SAGE GROUSE HABITAT USE AND SEASONAL MOVEMENTS IN A NATURALLY FRAGMENTED LANDSCAPE, NORTHWESTERN COLORADO

BY

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A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF NATURAL RESOURCES MANAGEMENT

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FACULTY OF GRADUATE STUDIES
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ABSTRACT

Sage grouse (*Centrocercus urophasianus*) populations throughout North America have declined by at least 30% since the 1980's. Such declines have corresponded with habitat degradation caused by both natural and anthropogenic perturbations to sagebrush (*Artemisia* spp.) landscapes. Thus, conservation and management of sage grouse has become a priority throughout its range. Sage grouse numbers in Colorado have declined between 45 and 82% since 1980. Several populations now occur in highly fragmented and isolated habitats throughout Colorado. Future management of sage grouse will require knowledge of the seasonal requirements in fragmented landscapes.

The primary goal of this study was to evaluate the ecological requirements of a small, naturally fragmented sage grouse population in northwestern Colorado. The topography of this region naturally fragmented the sagebrush habitats, thus affecting movements and habitat use. I analyzed sage grouse spatial distribution and seasonal movements (Chapter 2) to identify how this heterogeneous landscape may affect dispersion and migration. I also analyzed habitat use as it varied from the landscape to foraging site scale (Chapter 3). Radiotelemetry was used to identify movement and habitat use patterns. I provided management recommendations for this isolated population (Chapter 4) as an adaptive resource management framework, to progressively test habitat manipulations and enhancement projects.

I found that sage grouse were highly clustered on the landscape and that movements did not exceed the geographic area. This indicated that not only was the population a local migrant, but seasonal use areas were clustered on the landscape. Clustering was reflected in patterns of habitat use as sage grouse selected habitats at large (patch) scales and microhabitat variables (e.g., percent cover and height of vegetation) did not differ within patches but, differed among patches. Differences were found between male and female summer use sites, male sites had greater sagebrush and less serviceberry (*Amelanchier* spp.) cover than that of female sites. Both male and female winter use sites were characterized as having taller and denser stands of sagebrush. Sage grouse tended to use habitats along ridge tops and upper slopes throughout the year; however, there was a trend to use drainages more during winter.

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Commons, Matthew Dupire, Alison G. Lyon, Sara Oyler-McCance, Steve T. Peter, Kerry Petterson, Eric Rock, and Aaron R. Welch. Several natural resource professionals from the Colorado Division of Wildlife contributed to this research. Claude Wood provided logistical support at the Little Hills Experiment station, not to mention several hot meals and good conversations. Barry L. Dupire provided assistance with lek counts and interesting insights to the recent-past of the Piceance Basin. Josh Thompson provided aerial support. Chuck Reichert assisted with ground searches of historic sites. Joe Gumber provided advice and support for the southern region of the Basin. Rick Hoffman provided advice and technical support with the bumper-mounted cannon net. Bureau of Land Management biologists Ed Hallowed and Mark Robertson provided maps and advice. Carol Hallowed assisted with the GIS vegetation data for the Basin.

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- for the birds -

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CHAPTER 1.

INTRODUCTION

1.0. BACKGROUND

Prairie populations of North American Tetraoninae have declined, corresponding to the removal of native grass and shrublands in which they occurred (Aldrich 1963, Johnsgard 1983). The tall and short-grass prairies of the eastern plains were converted into agricultural lands and urban centers (Aldrich 1963). Current populations of prairie grouse (*Tympanuchus* spp.) are limited to remnant patches of prairie throughout the United States and southern Canada (Connelly et al. 1998). However, populations in northern Canada and Alaska remain relatively intact. Analogous habitat losses have occurred in the shrub-steppe habitats of western North America (Schneegas 1967, Braun et al. 1976). The removal of sagebrush (*Artemisia* spp.) for dryland agriculture has led to losses of at least 2.5 million ha of sagebrush type habitats (Schneegas 1967). Columbian sharp-tailed grouse (*T. phasianellus columbianus*) and sage grouse (*Centrocercus urophasianus*) have responded negatively to these alterations in shrub-steppe landscapes. Each of these species has been extirpated at regional and local levels (Rogers 1964, Johnsgard 1983, Connelly and Braun 1997, Connelly et al. 1998).

Historically, sage grouse were considered the most abundant game bird that occurred throughout sagebrush-steppe habitats of western North America (Johnsgard 1983) as they are obligatory to such habitats for survival (Patterson 1952). Sagebrush habitats are used for nesting, winter forage, and cover. Patterson (1952) and Klebenow (1969) demonstrated a positive correlation between nest success and the selection of sagebrush as nesting shrub-type. Although sagebrush is most important, a variety of herbaceous habitats is used in the summer (Dalke et al. 1963, Connelly and Markam 1983). Interspersed grasslands and wet meadows that occur in sagebrush steppe are used for brooding, and summer foraging. Agricultural landscapes, such as alfalfa or beans, have been used in the absence of native vegetation (Connelly and Markam 1983, Commons 1997, Sveum et al. 1998). Comparatively, tall dense patches of sagebrush are essential for food and cover during the winter (October to March). Such specialization makes sage grouse vulnerable to habitat loss or degradation as sub-optimal habitats can negatively affect reproduction and survival (Wallestad 1975, Swenson et al. 1987).

The progression of European settlement reduced sage grouse populations (Fig. 1-1). The conversion of sagebrush-bunchgrass habitats into agricultural lands contributed to loss of native vegetation types (Schneegas 1967, Braun et al. 1976, , Johnsgard 1983). Consequently, sage grouse have been extirpated from British Columbia, Arizona, Kansas, Nebraska, New Mexico, and Oklahoma (Johnsgard 1983, Connelly and Braun 1997).

Sage grouse populations in Colorado responded similarly, and have been eliminated from 12 of 27 counties (Braun 1995) (Fig. 1-2). Most loss has occurred in the southwestern part of the state (Rogers 1964, Braun 1995). Four of these populations have been extirpated since the 1980's (Braun 1995, Commons 1997). Land-use practices have also led to reductions of sage grouse habitat in northern Colorado (Rogers 1964, Braun 1995). Conservation efforts were initiated earlier this century for sage grouse in Colorado as hunting seasons were closed from 1937 to 1952 (Rogers 1964). However, as populations increased following the 1930's drought, hunting seasons reopened

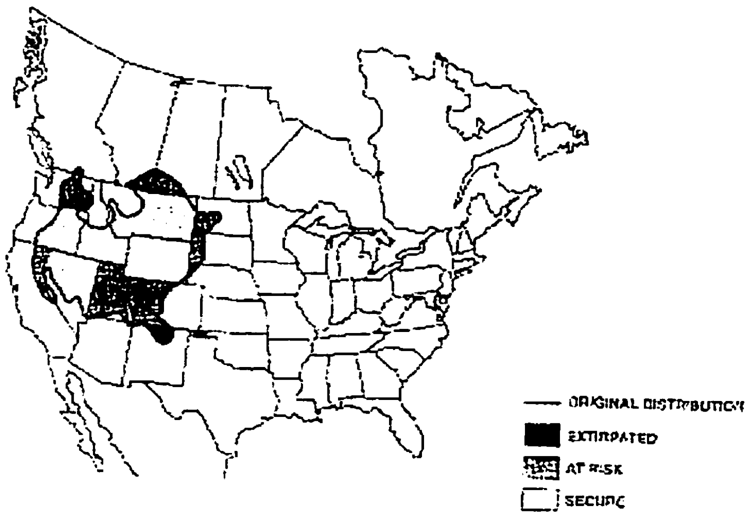

Fig 1-1. Historical distribution of sage grouse in North America (After Connelly and Braun 1997.)

in 1953. Paradoxically, populations appeared stable but by the early 1980's the long-term decline became apparent (Braun 1995).

1.1. ISSUE STATEMENT

Continual downward trends in sage grouse populations have resulted from the conversion of optimal sagebrush rangelands into agriculture, mining, roads, housing, and other human developments. Sagebrush-steppe habitat has been fragmented as a result of these land-uses (Braun 1995). Fragmentation has occurred at both "geographical" and "structural" scales (Lord and Norton 1990). Plowing for agriculture (Rogers 1964, Swenson et al. 1987) has altered large sagebrush landscapes (geographical). Vegetation structure of the sagebrush steppe has been compromised by invasions of coniferous trees (Commons et al.1998) and noxious weeds (Knick and Rotenberry 1995), and depletion of

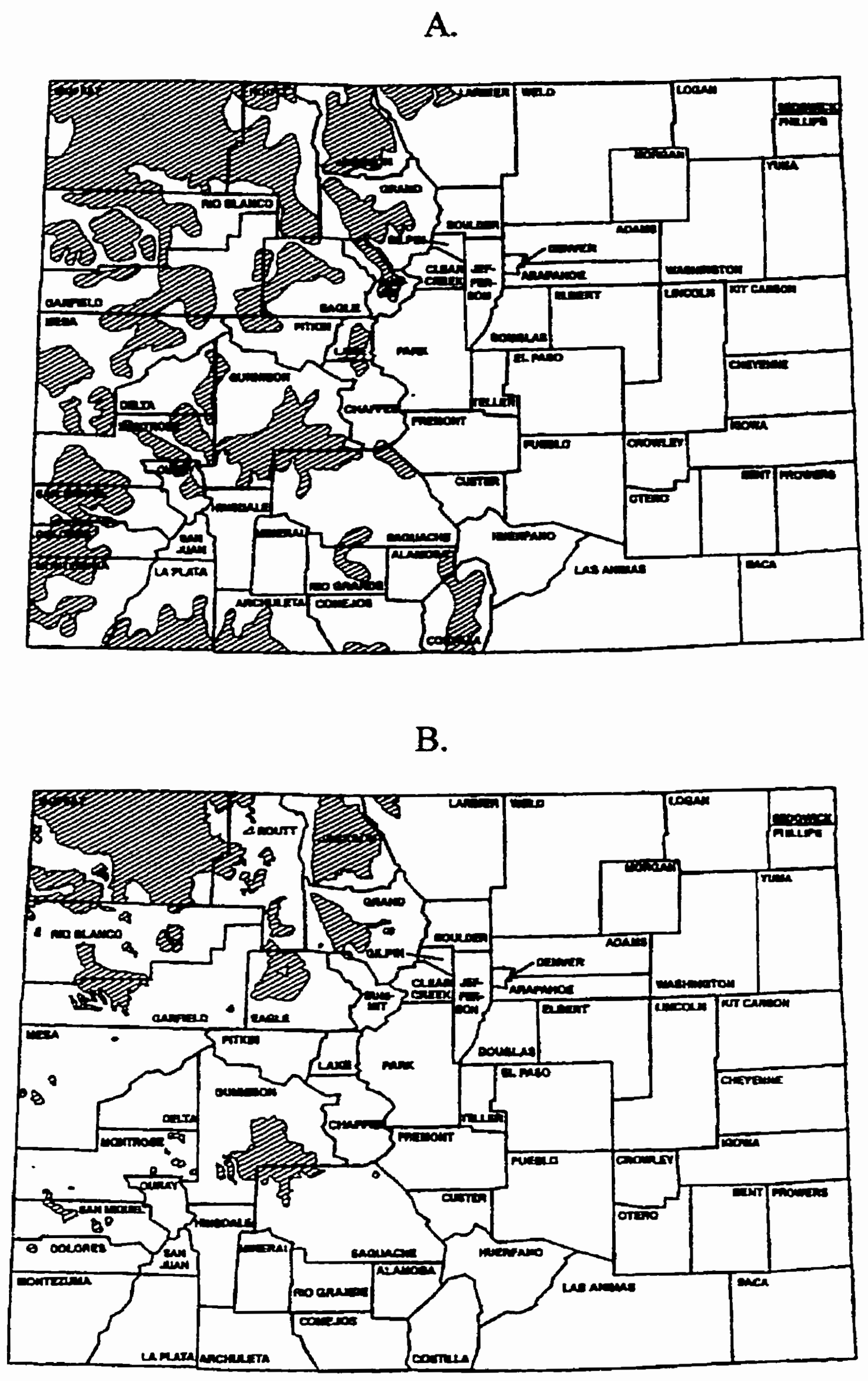

Fig. 1-2. Historical (A) and current (B) distribution of sage grouse in Colorado (After Braun 1995).

residual herbage due to cattle grazing (structural). Fragmentation compels animals to use marginal habitats that have been increasingly isolated and reduced in size and quality (Patsitschniak-Arts and Messier 1996).

Fragmentation can also describe the natural spatial pattern of patchiness in a landscape (Wiens 1994). Such fragmentation is manifested in either topographic features (e.g., alpine tundra) or temporal variations (e.g., annual snow pack or rainfall, wildfire) (Milne et al. 1992, Wiens 1994; and references therein) that limit the extent of a habitat patch. These natural phenomena may affect species in similar fashion as anthropogenic fragmentation (Milne et al. 1992). Most ecological studies of species requirements in fragmented habitats have focused on forest systems, while few have assessed species in grassland and shrub-steppe ecosystems (Knick and Rotenberry 1995, Patsitschniak-Arts and Messier 1996). Further, no field studies have examined shrub-steppe species in a naturally fragmented landscape.

Sage grouse populations in continuous habitat of Colorado have been well studied (Rogers 1964; Beck 1977; Schoenberg 1982;\, Dunn and Braun 1986*a*,*b*; Hupp and Braun 1989; Young 1994). Marginal populations and/or populations persisting in agriculturally fragmented habitats have only recently been examined (Commons 1997). Thus, there is a need to examine the habitat requirements and movements of sage grouse in naturally fragmented landscapes. The primary goal of this study was to evaluate the ecological requirements of a small, naturally fragmented sage grouse population in northwestern Colorado.

1.2. OBJECTIVES

This study was conducted to examine seasonal movements and habitat use of an isolated population of northern sage grouse in Rio Blanco County, Colorado. Specific objectives were:

1. record seasonal movements of sage grouse in the study area,
2. estimate home range size of sage grouse,
3. quantify vegetation composition at sage grouse use and random sites,
4. identify topographic distribution of sage grouse use sites,
5. compare habitat use to availability, and
6. provide management recommendations for the region including 2 specific habitat treatments based on the findings of the study.

1.3. SCOPE

Currently, sage grouse occupy 9 counties in northern Colorado. Four of these populations are considered secure (>500 birds). Substantial natural and anthropogenic fragmentation occur throughout this range.

The diverse topography and heterogeneous vegetation, coupled with the land use practices of the Piceance Basin-Roan Plateau of northwestern Colorado (Fig. 1-3) provided ample opportunity for examining the ecological significance of a naturally fragmented landscape and to establish habitat management recommendations. Topography and elevation of this structural basin limit sagebrush habitats to ridge tops and upper slopes at elevations >2,100 m. Lower elevations are dominated by pinyon pine (*Pinus edulis*) and juniper (*Juniperus* spp.) woodlands and unsuitable shrub

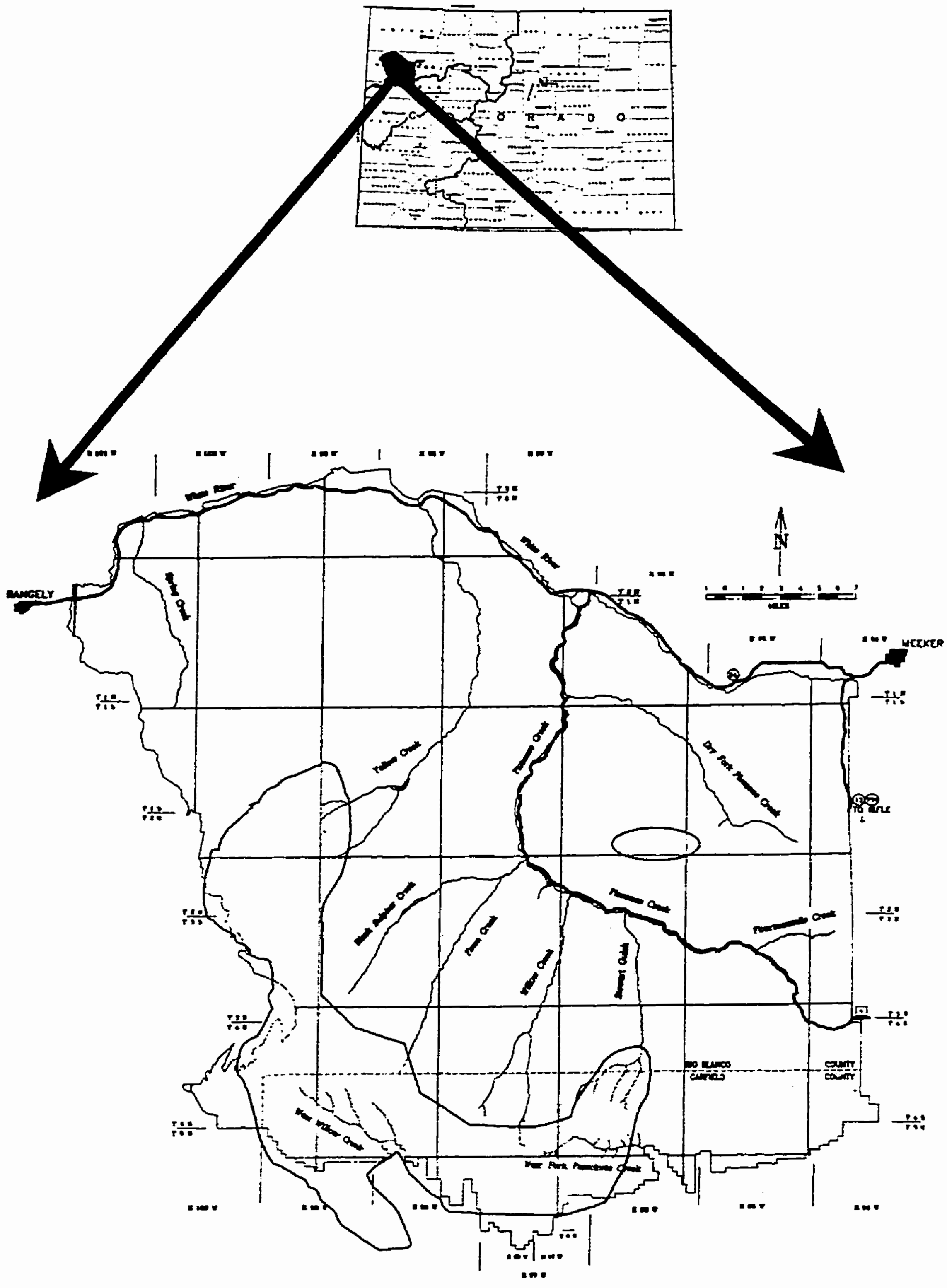

Fig. 1-3. The study area and sage grouse range (shaded areas) in Piceance Basin, Rio Blanco and Garfield counties, Colorado (Maps; BLM 1985).

communities (i.e., devoid of sagebrush). Human uses of the area have further fragmented and degraded the area through gas development and livestock grazing. Natural gas deposits are abundant throughout the White River Basin, and several natural gas pipelines transect the area. This region is also rich in mineral deposits including oil shale and soda ash (Tiedeman and Terwilliger 1978). Although sagebrush habitat is fragmented by both natural and anthropic factors, natural fragmentation occurs predominantly at the landscape scale. Anthropic fragmentation occurs at several scales from landscape (e.g., compression stations, oil/gas drilling) to structural (e.g., livestock grazing). For the purposes of this study *fragmentation* refers to the natural patchiness, unless otherwise stated.

A baseline study of sage grouse in this region conducted during 1976-77 (Krager 1977) investigated the overall distribution of sage grouse and sagebrush habitat. That project did not focus on seasonal movements and habitat use of radio-marked grouse. Further, the study did not identify critical winter habitat in 1978 (C. E. Braun, pers. commun.). Harvest data collection (C.E. Braun, Colorado Division of Wildlife, unpubl. data) and sporadic counts of males on leks indicated substantial decreases in population size in this area. Subsequently, the sage grouse hunting season was closed in 1995 until the status of the population could be ascertained in this region.

1.3.1. STUDY AREA

This study was conducted south of Meeker in Rio Blanco and Garfield counties, Colorado. The Piceance Basin-Roan Plateau is bordered on the north by the White River and on the south by the Colorado River. The Utah border is ~80 km to the west and the Grand Hogback borders the basin on the east. The study area encompasses approximately

1,400 km^2 of the ~3,000-km^2 region. The specific boundaries of the study area are the Dry Fork of Piceance Creek and Big Duck Creek to the north, and Skinner Ridge, Jack Rabbit Ridge, and Roan Creek to the southwest and south. Cathedral Bluffs defines the western limit and Colorado Highway 13 is the eastern boundary. Piceance Creek bisects the eastern third of the study site.

The climate of the Piceance Basin is semiarid and exhibits extreme differential levels of monthly precipitation. Consecutive months often receive little precipitation. Mean annual precipitation was 35.3 ± 18.7 cm for eight weather stations in the region for 1951-70 (Cottrell and Bonham 1992) and snowfall comprised ~ 50% of the total precipitation. The mean annual temperature varies from 7 C at 1,800 m to – 1 C at 2,700 m.

The topography of the study area has been described as a structural basin (Tiedeman and Terwilliger 1978) or a plateau that is dissected by narrow drainages. The sagebrush steppe consists of undulating north-south ridges parallel to each other. The ridge tops vary in width from 0.5 to 3 km, and 1 to 30 km in length. The ridges are gently rolling; however, the drainages that separate them are steep. Specifically, the ridges in southern part of the study area are divided by canyons that drop nearly 1 km, vertically, in <500 m, horizontally; typically the elevation change is more gradual. Elevations vary from 1,800 m on Piceance Creek to 2,700 m at the upper reaches of the plateau. The higher elevation areas are known locally as the "summer range" as they are the location for summer grazing of livestock.

Vegetation type is dependent upon slope, aspect, and elevation. Three subspecies of sagebrush (*Artemisia tridentata*) occupy the basin, and location of *Artemisia* *tridentata* ssp. is dependent upon soil type (Cottrell and Bonham 1992). Basin big sagebrush (*A.t.tridentata*) is the prevalent vegetation throughout the drainages at elevations of 1,800 – 2,000 m (Cottrell and Bonham 1992). Typically basin big sagebrush grows taller and denser than mountain big sagebrush (*A.t.vaseyana*) and Wyoming big sagebrush (*A.t. wyomingensis*) (Cottrell and Bonham 1992). *A.t. wyomingensis* is restricted to upland ridges at elevations of 1,900 – 2,000 m (Cottrell and Bonham 1992). *A.t.vaseyana* is confined to high mountain areas at elevations > 2,100 m (hereafter all references to big sagebrush will refer to *A.t.vaseyana*, unless otherwise noted).

Pinyon pine (*Pinus edulis*) and juniper (*Juniperus* spp.) woodlands dominate the landscape until ~2,100 m. Big sagebrush, Utah serviceberry (*Amelanchier utahensis*), Gambel oak (*Quercus gambelii*), and antelope bitterbrush (*Purshia tridentata*) comprise most of the transition vegetation type. Low and rubber rabbitbrushes (*Chrysothamnus viscidiflorus, C. nauseosus*) are prevalent throughout the basin. Elevations of 2,400 to 2,600 m are dominated by big sagebrush interspersed with bunchgrass meadows. North aspects often host substantial groves of quaking aspen (*Populus tremuloides*), serviceberry, and mountain snowberry (*Symphoricarpos oreophilus*). Big sagebrush and Douglas-fir (*Pseudotsuga menziesii*) dominate south and northwest aspects at elevations > 2,500 m, respectively. Free water can be scarce in dry years or late in the summer as most springs are in the bottom of steep canyons.

The land ownership in the region is a mix of private and public lands. Private holdings are largely owned by petro-corporations. The Bureau of Land Management (BLM) is the federal land manager for public lands. Lands owned by petro-corporations are leased to ranchers who graze them with cattle from about May into November. While the BLM manages significant land holdings in the area, only a fraction is considered sage grouse habitat.

Historically, sheep and cattle extensively grazed the Piceance Basin. Currently, cattle ranching is the predominant agricultural business. The majority of riparian areas in the region have been converted to hay fields for feeding cattle. In the late 1970's there was an interest in shale oil deposits in the substrate of the plateau and two processing plants were established. Currently, shale oil is not economically viable and natural gas development is the focus of resource extraction. The Greasewood Compression Station supports several pipelines that transect the Basin, especially the TransColorado pipeline. Construction of this line was initiated in 1998 and was routed through patches of sage grouse habitat. The proposed Yankee Gulch sodium bicarbonate mine would require a pipeline that would transport water from the Colorado River to the mine for material processing. These land uses provide opportunities to mitigate and manage habitat alteration to benefit sage grouse and other wildlife.

1.3.2. METHODS

Sage grouse movements and habitat use were documented using radiotelemetry and a Global Positioning System (GPS) from April 1997 through December 1998. Locations were plotted on 7.5 minute USGS topographic maps. Relocation points were transferred into a database that enabled input into a Geographic Information System (GIS), which contained habitat cover type maps of the study area. Vegetation at the within patch scale was sampled via quadrat cover estimates and calculating mean height of vegetation for each plot.

1.32a. VEGETATION SAMPLING

The wildlife literature (grouse studies in particular) has widely used microhabitat variables to identify parameters that animals "prefer" or "avoid". The methods to collect such data are numerous, but Daubenmire (1959) frames and the line intercept (Canfield 1941) are two of the most commonly used. Typically, workers establish a plot at the center of an activity site and quantify the surrounding vegetation. However, one derived method uses a perpendicular placement of the transects; such methods over sample the middle of the plot (Greig-Smith 1957). The alternative method would be a dispersed model or grid sampling regime that adequately covers the periphery of the sampling area (Greig-Smith 1957). The systematic grid sampling method should provide a uniform and statistically robust representation of the habitat of the sampling plot. Consequently, a protocol was established to compare the intercept and grid methods.

During the 1998 field season vegetation transects were sampled from 25 paired locations of radio-marked grouse and random sites ($n = 50$) to evaluate the bias associated with the intercept method. This may impact methodologies implemented by biologists in the future. The theoretical background and comparison of these two methodologies using the 1998 field data are presented in Appendix C.

1.4. ORGANIZATION

This thesis is presented in 4 chapters. Chapter 2 focuses on seasonal movements and home range estimation. Chapter 3 examines habitat selection of micro and macrohabitat characteristics, and topographic distributions of sage grouse use sites. All chapters are written as self-contained papers in the style of the Journal of Wildlife Management. Chapter 4 contains management recommendations derived from the data analyses and field observations from this research.

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CHAPTER 2.

SEASONAL MOVEMENTS AND SPATIAL DISTRIBUTION OF SAGE GROUSE IN A NATURALLY FRAGMENTED LANDSCAPE

Abstract: Seasonal movements and spatial distribution of sage grouse (*Centrocercus urophasianus*) were studied in the Piceance Basin of northwestern Colorado from April 1997 through December 1998. The spatial distribution of radio-marked grouse (n = 19) was highly clustered (fractal D = 1.06) and exhibited scale invariant properties (R^2 = 0.992). Male (n = 11) and female (n = 5) sage grouse moved average maximum distances of 8.8 and 2.8 km from lek of capture during the summer, respectively. Maximum male distances were greater (P = 0.03) than for females in summer but, similar (P = 0.69) during winter. Distances traveled from winter to breeding (P = 0.92) and breeding to summer ranges were similar (P = 0.07) between male and female sage grouse. Males traveled further (P = 0.047) between winter to summer areas than did females. However, juvenile male sage grouse (n = 3) movements ($\bar{x}$ = 1.7 km) between summer to winter seasonal ranges were less than those of adult males (P = 0.02) but similar to females (P = 0.6). The movements of sage grouse likely reflected the limited suitable habitat available to sage grouse in this landscape.

2.0 INTRODUCTION

Habitat loss and fragmentation reduce species richness and, as a result community compositions are altered. Sedentary specialist or large predators are vulnerable to such changes, and loss of these species may account for the change in species composition (Wiens 1994). However, fragmentation can refer to the natural heterogeneity (patchiness) that produces such landscapes (Wiens 1994). Movement and the resulting dispersal of individuals are important parameters in determining how habitat fragmentation affects a population (Wiens 1994, 1997). Wiens (1997) asserted that proper management of habitat patches and mosaics can be based on understanding species movement patterns in and among fragmented landscapes.

Sage grouse use distinct seasonal habitats on an annual basis. Loss and/or degradation of these habitats has proven to be detrimental to sage grouse (Braun 1995, Connelly and Braun 1997). Braun et al. (1977) established guidelines for managing these seasonal use areas and emphasized protection of habitats within 3.2 km of the lek. Roberson (1986) suggested these guidelines were only applicable to sedentary populations. Subsequently, researchers have reported movement patterns of sage grouse that exceed the former recommendations (Berry and Eng 1985, Connelly et al. 1988). Connelly et al. (1988) suggested that migratory sage grouse populations should be identified and managed on temporal and geographical scales. Use of seasonal habitats and movements by sage grouse have been documented throughout its range (Berry and Eng 1985, Connelly et al. 1988, Commons 1997). The magnitude of sage grouse seasonal movements varies among populations (Connelly et al. 1988). Differences have been related to the proximity of suitable seasonal habitats (Patterson 1952, Dalke et al.1963).

Sage grouse in Idaho (Connelly et al. 1988) and Wyoming (Patterson 1952, Berry and Eng 1985) have been described as migratory, traveling ≥80 km between seasonal ranges. Sage grouse in Colorado appear to be sedentary as most populations disperse on average <20 km to seasonal ranges within a geographical area (Rogers 1964, Beck 1977, Schoenberg 1982, Dunn and Braun 1986, Commons 1997).

Most of the existing literature has focused on large populations (>500 birds) in contiguous habitats. Few studies have examined the seasonal movements of sage grouse in fragmented landscapes. Commons (1997) and Schroeder (1998) investigated populations that occurred in highly fragmented agricultural landscapes in southwestern Colorado and north-central Washington, respectively. Currently, no studies have examined the seasonal movements of small populations occurring in naturally fragmented landscapes. Further, no studies have documented the spatial distribution of sage grouse movements. Sedentary sage grouse populations may be susceptible to habitat loss as alternative habitats become increasingly distant and impractical to occupy. Thus, identifying the seasonal movements of isolated sage grouse populations is necessary for proper management and enhancement of these fragmented landscapes.

The objectives of this study were to: 1) identify the spatial distribution of radio-marked sage grouse, 2) describe seasonal movements in terms of maximum distance and inter-lek distance, 3) and identify seasonal home range sizes and distance between core areas within home ranges.

2.1. STUDY AREA

The Piceance Basin lies between the White and Colorado rivers in northwestern Colorado in Rio Blanco and Garfield counties. The study area encompassed approximately 1,400 of the 3,000 km^2 structural basin. The boundaries of the specific study area were the Dry Fork of Piceance Creek and Big Duck Creek to the north. Skinner Ridge and Roan Creek were the southwest and southern boundaries. Cathedral Bluffs defined the western limit and Colorado Highway 13 was the eastern boundary. Piceance Creek flows through the eastern third of the study area. The climate of the Piceance Basin is semi-arid and exhibits extreme differential levels of monthly precipitation. The mean annual precipitation was 35 ± 18.7 cm in the region for 1951-70 (Cottrell and Bonham 1992). Snowfall comprised approximately half of the total precipitation.

This structural basin (Tiedeman and Terwilliger 1978) consists of undulating north-south ridges that parallel one another. The ridges are gently rolling divided by steep drainages. The ridgetops vary in width from 0.5 to 3 km, while length varies from 1.0 to 30 km. The southwestern region of the study area consisted of canyons that drop nearly 1 km vertically, in <500 m, horizontally; typically the elevation change is more gradual. Elevations vary from 1,800 m on Piceance Creek to 2,700 m at the upper reaches of the plateau.

The topography of this region provided a mosiac of vegetation types that reflect variation in slope, aspect, and elevation. Pinyon pine (*Pinus edulis*) and juniper (*Juniperus* spp.) woodlands dominate the landscape until ~2,100 m. Mountain big sagebrush (*Artemisia tridentata vaseyana*), Utah serviceberry (*Amelanchier utahensis*), Gambel oak (*Quercus gambelii*), and antelope bitterbrush (*Purshia tridentata*) comprise most of the transition vegetation type. Rabbitbrush (*Chrysothamnus* spp.) was common throughout the basin. Elevations of 2,400 to 2,600 m were dominated by mountain big sagebrush and antelope bitterbrush interspersed with bunch grass meadows. North aspects were dominated by quaking aspen (*Populus tremuloides*), Douglas-fir (*Pseudotsuga menziesii*), serviceberry, and mountain snowberry (*Symphoricarpos oreophilus*). The vegetation of the Piceance Basin has also been described by Bartmann (1983) and Bartmann et al. (1992).

2.2. METHODS

2.2.1. FIELD TECHNIQUES

Trapping—Male and female grouse were trapped at night on or near lek sites using a spotlight and a long-handled net (Giesen et al. 1982) during the breeding seasons of 1997 and 1998. After the breeding season, radio-marked birds were tracked at night to trap grouse associating with marked birds. A bumper-mounted canon net was used in early morning hours (< 3hr after sunrise) to trap birds along roadsides (Giesen et al. 1982). Once captured, grouse were placed in a burlap sack and held for processing. Age was ascertained by shape and appearance of primaries (Beck et al. 1975). All captured grouse were banded on one tarsus with an aluminum Colorado Division of Wildlife (CDOW) band with a green bandette placed on the other tarsus. Grouse were fitted with either a lithium or solar-powered radio. Battery-powered radios (Holohil Systems Ltd., Carp, Ontario) were placed at the base of the neck using a cable tie. Solar-powered radios (Telemetry Systems Inc., Mequon, WI) were mounted on naugahyde ponchos (Amstrup 1980) that were fitted around the neck. Radios weighed between 14 - 20 g, which was < 3% of a bird's body mass.

Radiotelemetry—Radio-marked grouse were relocated using a portable Telonics receiver (Mesa, AZ) and a hand-held 3-element Yagi antenna. Additionally, a CB radio antenna placed on a vehicle, connected to the portable receiver, was used as a non-directional antenna. This method was effective in reducing search time for radio signals on the ground. Aerial searches were conducted when ground searches were unsuccessful for more than a week or not practical during the winter. The goal was to locate each radio-marked grouse once per week from June through August and once every 2 weeks during winter months. Grouse located > 1 per week were not flushed on subsequent locations. During these locations radio-marked birds were circled at a distance of ≤ 50 m to reduce the error associated with triangulation (Springer 1979).

2.2.2. DATA ANALYSIS

Data—Aerial and ground locations were recorded using Global Positioning System (GPS) and Universal Transverse Mercator (UTM) coordinates. Locations were plotted on USGS topographic maps (1:24,000 scale) to adjust for the selective availability (SA) error associated with GPS. This correction was coarse, but enabled adjustments to obvious location errors resulting from SA (e.g., opposite side of a ridge or road). The calendar year was divided into three biologically important seasons for sage grouse, spring/breeding (Apr – May), summer/brood-rearing (Jun – Sep), and winter/limited resources (Oct – Mar). The timing of long distance movements between seasonal use areas and availability of forage supported this stratification.

Sage grouse were captured on 6 of the 9 active leks. Chicks that were radio-marked were defined as juvenile. First and second year adults were pooled within male and female strata due to small sample sizes. Movement data were obtained for 44 radio-marked sage grouse (males, $n = 24$; females, $n = 20$). Radio failure ($n = 4$), mortality ($n = 16$), and inadequate sampling ($n = 5$) resulted in a sample size of 19 (43%) of the 44 sage grouse (males, $n = 14$; females, $n = 5$) with adequate data for analysis. Annual data were collected on 3 juvenile males from this sample. These birds were captured as chicks ~10-12 weeks of age. Two females that were tracked to nests were depredated shortly into the post-nesting period. Consequently, these females were only considered for the distance from lek to nest analysis ($n = 6$). Summer movements by females were pooled for data analysis, despite nesting success. The point pattern analysis consisted of the birds described minus the 2 depredated post-nesting females ($n = 19$).

Spatial Distribution—I used fractal geometry (Mandelbrot 1983) to examine the spatial distribution of sage grouse location data. Specifically, I was interested in identifying dispersal, and the extent to which grouse locations were clustered or deviated from a uniform distribution. Point pattern data were analyzed using an estimate of the fractal dimension (D). This statistic, D, was used to examine the extent to which the point pattern of sage grouse locations was self similar across spatial scales (Appleby 1996, Kenkel and Walker 1996). It tested the null hypothesis that locations occur randomly on the landscape at each resolution. That is, $1 < D < 2$ and as D approached 2 it described a random spatial pattern and, as D approached 1 it indicated a highly clustered pattern (Appleby 1996, Kenkel and Walker 1996). Estimating the fractal dimension of movement data is dependent upon the cumulative time an animal is tracked; the longer an animal is tracked the greater the fractal dimension (Milne 1991). Thus, data used in the spatial distribution analysis only included one year of data for birds that survived >1 year. Male, female, and juvenile grouse were pooled for this analysis as it used a population approach.

Calculation of D was achieved using the box counting method and information theory (Milne 1991, Hastings and Sugihara 1993, Appleby 1996). The UTM coordinates of all radiolocations were plotted, and the observed point pattern was overlaid with a square grid scaled to 44 km^2. Count and proportion data were then used to calculate the box ($Iq = 0$) and information dimension ($Iq = 1$), respectively. These dimensions are referred to as generalized q-dimensions. Examining the generalized dimensions as a function of q provides more information about a distribution than just a single dimension (Appleby 1996). The first grid superimposed was comprised of boxes (quadrats) that were 1.83 km^2. This set of boxes (factors of 44 divisible by 2) was then doubled at successive scales of 3.67 and 7.33 km^2. The second sets of quadrats (factors divisible by 3) were 2.75 and 5.5 km^2. All 5 resolutions were combined to evaluate the scaling properties of the point pattern.

The box dimension calculates the number of quadrats ($N\delta$) it takes to cover the point pattern and does not account for the number of points in a quadrat (Appleby 1996, Kenkel and Walker 1996). The box dimension is defined by plotting $\ln N(\delta)$ against $\ln(\delta)$ and calculating the slope of the line (Appleby 1996). The information dimension is derived from the proportion of points (p_i) occupying each quadrat and calculated using Shannon's entropy:

$$H_\delta = -\sum_{i=1}^{N(\delta)} p_i \ln p_i$$

where $N(\delta)$ is the total number of occupied quadrats of size δ (Kenkel and Walker 1996). Information dimension is defined by the plotting H_δ against $\ln(\delta)$. The slope of the ln-ln plot [$\ln(\delta)$ vs. H] determines D and the slope was estimated with linear regression.

Calculations of the fractal dimension require large sample sizes (>1000) to approach D = 2 (N.C. Kenkel, Univ. Manitoba, unpubl. data). Thus, random simulations were generated (n = 519) to test for deviations from a random pattern (Hastings and Sugihara 1993).

Maximum Distance—Individual movements were calculated as the straight-line distance (km) from the last known location to lek of capture (DLC) and to the nearest lek (DNL). These distances were used to identify maximum distances from point of capture and to test for differences in seasonal movements among sage grouse. Student's t test was used to identify differences in DLC between males and females. Hotelling's T^2 was used to detect differences in movements between years (White and Garrot 1990). The calculated T^2 was transformed to an F statistic in testing of statistical significance (Manly 1986). Movement distances of juveniles were calculated from capture areas. I did not assume that the nearest lek would be their lek of capture, as a result comparisons of maximum distances were not made between adults and juveniles.

Lek Dispersion—I used correlation to examine the lek tenacity of male and female grouse. Monthly means were calculated for DLC and DNL of each individual to document timing of movements. Pearson's product moment correlation coefficient (r) was calculated for the seasonal mean DLC and DNL of each grouse, referred to as the dispersion coefficient. This correlation described the relationship between an individual's home lek and seasonal use areas. As the dispersion coefficient approached +1, it described greater tenacity to one's home lek. Alternatively, as grouse moved away from their home lek and were more closely associated with other leks the dispersion coefficient approached 0. The dispersion coefficient was not <0 as all calculations were based on non-directional distances. Dispersion coefficients were calculated for male and female sage grouse.

Home Range—I used two measures to examine individual spacing; home range estimation and distance between core areas. Home range was estimated using minimum convex polygon (Mohr and Stumpf 1966) for both winter and summer seasons (Calhome 1.0 Software [Kie et al.1996]). Although there are limitations to comparing home range size between studies (White and Garrott 1990), I used other measures in conjunction with home range to support these comparisons. The number of locations (n) and home range size were plotted to identify minimum n to adequately describe the seasonal home range. Generally, when $n \geq 9$ the slope of the line indicated a negative relationship. Thus, birds with ≥9 seasonal locations were included. Sample sizes were inadequate to calculate home range during the breeding season. The Mann-Whitney U test was used to test for differences in seasonal home range size among males, females, and juveniles.

Seasonal Use Areas—The spacing of core areas within seasonal ranges was examined by calculating the center of use areas and the distance from other seasonal centers. Distance between seasonal areas was defined as the arithmetic mean (± SE) of ≥4 locations per season for each individual (Schroeder and Braun 1993). The distances between individuals' core areas were pooled and averaged among males, females, and juveniles and tested for differences of means using Student's t test. Individuals that survived from capture to ≥4 winter locations were included in the analysis. Statistical differences were considered significant at $P \leq 0.05$.

2.3. RESULTS

Summer movements did not differ between years in either DLC or DNL ($F_{2,320}$ = 1.265, $P > 0.5$). Winter movements were similar ($F_{2,187}$ = 1.393, $P > 0.5$) between years as well. Data were pooled for grouse ($n = 5$) that survived both years as they exhibited similar ($F_{2,187}$ = 1.393, $P > 0.5$) movement patterns between years, and distances were averaged.

2.3.1. SPATIAL DISTRIBUTION

Fractal Analysis—Point pattern analysis among 5 scales of resolution (box size) indicated that sage grouse spatial distribution was scale invariant (R^2 = 0.992) and highly clustered. This was evident in both the box ($Iq = 0$) and the information dimension ($Iq = 1$) (Fig.2-1a,b). The fractal D (q1) = 1.06 differed from 100 simulated random distributions of 519 points (mean fractal D = 1.57 ± 0.02, range 1.53 – 1.63) (Fig. 2-2). This indicates that sage grouse do not occur randomly on the landscape, and that seasonal movements reflect distinct dispersion to seasonal areas of suitable habitat.

2.3.2. SEASONAL MOVEMENTS

Site Fidelity—Six radio-marked sage grouse were tracked through 2 breeding seasons and all returned to their respective lek sites by 2 April 1998. Five of these birds survived the following summer and exhibited high fidelity to their previous summer range (Appendix A, Table A-1). Differences in mean seasonal use areas varied between 0.1 and 5.0 km ($\bar{x}$ = 2.1 ± 1.0) between years. Male 1559 was an exception as he did not travel to Skinner Ridge in his second year. Instead, he occupied his June 1997 stopover area during summer 1998, which was not as far south as Skinner Ridge. This area was near the

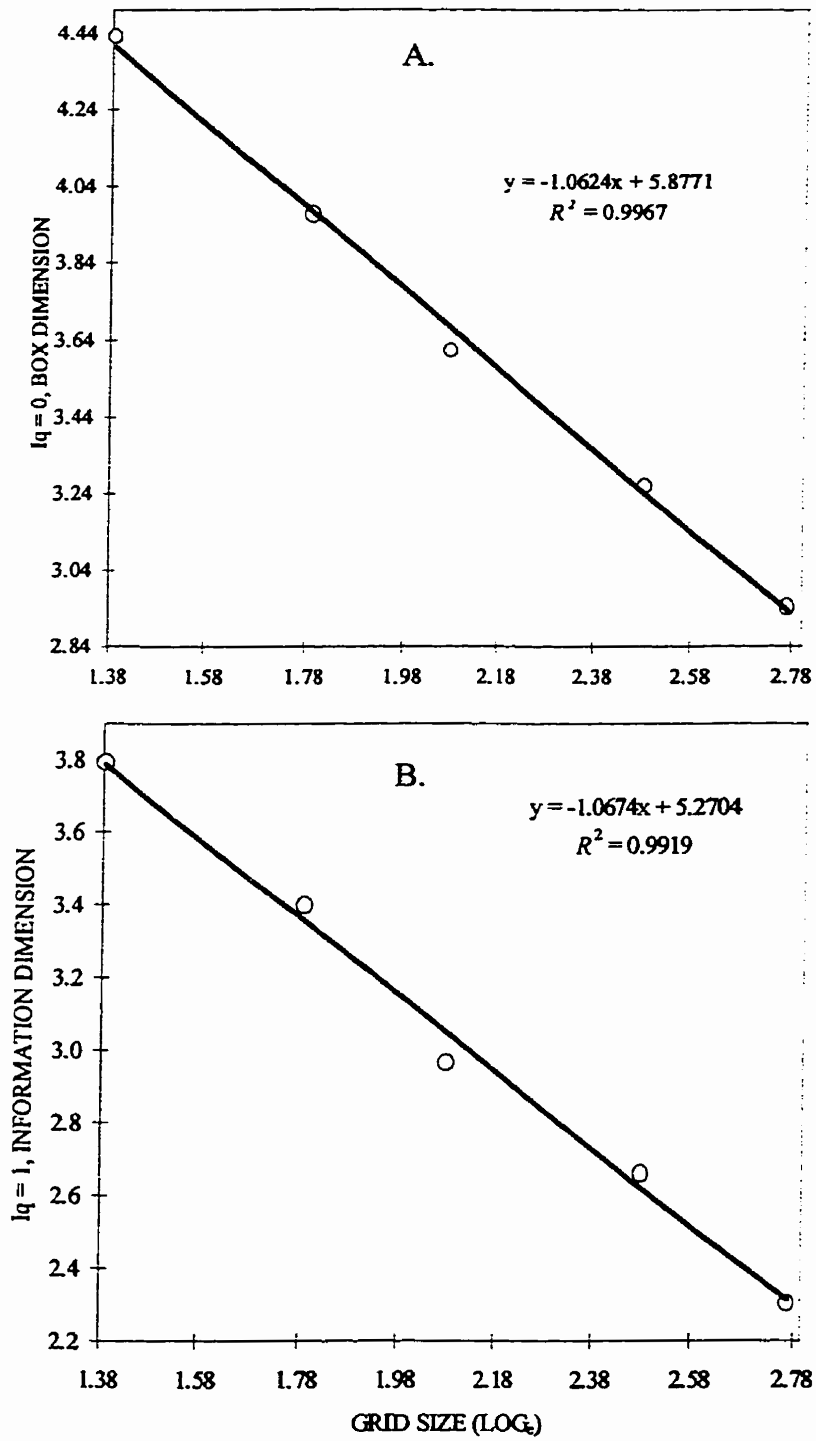

Fig. 2-1. Fractal dimension (*D*) for sage grouse in the Piceance Basin, Colorado, 1997-98. R^2 signifies that scaling properties are evident in the observed fractal pattern. The slope of the line estimates the dimension and this observed pattern was highly clustered.

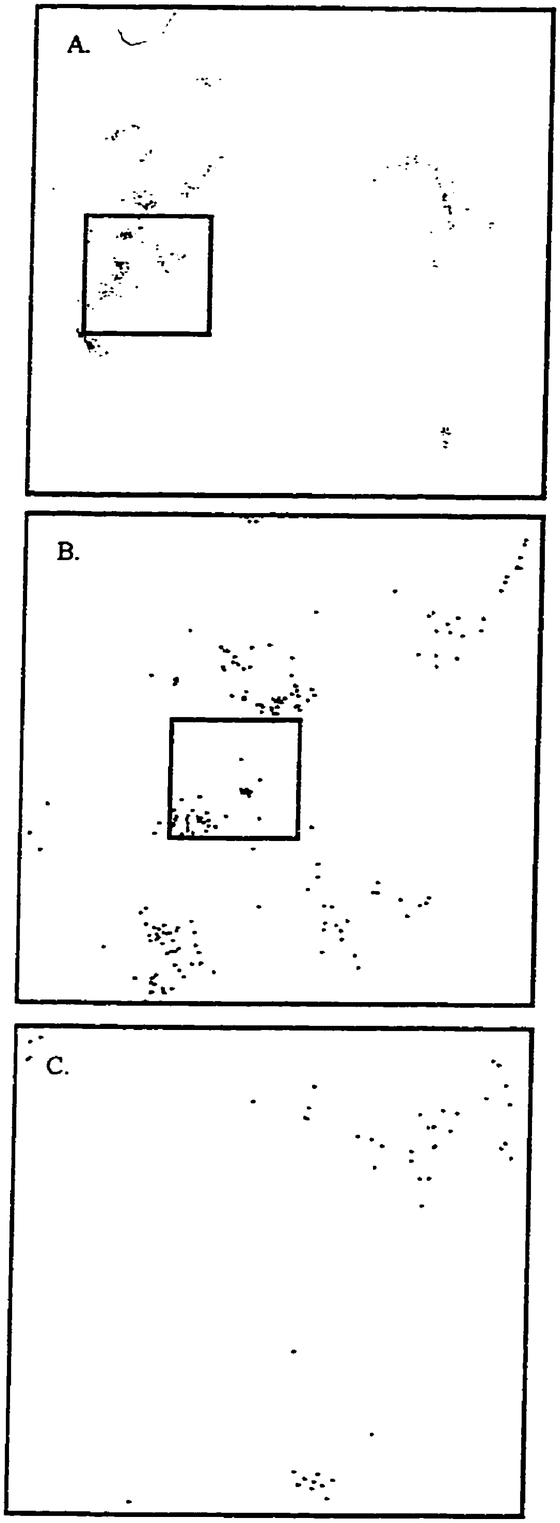

Fig. 2-2. Spatial distribution of sage grouse at 3 scales (A) 44 km^2, (B) 11 km^2, and (C) 2.75 km^2 in the Piceance Basin, Rio Blanco County, Colorado, 1997-98. Clustering of locations occurs at all scales. These patterns resemble those of a Lévy Flight (Mandelbrot 1983).

Nests—Females moved only short distances to nests from lek of capture. Nest locations for females ($n = 6$) had an average DNL of 1.0 ± 0.4 and DLC of 1.4 ± 0.8 km. Five of 6 females nested closest to their lek of capture. One female trapped at Bar D Mesa traveled 5.7 km south to her nesting site which was closer to the Canyon Creek lek. It was unclear as to her lek of breeding. Two females were located on nests in both years; successive locations were 100 and 500 m from previous nests.

Summer—Female movements varied between 0.2 and 12.5 km ($\bar{x} = 2.8 \pm 2.7$) during summer. Unsuccessful females ($n = 3$) tended to depart brood areas before successful females. Female 031 successfully nested in 1997 but not in 1998. Although post nesting distances did not differ from year to year timing did, as she arrived within 1 km of her October 1997 area in late July 1998. Female 035 (Yankee lek) unsuccessfully nested in 1997 and 1998 and dispersed ($\bar{x}$ = 7.3 km) to Skinner Ridge in early July each year. Female 044 was captured 24 June 1998 and examination of her brood patch indicated that she had nested, but had lost her nest or brood at some point. Female 044 departed the Yankee area by 8 July and remained near Cathedral Bluffs for the duration of the season. Movements of females with broods were within 1 km of nest and lek areas until early October.

Male sage grouse traveled farther ($t = 2.42$, $P = 0.030$) from lek of capture to summer areas ($\bar{x} = 8.8 \pm 0.5$, range = 0.7 – 23.2 km) than females (Appendix A; Table A-2.). Most males moved to habitats along the Divide road area and, generally, remained in flocks of 5 – 20 individuals. This ridge complex encompasses the head of East Willow Creek southeast to the head of Mud Springs Creek. Males from the Bragg Spring and

Bar D Mesa leks had the longest mean dispersion to this area (21.4 ± 0.7 and 12.5 ± 0.2 km, respectively). Males from Yankee lek traveled on average 5.0 ● 0.9 km to similar summer range. Two males (1559-Bar D, 1561-Yankee) traveled to the Cathedral Bluffs area in August 1997 and 1998, respectively. Generally, these males were found with 1 or 2 other males and broods. Two males (1572 at Bar D, 1573 at Bragg Spring) remained within an average of 0.6 ± 0.7 km of their respective leks throughout the summer. Male 1572 was usually associated with a flock of 10 males. Male 1573 was located alone but associated with brood flocks in mid-August. Males that dispersed for the summer made quick long flights to their summer areas near the end of May. Unsuccessful females did not leave the breeding area until mid-June to early July, and successful females did not depart until October (Fig. 2-3.).

Winter—Females dispersed a mean distance of 5.0 ± 0.7 km to winter areas although 3 females remained within 3 km of their lek of capture. Female 029 was generally found with a mixed flock of females and juveniles (~15 birds) throughout the winter. Female 031 moved to higher elevations for the winter near Cutoff Gulch. Female 035 remained along Skinner Ridge but moved 7 km south of her summer area. Male DLC ($\bar{x} = 6.4 \pm 0.6$ km) was similar to that of females during winter ($t = 0.412$, $P = 0.686$). This indicated that males and females occupied spatially similar winter ranges. The core winter area for males of Yankee and Bar D leks was near the Cathedral Bluffs north from Wagonroad Ridge Road to Galloway Gulch. Males from the Bragg Spring lek tended to winter along the ridges north of Cutoff Gulch.

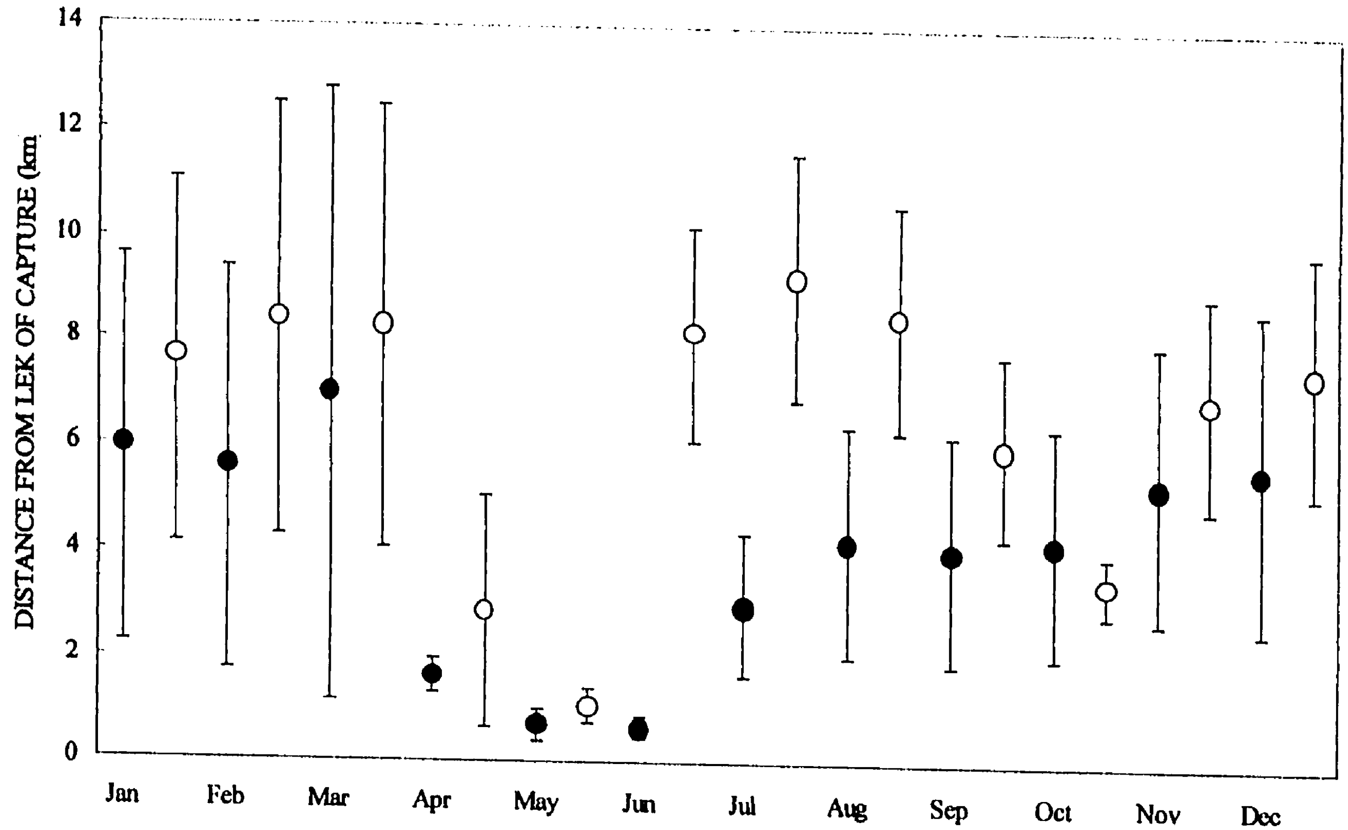

Fig. 2-3. Mean monthly distance (±1 SE) from lek of capture for male (empty circles) and female (filled circles) sage grouse, Piceance Basin, Rio Blanco County, Colorado, 1997-98. Weather conditions in October 1997 limited the number of males sampled and may have resulted in the unusually low value in that month.

2.3.3. LEK DISPERSION

Summer— The dispersion coefficient for female sage grouse was highly significant ($r = 0.941$, $P < 0.001$) as most locations were near nest areas and capture areas throughout the summer (Fig. 2-4a). The dispersion coefficient for males was not significant ($r = 0.340$, $P = 0.172$) as males traveled between 0.7 and 23.2 km ($\bar{x} = 8.8 \pm 0.5$) to summer areas from lek of capture (Fig. 2-4a).

Winter—Four of 5 females were associated with their home lek ($r = 0.875$, $P = 0.005$) throughout the winter (Fig. 2-4b). Most male sage grouse moved towards their lek of capture for winter. Although the dispersion coefficient indicated that males were dispersed ($r = 0.107$, $P > 0.5$), one male (1560) weakened the correlation as he was 21 km from Yankee and within 2 km of the Stewart lek. However, it was apparent (Fig. 2-4b) that most males made distinct movements back to near their leks of capture for winter.

2.3.4. SEASONAL USE AREAS

Home Range—Sixteen sage grouse were included in summer home range estimation. However, small winter sample sizes resulted in home range estimation for 12 grouse (5 males, 4 females, and 3 juvenile males). Median summer MCP home range size of 614 ha for females and 564 ha for males were similar ($U = 7$, $P = 0.727$). Although similar in size, use of home range area was different as males dispersed to summer areas at a different rate than females. The wandering of unsuccessful females (2-4 weeks) resulted in a greater number of points occurring over a larger area. Males made relatively direct flights (1-3 days) from breeding areas to summer ranges (Fig. 2-3.) as evidenced by the sudden loss of radio signals at lek sites. Subsequent locations found

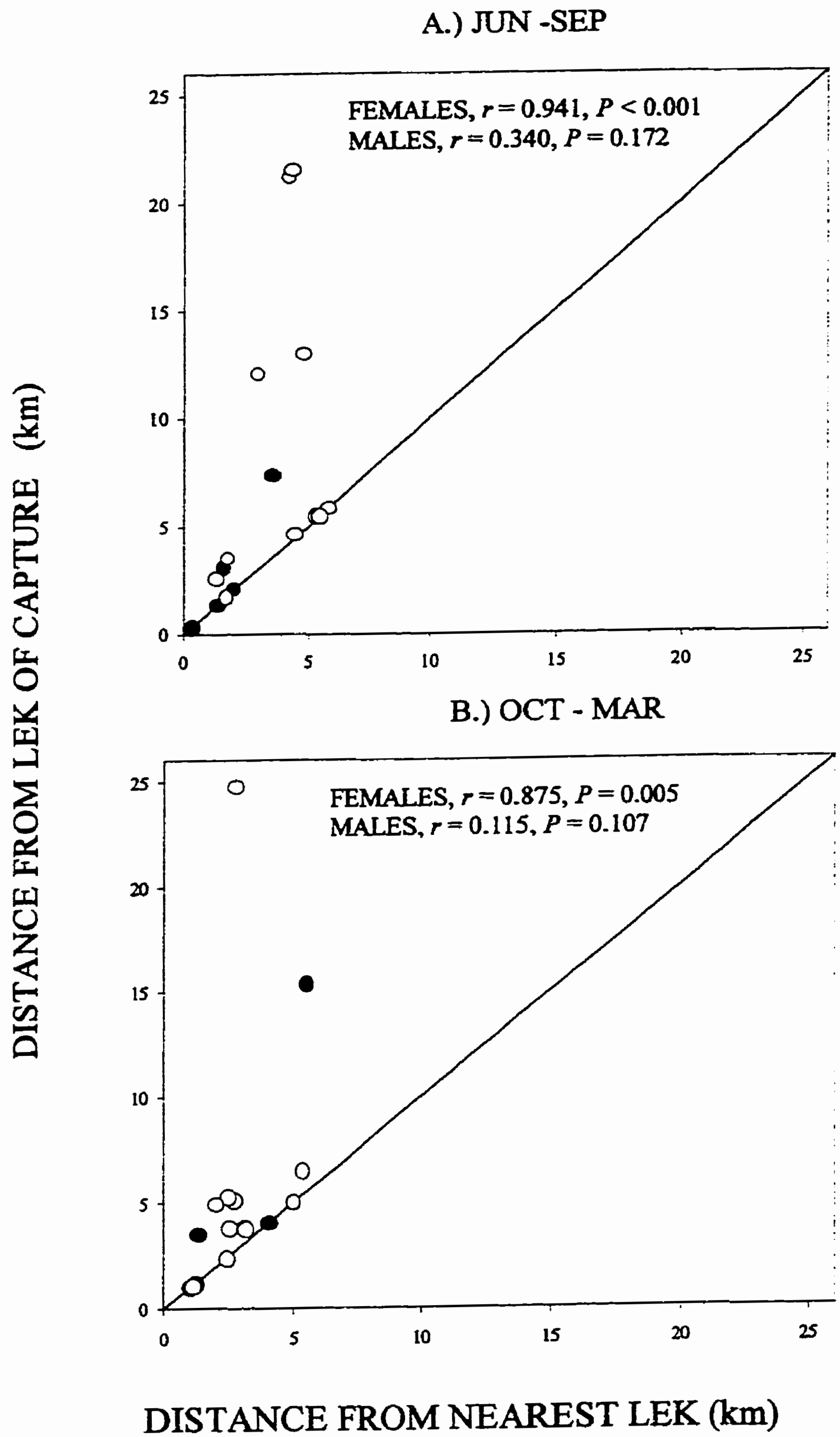

Fig. 2-4. Pearson's product moment correlation (r) for distance to nearest lek and lek of capture for male (empty circles) and female (filled circles) sage grouse, Piceance Basin, Rio Blanco County, Colorado, 1997 - 98. The line identifies the point at which DNL = DLC, $r = 1$. All points above the line indicate movements away from home breeding area.

males closer to summer range than leks. Males used a relatively small area within the summer range. Thus, only the small core areas of males were estimated and areas inclusive of spring range were estimated for females. Home range size was highly variable among males and females. There did not appear to be a geographic breakdown of home range size, except for the 2 juveniles and 1 female from Magnolia as they had 3 of the smaller home ranges within the sample. Winter home ranges did not differ ($U = 26$, $P = 0.919$) between males (median 709 ha) and females (median 976 ha) nor were there differences among adults and juveniles ($U = 6$, $P = 0.279$). Thus, data were pooled to test for differences between summer and winter home range size. Summer (median = 564 ha) and winter (median = 447 ha) home ranges were similar ($U = 76.5$, $P = 0.430$).

Core Use Areas—Spacing of seasonal ranges was different as the distance ($\bar{x}$ = 9.4 ± 2.8 km) between male summer and winter home range center was greater (t = 2.196, $P = 0.047$) than for females ($\bar{x} = 2.7 \pm 1.2$ km) (Fig. 2-5). Although not significant, there was a trend ($t = 1.554$, $P = 0.071$) for male summer ranges to be greater distances ($\bar{x}$ = 8.2 ± 2.2 km) from spring range centers than that of females ($\bar{x} = 2.7 \pm 1.8$ km). Distances between centers of winter and breeding ranges did not differ (t = 0.106, $P = 0.917$) between males (5.1 ± 1.9 km) and females (4.7 ± 2.7 km).

Juveniles remained within 0.5 ± 0.2 km of their capture locations through August – October. However, juveniles began to move away from these areas in November and continued to disperse between 0.4 and 7.6 ($\bar{x} = 1.6 \pm 1.5$) km to winter areas through December. These movements were significantly ($t = 2.69$, $P = 0.021$) shorter than for adult males, but similar to females ($t = 0.625$, $P = 0.555$). Juveniles were located closer to

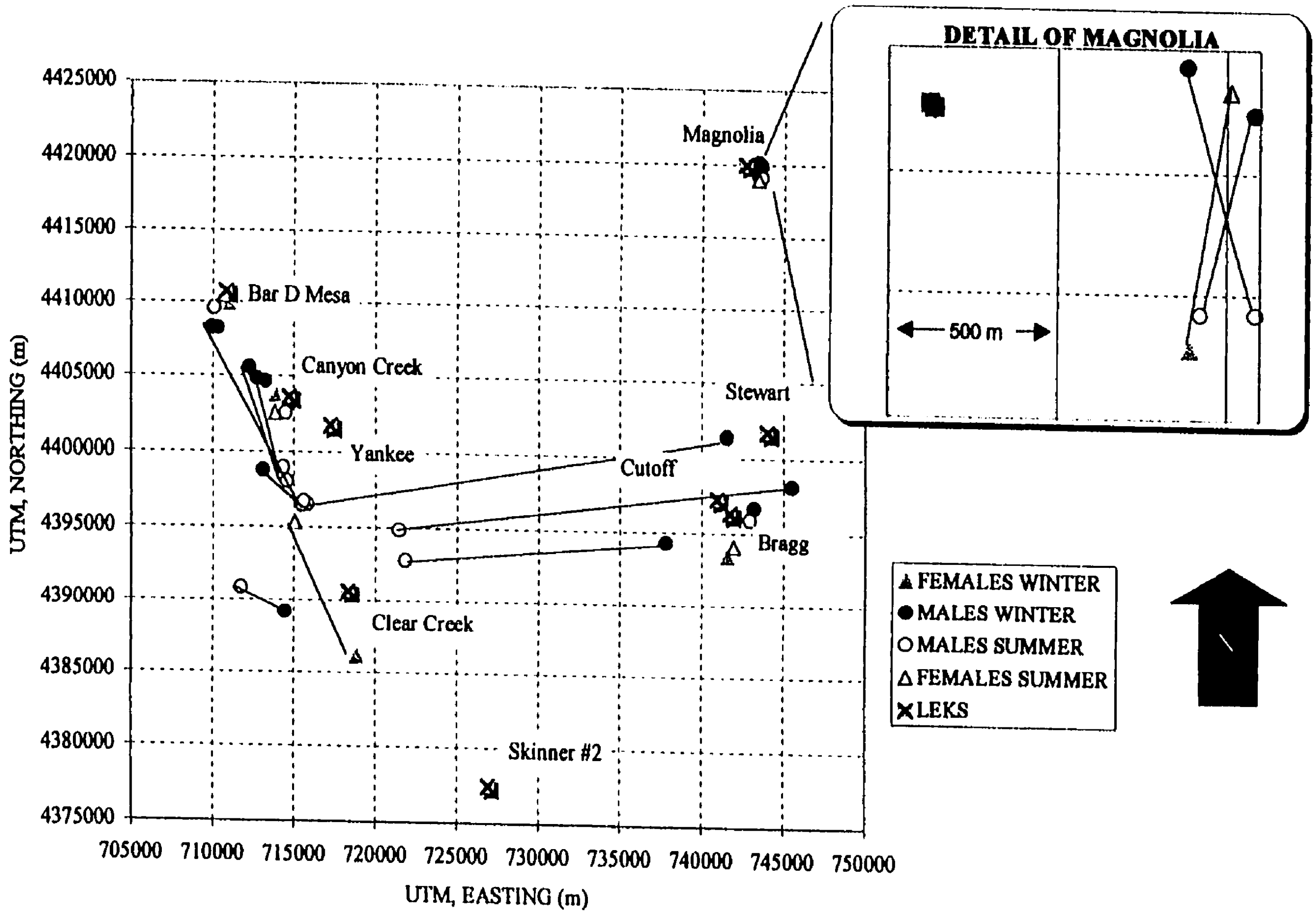

Fig. 2-5. Seasonal use areas of sage grouse (n = 19), Piceance Basin, Rio Blanco County, Colorado, 1997-98.

leks than winter sites by 3 April. Movements from winter areas to leks did not differ between juveniles and adult males (t = 1.045, P = 0.317) nor adult females (t = 1.01, P = 0.352).

2.4. DISCUSSION

Spatial Distribution—Sage grouse locations were highly clustered on the landscape at 5 scales. The scale invariance exhibited by sage grouse may reflect a specialized foraging strategy in a heterogeneous landscape. The distribution of core use areas may also exhibit scale invariant properties to which the grouse must adapt. If this assumption was correct, one would expect to find large voids of suitable habitat on all grid scales (Viswanathan et al. 1996). Thus, grouse must either make long flights to suitable habitats or remain in their respective patch and find suitable patches at finer scales. Either strategy has resulted in the highly clustered scale invariant distribution.

Viswanathan et al. (1996) reported that wandering albatross (*Diomeda exulans*) exhibited scale invariant foraging behavior described as long flights interrupted by short periods of clustered foraging (Lévy flight). Although their data were based on a time series analysis, they demonstrated that wandering albatross use such a foraging tactic to overcome biological complexity. Scale invariant clustering has also been suggested as an anti-predator behavior (Bascompte and Vila 1997). Sage grouse tended to move long distances (flights) and use relatively small seasonal areas (clustered foraging) exemplifying the theory of a Lévy Flight (Mandelbrot 1983, Viswanathan et al. 1996).

Although spatial distribution of sage grouse seasonal movement has not been previously analyzed, inferences to clustering in seasonal areas can be gleaned from the literature. Beck (1977) reported similar findings on movements to winter habitat in North Park, Colorado, which was a more contiguous habitat than the Piceance Basin. Although 50% of North Park had exposed sagebrush, only 6.8% was used intensively as winter habitat (Beck 1977). Connelly and Markham (1983) described movements >80 km between seasonal areas with relatively small summer home ranges ($\bar{x} = 260 \pm 85.9$ ha, $n = 8$). Robertson (1991) found that sage grouse moved 7.2 ± 0.8 km from lek of capture to winter sites with mean daily movements of 0.8 ● 0.08 km. Sage grouse in southwestern Colorado exhibited similar movement patterns as they moved on average <8 km between seasonal areas and maintained average summer home ranges of 320 ha (Commons 1997). In general, nest placement was clustered near or between adjacent lek sites (Wallestad and Schladweiler 1974, Wakkinen et al. 1992). These findings support the similar clustering found in the Piceance Basin and provided evidence that sage grouse distributions were not uniform.

Seasonal Movement and Interlek Distances— Seasonal movements of sage grouse in the Piceance Basin resemble those of populations throughout the species' range. However, some differences did occur. Females with broods ($n = 4$) remained close to nest sites until late August-early September. In Idaho, females and chicks moved to summer areas up to 8.8 and 20 km away by early July (Dalke et al. 1963, Connelly et al. 1988). This distinction could occur for two reasons: 1) the topography of the Piceance Basin would require young birds to make long flights or walks that might increase mortality, and 2) my study area may have been a more mesic habitat than other areas and herbaceous cover did not desiccate as quickly. Further, most males ($n = 8$) tended to move away from lek of capture to a separate summer area. These average distances were different from those reported elsewhere. Male sage grouse moved ($\bar{x}$ = 8.8 km) shorter average distances than Idaho populations, as maximum distances of 31 and 80 km to summer ranges and winter ranges were reported, respectively (Connelly et al. 1988, Robertson 1991, Fischer et al. 1997). My findings support the classification of sage grouse in Colorado as "sedentary." Although 'migrations' occurred to seasonal use areas, these movements were contained within a geographic area.

Differential Movements—The differences between male and female summer movements was not surprising, as the timing and distance of female dispersion is tempered by nesting and brood-rearing (Connelly et al. 1988). Juvenile movements tended to reflect those of females, as juvenile males tend to associate with females throughout the winter (Beck 1977). However, it was surprising to find extreme differences in males from the same lek. Three radio-marked males from 3 leks remained within 2.6 ± 0.5 km of lek of capture. Male 1572 (Bar D) was relocated throughout the summer 1.1 km from his capture area. Usually he was tracked near the Bar D burn with a flock of ~10 males. Two males from the same lek traveled on average (12.5 km) to summer and winter use areas. Differential movement patterns in male and female tetraonids have been documented in blue grouse (*Dendragapus obscurus*)(Cade and Hoffman 1993) and greater prairie-chicken (*Tympanuchus cupido*) (Schroeder and Braun 1993). However, differential pattern in movement of male sage grouse from the same leks has not been explicitly identified. Reasons for this differential movement pattern may be attributed to annual variation in moisture levels. Males may remain closer to leks in wet years and move greater distances in dry years. Vegetal moisture has been correlated to initiation of summer migration, and annual variation in movements by female sage grouse (Fischer et al. 1996). Thus, it seems probable that annual precipitation could influence habitat use and seasonal movements of male sage grouse.

Core Areas and Home Range—Distances between seasonal areas contrasted with those reported in North Park, Colorado as sage grouse moved between 10 and 20 km from breeding to winter areas (Beck 1977, Schoenberg 1982). However, spacing of seasonal ranges resembled that reported in Idaho (Dalke et al. 1963, Robertson 1991) and Montana (Eng and Schladweiler 1972) as winter habitat was more closely associated with home lek areas than summer areas. Comparatively, average seasonal movements rarely exceeded 6 km from the nearest lek or inter-lek distance. Robertson (1991) inferred that this distance ($\bar{x} = 2.4 \pm 0.4$ km) was related to the abundance of leks in his study area. Although only 9 active leks are known in the Piceance Basin, it is apparent that the leks represent suitable habitat for different seasonal needs (Fig. 2-4a,b). For instance, the Yankee lek was the largest breeding center with a maximum count of 28 males. However, this area lacked winter habitat as all radio-marked birds from this lek moved considerable distances for the winter. Conversely, the Canyon Creek lek which hosted only 4 males was within 2 km of the core winter area for the northern part of the Basin.

Home ranges were highly variable, which may be attributable, in part, to small sample sizes. Individual home ranges were similar to those in the highly fragmented agricultural landscapes of southwestern Colorado (Commons 1997). Habitat fragmentation may have affected the size of the seasonal use areas (Commons 1997). However, Commons used 95% ellipse which calculates an area larger than the maximum distance between locations (White and Garrott 1990). Thus, estimates for southwestern Colorado were probably slightly smaller than those in my study area. Connelly and

Markham (1983) reported sage grouse home ranges that were similar to my study. Although the habitat was contiguous in their study area, the grouse were concentrated on an artificial lawn. The abundance of succulent forbs may have provided enough forage such that sage grouse did not need to travel, hence the small home ranges. Although habitat fragmentation can interfere with movement patterns and spatial distributions (Weins 1997), further work is needed to examine the relationship between sage grouse home range size and habitat fragmentation.

2.5. MANAGEMENT RECOMMENDATIONS

Sage grouse locations were highly clustered in the Piceance Basin. The self similarity demonstrated in this study emphasizes the importance of critical habitats to sage grouse. Despite the distance traveled between seasonal areas, movements within core areas were clustered. This indicates that sage grouse are highly selective from the landscape scale (Chapter 3) to the foraging site (Remingtion and Braun 1985). This self similar aggregation (Fig. 2-2) may be indicative of sage grouse occurring in fragmented landscapes. However, no other studies have examined this relationship and further study is needed to compare the spatial distribution of sage grouse in contiguous landscapes. Thus, I recommend that managers incorporate measurements of scale and self-similarity to examine the characteristics of the landscape and its affects on site tenacity and dispersal of a population.

Sage grouse moved 0.3 to 25.0 km from summer to winter and breeding areas. This pattern was similar, but distances were less than for populations in southeastern Idaho (Dalke et al. 1963, Connelly et al. 1988). Conversely, Piceance Basin sage grouse moved similar distances to winter habitat that was further removed from breeding and summer ranges than in other areas of Colorado (Beck 1977, Schoenberg 1982). No movements were detected between Magnolia and the western side of the Basin. Although the intervening habitat was predominately pinyon-juniper woodlands, there were several sagebrush patches that potentially could serve as links between these sub-populations. It appears the Piceance Basin sage grouse population is sedentary at the geographic scale as seasonal movements were confined within the Basin. It is unclear if the general guidelines for managing sage grouse habitats (Braun et al. 1977) would be adequate for the Piceance population as summer habitats were often greater than 3.2 km from capture areas. Wakkinen et al. (1992) and others have expressed similar concerns regarding this protected radius around the lek. Most studies have evaluated guidelines by Braun et al. (1977) in terms of straight-line distances from point of capture (Connelly et al. 1988, Wakkinen et al. 1992). While this measure is useful in identifying maximum distances individuals travel, it overlooks the spatial relationship of the end points of sage grouse movements. Further, what is often overlooked is that distance from nearest lek is less than the distance from lek of capture, and substantially so. If managers are concerned with protecting only a few selected leks in a region, then it may be inappropriate to use the general guidelines as some seasonal areas would not be included. However, if most leks can be protected then the guidelines of Braun et al. (1977) may be more appropriate as most seasonal areas would be included. Therefore, I recommend that distance to nearest lek (DNL) be the measure to which management guidelines are prescribed for a population as DNL better describes the spatial relationship of seasonal movements to breeding areas.

Fragmented landscapes may require a re-evaluation of the 3.2-km buffer as a suitable amount of habitat may not occur within those boundaries. Although the buffer may need to be enlarged, not all habitat within the radius would require protection as some would not be suitable. This study demonstrated that distances from capture varied from 0.2 to 25.0 km and distance from nearest lek varied from 0.3 to 6.1 km. Adhering to the 1977 guidelines (3.2 km buffer) and using DLC as the gauge, 31% of the critical habitat would be protected, but DNL would provide 63% protection. Arguably, 63% is not adequate protection. However, it demonstrates that re-examining movement data with DNL allows for greater application of Braun et al.'s (1977) recommendations. Thus, it may provide support for theory that leks are centers of a breeding complex and potentially other seasonal habitats.

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CHAPTER 3.

SAGE GROUSE HABITAT USE IN A NATURALLY FRAGMENTED LANDSCAPE, NORTHWESTERN COLORADO

Abstract: Habitat use of sage grouse (*Centrocercus urophasianus*) in the Piceance Basin of northwestern Colorado was examined from April 1997 through December 1998. Three vegetation cover class maps of habitat availability were generated using a geographic information system (GIS). Habitat use was determined from 501 locations of 16 radio-marked sage grouse (male = 11, female = 5) that were integrated with each vegetation cover class map of availability. Vegetation structure and composition data were collected at sites used by sage grouse ($n = 225$) and paired random sites. Topographic distribution was described for 429 locations. Male and female habitat selection was similar among the 3 landscape analyses ($P = 0.068$), but vegetation structure differed among summer use sites ($P < 0.001$). Use sites did not differ ($P > 0.5$) from paired random sites for male or female sage grouse. Shifts in habitat use were detected between summer and winter sites at the landscape scale ($P < 0.001$) and within habitat patches ($P < 0.001$). Examination of topographic distribution indicated that sage grouse used ridgetops greater than other areas, but drainages were used more frequently in winter ($P = 0.02$). The changes in selection across scales offered insight as to the importance of certain habitat types.

3.0. INTRODUCTION

Loss of species and species diversity in regional and local landscapes has been attributed to anthropic habitat fragmentation and edge effect (Harris 1988). These topics have been at the forefront of conservation biology for at least 20 years (Harris 1988). The goal has been to provide evidence that species persistence is negatively affected by habitat loss and isolation. The majority of this knowledge has focused on either fragmented forest or agricultural landscapes as they pertain to community diversity, survival and/or reproductive success (Redpath 1995, Patsitschniak-Arts and Messier 1996). Few studies have examined fragmentation as it pertains to species of the shrub-steppe ecosystem (Knick and Rotenberry 1995), and recent research has focused on these effects in anthopogenically fragmented landscapes. Fragmentation can also occur naturally as geographic and topological barriers divide and sometimes limit the extent of habitat (Brown 1971, Wiens 1994).

Sage grouse are dependent upon sagebrush (*Artemisia* spp.) in all seasons for survival. Removal of large tracts of sagebrush has proved to be detrimental to sage grouse populations (Wallestad 1975, Swenson et al. 1987). Sage grouse use mesic habitats in summers that are comprised of greater herbaceous cover (Patterson 1952, Dalke et al. 1963). Occasionally, these mesic habitats have been anthropogenic landscapes such as agricultural fields (beans and alfalfa) and lawns (Connelly and Markham 1983, Commons 1997). However, these artificial landscapes require adequate escape and roosting cover in sagebrush (Wallestad 1975, Commons 1997). Sage grouse shift to more xeric habitats for winter use because of the availability of sagebrush exposed above the snow pack

(Connelly et al. 1988). Typically, winter habitats have been quantified as taller and denser stands of sagebrush (Beck 1977, Hupp and Braun 1989, Roberston 1991). Winter habitat tends to occur in drainages or relatively large sagebrush flats (Hupp and Braun 1989). However, Hupp and Braun (1989) concluded that topographic use might not adequately describe winter habitat as steeper slopes may be used if prevailing winds do not keep sagebrush snow-free and readily available.

Researchers have examined habitat use by sage grouse to better manage regional and local populations. However, studies have focused on large populations (>500 birds) occurring in contiguous habitats (Remington and Braun 1985, Dunn and Braun 1986) or migratory populations (Robertson 1991). Habitat selection studies of sage grouse have analyzed habitat use relative to a larger geographic area (study area) or at the structural scale assessing forb species composition or vegetation structure/composition at sites used by sage grouse (Dunn and Braun 1986, Drut et al. 1994, Gregg et al. 1994). Further, nesting and brood habitat use has been well documented (Klebenow 1969, Wallestad 1971, Wallestad and Pyrah 1974, Connelly et al. 1991, Fisher et al. 1996, Sveum et al. 1998). Habitat use by sage grouse occurring in fragmented landscapes is relatively unstudied (Commons 1997). No studies have examined habitat use in a naturally fragmented landscape. Few studies have identified habitat selection as it varies across explicit scales of availability (i.e., geographic range, study area, home range, and within the home range [Robertson 1991, Sveum et al. 1998]). Results of selection studies are dependent upon what resources are deemed available (Johnson 1980). Thus, it is important that selection is properly identified as management may be based upon such findings.

I examined habitat use of a small (~250 birds) isolated population of sage grouse in northwestern Colorado to provide management recommendations. The main objectives of this study were to identify: 1) habitat use as it varies with scales of availability (resource selection), 2) shifts in seasonal habitat use, and 3) topographic distribution of sage grouse use sites.

3.1. STUDY AREA

The vegetation of the Piceance Basin in northwestern Colorado is comprised primarily of pinyon pine (*Pinus edulis*) and juniper (*Juniperus* spp.) woodlands at elevations of 1,800 - 2,100 m. Mountain big sagebrush (*Artemisia tridentata vaseyana*), Utah serviceberry (*Amelanchier utahensis.*), Gambel oak (*Quercus gambelii*), and antelope bitterbrush (*Purshia tridentata*) constitute a transitory habitat from 2,100 to 2,300 m. Rabbitbrush *(Chrysothamnus* spp.) is common throughout the Basin. Elevations of 2,400 to 2,600 m are dominated by mountain big sagebrush interspersed with bunch grass meadows. North aspects are comprised of quaking aspen (*Populus tremuloides*), serviceberry, and mountain snowberry (*Symphoricarpos oreophilus*). Douglas-fir (*Pseudotsuga menziesii*) dominates northwest aspects at elevations > 2,500 m. The climate of the Piceance Basin is semi-arid with extreme differential levels of monthly precipitation. Consecutive months often receive little precipitation. Snowfall comprises approximately one half of the total precipitation. The average annual temperature varies from 7 C at 1,800 m to – 1 C at 2,700 m.

The topography of the study area dissects these habitats with undulating north-south ridges that parallel one another. The ridges are gently rolling, but, the drainages that separate them are steep. The ridgetops vary in width from 0.5 to 3 km with length of the ridges from 1 to 30 km. The southwestern region of the study area consists of canyons that drop nearly 1 km vertically, in <500 m horizontally, but typically the elevation change is more gradual. The topography in this region naturally fragments sagebrush within the plateau and isolates this sage grouse population.

3.2. METHODS

3.2.1. FIELD TECHNIQUES

Trapping—Male and female grouse were trapped at night on or near lek sites using a spotlight and a long-handled net (Giesen et al. 1982) during the breeding seasons of 1997 and 1998. After the breeding season, radio-marked birds were tracked at night to trap grouse associating with them. All captured grouse were banded with a Colorado Division of Wildlife (CDOW) aluminum band with a green bandette placed on the opposing tarsus. Age was ascertained by shape and appearance of primaries (Beck et al. 1975). Grouse were fitted with either a lithium or solar-powered radio. Battery-powered radios (Holohil Systems Ltd., Carp, Ontario) were placed at the base of the neck using a cable tie. Solar-powered radios (Telemetry Systems Inc., Mequon, WI) were mounted on naugahyde ponchos (Amstrup 1980) that were fitted around the neck. Radios weighed 14 to 20 g, which was <3% of a bird's body weight.

Radiotelemetry—Radio-marked grouse were relocated using a portable Telonics receiver (Mesa, AZ) and a hand held 3-element Yagi antenna. Aerial searches were conducted when ground searches were unsuccessful for more than a week or impractical during the winter. The goal was to locate grouse once per week from June through August and once every 2 weeks during winter months. At each location the number of birds seen, slope, aspect, topographic location (ridge top, ridge side, saddle, or bench), general habitat type, and UTM coordinates were recorded.

3.2.2. HABITAT USE

Selection Orders—Johnson (1980) suggested the hierarchical nature of habitat selection should be recognized in use-availability comparisons, as selected resources will depend upon what is defined as available to a population. He described 4 orders of selection: 1) the selection of a geographical range of a population, 2) home range of an individual or social group, 3) use made of various habitat components within the home range (e.g., location of feeding sites), and 4) consumption of food items within the feeding site. These orders are useful in the exclusion/inclusion of some habitats and enable analyses across various scales that may be most important in the management of a species (Johnson 1980). This hierarchical approach was implemented to examine how habitat selection changed across spatial scales.

Database and Cover Map—A Geographic Information System (GIS) was used to identify habitat use and availability. A digital vegetation cover-class map (1982) that included 95% of the study area was obtained from the Bureau of Land Management (BLM). The classification scheme followed Anderson et al. (1976). The map and grouse locations were imported into ARCview 3.1 software (ESRI 1998). Although the cover map included 5 levels of detail, only the 'dominant cover' category was considered as details of percent cover of a given type were not validated on the ground. When dominant classification was split between cover types, the predominant cover was used for the analysis. Sagebrush/upland shrub was the only composite classification used in the analysis. This habitat type was considered as it was the dominant stand occurring at higher elevations of the plateau. The sagebrush/upland shrub classification was supported by the work of Teideman and Terwilliger (1978: 110) that identified two high elevation sagebrush types: 1) big sagebrush and 2) sagebrush–antelope bitterbrush type. Each of these types contained at least 12% of other shrubs. The cover types initially classified were sagebrush, sagebrush/upland shrub, oakbrush, grass, bare ground, pinyon pine, Douglas-fir, aspen, and agricultural land. Three maps were generated within the GIS to identify the habitat availability for sage grouse: 1) geographic range of the Piceance population, 2) the extent range of radio-marked grouse was created as a minimum convex polygon of all locations (Mohr and Stumpf 1966), and 3) 95% ellipses were generated for individual home ranges and each habitat type was totaled from all ellipses. These maps represented the first 3 selection orders described by Johnson (1980). However, 3rd order selection was also examined by comparing microhabitat variables of different patches (e.g., winter and summer, female and male sites). The fourth order did not directly examine dietary selection; however it described the structure and composition of the vegetation at foraging and paired random sites.

Microhabitat Variables—Vegetation cover at radio-marked grouse flush and brood sites was compared to that of randomly chosen sites (4th order selection). Random sites were selected using the second hand on a watch. First, a reading of 1-60 was taken and multiplied by 5 to obtain a compass direction. This was the direction traveled from the center of the use transect. A second reading of a watch was used to determine distance traveled. By dividing the seconds of the watch into 5 equal parts, random distances of 100-500 m were ascertained. To avoid bias in either the distance or direction traveled, one watch reading was taken at the beginning of a use transect, and the other when the vegetation measurements were completed.

At both random and use sites 9 1-m^2 quadrats were placed along 2 30-m perpendicular transects (modified from James and Shugart 1970). Transects were centered on the flush site or observed location of a grouse. The lines of the transect were placed in the 4 cardinal directions and each quadrat was spaced 7.5 m apart. Percent cover was recorded to the nearest 5% for: big sagebrush, serviceberry, other brush, grass, forb, and bare ground. A mean height of each cover type was calculated by averaging 3-5 samples of each type in the quadrat. Only shrub vegetation was estimated and measured at winter sites. These plots were not measured until the following summer and the amount of exposed ground or herbaceous cover was not known.

Topographic Distribution—Slope was recorded using an Abney level, and aspect was ascertained using a Silva compass. Topographic location was categorized as ridge-top, ridge-side 1 (upper third), ridge-side 2 (middle third), ridge-side 3 (lower third), or a drainage. Topographic locations were verified from plotted points on digital topographic maps (Toposcout™ Software, Maptech™, Greenland, NH). A straight line was drawn through the point and perpendicular to the slope. The elevation of the ridge was then divided into 5 equal parts and points were identified accordingly.

3.2.3. DATA ANALYSIS

Landscape Level Analyses—Data were analyzed according to the seasonal availability of sagebrush: 1) sagebrush and herbaceous forage readily available (Apr – Sep) and 2) herbaceous and sagebrush cover limited by desiccation in late autumn or snowfall (Oct – Mar). Heterogeneity chi-square tests were used to justify pooling landscape level samples between years and sex (Zar 1999: 471). This test was also used to identify shifts in seasonal use of habitats. For each selection order, a log-likelihood chi-square test (*G* test) was used to examine habitat use relative to proportions available (Manly et al. 1993). If the null hypothesis was rejected, then Bailey's simultaneous confidence intervals were implemented to identify which habitats were selected. Bailey's intervals provide a more robust model, with less error (≤5%), and are less sensitive to small sample sizes than Bonferroni intervals proposed by Neu et al. (1974) and Byers et al. (1984) (Cherry 1996). Manly et al. (1993:55) suggested a selectivity index (w_i) to identify the extent to which a habitat was selected over others. Confidence intervals were constructed for each index to identify differences in selection relative to other habitat types (Manly et al. 1993:59). Selectivity indices include the proportion of points occurring in a habitat (use). Although availability varied across scales, use data did not. These data were not independent among scales. Such dependency in the data violates assumptions of randomness and standard statistical procedures are not valid (Zar 1999: 127). Thus, selectivity indices were not formally tested between scales.

Microhabitat Variables—Hotelling's T^2 was used to examine differences among 4^{th} order selection variables. Seven variables were included in analyzing summer use and random sites: percent cover estimates for sagebrush, serviceberry, other brush, grass, forb, bare ground, and shrub height. Shrub height was derived by taking a weighted mean (percent cover x mean height) among shrub classes. If the results of T^2 tests indicated that shrub height was a significant variable, then univariate t tests were conducted on each shrub type to identify which shrub type was contributing to the variable weight. Winter data analysis included 4 variables: sagebrush, serviceberry, other shrubs, and shrub height. Paired tests were used for use and dependent random sites and unpaired tests were used for all other test groups (Johnson and Wichern 1998). Hotelling's T^2 was implemented to justify pooling 4th order data among years and sex. The use of two measurement scales among these variables required a data transformation to standardize the values. All variables were log-transformed: $\log_e(X + 1)$. Log transformation was effective in converting a positively skewed frequency into an approximate normal distribution (Krebs 1989: 446). Critical values for T^2 were transformed to F statistics for tests of significance (Manly 1986). Topographic distribution and aspect were tested for deviations from a random distribution using chi-square goodness of fit tests. Chi-square tests were also used to examine shifts in seasonal use of topographic locations. Slope was examined against dependent random sites and between male and female use sites with t tests. All statistical tests were considered significant at $P < 0.05$.

3.3. RESULTS

Summer Landscape Analysis—Habitat use data were analyzed for 16 grouse (male, $n = 11$; female, $n = 5$) and 501 locations ($n = 352$ summer, $n = 149$ winter) for 1997 and 1998. Although information was available for aspen, Douglas-fir, and agriculture cover types (Table 3-1.), these were excluded from the analyses for two reasons. First, sage grouse are not a forest-dwelling species and would not be expected to use these habitats. Second, the agricultural cover was at elevations <1,400 m, and sage grouse were not known to inhabit or migrate to these areas. Although pinyon-juniper is a woodland class, it was included as it often had a sagebrush understory and sage grouse were found near the periphery of this habitat. Summer and winter habitat use for 7 cover types were similar between years ($\chi^2 = 7.96$, $P = 0.243$; $\chi^2 = 11.38$, $P = 0.081$). Male and female sage grouse also appeared to use habitats similarly in summer and winter ($\chi^2 = 11.86$, $P = 0.069$; $\chi^2 = 5.43$, $P = 0.492$). Thus, seasonal data were pooled between years and gender classes.

Table 3-1. Habitat types in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	First Order		Second Order		Third Order[a]	
Habitat Type	ha	%	ha	%	ha	%
Pinyon-Juniper	99,773	0.32	28,978	0.29	18,986	0.07
Sagebrush	72,771	0.23	21,184	0.21	57,311	0.21
Sagebrush/Upland	62,970	0.20	26,078	0.26	101,758	0.37
Upland	17,194	0.05	5,550	0.06	22,225	0.08
Oakbrush	15,088	0.05	3,030	0.03	14,850	0.05
Grass	10,875	0.03	4,957	0.05	21,067	0.08
Bare Ground	8,805	0.03	1,796	0.02	5,113	0.02
Agriculture	8,322	0.03	3,146	0.03	0	0.00
Aspen	10,770	0.03	5,194	0.05	28,632	0.10
Douglas-fir	6,726	0.02	574	0.01	3,870	0.01
Totals	313,294	1.00	100,487	1.00	273,811	1.00

[a]Habitat availability was determined from total area (ha) of each habitat occurring in 95% ellipses ($n = 16$).

Summer habitats were not used proportional to their availability and at each of the 3 selection orders. First order selection was highly significant ($G = 444.43$, $P < 0.001$) and confidence intervals suggested that sagebrush/upland and grassland habitats were used greater than their availability (Table 3-2). Sagebrush and bare ground habitats were used equal to their proportion on the landscape. Pinyon, oakbrush, and upland habitats were used less than their availability. Second order selection also yielded a highly significant result ($G = 319.87$, $P < 0.001$). However, habitat use of individual cover types differed only for oakbrush as it was used equal to its availability (Table 3-2). Third order selection indicated habitat use was not uniform ($G = 93.07$, $P < 0.001$). However, the reduced G statistic indicated a trend towards proportional use within the home range.

Table 3-2. Summer habitat selection by sage grouse ($n = 16$) at 3 scales of availability in the Piceance Basin, Rio Blanco County, Colorado, 1997-1998.

	Use	95% Confidence Limits (χ^2)		Selection Order (% Available)			
Habitat Type	(%)	Lower	Upper	1st	2nd	3rd	Selection[a]
Pinyon-Juniper	0.02	0.003	0.044	0.347	0.316	0.081	1A, 2A, 3A
Sagebrush	0.21	0.151	0.270	0.253	0.231	0.245	1E, 2E, 3E
Sagebrush/Upland	0.59	0.516	0.659	0.219	0.285	0.436	1S, 2S, 3S
Upland	0.02	0.006	0.052	0.060	0.061	0.095	1A, 2A, 3A
Grass	0.14	0.095	0.197	0.038	0.054	0.090	1S, 2S, 3S
Oakbrush	0.01	0.001	0.035	0.052	0.033	0.022	1A, 2E, 3E
Bare Ground	0.01	0.000	0.031	0.031	0.020	0.030	1E, 2E, 3E

[a]The number corresponds to the selection order and the letter indicate relative use: A = use was less than proportion available; E = use was equal to proportion available; and S = use was greater than proportion available.

Selectivity analysis indicated that grassland habitat was selected above all other habitat types at the landscape scale (Table 3-3). However, grassland selectivity decreased and sagebrush remained constant as a function of scale. Sagebrush/upland shrub selectivity remained significant at all levels despite variation in availability. Sage grouse appeared to

Table 3-3. Sage grouse summer habitat selectivity based upon 3 selection orders, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

STUDY AREA	Index w_i	P/J[a]	Oakbrush	Bare Ground	Upland Shrub	Sagebrush	Sagebrush/Upland
Oakbrush	0.217	o					
Bare Ground	0.278	o	o				
Upland Shrub	0.380	o	o	o			
Sagebrush	0.896	+	+	o	o		
Sagebrush/Upland	2.698	+	+	+	+	+	
Grass	3.755	+	+	+	+	+	+
EXTANT RANGE							
Oakbrush	0.343	o					
Bare Ground	0.435	o	o				
Upland Shrub	0.375	o	o	o			
Sagebrush	0.896	+	o	o	o		
Sagebrush/Upland	2.075	+	+	+	+	+	
Grass	2.624	+	+	o	+	-	-
HOME RANGE							
Oakbrush	0.374	o					
Bare Ground	0.389	o	o				
Upland Shrub	0.239	o	o	o			
Sagebrush	0.845	+	o	o	+		
Sagebrush/Upland	1.356	+	+	+	+	+	
Grass	1.575	+	o	o	+	o	-

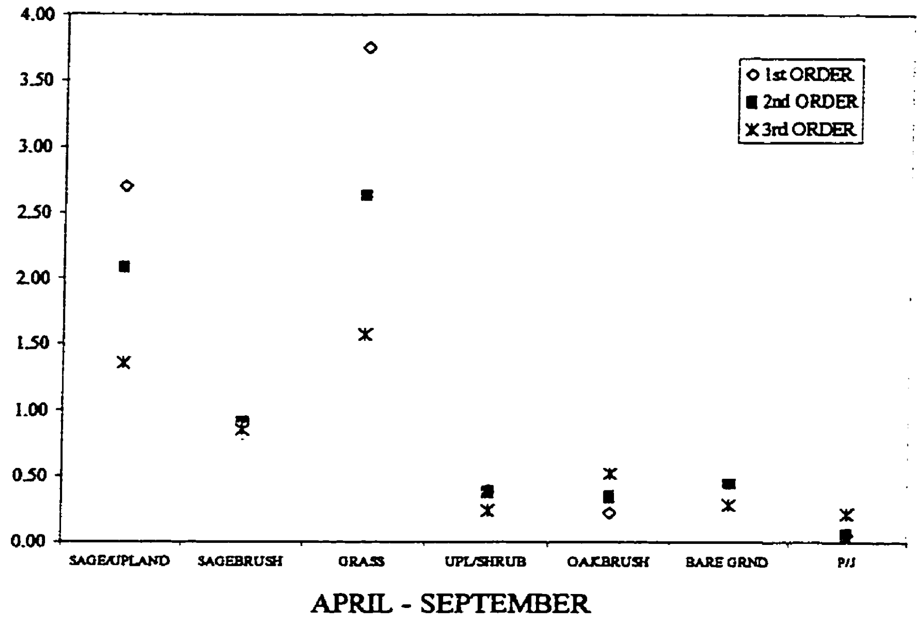
[a]Pinyon - juniper indices were 0.049, 0.054, and 0.210, respectively.
"+" row habitat selectivity was greater ($P < 0.05$) than column habitat.
"-" row habitat selectivity was less ($P < 0.05$) than column habitat.
"o" row habitat selectivity was similar ($P > 0.05$) to that of the column habitat.

avoid pinyon-juniper although it increased at the home range scale. Selectivity for oakbrush, upland shrub, and bare ground was low at all scales. Generally, use of these habitats closely approximated proportional use (Table 3-2.). However, preferred habitat was selected at the largest scale and maintained high selectivity values at finer scales (Fig. 3-1a).

Summer Fourth Order Selection—Data were collected on 100 sage grouse summer use and paired random sites in 1997 (males, $n = 60$; females, $n = 40$) and 1998 (males, $n = 56$; females, $n = 44$) (Table 3-4.). Vegetation composition at male and female sage grouse use sites differed ($F_{7,191} = 9.67$, $P < 0.001$) as male use sites had greater sagebrush ($\bar{x}$ = 20.8 ± 1.1) and less serviceberry ($\bar{x}$ = 1.6 ● 0.4) canopy cover than female use sites (sagebrush: $\bar{x}$ = 12.9 ± 1.1%, serviceberry: $\bar{x}$ = 5.1 ± 0.8%). Vegetation composition was similar between years for males ($F_{7,107} = 1.91$, $P = 0.124$) and females ($F_{7,77} = 1.40$, $P = 0.456$) and these data were pooled, respectively. Male use sites did not differ from random sites ($F_{7,107} = 1.67$, $P = 0.271$). Vegetation composition at female use sites was also similar to paired random sites ($F_{7,77} = 1.577$, $P = 0.342$).

Winter Landscape Analysis—The shift in seasonal habitat use was evident at both the landscape and within patch scale. Habitat selection in winter shifted to stands dominated by sagebrush with less sagebrush/upland shrub ($G = 24.72$, $P < 0.001$). Habitat was not used in proportion to its availability at the geographic scale ($G = 164.85$, $P < 0.001$) as sagebrush and sagebrush/upland were used greater than available. Pinyon-juniper and bare ground were used less than available. Grassland, upland, and oakbrush were used proportional to their availability (Table 3-5). Habitat use was disproportional

A.



B.

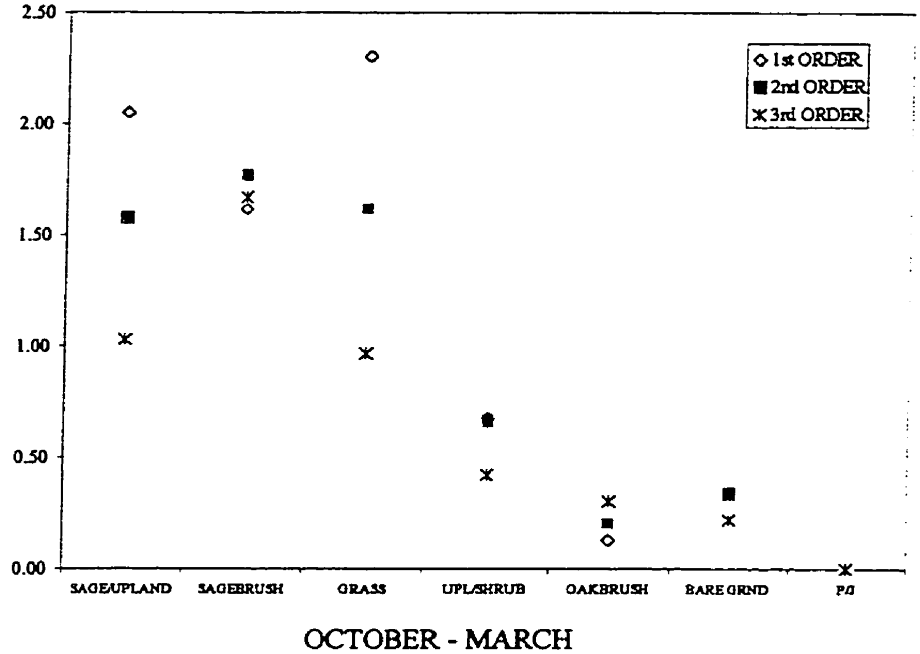


Fig. 3-1. Selectivity indices (w_i)at three scales of availability for summer (a) and winter (b) habitat use by sage grouse in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Table 3-4. Canopy cover (%) and vegetation height at female (n = 84) and male (n = 116) sage grouse summer use and random locations, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Female				Male			
	Use		Random		Use		Random	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Sagebrush (%)	12.9	1.1	14.2	1.3	20.8	1.1	17.3	1.0
Height (cm)	46.6	2.0	48.2	1.7	49.3	1.2	49.6	1.5
Serviceberry (%)	5.1	0.8	4.2	0.8	1.6	0.4	2.0	0.4
Height (cm)	63.6	5.4	57.9	3.8	54.5	5.2	58.2	3.1
Other-shrubs (%)	8.7	0.8	10.9	1.3	9.5	0.9	12.5	0.9
Height (cm)	33.7	1.3	33.8	1.7	36.1	1.1	39.2	1.7
Grasses (%)	17.2	1.1	15.8	1.1	17.1	0.8	18.5	1.0
Height (cm)	19.8	0.8	20.2	0.8	21.7	0.7	23.7	1.0
Forbs (%)	10.7	1.0	10.0	0.8	11.0	0.5	10.5	0.6
Height (cm)	21.3	0.9	22.8	1.0	21.1	0.7	23.8	1.4
Bare Ground (%)	45.6	1.7	45.1	2.0	40.4	1.5	39.5	1.6
Shrub Height (cm)[a]	45.2	1.9	47.1	2.3	48.1	1.3	48.5	1.5

[a] Shrub height was a weighted mean height of 3 shrub classes used in the multivariate analyses.

at 2nd selection order ($G = 133.02$, $P < 0.001$) with bare ground shifting to proportional use. Third order selection also exhibited disproportional use ($G = 55.10$, $P < 0.001$) as sagebrush continued to be used greater than its availability. Pinyon-juniper was not used during the winter (Table 3-5). Sage grouse used sagebrush/upland proportional to its availability at this scale.

Table 3-5. Winter habitat selection by sage grouse ($n = 16$) at 3 scales of availability in the Piceance Basin, Rio Blanco County, Colorado, 1997-1998.

	Use	95% Confidence Limits (χ^2)		Selection Order (% Available)			
Habitat Type	(%)	Lower	Upper	1st	2nd	3rd	Selection[a]
Pinyon-juniper	0.00	0.000	0.000	0.347	0.316	0.081	1A, 2A, 3A
Sagebrush	0.41	0.299	0.519	0.253	0.231	0.245	1S, 2S, 3S
Sagebrush/Upland	0.45	0.336	0.559	0.219	0.285	0.436	1S, 2S, 3E
Upland	0.04	0.008	0.102	0.060	0.061	0.095	1E, 2E, 3E
Grass	0.09	0.034	0.165	0.038	0.054	0.090	1E, 2E, 3E
Oakbrush	0.01	0.012	0.048	0.052	0.033	0.022	1A, 2E, 3E
Bare ground	0.01	0.012	0.048	0.031	0.020	0.030	1E, 2E, 3E

[a]The number corresponds to the selection order and the letter indicate relative use: A = use was less than proportion available; E = use was equal to proportion available; and S = use was greater than proportion available.

Selectivity analysis of winter habitat indicated that sagebrush was the most important cover at all orders of selection (Table 3-6). The index remained constant across 1st and 2nd order selection and was consistently greater than all habitat except for sagebrush/upland and grassland. However, selectivity of sagebrush/upland and grassland diminished at 3rd order selection as sagebrush was selected above all other habitats.

Table 3-6. Sage grouse winter habitat selectivity based upon 3 selection orders Piceance Basin, Rio Blanco County, Colorado, 1997- 98.

STUDY AREA	Index w_i	P/J[a]	Oakbrush	Bare Ground	Upland Shrub	Sagebrush	Sagebrush/Upland
Oakbrush	0.128	o					
Bare Ground	0.219	o	o				
Upland Shrub	0.673	o	o	o			
Sagebrush	1.617	+	+	+	+		
Sagebrush/Upland	2.053	+	+	+	+	o	
Grass	2.306	+	+	+	+	o	o
EXTANT RANGE							
Oakbrush	0.203	o					
Bare Ground	0.342	o	o				
Upland Shrub	0.664	o	o	o			
Sagebrush	1.770	+	+	+	+		
Sagebrush/Upland	1.579	+	+	+	+	o	
Grass	1.612	+	+	+	+	o	o
HOME RANGE							
Oakbrush	0.221	o					
Bare Ground	0.307	o	o				
Upland Shrub	0.423	o	o	o			
Sagebrush	1.668	+	+	+	+		
Sagebrush/Upland	1.032	+	+	o	+	-	
Grass	0.967	+	+	o	+	-	o

[a]Pinyon - juniper indices were 0.000 for all levels of availability.

"+" row habitat selectivity was greater ($P < 0.05$) than column habitat.

"-" row habitat selectivity was less ($P < 0.05$) than column habitat.

"o" row habitat selectivity was similar ($P > 0.05$) to that of the column habitat.

Pinyon-juniper was not used during the winter and this avoidance did not differ from the minimal use of oakbrush, upland shrub, or bare ground cover types. Preferred habitats that were selected at the largest scale and maintained high selectivity values at finer scales (Fig. 3-1b) were those dominated by sagebrush.

WinterFourth Order Selection--Vegetation was sampled at 25 winter use and random sites (male, n = 14; female, n = 11). Male and female winter sites were compared to their respective summer sites as they demonstrated differential summer habitat use. Fourth order selection indicated that sage grouse winter sites had different vegetation composition than summer sites (Tables 3-3 and 3-7). Male sage grouse winter sites had taller overall shrub cover and greater sagebrush canopy cover ($F_{4,124}$ = 5.99, $P < 0.001$). Sagebrush was taller (t = -4.24, $P < 0.001$) at winter male sites ($\bar{x}$ = 63.9 ± 2.8 cm) than at summer use sites ($\bar{x}$ = 49.3 ± 1.2 cm). Serviceberry height was similar (t = -1.69, P = 0.099) as was other brush height (t = -1.52, P = 0.155) between summer and winter male use areas. Sagebrush canopy cover was on average 20.8 ± 1.1% at summer male sites. Comparatively, sagebrush comprised 30.5 ± 3.5 % of the vegetation at winter sites. Females used sites that had greater sagebrush cover and taller shrub cover than summer female sites ($F_{4,124}$ = 2.55, $P < 0.001$) (Tables 3-3 and 3-7). Sagebrush canopy cover nearly doubled between female summer ($\bar{x}$ = 12.9 ± 1.1%) and winter sites ($\bar{x}$ = 25.4 ± 4.2%). Sagebrush was markedly taller (t = -4.42, $P < 0.001$) at winter sites ($\bar{x}$ = 69.6 ± 3.3 cm) than at summer sites ($\bar{x}$ = 46.6 ± 2.0 cm). Serviceberry was taller (t = -2.61, P = 0.01) at winter female sites ($\bar{x}$ = 131.5 ± 38.4) than at summer locations ($\bar{x}$ = 63.6 ±

Table 3-7. Canopy cover (%) and vegetation height at female (n = 11) and male (n = 14) sage grouse winter use and random locations, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Female				Male			
	Use		Random		Use		Random	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Sagebrush (%)	25.4	4.2	19.0	4.1	30.5	3.5	22.7	2.7
Height (cm)	69.6	3.3	22.7	2.7	63.9	2.8	58.6	2.5
Serviceberry (%)	10.3	4.1	11.2	3.5	4.4	1.8	7.7	3.5
Height (cm)	131.5	38.4	7.7	3.5	79.0	18.5	89.0	15.8
Other-shrubs (%)	13.2	3.3	20.3	6.6	5.4	1.6	7.4	1.8
Height (cm)	62.7	14.8	7.4	1.8	54.3	11.9	39.2	4.9
Shrub Height (cm)[a]	74.4	13.1	95.6	21.4	64.7	3.8	68.1	11.2

[a] Shrub height was a weighted mean height of 3 shrub classes used in the multivariate analyses.

5.4). Although summer habitat use by male and female sage grouse differed, vegetation was similar at male and female winter use locations ($F_{4,7}$ = 0.161, $P > 0.5$).

Topographic Distribution—Data were analyzed for 429 (summer = 283, winter = 146) locations to examine topographic distribution. The resolution of GPS data left several (n = 72) data points difficult to classify, consequently they were not included in the analysis. Male and female sage grouse occupied similar topographic locations during summer (χ^2 = 3.72, P = 0.455) and winter (χ^2 = 3.97, P = 0.424). Thus, these samples were pooled to test for differences between seasonal use of topographic features. Ridgetops and the upper slopes comprised 53 and 20% of summer use sites (n = 280), respectively (Table 3-8.). Mid-slope (17%), lower-slope (7%), and drainages (4%)

Table 3-8. Topographic distribution and proportion (%) of use by male and female sage grouse, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Summer			Winter		
Topographic Location	Female	Male	Both Sexes	Female	Male	Both Sexes
Drainage	4	6	10	5	10	15
%	0.04	0.04	0.04	0.07	0.14	0.11
Upper slope	23	33	56	20	17	37
%	0.21	0.20	0.20	0.27	0.21	0.24
Middle slope	13	34	47	7	9	16
%	0.12	0.20	0.17	0.10	0.11	0.10
Lower slope	7	12	19	2	3	5
%	0.06	0.07	0.07	0.03	0.04	0.03
Ridge top	64	84	148	39	42	81
%	0.58	0.50	0.53	0.53	0.52	0.53
Totals	111	169	280	73	81	154

accounted for the remainder of use sites. Topographic locations differed ($\chi^2 = 12.36$, $P = 0.016$) between summer and winter use sites as drainage areas were used greater in winter (10%) than in summer (4%). All other topographic locations were used proportionally between seasons.

Female sage grouse occupied northwest slopes more than and south slopes less than males ($\chi^2 = 19.98$, $P = 0.006$) in summer. Male and female sage grouse used ridgetops similarly during winter ($\chi^2 = 9.38$, $P = 0.23$). North facing slopes were occupied more frequently, and southwest aspects were used less than random in winter ($\chi^2 = 60.02$, $P < 0.001$). There appeared to be a shift to north aspects by male (15 to 27%) and female sage grouse (17 to 38%) from summer to winter use sites. Sage grouse summer use sites occurred on slopes ranging from 0 to 47% and winter sites of 0 to 27%. Male use sites had an average slope of 13.3 ± 0.83%. The average slope of female use sites ($\bar{x} = 11.4 \pm 0.83\%$) was not different ($t = 1.59$, $P = 0.114$) from male sites. Winter sites tended to have less slope than summer use areas ($t = 2.55$, $P = 0.015$).

3.4. DISCUSSION

Selection As A Function Of Scale—Sage grouse exhibited the greatest selection of habitat at the geographic scale as underused habitats, specifically pinyon-juniper, were in greatest abundance. This relationship did not change at the extent range, but did considerably at the home range scale. Sage grouse may avoid pinyon-juniper/sagebrush habitats as an anti-predator behavior, especially during the breeding season when displaying males are vulnerable at the lek (Commons et al. 1998). Conversely, sage grouse selection for grassland was greatest at the landscape scale as it was relatively less abundant. Sage grouse use grassland and meadow habitats during the summer in search of succulent forbs (Dalke et al. 1963). The use of grassland during winter was surprising; however, Hupp and Braun (1989) noted that sage grouse used open habitats with <10% sagebrush cover when snow pack was not a limiting factor. Thus, sage grouse in the Piceance Basin may have been using grassland sites with scattered aggregations of sagebrush. Summer use of sagebrush/upland sites may have indicated selection for more mesic sites (Connelly et al. 1988, Fischer et al. 1996) that occurred at higher elevations than those of winter sites. Teideman and Terwilliger (1978) identified high elevation sagebrush types as the most productive of all sagebrush types in the Basin. Interestingly, sagebrush availability and proportional use were scale invariant (~24%). This re-emphasizes the importance of large patches of sagebrush for sage grouse at all scales. Further, my data did not indicate differences at the 4^{th} order selection, suggesting that vegetation within a given patch was relatively homogenous. Evidence of sage grouse use (e.g., feathers or pellets) was documented at 79 of 200 random locations. The highly clustered distribution (Chapter 2) of sage grouse locations further supports this finding. These results were similar to those reported in the literature (Hupp and Braun 1989, Robertson 1991, Commons 1997) that found only subtle differences between use and dependent random sites. Commons (1997) suggested that the lack of difference between use and random locations may have been related to the lack of available habitat. However, sage grouse habitat in southwestern Colorado is a highly fragmented agricultural landscape. Comparatively slope and aspect could limit the available habitat for sage grouse in the Piceance Basin.

My data indicated that patches occupied by males and females were structurally different (3rd order). The difference in elevation may explain this compositional difference. However, it does not account for the selection of these mixed habitats by females. This differential habitat use could have occurred for two reasons: 1) hens actively selected these areas as they provided greater forb cover for brood rearing (Sveum et al. 1998), or 2) hens selected these areas for nesting as they are the first to be free of snow. Although the latter seems most probable further study is required to validate these suggestions.

Seasonal Shift In Habitat Use—Male and female sage grouse made dramatic shifts to winter habitat using sagebrush greater than its availability within the first 3 selection orders. This was similar to other studies that reported sagebrush was used almost exclusively for food and cover in winter (Patterson 1952, Eng and Schladweiler 1972, Remington and Braun 1985, Robertson 1991). Winter habitat use shifted away from sagebrush/upland and grassland cover types to lower elevation sagebrush sites. Such vertical migration by sage grouse has been documented in Montana (Wallestad 1975) and Idaho (Connelly et al. 1988). Sage grouse in Idaho used winter sites that had taller and greater sagebrush canopy cover than those of independent random sites (3rd order), thus further supporting selection at larger scales (Robertson 1991). However, 3rd order selection supported this result as female winter sites had 10% more sagebrush canopy cover and sagebrush was ~ 30 cm taller than at summer sites. Male winter sites had 10% more sagebrush cover and ~10 cm increase in height from summer areas. Winter habitat use for male and female sage grouse was similar at all 4 selection orders. Further, male and female sage grouse occupied winter habitats that were spatially similar (i.e., both were close to lek of capture).

Topographic Distribution—Sage grouse used habitats along ridgetops and upper slopes in both summer and winter (75%). However, there was a shift to drainage areas in winter. Hupp and Braun (1989) reported that sage grouse used drainages in higher proportion than available in the Gunnison Basin, Colorado. The use of north aspects was disproportional in winter and indicative of occupied areas occurring at the heads of drainages. These areas were comprised of taller and denser sagebrush described in the 4th order analysis. This shift may indicate two strategies for winter habitat use: 1) shrub patches in drainages provided best food and cover suitable for foraging and 2) north aspects may have provided some shelter from the prevailing southwest winds. This follows the suggestion of Hupp and Braun (1989) that topographic use may vary locally as sage grouse seek the best available habitats. Several relocations of radio-marked birds at winter use sites revealed that sage grouse had used snow burrows for roosting. This suggests that thermoregulatory requirements were not satisfied with the cover available in this harsh environment. Not surprisingly, slope did not differ among sites, as the topography was highly variable. It was evident that ridgetops were used differently than would be expected from random. However, the proportion of available ridgetops was not quantified and this use may in fact reflect the distribution of the topography in the Basin.

3.5. MANAGEMENT IMPLICATIONS

These data support the early suggestions of Patterson (1952) and Rogers (1964) that sage grouse require large tracts of sagebrush habitat to persist in a region. It has been demonstrated that sage grouse tend to select habitat within the first 3 selection orders. Microhabitat variables differed at 3rd but, not 4th order selection. This indicated that the patches occupied by sage grouse were relatively homogeneous. These larger patches should receive the focus for management, protection, and enhancement where possible. It was evident that sagebrush/upland and grasslands along ridgetops and upper slopes were habitats of choice during summer. It is recommended that further study of fragmented populations examine the scaling properties of the patch(es) in which sage grouse occur as habitat selection seems to occur at this level. Further research is required to identify area:perimeter relationships, or species composition of suitable seasonal habitat patches.

A multiscale approach is recommended to examine the relationships of habitat use by animals as relative selection and its variability can be evaluated across scales. Such variability can result from the inclusion/exclusion of habitats at a given order (Johnson 1980). I concur with Johnson (1980) and White and Garrott (1990) that estimates of habitat use within the home range may be misleading as a series of habitat selections has occurred at larger scales. However, I suggest that incorporating home range analysis with other selection orders may clarify such habitat selection. Identifying the proper resolution at which habitat selection occurs should provide opportunities for more effective management.

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CHAPTER 4

MANAGEMENT RECOMMENDATIONS FOR THE PICEANCE BASIN SAGE GROUSE

4.0. INTRODUCTION

Sage grouse (*Centrocercus urophasianus*) populations throughout North America have declined by at least 30% since the 1980's (Connelly and Braun 1997). Sage grouse populations in Colorado have declined between 45 and 82% since 1980 (Braun 1995). Such declines have corresponded with habitat degradation caused by both natural (drought, wildfire) and anthropogenic (agriculture, oil/gas development, grazing, housing) treatments (Braun 1998). Braun (1998) suggested that adaptive resource management (Walters 1986) should be implemented on altered landscapes to progressively test habitat enhancement and restoration treatments. Generally, habitat enhancement includes reducing overall sagebrush cover (≥ 15 - 20%) and increasing forb production (Johnson and Braun 1999). Further, thinning over mature sagebrush has lowered rates of nest predation (Ritchie et al. 1994). Habitat restoration includes removing agricultural land from production, replanting sagebrush and important forbs in disturbed soils, and possibly thinning of over mature sagebrush. It is possible to increase survival and reproductive rates with habitat improvement projects (Johnson and Braun 1999). However, few of the above manipulations have been tested as large-scale management treatments, and subsequently monitored for success over time. Such a scenario lends itself to the use of adaptive resource management (ARM) for examining habitat restoration and enhancement treatments in a scientifically controlled framework.

The objectives of this chapter are to: 1) summarize adaptive resource management and its implications for the region, 2) describe trends of the Piceance Basin sage grouse population, 3) summarize the findings of my work in the context of managing this population, 4) and propose methods and habitat treatments to be implemented under the adaptive resource management framework.

4.1. ADAPTIVE RESOURCE MANAGEMENT

"...[A]ctive habitat management is needed at a landscape scale if [sage grouse] populations are to remain viable, especially at the present periphery of the distribution (Braun 1998: 150)." I concur with this recommendation and advocate implementation of an adaptive resource management (ARM) strategy for the Piceance Basin. What is ARM? When the goals of achieving management objectives and gaining reliable knowledge are concurrent, then ARM is in place (Walters and Holling 1990, Lancia et al. 1993). Thus, learning and uncertainty are embraced as integral parts of management (Lancia et al. 1993). ARM is learning by doing (Macnab 1983, Nudds 1999), and it is an iterative process that enables managers to evaluate the effectiveness (e.g., range or cattle condition) of their management decisions (e.g., harvest quotas, habitat projects), and researchers gain information on system response (e.g., nesting success, recruitment) to the treatment (Lancia et al. 1993). Thus, divergent hypotheses can be tested simultaneously. An example might be as follows: H_1—Mechanical brush treatments will enhance sage grouse survival; and H_2—Mechanical brush treatments will enhance calf weight in the fall. Based on the system response managers and researchers can adjust policy or treatment accordingly and the process continues.

Initiating ARM in the Basin is not a trivial task as there is an array of land-uses and stakeholders. However, I advocate this approach for the Basin as each land-use can be perceived as an experiment, and in turn each experiment can be learned from and management improved upon. ARM has been applied to a variety of wildlife management scenarios (Nudds and Clark 1993, Schmiegelow and Hannon 1993, Baydack 1997). Baydack's (1997) study was similar to the situation in the Piceance Basin in the preponderance of private land and the need to evaluate the results of divergent hypotheses. He evaluated the treatment (i.e., removal) of aspen (*Populus tremuloides*) as it pertained to the enhancement of sharp-tailed grouse (*Tympanuchus phasianellus*) habitat and livestock rangeland. A portion of his work focused on treatments on private land, and the goals established for these experiments were to identify the biological (researcher) and economic (managers, ranchers) benefits of these habitat experiments (Baydack 1997).

I developed a working outline for ARM in the Piceance Basin and the remainder of this Chapter identifies this framework. The first section (and Introduction) addresses the need to change current habitat management practices based on my findings in the Basin. The next sections examine predictions and hypotheses regarding possible management actions. The remaining sections are presented as a proposal: methods for treatments and evaluation, and a set of potential treatment areas. The methods and recommendations provided for the Basin are based on two types of data, direct results of my study, and general field observations.

4.2. SUMMARY OF SAGE GROUSE STATUS IN THE BASIN

Population Trends—The Piceance Basin sage grouse population has declined considerably since 1977, at which time there were ~25 active leks. During the course of my research, only 9 of the 25 were active. It was difficult to assess the overall population size in 1977 as Krager (1977) reported the data as ranges of lek size and not actual counts of males. Conservative use of these data included the lowest number in a given range (e.g., '3-5 males', 3 was used), and excluded sightings of ≤2 displaying males (*n* = 5). This resulted in an estimated spring breeding population (2:1 female to male ratio) of 475 – 485 birds for 1977. I found an average of 75 displaying males in 1997-98. Thus, I estimated a spring population size of 220 – 230 sage grouse. The decline in total numbers corresponded with the reduction in the number of active leks as sage grouse are poorly distributed throughout the Basin. Notably, the largest reduction in numbers of active leks occurred in the northern part of the Basin. The lack of large sagebrush patches and the preponderance of mountain shrub in these peripheral areas compounded by land-use practices (e.g., gas drilling, powerlines, feral horse grazing) may have led to loss of habitats necessary to these lek sites. Further, hunting may have had an additive effect, especially in years of poor recruitment (Johnson and Braun 1999). However, the lack of a management plan to maintain suitable habitat in the Piceance Basin can not be overlooked as a factor in the declining population.

Future management of the Piceance Basin sage grouse will depend primarily on enhancing and maintaining sagebrush habitat. This will be a challenge as most sagebrush habitat is on private lands. This will require extensive efforts by federal and state agencies to offer incentive and cooperative programs to landowners to maintain and enhance their land for sage grouse. The following sections outline general maintenance and enhancement guidelines for land-use practices, as well as, specific prescriptions for management experiments at Magnolia and the Square S State Wildlife Area.

4.3. SUMMARY OF RADIOTELEMETRY DATA

Sage grouse location data indicated that radio-marked birds were highly clustered on the landscape and within the sagebrush types. Sagebrush areas as near as 84 Mesa, Stake Springs, and Wolf Ridge were avoided by radio-marked sage grouse. Further, ground surveys indicated there was little to no use of these areas. This reflects the loss of breeding activity in these peripheral habitats. Female grouse were more sedentary than males. This was due in part to brood rearing and the relatively close proximity of winter habitat to nesting areas. Males dispersed further to summer range but all grouse remained within 6 km of the nearest lek. Males from 4 of 9 leks moved to the Divide area for summer. Broods and hens were also observed in these areas, suggesting that nesting activity was occurring here. However, it was not clear as to which lek these hens would have been breeding. Core winter areas were found from Wagonroad Ridge north to Galloway Gulch. There was also winter use on the ridge south and adjacent to Bar D Mesa. Grouse from the Bragg Spring lek used ridgetops and drainages from Cutoff Gulch and north to Connelly Gulch. Grouse remained within ~6 km of the nearest lek, annually. No movements were recorded between Magnolia and the western part of the Basin.

At the landscape level, sage grouse used mixed sagebrush/upland shrub sites more in summer than winter. Winter habitat use shifted to sagebrush dominant sites. Vegetation structure differed between male and female summer use sites. This was attributed to females which remained at lower elevations and closer to lek sites than males. Grassland types were also important during the summer as these areas tended to have abundant forbs and interspersed with small clusters of sagebrush. Vegetation structure differed between summer and winter sites as well. The percent cover and height of sagebrush used in winter increased for both males and females. Sage grouse occupied ridgetops and upper slopes throughout the year. There was a trend for grouse to use drainages more in winter. The location of these areas was predominately near the head of a drainage, where slopes were more gentle. Grouse occupied north aspects greater than expected during winter; this was highly related to the locations of the drainages and the taller denser sagebrush habitat types. Further study is needed in the Piceance Basin to critically examine nesting and brood rearing habitat use, and the genetic composition of this population.

4.4. THE LANDSCAPE

The diverse topography of the Piceance Basin limits sagebrush habitats to ridgetops and upper slopes. Thus, human uses of the Basin, such as pipeline construction, gas drilling, or livestock grazing could negatively impact these limited patches. Conversely, proper management of such treatments can benefit sage grouse.

As management of the Piceance Basin is discussed and implemented it would be helpful for those involved to view this region as a patchwork of habitat treatments. This landscape has sustained several habitat modifications both natural and artificial. These treatments have affected individual leks and impacted local sub-populations. However, two treatments seemed to have benefited sage grouse: 1) the 1982 burn at Bar D Mesa, and 2) the 1984 roller-chop at Magnolia.

It is unclear as to the time that occurred prior to sage grouse returning to the Bar D Mesa burn area. It was noted that the lek had moved by 1987. I documented lek activity in areas similar to those reported by Krager (1977). It appears that summer habitat was enhanced but some winter habitat may have been lost. The radio-marked female successfully reared broods in the burn in both summers. Often unmarked females and broods were flushed while I was radio-tracking the marked female. Notably, in August of both years mixed-flocks of ~20 females and juveniles were observed. However, the burn was avoided throughout winter and was not used for roosting at night in summer. This was probably due to a lack of shrub cover required for roosting and winter forage. Two radio-marked males spent most of the winter near Wagonroad and Galloway drainages. The female and one male remained in close proximity to the burn area, but resided on an adjacent ridge where sagebrush was taller and denser.

The northern section of the Magnolia roller-chop area was used intensively in the winter of 1997-98 by a flock of ~15 grouse, including 3 radio-marked birds (75% of all winter radiolocations were in the treatment). No activity was documented in this area during either summer. One radio-marked female used (90% of her locations were in the treatment) the southern section of the treatment south of the access road and other females were observed in this area during summer. It was unclear as to the short-term effects of this treatment but it has developed into suitable habitat. The Magnolia area had several natural-gas drilling sites and two large compression stations. Although there were substantial patches (~100 ha) of sagebrush near these disturbances, several winter and summer ground surveys provided evidence that these habitats were avoided. Interpretation of such findings is problematic, as either the habitat suitability or land uses could have affected sage grouse avoidance of these areas. Such areas would be ideal for management experiments such as treating sagebrush near active and idle drilling sites to examine trends in use and avoidance.

Treatments perceived as negative included powerlines (C.E. Braun, Colorado Division of Wildlife, unpubl. data) and the small generator station on Wolf Ridge as the ~10 male lek was abandoned in the years shortly following its installation (although the exact timing of this abandonment is unknown). Lek abandonment by sage grouse has been correlated to similar disturbances near coal mining activity (within 6-8 years; [Braun 1985]). The pipeline right of way on Barnes Ridge could have benefited sage grouse, however, two years of aerial spraying for noxious weeds and the preponderance of seeded crested wheatgrass (*Agropyron cristatum*) has removed most if not all favorable forbs. The use of desirable seed mixtures and controlled (e.g., spot spraying) eradication of noxious weeds could have maintained suitable forage for sage grouse. Grouse activity has not been documented in the Airplane Ridge area since the 1980's (B. L. Dupire, Colorado Division of Wildlife, pers. commun.). Powerline construction and a housing facility may have negatively impacted the lek on Airplane Ridge.

4.5. PREDICTIONS

The three most important points from the summaries above are: 1) sage grouse numbers have declined, 2) habitat use and movements were limited in context of the landscape, 3) and habitat modifications may benefit sage grouse. Currently, sage grouse are considered in environmental impact assessments as they are listed as a sensitive species by the BLM. This listing provides little opportunity for protection or mitigation. Twenty years of minimal protection has not maintained sage grouse numbers. Thus, the predictable outcome of current policy is that sage grouse numbers will continue to decline in light of limited habitat and pervasive land uses. Therefore, the goal should be to enhance and increase the amount of suitable habitat for sage grouse.

4.6. PROPOSED METHODOLOGY

Research Design—The methods provided in the following sections could potentially test these general hypotheses:

- H_1-*Sage grouse numbers will not change with the advent of large scale mechanical brush beating.*
- H_2-*Sage grouse numbers will not change with the advent of rest-rotation grazing systems.*
- H_3-*Livestock condition will not change with the advent of large scale mechanical brush beating.*
- H_4- *Livestock condition will not change with the advent of rest-rotation grazing systems.*

Sage grouse numbers and livestock condition are used as general working hypotheses. More specific hypotheses would need to be developed for each treatment area based on specific sites and methods to be used. Replication and control are necessary to separate these treatments from large-scale effects (Walters and Holling 1990). The limited available sagebrush habitat and the abundance of private land may hinder managers' ability to meet this criterion. However, statistical techniques are available to identify the proper level of replication (Walters and Holling 1990, Schmiegelow and Hannon 1993).

There are three main approaches for treatments in the Basin: 1) no treatment, 2) habitat maintenance, and 3) enhancement. Each can be applied to different areas within the Basin and monitored for their effectiveness. Furthermore, the methods used (e.g., listed below) within each approach can also be tested and evaluated. Thus, the guidelines and methods outlined are provided as an initial set of tools for implementation. The actual treatment area and method(s) selected are left to the managers ("manager" refers to all resource managers, including ranchers) as the specific goals may vary from site to site. Although range enhancement/maintenance is the overall goal, different means may be pursued to achieve this end. An example might be, managers are interested in how sagebrush and sage grouse respond to different blade settings on the mower or different size strips cut into the brush. The effects of these manipulations are evaluated in terms of range enhancement and rate of regeneration. The results of these evaluations determine whether the experiment (e.g., mower blade height) is adopted, or rejected. If rejected, the technique is modified and tested again, an iterative process. The specific treatments in Sec 4.6. are provided as a set of enhancement treatments that should be implemented as the first step in ARM.

4.6.1. HABTIAT MAINTENANCE

Buffers—Braun et al. (1977) recommended that the eradication of sagebrush within a 3.2 km of all leks should be avoided. This recommendation was intended to maintain critical brood-rearing habitats. Further, winter habitat was also identified within this proximity to the lek for some populations (Commons 1997). Although the 3.2 km buffer would satisfy much of the brood rearing needs in the Piceance Basin, male summer habitats were further removed. I advocate 6 km (radius) buffers around each active lek for two reasons: 1) the patchiness of the landscape equates to considerable area not available to sage grouse, and 2) sage grouse remained within an average of 6 km of the nearest lek. This will include large amounts of private land, however, it may also identify habitat patches on public land that could be protected. Furthermore, not all habitat within a large buffer would need protection (e.g., aspen, pinyon-juniper) which could provide alternative routes for utility right of ways and other land uses. Thus, managers should strive to construct a habitat mosaic or patchwork within a buffer. Clearing >50 ha contiguous tracts of habitat for road construction, oil/gas developments, etc., should be avoided in these designated areas. These buffers may be useful in identifying marginal habitats on public land that need enhancement (e.g., pinyon-juniper thinning). Currently, Magnolia is the only active lek that could receive the most protection as it is on BLM land.

Grazing—Livestock grazing is an integral part of the ecology of the Piceance Basin. However, current grazing regimes are repetitive either annually or biennially. This differs from the grazing/browsing behaviors of herbivorous wildlife that roam and forage over vast areas (Mack and Thompson 1982, Huntly 1991). The sustainability of repetitive grazing regimes is questionable, as above and below ground biomass may decrease by as much as 25% a year (Rickard and Vaughn 1988). The alternative method is rest-rotation grazing. Rest-rotation grazing requires that one pasture in the system not be grazed for an entire year, while the other pastures may rest periodically throughout a given season. Such efforts will require the support of habitat partnership programs for educational and financial support.

Pipelines—Construction activities should not occur prior to 1 June to avoid possible disturbance of breeding activity within a minimum 3 km of an active lek (i.e., when routing around the 6 km buffer can not be avoided). Areas considered potential nesting/brood-rearing habitats should not have any construction between 1 June and 1 July. Surface reclamation of the corridor is also of concern as vegetation on the previous pipeline installation on Barnes Ridge has recovered poorly (i.e., no native species has re-established). The lack of topsoil and rocky conditions will require live topsoiling techniques (E. F. Redente, Colorado State Univ., pers. commun.) to enhance establishment of native plant species beneficial to sage grouse. Fertilizing with nitrogen should be avoided as this can stimulate the growth of weedy plants (E. F. Redente, Colorado State Univ., pers. commun.). Pipeline corridors have an inherent seed bank from the surrounding vegetation. This natural succession should be taken advantage of by establishing a community that is open to colonization from native species, and highly competitive introduced species should be avoided. Thus, a seed mix consisting of mid to late-seral native species should promote natural succession (E. F. Redente, Colorado State Univ., pers. commun.). Plantings should include big sagebrush, which could eventually provide escape cover on the corridor.

Disturbed soils in this region are susceptible to invasive weeds (Redente et al. 1982). Invasions of noxious weeds pose a threat to sage grouse habitat as they can compete with desirable species (Knick and Rotenberry 1995) but indiscriminate (e.g., aerial application of herbicides) eradication of broad leaf plants can negatively impact sage grouse (Wallestad 1975). Aerial and tractor-applied herbicides should be avoided. All treatments should be spot sprayed after examining the corridor both in early and late summer. The habitat reclamation described above is limited by the willingness of private landowners as they can request reclamation methods and seed mixes that will benefit their needs. Landowners should be encouraged to plant native or non-competitive introduced species. The abundance of private land may limit the total acreage improved for sage grouse along pipeline corridors. Thus, habitat mitigation will be required, preferably in the form of funding separate habitat treatments such as mechanical brush control. The size and location of such projects should be determined based on the size of the negatively impacted area.

4.6.2. HABITAT ENHANCEMENT

The following prescriptions can be used as guidelines to habitat improvement projects. The goal is to provide a model of habitat enhancement on public land that can be cooperatively adopted by private landowners. These improvements should benefit grouse, livestock, and other wildlife species. Future treatments should be prioritized based on: 1) proximity to active lek sites, 2) current status of the associated lek, 3) type of habitat treated (brood rearing or winter), and 4) perceived benefit for sage grouse. The prescriptions described advocate two basic treatments, mechanical brush control (brush beating) and pinyon-juniper removal. Fire could be used to reduce shrub cover. However, fire should be used cautiously as it can potentially treat a larger area than desired. Further sagebrush is not a fire respondent species (Braun 1998) and recovery time may be prolonged relative to brush beating.

Mechanical brush manipulations should follow the guidelines established by Braun et al. (1977). The advantage of brush beating over other methods is that vegetation is not removed from a site. Alternatively, vegetation is shortened to improve predator detection, forb enhancement, and create a multi-aged stand of sagebrush. All drainages within 1 km of their origin should not be cleared of sagebrush as these areas were important for winter use (Chapter 3). The following summarizes the recommendations of Braun et al. (1977). Treatment areas should not exceed 40 m in width, and untreated areas should be twice the width of treated areas. These treatment strips should follow the contour of the land, and perpendicular to prevailing winds. This serves as a snow catchment that will enhance soil moisture and the growth of herbaceous cover. The mower blades should be set to 20-25 cm (8-10 in) above the ground for strip beating as this will result in thinning the brush and not a total kill (C.E. Braun, Colorado Division of Wildlife, pers. commun.). The improvement or creation of lek sites will require the blade be set at ground level, this will ensure a slower rate of regeneration than the strip treatments (C.E. Braun, Colorado Division of Wildlife, pers. commun.). Mixed habitats of sagebrush and montane shrubs should also be considered for treatment as serviceberry can grow ≥ 2 m in height.

Pinyon-juniper removal should occur where this vegetation has encroached into sagebrush habitat. This treatment should be implemented with hand tools (chain saw). An alternative method is chaining where large-heavy chain is attached to 2 tractors or bulldozers and dragged across the landscape. This is effective in removing numerous pinyon trees at once. It can also aid in thinning of sagebrush. The general treatment is to remove all short (<3 m) pinyon-juniper trees that have encroached into the sagebrush range and cut them back to the woodland edge. This would create a distinct habitat edge and maintain the integrity of a sagebrush patch (Commons et al. 1998). Although the focus would be on young trees that have encroached into the sagebrush rangeland, this does not preclude the removal of larger trees (> 3 m) in sage grouse habitat.

Treatment areas should not be grazed for 1 entire growing season post-treatment. This will allow re-establishment of forbs and grasses where shrubs have been thinned. Rest-rotation grazing systems would be preferred for these areas to allow herbaceous cover a growing season to rejuvenate. The first year following the treatment could be the first rest cycle for initiating a rest-rotation system.

4.6.3. EVALUATION

Biological Assessment—Response to habitat treatments by sage grouse should be through sage grouse pellet transects. Transects measuring 100 m long and 1 m wide should be randomly placed in a treatment area. Only, trained workers (biologists, technicians, or volunteers) should conduct monitoring and assessment of these treatments. Pellets observed should be recorded as individual points and classified in groups of 1-5, 6-10, and >11. The latter generally indicates a roost pile, however, if the pellets are scattered it should be noted. The densities of pellets per transect serves as an indicator of sage grouse use. Pellets observed along the transect should be removed if permanently marked transects are used. Further, vegetation composition and structure should be recorded at each transect. This should include percent cover and height of sagebrush, forb frequency and composition, and percent grasses (Kituku et al. 1993). Permanent transects should be established prior to each treatment, and should be assessed in early June to late August of each year for a minimum of 5 years post-treatment. The purpose of each measure is to correlate vegetation structure to sage grouse use of the treatment.

Range and Cattle Assessment—I present a basic but effective set of tools for managers to use. These methods have been used as part of the Integrated Resource Management (IRM) program through the Colorado State University Cooperative Extension (B. Vaughn, IRM participant, Piceance Creek, Colorado). Range monitoring cages are placed in the spring prior to grazing, and a photograph is taken of the cage and surrounding area. The cages are then visited again post grazing and a photograph is taken.

At this time the amount of forage removed is ranked as heavy, moderate, or light. Additionally, rain gauges are placed in pastures where the monitoring cages are present. A drop of oil is placed in the rain gauge to reduce evaporation over the season. Cattle can be evaluated at the end of each grazing season. Two techniques of evaluation are calf weight and condition scores. The former is the most objective and can easily be translated into dollars when animals are sold. Combining the above measures (range condition, precipitation, and livestock condition) allows for the correlation between these variables to be examined. The resulting correlation enables managers to evaluate the effectiveness of the experiment.

4.7. TREATMENT AREAS

4.7.1. MAGNOLIA

A table and map is provided for reference. Each treatment is listed (Tables 4-1,2) in order of priority (e.g., MA-1, MA-2, etc.,). Each treatment is subdivided into treatment zones (Figs. 4-1,2,3) and are listed in order of priority (e.g., MA-1a, MA-1b, etc.,). These zones were created to assist managers in implementing treatments, while meeting budget restraints and providing opportunities for replication. All treatments should follow guidelines described above. The prescribed zones and treatment guidelines can potentially be modified to enhance the experimental design of these treatments.

MA-1a.—This area is adjacent to the lek and should be considered a priority for habitat enhancement. The area is comprised of mountain shrub and sagebrush. The pinyon-juniper edge is < 500 m. Small trees were found in this area and should be removed to the woodland edge. Sagebrush south and adjacent to the road should not be treated. This is the display area and is relatively open. However, several tall serviceberry shrubs could be removed.

MA-1b.—This area was surveyed as a part of the 1982 treatment but was not treated. This area had some use in winter and spring by radio-marked grouse. Two alternative lek sites could be created north of the main road; this would provide display areas somewhat removed from the road. The blade should be set to ground level to clear 2 patches (< 1ha[Dalke et al. 1963]) approximately 0.8 km (0.5 miles) north of the road and a similar distance from one another. Thinning of brush should suffice in this area as most pinyon-juniper was lower on the ridge near the drainage. This is one of the larger sagebrush patches at Magnolia and enhancement of this site should benefit sage grouse.

MA-1c and 1d.—Although this area is close to the lek, it is closer to the Greasewood Compression station and other disturbances. There was no indication that sage grouse used these areas. However, MA-1d has potential as it is a relatively large patch of sagebrush. MA-1c is relatively small patch with a drilling site, however, the mixed shrub could be thinned with a mechanical treatment. This zone has good potential for experimental work with proximity to disturbances.

MA-1e and 1f.—These zones are marginal habitat as pinyon-juniper increases as elevation decreases. However, these sagebrush patches have potential as they could provide lower elevation habitat in a severe winter. Pinyon-juniper removal via chaining should be the primary treatment of these areas with a few strips brush beat towards the middle of each.

MA-2a and 2b.—The mountain shrub community predominates at these areas and most of the region to the east. Further, treatments should remain ≥1 km from all powerlines. Thus, treatments should not continue to the east as there is a powerline right of way. Thinning of the mountain shrub communities would be beneficial, especially in MA-2a as sagebrush is prevalent in this mixed shrub habitat.

MA-2c.—The 1982 treatment should be evaluated for pinyon-juniper removal. Specifically, several trees could be removed south of the road. Trees are sparse and hand tools should suffice.

MA-3a and 3b.—These treatments should remain on the east slope as a powerline bisects the ridge top. Strips can be brush beat in both zones, however, MA-3b will require considerable pinyon-juniper removal, chaining may be required. MA-3a has good potential for habitat improvement as it dominated by sagebrush with a mix of deciduous shrubs.

MA-4a and 4b.—Sage grouse avoided these sagebrush patches and it is not clear if human disturbance, vegetation structure or both were factors. Although each zone contains some drilling activity and the compression station can be heard, brush-beating and pinyon-juniper removal could enhance the area and expand the range for sage grouse.

MA-4c and 4d.—Each of these areas are marginal as they are relatively small and are occupied by substantial amounts of pinyon-juniper. However, these are further removed from the compression station, and have fewer disturbances, with potential for winter use.

MA-R.—Roads and trails leading or parallel to treatment zones should receive one pass with the mower on each side of the road. Sage grouse broods use dirt roads for dust bathing and foraging (Rogers 1964). This will also provide secure spring roosting areas and enhance trapping opportunities if further research is conducted.

Table 4-1. Habitat treatments projects listed in rank of priority at Magnolia Oil Camps, Rio Blanco County, Colorado.

Treatment	Legal Description[a]	Treatment Type[b]
MA-1a	T2S / R96W / Sec 9,10	BRC/PJR
MA-1b	T2S / R96W / Sec 3,10	BRC/PJR
MA-1c	T2S / R96W / Sec 9	BRC
MA-1d	T2S / R96W / Sec 4,9	BRC
MA-1e	T1S / R96W / Sec 33	PJR/BRC
MA-1f	T1S / R96W / Sec 34	PJR/BRC
MA-2a	T2S / R96W / Sec 11,14	BRC
MA-2b	T2S / R96W / Sec 14,15	BRC
MA-2c	T2S / R96W / Sec 3,10,15	PJR
MA-3a	T2S / R96W / Sec 4	BRC
MA-3b	T1S / R96W / Sec 33	PJR
MA-4a	T2S / R96W / Sec 7,8	BRC
MA-4b	T2S / R96W / Sec 6	BRC
MA-4c	T1S / R96W / Sec 32	BRC
MA-4d	T1S / R97W / Sec 31	BRC
MA-R	N/A	BRC

[a] Descriptions include only township where the majority of the treatment will occur when treatment zones cover > 1 township.
[b] Treatment types are listed in order primary method. PJR = pinyon-juniper removal, BRC = mechanical brush removal.

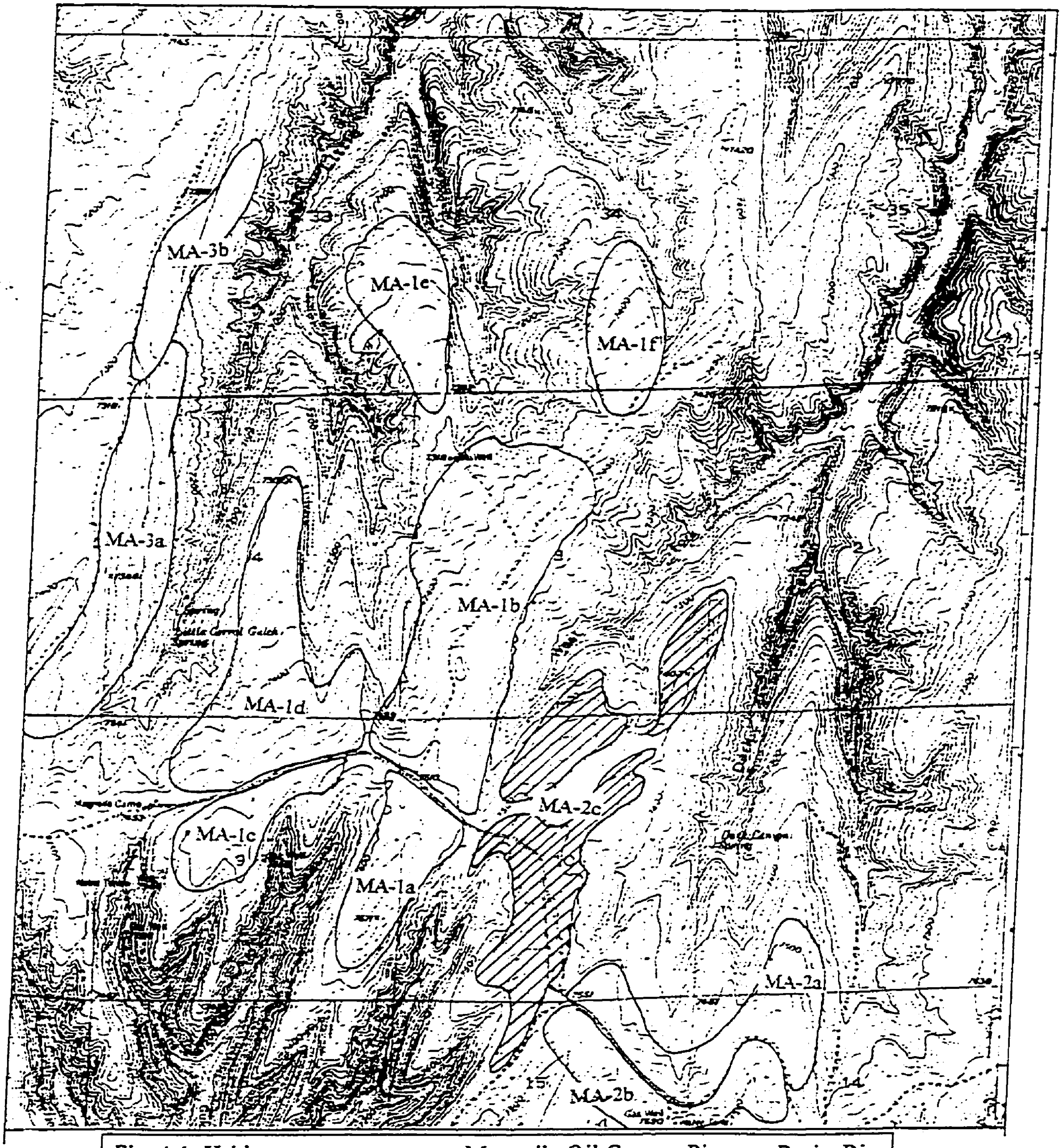

Fig. 4-1. Habitat treatment zones at Magnolia Oil Camps, Piceance Basin, Rio Blanco County, Colorado. The hatched area is the 1982 mechanical brush treatment.

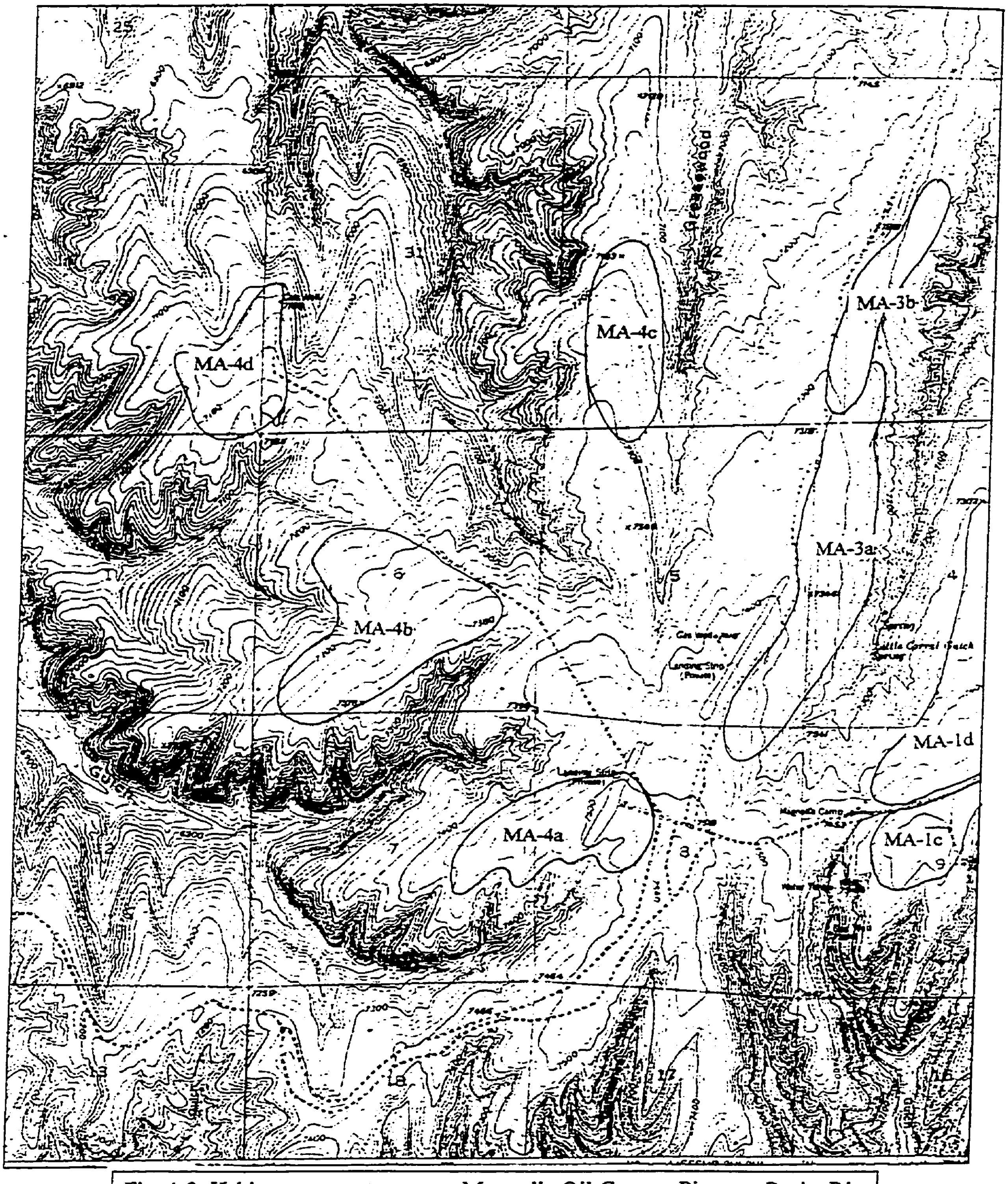

Fig. 4-2. Habitat treatment zones at Magnolia Oil Camps, Piceance Basin, Rio Blanco County, Colorado.

4.7.2. SQUARE S STATE WILDLIFE AREA

The Square S area provides an opportunity to expand the range westward for sage grouse. The vegetation and topography of this area confines most treatments to south aspects. Summer habitat use by male sage grouse was similar to the proposed treatment areas. Thus, these treatments would be enhancing typical summer habitat. The recent construction of a fence around this area further enhances its value for treatments, as grazing could be readily monitored following the initial mowing. Pinyon-juniper is absent in this area and aspen/Douglas-fir stands are confined to north slopes and drainages. Several sagebrush patches have potential for enhancement projects.

SS-1a and 1b.—The first treatment area and zones were selected as highest priority based on the proximity to known summer habitat. Several strips can be mowed in each of these zones. The habitat in the northern half of Section 13 is on the BLM. SS-1b can and should be extended into the BLM property if possible.

SS-1c and 1d.—These patches are smaller but the sagebrush could be thinned with several strips in each zone. The habitat in the northern half of Section 14 is on the BLM. SS-1c can and should be extended into the BLM property if possible.

SS-2a and 2b.—Each of these zones are adjacent to the BLM boundaries. The southwest portion of SS-2b shares a BLM boundary to the east, as does most of SS-2a. BLM properties should be considered as extensions in these treatment plans.

SS-2c and 2d.—These relatively small ridges could use 3-4 strips along the southwest aspect.

SS-3a.—Sagebrush extends ~500 m on the west ridge providing substantial area for treatment. Zone 3a could be enlarged by extending it onto BLM land.

SS-3b, 3c, and 3d.—These zones are marginal due to small size and proximity to forest edge. However, the tall sagebrush and rich forb understory should respond well to thinning strips.

SS-R.—Roads and trails leading or parallel to treatment zones should receive one pass with the mower on each side of the road. Sage grouse broods use dirt roads for dust bathing and foraging (Rogers 1964). This will also provide secure spring roosting areas and enhance trapping opportunities if further research is conducted.

4.8. CONCLUSIONS

The recommendations and guidelines provided are meant to serve as a first step towards the iterative management process (ARM) for sage grouse in the Piceance Basin. Private lands in the Basin have good potential for habitat enhancement, but landowner cooperation will be needed. Concerted efforts will be required by state and federal agencies to provide and promote habitat programs in which landowners can actively participate in decision making (consensus) and cost sharing of habitat improvement projects. Areas such as Skinner Ridge, Bar D Ridge (southwest part of the Basin, Clear Creek), and Stake Springs should be evaluated and strongly considered for habitat treatments if landowners are willing to participate. I advocate implementing ARM in this region as it allows managers and biologists to conduct habitat experiments and simultaneously evaluate the benefits for sage grouse, wildlife, and livestock. This framework is an iterative process that allows managers to adopt/reject management strategies/treatments based on scientifically controlled methodology. The goal is to reduce uncertainty about the ecosystem, and provide more effective management for wildlife and livestock based upon tried and tested methods.

Table 4-2. Habitat treatments projects listed in rank of priority at Square S State Wildlife Area, Rio Blanco County, Colorado.

Treatment	Legal Description[a]	Treatment Type[b]
SS-1a	T4S / R101W / Sec 13	BRC
SS-1b	T4S / R101W / Sec 13,24	BRC
SS-1c	T4S / R101W / Sec 14,23	BRC
SS-1d	T4S / R101W / Sec 14,22,23	BRC
SS-2a	T4S / R101W / Sec 24,25	BRC
SS-2b	T4S / R101W / Sec 25	BRC
SS-2c	T4S / R101W / Sec 26,27,35	BRC
SS-2d	T4S / R101W / Sec 27,34	BRC
SS-3a	T4S / R101W / Sec 22,15	BRC
SS-3b	T4S / R101W / Sec 22	BRC
SS-3c	T4S / R101W / Sec 21,22	BRC
SS-3d	T4S / R101W / Sec 28,27	BRC
SS-R	N/A	BRC

[a] Descriptions include only township where the majority of the treatment will occur when treatment zones cover > 1 township.
[b] Treatment types are listed in order primary method. BRC = mechanical brush removal.

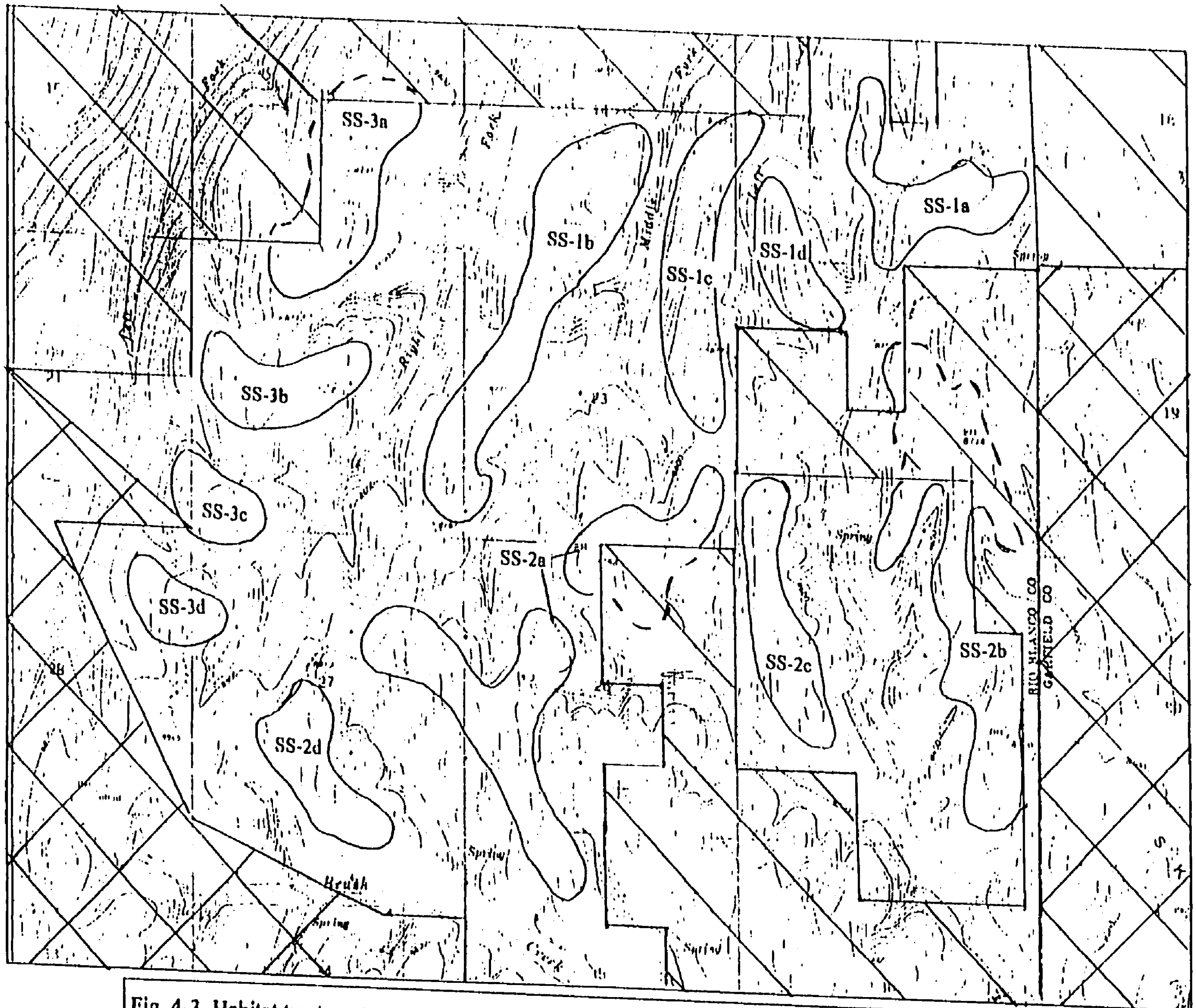

Fig. 4-3. Habitat treatment zones at Square S State Wildlife Area, Piceance Basin, Rio Blanco County, Colorado. The diagonal hatched area is BLM and cross-hatched is private property. Treatment zones drawn with dashed lines are hypothetical treatments on BLM property.

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APPENDIX A
Movement Data

Table. A-1. Annual shift in seasonal movements of sage grouse, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Differences[b] (km)	
Band #	Easting	Northing
31	-0.08	0.69
33	0.02	-0.19
35	0.04	-1.30
1559[a]	0.62	-3.97
1560	-0.60	-0.35

[a] 1559 was the only grouse to move to different ($P < 0.05$) locations between years.
[b] Negative values indicate locations further north or east in 1998.

Table A-2. Average maximum distance from lek of capture (DLC) and nearest lek (DNL) for sage grouse in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

		Breeding				Summer				Winter			
		DLC		DNL		DLC		DNL		DLC		DNL	
Sex	n	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Males	11	1.5	0.5	1.5	0.5	8.5	0.5	3.8	0.1	5.8	0.6	2.9	0.2
Females	5	1.1	0.2	1.1	0.2	2.9	0.4	1.9	0.2	5.2	0.7	2.8	0.3
Juveniles[a]	3	2.5	1.2	0.9	0.2	0.5	0.1	3.0	0.6	1.3	0.3	1.9	0.3

[a] The 3 juveniles were males.

Table A-3. Average distances between core seasonal use areas of sage grouse in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

		Spring - Summer		Summer - Winter		Winter - Spring	
Sex	*n*	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Males	11	8.2	2.2	9.4	2.8	5.1	1.9
Females	5	2.7	1.8	2.7	1.2	4.7	2.7
Juveniles[a]	3	1.9	1.1	1.7	0.8	1.1	0.3

[a]The 3 juveniles were males.

Table. A-4. Home range estimation using minimum convex polygon (MCP) and 95% ellipse methods for sage grouse in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

		Summer			Winter		
Band	Sex[a]	*n*	MCP	95% Ellipse	*n*	MCP	95% Ellipse
29	F	16	100	267		--	--
31	F	25	614	2103	15	4154	11030
33	F	30	44	93	22	334	1115
35	F	27	4244	13730	16	1506	4185
44	F	17	857	1448	11	447	1575
1556	M	12	74	275		--	--
1558	M	13	564	2045		--	--
1559	M	35	1672	3599	19	1007	2022
1560	M	28	388	853	12	19,450	82,450
1561	M	18	3251	7515		--	--
1562	M	16	959	2914	9	323	1569
1572	M	17	32	69	9	412	1960
1573	M	16	182	537		--	--
1575	M	16	243	697		--	--
1580	M	20	717	2920		--	--
1581	M	16	599	1941	9	5345	20690
1565	M		--	--	12	80	232
1567	M		--	--	10	1724	8003
1569	M		--	--	11	32	92

[a] Males 1565, 1567, and 1569 were radio-marked as juveniles.

APPENDIX B
Habitat Use Data

Table. B-1. Landscape scale summer habitat use by sage grouse (n = 16) between years Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Habitat	1997	1998	n	χ^2	df
Sagebrush/upland	98	110	208	0.418	1
f(i)	*93.4*	*114.6*			
Sagebrush	26	47	73	2.536	1
f(i)	*32.8*	*40.2*			
Upland shrub	2	6	8	0.095	1
f(i)	*2.4*	*5.6*			
Grass	25	25	50	0.529	1
f(i)	*22.4*	*27.6*			
Bare ground	1	2	3	0.162	1
f(i)	*1.3*	*1.7*			
Oakbrush	1	3	4	0.639	1
f(i)	*1.8*	*2.2*			
Pinyon-juniper	5	1	6	3.585	1
f(i)	*2.7*	*3.3*			
Totals	158	194	352	7.964	7
f(i)	*156.809*	*195.191*		0.016	1
χ^2 of total				7.947	6

Heterogeneity χ^2 critical value (6 df) = 12.592, *f (i)* = expected frequency.

Table. B-2. Landscape scale winter habitat use by sage grouse (n = 16) between years Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Habitat	1997	1998	n	χ^2	df
Sagebrush/upland	35	32	67	0.134	1
f(i)	*33.5*	*33.5*			
Sagebrush	35	26	61	1.328	1
f(i)	*30.5*	*30.5*			
Upland shrub	0	6	6	6.000	1
f(i)	*3.0*	*3.0*			
Grass	4	9	13	1.923	1
f(i)	*6.5*	*6.5*			
Bare ground	1	0	1	1.000	1
f(i)	*0.5*	*0.5*			
Oakbrush	0	1	1	1.000	1
f(i)	*0.5*	*0.5*			
Pinyon-juniper	0	0	0	0.000	1
f(i)	*0.0*	*0.0*			
Totals	75	74	149	11.385	7
f(i)	*74.5*	*74.5*		0.007	1
χ^2 of total				11.379	6

Heterogeneity χ^2 critical value (6 df) = 12.592, *f (i)* = expected frequency.

Table. B-3. Landscape scale summer habitat use by female (n = 5) and male (n = 11) sage grouse Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Habitat	Female	Male	n	χ^2	df
Sagebrush/upland	70	138	208	0.960	1
f(i)	*76.8*	*131.2*			
Sagebrush	26	47	73	0.054	1
f(i)	*27.0*	*46.0*			
Upland shrub	27	23	50	6.254	1
f(i)	*18.5*	*31.5*			
Grass	1	7	8	2.050	1
f(i)	*3.0*	*5.0*			
Bare ground	1	3	4	0.244	1
f(i)	*1.5*	*2.5*			
Oakbrush	1	2	3	0.017	1
f(i)	*1.1*	*1.9*			
Pinyon-juniper	4	2	6	2.278	1
f(i)	*2.2*	*3.8*			
Totals	130	222	352	11.856	7
f(i)	*130.0*	*222.0*		0.0000	1
χ^2 of total				11.856	6

Heterogeneity χ^2 critical value (6 df) = 12.592, *f (i)* = expected frequency.

Table. B-4. Landscape scale winter habitat use by female (n = 5) and male (n = 11) sage grouse Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Habitat	Female	Male	n	χ^2	df
Sagebrush/upland	23	44	67	1.462	1
f(i)	*27.9*	*39.1*			
Sagebrush	29	32	61	0.883	1
f(i)	*25.4*	*35.6*			
Upland shrub	6	7	13	0.110	1
f(i)	*5.4*	*7.6*			
Grass	2	4	6	0.169	1
f(i)	*2.5*	*3.5*			
Bare ground	1	0	1	1.403	1
f(i)	*0.4*	*0.6*			
Oakbrush	1	0	1	1.403	1
f(i)	*0.4*	*0.6*			
Pinyon-juniper	0	0	0	0.000	1
f(i)	*0.0*	*0.0*			
Totals	62	87	149	5.431	7
f(i)	*62.0*	*87.0*		0.00	1
χ^2 of total				5.431	6

Heterogeneity χ^2 critical value (6 df) = 12.592, *f (i)* = expected frequency.

Table. B-5. Landscape scale habitat use by sage grouse (n =16) between winter and summer habitat Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Habitat	Winter	Summer	n	χ^2	df
Sagebrush/upland	67	208	275	4.160	1
f(i)	*82.5*	*192.5*			
Sagebrush	61	73	134	15.375	1
f(i)	*40.2*	*93.8*			
Upland shrub	6	8	14	1.102	1
f(i)	*4.2*	*9.8*			
Grass	13	50	63	2.631	1
f(i)	*18.9*	*44.1*			
Bare ground	1	3	4	0.048	1
f(i)	*1.2*	*2.8*			
Oakbrush	1	4	5	0.238	1
f(i)	*1.5*	*3.5*			
Pinyon-juniper	0	6	6	2.571	1
f(i)	*1.8*	*4.2*			
Totals	149	352	501	26.125	7
f(i)	*150.3*	*350.7*		0.016	1
χ^2 of total				26.109	6

Heterogeneity χ^2 critical value (6 df) = 12.592, $f(i)$ = expected frequency.

Table B-6. Summer habitat selection by sage grouse defined by 1st order availability in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

cover	n	ϕ	π	θ	Lower	Upper	X_L
Pinyon-juniper	6	122.17	0.35	0.02	0.003	0.044	-18.082
Sagebrush	73	89.10	0.25	0.21	0.151	0.270	-14.553
Sagebrush/Upland	208	77.10	0.22	0.59	0.516	0.659	206.417
Upland	8	21.05	0.06	0.02	0.006	0.052	-7.741
Grass	50	13.32	0.04	0.14	0.095	0.197	66.153
Oakbrush	4	18.47	0.05	0.01	0.001	0.035	-6.120
Bare ground	3	10.78	0.03	0.01	0.000	0.031	-3.838
Totals[a]	352	352	1	1			444.477

[a] Total for X_L is the log likelihood chi-square statistic = $2(\sum X_{Li})$.

ϕ = expected frequency of use, π = observed percent habitat available, θ = observed percent use.

Table B-7. Summer habitat selection by sage grouse defined by 2nd order availability in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

cover	n	ϕ	π	θ	Lower	Upper	X_L
Pinyon-juniper	6	111.39	0.32	0.02	0.003	0.044	-17.528
Sagebrush	73	81.43	0.23	0.21	0.151	0.270	-7.978
Sagebrush/Upland	208	100.24	0.28	0.59	0.516	0.659	151.830
Upland	8	21.33	0.06	0.02	0.006	0.052	-7.847
Grass	50	19.05	0.05	0.14	0.095	0.197	48.236
Oakbrush	4	11.65	0.03	0.01	0.001	0.035	-4.275
Bare ground	3	6.90	0.02	0.01	0.000	0.031	-2.500
Totals[a]	352	352	1	1			319.88

[a] Total for X_L is the log likelihood chi-square statistic = $2(\sum X_{Li})$.

ϕ = expected frequency of use, π = observed percent habitat available, θ = observed percent use.

Table B-8. Winter habitat selection by sage grouse defined by 3[st] order availability in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

cover	n	ϕ	π	θ	Lower	Upper	X_L
Pinyon-juniper	6	28.62	0.08	0.02	0.003	0.044	-9.373
Sagebrush	73	86.38	0.25	0.21	0.151	0.270	-12.284
Sagebrush/Upland	208	153.37	0.44	0.59	0.516	0.659	63.377
Upland	8	33.50	0.10	0.02	0.006	0.052	-11.456
Grass	50	31.75	0.09	0.14	0.095	0.197	22.704
Oakbrush	4	7.71	0.02	0.01	0.001	0.035	-2.623
Bare ground	3	10.68	0.03	0.01	0.000	0.031	-3.810
Totals[a]	352		1	1			93.070

[a] Total for X_L is the log likelihood chi-square statistic = $2(\sum X_{Li})$.

ϕ = expected frequency of use, π = observed percent habitat available, θ = observed percent use.

Table B-9. Winter habitat selection by sage grouse defined by 1[st] order availability in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

cover	n	ϕ	π	θ	Lower	Upper	X_L
Pinyon-juniper	0	51.71	0.35	0.00	0.000	0.000	0
Sagebrush	61	37.72	0.25	0.41	0.299	0.519	31.221
Sagebrush/Upland	67	32.64	0.22	0.45	0.336	0.559	2.112
Upland	6	8.91	0.06	0.04	0.008	0.102	-5.160
Grass	13	5.64	0.04	0.09	0.034	0.165	-0.432
Oakbrush	1	7.82	0.05	0.01	0.012	0.048	-1.182
Bare ground	1	4.56	0.03	0.01	0.012	0.048	-1.509
Totals[a]	149	149	1	1			164.858

[a] Total for X_L is the log likelihood chi-square statistic = $2(\sum X_{Li})$.

ϕ = expected frequency of use, π = observed percent habitat available, θ = observed percent use.

Table B-10. Winter habitat selection by sage grouse defined by 2[st] order availability in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

cover	*n*	ϕ	π	θ	Lower	Upper	X_L
Pinyon-juniper	0	47.15	0.32	0.00	0.00	0.00	0.00
Sagebrush	61	34.47	0.23	0.41	0.30	0.52	34.82
Sagebrush/Upland	67	42.43	0.28	0.45	0.34	0.56	30.60
Upland	6	9.03	0.06	0.04	0.01	0.10	-2.45
Grass	13	8.07	0.05	0.09	0.03	0.16	6.21
Oakbrush	1	4.93	0.03	0.01	0.01	0.05	-1.60
Bare ground	1	2.92	0.02	0.01	0.01	0.05	-1.07
Totals[a]	149	149	1	1			133.019

[a] Total for X_L is the log likelihood chi-square statistic = $2(\sum X_{Li})$.
ϕ = expected frequency of use, π = observed percent habitat available, θ = observed percent use.

Table B-11. Winter habitat selection by sage grouse defined by 3[st] order availability in the Piceance Basin, Rio Blanco County, Colorado, 1997-98.

cover	*n*	ϕ	π	θ	Lower	Upper	X_L
Pinyon-juniper	0	12.11	0.08	0.00	0.000	0.000	0
Sagebrush	61	36.56	0.25	0.41	0.299	0.519	31.2211
Sagebrush/Upland	67	64.92	0.44	0.45	0.336	0.559	2.11288
Upland	6	14.18	0.10	0.04	0.008	0.102	-5.1602
Grass	13	13.44	0.09	0.09	0.034	0.165	-0.4329
Oakbrush	1	3.26	0.02	0.01	0.012	0.048	-1.1823
Bare ground	1	4.52	0.03	0.01	0.012	0.048	-1.509
Totals[a]	149	149	1	1			55.099

[a] Total for X_L is the log likelihood chi-square statistic = $2(\sum X_{Li})$.
ϕ = expected frequency of use, π = observed percent habitat available, θ = observed percent use.

Table. B-12. Habitat components at female (n = 84) and male (n = 115) sage grouse summer use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites					
	Female		Male		Variable weights[a]	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	Lower	Upper
Sagebrush	12.9	1.1	20.8	1.1	-1.211	-0.101
Serviceberry	5.1	0.8	1.6	0.4	0.194	1.326
Other-shrubs	8.7	0.8	9.5	0.9	-0.564	0.477
Grasses	17.2	1.1	17.1	0.8	-0.337	0.287
Forbs	10.7	1.0	11.0	0.5	-0.542	0.173
Bare Ground	45.6	1.7	40.4	1.5	-0.113	0.395
Shrub Ht.(cm)	45.2	1.9	48.1	1.3	-0.288	0.107

[a] Variable weights defined by difference of means (log transformed) simultaneous confidence intervals from Hotelling's T^2, intervals excluding zero were significant.

Table. B-13. Vegetation height (cm) at female ($n = 84$) and male ($n = 115$) sage grouse summer use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites				
	Female		Male		
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	P-values[a]
Sagebrush	49.3	1.2	46.6	2.0	N/A
Serviceberry	54.5	5.2	63.6	5.4	N/A
Other-shrubs	36.1	1.1	33.7	1.3	N/A
Grasses	21.7	0.7	19.8	0.8	N/A
Forbs	21.1	0.7	21.3	0.9	N/A

[a] P-values from univariate t-tests (log transformed data) were conducted after Hotelling's T^2 resulted in significant differences in total shrub height.

Table. B-14. Habitat components at male sage grouse summer use ($n = 115$) and random ($n = 115$) sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites					
	Use		Random		Variable weights[a]	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	Lower	Upper
Sagebrush	20.8	1.1	17.3	1.0	-0.758	0.243
Serviceberry	1.6	0.4	2.0	0.4	-0.368	0.554
Other-shrubs	9.5	0.9	12.5	0.9	-0.208	0.798
Grasses	17.1	0.8	18.5	1.0	-0.234	0.317
Forbs	11.0	0.5	10.5	0.6	-0.358	0.160
Bare Ground	40.4	1.5	39.5	1.6	-0.318	0.192
Shrub Ht.(cm)	48.1	1.3	48.5	1.5	-0.163	0.164

[a] Variable weights defined by difference of means (log transformed) simultaneous confidence intervals from Hotelling's T^2, intervals excluding zero were significant.

Table. B-15. Vegetation height (cm) at male ($n = 115$) sage grouse summer use and random sites ($n = 115$), Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites				
	Use		Random		
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	P-values[a]
Sagebrush	46.6	2.0	49.6	1.5	N/A
Serviceberry	63.6	5.4	58.2	3.1	N/A
Other-shrubs	33.7	1.3	39.2	1.7	N/A
Grasses	19.8	0.8	23.7	1.0	N/A
Forbs	21.3	0.9	23.8	1.4	N/A

[a] P-values from univariate t-tests (log transformed data) were conducted after Hotelling's T^2 resulted in significant differences in total shrub height.

Table. B-16. Habitat components at female sage grouse summer use (n = 84) and random (n = 84) sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites					
	Use		Random		Variable weights[a]	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	Lower	Upper
Sagebrush	12.9	1.1	14.2	1.3	-0.720	0.719
Serviceberry	5.1	0.8	4.2	0.8	-0.943	0.521
Other-shrubs	8.7	0.8	10.9	1.3	-0.425	0.649
Grasses	17.2	1.1	15.8	1.1	-0.528	0.259
Forbs	10.7	1.0	10.0	0.8	-0.466	0.413
Bare Ground	45.6	1.7	45.1	2.0	-0.300	0.208
Shrub Ht.(cm)	45.2	1.9	47.1	2.3	-0.208	0.279

[a] Variable weights defined by difference of means (log transformed) simultaneous confidence intervals from Hotelling's T^2, intervals excluding zero were significant.

Table. B-17.Vegetation height (cm) at female sage grouse summer use (n = 84) and random (n = 84) sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites				
	Use		Random		
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	P-values[a]
Sagebrush	49.3	1.2	48.2	1.7	N/A
Serviceberry	54.5	5.2	57.9	3.8	N/A
Other-shrubs	36.1	1.1	33.8	1.7	N/A
Grasses	21.7	0.7	20.2	0.8	N/A
Forbs	21.1	0.7	22.8	1.0	N/A

[a] P-values from univariate t-tests (log transformed data) were conducted after Hotelling's T^2 resulted in significant differences in total shrub height.

Table. B-18. Habitat components at male sage grouse summer (n = 116) and winter (n = 14) use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites					
	Summer		Winter		Variable weights[a]	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	Lower	Upper
Sagebrush	20.8	1.1	30.5	3.5	0.225	1.149
Serviceberry	1.6	0.4	4.4	1.8	-0.210	1.330
Other-shrubs	9.5	0.9	5.4	1.6	-1.330	0.266
Grasses	17.1	0.8	N/A	N/A	N/A	N/A
Forbs	11.0	0.5	N/A	N/A	N/A	N/A
Bare Ground	40.4	1.5	N/A	N/A	N/A	N/A
Shrub Ht.(cm)	48.1	1.3	64.7	3.8	.005	0.564

[a] Variable weights defined by difference of means (log transformed) simultaneous confidence intervals from Hotelling's T^2, intervals excluding zero were significant.

Table. B-19. Vegetation height (cm) at male sage grouse summer (n = 116) and winter (n = 14) use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites				
	Summer		Winter		
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	P-values[a]
Sagebrush	49.3	1.2	63.9	2.8	<0.0001
Serviceberry	54.5	5.2	79.0	18.5	0.099
Other-shrubs	36.1	1.1	54.3	11.9	0.155
Grasses	21.7	0.7	N/A	N/A	N/A
Forbs	21.1	0.7	N/A	N/A	N/A

[a]P-values from univariate t-tests (log transformed data) were conducted after Hotelling's T^2 resulted in significant differences in total shrub height.

Table. B-20. Habitat components at female sage grouse summer (n = 84) and winter (n = 11) use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Females					
	Summer		Winter		Variable weights[a]	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	Lower	Upper
Sagebrush	12.9	1.1	25.4	4.2	-0.181	2.025
Serviceberry	5.1	0.8	10.3	4.1	-0.939	1.486
Other-shrubs	8.7	0.8	13.2	3.3	-0.614	1.218
Grasses	17.2	1.1	N/A	N/A	N/A	N/A
Forbs	10.7	1.0	N/A	N/A	N/A	N/A
Bare Ground	45.6	1.7	N/A	N/A	N/A	N/A
Shrub Ht.(cm)	45.2	1.9	74.4	13.1	-0.005	0.832

[a] Variable weights defined by difference of means (log transformed) simultaneous confidence intervals from Hotelling's T2, intervals excluding zero were significant.

Table. B-21. Vegetation height (cm) at female sage grouse summer (n = 84) and winter (n = 11) use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites				
	Summer		Winter		
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	P-values[a]
Sagebrush	46.6	2.0	69.6	3.3	<0.0001
Serviceberry	63.6	5.4	131.5	38.4	0.129
Other-shrubs	33.7	1.3	62.7	14.8	0.080
Grasses	19.8	0.8	N/A	N/A	N/A
Forbs	21.3	0.9	N/A	N/A	N/A

[a]P-values from univariate t tests (log transformed data) were conducted after Hotelling's T^2 resulted in significant differences in total shrub height.

Table. B-22. Habitat components at female ($n = 11$) and male ($n = 14$) sage grouse winter use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites					
	Female		Male		Variable weights[a]	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	Lower	Upper
Sagebrush	25.4	4.2	30.5	3.5	-1.102	0.710
Serviceberry	10.3	4.1	4.4	1.8	-1.543	2.248
Other-shrubs	13.2	3.3	5.4	1.6	-0.654	2.234
Grasses	N/A	N/A	N/A	N/A	N/A	N/A
Forbs	N/A	N/A	N/A	N/A	N/A	N/A
Bare Ground	N/A	N/A	N/A	N/A	N/A	N/A
Shrub Ht.(cm)	74.4	13.1	64.7	3.8	-0.740	0.724

[a] Variable weights defined by difference of means (log transformed) simultaneous confidence intervals from Hotelling's T2, intervals excluding zero were significant.

Table. B-23. Vegetation height (cm) at female ($n = 11$) and male ($n = 14$) sage grouse winter use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites				
	Female		Male		
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	*P*-values[a]
Sagebrush	69.6	3.3	63.9	2.8	N/A
Serviceberry	131.5	38.4	79.0	18.5	N/A
Other-shrubs	62.7	14.8	54.3	11.9	N/A
Grasses	N/A	N/A	N/A	N/A	N/A
Forbs	N/A	N/A	N/A	N/A	N/A

[a]*P*-values from univariate *t*-tests (log transformed data) were conducted after Hotelling's T^2 resulted in significant differences in total shrub height.

Table. B-24. Habitat components at male sage grouse winter use ($n = 14$) and random ($n = 14$) sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites					
	Use		Random		Variable weights[a]	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	Lower	Upper
Sagebrush	30.5	3.5	22.7	2.7	-1.752	1.009
Serviceberry	4.4	1.8	7.7	3.5	-2.020	2.604
Other-shrubs	5.4	1.6	7.4	1.8	-0.787	1.331
Grasses	N/A	N/A	N/A	N/A	N/A	N/A
Forbs	N/A	N/A	N/A	N/A	N/A	N/A
Bare Ground	N/A	N/A	N/A	N/A	N/A	N/A
Shrub Ht.(cm)	64.7	3.8	68.1	11.2	-0.495	0.462

[a]Variable weights defined by difference of means simultaneous confidence intervals from Hotelling's T^2. Intervals excluding zero were significant

Table. B-25. Vegetation height (cm) at male (n = 14) sage grouse winter use and random sites (n = 14), Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites				
	Use		Random		
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	P-values[a]
Sagebrush	63.9	2.8	58.6	2.5	N/A
Serviceberry	79.0	18.5	89.0	15.8	N/A
Other-shrubs	54.3	11.9	39.2	4.9	N/A
Grasses	N/A	N/A	N/A	N/A	N/A
Forbs	N/A	N/A	N/A	N/A	N/A

[a]P-values from univariate t-tests (log transformed data) were conducted after Hotelling's T^2 resulted in significant differences in total shrub height.

Table. B-26. Habitat components at female sage grouse winter use (n = 11) and random (n = 11) sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites					
	Use		Random		Variable weights[a]	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	Lower	Upper
Sagebrush	25.4	4.2	19.0	4.1	-1.925	1.400
Serviceberry	10.3	4.1	11.2	3.5	-1.931	2.509
Other-shrubs	13.2	3.3	20.3	6.6	-1.344	1.645
Grasses	N/A	N/A	N/A	N/A	N/A	N/A
Forbs	N/A	N/A	N/A	N/A	N/A	N/A
Bare Ground	N/A	N/A	N/A	N/A	N/A	N/A
Shrub Ht.(cm)	74.4	13.1	95.6	21.4	-1.108	1.194

[a]Variable weights defined by difference of means simultaneous confidence intervals from Hotelling's T^2. Intervals excluding zero were significant

Table. B-27. Vegetation height (cm) at female sage grouse winter use (n = 11) and random (n = 11) sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

	Sites				
	Use		Random		
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE	P-values[a]
Sagebrush	69.6	3.3	22.7	2.7	N/A
Serviceberry	131.5	38.4	7.7	3.5	N/A
Other-shrubs	62.7	14.8	7.4	1.8	N/A
Grasses	N/A	N/A	N/A	N/A	N/A
Forbs	N/A	N/A	N/A	N/A	N/A

[a]P-values from univariate t-tests (log transformed data) were conducted after Hotelling's T^2 resulted in significant differences in total shrub height.

Table. B-28. Topographic locations of sage grouse summer use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Topographic location	Female	Male	*n*	χ^2	df
Drainage	4	6	10	0.0	1
f (i)	*4.0*	*6.0*			
Upper slope	23	33	56	0.026	1
f (i)	*22.4*	*33.6*			
Middle slope	13	34	47	2.982	1
f (i)	*18.8*	*28.2*			
Lower slope	7	12	19	0.078	1
f (i)	*7.6*	*11.4*			
Ridge top	64	84	148	0.648	1
f (i)	*59.2*	*88.8*			
Totals	111	169	280	3.737	4

χ^2 Critical value (4 df) = 9.488, *f (i)* = expected frequency.

Table. B-29. Topographic locations of sage grouse winter use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Topographic location	Female	Male	*n*	χ^2	df
Drainage	5	10	15	1.085	1
f (i)	*7.0*	*8.0*			
Upper slope	20	17	37	0.792	1
f (i)	*17.3*	*19.7*			
Middle slope	7	9	16	0.058	1
f (i)	*7.5*	*8.5*			
Lower slope	2	3	5	0.092	1
f (i)	*2.3*	*2.7*			
Ridge top	39	42	81	0.063	1
f (i)	*37.9*	*43.1*			
Totals	73	81	154	2.090	4

χ^2 Critical value (4 df) = 9.488, *f (i)* = expected frequency.

Table. B-30. Topographic locations of sage grouse summer and winter use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Topographic location	Summer	Winter	*n*	χ^2	df
Drainage	10	15	25	6.564	1
f (i)	*16.1*	*8.9*			
Upper slope	56	37	93	0.752	1
f (i)	*60.0*	*33.0*			
Middle slope	47	16	63	2.800	1
f (i)	*40.6*	*22.4*			
Lower slope	19	5	24	2.250	1
f (i)	*15.5*	*8.5*			
Ridge top	148	81	229	0.001	1
f (i)	*147.7*	*81.3*			
Totals	280	154	434	12.366	4

χ^2 Critical value (4 df) = 9.488, *f (i)* = expected frequency.

Table. B-31. Ridge aspect of sage grouse summer use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Aspect	Female	Male	*n*	χ^2	df
East	17	21	38	0.412	1
f (i)	*15.1*	*22.9*			
North	19	25	44	0.230	1
f (i)	*17.4*	*26.6*			
Northeast	5	5	10	0.448	1
f (i)	*4.0*	*6.0*			
Northwest	17	12	29	4.365	1
f (i)	*11.5*	*17.5*			
South	7	39	46	11.47	1
f (i)	*18.2*	*27.8*			
Southeast	3	10	13	1.491	1
f (i)	*5.2*	*7.8*			
Southwest	5	11	16	0.471	1
f (i)	*6.3*	*9.7*			
West	38	46	84	1.099	1
f (i)	*33.3*	*50.7*			
Totals	111	169	280	19.987	7

χ^2 Critical value (7 df) = 14.067, *f (i)* = expected frequency.

Table. B-32. Ridge aspect of sage grouse winter use sites, Piceance Basin, Rio Blanco County, Colorado, 1997-98.

Aspect	Female	Male	*n*	χ^2	df
East	6	14	20	2.254	1
f (i)	*9.4*	*10.6*			
North	27	22	49	1.372	1
f (i)	*22.9*	*26.1*			
Northeast	6	12	18	1.302	1
f (i)	*8.4*	*9.6*			
Northwest	7	7	14	0.059	1
f (i)	*6.5*	*7.5*			
South	9	8	17	0.261	1
f (i)	*7.9*	*9.1*			
Southeast	9	5	14	1.728	1
f (i)	*6.5*	*7.5*			
Southwest	3	2	5	0.352	1
f (i)	*2.3*	*2.7*			
West	5	12	17	2.053	1
f (i)	*7.9*	*9.1*			
Totals	72	82	154	9.384	7

χ^2 Critical value (7 df) = 14.067, *f (i)* = expected frequency.

APPENDIX C

CLARIFICATION OF VEGETATION

SAMPLING METHODOLOGY

C.0. INTRODUCTION

Studies of wildlife often attempt to identify the structure or composition of habitat that animals are 'selecting.' Such analyses vary in scale from macrohabitat (e.g., cover types, patch size) to microhabitat (e.g., species composition, vegetation height) and some encompass a gradient of the two. Further, one can generate predictive models of habitat use based on these parameters (Manly et al. 1993). Enumerating such relationships can assist biologists in identifying important habitats and managing them accordingly. A common approach is to quantify the abundance/composition of habitat variables (biotic or abiotic) at activity sites, and compare these values to those at random points (Litvaitis et al. 1996). One approach involves establishing a sampling plot (e.g., between 25 to 900 m^2) over the center of the observed activity site (e.g., nest, den, forage, or flush location) and another point at some random distance and direction (Duesser and Shugart 1978, Litvaitis et al. 1996). Habitat composition is then compared between 'use' and 'random,' sites and relationships of selection, preference, or avoidance are then determined from these habitat associations (Johnson 1980).

Recently, much debate has focused on definitions of habitat availability (Johnson 1980), seasonal variation (Schooley 1994), and statistical analyses of these data (Alldredge and Ratti 1986, 1992; Thomas and Taylor 1990; Cherry 1996). Comparatively, the collection of microhabitat data, which can determine use and availability, may have been overlooked. Workers often use a systematic design such that the lines of the transect (or layout of quadrats) emanates in the four cardinal directions from the plot center (Fig. C-1). Admittedly, the example given (Fig. C-1.) is superficial, but it illustrates the bias associated with perpendicular layout of sampling units. This layout is problematic as the center of the plot is over sampled while some peripheral areas are ignored (Greig-Smith 1957). Thus, estimates of the mean, standard error, etc., will be biased by this sampling (Anderson et al. 1979). There is a need to clarify systematic sampling design as it pertains to locating sampling units (e.g., quadrats, line-intercepts) for characterizing wildlife habitats.

My objectives in this appendix are to 1) clarify the use of systematic sampling design in the context of the established methods (e.g., Canfield 1941, Daubenmire 1959) to provide an alternative protocol, 2) and compare the results of these methods with an example data set from a sagebrush (*Artemisia* spp.) ecotype.

C.1. METHODS

Literature—I reviewed papers published in the *Journal of Wildlife Management* from 1966 to 1996 that examined habitat use as it pertained to microhabitat variables. I evaluated the methods used for quantifying variables at 'use' and 'random' sites. I specifically assessed whether the sampling design used a perpendicular or intersecting set of transects or quadrats. I reviewed only those papers that evaluated habitat use at the microhabitat scale. Papers that were examining macrohabitat variables were considered only if they included microhabitat analyses. I also reviewed the original articles by Canfield (1941), Daubenmire (1959), and James and Shugart (1970) to verify the methodologies that had been established.

Example Data—Data were from a study of radio-marked sage grouse (*Centrocercus urophasianus*) in northwestern Colorado, 1997-98. Vegetation cover was estimated at radio-marked grouse flush sites ($n = 25$) and randomly chosen sites ($n = 25$). However, for the purposes of this paper these samples were pooled as the objective was to identify bias in sampling technique, not between use and random locations. Both distance and direction traveled to random sites were selected using the second hand on a watch. Nine 1-m^2 quadrats were placed along 2 30-m transects that were centered on the location that a grouse flushed or was observed foraging. The transect lines were placed in the 4 cardinal directions and each quadrat was spaced 7.5 m apart. Percent cover was recorded to the nearest 5% as well as height (cm) for big sagebrush (*A. tridentata*), serviceberry (*Amelanchier utahensis*), antelope bitterbrush (*Purshia tridentata*), rabbitbrush (*Chrysothamnus* spp.), snowberry (*Symphoricarpus oreophilus*), other brush, grass, forb, and bare ground (no height). Grid samples were recorded at corresponding use and random sites. Additionally, 4 1-m^2 quadrats were placed 15 m and parallel to the outer most quadrats (Fig. C-1.). The end of each transect was marked with a stake and compass readings were noted for each transect line. The location of the 4 quadrats was ascertained as one worker paced 15 m from the end of each transect. Compass bearings were taken from the new quadrat location to ensure that it was parallel to endpoints of each transect.

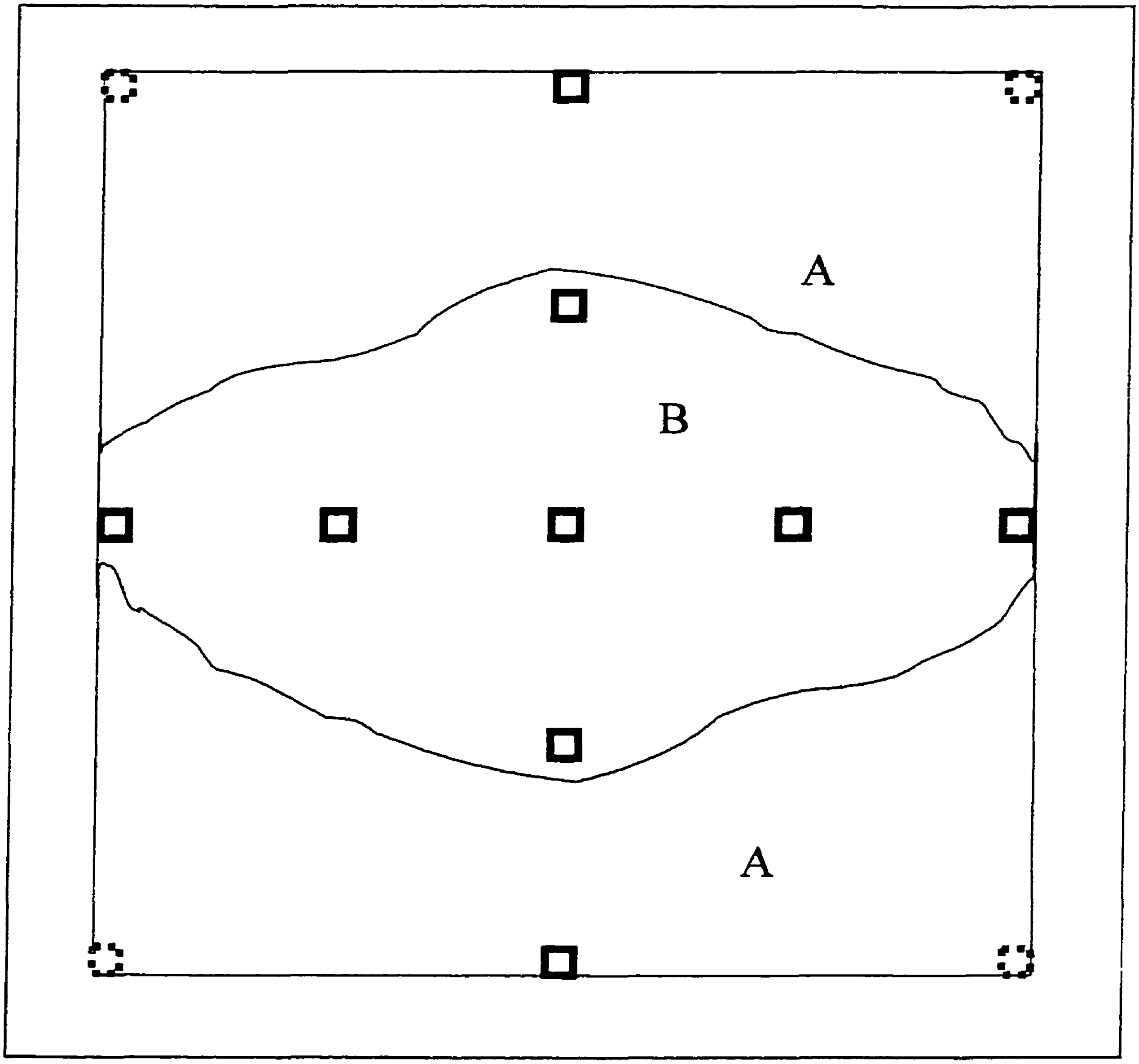

Fig. C-1. A common quadrat layout (solid quadrats) implemented for sampling wildlife microhabitat variables. Habitat A represents ~60% of the plot and B ~40% and the perpendicular layout oversamples Habitat B with 7/9 of the sampling units. The grid method (dashed-line quadrats) would include the outer 4 quadrats and exclude the 4 plots adjacent to the center point. The grid layout would represent each habitat proportionally as they occur on the landscape. The quadrat is used by way of example, this diagram would also apply to the line intercept method, using 3 parallel lines.

C.2. RESULTS

Literature—Thirty-three of 85 microhabitat studies (39%) implemented the perpendicular layout. The majority (78%) were avian studies ($n = 26$) followed by 'hooved' ($n = 5$) and small mammals ($n = 2$) (Table C-1). Gallinaceous bird studies represented the majority (57%) of papers that used a perpendicular layout.

Table C-1. Vegetation sampling design from microhabitat studies ($n = 85$) published in the *Journal of Wildlife Management*, 1966-96. All sampling units were centered on the activity site of the animal.

		Vegetation Sampling			
Animal	n	Transect[a]	Circular[b]	Random[c]	Perpendicular[d]
Birds					
Upland Game	27	2	2	4	19
Raptors	6	0	3	1	2
Waterfowl	6	1	2	2	1
Other	17	4	6	3	4
Mammals					
'Hooved'	19	7	3	4	5
Small	10	5	1	2	2
Totals	85	19	17	16	33

[a] A parallel set or single line transect was centered on the use site.
[b] Ocular estimation of a circular plot centered on the use site.
[c] Random sampling was implemented using quadrats near the use site.
[d] Perpendicular transects from which line intercept or quadrats were used.

Example Data—The average percent cover estimates ($n = 50$) showed little difference between sampling methodology (Table C-2). There was some variability between height. This suggested that some sites had taller shrubs which the grid layout detected while the perpendicular did not. However, the differences did not suggest statistical nor biological significance.

Table C-2. Habitat components (% cover) at 50 sites using grid and perpendicular layouts of 1-m^2 quadrats.

	Grid		Perpendicular	
Habitat Components	$\bar{x}$	SE	$\bar{x}$	SE
Sagebrush, %	15.9	1.5	18.0	1.7
Height, cm	56.0	2.1	53.1	2.0
Serviceberry, %	2.0	0.4	2.6	0.6
Height, cm	71.7	9.1	62.3	6.4
Bitterbrush, %	2.6	0.7	2.3	0.7
Height, cm	37.5	2.6	37.2	2.8
Rabbitbrush, %	4.0	0.5	4.0	0.5
Height, cm	36.0	1.3	35.3	1.2
Snowberry, %	5.3	0.8	5.0	0.8
Height, cm	37.1	1.4	36.1	1.4
Otherbrush, %	2.2	1.1	1.8	1.0
Height, cm	70.1	20.1	59.9	17.0
Grass, %	15.5	1.3	15.3	1.6
Height, cm	19.3	1.0	19.4	1.1
Forbs, %	8.9	0.7	8.5	0.7
Height, cm	20.7	1.0	20.3	1.1
Bare Ground, %	44.1	2.2	43.0	2.3

C.3. DISCUSSION

Literature—The prevalence of this layout used in avian studies was. Birds were either observed at nest or foraging sites; these centers of use were readily identified. The lack of ungulate studies using this design may be attributed in part to the abundance of nutritional studies, which use different methods of sampling (e.g., Hobbs et al. 1983).

The use of the perpendicular layout may be more widespread in the small mammal literature, but studies of this type may be under represented in *JWM* (see Duesser and Shugart 1978 and references therein). One peripheral goal of reviewing the broad scope of *JWM* papers was to identify the original reference for the perpendicular layout. Workers were implementing this design as early as 1966. However, no reference was located that cited a primary source of the perpendicular layout. James and Shughart (1970) were the first to clearly describe the layout of perpendicular arms-length transects to estimate shrub density in the *Journal of Field Ornithology*, but did not describe the use of quadrats or line-intercepts along these axis. However, these authors were rarely cited in the *JWM*.

The authors from plant ecology that established the common sampling methods, all describe using a random or systematic placement of the sampling unit. In the latter case this design is also referred to as the representative sample (e.g., uniform, dispersed). The systematic placement of quadrats or transects within a plot is often implemented for either efficiency or replication of the design. Systematic design can provide more information per unit cost than simple random designs (Krebs 1989, Ratti and Garton 1996). However, if the sample population is non-uniform (e.g., periodic) then systematic design might give biased estimates (Krebs 1989, Ratti and Garton 1996). To alleviate/reduce the chance of such biases, the initial plot should be established with the first element being randomly chosen (e.g., animal location) and each element is sampled at a fixed interval thereafter (Ratti and Garton 1996). Thus, a systematic design should provide a dispersed (e.g., uniform) representation of the sample plots (Greig-Smith

1957). The perpendicular layout adheres to the requisite of fixed intervals. However, it is the disproportional representation of the plot inherent in this design that produces biases.

> "If systematic sampling is desired for a particular investigation, it is important that the pattern of sampling adopted should be such as to give uniform representation over the area. Otherwise the advantage that may result from its use will be lost. This point is not always appreciated. For, example Brown [1954] quotes an investigation in which plots, presumably rectangular, were examined by points placed at equal distances along the two diagonals of the plot and along lines joining the midpoints of the opposite sides. This results in a much greater intensity of sampling towards the centre of the plot; half the samples are in fact taken from a quarter of the area (Greig-Smith 1957: 22)."

Thus, the alternative method should be one that proportionally samples the entire plot. The alternative approach (hereafter, grid sampling) is drawn from standard sampling theory (Eberhart 1978, Anderson et al. 1979, Burnham et al. 1980, Seber 1982).

Protocol for population density estimation via transect sampling asserts that transect lines should not overlap as these lines are statistically dependent (Anderson et al. 1979: 76). Sampling theory dictates that overlapping or intersecting lines are not statistically independent and will result in biased parameter estimation (Anderson et al. 1979, Burnham et al. 1980). Biased parameters invalidate the use of standard statistical tests. Thus, vegetation samples drawn from a dispersed layout (grid) are required (e.g., see Burnham et al. 1980: 33). One may argue that to adequately characterize a nest site, it is important to sample the area in close proximity to the nest. Such an argument is plausible, however to violate the fundamentals of sampling theory renders parameter estimation and subsequent analyses useless. Furthermore, to oversample the middle is erroneous as it is only describes ~25 % of the plot with ≥ 50% sampling units. The other 75% may provide data that elucidates trends of "selection" for habitat structures near the middle of the plot and require equal consideration. An alternative method is to use a series of nested grids placed at fixed intervals emanating from the middle of the plot. This will provide an unbiased sample of the vegetation at set intervals away from the nest. Nested sampling may also enable one to apply spatial analyses to identify patterns of selection (P. E. Joyce, Univ., of Manitoba, unpubl. data).

Example Data—Use of the grid method suggested that taller shrubs were present at sites that went undetected by the perpendicular layout. Although this may have little impact biologically (or statistically), it indicates the plots may not be adequately described with the perpendicular method. Although grid and perpendicular methods yielded comparable results from the sagebrush ecotype, vegetation is patchily distributed and perpendicular sampling layouts will bias the results. Other ecosystems may have a greater extent of fine scale heterogeneity. This will have significant impacts on statistical and biological interpretation of the results. Rigorous systematic protocols must be implemented to ensure that parameter estimation is unbiased.

C.4. CONCLUSIONS

The perpendicular layout is prevalent in wildlife literature. The biases associated with this design can be easily remedied. A simple modification of the perpendicular layout includes, moving the inner quadrats (i.e., adjacent 4 to the center of the plot) to the outer corners (Fig. C-1). Similarly, three parallel line-intercepts can be used with one of these lines intersecting the center of the activity site. The lines should be arranged in a randomly selected cardinal direction. The use of quadrats or line-intercept in the grid layout will alleviate biased parameter estimation and provide robust models for microhabitat analyses.

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