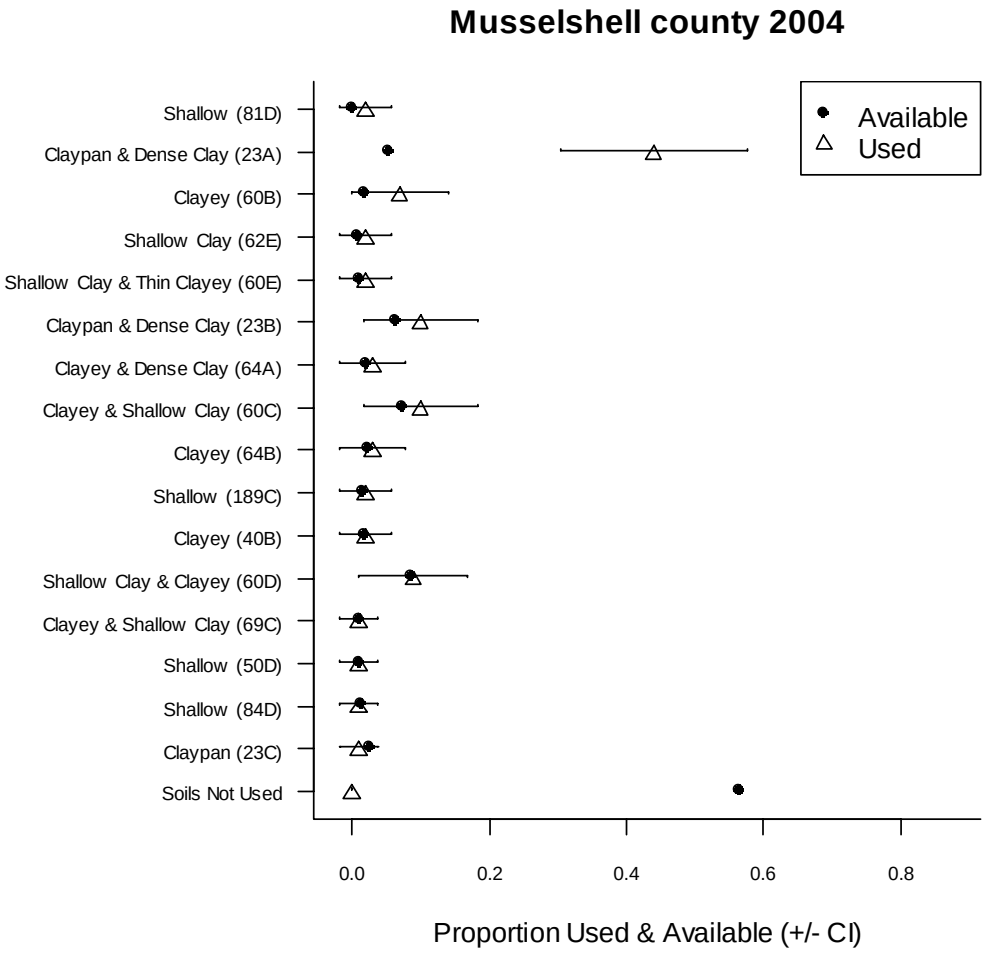

Figure 10. Proportion of use versus availability of soils (ecological site and map unit symbol) and bonferroni confidence interval for sage-grouse locations collected during the winter of 2004-2005 in Musselshell county.

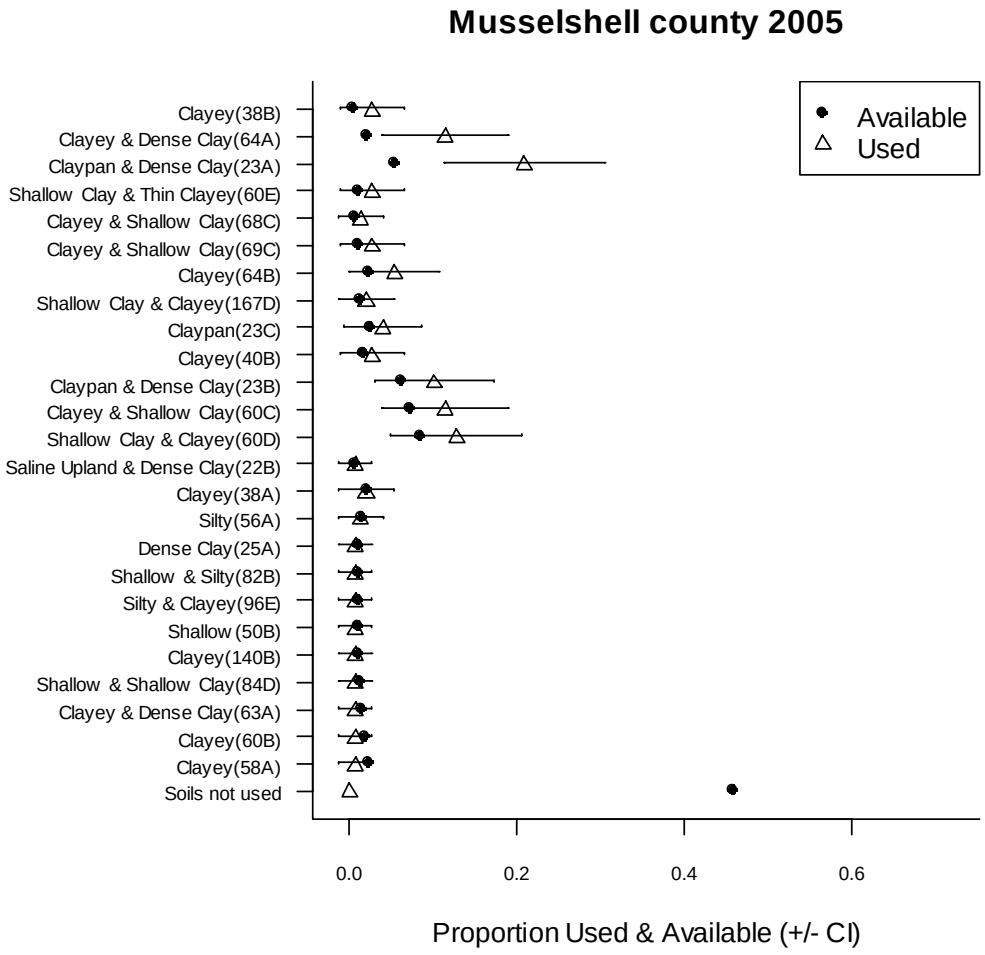

Figure 11. Proportion of use versus availability of soils (ecological site and map unit symbol) and bonferroni confidence interval for sage-grouse locations collected during the winter of 2005-2006 in Musselshell county.

APPENDIX C:

HERBACEOUS SPECIES

Table 30. Cover values (%) for all species averaged over all plots at nest, brood and random sites in 2005.

Species	Nest cover (%)	Nest Random cover (%)	Brood cover (%)	Brood Random cover (%)
Grass and Grass-like				
Agropyron dastachyum	1.68	1.41	3.22	3.12
Agropyron cristatum	0.05	0.37	0.15	0.51
Agropyron intermedium	T[1]	T	0.26	0.26
Agropyron smithii	2.60	2.26	4.68	3.75
Agropyron spicatum	1.37	0.70	0.27	0.47
Agropyron spp.	0.35	0.16	0.04	T
Agropyron trachycalum	0.02	T	0.38	0.52
Arisitida purpurea	0.02	0.02	0.02	0.03
Bouteloua gracilis	2.18	3.11	1.60	2.14
Bromus inermis	T	T	T	T
Bromus japonicus	0.35	0.25	1.53	0.65
Bromus tectorum	0.61	0.10	0.19	0.29
Carex fillifolia	1.57	2.28	0.85	1.35
Carex duriuscula	0.39	0.61	0.54	0.58
Distichilis spicata	0.04	0.14	0.48	0.98
Hordeum jubatum			0.08	T
Koleria macrantha	0.68	0.36	0.48	0.50
Poa juncifolia	T	0.05	0.21	0.14
Poa pratensis	0.01	T		
Poa secunda	4.97	5.99	4.38	4.57
Schedonnardus paniculatus			0.01	0.10
Sitanion hystrix	0.02	0.05	0.02	0.02
Sporobolus airoides	0.16	T		
Sporobolus cryptandrus	T	T	0.03	T
Stipa comata	1.43	1.63	1.03	1.11
Stipa viridula	1.12	0.91	1.31	1.49
Trisetum aestivum		0.01		
Vulpia octaflora	0.04	0.04	0.11	0.09
Forbs				
Achillea millifolium	0.10	0.01	0.08	0.03
Alyssum alyssoides	0.24	0.20	0.79	0.67
Allium textile	0.29	0.64	0.31	0.28

Species	Nest	Nest Random	Brood	Brood Random
Arenaria hookeri	0.35	0.27	0.12	0.20
Astragalus spp.	0.16	0.13	0.13	0.18
Bahia oppositifolia	0.89	0.44	0.77	0.79
Calochortus nuttallii			0.01	0.01
Camelina microcarpa	0.70	0.03	1.21	0.83
Cardus nutans	T	T		
Castilleja sessiflora	T	T	T	T
Cerastium arvense			0.02	T
Chenepodiaceae spp.	0.06	0.03	0.14	0.13
Convolvulus arvensis	T	0.01	0.03	0.02
Collomia linearis	0.01	0.01	0.03	0.02
Commandra umbellata	0.09	0.05	0.16	0.26
Conringia orientalis	0.07	0.04	0.06	0.02
Crepis spp.			0.04	0.02
Cymopterus acaulis	0.03	0.04	0.01	0.01
Dalea purpurea	T	0.02		
Draba spp.	0.02	0.01	0.03	0.01
Descurainia spp.	0.05	0.08	0.18	0.12
Erigeron spp.	0.15	0.24	0.05	0.05
Erigonium spp.	T	0.02	T	T
Gaura coccinea	0.04	0.03	T	0.03
Grindelia squarossa			0.02	T
Helianthus spp.			0.02	T
Heuchera sp.			T	0.02
Iva axillarius	0.21	0.16	0.19	0.26
Kochia scoparia	T	0.04	0.44	0.20
Lesquerella ludoviciana	0.02	0.02	0.02	0.03
Lappula redowskii	0.12	0.04	0.21	0.11
Lactuca serriola	T	0.02		
Lepidium densiflorum	T	T	T	T
Lepidium perfoliatum	0.08	T	T	0.18
Leucocrinum montanum	0.05	0.07	0.03	0.06
Linium lewisii	T	T	T	0.02
Liatris punctata	T	T	T	T
Lomatium foeniculaceum	0.26	0.40	0.35	0.61
Lygodesmia juncea	0.02	T		
Machaeranthera grindeliodes	0.01	0.01	T	T

Species	Nest	Nest Random	Brood	Brood Random
Medicago sativa	0.01	T	0.38	0.30
Monolepsis nuttalliana	0.05	0.10	0.56	0.15
Oenthera ceaspitosa	T	0.01		
Penstemon spp.	T	T	T	0.01
Penstemon nitidus	0.02	T		
Phlox hoodii	0.34	0.37	0.23	0.22
Plantago patagonica	0.08	0.05	0.50	0.22
Plantago sp.			0.03	T
Polgyonum spp.	0.01	0.02	0.04	0.01
Potentilla spp.			T	T
Psoralea spp.	0.20	0.01	0.13	0.14
Tragopogon dubius	T	T	T	T
Salsola iberica	T	T	T	0.14
Salicornia rubra			T	0.10
Senecio spp.	T	0.03	0.01	0.01
Sisymbrium spp.	0.02	0.02	0.02	T
Sphaeralcea coccinea	1.33	1.62	1.23	1.66
Taraxicum offinialis	0.43	0.33	0.68	0.30
Thalaspi arvense	0.04	0.18	0.29	0.32
Thelesperma marginatus	0.08	0.11	0.31	0.03
Thermopsis rhombifolia	0.04	0.02	T	0.05
Tragopogon dubius	0.07	0.03	0.09	0.08
Vicea americana	1.41	0.94	2.18	1.82
Viola nuttallii	0.01	0.04	0.03	0.02
Zigadenus venenosus	0.08	0.11	0.05	0.03
Half-Shrubs				
Artemisia frigida	0.41	0.57	0.54	0.41
Atriplex argentea	T	T	0.06	T
Atriplex gardneri	0.15	0.10	0.32	0.25
Certoides lanata	0.02	0.05	0.02	T
Guterizea sarothrae	0.13	0.11	0.16	0.20

Species	Nest	Nest Random	Brood	Brood Random
Artemisia cana	T	0.08	T	0.04
Artemisia tridentata wyomingensis	4.67	3.00	4.95	4.88
Rosa spp.	T	T	T	T
Sarcobatus vermiculatus	0.24	0.01	0.28	0.10
Yucca glauca	T	0.09		
Others				
Selaginella densa	0.51	0.05	0.19	0.25
Opuntia polycantha	0.68	0.77	0.63	0.96
Orobanche fasciculata			T	T

[1] Trace amounts

APPENDIX D:

LEK COUNTS 1996-2006

Table 29. Unpublished lek count data for leks counted for Montana Fish, Wildlife, and Parks region 5, 1996-2006.

Strutting Ground	Year										
Golden Valley County	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1 SG-2	22	30	32	49	92	69	54	71	76	64	85
2 SG-5	39	32	44	78	102	104	60	64	73	58	85
3 SG-9	27	46	33	38	45	65	35	32	59	34	50
4 SG-11	19	31	27	42	42	50	41	39	19	20	16
5 SG-17	34	7	27	22	41	34	18	23	17	38	32
6 SG-39	21	30	22	39	54	52	50	41	53	55	62
7 SG-43	11	35	25	40	88	77	47	52	47	39	66
8 SG-45	6	8	12	16	14	18	16	27	17	9	17
9 SG-34	21	12	22	24	8	12	9	14	7	7	0
10 SG-2s	15	6	0	0	0	1	0	0	0	0	0
11 SG-36	8	16	15	21	33	35	31	35	50	38	50
12 Barber N.					21	23	16	16	13	8	16
13 Lone Pine							11	11	9	5	8
14 C-Lek							19	25	43	32	37
Musselshell County											
1 SG-24	7	18	25	22	25	25	16	26	33	23	35
2 SG-25	21	16	20	19	26	14	8	6	11	9	9
3 SG-27	2	0	2	3	0	0	0	0	0	0	0
4 SG-29	40	21	39	31	106	81	69	58	30	43	80
5 SG-31	24	22	26	16	24	35	22	24	22	33	51
6 Devil's Basin 1	44	23	57	47	52	65	43	62	52	37	64
7 Schmeckel's	12	11	26	26	39	23	19	29	20	34	38
8 Adolph BLM	3	7	9	14	24	24	22	23	13	11	14
9 Devil's Basin 2				29	51	51	25	45	24	53	70
10 Graves 2					37	33	20	15	8	6	29
11 Crooked Creek 2					37	31	25	20	22	15	22
12 Eagle Post							10	30	23	41	55
13 Nirvana							14	11	7	10	16
14Lost Wacker									15	28	33

APPENDIX E:

TOPOGRAPHY OF WINTER USE SITES

Table 32. Number of bird locations within each percent slope in 2004 and 2005.

	2004	2005
Slope (%)	Count	Count
0	12	17
1	26	14
2	13	23
3	17	26
4	14	11
5	8	6
6	3	3
>6	7	6

Table 33. Number of birds locations in each aspect for winter use sites sampled in 2004 and 2005.

	2004	2005
Aspect	count	count
N	19	20
NE	17	16
E	7	10
SE	19	12
S	6	10
SW	6	5
W	5	5
NW	11	2
level	12	17