THESIS

SAGE GROUSE MOVEMENTS AND HABITAT SELECTION IN NORTH PARK, COLORADO

Submitted by

Thomas John Schoenberg

Department of Fishery and Wildlife Biology

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring, 1982

COLORADO STATE UNIVERSITY

Spring, 1982

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY THOMAS JOHN SCHOENBERG ENTITLED SAGE GROUSE MOVEMENTS AND HABITAT SELECTION IN NORTH PARK, COLORADO BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

____

____

Clait E. Braun

Richard J. Walter

Dale Hein

Ronald A. Ryder

Adviser

ABSTRACT OF THESIS

SAGE GROUSE MOVEMENTS AND HABITAT SELECTION
IN NORTH PARK, COLORADO

Sage grouse (Centrocercus urophasianus) movements and habitat selection were studied in North Park, Colorado during April-August 1979 and February-August 1980. Sixteen male (12 adults, 4 juveniles) and 22 female (13 adults, 9 juveniles) sage grouse were captured and fitted with radio transmitters. Mortality of radio-marked sage grouse during the monitoring period was low (13%). Raptors were the most important predators. Twenty-two of 36 (61%) transmitters were recovered after use on sage grouse. Wildlife Materials transmitters had longer ($P < 0.05$) average life (209 days) than AVM transmitters (136 days).

Sage grouse used 2 major wintering areas in the northeast and southeast quadrats of North Park in 1980. Preferred winter habitat encompassed only 3.7% of the sagebrush (Artemisia spp.)-dominated land in North Park. There was no difference ($P > 0.05$) between sexes in average daily winter movements or size of winter range areas. Daily movements averaged 1.6 and 1.5 km for males and females, respectively. Winter flock break-up and dispersal to breeding areas began during the 2nd week of April coincident with the onset of the spring thaw. Movements of 3 radio-marked males from the wintering area to leks averaged 27.5 km. Four hens traveled an average of 29.9 km from the wintering area to nests.

Daily movements of males from leks to feeding-loafing (FL) sites averaged 0.9 km. Dispersal direction from Raven Lek to FL sites was nonrandom ($\underline{P} < 0.001$). Average distance that hens traveled from leks to nest sites was 2.7 km. Adult hens traveled farther ($\underline{P} < 0.05$) than juvenile hens. Preincubation movements from nests to FL sites averaged 0.4 km.

Movements of both sexes from breeding areas and nests to meadows along the Michigan and Canadian rivers occurred throughout June, primarily during the latter half of the month. Four of 5 radio-marked males and 5 of 6 radio-marked hens moved to the meadow nearest the lek attended or nest site, respectively. Summer movements were restricted to relatively small areas along the Michigan and Canadian rivers.

Few differences in slope and aspect were observed between habitats selected by sage grouse and random sites. Greater differences in habitat selection were seen when topographic features were examined. Sage grouse winter FL sites were primarily in sagebrush-dominated draws and on windswept ridges whereas breeding season FL sites were predominantly on 0-5 and 6-10% open slopes. Hens with broods preferred draws with little sagebrush and high forb and grass cover.

Sage grouse selected winter FL habitats with better ($\underline{P} \leq 0.05$) structural cover (sagebrush clump size, plant dimensions, canopy cover) than breeding season FL sites. Structural characteristics of nest sites, however, were more similar to winter FL sites. Only leks had poorer ($\underline{P} \leq 0.05$) structural cover than random sites. Except for FL sites of males during the breeding season, sage grouse chose sagebrush with higher ($\underline{P} < 0.05$) percent foliation (75-78%) than found at random sites (65%). Males, hens with broods, and unsuccessful hens chose summer meadow habitats with similar ($\underline{P} > 0.05$) forb and grass cover and grass height.

Males selected breeding season FL sites with higher ($\underline{P} < 0.05$) soil organic matter content than did hens or that found at random sites. The higher organic matter content was attributed to 2,4-D spraying of the area around Raven Lek in 1963 and subsequent decomposition of sagebrush plants.

Discriminant function and principal components analyses were also used to investigate sage grouse habitat selection. Three discriminant functions explained 93.6% of the total sample variance whereas 5 principal components explained 94.1% of the sample variance. In both analyses, sagebrush plant size was the most important habitat factor separating different types of sage grouse use and random sites. Degree of microhabitat selection was the 2nd most important factor followed by sagebrush clump size and canopy cover. These analyses revealed differences in habitats selected by sage grouse between and within seasons as well as habitat differences between random and sage grouse use sites.

Thomas John Schoenberg
Department of Fishery and
Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523
Spring, 1982

ACKNOWLEDGMENTS

Financial support was provided by the U.S. Department of the Interior, Bureau of Land Management, and the Colorado Division of Wildlife, Federal Aid to Wildlife Restoration Project W-37-R. The support of these agencies is gratefully acknowledged.

Special thanks are extended to my committee members. I sincerely appreciate the assistance of Dr. R. A. Ryder, my major professor, for his academic and administrative support and critical review of my thesis. I am especially grateful for the advice and assistance of Dr. C. E. Braun, my research advisor, for initiating this study and for his constant encouragement and support. His sincere interest in my professional achievement is greatly appreciated. I am grateful to committee member Dr. D. A. Hein for advice during all phases of my study and for critical review of my thesis. I extend special thanks to committee member R. G. Walter for his expert assistance in plant identification and for critical review of my thesis.

I thank Bureau of Land Management biologist C. Cesar for administrative support and field assistance during the study. I am also grateful to J. Bourassa and L. Kolz of the U.S. Fish and Wildlife Service, Denver Research Center. Their assistance in providing radio transmitters and telemetry equipment was invaluable.

I am grateful to the Kerr Coal Company and private landowners in North Park who allowed access to their property and facilitated data collection.

I greatly appreciate the cooperation of Colorado Division of Wildlife personnel: H.D. Funk for administrative support and thesis review, D. Benson for use of state facilities in Walden, and J. Wagner, S. Porter, and D. Gore who stayed out late and rose early to assist with banding and lek counts during the field season. The assistance of these individuals and all other Division of Wildlife personnel who assisted during all phases of this study is gratefully acknowledged.

Finally, the long hours of field assistance under less than ideal conditions in North Park provided by K. Giesen, S. McElderry, S. Emmons, and B. Petersen is sincerely appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

INTRODUCTION

Sage grouse are widely distributed throughout western North American rangelands dominated by sagebrush. Their dependence on sagebrush for breeding, nesting, brood-rearing and wintering activities has been extensively documented (Girard 1937, Rasmussen and Griner 1938, Patterson 1952, Klebenow 1969, Eng and Schladweiler 1972, Wallestad and Schladweiler 1974, Wallestad et al. 1975, Beck 1977).

Elimination and alteration of sagebrush for agriculture, grazing, and other developments have reduced both numbers and distribution of sage grouse throughout their historic range (Patterson 1952, Aldrich 1963). Schneegas (1967) estimated that 2-2.5 million hectares of sagebrush range had been disturbed during the previous 35 years by burning, spraying, plowing, discing, chaining, cutting, and beating. Approximately 30% of all sagebrush lands in Colorado had been treated between 1900 and 1974 (Braun et al. 1976). Beck (1975) estimated that 32% of the sagebrush lands in Jackson County, Colorado had been disturbed by 2,4-D spraying, plowing and seeding, and burning since 1957. Detrimental effects of sagebrush control practices on sage grouse have been documented for breeding habitat (Peterson 1970a, Wallestad 1975), nesting and brood-rearing habitats (Klebenow 1970, Martin 1970), and wintering areas (Higby 1969, Pyrah 1972).

Many important sage grouse habitats are underlain by extensive coal deposits. With increasing demands for western surface-mined coal, a substantial reduction in sage grouse habitat can be expected in Colorado and other western states. In 1968, western surface-mined coal accounted for less than 2% of all coal mined in the United States compared to 20% in 1978 (Slatick 1980). Although reclamation of mined areas is required by state and federal laws, current rehabilitation practices emphasize introduced grasses and forbs. Because re-establishment of the sagebrush community through succession is a long term process, mined areas will be lost as sage grouse habitat for decades.

In the face of decreasing amounts of sagebrush rangeland throughout the West, management of sage grouse populations will require a more complete understanding and detailed description of the sage grouse-sagebrush relationship. Previous studies of habitat use by sage grouse have been conducted during all seasons but have been limited primarily to discussion of sagebrush canopy cover and height or have been too general to be of value. Examination of a greater number of habitat factors and comparative data between sites used by sage grouse and random or nonuse sites will be necessary to fully understand how sage grouse select breeding, nesting, brooding, and winter habitats. Klebenow's (1969) study of nesting and brood habitats in Idaho using discriminant function analysis with 20 habitat variables has been the best attempt to identify critical factors in sage grouse habitat selection. Martinka (1972) was able to distinguish blue grouse (Dendragapus obscurus) breeding territories from non-territories 96% of the time using discriminant function analysis with 10 habitat variables.

It is especially important to identify critical seasonal ranges and specific habitat preferences of sage grouse in areas to be disturbed by mining or other developments. After a better understanding of sage grouse habitat needs is gained, mitigation and rehabilitation guidelines can be developed to improve disturbed and undisturbed sage grouse habitats. Existing and proposed coal mines in Jackson County, Colorado will impact historic breeding, nesting, brood-rearing, and winter habitats. The sage grouse population in this area is locally migratory with major wintering concentrations in the principal mining area in the northeast portion of the Park (Beck 1975). Consequently, habitat disturbance in northeastern North Park will impact the entire sage grouse population in Jackson County.

This study was conducted to identify specific seasonal habitat preferences of sage grouse throughout North Park, Jackson County, Colorado during April-August 1979 and February-August 1980. Hypotheses tested were: 1) sage grouse movement patterns differ between sexes within seasons, 2) sage grouse movement patterns for each sex vary during critical periods of the annual cycle (winter, breeding, nesting, brood-rearing), 3) sage grouse habitat selection differs between sexes within seasons, and 4) sage grouse habitat selection varies seasonally for each sex.

STUDY AREA

The investigation was conducted in North Park, Jackson County, Colorado. The study area was centered in the northeast quarter of North Park 13 km east of Walden although all areas of North Park were included depending on movements of radio-marked birds (Fig. 1). The primary study area lies within townships 8 and 9 north, and ranges 78 and 79 west (40° 38-48' N, 106° 05-15' W). It is bounded on the north and east by the Canadian River and on the west and south by the Michigan River (Fig. 2). Total area within these boundaries is approximately 250 km^2.

Topography of the area varies from relatively flat to rolling terrain with numerous ridges and benches separated by tributary drainages of the Canadian and Michigan rivers. Drainage of the major rivers is to the northwest into the North Platte River north of Cowdrey. Elevation ranges from 2,420 m along the Canadian River on the northern boundary to 2,758 m atop Johnny Moore Mountain.

Geologic formations and soils of the study area are derived from Pierre shale sediments of the late Cretaceous period (Miller 1934) and Coalmont shales, coal beds, sandstones and conglomerates of the Paleocene and Eocene epochs (Hail and Leopold 1960). Alluvial materials of the Canadian and Michigan river valleys are of more recent origin.

Beekly (1915) considered the coal beds of the McCallum anticline district to be of greater commercial importance than all the

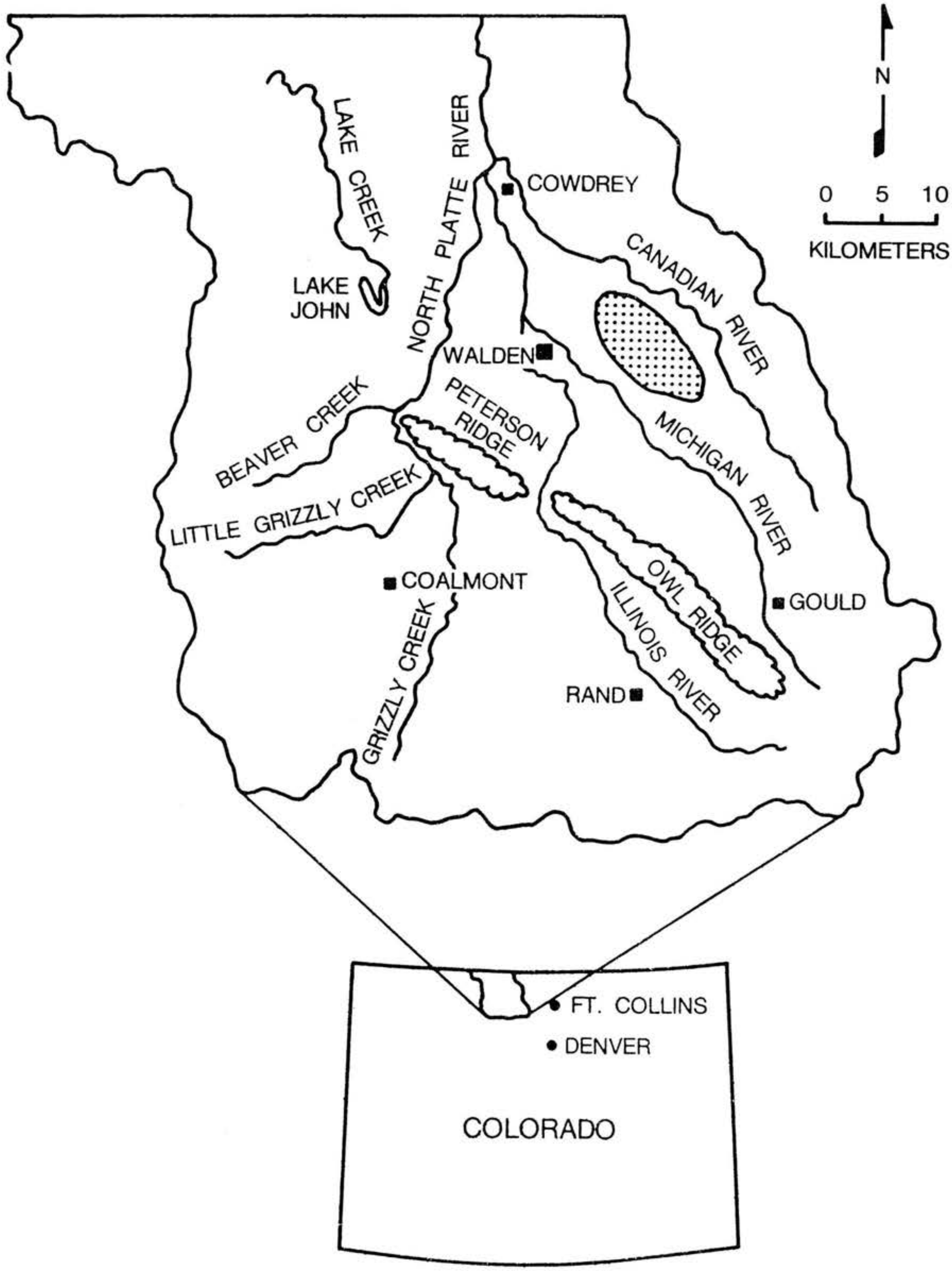

Fig. 1. North Park, Jackson County, Colorado. Intensive study area is the stippled area lying between the Canadian and Michigan rivers.

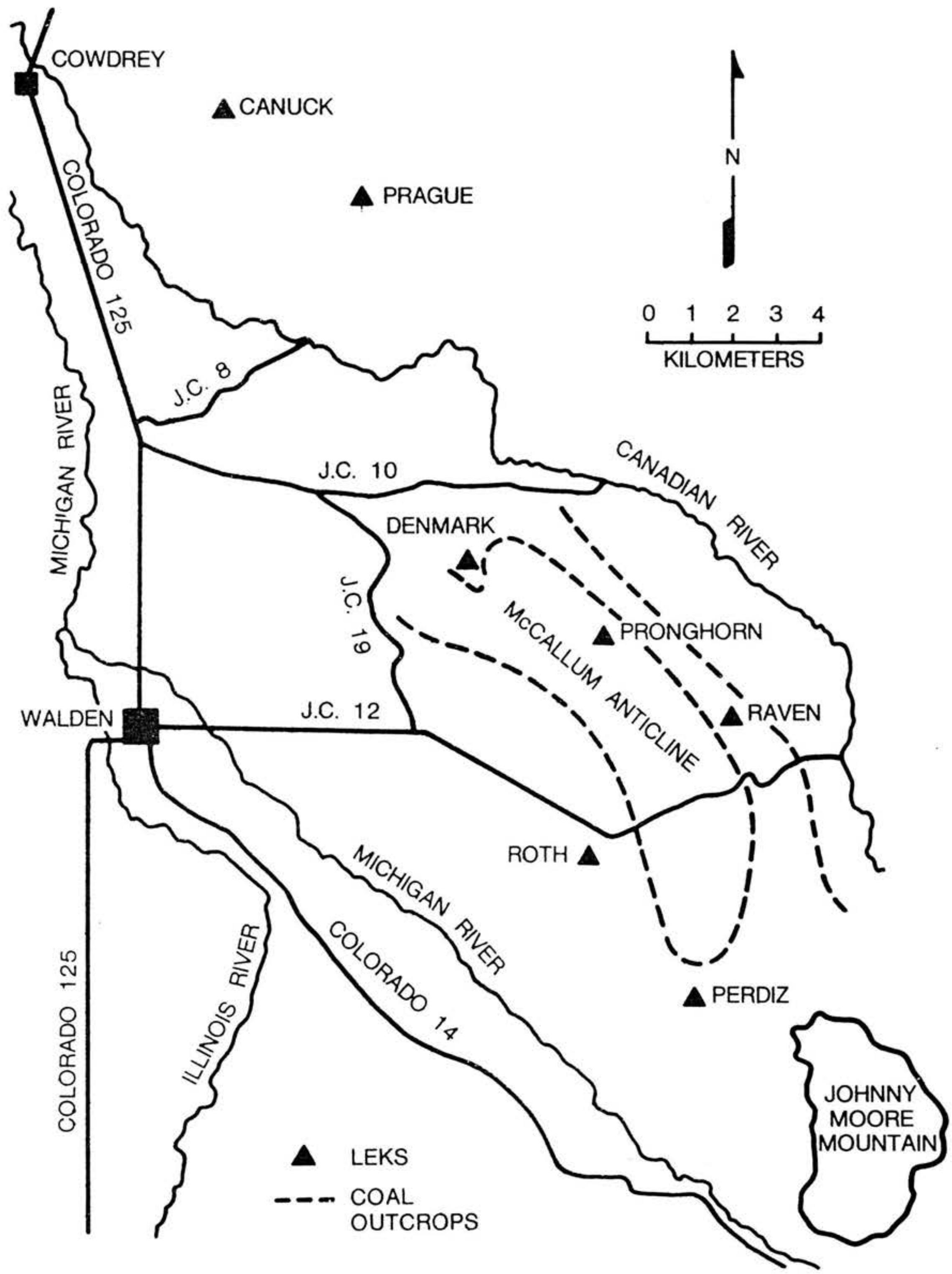

Fig. 2. Sage grouse leks and coal outcrops in the study area, North Park, Jackson County, Colorado.

remaining coal areas in North Park combined. The district occupies most of the region between the Canadian and Michigan river valleys (Fig. 2). With the exception of the anticlinal crest, the entire region is underlain by coal. Present mining activity is concentrated on the coal outcrops along the eastern boundary of the McCallum anticline from Perdiz Lek in the south to Denmark Lek in the north (Fig. 2).

There are 5 known leks in the study area and an additional 2 leks north of the Canadian River. Studies of sage grouse movements and habitat selection were primarily of birds radio-marked on Raven Lek but also from Perdiz and Denmark leks (Fig. 2).

The vegetative community of the area is dominated by sagebrush on upland sites, and grasses and sedges along native and irrigated hay meadows of the Canadian and Michigan rivers. Herbaceous vegetation consists primarily of perennial bunch grasses and forbs. Beetle (1960) identified 5 species of sagebrush in North Park. Approximately 90% of the sagebrush type is occupied by big sagebrush (Artemisia tridentata) (Smith 1966). Within the study area, big sagebrush dominates on loamy soils whereas alkali sagebrush (A. longiloba) dominates on shallow claypan and alkaline soils (Robertson et al. 1966). Silver sagebrush (A. cana viscidula) occurs in limited areas on poorly drained nonalkaline soils.

Other dry site shrubby species occurring on the study area include black greasewood (Sarcobatus vermiculatus), rabbitbrush (Chrysothamnus spp.), and antelope bitterbrush (Purshia tridentata). Shrubby species occurring on limited moist upland sites and river valleys include whortleleaf snowberry (Symphoricarpos vaccinioides), gooseberry currant (Ribes montigenum), and willows (Salix spp.).

Average annual herbage productivity of sagebrush rangeland in the study area ranges from 129-152 kg/ha on the Sandstone-Gravel and Coalmont Shale resource types to 62-80 kg/ha on the Coalmont-Claypan and Shale-Alkali resource types (Terwilliger and Smith 1978).

Sagebrush control practices in the study area were conducted in 4 areas between 1958 and 1964. Approximately 2,250 ha (9%) of the study area have been disturbed by plowing and reseeding, and spraying with 2,4-D. A 138-ha area 2 km north of Denmark Lek was plowed and planted to crested wheatgrass (Agropyron cristatum) and yellow clover (Trifolium sp.) in 1958. The most massive spraying operations were conducted in the areas around Raven and Perdiz leks. In 1963, 955 ha of sagebrush were block-sprayed around Raven Lek. In 1964, 777 ha of sagebrush were block-sprayed around Perdiz Lek. A 378-ha block, 4 km west of Denmark, was sprayed in 1963. Most of these sprayed areas have recovered well after 17-18 years although dead sagebrush plants remain standing throughout the treated areas.

The climate of North Park is cold and dry with an average annual frost-free period of 46 days (U.S. Dep. of Commerce 1979). Strong southwesterly winds are common from winter through early summer. Precipitation and temperature records were obtained from the Walden weather station (Table 1). January-June precipitation in 1979 and 1980 was 26 and 59% above the 30-year average, respectively. Winter-early summer temperatures did not vary greatly from the 30-year averages.

There was heavy snowfall and snow accumulation during both years (Table 2). Total snowfall during November-March was similar

Table 1. January-June precipitation and temperature, Walden, Colorado, 1979-80.

Year	Precipitation (cm)							Mean temperature (C)					
	Jan	Feb	Mar	Apr	May	Jun	Totals	Jan	Feb	Mar	Apr	May	Jun
1979	1.65	0.71	3.53	1.24	3.45	3.15	13.73	-12.4	-6.3	-3.8	1.6	6.3	11.2
1980	5.74	1.98	1.88	1.47	6.17	0.10	17.34	-7.1	-5.7	-4.6	-0.1	6.6	12.3
Avg[a]	1.30	1.07	1.27	1.83	2.59	2.82	10.88	-9.2	-7.7	-4.6	1.8	7.1	11.6

[a]Thirty-year average, 1941-70.

Table 2. November-March snowfall and snow depth, Walden, Colorado, 1978-79 and 1979-80.

Year	Total snowfall (cm)						Maximum snow depth (cm)				
	Nov	Dec	Jan	Feb	Mar	Totals	Nov	Dec	Jan	Feb	Mar
1978-79	9.9	56.1	30.7	9.9	32.0	138.6	5.1	30.5	38.1	38.1	7.6
1979-80	18.8	11.4	75.7	14.7	22.9	143.5	12.7	10.2	45.7	38.1	20.3

between years although snowfall patterns were different. Snowmelt was 1 month later than usual in both winters, occurring during early to mid-April.

METHODS

Sage grouse were captured while roosting along roads and on leks throughout the study area. Birds were located from a truck or on foot using a spotlight and were captured with a long-handled hoop net (Braun and Beck 1976). Captured grouse were marked with serially-numbered size 14 (females) and size 16 (males) aluminum leg bands and unnumbered plastic bandettes color-coded to year of capture. Sex, age (Eng 1955, Beck et al. 1975), weight, and primary molt were determined for all birds captured.

In 1979, 3 males and 4 females trapped on or near Raven Lek were fitted with 14-25 g 164 MHz radio transmitters mounted on tail clips (Bray and Corner 1972) attached to the 2 central rectrices. During 1980, 12 males and 17 females trapped throughout the study area were fitted with 15-21 g tail-clip radio packages. In addition, a 17-g solar-powered radio-collar and a 26-g battery-powered radio-collar (Amstrup 1980) were placed on a female and male, respectively. Transmitter packages were obtained from the U.S. Fish and Wildlife Service (Denver Research Center, Denver, Colo.), AVM Instrument Company (Champaign, Ill.), and Wildlife Materials, Inc. (Carbondale, Ill.).

Daily locations of radio-marked sage grouse were made at leks, feeding-loafing sites, and nests using a portable receiver and 3-element yagi antenna. A snowmobile was used during winter to approach birds in areas inaccessible by 4-wheel drive vehicles. All locations, determined by triangulation or by flushing birds, were plotted on 7.5-minute U.S. Geological Survey topographic maps. Movement distances were measured with a compass caliper. Size of study area and sage grouse ranges were determined with a planimeter following Mohr (1947).

Weather conditions, physiographic features, flock size, and composition were recorded at each site where radio-marked birds were flushed. Weather conditions included temperature, precipitation, wind direction, and a wind speed estimate recorded as none, light, moderate, strong, or very strong. Slope and aspect were measured with an Abney level and compass, respectively. Snow depth and percent snow cover were recorded during winter.

Vegetation measurements were made at leks, feeding-loafing sites, nests, and randomly located sites using a modification of Canfield's (1941) line interception method. Two 10-m transects were measured at each site. Transects were oriented along north-south and east-west axes with the bird location as the center of the plot at feeding-loafing and nest sites. The approximate mating center served as the center of the plot on leks. Random vegetation measurements were made along 20 randomly located 500 x 2.5-m sage grouse pellet transects. Four sites were randomly chosen along each transect.

Vegetation parameters recorded included percent canopy cover of foliated and unfoliated sagebrush, forbs, grasses, litter, and bare ground. All shrubs, forbs, and unknown grasses encountered on transects (Appendix) were collected and identified following Harrington (1954). Measurements were also made of sagebrush crown length and width, and live and dead height of the tallest branch on the largest plant in each clump intersected by the transect. In 1980, sagebrush density was measured under a 2-m-wide band along both transects at each site. Winter vegetation measurements were restricted to sagebrush and included both exposed and actual measurements after snow had been cleared from the transects. Grass height as well as canopy cover was measured in meadow areas where it provided most of the cover.

Soil samples, 15 cm in depth, were collected at each site measured in 1979. From these, 60 samples were randomly selected for analysis: 20 each from male feeding-loafing sites; female feeding, nesting and brooding sites; and randomly selected sites. Chemical analyses of the samples were performed by the Colorado State University Soil Testing Laboratory. Determinations of the following 12 soil characteristics were obtained: pH, conductivity (soluble salts), lime, organic matter, nitrate nitrogen, phosphorus, potassium, zinc, iron, manganese, copper, and soil texture. Conductivity and pH were evaluated using a saturated soil paste (Richards 1954). The lime test was an estimate based on sulfuric acid effervescence of the soil. Percent organic matter was determined using a potassium dichromate solution (Graham 1959). Nitrate nitrogen was extracted with water and evaluated using the chromotropic acid method of nitrate analysis (West and Ramachandran 1966). Phosphorus, potassium and micronutrients (Zn, Fe, Cu, Mn) were simultaneously extracted using ammonium bicarbonate in a diethylene triamine penta-acetic acid (NH_4HCO_3-DTPA) solution (Soltanpour and Schwab 1977). Phosphorus was determined by colorimetric evaluation and potassium and micronutrients were analyzed by atomic absorption (Soltanpour et al. 1979). Soil texture estimates were based on tactile examination.

Soil types and capability classes were obtained from 7.5-minute U.S. Geological Survey soil type maps of Jackson County, Colorado.

The Statistical Package for the Social Sciences (SPSS) programs (Nie et al. 1975) were used in data analysis. Student's *t* test was used to compare means of habitat variables among all sites. Frequency distributions of classification data were compared using chi-square analysis. Multivariate analysis of variance (MANOVA) was used to determine if differences ($P < 0.05$) existed among sites based on habitat factors, and what factors were accounting for the observed differences. Stepwise discriminant function analysis was used to form linear functions of the habitat variates to distinguish between sage grouse use and random sites. Principal components analysis with varimax factor rotation was used to ordinate sites based on linear functions of highly correlated habitat variables. Whereas discriminant function analysis maximizes distances between sites in multi-dimensional space, principal components analysis describes the relative positions of each site in space without maximizing intersite distances (James 1971). All tests were considered significant at $P \leq 0.05$ unless otherwise noted.

RESULTS

Radiotelemetry

During 1979-80, 36 transmitters were fitted on 22 female (13 adults, 9 juveniles) and 16 male (12 adults, 4 juveniles) sage grouse (Tables 3, 4). Three adult cocks and 4 hens (2 adults, 2 juveniles) were equipped with tail-clip transmitters between 18 April and 9 May 1979. Twelve males (8 adults, 4 juveniles) and 17 hens (10 adults, 7 juveniles) were fitted with tail-clip transmitters between 1 February and 29 June 1980. Adult male 8991 and adult hen 5088 were equipped with battery- and solar-powered radio-collars, respectively (Tables 3, 4).

Breeding season captures of sage grouse were concentrated around Raven Lek in 1979 and around Raven, Denmark, and Perdiz leks in 1980 (Fig. 2). Winter captures in 1980 were concentrated along J.C. roads 10 and 12.

Sage grouse hens were equipped primarily with AVM and U.S. Fish and Wildlife Service transmitters (Table 3) which were lighter ($\bar{x}$ = 15.7 g) than transmitters obtained from Wildlife Materials (WM) ($\bar{x}$ = 20.4 g). Sage grouse cocks were equipped primarily with WM transmitters (Table 4). Transmitter packages weighed an average of 1.09 and 0.73% of female and male grouse body weights, respectively.

Mortality of radio-marked sage grouse during the monitoring period was low. Only 2 of 22 hens (9%) and 3 of 16 cocks (19%)

Table 3. Transmitter data and known mortality of radio-marked female sage grouse in North Park, Colorado, 1979-80.

Age Band number	Transmitter Manufacturer[a]	 Weight (g)	 Percent of bird weight	Comments
Juveniles				
3401	USFWS	14.8	0.95	Shot 13 Sep 1980
3415	AVM	15.0	0.91	
3428	AVM	15.9	1.33	
3492	AVM	16.2	1.08	
5072	AVM	15.5	1.01	
5072[b]	AVM	15.7	1.26	
5086	AVM	15.6	1.07	Shot 21 Sep 1980
5087	AVM	15.9	1.05	
5089	AVM	16.3	1.06	
5090	AVM	16.2	1.08	
Adults				
3411	AVM	15.0	1.01	
3427	AVM	15.9	0.96	
3429	AVM	15.4	1.10	
3430[c]	AVM	16.1	0.88	Great horned owl predation
3432[c]	AVM	16.1	1.05	
3490[d]	AVM	15.9	1.06	
4499[d]	AVM	15.9	1.33	Unknown cause of death
4796	USFWS	14.5	0.97	Raptor predation
5032	WM	20.3	1.39	
5063	AVM	16.2	0.99	Shot 13 Sep 1980
5064[d]	AVM	15.9	1.42	
5075	AVM	16.2	1.00	
5088[e]	WM	17.1	1.17	
Avg		16.0	1.09	
Range		14.5-20.3	0.88-1.42	

[a]USFWS = U.S. Fish and Wildlife Service, AVM = AVM Instrument Co., WM = Wildlife Materials.

[b]Two different transmitters used on 5072 since the initial transmitter expired after 47 days.

[c]Same transmitter used on 3430 and 3432.

[d]Same transmitter used on 3490, 4499, and 5064.

[e]Solar-powered radio-collar.

Table 4. Transmitter data and known mortality of radio-marked male sage grouse in North Park, Colorado, 1979-80.

Age Band number	Transmitter Manufacturer[a]	 Weight (g)	 Percent of bird weight	Comments
Juveniles				
8731	WM	19.7	0.78	
8801	WM	20.1	1.00	Recaptured 15 Apr 1981
8981	WM	20.2	0.83	
8982	WM	20.4	0.78	
Adults				
7016	WM	20.8	0.70	Golden eagle predation
7149	WM	20.5	0.85	
7181	WM	21.3	0.67	
7327	USFWS	15.3	0.48	Recaptured 7 May 1981
7367	AVM	15.8	0.53	Recaptured 23 Apr 1980
8745	WM	20.1	0.71	
8747	WM	20.6	0.79	Raptor predation
8802	WM	20.3	0.80	
8829	AVM	15.8	0.58	Recaptured 23 Apr 1981
8879	WM	20.7	0.63	Recaptured 7 May 1981
8882	WM	19.7	0.65	Raptor predation
8991[b]	WM	26.3	0.89	
Avg		19.8	0.73	
Range		15.3-26.3	0.48-1.00	

[a]WM = Wildlife Materials, USFWS = U.S. Fish and Wildlife Service, AVM = AVM Instrument Co.

[b]Battery-powered radio-collar.

were known to have been killed by predators (Tables 3, 4). Hen 3430 was killed by a great horned owl (Bubo virginianus) on the same night she was captured and radio-marked. Hen 4796 was killed by a raptor approximately 2 weeks after she had left the nest with her brood. Cause of death of hen 4499 was unknown. She was found frozen into a snowbank with no apparent injuries 4 days after capture and radio-marking. She was at least 5 years old and the trauma of capture combined with severely cold weather (-38 C) during early February may have contributed to her death. Three hens monitored during 1979 (3401) and 1980 (5063, 5086) were shot during the 1980 hunting season. Male 7016 was killed by a golden eagle (Aquila chrysaetos) while traveling from breeding to summer range. Both other raptor kills (males 8747, 8882) occurred during the breeding season and appeared to have been by golden eagles.

The remaining radio-marked birds were monitored for varying periods depending upon transmitter life, movements beyond receiving distance limitations, and premature or normal molt of the central rectrices and transmitter package. Five cocks were recaptured on leks 1 or 2 years following original capture and monitoring (Table 4).

Twenty-two of 36 (61%) transmitters were recovered. The recovery rates of AVM and WM transmitters were approximately equal. Eleven of 18 AVM transmitters and 10 of 15 WM transmitters were recovered. Only 1 of 3 USFWS transmitters was recovered. Tail-clip radio package recoveries were made after premature loss of the central rectrices (6), predation (5), recapture (4), rectrix molt (4), hunter kill (1), and unknown mortality (1). The solar-powered radio-collar was recovered after it had either slipped from or had been pulled off by the hen.

Transmitter life was calculated for AVM (Table 5) and WM (Table 6) transmitters used during 1980. No data were available for 1979. Average transmitter life was evaluated using only those radios which were recovered and monitored or those which shut off while the bird was being tracked. Transmitters on birds with which radio contact was lost were not included since the birds may have moved out of the area while transmitters were still functioning. It was especially difficult to maintain radio contact with AVM transmitters since the maximum line-of-sight receiving distance was usually <5 km whereas WM transmitters could often be heard as far as 15 km. Differences in maximum line-of-site receiving distances between AVM and WM transmitters were attributed to differences in power output. WM transmitters contained 3.0 V lithium batteries whereas AVM transmitters contained 1.35 V mercury batteries.

Average transmitter life of WM radios was greater ($\underline{P} < 0.05$) and averaged 73 days longer than the average transmitter life of AVM radios (Tables 5, 6). Average transmitter life of WM radios would have been even greater had not 7 transmitters been returned to the manufacturer for battery replacement before the old batteries had expired.

Movements

Winter

Sage grouse winter movements were studied from early February to early April 1980. Sage grouse began moving into the study area

Table 5. Life of AVM transmitters[a] used on sage grouse in North Park, Colorado, 1980.

Channel	Pulse	Transmitter life (days)[b]	Comments
1	56	249	Radio package recovered and monitored
2	47	207	" " " " "
2	58	213	" " " " "
3	42		Lost radio contact after 212 days
3	60		Radio package recovered and shut off
4	60		Lost radio contact after 10 days
5	47		" " " " 121 "
5	67	34	Radio shut off when tracking bird
6	44		Lost radio contact after 73 days
6	64		" " " " 17 "
8	51	37	Radio shut off when tracking bird
8	65	129	Radio package recovered by hunter
9	47	47	Radio shut off when tracking bird
10	64	169	Radio package recovered and monitored
12	45		Lost radio contact after 72 days
Avg		136	
Range		34-249	

[a]SM1 with 1.35 V Hg batteries.

[b]Only those radios which were recovered or which shut off while tracking bird were included.

Table 6. Life of Wildlife Materials transmitters[a] used on sage grouse in North Park, Colorado, 1980.

Channel	Pulse	Transmitter life (days)[b]	Comments
2	50	199+	Radio package recovered and monitored
5	47	215+	" " " " "
6	51	214+	" " " " "
7	48		Lost radio contact after 128 days
8	42	246	Radio package recovered and monitored
8	43		Lost radio contact after 11 days
9	46	208+	Radio package recovered and monitored
9	59	145	" " " " "
9	60	260+	" " " " "
10	59	193+	" " " " "
11	53	199+	" " " " "
11	66		Lost radio contact after 87 days
11	72		" " " " 81 "
Avg		209	
Range		145-260+	

[a]HLP-2750-LD with 3.0 V Li batteries.

[b]Only those radios which were recovered were included.

+Transmitter returned to manufacturer for battery replacement prior to shut off.

following a 2-day blizzard in North Park on 28-29 January. Few birds had been located and none had been trapped prior to this time. Maximum snow depth in Walden before the storm was approximately 10 cm but increased to almost 46 cm following the storm (Table 2).

There were 2 major wintering areas used by sage grouse in the northeast and southeast quadrats of North Park in 1980 (Fig. 3). Use of these areas was documented by Beck (1975) during the winters of 1973-74 and 1974-75. Both areas are topographically diverse with sagebrush available in deep draws and swales, and on windswept ridges and hillsides. Because deep snow (up to 67 cm) covered most of the flat, open areas throughout North Park after the blizzard on 28-29 January, sage grouse sought food and cover in areas with numerous ridges, benches, and drainages.

Known movements of all radio-marked sage grouse encompassed 20,692 ha (Fig. 3). The northeast and southeast quadrat wintering areas were approximately 6,077 and 5,051 ha, respectively. Intensively used areas in the north and south were 2,282 and 2,410 ha, respectively. These 2 preferred areas encompassed only 3.7% (4,692/125,200) of the sagebrush-dominated land in North Park.

Although all birds followed were radio-marked in the northeast quadrat, they all eventually moved into the southeast quadrat, a distance of approximately 12 km. Adult male 7149 was the only bird known to have moved back and forth between the 2 areas on 2 occasions.

Average daily winter movements were similar ($\underline{P} > 0.05$) between sexes (Table 7). The greater range of daily movements by males was due to the difference in receiving distance between WM and AVM

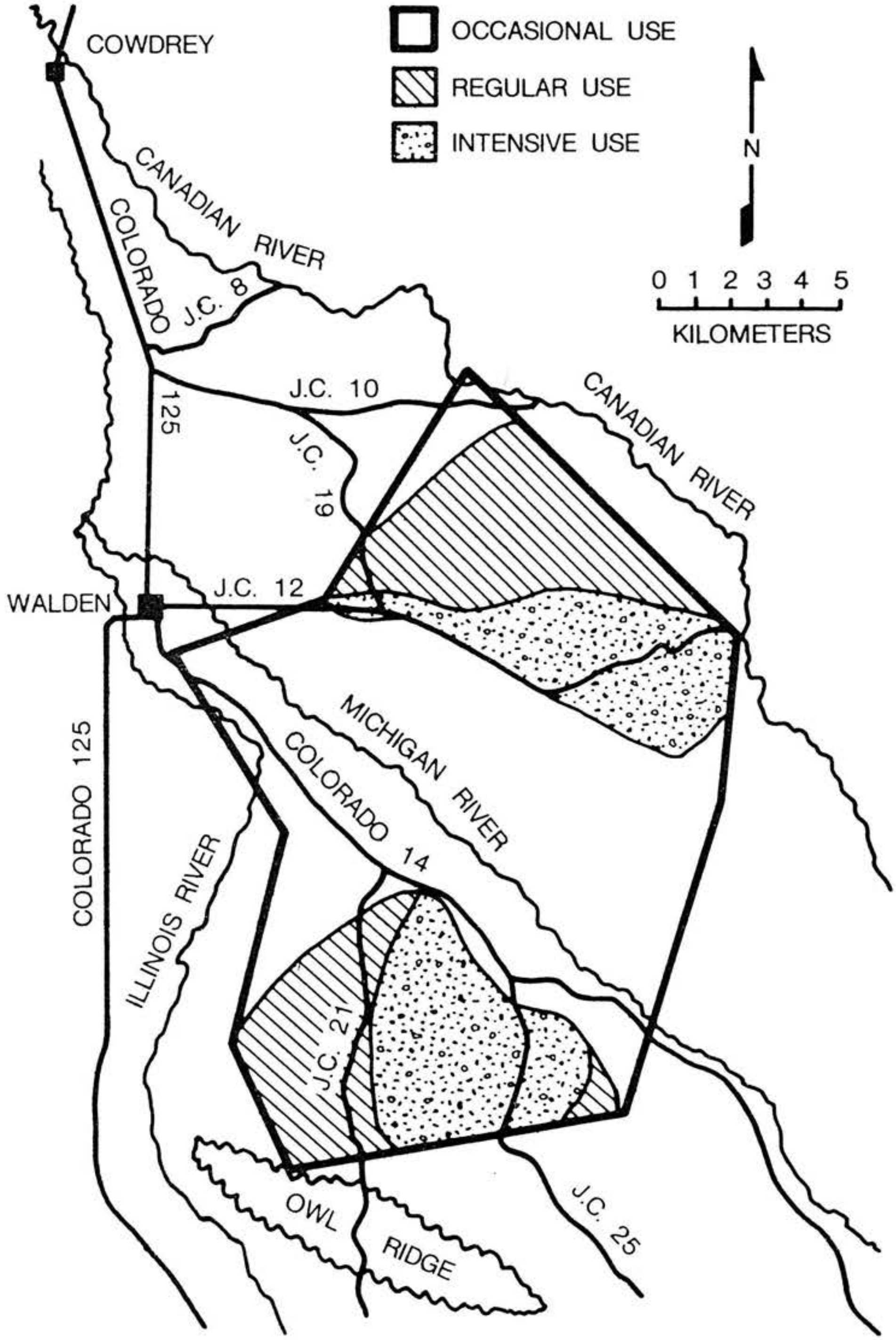

Fig. 3. Winter use areas of radio-marked sage grouse in North Park, Jackson County, Colorado, 1980.

transmitters used on males and females, respectively. Cocks could easily be located daily even after movements of 8-10 km whereas if a hen moved a long distance, it often took several days to relocate her.

Table 7. Daily movements and winter ranges of sage grouse in North Park, Colorado, 1980.

	Daily movements (km)			Winter range (ha)		
Sex	N	$\bar{x}$	Range	N	$\bar{x}$	Range
Males	57	1.6	0 -10.9	4	7,212	2,564-10,692
Females	34	1.5	0.1- 5.3	4	5,314	3,846- 7,487

Distance and direction of daily movements did not appear to have been influenced by my activities but rather by preference for suitable habitat and disturbance by golden eagles. As many as 5-6 eagles were seen daily flushing and pursuing flocks of sage grouse in wintering areas.

Winter range sizes were similar ($P > 0.05$) for males and females and both sexes used the same wintering areas. The greater average size of winter range for males was probably due to the shorter receiving distance of AVM radios used on hens.

A long distance movement by adult male 8802 and 3 other banded adult cocks to the northwest quadrat during a 2-day warm period in late February was not included as part of his winter range. This erratic move was interpreted as a premature movement to his breeding area since he later attended Bighorn Lek in the northwest quadrat during the breeding season.

Spring Migration

Winter flock break-up and dispersal to breeding areas began during the 2nd week of April 1980 coincident with the onset of the spring thaw. There was little difference in departure dates between sexes. Adults were located in breeding areas approximately 1 week following departure from wintering areas. Travel time to breeding areas was probably less than 1 week for most birds. At least 1 adult cock (7149) and 1 adult hen (5032) moved as far as 20 km during a 2-day period.

All radio-marked birds had left the northeast quadrat wintering area by the first week of April. Peak of departure from the southeast quadrat wintering area occurred only 2 weeks prior to the peak of hen attendance on leks. The southeast quadrat wintering area apparently also served as a staging area prior to dispersal to breeding areas.

Known movements from the southeast quadrat wintering area were to the northwest (2 cocks, 1 hen) and southwest (1 cock, 3 hens) quadrats (Fig. 4). Adult male 8829 remained in the southeast quadrat to breed and attended Spring Creek #2 Lek, 4 km southwest of the center of the wintering area. Movements of 3 radio-marked cocks from the southeast quadrat to leks in the northwest and southwest quadrats averaged 27.5 km (range 20.5-34.7). Four hens traveled an average of 29.9 km (range 25.6-35.1) from the southeast quadrat to nests in the northwest and southwest quadrats.

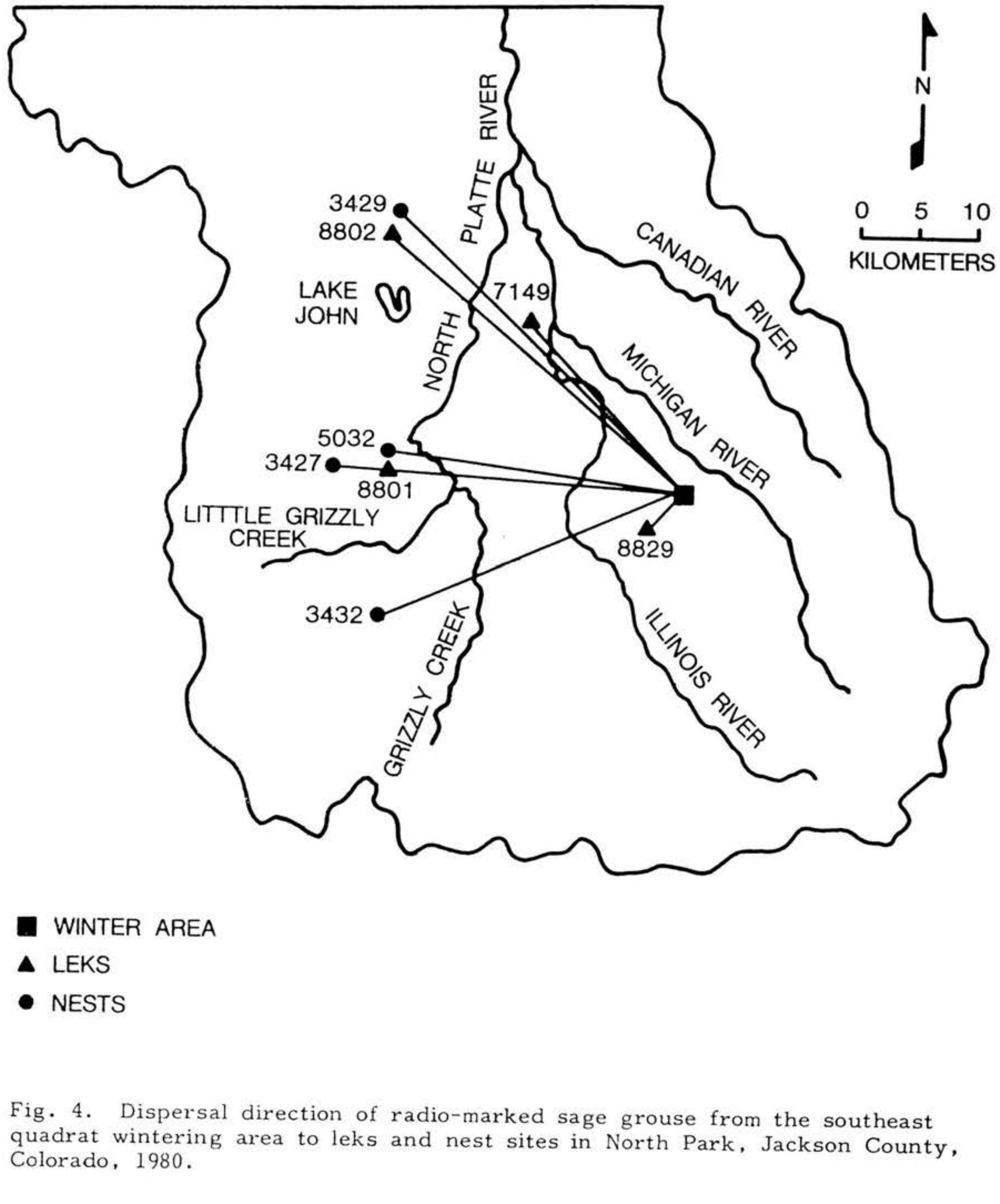

Fig. 4. Dispersal direction of radio-marked sage grouse from the southeast quadrat wintering area to leks and nest sites in North Park, Jackson County, Colorado, 1980.

Breeding Season

Six adult and 2 juvenile males from Raven Lek, 1 adult and 1 juvenile male from Perdiz Lek, and 2 adult males from Denmark Lek were monitored from late April to early June 1979-80. Only 1 of 9 adult males but all 3 juvenile males attended more than 1 lek during the breeding season.

Daily movements from all leks to feeding-loafing (FL) sites averaged 0.9 km (range 0.03-2.4). Daily movements from Raven Lek differed ($\underline{P} < 0.01$) between years. Distance from lek to FL sites averaged 0.9 km in 1979 and 1.3 km in 1980. The difference between years was attributed to a smaller sample size in 1980 ($\underline{N} = 12$) than 1979 ($\underline{N} = 80$) and timing of locations. In 1980, most locations were made during the 2nd half of May toward the end of the breeding season when daily movements from the lek tend to be greater ($\underline{P} < 0.10$) than during the 1st half of the month. Approximately 62% (61.9) of all FL movements from Raven Lek were within 1 km and 95.7% of all movements to FL sites were within 2 km of the lek.

Dispersal direction from Raven Lek to FL sites was nonrandom ($\chi^2 = 48.65$, df = 3, $\underline{P} < 0.001$). Forty-eight percent (62 of 130) of all FL movements were to the northwest, 28.5% (37) to the southwest, 17.7% (23) to the southeast, and only 6.2% (8) to the northeast (Fig. 5). Thirty-three percent (32 of 96) of all FL sites for which accurate locations were recorded were within the proposed Kerr coal lease.

Dispersal direction may be due to selection for sagebrush on more productive range sites. Seventy-six percent (99 of 130) of all movements from Raven Lek were to the west of Williams Draw in the

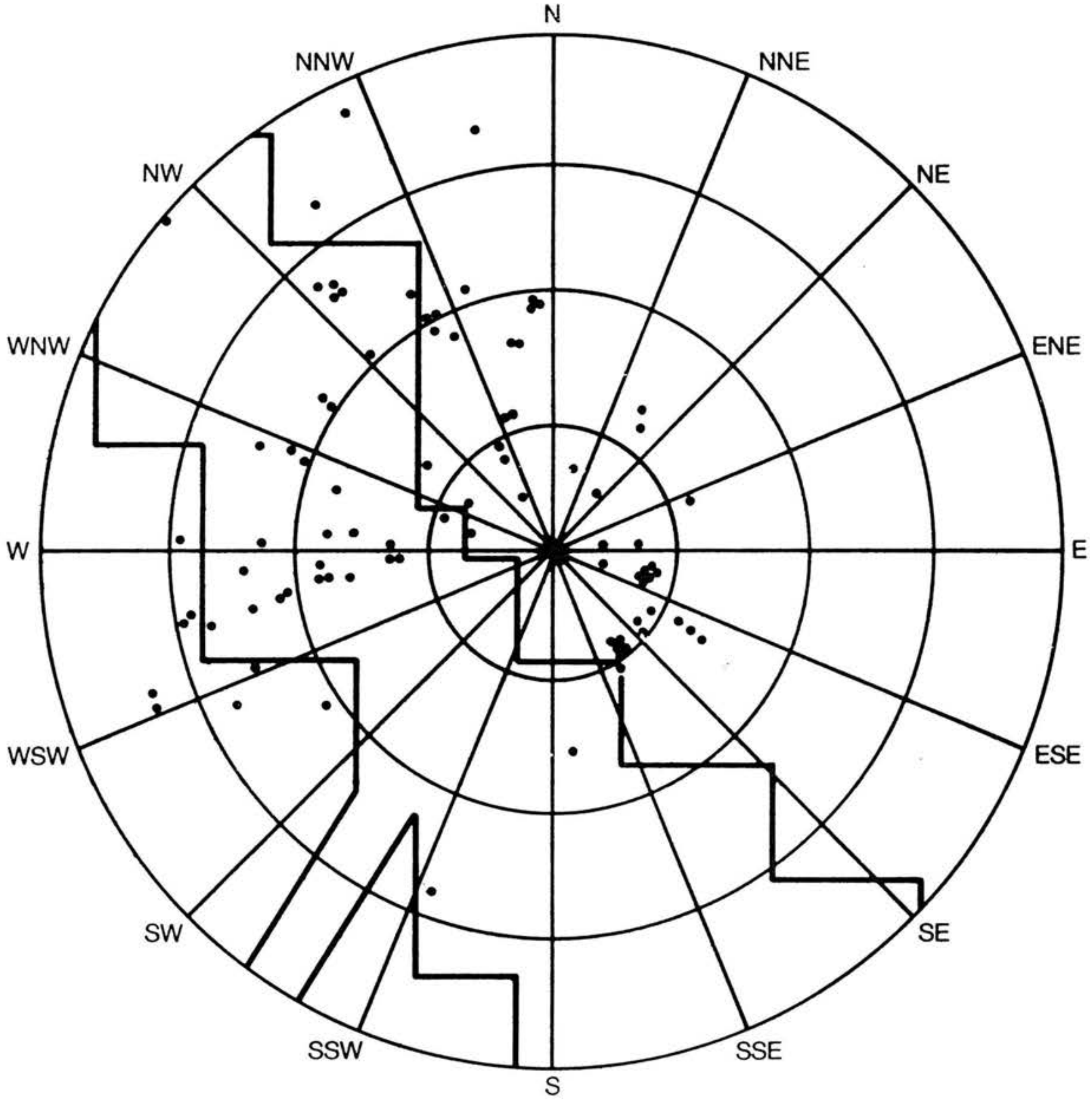

Fig. 5. Daily movements of male sage grouse from Raven Lek to feeding-loafing sites during 1979-80. Each concentric circle represents 0.5 km. The proposed Kerr coal lease is outlined. Four locations >2.0 km are not shown.

Sandstone-Gravel and Coalmont Shale resource types where average herbage productivity is 129 and 152 kg/ha/year, respectively (Terwilliger and Smith 1978). Coalmont-Claypan soils predominate to the east of Williams Draw where average herbage productivity is the lowest (62 kg/ha/yr) in North Park. Big sagebrush dominates on deeper, more productive soils west of Williams Draw, whereas alkali sagebrush dominates on the shallow, less productive claypan soils east of Williams Draw (Robertson et al. 1966, Terwilliger and Smith 1978).

Few data were available on daily movements from Denmark and Perdiz leks to FL sites but dispersal direction appeared to be non-random from both leks. Dispersal direction was predominantly northwest (8 of 9) from Denmark Lek, and northwest (5 of 11) and southeast (3 of 11) from Perdiz Lek.

Movements of 11 hens from leks to nests were obtained during 1979-80. The mean distance was 2.7 km for all known lek-to-nest movements. Adult hens traveled farther ($\underline{P} < 0.05$) from leks to nest sites than juvenile hens. The average lek-to-nest distance was 3.8 km (range 0.8-7.9) for adult hens and 0.5 km (range 0.3-1.4) for juvenile hens. Sixty-four percent of all hens nested within 1.5 km of the lek where bred. The remaining 36% nested beyond 3.0 km.

The mean distance from Raven Lek to 7 nests was 2.5 km (range 0.3-6.4). Five of 7 hens breeding on Raven Lek moved south to southwest to select nest sites. The other 2 hens selected nest sites northeast and southeast of the lek. Only 1 radio-marked hen breeding on Raven Lek nested within the proposed Kerr coal lease.

Nests of adult hens 3411 and 5063, however, were within 100 m of overburden piles on areas currently being mined south of Raven Lek.

Preincubation movements of hens from nests to FL sites averaged 0.4 km (range 0.1-1.8). Movements averaged 0.3 km for adults and 0.5 km for juveniles ($\underline{P} < 0.05$). Approximately 89% (88.9) of adult hens but only 63.9% of juvenile hens ($\underline{P} = 0.05$) fed within 0.5 km of the nest prior to incubation. Preincubation movements from nests to FL sites were shorter ($\underline{P} < 0.001$) than daily movements of males from leks to FL sites.

Feeding sites used during incubation were located 4 times. Mean distance from the nest was 160 m and ranged from 40 to 420 m.

Postbreeding

Daily movements of 3 hens with broods averaged 320 m ($\underline{N} = 12$, range 70-910). Distance traveled from the nest by each of 3 broods during the first week after hatch varied from 0.3 to 1.5 km. Total distance traveled during the first week, however, was more consistent with each of the broods traveling approximately 1.7, 1.8, and 1.8 km.

Movements to meadows by 2 hens (3415, 4796) with broods in 1979 were later than in 1980 by hen 5063 and her brood. Broods of hens 3415 and 4796 remained in sagebrush uplands for 2 weeks after hatching. Although movements toward meadow areas had begun, these broods had only moved 0.8 and 0.9 km from their nests, approximately one-fourth and one-half the distance to the nearest meadow area, respectively. In 1980, hen 5063 and her brood had arrived at the meadow area 2 weeks after hatching, a distance of 3.8 km from the nest.

In 1980, movements to meadows by unsuccessful hens and males occurred primarily during mid- to late June. In 1979, movements to meadows appeared to be 1-2 weeks later although there were insufficient data to accurately assess any difference between years. It is interesting to note, however, that movements of broods, unsuccessful hens, and males occurred simultaneously, probably as a response to vegetation dessication in sagebrush uplands.

In 1980, 4 of 5 radio-marked males and 5 of 6 radio-marked females moved to the meadow area nearest the lek attended or nest site, respectively. Distances moved to meadows were similar ($P > 0.05$) between sexes averaging 4.6 km (range 3.0-7.5) for cocks and 4.5 km (range 1.8-7.0) for hens. One male attending Perdiz Lek and both hens nesting near Perdiz Lek moved to the Michigan River meadows for the summer. Birds from Denmark and Raven leks generally moved to the Canadian River meadows. However, male 8991 from Raven Lek and hen 5086, nesting 1.0 km southwest of Raven, moved to the Michigan River meadows during the summer.

Summer

All birds restricted their summer (late Jun through Aug) movements to relatively small areas along the Michigan and Canadian river meadows. Summer ranges along the Canadian River meadows overlapped for birds from Denmark and Raven leks. Similarly, summer ranges along the Michigan River meadows overlapped for birds from Perdiz and Raven leks. Approximate areas of summer ranges along the Michigan and Canadian river meadows were identical at 333 ha each. Hen 5063 and her brood, however, remained within a 128-ha area along the Michigan River meadows apart from all other radio-marked birds.

Habitat Selection

Sage grouse habitat selection was analyzed using 26 habitat variables (Table 8). Variables chosen for analysis were limited to those which were thought to be important to sage grouse in selection of habitats. Average intercept distance (ATINDIS) was used as a measure of clump size since it explained 75.4% ($r = 0.868$, $P < 0.001$) of the variation in clump width. Approximately 92% ($R = 0.957$, $P < 0.001$) of the variation in clump width was explained by a regression of clump width on ATINDIS and average plant height ($F = 169.73$, df = 2, 31; $P < 0.001$). Microhabitat selection was examined with ABRDPLEN, ABRDPWID, and ABRDPTHT.

Slope

There were few differences in average slope or frequency of occurrence within each (0-5, 6-10, 11-15, and > 15%) slope class among random and sage grouse use sites except at unsuccessful hen FL sites and leks (Table 9). Mean slope at leks and unsuccessful hen FL sites was less ($P < 0.05$) than at all other sites. The difference between sites used by unsuccessful hens and other sites was probably the result of the small sample size ($N = 13$) for a few unsuccessful hens that restricted their movements to relatively flat areas.

Aspect

Mean values of aspect compared among sites indicated possible selection of south-facing slopes by grouse during winter and preference for east- to south-facing slopes during the breeding season (Table 10). Mean aspect at random sites was similar ($P > 0.05$) to

Table 8. Habitat variables[a] used in analysis of sage grouse use and random sites in North Park, Colorado, 1979-80.

Mnemonic	Description
SLOPE	Percent slope at site
ASPECT	Aspect corrected for declination
ATINDIS	Average sagebrush intercept distance under the line transect, cm
APLNLEN	Average crown length of sagebrush plants under the line transect, cm
APLNWID	Average crown width of sagebrush plants under the line transect, cm
APLNTHT	Average height of sagebrush plants under the line transect, cm
ABRDPLEN	Crown length of the plant beside which the bird was feeding-loafing or under which nest was located, center of plot at random sites
ABRDPWID	Crown width of the plant beside which the bird was feeding-loafing or under which nest was located, center of plot at random sites
ABRDPTHT	Height of the plant beside which the bird was feeding-loafing or under which nest was located, center of plot at random sites
AFSBCC	Foliated sagebrush canopy cover, %
ATSBCC	Total sagebrush canopy cover, %
PERFOLCC	Percent foliation of sagebrush canopy cover, = AFSBCC ÷ ATSBCC at breeding season and random sites, = EFSBCC ÷ ETSBCC at winter use sites
SBDENS	Sagebrush density, plants/m^2
FORBCC	Forb canopy cover, %
GRASSCC	Grass canopy cover, %
ETINDIS	Average sagebrush intercept distance under the line transect exposed above the snow, cm
EPLNWID	Average crown width of sagebrush plants under the line transect exposed above the snow, cm

Table 8. (Continued)

Mnemonic	Description
EPLNTHT	Average height of sagebrush plants under the line transect exposed above the snow, cm
EBRDPWID	Crown width of the plant exposed above the snow beside which the bird was feeding-loafing, cm
EBRDPTHT	Height of the plant exposed above the snow beside which the bird was feeding-loafing, cm
EFSBCC	Foliated sagebrush canopy cover exposed above the snow, %
ETSBCC	Total sagebrush canopy cover exposed above the snow, %
TOTCC	Total canopy cover of forbs and grasses in summer meadows, %
TARAXAC	Canopy cover of dandelion in meadows, %
TRIFOL	Canopy cover of clover in meadows, %
GRASSHT	Grass height in meadows, cm

[a]Variables are presented in the order in which they appear in the text.

Table 9. Slope at sage grouse use and random sites in North Park, Colorado, 1979-80.

Site[a]	N	$\bar{x}$(%)	Slope class (%) 0-5	6-10	11-15	>15
Male winter FL	63	7.5	38.1[b]	41.3	12.7	7.9
Female winter FL	50	7.6	40.0	38.0	14.0	8.0
Male spring FL	93	6.5	49.5	35.5	10.8	4.2
Female PIFL	44	6.8	56.8	25.0	15.9	2.3
Nests	17	7.4	50.0	22.2	16.7	11.1
Brood FL	23	5.7	60.9	26.1	8.7	4.3
Unsuccessful hen FL	13	2.2	100			
Leks	5	1.8	100			
Random	80	6.2	58.8	20.0	13.7	7.5

[a]FL = feeding-loafing site, PIFL = preincubation feeding-loafing site.

[b]Values are percent in each slope class.

Table 10. Aspect at sage grouse use and random sites in North Park, Colorado, 1979-80.

Site[a]	N	$\bar{x}$(°)	Aspect class N-E	E-S	S-W	W-N
Male winter FL	63	189	25.4[b]	25.4	25.4	23.8
Female winter FL	50	185	20.0	28.0	34.0	18.0
Male spring FL	90	116	55.5	30.0	6.7	7.8
Female PIFL	58	143	41.4	27.6	15.5	15.5
Nests	19	157	31.6	36.9	10.5	21.0
Brood FL	23	141	43.5	30.4	8.7	17.4
Unsuccessful hen FL	13	106	61.5	15.4	15.4	7.7
Leks	5	129	40.0	20.0	40.0	
Random	76	159	35.5	23.7	25.0	15.8

[a]FL = feeding-loafing site, PIFL = preincubation feeding-loafing site.

[b]Values are percent in each aspect class.

breeding season sites. Comparison of the frequency distribution in each (N-E, E-S, S-W, and W-N) aspect class, however, indicated no preference for aspect by males during winter and only slight preference for E-S and S-W aspects by hens during winter.

Disproportionately higher use of N-E and E-S aspects by sage grouse during the breeding season may be representative of the study area since the frequency distribution of aspect at random sites was fairly similar to breeding season sites. However, sage grouse may be selecting N-E and E-S facing slopes to avoid strong prevailing southwest winds during April-June.

Topography

It is more instructive to consider the overall topographic situation rather than slope or aspect separately. Sage grouse use and random sites were classified into 5 topographic categories based on physiographic features of the habitat (Table 11). Sage grouse selected winter FL sites primarily in draws and swales, and on windswept ridges and hilltops whereas breeding season sites and random sites were predominately on 0-5 and 6-10% open slopes. The only exception was at brood FL sites where 43.5% of all locations were in draws. There were, however, great differences in vegetation found in draws used by grouse in winter and those used by broods. Draws used during winter contained tall stands of sagebrush with high canopy cover where sagebrush plants were available above deep snow. Draws used by broods contained little sagebrush but had good forb and grass cover. Preferential use of draws can be explained by selection for sagebrush in winter and selection for forbs and insects by broods in late spring and early summer.

Table 11. Topographic features of sage grouse use and random sites in North Park, Colorado, 1979-80.

		Topographic feature				
Site[a]	N	0-5% open slopes	6-10% open slopes	>10% open slopes	Windswept ridges & hilltops	Draws and swales
Male winter FL	66	19.7[b]	18.2	10.6	19.7	31.8
Female winter FL	50	18.0	8.0		28.0	46.0
Male spring FL	93	43.0	31.2	10.8		15.0
Female PIFL	59	49.2	20.3	16.9	1.7	11.9
Nests	19	36.8	26.3	21.1		15.8
Brood FL	23	30.4	13.0	4.4	8.7	43.5
Unsuccessful hen FL	13	100				
Leks	5	100				
Random	80	57.5	20.0	13.7	7.5	1.3

[a]FL = feeding-loafing site, PIFL = preincubation feeding-loafing site.

[b]Values are percent in each topographic type.

Preference for windswept ridges and hilltops in winter can also be understood in terms of sagebrush availability since little or no snow accumulated and sagebrush was always available. Open slopes used during winter were adjacent to draws and ridgetops in the intensively used wintering areas (Fig. 3) and were therefore distinct from open slopes used during the breeding season. Extensive open areas (benches) with little topographic diversity that were preferred during the breeding season were covered with deep snow in winter 1980.

Habitat Structure - Univariate Analysis

Sample means of 10 habitat variables were compared among sage grouse use and random sites (Table 12). Sage grouse selected better ($P \leq 0.05$) structural cover at winter FL sites than at any of the breeding season use sites except nests. There were no differences ($P > 0.25$) between sexes during winter, however. The only significant difference ($P < 0.01$) between winter FL sites and nests was in average plant width although values of this and other habitat variables were lower at nest sites.

Due to heavy snow accumulation during winter 1979-80, it would be expected that average values of habitat variables would be much greater at winter FL sites since sage grouse sought areas where sagebrush was available above the snow. Snow depth averaged 40 cm at winter nonuse sites and approximately 20 cm at sage grouse winter FL sites.

Among breeding season sites, nesting hens selected habitats with the greatest ($P < 0.05$) average sagebrush clump size, plant dimensions, and canopy cover. Values of these habitat variables at nest sites were

Table 12. Habitat variables compared among sage grouse use and random sites in North Park, Colorado, 1979-80.

Site[a]	Habitat variable[b]									
	ATINDIS	APLNWID	APLNTHT	ABRDPWID	ABRDPTHT	AFSBCC	ATSBCC	PERFOLCC	SBDENS	FORBCC
Female winter FL										
$\bar{x}$	70.1	57.7	42.3	72.3	51.0	39.1	50.9	77.9	ND[c]	ND
SE	5.3	2.6	3.5	3.6	3.9	2.6	3.2	1.7		
N	49	50	50	50	50	49	49	49		
Male winter FL										
$\bar{x}$	63.8	57.2	40.6	75.0	50.2	38.9	49.6	77.1	ND	ND
SE	4.3	2.5	3.1	3.5	3.6	2.1	2.7	1.3		
N	50	53	53	53	53	50	50	50		
Nests										
$\bar{x}$	57.6	42.6	34.8	72.1	52.0	32.2	44.0	74.8	3.3	1.7
SE	7.1	3.6	2.7	4.3	2.6	3.0	4.2	3.0	0.3	0.4
N	19	17	19	17	19	19	19	19	13	19
Unsuccessful hen FL										
$\bar{x}$	43.7	42.0	32.5	61.0	42.1	28.7	38.2	75.9	3.1	5.2
SE	3.9	3.3	2.4	7.1	3.5	3.4	4.5	2.8	0.4	1.8
N	13	12	13	12	12	13	13	13	11	13
Male spring FL										
$\bar{x}$	40.2	37.2	29.6	63.9	45.8	24.5	35.0	66.5	3.2	2.6
SE	1.8	1.8	1.1	3.0	1.4	1.6	1.5	2.5	0.4	0.8
N	92	68	92	67	88	92	92	92	26	92
Brood FL										
$\bar{x}$	37.4	36.6	26.3	65.5	38.9	22.2	27.3	77.0	3.2	6.9
SE	4.3	4.3	2.5	4.0	2.3	3.2	3.3	6.7	0.6	2.4
N	23	18	23	18	22	23	23	23	9	23
Female PIFL										
$\bar{x}$	35.2	34.5	23.6	58.9	38.2	21.6	29.1	74.5	3.2	3.2
SE	1.7	1.6	1.2	4.3	2.1	1.3	1.6	2.2	0.3	0.4
N	59	41	59	41	50	59	59	59	19	59
Random										
$\bar{x}$	26.2	28.0	21.0	34.7	24.8	17.4	26.0	65.2	3.3	2.5
SE	1.2	1.1	1.0	2.2	1.6	1.2	1.6	2.5	0.4	0.3
N	80	77	77	69	69	80	80	80	19	80
Leks										
$\bar{x}$	19.6	20.4	10.4	ND	ND	10.2	11.2	93.4	2.1	4.8
SE	2.9	2.7	2.0			2.2	2.6	4.1	0.7	1.8
N	5	5	5			5	5	5	5	5

[a]FL = feeding-loafing site, PIFL = preincubation feeding-loafing site.

[b]Mnemonics of habitat variables described in Table 8.

[c]ND = no data.

not greater ($\underline{P} > 0.10$) than at unsuccessful hen FL sites. Males also chose spring FL habitat similar ($\underline{P} > 0.25$) to unsuccessful hens but not as good ($\underline{P} \leq 0.05$) as nest sites. Preincubation and brood FL sites were essentially identical. There were no differences ($\underline{P} > 0.25$) among any of the habitat variables measured between these 2 sites.

Only leks had lower ($\underline{P} \leq 0.05$) average sagebrush clump size, plant dimensions and canopy cover than random sites. Most habitat variables at all other sage grouse use sites were greater ($\underline{P} \leq 0.05$) than at random sites. Average sagebrush canopy cover at preincubation and brood FL sites was similar ($\underline{P} > 0.10$) to random sites. Average sagebrush plant height was also similar ($\underline{P} > 0.10$) between preincubation FL and random sites. Microhabitat plant dimensions were greater ($\underline{P} < 0.05$) at all sage grouse FL and nest sites than at random sites.

Sage grouse preferred sagebrush with higher ($\underline{P} < 0.05$) percent foliation (PERFOLCC) than at random sites (Table 12). PERFOLCC at male spring FL sites, however, was similar ($\underline{P} > 0.25$) to random sites. Except for leks, which had greater ($\underline{P} < 0.05$) percent foliation than any other site, there was uniform selection of percent sagebrush foliation (74.5-77.9) among all other sage grouse use sites.

The reason male sage grouse did not select higher percent foliated sagebrush during the breeding season may be explained by their tolerance for sprayed areas around Raven Lek. Because many defoliated sagebrush plants remained standing after 17 years, the percent foliated sagebrush canopy cover was low. There was good regeneration of sagebrush, however, and foliated sagebrush canopy cover (AFSBCC) and total sagebrush canopy cover (ATSBCC) were still much greater ($\underline{P}$ < 0.001) at male spring FL sites than at random sites.

There were no differences ($\underline{P}$ > 0.05) in sagebrush density (SBDENS) among any of the sage grouse use and random sites (Table 12). Whereas structural differences in habitat selection were evident with several of the other habitat variables, sagebrush density was uniform among all sage grouse use and random sites. Taken alone, sagebrush density gives no indication of differences in habitat selection between different types of sage grouse use or random sites. When considered along with sagebrush plant dimensions or canopy cover, however, it is a useful and necessary component in understanding sage grouse habitat selection.

The highest forb cover was found at brood and unsuccessful hen FL sites (Table 12). This did not appear to be the result of plant phenology since these 2 sites were not measured later than other breeding season sage grouse use or random sites. Although the only significant difference ($\underline{P}$ < 0.05) in forb cover was between brood FL and nest sites, the greater average forb cover at brood and unsuccessful hen FL sites can probably be attributed to selection of more forbs in the diet later in the breeding season. High forb cover at leks may be partly due to low sagebrush canopy cover ($\underline{r}$ = -0.456, $\underline{P}$ = 0.001).

Comparison of the ranges of sagebrush canopy cover (Table 13) and height (Table 14) classes selected by sage grouse and at random sites provided another useful means of viewing overlap and differences in habitat selection. Whereas sage grouse frequently selected sagebrush with >60% canopy cover and >50 cm height during winter

Table 13. Frequency distribution of sagebrush canopy cover at sage grouse use and random sites in North Park, Colorado, 1979-80.

Site[a]	N	Canopy cover class (%) 0-10	11-20	21-30	31-40	41-50	51-60	>60
Female winter FL	49		8.2[b]	14.3	20.4	4.1	16.3	36.7[c]
Male winter FL	50	2.0	6.0	12.0	10.0	24.0	14.0	32.0
Nests	19		10.5	15.8	21.1		31.6	21.1
Male spring FL	92	1.1	17.4	25.0	18.5	21.7	10.9	5.4
Female PIFL	59	3.4	20.3	35.6	23.7	11.9	3.4	1.7
Brood FL	23	17.4	13.0	30.4	21.7	8.7	4.3	4.3
Unsuccessful hen FL	13	7.7	7.7		53.8	7.7	7.7	15.4
Leks	5	40.0	60.0					
Random	80	17.5	21.3	22.5	17.5	21.3		

[a]FL = feeding-loafing site, PIFL = pre-incubation feeding-loafing site.

[b]In percent. Totals may only approximate 100%.

[c]Underlined values indicate most frequently used canopy cover class.

Table 14. Frequency distribution of sagebrush height at sage grouse use and random sites in North Park, Colorado, 1979-80.

Site[a]	N	Height class (cm)					
		0-10	11-20	21-30	31-40	41-50	>50
Female winter FL	50	2.0[b]	22.0	22.0	6.0	10.0	38.0[c]
Male winter FL	53	9.4	9.4	17.0	18.9	15.1	30.2
Nests	19			52.6	15.8	15.8	15.8
Male spring FL	92	2.2	12.0	44.6	31.5	6.5	3.3
Female PIFL	59	5.1	30.5	49.2	6.8	8.5	
Brood FL	23	8.7	17.4	43.5	17.4	8.7	4.3
Unsuccessful hen FL	13		7.7	30.8	46.2	15.4	
Leks	5	60.0	40.0				
Random	77	11.7	40.3	36.4	9.1	2.6	

[a]FL = feeding-loafing site, PIFL = preincubation feeding-loafing site.

[b]In percent. Totals may only approximate 100%.

[c]Underlined values indicate most frequently used height class.

1980, breeding season FL sites were more commonly selected in the 21-30% canopy cover and 21-30 cm height classes. Preferred nest sites were in canopy cover and height classes intermediate between winter and breeding season FL sites. No nests were found where sagebrush height averaged < 21 cm. Unsuccessful hens frequently selected greater sagebrush canopy cover and height than males, hens prior to incubation, and broods. All 5 leks were on sites where sagebrush canopy cover and height were < 21% and 21 cm, respectively.

Sage grouse selected a broad range of canopy cover and height classes of sagebrush at FL and nest sites. However, sage grouse selected greater canopy cover and height classes more often than what was typically available as indicated by random sites. Only 11.7% of the random sites but 44.9% of the FL and nest sites selected by grouse were in sagebrush averaging >30 cm tall. No random sites had average sagebrush canopy cover >50% or height > 50 cm, the cover and height classes used most frequently by grouse during winter 1980 and often as nest sites. This suggests that the available habitat contains substantially less preferred winter FL and nesting habitat than spring-early summer FL habitat for males, hens prior to incubation, unsuccessful hens, and broods.

Sagebrush clump size, plant dimensions, and canopy cover exposed above the snow were measured at FL sites of hens and cocks and at random sites in winter 1980 (Table 15). Although hens appeared to be selecting sites with better structural cover than cocks, the only difference ($\underline{P} < 0.05$) between sexes was in average plant height above the snow.

Table 15. Habitat variables compared among sage grouse winter FL[a] and random sites in North Park, Colorado, 1980.

Site	Habitat variable[b]						
	ETINDIS	EPLNWID	EPLNTHT	EBRDPWID	EBRDPTHT	EFSBCC	ETSBCC
Female winter FL							
$\bar{x}$	68.1	54.5	34.3	69.2	40.9	33.7	43.3
SE	5.0	2.5	2.9	3.6	3.1	2.8	3.5
N	46	46	46	46	46	46	46
Male winter FL							
$\bar{x}$	56.7	48.9	26.1	67.8	35.7	28.9	37.5
SE	4.4	2.6	2.4	3.5	3.3	2.4	3.2
N	49	49	49	49	49	49	49
Random							
$\bar{x}$	15.0	33.5	11.8	ND[c]	ND	1.8	2.4
SE	2.4	2.2	1.3			0.5	0.6
N	52	33	33			52	52

[a]FL = feeding-loafing site.

[b]Mnemonics of variables described in Table 8.

[c]ND = no data.

Both male and female sage grouse selected winter FL sites with much greater ($P < 0.001$) exposed sagebrush cover than at random sites. Exposed sagebrush clump size averaged 4 times greater and exposed sagebrush plant height was 2-3 times greater at grouse FL sites. Sagebrush was not encountered on 19 of 52 (36.5%) random winter transects.

Differences in exposed sagebrush height between sexes cannot be attributed to selection of FL sites with lower snow depth by hens. There were no differences ($P > 0.05$) in snow depth at sites used by male and female grouse during any month in winter 1980 (Table 16). Small differences in exposed sagebrush clump size, plant width, and canopy cover between sexes may be attributed to preference for lower ($P < 0.05$) percent snow cover by hens during February and March. Selection of FL sites with lower ($P < 0.05$) percent snow cover and snow depth than random sites was apparent during March and April.

Table 16. Snow cover and depth at sage grouse winter FL[a] and random sites in North Park, Colorado, 1980.

	Snow cover (%)			Snow depth (cm)		
Site	Feb	Mar	Apr	Feb	Mar	Apr
Male FL	93.8	84.7	71.4	30.8	15.7	8.5
Female FL	79.9	73.0	69.4	30.5	19.4	8.8
Random	ND[b]	95.8	86.4	ND	37.5	34.5

[a]FL = feeding-loafing site.

[b]ND = no data.

There were no differences ($P > 0.05$) in 6 habitat variables measured during summer 1980 in meadows at male, unsuccessful hen, and brood FL sites (Table 17). Summer ranges of males, unsuccessful hens, and broods overlapped so few differences could be expected. Percent forb cover and percent cover of alsike clover (Trifolium hybridum) were highest at brood FL sites. Percent cover of common dandelion (Taraxacum officinale) at brood FL sites, however, was lower than at sites used by males. Although sample sizes were small and differences were not significant, there is some indication that hens with broods might be selecting areas with slightly greater forb cover than either males or unsuccessful hens.

Soils Analysis

A soil sample analysis was done on soils collected during 1979 at male spring FL sites, preincubation FL sites, and random sites. Mean values of 9 soil variables were compared among sites (Table 18). Percent organic matter was higher ($P < 0.05$) in soils from male FL sites than in soils from preincubation FL or random sites. Soils from male spring FL sites also had lower ($P < 0.01$) pH, and higher ($P < 0.05$) copper and manganese concentrations than soils from random sites. Manganese concentrations were also higher ($P < 0.05$) at preincubation FL sites than at random sites.

Higher organic matter in soils from male FL sites can be attributed to 2,4-D spraying of the area around Raven Lek in 1963 and subsequent decomposition of dead sagebrush plants. Ninety percent (90.0) of the soil samples from male FL sites were collected in the

Table 17. Habitat variables compared among sage grouse summer FL[a] sites in meadows in North Park, Colorado, 1980.

Site	Habitat variable[b]					
	TOTCC	GRASSCC	FORBCC	TARAXAC	TRIFOL	GRASSHT
Brood FL						
$\bar{x}$	93.0	51.7	41.3	21.7	18.5	42.5
SE	2.2	8.1	9.5	9.1	10.4	3.5
N	10	9	9	10	10	10
Unsuccessful hen FL						
$\bar{x}$	96.8	63.4	33.4	13.6	6.3	40.3
SE	0.9	8.6	9.0	7.0	5.7	2.0
N	8	7	7	8	8	6
Male FL						
$\bar{x}$	94.0	53.2	40.8	25.1	6.5	39.9
SE	1.9	6.1	5.8	5.2	4.7	4.2
N	19	19	19	19	19	18

[a]FL = feeding-loafing site.

[b]Mnemonics of variables described in Table 8.

Table 18. Soil variables compared among sage grouse spring FL[a] and random sites in North Park, Colorado, 1979.

Site	Sample size	Soil variables[b]								
		pH	OM	NO_3	P	K	Zn	Fe	Mn	Cu
Male spring FL	20									
$\bar{x}$		6.3	4.0	4.1	9.7	290	3.5	35.8	21.9	3.1
SE		0.1	0.4	0.4	1.7	37.3	0.7	6.6	2.4	0.3
Female PIFL	13									
$\bar{x}$		6.5	2.9	3.8	6.6	331	2.5	36.2	15.8	2.3
SE		0.2	0.2	0.5	1.0	79.5	0.6	7.3	2.1	0.3
Random	20									
$\bar{x}$		6.7	2.9	3.1	7.9	269	2.2	23.9	11.2	2.3
SE		0.1	0.3	0.5	1.4	34.5	0.5	4.2	1.2	0.2

[a]FL = feeding-loafing site, PIFL = preincubation feeding-loafing site.

[b]OM = percent organic matter; all soil nutrients in ppm.

sprayed area whereas only 38.5% of preincubation FL site soil samples and 5.0% of random site soil samples were collected in the sprayed area.

The pattern of lower pH and higher concentrations of micronutrients (Zn, Fe, Mn, Cu) in soils from male FL sites is a result of higher percent organic matter. Breakdown of organic matter by microbial activity increases production of CO_2 and organic acids in the soil. The organic acids lower soil pH and cations of micronutrients become more available under these slightly acidic conditions (Sauchelli 1969). Slightly higher nitrate nitrogen concentration in soils from male FL sites is also related to organic matter since approximately 99% of the nitrogen in soil is provided by breakdown of organic matter (Thompson and Troeh 1973).

Sagebrush clump size, plant dimensions, and canopy cover reflect the same pattern found in organic matter among male FL, preincubation FL, and random sites. Structural attributes of sagebrush and organic matter were greater ($\underline{P} < 0.05$) at male spring FL sites than at either female preincubation FL or random sites. There were no differences ($\underline{P} > 0.05$) in organic matter and several habitat variables measured between preincubation FL and random sites.

Kononova (1966) reported a high positive correlation between soil organic matter and plant growth. Significant proportions of the variations in sagebrush clump length ($\underline{r} = 0.616$, $\underline{P} = 0.017$, $\underline{N} = 12$), live plant height ($\underline{r} = 0.589$, $\underline{P} = 0.001$, $\underline{N} = 59$), and canopy cover ($\underline{r} = 0.425$, $\underline{P} = 0.001$, $\underline{N} = 60$) can be explained by percent soil organic matter.

No differences ($\underline{P} > 0.25$) in soil capability classes were found between sage grouse use and random sites. Only poor soils (classes

6, 7, 8) occur in Jackson County, Colorado (U.S. Dep. Agriculture 1981). Approximately 89% (89.4) of all sage grouse use sites were on soil class 6 with the remaining 10.6% on soil class 7. This was similar to random sites where 86.2% of the sample was from soil class 6 and 13.8% from soil class 7.

Habitat Structure - Multivariate Analyses

Multivariate analysis of variance (MANOVA) was used to test for differences in multivariate (11 habitat variables) means among 7 types of sage grouse use and random sites. Since a highly significant ($\underline{P} < 0.001$) difference was found, a univariate analysis of variance (ANOVA) was performed to identify the habitat variables responsible for the observed difference. Highly significant ($\underline{P} < 0.001$) differences among sites occurred in 10 of 11 habitat variables (Table 19). Percent slope also contributed ($\underline{P} = 0.019$) to group separation so all 11 habitat variables were included in subsequent multivariate analyses.

Discriminant function and principal components analyses offer a means of viewing habitat selection by sage grouse using several habitat variables simultaneously. Similarities and differences in habitat selection can be more readily seen than when univariate analysis is used.

A stepwise discriminant function analysis was done for 323 vegetation plots at 7 types of sage grouse use and random sites. Leks were eliminated from the analysis because of insufficient sample size ($\underline{N} = 5$). Seven habitat variables provided significant ($\underline{P} \leq 0.10$) discriminating power between groups (Table 20). The 1st 3 discriminant functions (DFs) explained 93.6% of the total sample variance and were all highly significnat ($\underline{P} \leq 0.0015$).

Table 19. Univariate F tests[a] among sage grouse use and random sites in North Park, Colorado, 1979-80.

Habitat variable[b]	F	P
SLOPE	2.43	0.019
ATINDIS	19.66	< 0.001
APLNLEN	26.32	< 0.001
APLNWID	27.82	< 0.001
APLNTHT	11.16	< 0.001
ABRDPLEN	18.62	< 0.001
ABRDPWID	18.12	< 0.001
ABRDPTHT	12.67	< 0.001
AFSBCC	13.88	< 0.001
ATSBCC	12.50	< 0.001
PERFOLCC	4.90	< 0.001

[a]df = 7,311.

[b]Mnemonics of habitat variables from Table 8.

Table 20. Discriminant function analysis of sage grouse use and random sites in North Park, Colorado, 1979-80.

Habitat variable[a]	DF 1	DF 2	DF 3
SLOPE	-0.201	0.026	-0.257
ATINDIS	-0.036	-0.406	0.629
APLNWID	-1.301[b]	0.227	-0.127
APLNTHT	0.615	1.213	-0.097
ABRDPTHT	-0.043	-1.737	0.085
ATSBCC	-0.063	0.315	-0.921
PERFOLCC	-0.316	0.250	0.826
Percentage of variance explained by function	66.8	19.6	7.2
Cumulative percentage	66.8	86.4	93.6
P	<0.0001	<0.0001	0.0015

[a]Mnemonics of habitat variables from Table 8.

[b]Underlined coefficients indicate key habitat variables defining each function.

The 1st DF was primarily a function of sagebrush plant size (APLNWID, APLNTHT) and explained 66.8% of the sample variance. Although APLNWID and APLNTHT measured a similar attribute of the habitat (plant size), each provided significant ($P < 0.001$) discriminating power between groups. A high correlation ($r = 0.848$, $P = 0.001$) between APLNWID and APLNTHT resulted in opposite signs for the coefficients and contrasting effects on the function. Since the coefficient for APLNWID (-1.301) was over twice as large as the coefficient for APLNTHT (0.615), the contrasting effect of APLNTHT was diminished. Percent foliation of sagebrush (PERFOLCC) was also an important habitat variable distinguishing between sites in the 1st DF.

The 2nd and 3rd DFs explained an additional 19.6 and 7.2% of the discriminating power available in the 7 habitat variables, respectively. The 2nd DF can be understood in terms of microhabitat (ABRDPTHT) selection relative to preferred macrohabitat (APLNTHT). The 3rd DF was a function of sagebrush cover characteristics (ATSBCC, PERFOLCC) and clump size (ATINDIS).

Relative positions of sage grouse use and random sites were examined on the 1st 2 DF axes (Fig. 6). The 1st DF axis separated 3 distinct groups along a gradient of increasing plant size. Sage grouse selected large plants at FL sites during winter relative to breeding season FL or nest sites. Among breeding season sites, nesting hens selected the largest plants. Although males preferred spring FL sites with greater average plant size than broods or preincubating hens, the relative position of male spring FL sites was lower than either due to the influence of low percent foliation of

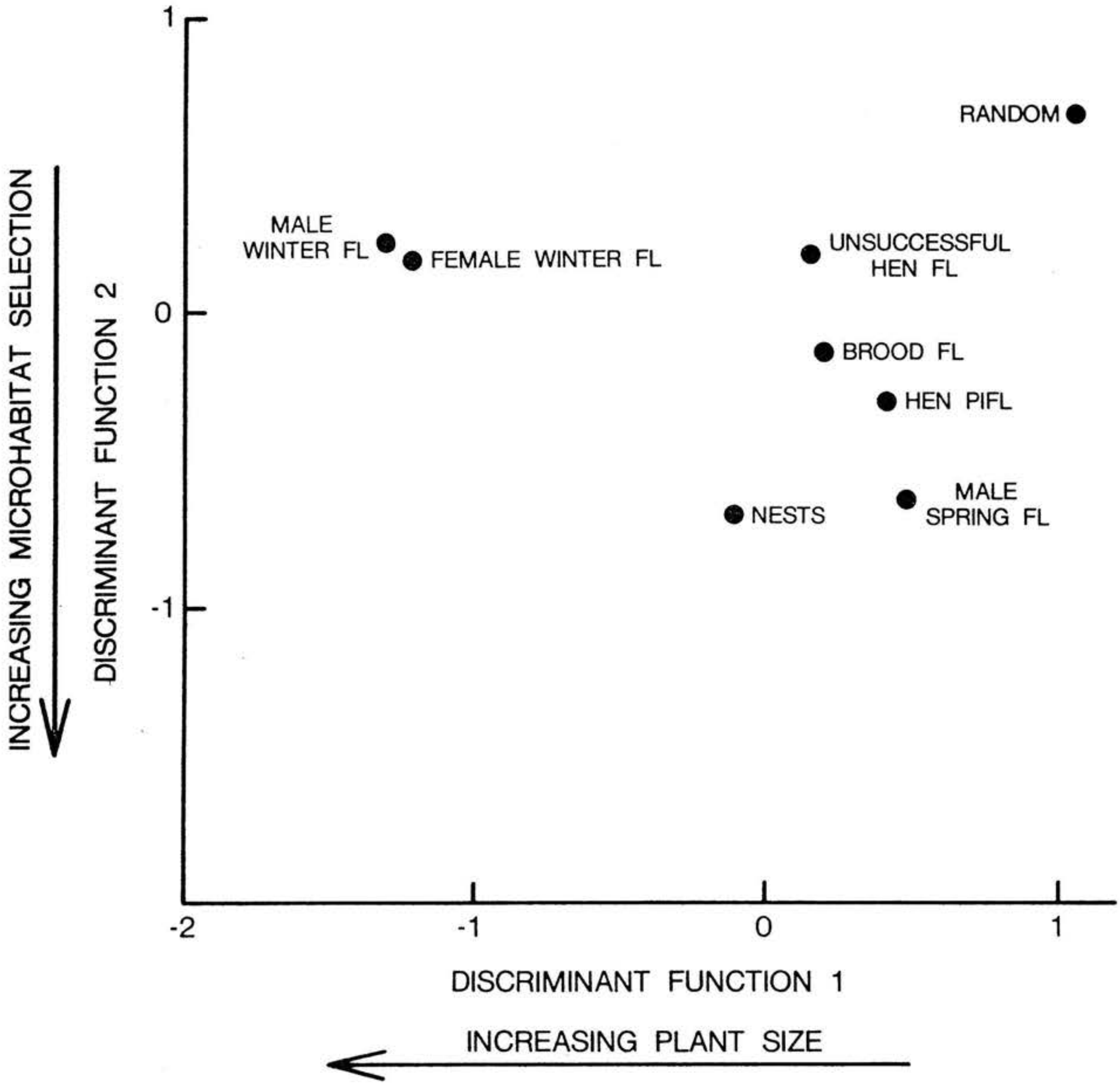

Fig. 6. Habitat relationships of sage grouse use and random sites along the 1st and 2nd discriminant function axes.

sagebrush. Random sites occupied the lowest position on the 1st DF axis since average plant size and percent sagebrush foliation were lower than at any of the sage grouse use sites.

The 2nd DF axis represented microhabitat selection. Microhabitat selection was most evident at nest sites. Hens selected plants under which to nest that were much larger than the average plant in the area (i.e., on the transect). Males also selected large plants beside which to feed and/or loaf during the breeding season.

Microhabitat selection was not as evident at winter FL sites as at most breeding season FL sites. With snow covering most of the sagebrush during winter, sage grouse were more limited in their ability to select microhabitats distinct from available cover. However, microhabitat selection was evident at all types of sage grouse use sites and further separated sage grouse use from random sites.

The overall correct classification of sites was low (42.72%) due to overlap in habitat selection among sage grouse use sites (Table 21). Preincubation FL and nest sites were frequently misclassified as male spring FL sites. Winter FL sites of hens and cocks were similar and were also frequently misclassified. Approximately 70% (69.6) of the random sites were correctly classified, however, indicating that sage grouse selected habitats quite distinct from that generally available.

The percentage misclassification of random sites as use sites for a given species has been used as an estimate of suitable habitat for the species (Titus and Mosher 1981). Overall, 30.4% of the random sites were misclassified as sage grouse use sites suggesting that only about 30% of the habitat is suitable for sage grouse. Random sites

Table 21. Classification results of discriminant function analysis at sage grouse use and random sites in North Park, Colorado, 1979-80.

Actual group membership[a]	N	Predicted group membership (%) Male spring FL	Female PIFL	Nests	Brood FL	Unsuccessful hen FL	Female winter FL	Male winter FL	Random
Male spring FL	67	47.8[b]	7.5	4.5	4.5	4.5	6.0	11.9	13.4
Female PIFL	41	22.0	9.8	7.3	19.5	7.3	7.3	2.4	24.4
Nests	17	35.3	5.9	29.4	17.6		5.9	5.9	
Brood FL	18	11.1	5.6	5.6	55.6	5.6	11.1	5.6	
Unsuccessful hen FL	12	8.3		8.3	33.3	16.7		16.7	16.7
Female winter FL	49		6.1	8.2	2.0	14.3	34.7	30.6	4.1
Male winter FL	50	2.0		8.0	6.0	16.0	24.0	40.0	4.0
Random	69	10.1	1.4	2.9	8.7	2.9	2.9	1.4	69.6
Percent of grouped cases correctly classified = 42.72%									

[a]FL = feeding-loafing site, PIFL = preincubation feeding-loafing site.

[b]Underlined values = percent correctly classified in each group.

were most frequently misclassified as male spring FL sites (10.1%) and brood FL sites (8.7%) suggesting that the total available habitat has more suitable areas for these uses than for other requirements such as nesting or winter FL sites.

Principal components analysis provided another method of examining habitat relationships among sage grouse use and random sites. Linear functions (components) of correlated habitat variables were derived, each of which defined a common habitat factor (Cooley and Lohnes 1971). Varimax factor rotation was used to simplify interpretation of the principal components. The 1st 5 principal components were readily interpretable and explained 94.1% of the total sample variance (Table 22).

The 1st principal component identified plant size (APLNLEN, APLNWID, APLNTHT) as the most important habitat factor separating different types of sage grouse use and random sites. Approximately 59% (59.4) of the total sample variance was explained by this component. The 2nd principal component was primarily a function of microhabitat selection (ABRDPLEN, ABRDPWID, APRDPTHT) and explained an additional 11.5% of the total sample variance. The 3rd component accounted for another 10.0% of the total sample variance and identified sagebrush canopy cover (AFSBCC, ATSBCC) and clump size (ATINDIS) as the most important habitat factors. Percent foliation of sagebrush and slope were the habitat factors most highly correlated with the 4th and 5th principal components, respectively. These last 2 components together accounted for 13.2% of the total sample variance.

Table 22. Varimax rotated principal components analysis of sage grouse use and random sites in North Park, Colorado, 1979-80.

Habitat variable[a]	Principal components I	II	III	IV	V
SLOPE	0.047	0.075	0.017	0.001	0.996
ATINDIS	0.574	0.229	0.702	-0.024	0.007
APLNLEN	0.842[b]	0.338	0.362	-0.005	0.056
APLNWID	0.824	0.332	0.395	0.017	0.039
APLNTHT	0.846	0.376	0.228	-0.032	0.027
ABRDPLEN	0.273	0.894	0.249	0.070	0.065
ABRDPWID	0.314	0.875	0.219	0.117	0.048
ABRDPTHT	0.528	0.723	0.201	0.021	0.051
AFSBCC	0.268	0.251	0.849	0.346	0.024
ATSBCC	0.310	0.238	0.902	0.011	0.015
PERFOLCC	-0.038	0.096	0.127	0.985	-0.000
Percentage of variance explained by function	59.4	11.5	10.0	8.5	4.7
Cumulative percentage	59.4	70.9	80.9	89.4	94.1

[a]Mnemonics of habitat variables from Table 8.

[b]Underlined coefficients indicate key habitat variables defining the component.

Relative positions of sage grouse use and random sites were plotted on the 1st 3 principal component axes (Fig. 7). The 1st axis (plant size) separated winter FL sites from all sage grouse breeding season and random sites. The 2nd axis (microhabitat) separated random sites from all sage grouse use sites. The 3rd axis (canopy cover and clump size) provided additional separation between different types of sage grouse use sites.

As with discriminant function analysis, 3 distinct groups were identified using principal components analysis. Furthermore, groups were distinguished primarily on the basis of plant size, secondarily by differences in degree of microhabitat selection, and finally on the basis of sagebrush cover characteristics. Male and female sage grouse selected similar winter FL habitats which were distinct from breeding season FL and nest sites. Sage grouse selected habitats which were distinct from random sites during all seasons. Nest sites were the most distinct breeding season site but differences in habitat selection were evident among all breeding season sites. However, relative positions of unsuccessful hen and brood FL sites in 3-dimensional habitat space would probably be somewhat different with larger sample sizes.

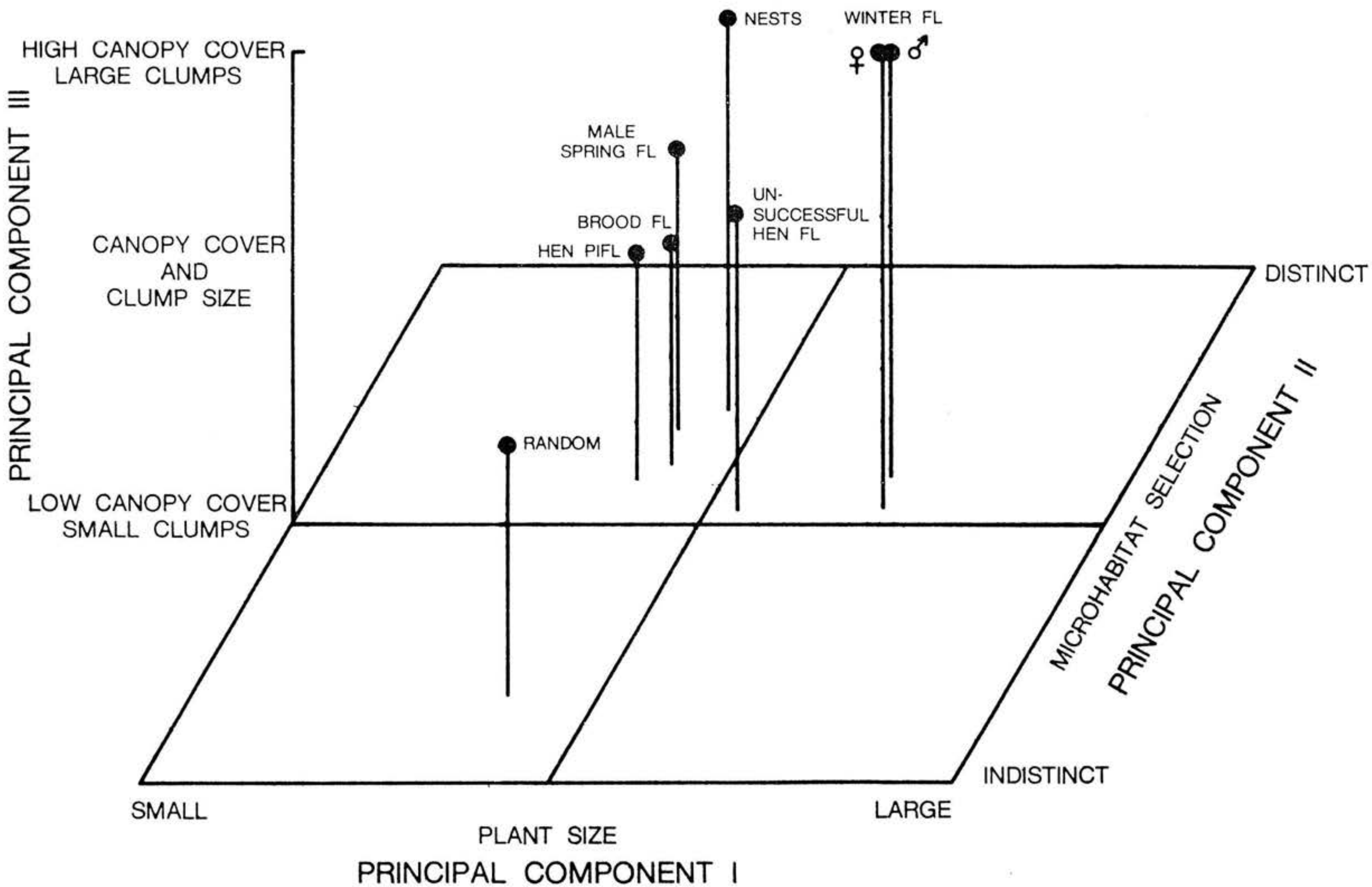

Fig. 7. Habitat relationships among sage grouse use and random sites on the first 3 principal component axes.

DISCUSSION

Radiotelemetry

Tail-clip transmitters used during 1979-80 worked well overall. There was no apparent interference with daily or seasonal movements or behavior, nor was there high predation of radio-marked birds. The slightly heavier WM transmitters were easily carried even by hens. Hen 5032 carried a WM transmitter equaling 1.39% of her body weight for at least 4 months. She moved approximately 32 km from winter to breeding range without apparent difficulty and laid a fertile clutch of 7 eggs.

Perhaps the best transmitter package for future studies will be solar-powered radio-collars. The solar-powered radio-collar used during this study had excellent line-of-sight receiving distance. The potential life and usefulness of solar-powered radio-collars for long-term data collection are much greater than for battery-powered radios. Premature loss of the radio package, the most common problem encountered with tail-clip models, could be alleviated using solar-powered radio-collars. Whether or not radio-collars interfere with male displays during the breeding period is unknown.

Movements

Movements by sage grouse to winter ranges in response to heavy snowfall and subsequent lack of available sagebrush in breeding and summer ranges has been well documented (Patterson 1952, Dalke et al. 1963, Beck 1977). Distances traveled, however, have varied depending on how far sage grouse have to go to find suitable cover above snow. Dalke et al. (1963) reported sage grouse flocks traveling up to 50 miles (80.5 km) from breeding and summer range to winter range in Idaho. Beck (1977) recorded greater average distances traveled during a severe winter in North Park than during a mild winter. Eng and Schladweiler (1972) reported that sage grouse concentrated in areas with dense stands of sagebrush during winter.

Winter concentration areas used in 1980 were outlined by Beck (1975) during the winters of 1973-74 and 1974-75. The fact that sage grouse from all quadrats of North Park depend on habitat in the northeast quadrat at least part of the winter and that the northeast quadrat intensive use area comprises only 3.7% of the sagebrush habitat in North Park underlines its importance to the entire sage grouse population within the Park. Beck (1975) recognized 7 high use areas encompassing only 6.8% of the total available sagebrush rangeland in North Park. The intensive use area in the northeast quadrat is especially important since it provides essential winter habitat even during mild winters. Beck (1975) recorded the highest winter use in the northeast quadrat during the winters of 1973-74 and 1974-75 when precipitation averaged 26% above and 26% below normal, respectively.

Similar average daily movements and size of winter range areas for males and females during winter 1980 might be expected considering that all grouse were restricted to limited areas where sagebrush was available above snow. Eng and Schladweiler (1972) recorded shorter daily movements and smaller winter ranges for hens in Montana than was found in North Park. Differences between Montana and Colorado may be due to use of 2 widely separated (12 km) winter ranges in North Park in 1980 vs. only 1 winter range area in Montana.

Daily movements by males from leks to FL sites were similar to those reported by Emmons (1980) in the Lake John area of North Park. Emmons found that 90.1% of all daily movements were within 2.0 km of the lek compared to 95.7% in this study. Wallestad and Schladweiler (1974) reported that male sage grouse moved a maximum of 1.8 km from leks to FL sites in Montana.

Nonrandom dispersal from leks has been documented previously by Emmons (1980). Nonrandom dispersal can most likely be attributed to selection of preferred habitat around leks although topographic features may also influence movements. Selection of distinct FL habitat on the basis of sagebrush structure was evident. Preferred sagebrush species appeared to be an important factor determining dispersal direction from leks to FL sites.

There is considerable variability in average lek-to-nest distances reported in the literature. Average distance traveled by hens from leks where bred to nest sites in 1979-80 was 2.7 km. Comparable movements were observed by Poley (1969) in North Park and Wallestad and Pyrah (1974) in Montana. Petersen (1980), however, reported average lek-to-nest movements of 4.0 km in North Park. May (1970) also observed longer average movements in North Park; 4 juvenile hens moved an average of 8.2 km while 4 adult hens moved an average of 4.4 km from leks to nests. Variability in lek-to-nest movements in North Park may be due to small sample sizes but probably also reflects differences in availability of suitable nesting habitat close to leks.

There is also disagreement among studies of lek-to-nest movements regarding differences between age classes of hens. This study and Petersen (1980) documented adult hens traveling farther than juvenile hens to select nest sites. May (1970), however, reported juveniles traveling almost twice as far as adults to nest. Wallestad and Pyrah (1974) noted little differences between age classes with juveniles moving just slightly farther (2.8 km) than adults (2.5 km).

Observed differences between age classes in lek-to-nest distances may be related to quality of nesting habitat selected. Adult hens may be more selective in nesting habitat and therefore travel longer distances to find suitable sites. During 1979-80, adult hens fed closer to the nest site more often than juvenile hens suggesting that adults selected nest sites with better feeding cover nearby.

Movements from breeding to summer range were typically to the meadow area nearest the lek attended or nest site. Movements within summer ranges were more restricted than during any other period of the year. Sage grouse concentrated in meadow areas with abundant herbaceous vegetation so movements to find suitable FL habitats were minimal.

The only observed difference in movement patterns between sexes occurred during the breeding season. Males traveled farther from leks to FL sites than hens moved from nests to FL sites. Therefore, the hypothesis of differential movement patterns between sexes was rejected for winter and summer periods but was accepted for breeding season movements.

Differential movement patterns between seasons within sex class were evident for both sexes. All radio-marked birds underwent long migrations to wintering areas whereas movements to summer areas were generally restricted to movements to the nearest meadow area. Given a mild winter with little snowfall, however, little migration would be expected. Before the blizzard in late January 1980, there had been little snowfall and no observed migration of sage grouse into the northeast quadrat from other areas of North Park. Average daily movements and home ranges used during winter were greater than during the breeding season for both sexes. Hens restricted breeding season movements to areas around their nests and males restricted movements to FL areas around leks. Thus the hypothesis of differential movements between seasons within sex class was accepted.

Habitat Selection

Sage grouse selected habitats with fairly similar average slope and aspect as that found at random sites except at leks where flat, open areas were preferred. Selection of flat, open areas for lek sites has long been recognized (Patterson 1952, Rogers 1964, Rothenmaier 1979, Dingman 1980). There were distinct differences in topographic features selected during different periods of the year, however. During winter, sage grouse preferred sagebrush draws and swales more often than windswept ridges or open slopes. Beck (1977) recognized a preference for west- to southeast-facing slopes >5% where wind and solar irradiation kept sagebrush virtually free of snow throughout winter. Windswept ridges were the 2nd most frequently used winter FL site in 1980. Perhaps the reason Beck (1977) did not encounter sage grouse more frequently in sagebrush draws was due to sampling bias for areas where sage grouse could be readily observed.

Without radio-marked birds, it is difficult to locate sage grouse in heavy sagebrush cover in draws.

Use of 0-5 and 6-10% slopes by sage grouse during the breeding season was fairly similar to a random sample of the study area. Draws and swales, however, were used more frequently than they occurred in the random sample. Broods especially preferred draws where herbaceous vegetation was abundant. Selection for abundant forb cover by broods has frequently been encountered in North Park (Gill 1965, Poley 1969, May 1970, Petersen 1980) and throughout the West (Patterson 1952, Klebenow 1969, Peterson 1970b, Wallestad 1971).

Differences in structural habitat selection were evident at sage grouse use sites with winter FL sites being the most distinct. Given a milder winter in 1980, however, winter FL sites probably would have been more similar to breeding season FL sites. In Montana, Eng and Schladweiler (1972) reported similar mean sagebrush canopy cover at female winter FL sites (28%) as was found at male spring FL sites (32%) by Wallestad and Schladweiler (1974) in the same area. Sagebrush canopy cover and height at winter FL sites in North Park in 1980 were much greater than reported by Eng and Schladweiler (1972) during milder winters in Montana.

Exposed height of sagebrush above the snow at winter FL sites in 1980 was greater than found by Beck (1977) during a winter with heavy snowfall. Beck sampled flocks visible from a snowmobile and may have overlooked flocks which were concealed in heavier sagebrush cover.

The only observed difference between sexes in winter FL habitats was in exposed sagebrush height above the snow. Hens selected areas with greater exposed plant height than males. Beck (1977) found that during a winter with heavy snowfall, predominantly female flocks chose areas with greater sagebrush density than predominantly male flocks but that there was no difference between sexes in selection of sagebrush height above the snow. Differences between sexes in selection of exposed sagebrush height and density may not be real but hens selected FL areas with slightly better structural cover in both winters of Beck's study and again in winter 1980.

There were obvious differences and similarities among breeding season FL and nest sites. Nesting hens sought better average cover than was found at FL sites although a wide range of sagebrush canopy cover and height classes were used. Cover attributes at unsuccessful hen FL sites were intermediate between nests and male spring FL sites. However, the small sample size for unsuccessful hens may not accurately reflect preferred cover. Structural similarities in FL habitats selected by hens prior to incubation and during the brooding period suggest that hens continue to select similar habitats throughout the breeding season. Forb cover at brood sites, however, was over twice as great as that encountered at preincubation FL sites.

Nest sites had greater sagebrush canopy cover than previously reported by Klebenow (1969) in Idaho, Martin (1970) and Wallestad and Pyrah (1974) in Montana, and Petersen (1980) in North Park. Average canopy cover ranged from 18.4 to 27% in these studies compared to 44% in North Park during 1979-80. Average height of the plant over the nest and mean sagebrush height in the area around the nest were more comparable to previous studies. Differences in canopy cover may be partly due to small sample sizes for nest sites ($\underline{N}$ = 19) but it is unlikely that this would account for a 20% difference in canopy cover. Differences in canopy cover at nest sites between North Park and Idaho and Montana may be related to other factors including soils, climate, and species/subspecies composition of sagebrush.

Sagebrush canopy cover at brood FL sites was also greater than has been encountered during similar periods on brood ranges in Idaho (Klebenow 1969) and Montana (Martin 1970, Peterson 1970b, Wallestad 1971). As with nest sites, average sagebrush height at brood FL sites in North Park was comparable to brood ranges in Idaho and Montana. Average forb cover at brood FL sites in sagebrush was only 6.9%, markedly lower than average forb cover of 22-33% reported by Martin (1970), Peterson (1970b), and Wallestad (1971) in Montana. However, once broods reached summer ranges in meadows in North Park, forb cover increased to 41.3%.

Average sagebrush canopy cover of 35.0% at male spring FL sites was somewhat higher than that reported in previous studies. Wallestad and Schladweiler (1974) found 32% canopy cover at breeding season FL sites of males in Montana and Emmons (1980) reported 28% sagebrush canopy cover at male spring FL sites in the Lake John area of North Park.

Wallestad and Schladweiler (1974) stated that sagebrush height at male spring FL sites was representative of the study area in Montana rather than a result of selection by sage grouse. They did not, however, provide data to support this statement. Even if structural attributes of the habitat are similar between random and sage grouse use sites, as was true for several habitat variables measured at preincubation and brood FL sites in North Park, that is not an indication that sage grouse are not selecting habitats. They may simply be selecting habitats with similar structural attributes as random sites. Other habitat differences may be recognized, however. For example, broods and preincubating hens both chose sagebrush with higher percent foliation than random sites. In addition, microhabitat selection was evident at all sage grouse use sites compared to random sites.

Differences in habitat selection between different types of sage grouse use sites and between sage grouse use and random sites were easier to identify when all habitat variables were analyzed simultaneously using discriminant function and principal components analyses. Whereas preincubation and brood FL sites appeared to be more similar to random sites than other breeding season sites and nest sites appeared to be similar to winter FL sites using univariate analysis, multivariate analyses indicated that actual habitat relationships differed. It was evident that sage grouse selected habitats in a nonrandom fashion and that distinct habitats were selected within as well as between seasons.

Perhaps the most valuable contribution of the multivariate analyses was identification of habitat components which distinguish best between different types of sage grouse use sites and between sage grouse use and random sites. Sagebrush plant size was the key habitat variable which discriminated best between sites. Microhabitat plant dimensions were the 2nd most important component in selection of FL and nesting habitats. Finally, sagebrush canopy cover and clump size were important variables separating sites. Whereas canopy cover has long been deemed of primary importance in distinguishing between sage grouse breeding, nesting, brooding, and winter habitats, plant dimensions were the most important component in sage grouse habitat selection. This does not discount the fact that canopy cover is also important in sage grouse habitat selection. Sage grouse select habitats on the basis of both suitable plant size and canopy cover classes of sagebrush.

Selection of seasonal habitats with distinct plant dimensions and canopy cover may be understood in terms of cover needs and behavior. During the heavy snowfall winter of 1980, large plants were often sought since they were available despite deep snow cover. Nesting hens chose areas where relatively large plants provided concealment from predators and good feeding cover nearby. Males may have selected areas with larger plants than hens at FL sites during the breeding season due to larger body size and a need for better concealment since they are usually found in flocks whereas hens are solitary prior to incubation.

The differences in habitats used by sage grouse and random sites can be attributed to selection by grouse for better structural cover than what was generally available and may also be related to preference for different species and subspecies of sagebrush in the diet. Preference for Artemisia tridentata has long been recognized and recent work indicates that sage grouse prefer A. tridentata wyomingensis over A. tridentata vaseyana (Remington 1981).

Similarities in habitat selection between sexes within 2 seasons (winter, summer) and differences during the breeding season resulted in rejection of the hypothesis that sage grouse habitat selection differs between sexes within seasons for winter and summer periods but acceptance during the breeding season. The hypothesis that sage grouse habitat selection varies seasonally for each sex was accepted since FL habitats selected during winter, spring, and summer were all distinct from each other. However, the differences between winter and spring FL habitats probably would not have been as great had there been less snow during winter 1980.

Potential Impacts of Mining

Long-term, large-scale mining in the northeastern area of North Park would appear to be detrimental to sage grouse winter habitat. Sage grouse tolerated mining activity on winter range in 1980 but continued strip mining on current and proposed lease areas will reduce and perhaps eventually eliminate preferred winter range in the northeast quadrat. Since sage grouse from all areas of North Park depend on winter habitat in the northeast during at least part of the winter, loss of habitat from mining activity will impact the entire sage grouse population in North Park.

Immediate impacts of mining in the northeast quadrat may be most detrimental to the breeding male segment of the population. Approximately 33% (33.3) of the preferred FL sites of males from Raven Lek were within the proposed Kerr coal lease. Another 12.5% of preferred FL sites would be indirectly affected since the mine will bisect the preferred FL area and males would have to fly over the mine daily to reach these areas. Disturbance of 45.8% of the preferred FL habitat would affect all males since they all regularly fed in the proposed lease area. Loss of preferred FL areas may make the entire area unsuitable for breeding season use.

How great the impact to breeding males will be may depend on the extent of disturbance to preferred FL habitat. Wallestad (1975) reported a 63% decline in strutting males 2 years after a 31% loss of suitable habitat adjacent to a lek in Montana. Substantial declines in the number of strutting males and total abandonment of leks have been documented in areas disturbed by 2,4-D spraying and mechanical treatments of sagebrush adjacent to leks (Rogers 1964, Higby 1969, Peterson 1970a, Braun and Beck 1976).

Immediate impacts of mining on hens during the breeding season would probably be less detrimental than impacts on males. Hens were not as dependent on areas adjacent to Raven Lek for nesting habitat as males were for FL habitats. Only 64% of all hens nested within 2 km of leks where they bred whereas 95.7% of males sought FL sites within 2 km of the lek. Wallestad and Schladweiler (1974) and Emmons (1980) also noted close association of male spring FL habitat to leks whereas hens often move long distances from leks to find suitable nesting cover (May 1969, Poley 1970, Wallestad and Pyrah 1974, Petersen 1980).

Coal strip mining is not expected to impact summer meadow habitats since they are not currently within proposed mining areas. Brood habitat along travel routes to meadows will be impacted by mining. Loss of draws and other wet areas with lush herbaceous vegetation and abundant insects would be detrimental to broods dependent on such areas.

It is unknown whether large-scale, long-term coal mining will make the areas adjacent to mines unsuitable for use by sage grouse during any season. It is apparent that areas disturbed by strip mining will be removed from sage grouse use until suitable sagebrush cover returns. How long that period will be is unknown but will probably be at least several decades. Disturbance of preferred FL habitats will reduce available habitat for breeding males. Mining activity and large-scale habitat loss adjacent to a lek will probably reduce recruitment of juvenile grouse to the lek and breeding activity of hens on the lek. Production may be eliminated altogether in areas disturbed by mining activity. Long-term, large-scale mining can be expected to greatly reduce preferred winter habitats in the northeastern portion of the Park. Winter habitat in the northeast is especially critical for all grouse throughout North Park.

RECOMMENDATIONS FOR MITIGATION AND REHABILITATION

Sage grouse select winter, breeding, nesting, and brood-rearing habitats on the basis of suitable structure and probably sagebrush species and subspecies composition. It cannot be assumed that grouse will move elsewhere and maintain the same populations present prior to disturbance of preferred habitats. If populations of sage grouse are to be maintained, mitigation and rehabilitation practices must be developed to provide suitable year-round habitats for sage grouse.

Several mitigation techniques should be considered. Among methods of reducing and mitigating impacts of mining are:

1. Maintain or protect preferred habitats where possible.
2. Limit disturbance adjacent to and on winter concentration areas to be impacted by mining.
3. Limit disturbance adjacent to leks and on preferred feeding-loafing (FL) areas used by males around leks. Avoid road construction and placement of overburden piles adjacent to leks, preferred FL areas, and in flight paths of males moving from the lek to FL sites.
4. Curtail explosions during the mating period (1 hour before to 1 hour after sunrise) from 15 March to 1 June.
5. Reduce or eliminate grazing in areas around leks.
6. Fertilization of undisturbed preferred habitat and areas adjacent to coal mines may be useful but needs further documentation.
7. Obtain financial support from coal companies to monitor sage grouse movements and habitat use prior to and throughout the mining period and to develop better techniques to re-establish the sagebrush community on reclaimed areas.

Sage grouse require a diversity of habitat types throughout the year. Therefore, rehabilitation of sage grouse habitats must concentrate on restoring the diverse habitat structure present before mining. Possible rehabilitation techniques include:

1. Create topographic diversity in habitat. Flat, open areas (<10% slope) are used extensively during the breeding season whereas draws and swales with high sagebrush canopy cover and large plants are important in winters with heavy snowfall. Windswept south-facing ridges and hilltops are also important in winter. Draws with lush herbaceous growth are important for broods in early summer and are also used by unsuccessful hens and cocks.

2. Transplant and/or seed native grasses, forbs, and especially sagebrush. Special consideration should be given to species and subspecies of sagebrush preferred by sage grouse. Big sagebrush (Artemisia tridentata) was preferred over alkali sagebrush (A. longiloba) in the study area. Wyoming big sagebrush (A. t. wyomingensis) is preferred over mountain big sagebrush (A. t. vaseyana) (Remington 1981).

3. Transplant and/or seed sagebrush throughout reclaimed areas and create "patchy" areas with dense stands of sagebrush in draws and swales where greater moisture can support better sagebrush cover. Sagebrush density (average) should be at least 3 plants/m^2.

4. Fertilization of reclaimed areas should be done annually until sagebrush, forbs, and grasses have become well established.

5. Irrigate reclaimed areas to provide ample moisture during the growing season and build snow-fencing to hold snow on reclaimed areas for additional early spring moisture.

6. Strive to create a diversity in sagebrush structural types to meet sage grouse habitat requirements during all seasons. Preferred FL habitats are those between 25 and 50% average sagebrush canopy cover and 25 to 40 cm sagebrush height. Large plants and high canopy cover are preferred at FL sites during winters with heavy snowfall. Nesting hens also prefer excellent cover and larger plants. Smaller plants and lower canopy cover are preferred at FL sites during the breeding season and low canopy cover (11%) and sagebrush height (10 cm) are found at leks.

7. Provide vigorous stands of sagebrush with at least 75% foliation of sagebrush plants.

Sage grouse select distinct habitat types during different seasons and within seasons. All of these habitats must be managed properly to maintain stable populations of sage grouse in North Park and throughout the West. Mining activity will affect sage grouse distribution and abundance and careful consideration should be given to all habitat requirements of sage grouse as mining proceeds. While it is not known how severe impacts of mining will be to sage grouse populations, large-scale, long-term mining can be expected to be detrimental. The entire northeast quadrat of North Park is underlain with coal and, depending on the time interval over which the area is mined and the success of mitigation and rehabilitation practices, sage grouse populations will be maintained, reduced, or lost from the area.

Recently, there has been increasing interest but little success in re-establishing sagebrush communities on reclaimed mine spoils. If populations of sage grouse and other members of the sagebrush community are to be maintained in mining areas throughout the West, better methods of rehabilitation must be developed to re-establish sagebrush. With the poor soils and arid climate of much of the West, it will not be easy to rehabilitate wildlife habitats on mined areas. Wildlife populations cannot be maintained unless wildlife habitats are maintained.

LITERATURE CITED

Aldrich, J. W. 1963. Geographic orientation of North American Tetraonidae. J. Wildl. Manage. 27:529-545.

Amstrup, S. C. 1980. A radio-collar for game birds. J. Wildl. Manage. 44:214-217.

Beck, T. D. I. 1975. Attributes of a wintering population of sage grouse, North Park, Colorado. M.S. Thesis. Colorado State Univ., Fort Collins. 49pp.

______. 1977. Sage grouse flock characteristics and habitat selection in winter. J. Wildl. Manage. 41:18-26.

______, R. B. Gill, and C. E. Braun. 1975. Sex and age determination of sage grouse from wing characteristics. Colo. Div. Wildl., Game Inf. Leafl. 49 (Revised). 4pp.

Beekly, A. L. 1915. Geology and coal resources of North Park, Colorado. U.S. Geological Survey Bull. 596. 121pp.

Beetle, A. A. 1960. A study of sagebrush, the section Tridentatae of Artemisia. Univ. Wyoming Agric. Exp. Stn. Bull. 368. 83pp.

______. 1970. Recommended plant names. Univ. Wyoming Agric. Exp. Stn. Res. J. 31. 124pp.

Braun, C. E., and T. D. I. Beck. 1976. Effects of sagebrush control on distribution and abundance of sage grouse. Colo. Div. Wildl., Final Rep., Fed. Aid Proj. W-37-R, Work Plan 3, Job 8a. Pp. 21-84.

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

Bray, O. E., and G. W. Corner. 1972. A tail clip for attaching transmitters to birds. J. Wildl. Manage. 36:640-642.

Canfield, R. H. 1941. Application of the line interception method in sampling range vegetation. J. For. 39:388-394.

Cooley, W. W., and P. R. Lohnes. 1971. Multivariate data analysis. John Wiley & Sons, New York, N.Y. 364pp.

Dalke, P. D., D. B. Pyrah, D. C. Stanton, J. E. Crawford, and E. F. Schlatterer. 1963. Ecology, productivity, and management of sage grouse in Idaho. J. Wildl. Manage. 27:811-841.

Dingman, J. D. 1980. Characteristics of sage grouse leks, North Park, Colorado. M.S. Thesis. Univ. Denver, Denver, Colo. 113pp.

Emmons, S. R. 1980. Lek attendance of male sage grouse in North Park, Colorado. M.S. Thesis. Colorado State Univ., Fort Collins. 69pp.

Eng, R. L. 1955. A method for obtaining sage grouse age and sex ratios from wings. J. Wildl. Manage. 19:267-272.

_______, and P. Schladweiler. 1972. Sage grouse winter movements and habitat use in central Montana. J. Wildl. Manage. 36:141-146.

Gill, R. B. 1965. Distribution and abundance of a population of sage grouse in North Park, Colorado. M.S. Thesis. Colo. State Univ., Fort Collins. 187pp.

Girard, G. L. 1937. Life history, habits, and food of the sage grouse, Centrocercus urophasianus Bonaparte. Univ. Wyoming Publ. 3. 56pp.

Graham, E. R. 1959. An explanation of theory and methods of soil testing. Univ. Missouri Agric. Exp. Stn. Bull. 734. 20pp.

Hail, W. J., Jr., and E. B. Leopold. 1960. Paleocene and Eocene age of the Coalmont formation, North Park, Colorado. U.S. Geological Survey Prof. Paper 400-B. 2pp.

Harrington, H. D. 1954. Manual of the plants of Colorado. Sage Books, Inc., Denver, Colo. 666pp.

Higby, L. W. 1969. A summary of the Longs Creek sagebrush control project. Proc. Bien. West. States Sage Grouse Workshop 6:164-168.

James, F. C. 1971. Ordinations of habitat relationships among breeding birds. Wilson Bull. 83:215-236.

Kelsey, H. P., and W. A. Dayton. 1942. Standardized plant names. 2nd ed. J. Horace McFarland Co., Harrisburg, Pa. 675pp.

Klebenow, D. A. 1969. Sage grouse nesting and brood habitat in Idaho. J. Wildl. Manage. 33:649-662.

_______. 1970. Sage grouse versus sagebrush control in Idaho. J. Range Manage. 23:396-400.

Kononova, M. M. 1966. Soil organic matter. Pergamon Press Ltd., Oxford, U.K. 544pp.

Martin, N. S. 1970. Sagebrush control related to habitat and sage grouse occurrence. J. Wildl. Manage. 34:313-320.

Martinka, R. R. 1972. Structural characteristics of blue grouse territories in southwestern Montana. J. Wildl. Manage. 36:498-510.

May, T. A. 1970. Effects of sagebrush control on distribution and abundance of sage grouse. Colorado Div. Wildl., Job Compl. Rep., Fed. Aid Proj. W-37-R-23, Work Plan 3, Job 8a. Pp. 115-138.

Miller, J. C. 1934. Geology of the north and south McCallum anticlines, Jackson County, Colorado, with special reference to petroleum and carbon dioxide: U.S. Geological Survey Circ. 5. 27pp.

Mohr, C. O. 1947. Table of equivalent populations of North American small mammals. Am. Midl. Nat. 37:223-249.

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner, and D. H. Bent. 1975. Statistical package for the social sciences. McGraw-Hill Book Co., New York, N.Y. 675pp.

Patterson, R. L. 1952. The sage grouse in Wyoming. Sage Books, Inc., Denver, Colo. 341pp.

Petersen, B. E. 1980. Breeding and nesting ecology of female sage grouse in North Park, Colorado. M.S. Thesis. Colorado State Univ., Fort Collins. 86pp.

Peterson, J. G. 1970a. Gone with the sage. Montana Outdoors 5(9):1-3.

_______. 1970b. The food habits and summer distribution of juvenile sage grouse in central Montana. J. Wildl. Manage. 34:147-155.

Poley, B. 1969. Effects of sagebrush control on distribution and abundance of sage grouse. Colorado Div. Wildl., Job Compl. Rep., Fed. Aid Proj. W-37-R-22, Work Plan 3, Job 8a. Pp. 61-86.

Pyrah, D. B. 1972. Effects of chemical and mechanical control on sage grouse. Montana Fish and Game Dep., Job Compl. Rep., Fed. Aid Proj. W-105-R-6. 12pp.

Rasmussen, D. I., and L. A. Griner. 1938. Life history and management studies of the sage grouse in Utah, with special reference to nesting and feeding habits. Trans. North Am. Wildl. Conf. 3:852-864.

Remington, T. E. 1981. Winter nutrition of sage grouse in North Park, Colorado. Proc. Bien. West. States Sage Grouse Workshop 12:10.

Richards, L. A., ed. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Dep. Agric. Handb. 60. 160pp.

Robertson, D. R., J. R. Nielson, and N. H. Bare. 1966. Vegetation and soils of alkali sagebrush and adjacent big sagebrush ranges in North Park, Colorado. J. Range Manage. 19:17-20.

Rogers, G. E. 1964. Sage grouse investigations in Colorado. Colorado Game, Fish and Parks Dep., Tech. Bull. 16. 132pp.

Rothenmaier, D. 1979. Sage grouse reproductive ecology: breeding season movements, strutting ground attendance and site characteristics, and nesting. M.S. Thesis. Univ. Wyoming, Laramie. 97pp.

Sauchelli, V. 1969. Trace elements in agriculture. Van Nostrand Reinhold Co., New York, N.Y. 248pp.

Schneegas, E. R. 1967. Sage grouse and sagebrush control. Trans. North Am. Wildl. and Nat. Resour. Conf. 32:270-274.

Scott, T. G., and C. H. Wasser. 1980. Checklist of North American plants for wildlife biologists. The Wildl. Soc., Washington, D.C. 58pp.

Slatick, E. R. 1980. Coal data: A reference. Energy Inf. Admin., U.S. Dep. Energy, Washington, D.C. 53pp.

Smith, E. L. 1966. Soil vegetation relationships of some Artemisia types in North Park, Colorado. Ph.D. Diss. Colorado State Univ., Fort Collins. 203pp.

Soltanpour, P. N., and A. P. Schwab. 1977. A new soil test for simultaneous extraction of macro- and micronutrients in alkaline soils. Commun. in Soil Sci. and Plant Anal. 8:195-207.

_______, S. N. Workman, and A. P. Schwab. 1979. Use of inductively-coupled plasma spectrometry for the simultaneous determination of macro- and micronutrients in NH_4HCO_3-DTPA extracts of soils. Soil Sci. Soc. Am. J. 43:75-78.

Terwilliger, C., Jr., and E. L. Smith. 1978. Range resource types in North Park, Colorado. Colorado State Univ., Range Science Dep. Sci. Ser. 32. 48pp.

Titus, K., and J. A. Mosher. 1981. Nest-site habitat selected by woodland hawks in the central Appalachians. Auk 98: 270-281.

Thompson, L. M., and F. R. Troeh. 1973. Soils and soil fertility. McGraw-Hill Book Co., New York, N.Y. 495pp.

U.S. Department of Agriculture. 1981. Soil survey of Jackson County Area, Colorado. U.S. Dep. Agric., Soil Conserv. Serv., Washington, D.C. 159pp.

U.S. Department of Commerce. 1979. Climatological data: annual summary, Colorado. Natl. Oceanic and Atmospheric Admin. 84(14). 14pp.

Wallestad, R. O. 1971. Summer movements and habitat use by sage grouse broods in central Montana. J. Wildl. Manage. 35:129-136.

_______. 1975. Male sage grouse response to sagebrush treatment. J. Wildl. Manage. 39:482-484.

_______, and D. Pyrah. 1974. Movement and nesting of sage grouse hens in central Montana. J. Wildl. Manage. 38:630-633.

_______, and P. Schladweiler. 1974. Breeding season movements and habitat selection of male sage grouse. J. Wildl. Manage. 38:634-637.

_______, J. G. Peterson, and R. L. Eng. 1975. Foods of adult sage grouse in central Montana. J. Wildl. Manage. 39:628-630.

West, P. W., and T. P. Ramachandran. 1966. Spectrophotometric determination of nitrate using chromotropic acid. Anal. Chimica Acta. 350:317-324.

APPENDIX

Plant species identified in the study area, North Park, Colorado, 1979-80.

Scientific name[a]	Common name[b]
SHRUBS AND UNDERSHRUBS	
Artemisia cana viscidula	silver sagebrush
A. frigida	fringed sagebrush
A. longiloba	alkali sagebrush
A. tridentata	big sagebrush
Chrysothamnus nauseosus	rubber rabbitbrush
C. viscidiflorus	Douglas rabbitbrush
Eurotia lanata	common winterfat
Gutierrezia sarothrae	broom snakeweed
Purshia tridentata	antelope bitterbrush
Ribes montigenum	gooseberry currant
Rosa arkansana	Arkansas rose
Salix sp.	willow
Sarcobatus vermiculatus	black greasewood
Symphoricarpos vaccinioides	whortleleaf snowberry
Tetradymia canescens	gray horsebrush
FORBS	
Achillea lanulosa	western yarrow
Androsace septentrionalis	pygmyflower rockjasmine
Antennaria microphylla	littleleaf pussytoes
Aquilegia caerulea	Colorado columbine
Arenaria congesta	ballhead sandwort
Arnica mollis	hairy arnica
Aster leucanthemifolius	daisyleaf aster
Astragalus agrestis	purple milkvetch
A. drummondii	Drummond milkvetch
A. flexuosus	flexile milkvetch
A. gracilis	slender milkvetch
A. kentrophyta	Nuttall kentrophyta milkvetch
A. pectinatus	narrowleaf poisonvetch
A. spatulatus	spoonleaf milkvetch
Atriplex rosea	tumbling orach
Berberis repens	creeping barberry
Calochortus gunnisonii	Gunnison mariposalily
Cardamine pennsylvanica	Pennsylvania bittercress

Appendix-Continued

Scientific name[a]	Common name[b]
Castilleja flava	yellow indianpaintbrush
C. integra	wholeleaf indianpaintbrush
Chenopodium sp.	goosefoot
Cirsium centaureae	fringed thistle
Clematis hirsutissima	hairy clematis
Cleome serrulata	Rockymountain beeplant
Comandra umbellata	common bastardtoadflax
Cordylanthus ramosus	bushy birdbeak
Cryptantha fendleri	Fendler cryptantha
C. virgata	miner's candle
Dodecatheon pulchellum	darkthroat shootingstar
Epilobium angustifolium	fireweed willowherb
E. paniculatum	autumn willowherb
Erigeron nematophyllus	mat fleabane
Eriogonum ovalifolium	cushion wildbuckwheat
E. subalpinum	subalpine wildbuckwheat
E. umbellatum	sulfur wildbuckwheat
Erysimum inconspicuum	smallflower wallflower
Fragaria americana	American strawberry
Gayophytum ramosissimum	branchy groundsmoke
Gentiana affinis	Rockymountain pleated gentian
Geum ciliatum	threeflowered avens
Gilia congesta	ballhead gilia
Gymnosteris parvula	leafless falsephlox
Heuchera parvifolia	littleleaf alumroot
Hymenoxys richardsonii	Colorado rubberweed
Iris missouriensis	Rockymountain iris
Lappula redowskii	bluebur stickseed
Lepidium ramosissimum	branched pepperweed
Leptodactylon pungens	granite pricklygilia
Lesquerella montana	mountain bladderpod
Linanthus harknessii	Harkness flaxflower
Linaria vulgaris	butter-and-eggs toadflax
Linum lewisii	Lewis flax
Lithophragma tenella	slender woodlandstar
Lupinus ammophilus	sand lupine
L. greenei	Greene lupine
Lygodesmia juncea	rush skeletonplant
Mammillaria vivipara	cushion ballcactus
Melilotus officinalis	yellow sweetclover
Mertensia humilis	bluebells
Monolepsis nuttalliana	Nuttall monolepsis
Oenothera caespitosa montana	tufted eveningprimrose
Opuntia polyacantha	plains pricklypear
Orthocarpus luteus	yellow owlclover
Oxytropis sericea	silky locoweed
Paronychia sessiliflora	creeping nailwort

Appendix-Continued

Scientific name[a]	Common name[b]
Pedicularis crenulata	meadow lousewort
P. groenlandica	elephanthead lousewort
Penstemon cyathophorus	Northpark penstemon
P. procerus	littleflower penstemon
P. strictus	Rockymountain penstemon
Petasites sagittata	arrowleaf coltsfoot
Phlox bryoides	squarestem phlox
P. multiflora	flowery phlox
Polygonum aviculare	prostrate knotweed
P. kelloggii	Kellogg knotweed
Potentilla anserina	silverweed cinquefoil
P. concinna	elegant cinquefoil
P. diversifolia	varileaf cinquefoil
Pulsatilla ludoviciana	American pasqueflower
Ranunculus glaberrimus ellipticus	sagebrush buttercup
Rumex triangulivalvis	Mexican dock
Salsola kali	common Russianthistle
Saxifraga rhomboidea	diamondleaf saxifrage
Sedum stenopetalum	wormleaf stonecrop
Senecio harbourii	Harbour groundsel
S. hydrophilus	water groundsel
S. integerrimus	lambstongue groundsel
Sidalcea neomexicana	Newmexican checkermallow
Sphaeralcea coccinea	scarlet globemallow
Taraxacum officinale	common dandelion
Thlaspi alpestre	alpine pennycress
Trifolium gymnocarpon	hollyleaf clover
T. hybridum	alsike clover
Viola nuttallii ellipticus	yellow prairie violet
GRASSES	
Agropyron dasystachyum	thickspike wheatgrass
A. spicatum	bluebunch wheatgrass
Deschampsia caespitosa	tufted hairgrass
Hordeum brachyantherum	meadow barley
H. jubatum	foxtail barley
Koeleria cristata	prairie junegrass
Phleum pratense	common timothy
Poa pratensis	Kentucky bluegrass
P. secunda	Sandberg bluegrass

[a]Scientific names follow Harrington (1954).

[b]Common names follow Kelsey and Dayton (1942), Beetle (1970), and Scott and Wasser (1980).