Gunnison Sage Grouse Research at the Black Canyon of the Gunnison National Park and Curecanti National Recreation Area

Review of Project Goals, Statistical Design, Methods, and Analysis

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Chapter I – General Project Review

1.1 Introduction

This report is a comprehensive review of the goals and objectives outlined for Gunnison sage grouse research conducted for the Black Canyon of the Gunnison National Park and Curecanti National Recreation Area. We also review the field methodologies, discuss the strengths and weaknesses in the study, and provide recommendations and examples of statistical analyses. Example analyses of resource selection, lek trends, and survival analyses are included in subsequent Chapters.

1.2 Study Area

The study area for our review includes the area where most of the vegetation data, lek data, and radio-relocations of telemetered sage grouse have occurred. The study area used in the initial resource selection function (RSF) example analyses was approximately 120,000 acres in size, and is a mix of public and private land. Most of the vegetation data, lek data, and radio relocations of telemetered sage grouse were collected within a smaller area (approximately 30,000 acres in size), especially after access to leks in the western portion of the area was no longer given (Figure 1.1).

1.3 Review of Project Goals and Objectives

The goal of this project is to determine the significance of habitat within and adjacent to Black Canyon of the Gunnison National Park and Curecanti National Recreation Area as it relates to dispersal and genetic interchange of Gunnison sage-grouse from the core population in the Gunnison Basin. Several study objectives have been identified. We list each reviewed objective below, followed by our review of the design, field, and statistical methods. We include example analyses in several cases.

1.3.1 Study Objectives Related to Defining Habitat Use and Habitat Selection

One of the primary objectives was to identify seasonal habitats by radio-tracking grouse to determine habitat use by time of day and season. Several other objectives are related to this first objective and are discussed in this section:

1. Determine community type where grouse are located by recording site characteristics including vegetation composition, slope and aspect.
2. Determine microhabitat characteristics of vegetation (by conducting vegetation transects) at nest sites
3. Characterize grouse habitat within "study area" according to Gunnison Basin ecological and community type classification

This primary objective is being addressed by relocating radio-marked sage grouse. In addition, new or readily available GIS data on project area habitat are being collected and assembled. Birds were first captured in April 2000. Through 2005, over 50 sage grouse were trapped, and fitted with radio collars. Chapter II provides a detailed example of a resource analysis method that can help identify habitat selection by sage grouse. Detailed vegetation mapping is on-going at this time, so resource selection analyses for the entire project area cannot yet be completed.

1.3.1.1 Limiting Factors in Modeling Resource Selection: Existing Study Area Wide Environmental Variables

The availability of variables such as habitat and other environmental characteristics at scales relevant for defining habitat selection is key to modeling resource use and resource selection. The utility of an existing broad scale habitat classification developed by CDOW (2004 see Figure 1.1) for use in sage grouse resource selection analysis was investigated. A map of the classification within and adjacent to a study area boundary is found in Figure 1.1, and the percentages of each of 25 types for the study area and for the characteristics of the locations are found in Table 1.1.

It appears, based on the description statistics found in Table 1.1, the scale of this classification is too broad to provide useful information on small scale habitat selection on this study area (comparing characteristics of relocations to characteristics of study area). Most of the relocations (>95%) occurred in the three community types (sagebrush, sagebrush/grass mix, and grass/forb rangeland), and approximately 90% of the study area is comprised of these three types. We did not investigate in great detail the potential interactions of these habitat variables and other environmental variables in multivariate resource selection. Such an analysis may provide more useful than this univariate analysis (see methods in Chapter II to illustrate this approach). However, it is our experience that if the univariate analyses do not provide much for patterns in resource selection, multivariate analyses likely will not provide distinctive patterns. Some logical combination of habitat types comprised of low available or use percentages might add some patterns as well.

Its usefulness for identifying very broad scale information on use and habitat selection cannot be well understood from this analysis. However, one might suspect the classification could provide a screening level analysis of potential suitable habitat at a much broader scale (Gunnison Basin wide). We suspect this level of analysis has already been completed.

1.3.1.2 Limiting Factors in Modeling Resource Selection: Detailed Habitat Mapping

A very detailed habitat mapping process following Johnston's Ecological Type (ET) method has been on-going in the study area since summer 2003. At an average yearly rate of 412 acres mapped per person-month (Table 1.2), it will take approximately 21 person-months to complete habitat mapping for the approximately 30,000-acre study area. According to Myron Chase (NPS, pers. comm), the mapping should be completed in 2006 or 2007 for the 30,000 acre area considered the current study area.

To date, 105 community/ecological types have been mapped. Given the number of sage grouse and number of relocations included in the study so far, fewer than approximately 10-12 habitat categories can be accommodated in a typical resource selection (RSF) modeling exercise. The 105 ecological/community types have been mapped so far (see Appendix 1.1), and will need to be collapsed into fewer than 10 or so habitat categories that are based on knowledge and expectations regarding sage grouse habitat requirements. While this would suggest a more simpler classification for habitat mapping that does not require so much field time, the simpler classification has not been derived yet, and would seem to need potential RSF modeling results first.

While only a portion of the study area has been mapped, we did compare the % of available habitat into our simpler classification (10 categories) to the % of relocations in this smaller area. We did not analyze information by season, but recommend such analyses when the mapping is completed.

By pooling information across all sage grouse (males and females), there were some selection ratios (ratio of use to availability) that differed measurably from 1.0. We did not test for statistical significance, because of the issues with pooling of data across males and females, and across seasons. Sagebrush dominant habitat types in this study area were used in proportion to availability (Table 1.3). The analysis showed a trend towards selection for Willow category (R>1), and selection against the tree categories (Juniper, Douglas Fir etc., R<1).

We believe the initial RSF modeling using this information may be used to design a vegetation mapping process that may be more efficient than the current mapping effort. This more efficient mapping process will be useful if seasonal sage grouse habitat is to be mapped outside the current study area. If this modeling method is to be applied outside of the current project area, the same habitat categories must be available for the different areas. The BLM is using this same approach for habitat mapping in the central portion of the Gunnison Basin (M. Chase pers. Comm.). However, detailed mapping of resource selection in other areas of the Basin will not likely be possible using models developed from this site, since the mapping at such a detailed level has not yet occurred.

1.3.1.3 Limiting Factors in Modeling Resource Selection: Sample Sizes

Chapter 2 provides some initial examples of resource selection modeling from data collected for this study.

Given the low sample sizes (number of radio relocations for individual grouse), current RSF modeling needs to be based on relocation characteristics pooled across individuals. A very general rule of thumb is that more than 30 relocations per individual should be collected for the period of interest. If a seasonal RSF model is derived, that would mean 30 relocations per season. Since annual survival of the grouse radioed in this study is relative low (see Chapter IV), it would be recommended that more than 1 relocation per week be collected if feasible. Eight males and 6 females were relocated more than 30 times each from the primary leks studied (Kezar Basin, Sapinero, and Powerline). For future modeling, we recommend an increase in the number of relocations for grouse be increased to 1 every 2 to 3 days, if possible, especially since there are seasonal differences in habitat selection. A potential alternative is to investigate the use of GPS collars on a few grouse to get detailed information on movements.

The project is now limited to studying habitat and birds associated with 3 sage grouse leks (Sapinero Powerline, Sapinero South, Kezar Basin North), with most of the information from the latter two leks. The study area of 30,000 acres that is being mapped is relatively small when in comparison to the home range estimates of the 14 grouse from those areas.

1.3.2 Study Objectives Related to Defining Movements

We will focus on objectives related primarily to movement within the population, and movement among grouse activity centers. I will specifically look at home range analyses and distances from capture locations to leks. A typical product of radio telemetry studies for understanding movements within a population is a home range estimate, including home range size. Various definitions have been proposed since Burt (1943: 351) first defined "home range" as the "that area traversed by the individual in its normal activities of food gathering, mating, and caring for young." A more recent definition (Kernohan et al. 2001) defines home range as the "extent of area with a defined probability of occurrence of an animal during a specified time period." Home range estimators are used to address a variety of research questions including home range size , home range shape, movement patterns, resource availability (Johnson 1980), and resource use (Manly et al. 2002).

Given the relatively low survival of sage grouse (see Chapter III), many of the sage grouse that are trapped and fitted with transmitters do not survive long enough to provide adequate information for defining home ranges when collection of location information occurs at a once per week rate. Again, to provide useful information on home range size and to be able to conduct home range resource selection, we suggest increasing the number of relocations to once every 2 to 3 days.

Over the course of the 5 years of monitoring, a total of 27 nest locations have been identified. Seven of the nest sites were from unmarked birds and were discovered incidental to other activities and are not discussed further. Of the remaining 20 nests, 7 were from birds marked at the Kezar Basin North lek, 8 from the Sapinero South lek, 2 from the Sapinero Powerline lek, and 1 each from the Sapinero 10-mile lek and Pine Creek Mesa lek (lek no longer in study). This type of data has been helpful in understanding the habitat requirements and sizes of areas important for reproduction around leks as well as for understanding nest site fidelity.

Nest site fidelity has been noted for Gunnison Sage-Grouse, with an average distance of 455 m between current and previous years' nests (Young 1994). Greater sage-grouse have also observed similar nest site fidelity, often nesting within 1 km of previous nesting areas (Berry and Eng 1985, Schroeder et al. 1999). So far during this study, a similar finding has been observed. The average distance between current and previous years' nests for the 4 radioed grouse that were documented to nest multiple years was approximately 600 m. The largest distance occurred for a female that also moved the farther away from the lek to nests (NPS # 205, Table

1.3). While the sample sizes are naturally small for this type of data, the nest distance data alone may be extremely valuable for Gunnison sage grouse management.

Only 50% of the nests were within 3.2 km (2 miles) of leks (Table 1.4). The average distance from the lek of capture and nest for females was 3.2 km (2 miles), or 2.8 miles when accounting for females with multiple nests. The females from the Kezar Basin North lek nested significantly farther (mean=5.6 km) from that lek compared to females from the Sapinero lek (mean=1.9 km, p=0.057).

Table 1.1. Habitat characteristics of the overall study area, and of the sage grouse relocations.

class_name	Area (acres)	Proportion	# Relocations	% Relocations
Agriculture Land	131	0.1%	3	0.2%
Alpine Meadow	140	0.1%	1	0.1%
Aspen	2023	1.4%	0	0.0%
Barren Land	1823	1.3%	13	1.0%
Douglas Fir	4125	2.9%	0	0.0%
Douglas Fir/Aspen Mix	3468	2.4%	1	0.1%
Englemann Spruce/Fir Mix	4	0.0%	0	0.0%
Gambel Oak	1390	1.0%	2	0.2%
Grass/Forb Rangeland	14450	10.1%	158	12.0%
Mesic Mountain Shrub Mix	293	0.2%	4	0.3%
Pinon-Juniper	281	0.2%	0	0.0%
PJ-Mtn Shrub Mix	181	0.1%	0	0.0%
PJ-Sagebrush Mix	180	0.1%	0	0.0%
Ponderosa Pine	2626	1.8%	3	0.2%
Riparian	418	0.3%	2	0.2%
Rock	2885	2.0%	4	0.3%
Sagebrush Community	35640	24.8%	341	26.0%
Sagebrush/Gambel Oak Mix	1245	0.9%	4	0.3%
Sagebrush/Grass Mix	65060	45.3%	769	58.6%
Saltbush Community	258	0.2%	2	0.2%
Sparse PJ/Shrub/Rock Mix	170	0.1%	0	0.0%
Spruce/Fir/Aspen Mix	523	0.4%	0	0.0%
Talus Slopes & Rock Outcrops	125	0.1%	0	0.0%
Upland Willow/Shrub Mix	145	0.1%	0	0.0%
Water	6064	4.2%	1	0.1%
Total	143647	100.0%	1312	100.0%

Table 1.2 Approximate effort to map and ground-truth habitat.

Year	people	months	acres	Person-months	**acres/person-month**
2003	2	5	3400	10	**340**
2004	5	5	11700	25	**468**
2005	3	5	6400	15	**427**
				average	**412**

Table 1.3. Characteristics of Available and used habitat when the 105 ecological/community types are collapsed into 10 categories. R is the selection ratio, the ratio of % used/% ratio and B is R/sum of the R's.

	Available Habitat		Used Habitat			
Habitat Type[a]	acres	%	# relocations	%	R	B
Big Sagebrush	14817	71.1%	419	72.5%	1.02	0.09
Black Sagebrush	756	3.6%	27	4.7%	1.29	0.12
Mountain Mahogany	1151	5.5%	2	0.3%	0.06	0.01
Needle-and-Thread	899	4.3%	14	2.4%	0.56	0.05
Oak	514	2.5%	0	0.0%	0.00	0.00
Aspen	359	1.7%	9	1.6%	0.90	0.08
Douglas-Fir	683	3.3%	4	0.7%	0.21	0.02
Juniper	286	1.4%	4	0.7%	0.50	0.05
Willow/Cottonwood	294	1.4%	32	5.5%	3.92	0.37
Other	1070	5.1%	67	11.6%	2.26	0.21
Subtotal	20829	1.00	578.00	1.00	10.73	1.00

Table 1.4. Distances from nest location to capture site

NPS_#	Area_of_Capture	Distances from Capture Location to Nest(m)	Distances Used for Statistical Comparisons (m)[a]
107	Kezar Basin North	4006	4052
107	Kezar Basin North	4098	
205	Kezar Basin North	9668	9021
205	Kezar Basin North	8373	
206	Kezar Basin North	8201	8201
207	Kezar Basin North	998	1124
207	Kezar Basin North	1249	
207	Kezar Basin North	1343	
Kezar Basin Average		4742	5599
2	Sapinero South	5713	5630
2	Sapinero South	5547	
3	Sapinero South	608	608
4	Sapinero South	1620	1620
303	Sapinero South	760	760
506	Sapinero South	3606	3606
521	Sapinero South	865	865
522	Sapinero South	645	645
Sapinero South Average		2421	1962
513	Sapinero 10 Mile Spr	146	146
11	Sapinero Powerline	6103	6103
308	Sapinero Powerline	817	817
Overall Average		3237	2853
Statistical Comparisons (T-test)			
Kezar Basin vs. Sapinero South		p=0.057	

[a] uses average distances for nests from the same individual to ensure independence of data for statistical comparisons

CHAPTER 2- EXAMPLE RESOURCE SELECTION ANALYSES

2.1 Introduction

This report describes preliminary analyses of resource selection in Gunnison sage grouse. The objective is to provide examples of analyses designed to determine which habitat characteristics, or resources, are selected by sage grouse. Because data are incomplete (e.g., additional vegetation mapping is required, and future radio locations of sage grouse may be obtained), a full analysis is not possible. Rather, these analyses are intended to illustrate how resource selection may be estimated when more data are available. These analyses focuses on three habitat variables – aspect, slope, and closest distance to power transmission lines – all obtained from a GIS. For most analyses, while these variables are continuous in character, each was expressed as a categorical variable. For example, aspect was categorized as either flat, north, east, south, or west. Furthermore, most analyses described below relied on selection ratios, an approach appropriate for categorical data. However, we also consider an approach based on logistic regression which is more flexible, capable of handling multiple covariates whether categorical, continuous, or both.

2.2 Methods

2.2.1 Preliminary GIS Analysis

Data consisted primarily of locations of radio-tagged sage grouse. Locations were originally classified as either “aerial” or “ground” though our analysis ignores this distinction. Attributes associated with each location included an identification number for the individual, the bird’s sex, time of day, and date. Locations were imported into a geographic database (in ArcView) that included slope and aspect (obtained from a Digital Elevation Map with 10 meter resolution) and the locations of two power transmission lines that the study area.

The study area was defined as follows. A ½ mile radius buffer was temporarily created around each location. The study area boundary was determined by the minimum convex polygon that enclosed all locations and their associated buffers (Figure 2.1).

For each sage grouse location, *aspect* was defined by the single value of the aspect layer at that point. Similarly, *distance* was calculated as the minimum distance from the point location to the nearest point on either power transmission line within the study area. Finally, *slope* was calculated as the mean of all slope values within a 100 meter radius circle centered on the location. Hereafter, sage grouse locations are referred to as “used” points.

“Available” habitat was defined as everything within the study area boundary, assumed to be equally accessible to all radio-tagged sage grouse. Characterization of available habitat (in terms of slope, distance, and aspect) was made possible by generating a grid of points. A random starting point within the study area was selected and then a systematic grid was generated (Fig. 2.2) such that the study area was well represented and there were approximately equal numbers of used and available points. Slope, aspect, and distance were determined for available points in the same way as described for used points. While the set of available points technically constituted a sample, it was treated in subsequent analyses as a census of available resources and assumed to have no sampling variability. In future analyses a denser grid of points could be established. Tabled values of slope, aspect, and distance for both used and available points, as well as other attributes of used points were exported for subsequent statistical analyses.

2.2.2 Selection Ratios

Because the three resource variables were continuous, categorical variables were created from each for analysis using selection ratios. Aspect was classified as either Flat, North ($x > 315°$ or $x \leq 45°$), East ($45° < x \leq 135°$), South ($135° < x \leq 225°$), and West ($225° < x \leq 315°$). Slope was divided into five categories: 1 ($x \leq 5°$), 2 ($5° < x \leq 10°$), 3 ($10° < x \leq 15°$), 4 ($15° < x \leq 20°$), and 5 ($x > 20°$). Similarly, distance was divided into five categories: 1 ($x \leq 2$km), 2 (2km $< x \leq$ 4km), 3 (4km $< x \leq$ 6km), 4 (6km $< x \leq$ 8km), and 5 ($>$ 8km).

2.2.2.1 Locations as the sample units

The idea behind selection ratios relies on a comparison (via a ratio) of the proportion of used resource units in a particular category to the proportion of available resource units in that same category. Let u_i represent the number of used units in category *i* in the sample (e.g., the number of observed animal locations with East aspect) and u_+ the total number of used units in all categories (e.g., the total number of observed animal locations). Then the proportion of used units in category *i* is $o_i = u_i / u_+$. Similarly, let A_i represent the number of available units in category *i* and A_+ represent the total number of available units in the population. Then $\pi_i = A_i / A_+$ is the proportion of available units in category *i*. (Again, in principle, π_i is known from a census though we actually estimate it with a sample from a GIS.) Finally, the selection ratio is estimated as

$$\hat{w}_i = o_i / \pi_i$$

A selection ratio equal to one for a particular category indicates that use and availability are equal in proportion and, thus, that there is no preference with respect to that category. However, $\hat{w}_i > 1$ represents selection for category *i* because the proportion of used units exceeds the proportion of available units. By the same token, $\hat{w}_i < 1$ represents selection against category *i*, i.e., lower use than would be expected if animals used that category in proportion to its availability. The standard error of the selection ratio is calculated as

$$\mathrm{se}\left(\hat{w}_i\right) = \sqrt{\frac{o_i\left(1 - o_i\right)}{u_+ \pi_i^2}}$$

and a test of whether the selection ratio differs from 1 is based on the statistic

$$X^2 = \left[\frac{\hat{w}_i - 1}{\mathrm{se}\left(\hat{w}_i\right)} \right]^2$$

which may be compared to the chi-squared distribution with one degree of freedom.

An overall test of selection (i.e., whether animals are randomly selecting habitat in proportion to availability) is

$$X^2 = 2\sum\nolimits_{i=1}^{m} u_i \log_e \left(\frac{u_i}{u_+ \pi_i} \right)$$

where m is the number of categories and $u_+\pi_i$ represents the expected number of used units if selection were not occurring. In practice, the overall test is generally conducted first, and if it is significant, then tests on individual selection ratios may subsequently be conducted.

2.2.2.2 Animals as the sample units

Individual animals were identified and repeatedly located in this study. In this circumstance, it may be more appropriate to treat the animal, rather than the location, as the sample unit. This would be especially true if observations were made frequently enough to induce dependence (temporal autocorrelation). Selection ratios are calculated separately for each individual and each resource type, and then averaged across individuals to obtain estimated selection ratios for each resource type.

Let u_{ij} represent the number of resource units of type i used by animal j (e.g., the number of locations for sage grouse #0308 with East aspect). Then u_{i+} is the total number of resource units of type i used by all animals (e.g., the total number of locations for all sage grouse with East aspect), u_{+j} is the total number of units of all types used by animal j (e.g., the total number of locations in all aspects for sage grouse #0308), and u_{++} is the total number of resource units used by all animals. As before, π_i is the proportion of available resources of type i. The selection ratio for the i^{th} resource type and the j^{th} animal is

$$\hat{w}_{ij} = \frac{u_{ij} / u_{+j}}{\pi_i}$$

and the selection ratio for resource type i can be calculated as an average

$$\hat{w}_i' = \sum\nolimits_{j=1}^{n} \hat{w}_{ij} / n$$

with standard error

$$\mathrm{se}\left(\hat{w}_i'\right) = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{w}_{ij} - \hat{w}_i'\right)^2}{n\left(n-1\right)}}$$

As with study designs in which individuals are not distinguished, a test of whether each selection ratio differs from 1 can be based on the statistic

$$X^2 = \left[\frac{\hat{w}_i' - 1}{\mathrm{se}\left(\hat{w}_i'\right)}\right]^2$$

which is approximately distributed chi-squared with 1 degree of freedom.

As described above, these separate tests for each resource type should be preceded by an overall test of selection. Under the null hypothesis that animals select resources in proportion to their availability

$$X^2 = 2\sum_{i=1}^{m}\sum_{j=1}^{n} u_{ij} \log_e\left(\frac{u_{ij}}{u_{i+}u_{+j} / u_{++}}\right)$$

has a chi-squared distribution with $n(m\text{-}1)$ degrees of freedom.

The number of observations (radio locations) per individual was extremely variable. To reduce problems associated with unequal sample size, for analyses treating the individual as the sample unit, we retained only those individuals with at least 30 observations.

2.2.2.3 Analysis by group

Different groups of animals may use resources differently. In particular, males may differ from females, or resource use may differ among age classes. Alternatively, resource use may vary over time. Manly et al. (2002) consider more sophisticated models for variation over time, where progression of time (e.g., day to day, or month to month) is an important component. Here, we instead consider time as a grouping variable similar to groupings defined by animal characteristics. We consider three separate groupings: sex, period (time of day – either morning, midday, or evening), and season of the year. Five seasons were constructed from the original 8 in the dataset: (1) breeding, 3/20 to 5/15; (2) spring/summer, 5/16 to 9/30; (3) movement to winter range, 10/1 to 11/30; (4) winter range, 12/1 to 2/14; and, (5) movement to breeding area, 2/15 to 3/19. The 3 remaining original seasons were collapsed into either the breeding or spring/summer seasons depending on the date of observation. Each group was analyzed separately and compared qualitatively (e.g., males with females). Because subdivision into groups reduces effective sample size, we analyze the data by treating locations as independent observations (as if individuals were not identified).

2.2.3 Logistic Regression

We also illustrate analysis of the sage grouse data using logistic regression as an alternative to selection ratios. For a single categorical variable, these two approaches are equivalent. However, logistic regression is generally much more flexible, so that resource use may be modeled as a function of multiple variables whether categorical, continuous, or both. The resource selection function based on logistic regression can be written

$$\mathrm{w}(\mathbf{x}) = \exp\left(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p\right)$$

where x_1, x_2, ..., x_p are variables representing particular resources (such as slope, aspect, and distance to power lines), the corresponding β's are coefficients to be estimated, and w(**x**) represents the relative probability of use as a function of the covariates.

2.3 RESULTS

2.3.1 Selection ratios

2.3.1.1 Locations as the sample units

Figures 2.3-2.5 depict proportions used, o_i, and available, π_i, for each of the five categories of the variables aspect, slope, and distance. For aspect (Figure 2.3), the plot suggests that North is used in greater proportion than available, while East is used less than available. Differences between used and available appear to be very small in the other 3 aspects. Probability of use increased as slope decreased (Figure.2.4). Estimated proportions for distance (i.e., minimum distance to power transmission lines) (Figure 2.5) do not present clear differences, but suggest that sage grouse use is relatively greater nearer to power lines (i.e., within 2 km), use is relatively lower at the greatest distances (> 8 km), and otherwise use is similar to availability.

Analysis of selection ratios confirms these general observations. For all 3 variables, the overall test for selection is highly significant, indicating that sage grouse do not use these resources in equal proportion to availability (for aspect, $X^2 = 31.8$, $p < 0.0001$; for slope, $X^2 = 992.1$, $p < 0.0001$; for distance, $X^2 = 74.6$, $p < 0.0001$; df = 4 in each case). Detailed results are shown in Tables 2.1-2.3.

Individual chi-squared statistics and associated p-values for aspect categories (Table 2.1) show strong evidence against the null hypothesis that the selection ratio equals one for both North and East. Examination of the corresponding selection ratios, $\hat{w}_i$, confirms that the North aspect is used more than would be expected if sage grouse selected habitat in proportion to availability. In contrast, sage grouse select against the East aspect, i.e., use it less than expected given its availability.

Table 2.1 Selection ratios and tests for aspect.

Category	o_i	π_i	$\hat{w}_i$	se($\hat{w}_i$)	X^2	p-value
Flat	0.0508	0.0573	0.8859	0.1055	1.1711	0.2792
North	0.3038	0.2406	1.2624	0.0526	24.8860	<0.0001
East	0.2333	0.2773	0.8414	0.0420	14.2710	0.0002
South	0.1523	0.1620	0.9402	0.0611	0.9588	0.3275
West	0.2599	0.2628	0.9888	0.0459	0.0596	0.8071

Results for slope categories (Table 2.2) show a consistent decrease in selection ratios with increasing slope. There is significant selection for lower slopes (those in the first two categories: 0-5° and 5-10°) and significant selection against steeper slopes (the remaining three categories).

Table 2.2. Selection ratios and tests for slope.

Category	o_i	π_i	$\hat{w}_i$	se($\hat{w}_i$)	X^2	p-value
0 – 5°	0.3902	0.1742	2.2399	0.0771	258.77	<0.0001
5 – 10°	0.4152	0.2636	1.5752	0.0515	124.93	<0.0001
10 – 15°	0.1508	0.2109	0.7150	0.0467	37.23	<0.0001
15 – 20°	0.0371	0.1597	0.2325	0.0326	554.57	<0.0001
> 20°	0.0068	0.1918	0.0356	0.0118	6666.50	<0.0001

As suggested by Figure 2.5, results for distance are less straightforward. Sage grouse exhibit significant selection for locations both near (0 – 2 km) and moderately far (6 – 8 km) from the two power lines in the study area. However, the greatest distances are selected against, while intermediate distances are selected in proportion to their availability.

Table 2.3. Selection ratios and tests for distance.

Category	o_i	π_i	$\hat{w}_i$	se($\hat{w}_i$)	X^2	p-value
0 – 2 km	0.3977	0.3438	1.1569	0.0392	16.041	0.0001
2 – 4 km	0.2083	0.2162	0.9636	0.0517	0.495	0.4818
4 – 6 km	0.1455	0.1513	0.9616	0.0642	0.358	0.5496
6 – 8 km	0.1652	0.1329	1.2424	0.0769	9.942	0.0016
> 8 km	0.0833	0.1558	0.5347	0.0488	90.855	<0.0001

2.3.1.2 Animals as the sample units

Nineteen[1] of 49 radio-tagged sage grouse throughout the entire study area were each located 30 or more times. These 19 individuals represented 79% (1039 of 1318) of all locations. Seven of the remaining individuals had either 1 or 2 locations each.

Results for this analysis are mostly similar to those of the analysis which treats locations as sample units (discussed above). Again, the overall test for selection is highly significant for each of the three variables (for aspect, $X^2 = 306.8$, $p < 0.0001$; for slope, $X^2 = 973.3$, $p < 0.0001$; for distance, $X^2 = 1210.4$, $p < 0.0001$; df = 76 in each case).

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[1] These included grouse from all leks

Aspect selection ratios for the 19 individual sage grouse are shown in Table 2.4. While tests were not conducted for individual birds, these results indicate substantial inter-individual variation. For instance, sage grouse 0207 and 0209 differ in nearly every respect. Grouse #0207 has selection ratios greater than 1 for North and West aspects (suggesting selection for these aspects), and selection ratios less than 1 otherwise. In contrast, grouse #0209 has selection ratios greater than 1 for Flat and South aspects. Variation notwithstanding, the overall pattern among individuals is fairly clear. Selection ratios averaged across the 19 individuals (Table 2.5) show significant selection for the North aspect ($X^2 = 8.78$, $p = 0.0030$) and significant selection against the East aspect ($X^2 = 8.92$, $p = 0.0028$). These results are consistent with the analysis that treated locations as the sample unit (Table 2.1).

Table 2.4. Selection ratios for individual sage grouse for aspect.

	Sage Grouse Number									
Category	0002	0006	0009	0010	0013	0017	0103	0106	0107	0108
Flat	0.00	0.39	0.63	1.32	1.15	1.22	0.25	0.51	0.20	0.94
North	1.57	1.20	1.59	1.72	1.41	0.58	1.26	0.61	1.82	1.57
East	0.49	0.56	0.59	0.34	0.68	1.09	1.10	1.38	0.75	0.49
South	0.67	0.27	0.56	0.47	0.35	1.01	1.34	2.18	0.00	0.42
West	1.44	1.86	1.25	1.29	1.33	1.24	0.61	0.34	1.31	1.39

Table 2.4. Continued.

	Sage Grouse Number								
Category	0111	0112	0116	0117	0205	0206	0207	0209	0211
Flat	0.55	2.35	1.38	0.48	0.00	0.34	0.53	1.75	1.59
North	1.95	1.28	1.31	1.50	0.36	1.55	1.39	1.66	0.57
East	0.34	1.18	0.66	0.50	1.27	1.20	0.76	0.54	0.82
South	0.96	1.42	0.81	1.20	1.95	0.36	0.56	0.72	2.95
West	0.95	0.00	1.10	1.06	0.93	0.82	1.27	0.89	0.26

Table 2.5. Average selection ratios and tests for aspect.

Category	$\hat{w}_i'$	se($\hat{w}_i'$)	X^2	p-value
Flat	0.8201	0.1480	1.4782	0.2241
North	1.3108	0.1049	8.7754	0.0031
East	0.7755	0.0752	8.9192	0.0028
South	0.9583	0.1708	0.0597	0.8070
West	1.0173	0.1050	0.0272	0.8690

Average selection ratios for slope (Table 2.6) are also similar to results from the previous analysis (Table 2.1-2.2). In particular, sage grouse show significant selection for shallower slopes (< 10°). In contrast, average selection ratios are not significant for any category of distance (Table 2.7), though selection against the greatest distance (> 8 km) is nearly significant at the 10% level. Inter-individual variation in selection ratios is substantial and there are many instances of zero use for one or more categories. Furthermore, even with the restriction on sample size (at least 30 observations per individual), sample sizes among individuals is highly variable. Thus, the absence of significant selection should not be too surprising. In any case, the magnitudes of average selection ratios (Table 2.7) is again consistent with results from the previous analysis (Table 2.3).

Table 2.6. Average selection ratios and tests for slope.

Category	$\hat{w}_i'$	se($\hat{w}_i'$)	X^2	p-value
0 – 5°	2.1996	0.2249	28.44	<0.0001
5 – 10°	1.5405	0.1022	27.99	<0.0001
10 – 15°	0.7752	0.1011	4.95	0.0261
15 – 20°	0.2465	0.0677	123.78	<0.0001
> 20°	0.0420	0.0135	5043.70	<0.0001

Table 2.7. Average selection ratios and tests for distance.

Category	$\hat{w}_i'$	se($\hat{w}_i'$)	X^2	p-value
0 – 2 km	1.1572	0.2032	0.5982	0.4393
2 – 4 km	0.9382	0.1954	0.1000	0.7519
4 – 6 km	0.9360	0.2619	0.0598	0.8068
6 – 8 km	1.1791	0.3667	0.2386	0.6252
> 8 km	0.6484	0.2138	2.7034	0.1001

2.3.1.3 Analysis by group

For these analyses, the groupings we considered were *sex* of sage grouse, *period* of day, and *season* of year. We show selected results only to illustrate the approach. No results are shown for analyses related to slope. However, the results for slope were remarkably consistent with the results discussed above. In particular, sage grouse preferred shallower slopes and avoided steeper slopes irrespective of sex, period, or season. The few exceptions that occurred were related to non-significant tests due to limited sample sizes.

Male and female selection for aspect is summarized in Table 2.8. Both sexes show selection for the North aspect, but females select against the Flat and South aspects whereas males select against East. There is moderate evidence, though not significant at the 5% level, indicating that females select for West while males select against West. These patterns are depicted graphically by plotting proportions of used and available units for each aspect category, separately for the two sexes (Figure 2.6).

Table 2.8. Selection ratios and tests for aspect, by sex.

Sex	Aspect	o_i	π_i	$\hat{w}_i$	se($\hat{w}_i$)	X^2	p-value
Female	Flat	0.0287	0.0573	0.5017	0.1322	14.2150	0.0002
	North	0.2875	0.2406	1.1946	0.0852	5.2147	0.0224
$X^2 = 21.0$	East	0.2628	0.2773	0.9478	0.0719	0.5268	0.4680
$p = 0.0003$	South	0.1212	0.1620	0.7480	0.0913	7.6161	0.0058
	West	0.2998	0.2628	1.1408	0.0790	3.1758	0.0747
Male	Flat	0.0639	0.0573	1.1145	0.1481	0.5975	0.4396
	North	0.3145	0.2406	1.3067	0.0670	20.9790	<0.0001
$X^2 = 33.0$	East	0.2157	0.2773	0.7777	0.0515	18.6480	<0.0001
$p < 0.0001$	South	0.1711	0.1620	1.0564	0.0807	0.4877	0.4850
	West	0.2349	0.2628	0.8940	0.0560	3.5832	0.0584

Selection for aspect by period is summarized in Table 2.9. Sage grouse select for North in all three periods. In morning and evening, the West aspect is used less than expected given its availability, while in midday, West is used more than expected. On the other hand, East is selected against in midday, but in morning and evening it is used in proportion to availability. Finally, Flat is selected against in the evening, but otherwise is used in proportion to availability. Figure 2.7 shows used and available proportions for the aspect categories in the three periods of the day.

Table 2.9. Selection ratios and tests for aspect, by period.

Sex	Aspect	o_i	π_i	$\hat{w}_i$	se($\hat{w}_i$)	X^2	p-value
Morning	Flat	0.0571	0.0573	0.9973	0.1899	0.0002	0.9888
	North	0.2989	0.2406	1.2421	0.0892	7.3695	0.0066
$X^2 = 11.0$	East	0.2703	0.2773	0.9748	0.0751	0.1124	0.7374
$p = 0.0263$	South	0.1626	0.1620	1.0042	0.1068	0.0016	0.9686
	West	0.2110	0.2628	0.8029	0.0728	7.3358	0.0068
Midday	Flat	0.0525	0.0573	0.9158	0.1529	0.3036	0.5816
	North	0.2994	0.2406	1.2441	0.0748	10.6600	0.0011
$X^2 = 39.0$	East	0.1852	0.2773	0.6678	0.0550	36.4480	<0.0001
$p < 0.0001$	South	0.1466	0.1620	0.9052	0.0858	1.2205	0.2693
	West	0.3164	0.2628	1.2038	0.0695	8.5957	0.0034
Evening	Flat	0.0327	0.0573	0.5709	0.2122	4.0881	0.0432
	North	0.3318	0.2406	1.3787	0.1338	8.0169	0.0046
$X^2 = 15.1$	East	0.2991	0.2773	1.0784	0.1129	0.4831	0.4870
$p = 0.0046$	South	0.1495	0.1620	0.9233	0.1505	0.2597	0.6103
	West	0.1869	0.2628	0.7113	0.1014	8.1075	0.0044

Selection for distance by season is summarized in Table 2.10 and Figure 2.8. Sage grouse select against the greatest distances (> 8 km) in all seasons (though in the 5th season, movement to the breeding area, there are insufficient data to conduct a test). There is also selection against the next largest distance category (6 – 8 km) in the 4th and 5th seasons (December through mid-

March), but selection for that category at all other times of year. Similarly, sage grouse select for the smallest distance category (0 – 2 km) in the 4th and 5th seasons, but at other times of year sage grouse use locations at these distances in proportion to availability. Use of the other distance categories (2 – 4 km and 4 – 6 km) does not exhibit consistent patterns across the seasons. In general, from Figure 2.8 it appears that sage grouse tend to be closer to power lines in the 4th and 5th seasons, while in other seasons they are more evenly distributed in terms of distance.

Table 2.10. Selection ratios and tests for distance, by season.

Season	Distance	o_i	π_i	$\hat{w}_i$	se($\hat{w}_i$)	X^2	p-value
3/20 – 5/15	0 – 2 km	0.3603	0.3438	1.0479	0.1101	0.1896	0.6633
	2 – 4 km	0.2050	0.2162	0.9481	0.1472	0.1245	0.7242
$X^2 = 53.0$	4 – 6 km	0.2050	0.1513	1.3551	0.2103	2.8500	0.0914
$p < 0.0001$	6 – 8 km	0.2236	0.1329	1.6822	0.2470	7.6253	0.0058
	> 8 km	0.0062	0.1558	0.0399	0.0397	584.0000	0.0000
5/16 – 9/30	0 – 2 km	0.3436	0.3438	0.9993	0.0555	0.0001	0.9906
	2 – 4 km	0.1936	0.2162	0.8953	0.0734	2.0373	0.1535
$X^2 = 20.8$	4 – 6 km	0.1597	0.1513	1.0556	0.0973	0.3274	0.5672
$p = 0.0003$	6 – 8 km	0.1871	0.1329	1.4075	0.1178	11.9620	0.0005
	> 8 km	0.1161	0.1558	0.7452	0.0826	9.5274	0.0020
10/1 – 11/30	0 – 2 km	0.3673	0.3438	1.0684	0.0846	0.6535	0.4189
	2 – 4 km	0.2291	0.2162	1.0596	0.1172	0.2589	0.6109
$X^2 = 11.8$	4 – 6 km	0.1236	0.1513	0.8174	0.1312	1.9368	0.1640
$p = 0.0187$	6 – 8 km	0.1782	0.1329	1.3405	0.1736	3.8463	0.0499
	> 8 km	0.1018	0.1558	0.6533	0.1170	8.7770	0.0031
12/1 – 2/14	0 – 2 km	0.6133	0.3438	1.7839	0.1053	55.4230	<0.0001
	2 – 4 km	0.1602	0.2162	0.7411	0.1261	4.2148	0.0401
$X^2 = 60.2$	4 – 6 km	0.0939	0.1513	0.6209	0.1434	6.9924	0.0082
$p < 0.0001$	6 – 8 km	0.0829	0.1329	0.6235	0.1542	5.9662	0.0146
	> 8 km	0.0497	0.1558	0.3191	0.1037	43.1380	<0.0001
2/15 – 3/19	0 – 2 km	0.5190	0.3438	1.5097	0.1635	9.7151	0.0018
	2 – 4 km	0.3544	0.2162	1.6394	0.2489	6.5976	0.0102
$X^2 = 51.7$	4 – 6 km	0.1139	0.1513	0.7532	0.2363	1.0910	0.2963
$p < 0.0001$	6 – 8 km	0.0127	0.1329	0.0952	0.0946	91.4290	<0.0001
	> 8 km	0.0000	0.1558	0.0000	--	--	--

2.3.2 Logistic Regression

When resource selection is modeled as a function of a single categorical variable, logistic regression yields results equivalent to those obtained from analysis of selection ratios. To illustrate, we fit a logistic regression model with *use* as the response variable (1=used, 0=available) and *slope* as the categorical explanatory variable. As defined above, slope has 5 categories, so it is actually represented by 4 indicator variables. In this case, the last (highest slope) category is the reference level to which the other 4 categories are compared. Individual radio-locations are treated as sample units.

The resource selection function can be written

$$\mathrm{w}(\mathbf{x}) = \exp(\beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4)$$

where x_1, ..., x_4 are 0/1 indicator variables representing slopes of 0–5°, 5–10°, 10–15°, and 15–20°, respectively. Results from SAS for the fitted model are shown in Table 2.11. The values of the estimated coefficients are not meaningfully interpreted in isolation. However, it is noteworthy that the estimates decrease (1.58, 1.23, etc.) as the slope categories "increase" (i.e., as slope increases) and that all the estimates are significant ($p < 0.0001$). The odds ratio estimates are more interpretable. For instance, the odds ratio for slope category 4 (relative to the reference level, category 5) is 6.538, indicating that on average a site with slope between 15° and 20° is roughly 6 ½ times more likely to be used by sage grouse than a site with slope greater than 20°. Similarly, a site with slope between 0° and 5° is 63 times more likely to be used than a site with slope greater than 20°. The same information is obtainable from simple calculations involving the corresponding selection ratios (Table 2.2). Note that $\hat{w}_1/\hat{w}_5$ = 2.2399/0.0356 = 62.92, which is the same (within rounding error) as the odds ratio of 62.992 for slope category 1 in Table 2.11. Similarly, from Table 2.2, $\hat{w}_4/\hat{w}_5$ = 0.2325/0.0356 = 6.53, the same as the odds ratio for slope category 4 in Table 2.11.

Table 2.11. SAS results for logistic regression model with *use* as response and *slope* as categorical explanatory variable.

Parameter	Estimate	Std Error	Chi-Square	p-value	Odds Ratio
Intercept	-0.7657	0.0800	91.6063	<0.0001	--
slope 1	1.5805	0.1010	244.9879	<0.0001	62.992
slope 2	1.2284	0.0961	163.4203	<0.0001	44.297
slope 3	0.4386	0.1076	16.5968	<0.0001	20.108
slope 4	-0.6849	0.1467	21.8005	<0.0001	6.538

As an alternative, we fit a logistic regression model in which slope is a continuous variable (the original form of the data as obtained from ArcView). The resource selection function can be written more simply as $\mathrm{w}(x) = \exp(\beta x)$ where x represents slope as a continuous variable. Note that only a single coefficient must be estimated rather than 4 when there are 5 categories of slope. Results for the fitted model are shown in Table 2.12. The estimated coefficient is highly significant ($p < 0.0001$), strong evidence that *use* is related to *slope*. The negative value indicates that probability of use decreases as slope increases. More particularly, the probability decreases by a multiplicative factor of 0.838 with each 1° increase in slope. Note that the odds ratio is 0.838 = exp(-0.1765). Relative probability of use predicted from the fitted equation is plotted as a continuous function in Figure 2.9.

Table 2.12. SAS results for logistic regression model with *use* as response and *slope* as continuous explanatory variable.

Parameter	Estimate	Std Error	Chi-Square	p-value	Odds Ratio
Intercept	1.6906	0.0883	366.63	<0.0001	--
Slope	-0.1765	0.0088	402.19	<0.0001	0.838

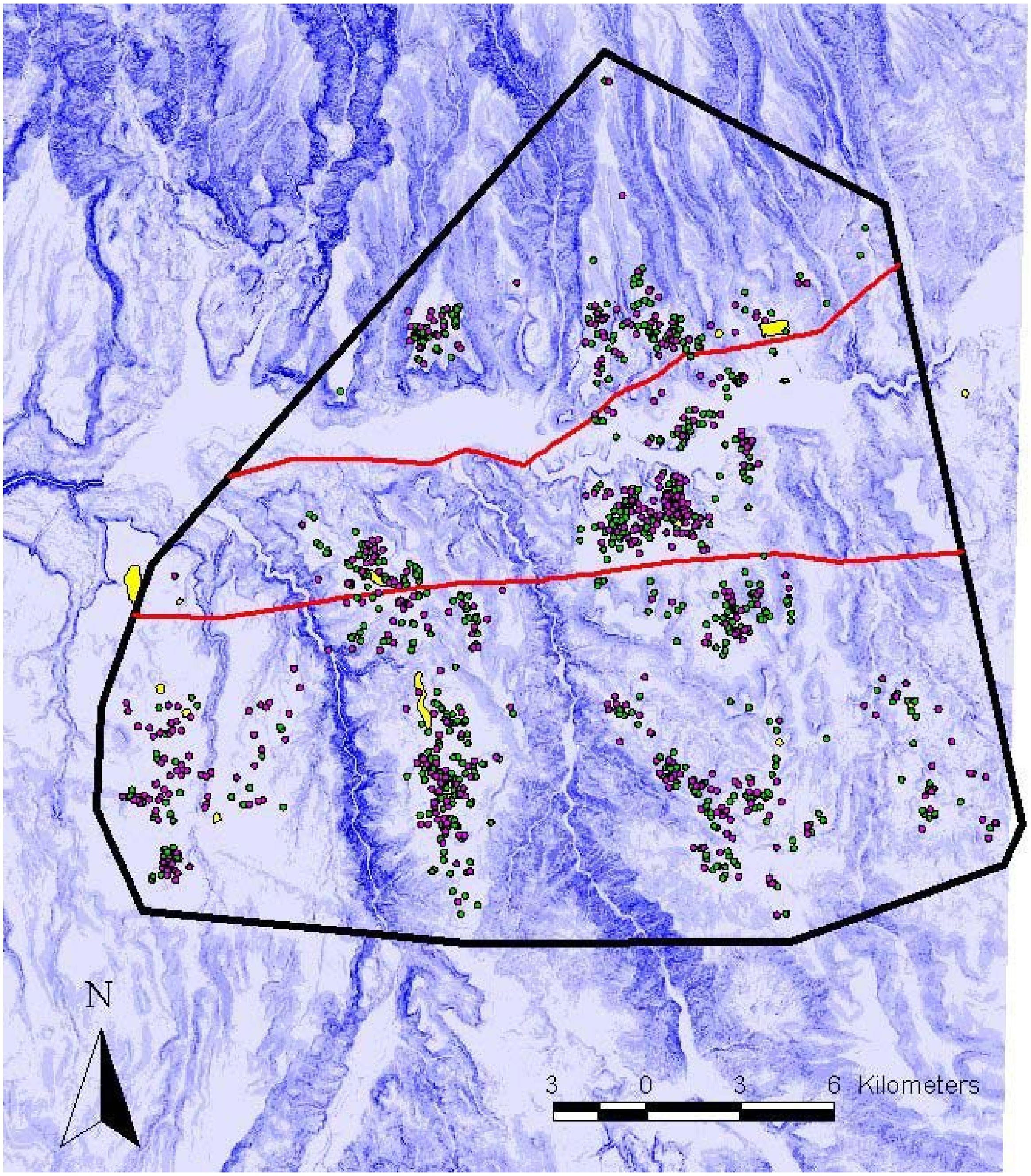

Figure 2.1. Study area (outlined in black) with observed locations of sage grouse including both aerial (purple circles) and ground (green circles) locations. The two red lines represent power transmission lines, irregular yellow polygons represent sage grouse leks, and the blue background represents slope.

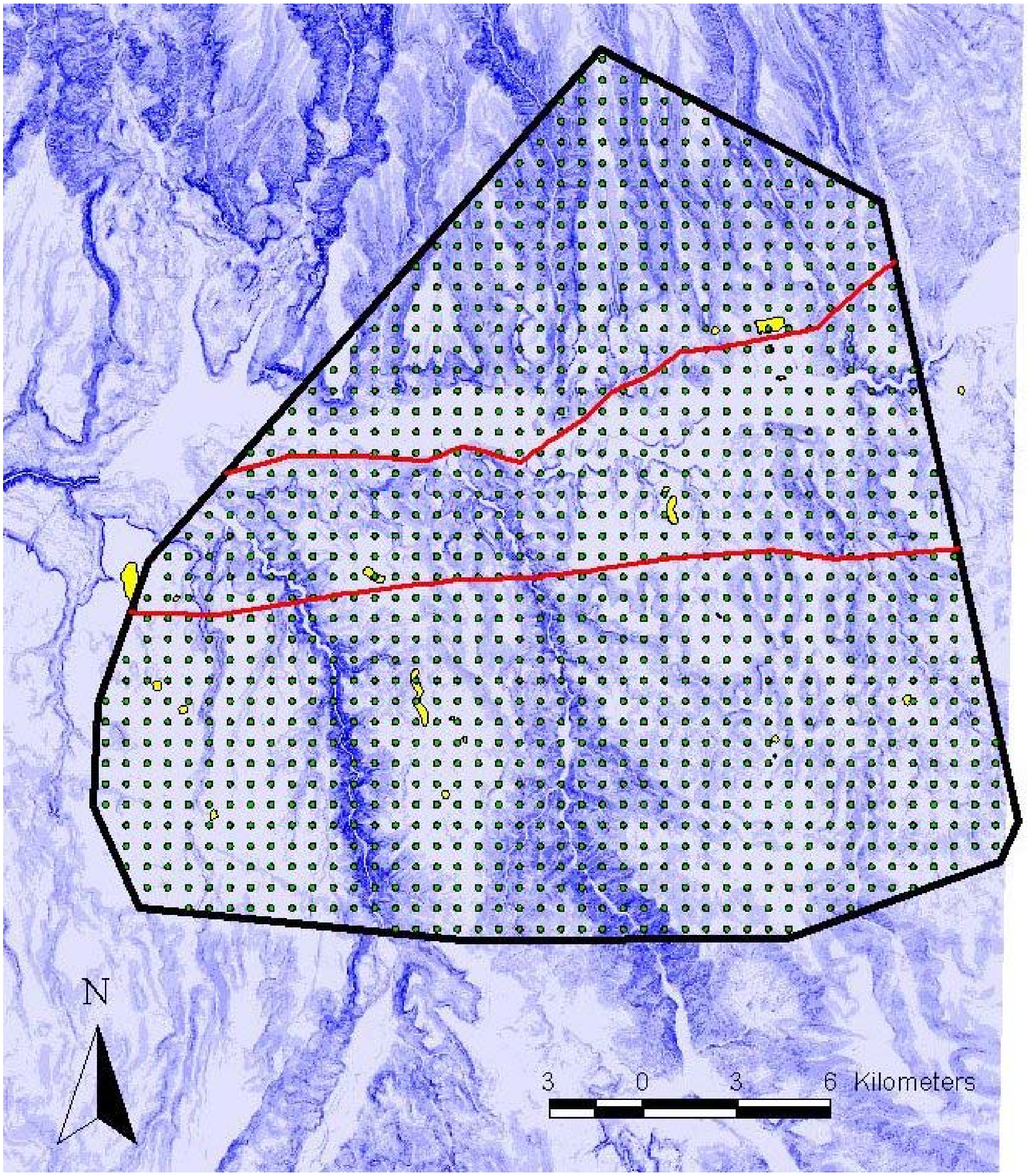

Figure 2.2. Study area as in Figure 2.1 except that green circles represent available locations, a systematic grid of points with a random start.

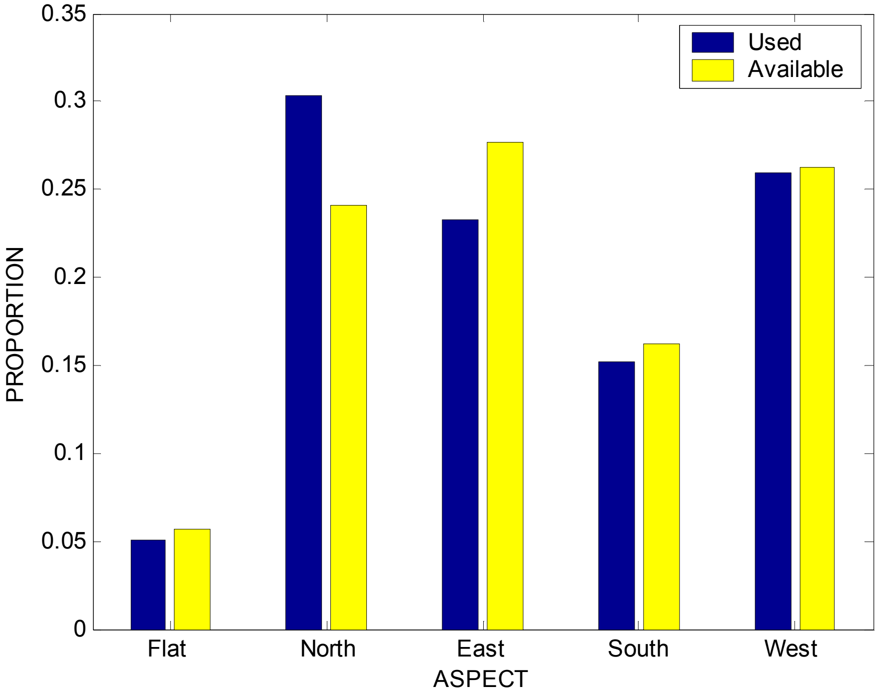

Figure 2.3. Proportions of used and available locations for 5 aspect categories.

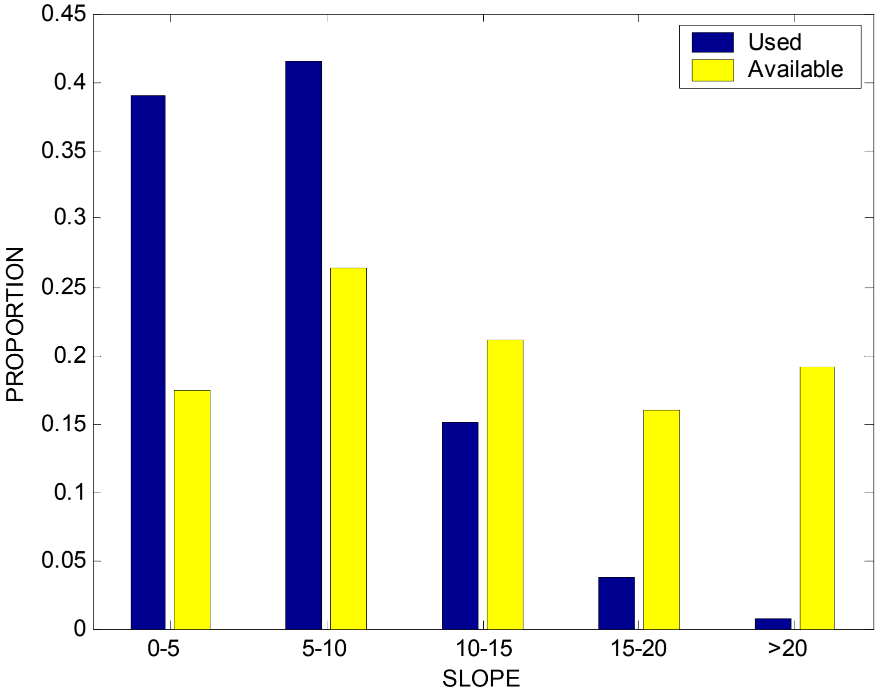

Figure 2.4. Proportions of used and available locations for 5 slope categories.

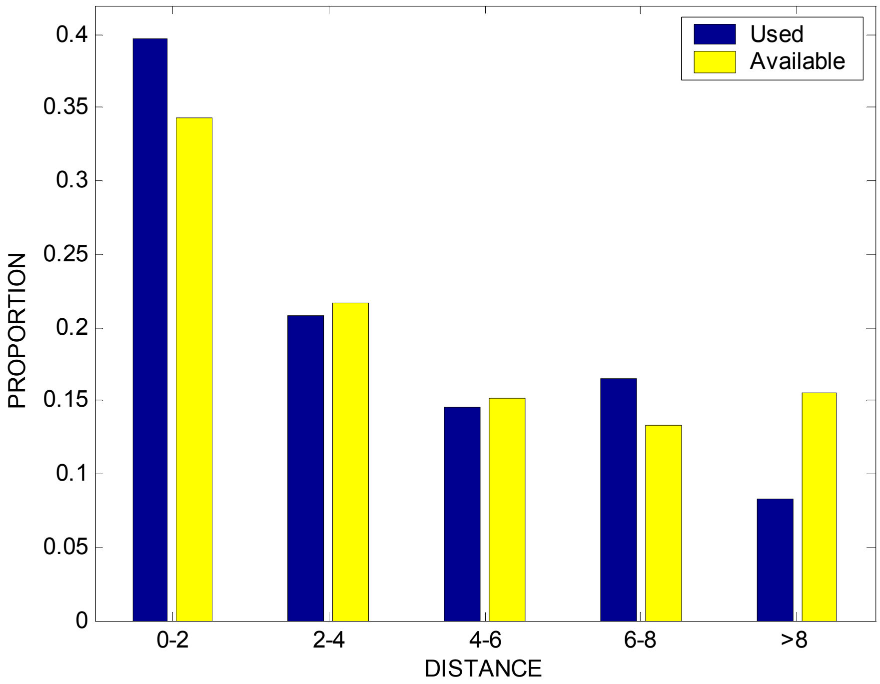

Figure 2.5. Proportions of used and available locations for 5 distance categories.

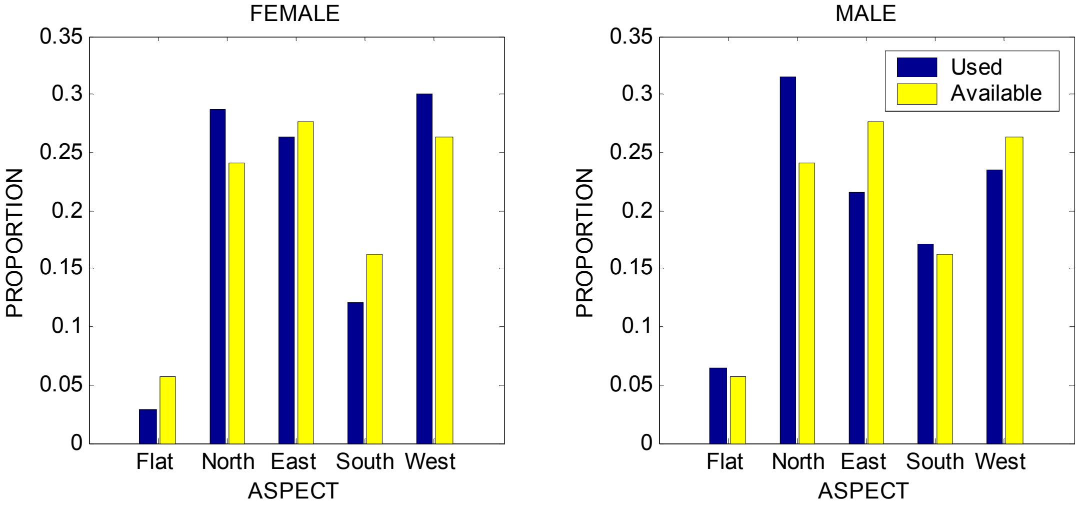

Figure 2.6. Proportions of used and available locations for 5 aspect categories, by sex.

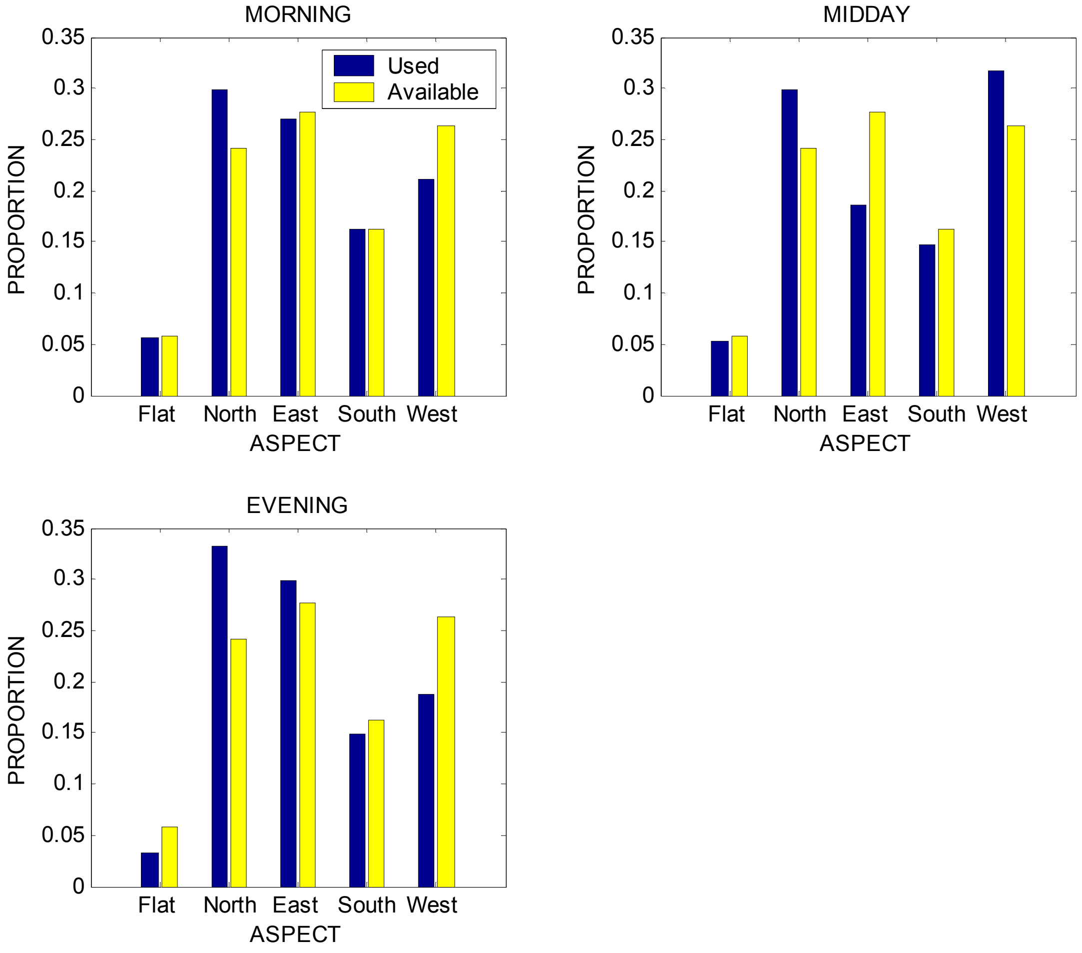

Figure 2.7. Proportions of used and available locations for 5 aspect categories, by period of day.

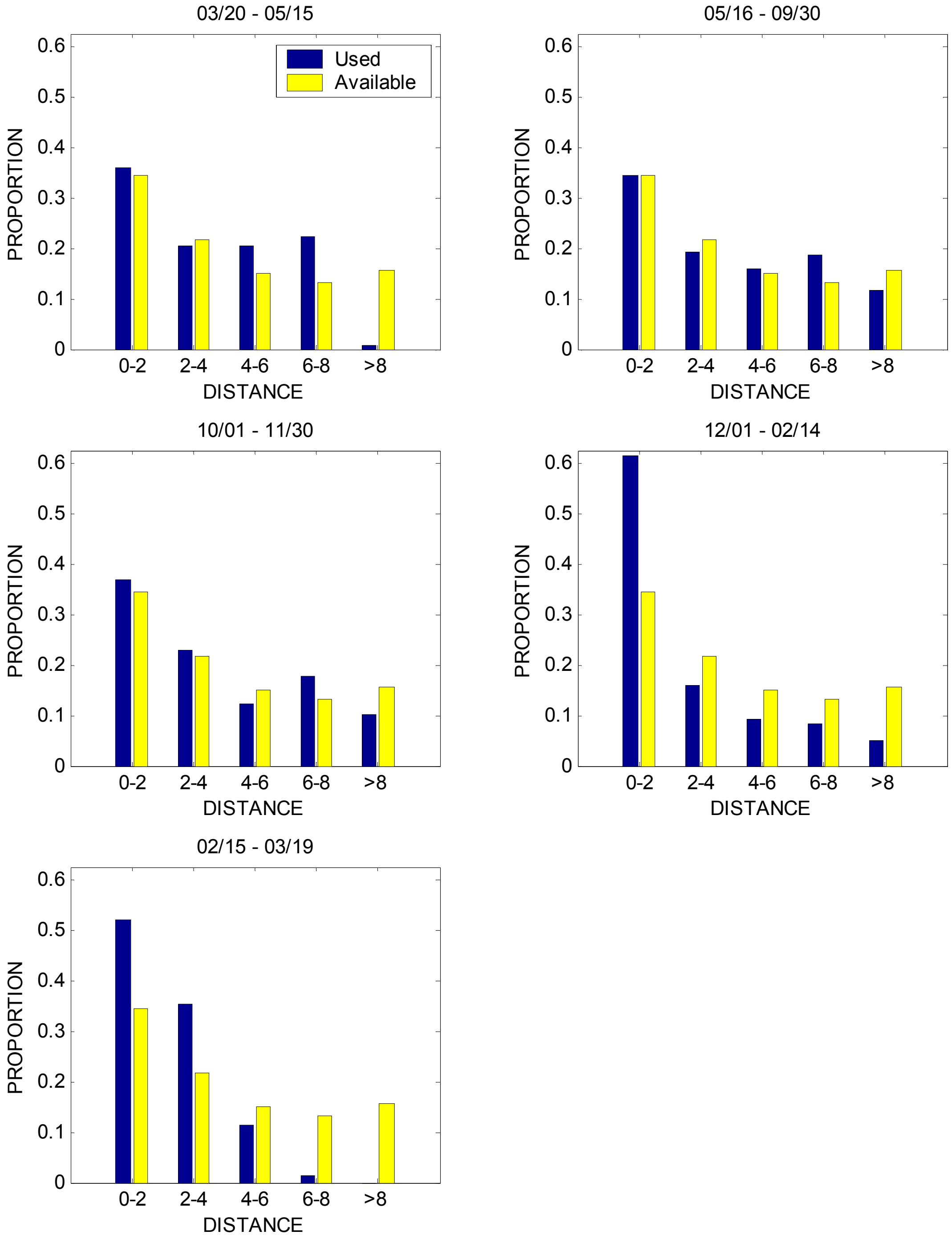

Figure 2.8. Proportions of used and available locations for 5 distance categories, by season of year.

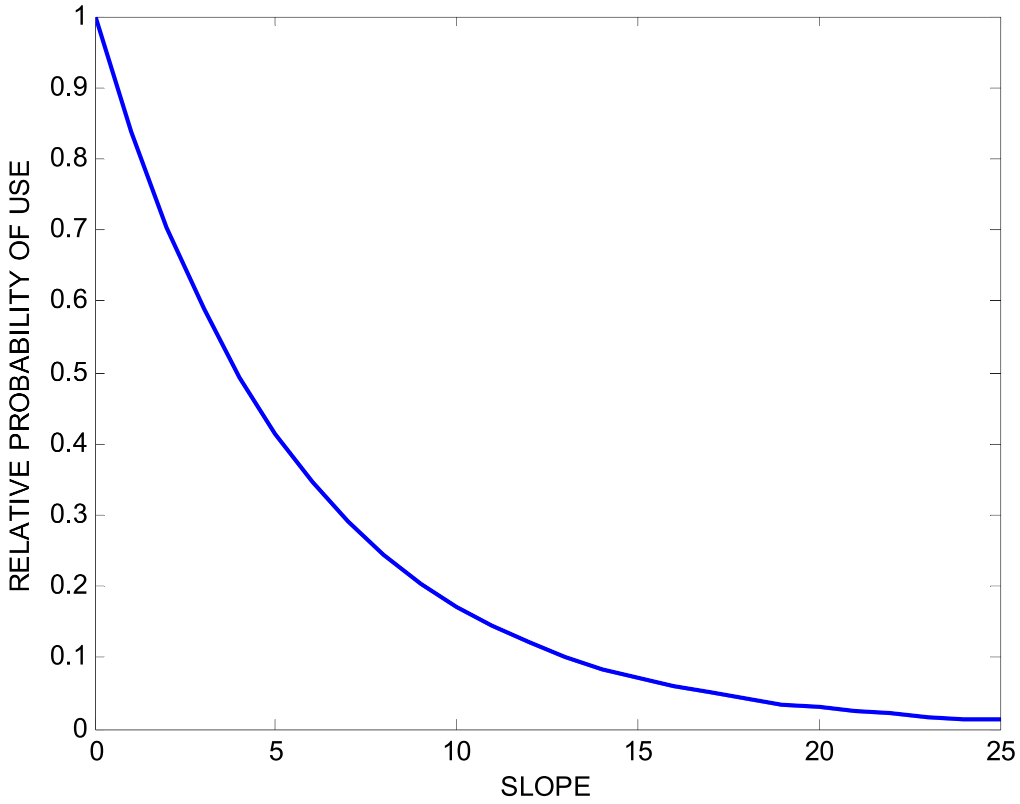

Figure 2.9. Predicted relative probability of use from logistic regression with slope expressed as a continuous variable.

Chapter 3- LEK COUNT TREND ANALYSES

3.1 Introduction

Gunnison sage-grouse leks are counted each spring (Oswald and Diamond 2004). Typically, 4 counts are made at each lek each year. Trends in the yearly High Male Count (HMC) are used to indicate trends in the Gunnison Basin populations. We fit linear trend lines to the HMC for different lek subgroups (different zones, trap site leks) to investigate direction and magnitude of trends. Specifically, we were interested in testing whether the trends at lek sites studied by the National Park Service were different than trends in other zones of the Gunnison Basin. If the trends were different (e.g., more negative), this would suggest that the research (trapping birds, attaching radio transmitters) might have some negative impact on the study leks.

For our analysis, 7 years (1998-2004) were available for evaluating high male count (HMC). Exact counts were not available when conducting this analysis. Instead, counts were approximated by estimating HMC values from the appendices in Oswald and Diamond (2004). Leks with more than 2 missing counts were excluded. Lek counts that were missing for one year were substituted with the average of the count from the year previous and the year after the missing value. Total counts by year for each of 5 zones (Doyleville, Gold Basin, Lost Canyon, Ohio Creek, Sapinero) were used in the trend analyses by zone. In addition, separate trend lines were fit for 3 leks that have been the focus of studies by NPS (Kezar Basin, Sapinero Powerline,Sapinero South). A trend line was also fit by combining the counts for these 3 leks into one set (labeled trap sites). These analyses should be considered approximate because we did not have the exact counts.

3.2 Methods for Lek Size Trend Analysis using Linear Regression

Using data collected during lek counts at Gunnison Basin, we fit regression models for each zone to investigate the magnitude and direction of HMC as a function of time. The linear regression models were all of the form

$$y = \beta_0 + \beta_1 x_1 + \varepsilon, \qquad [1]$$

where y was the HMC, x_1 was the year of the count, β_0 and β_1 were the parameters to be estimated, and ε was a random error term that was assumed to follow a normal distribution with mean 0 and unknown variance σ^2 (Neter et al. 1996). The 95% confidence intervals for the β_1s for each zone were compared to one another. The formula for the 95% confidence interval is

$$b_1 \pm t_{95\%,5} s\{b_1\} \qquad [2]$$

where b_1 was the slope estimate for the given zone, $t_{95\%,5}$ was 2.57 for all intervals, and $s\{b_1\}$ was the standard deviation for the slope estimate (Neter et al. 1996).

3.3 Results

Figures 3.1 and 3.2 show the fitted linear regression lines for each of the zones of interest. All slope estimates for the zones of interest were negative except Kezar Basin. Only four of the zones had slope parameters that were significantly different than zero (95% confidence intervals that do not contain zero; Table 3.1). This suggests that there is a significant negative trend in HMC over time for the Doyleville, Gold Basin, Ohio Creek, and Sapinero leks. The three leks within the Sapinero zone that have been the focus of research by the Park Service showed less negative trends than most other zones in the Basin.

Table 3.1. Slope parameter estimates and 95% confidence intervals for all zones. Confidence intervals that do contain zero are in bold.

Zone	β_1 Estimates	**95% Confidence Intervals**
Doyleville	-24.14	(-32.74, -15.54)
Gold Basin	-7.79	(-13.06, -2.52)
Lost Canyon	-0.04	**(-6.80, 6.73)**
Ohio Creek	-13.14	(-23.75,-2.54)
Sapinero	-5.82	(-9.20, -2.44)
Kezar Basin	0.14	**(-2.02, 2.30)**
Sapinero Powerline	-1.82	**(-3.65, 0.003)**
Sapinero South	-2.11	**(-5.05, 0.83)**
Trap Site	**-3.79**	**(-7.71, 0.14)**

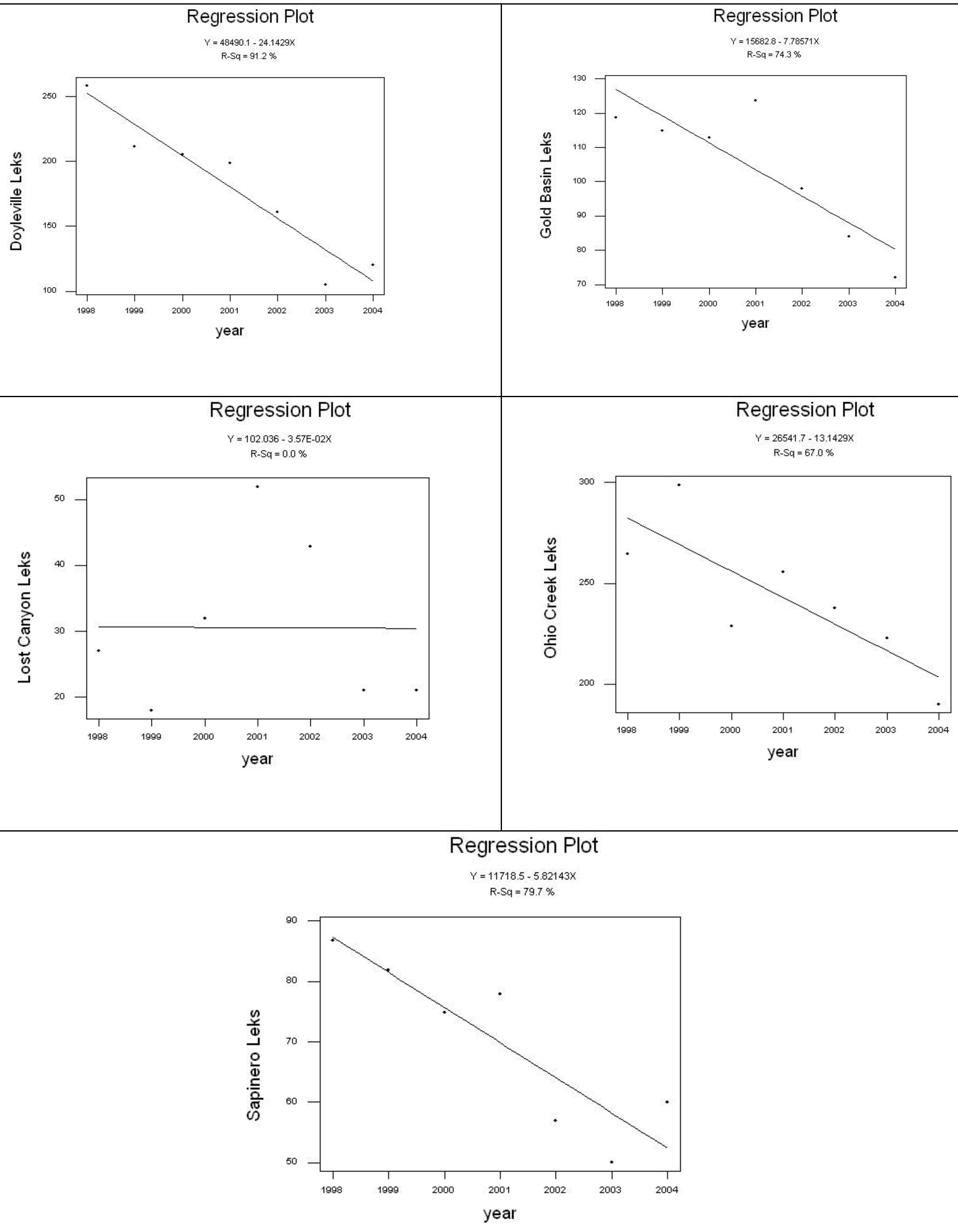

Figure 3.1. Fitted linear regression lines for the five combination zones.

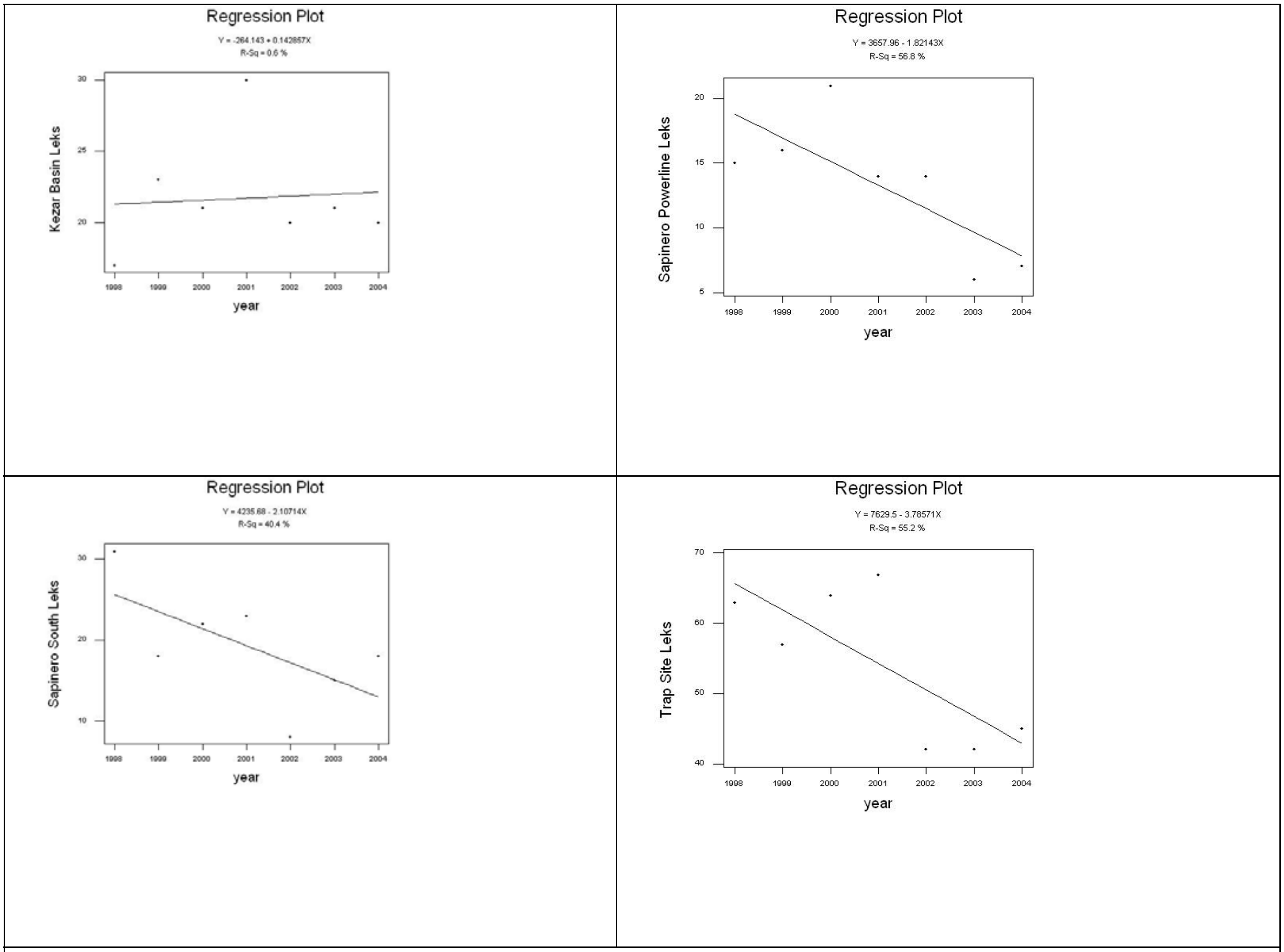

Figure 3.2. Fitted linear regression lines for the three individual leks and their combination.

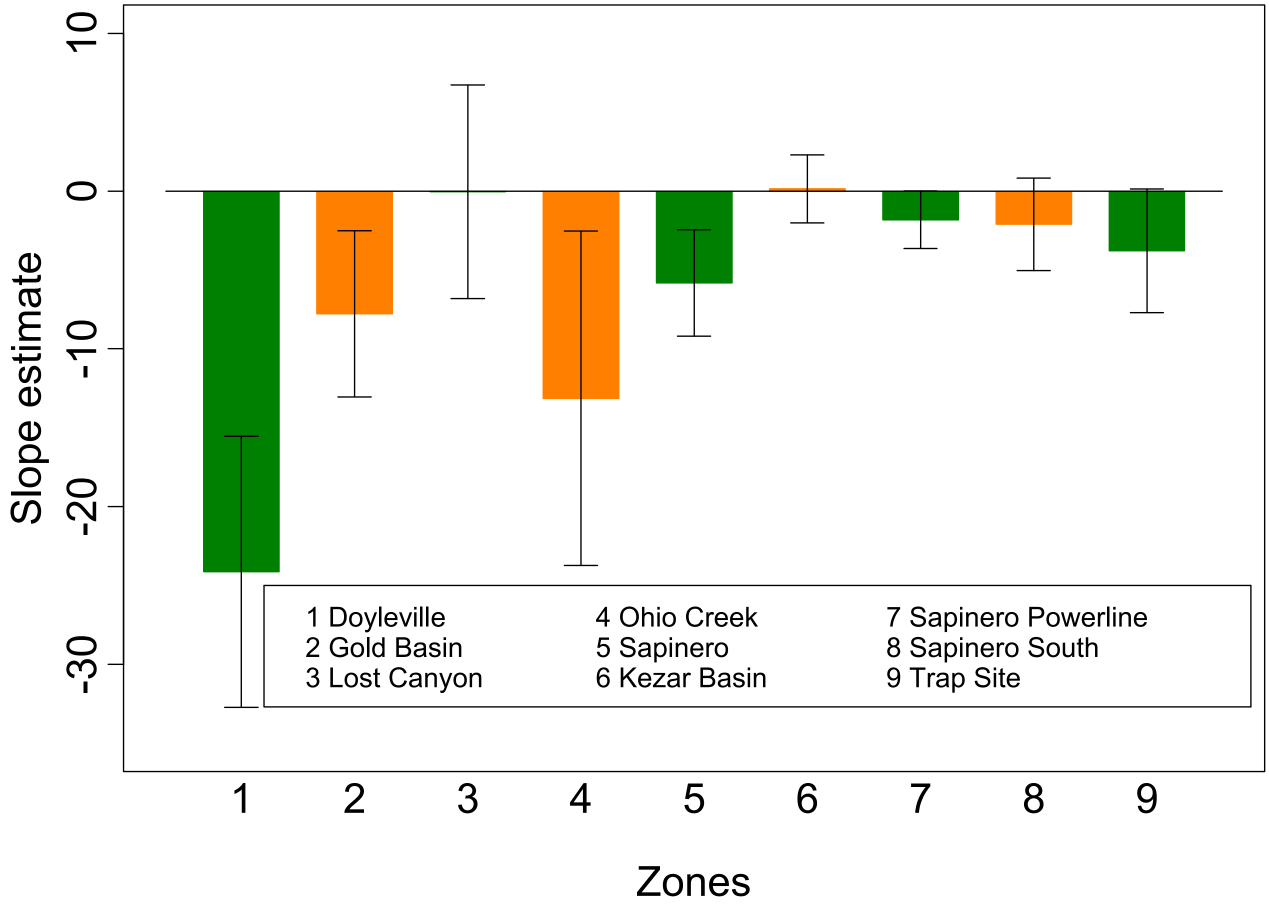

Figure 3.3. Slope parameter estimates and 95% confidence intervals for all zones.

Chapter 4 - SURVIVAL ANALYSIS

4.1 Data Description

A total of 76 Gunnison sage grouse were captured and released. These birds were then tracked to determine their life expectancy after release. Of 29 females, 16 died and 13 were censored (lost radio-signal or still alive at end of study) (44.8% of the sample). Of the 47 males, 31 died and 16 were censored (34.0% of the sample). The survival lengths (date last seen minus the capture/release date) were calculated for all birds. Survival lengths ranged from 3 days to 1,031 days. Age of bird was not considered.

4.2 Methods

The survival function was estimated using two different methods, Kaplan-Meier and Life-table. The hazard function was estimated using Life-table and Cox's proportional hazard.

4.2.1 Survival Function

Kaplan-Meier

The Kaplan-Meier estimate of the survival function consists of a product of the estimated probabilities for an individual surviving through a time interval. The time intervals are determined by the time between two complete observations, or the duration between two birds dying. The estimated probability for the j^{th} time interval is $1 - d_j/n_j$, where d_j are the subjects that did not survive the time interval and n_j is the number of subjects at risk during the interval. The censored subjects only affect the estimate by changing the number of subjects that are at risk, n_j in that time interval (Collett 1994).

Life-Table

The Life-table estimate of the conditional probability of failure is an estimate that a bird will die in any chosen interval, given that it survived to the start of the interval. For the k^{th} time interval, the conditional probability of the failure estimate is d_k/n_k where d_k is the number of subjects that died and n_k is the effective sample size, $n_k = n - c_k/2$. The number of subjects at risk is n and c_k is the number of censored birds. The censored individuals are assumed to be at risk for half of the interval. The survival function is one minus the conditional probability of failure (Collett 1994).

4.2.2 Hazard Function

Life-Table

The Life-table estimate of the hazard function, instantaneous death rate, is the probability that a bird dies at time i given that it survived up to that time. For the k^{th} time interval, the hazard function is $d_k/b_k(n_k - d_k/2)$, where b_k is the exposure time and n_k and d_k are the same as above

(Collett 1994). The hazard function is not a probability, but rather it is a ratio of the probability distribution function over the survival function for the given time interval.

Cox's Proportional Hazard

The proportional hazards function is $h_i(t) = \psi h_j(t)$ where, $\psi = \exp\{\beta'\mathbf{x}_i\}$. The $\beta'\mathbf{x}_i$ is considered the relative risk or hazard ratio, which does not depend on time. A proportional hazards model can be fit either as a semi-parametric or a parametric model. Cox's semi-parametric method is considered to be semi-parametric because it does not require a particular probability distribution to be used when estimating the proportional hazards model. Thus, the regression parameters can be estimated without estimating the hazard function.

The semi-parametric proportional hazards model is obtained by re-expressing $h_i(t) = \psi h_j(t)$ where, $\psi = \exp\{\beta'\mathbf{x}_i\}$ as $\log\left\{\frac{h_i(t)}{h_j(t)}\right\} = \beta'\mathbf{x}_i$. Estimates of the regression parameters for the proportional hazards model are reached by maximizing the partial log-likelihood function for these parameters (see Collett 1994, pg 62). There are many ways to test the significance of given models, including Wald, score, likelihood ratio tests, and Akaike's information criteria (AIC). The results of the Wald, score, and log-likelihood ratio tests are often similar. Given that only one covariate, sex, is of interest, only the likelihood ratio test is discussed.

The likelihood ratio test can be used to determine the significance of the model with the covariate sex included compared to the null model with no covariates using the following formula:

$$-2\log\left\{L\left(\hat{\beta}_{sex}\right)/L\left(\hat{\beta}_0\right)\right\} = -2\log L\left(\hat{\beta}_{sex}\right) + 2\log L\left(\hat{\beta}_0\right) \approx \chi^2$$, with $df = 1$. (Collett 1994)

This is the same formula used to test the significance of the sex variable to the model given that sex is the only covariate included.

4.3 Results

The survival and hazard functions are estimated for both sexes and for all of the data combined. SAS was used to complete all analyses (Allison 1995).

4.3.1 Survival Function

Figure 4.1 shows the survival functions for all birds combined from the Kaplan-Meier and Life-table methods. They both show a steady decline in survival lengths as time increases. Using the Kaplan-Meier method, the estimated mean survival time after being released is approximately 360 days.

Figure 4.2 shows the survival functions for males and females using the two methods. Males are more likely to die than females shortly after release, but as time increases, females become just as likely to die as males. The quartile estimates and their confidence intervals are presented in Table 4.1. These show that females had a long survival length for the 25th and 50th quartiles, and that males survived longer at the 75th quartile. None of the quartile estimates were significantly different from each other, as indicated by all quartile estimate confidence intervals overlapping.

The mean survival times after being released are approximately 367 days for females and 345 days for males. Both methods report log-rank ($\chi^2 = 0.1465$, p-value = 0.70) and Wilcoxon ($\chi^2 = 1.7661$, p-value = 0.18) statistics for the difference between the survival functions for males and females. The results from both test statistics show that there is no significant difference between the male and female survival functions.

4.3.2 Hazard Function

Life-Table Method

Figure 4.3 shows the hazard function for all birds combined from the life table method. This shows that the hazard of death after being released increases between approximately 250 days and 700 days and than it sharply decreases. Figure 4.4 shows the hazard functions for males and females. It can be seen from this figure that the hazard of death for females increases greatly after 500 days. For males there is a steady increase in the hazard of death between 250 days and 900 days and then there is a sharp decrease.

Cox's Proportional Hazards Method

Sex was the only covariate added to the null model, resulting in the following model:

$$\log\left\{\frac{h_i(t)}{h_j(t)}\right\} = \hat{\beta}_1 sex_i = 0.12106 sex_i .$$

The -2log likelihood for the null model was 308.61 and then changed to 308.46 after sex was added to the model. The likelihood ratio test ($\chi^2 = 0.1473$, p-value=0.70) showed that the coefficient for sex was not significantly different than zero. Thus, the model is not significantly different than the null model. Figure 4.5 shows the log-log survival functions. If the hazards are proportional, then the functions should be parallel. Since the functions in Figure 4.5 clearly are not parallel, a proportional hazards model is not appropriate with the covariate sex. The functions suggest that a possible interaction between sex and time is appropriate.

Figure 4.6 shows the cumulative hazard function for the above model. The cumulative hazard function should be a straight line if there is a constant hazard function. The function in Figure 4.6 shows a slight upward bend, which suggests a hazard that increases with time. The hazard function from the Life-table showed a similar result during some time periods.

4.3.3 Annual Mortality Estimates

Using the Life-table method, annual mortality of female Gunnison sage grouse with radio transmitters was 0.47 (se=0.10). For males, annual mortality was estimated to be 0.55 (se=0.08).

Table 4.1. Quartile estimates and their 95% confidence intervals for females and males.

Sex	%	Point estimates (days)	95% LCL	95% UCL
Females	25	102	53	348
	50	348	167	554
	75	554	348	759
Males	25	38	32	106
	50	160	94	578
	75	706	407	809

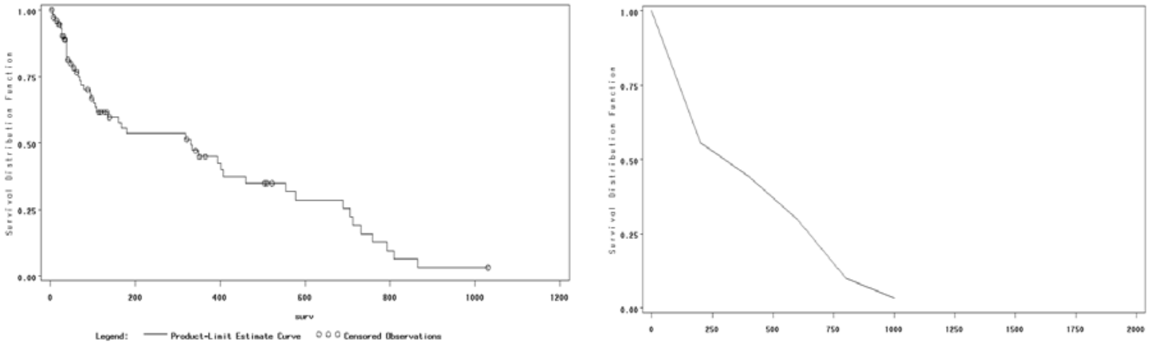

Figure 4.1. Kaplan-Meier and life table survival functions for all birds combined.

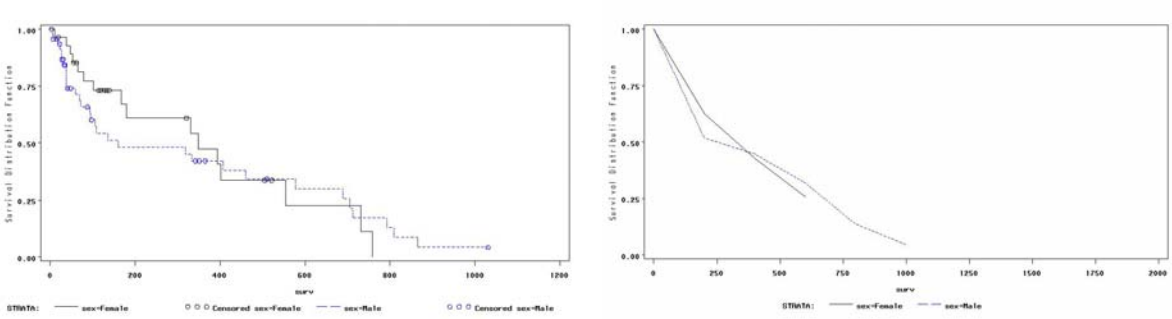

Figure 4.2. Kaplan-Meier and life table survival functions for the different sexes.

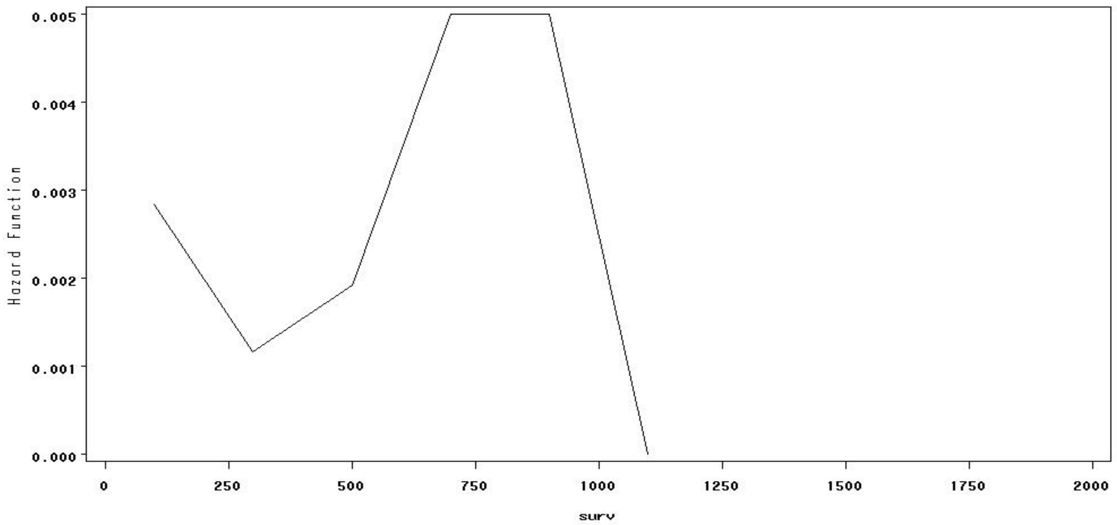

Figure 4.3. Life table hazard function for all birds combined.

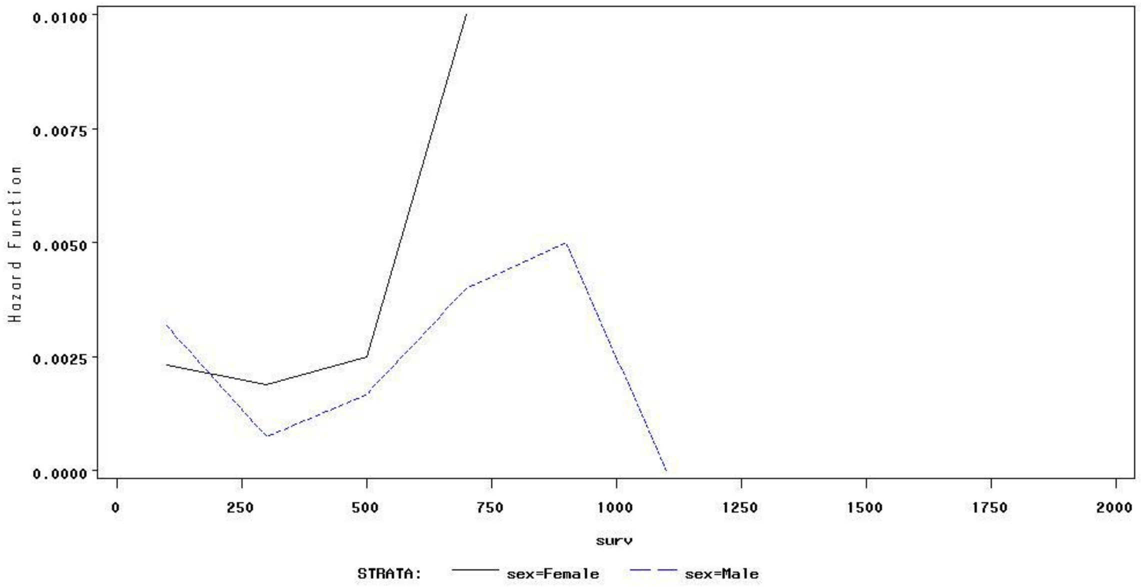

Figure 4.4. Life table hazard function for males and females.

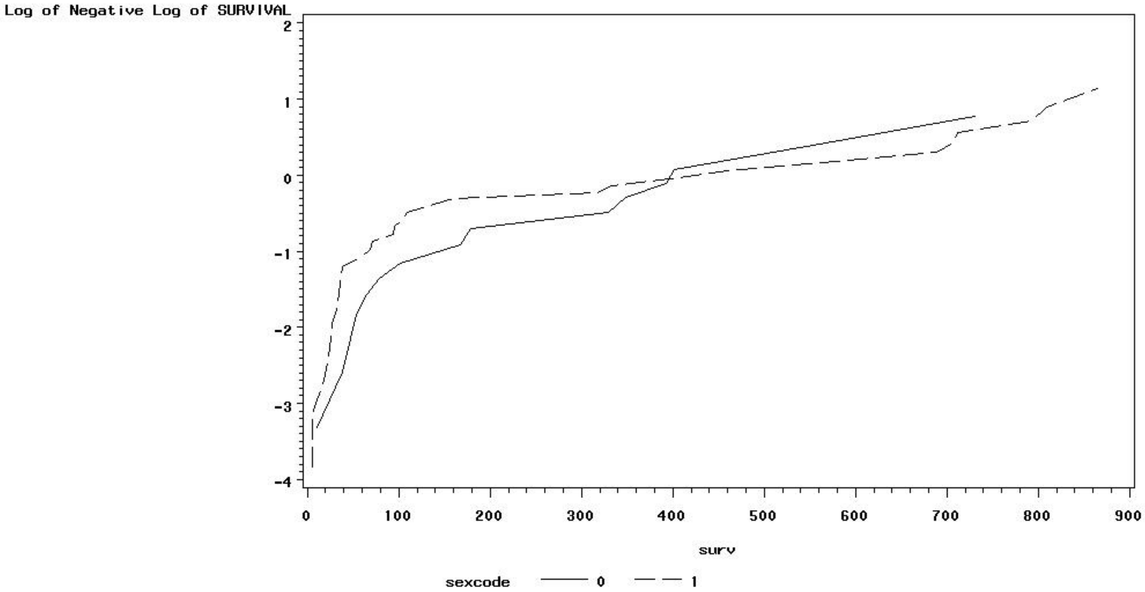

Figure 4.5. log-log survival function.

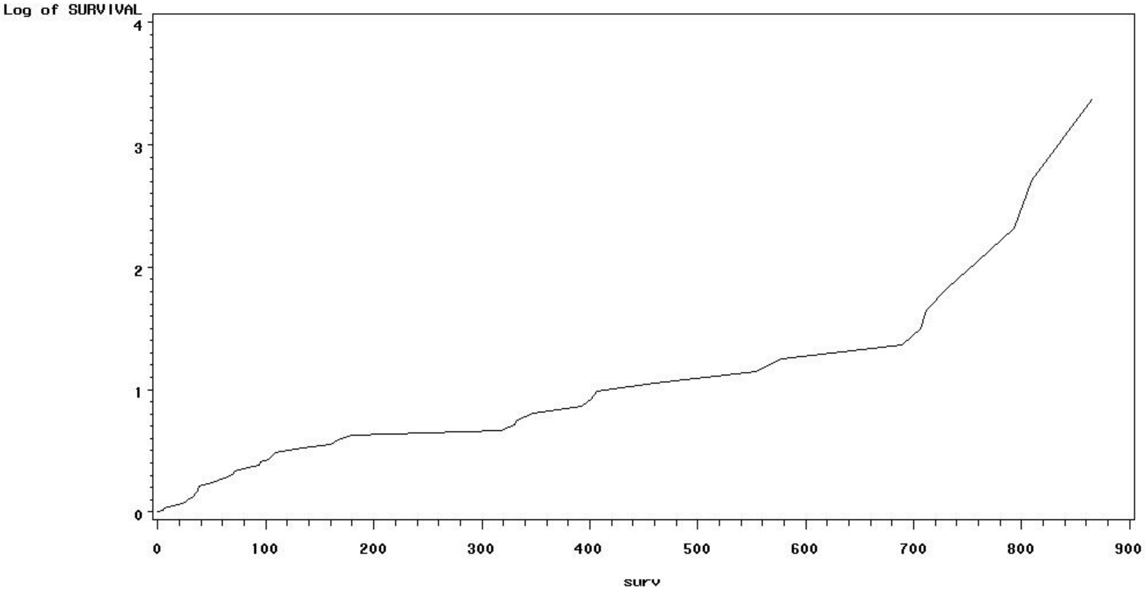

Figure 4.6. Cumulative hazard function.

5.0 REFERENCES

Allison, P.D. 1995. Survival Analysis using the SAS system. A Practical Guide, Cary NC: SAS Institute Inc. 292 pp.

Burt W.H. 1943. Territoriality and home range concepts as applied to mammals. Journal of Mammalogy. 24:346-352.

Collett, D. 1994. Modeling survival data in medical research. Chapman & Hall/ CRC. Boca Raton.

Colorado Division of Wildlife. 2004. Colorado vegetation classification project. http://www.ndis.nrel.colostate.edu/coveg/.

Johnson D.H. 1980. The comparison of useage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Kernohan, B.J., R.A. Gitzen, and J.J. MIllspaugh. 2001. Using home range estimators to analyze animal space use. Pgs 126-167 in Radio Tracking and Animal Populations, J. Millspaugh and J. Marzluff editors. Academic Press, Boston, MA.

Manly, B.F.J., L.L. McDonald, D. Thomas, T. McDonald and W.P. Erickson. 2002. Resource Selection by Animals, Statistical Design and Analysis of Field Studies. Kluwer Academic Publishers.

Neter, J., M. Kutner, C. Nachtsheim, and L. Wasserman. 1996. Applied Linear Statistical Models, 4th Edition. Irwin, Chicago, IL.

Oswald, M. and B. Diamond. 2004. Gunnison Basin Gunnison Sage-Grouse Lek Count Summary and Population Estimate. Final Report, 21 March – 10 May Lek Season, Gunnison Basin, Colorado. Colorado Divison of Wildlife.

Table 1.1 Approximate effort to map and ground-truth habitat.

Year	people	months	acres	Person-months	**acres/person-month**
2003	2	5	3400	10	**340**
2004	5	5	11700	25	**468**
2005	3	5	6400	15	**427**
				average	**412**

Table 1.2. Habitat characteristics of the overall study area, and of the sage grouse relocations.

class_name	Area (acres)	proportion	# Relocations	% Relocations
Agriculture Land	131	0.1%	3	0.2%
Alpine Meadow	140	0.1%	1	0.1%
Aspen	2023	1.4%	0	0.0%
Barren Land	1823	1.3%	13	1.0%
Douglas Fir	4125	2.9%	0	0.0%
Douglas Fir/Aspen Mix	3468	2.4%	1	0.1%
Englemann Spruce/Fir Mix	4	0.0%	0	0.0%
Gambel Oak	1390	1.0%	2	0.2%
Grass/Forb Rangeland	14450	10.1%	158	12.0%
Mesic Mountain Shrub Mix	293	0.2%	4	0.3%
Pinon-Juniper	281	0.2%	0	0.0%
PJ-Mtn Shrub Mix	181	0.1%	0	0.0%
PJ-Sagebrush Mix	180	0.1%	0	0.0%
Ponderosa Pine	2626	1.8%	3	0.2%
Riparian	418	0.3%	2	0.2%
Rock	2885	2.0%	4	0.3%
Sagebrush Community	35640	24.8%	341	26.0%
Sagebrush/Gambel Oak Mix	1245	0.9%	4	0.3%
Sagebrush/Grass Mix	65060	45.3%	769	58.6%
Saltbush Community	258	0.2%	2	0.2%
Sparse PJ/Shrub/Rock Mix	170	0.1%	0	0.0%
Spruce/Fir/Aspen Mix	523	0.4%	0	0.0%
Talus Slopes & Rock Outcrops	125	0.1%	0	0.0%
Upland Willow/Shrub Mix	145	0.1%	0	0.0%
Water	6064	4.2%	1	0.1%
Total	143647	100.0%	1312	100.0%

Appendix 1.1. Classification of habitat polygons mapped to date (see Figure 1.2), and classification of habitat of sage grouse relocations.

		Available Habitat			Used habitat	
Common Name	Category	# polygons	acres	%	# relocations	%
Arizona fescue-big sagebrush-Parry oatgrass	Other	1	1.034	0.00%	0	0.00%
Aspen/Serviceberry-deep dark soils, 8,000-9,700ft	Aspen	13	37.218	0.18%	0	0.00%
Aspen-common juniper-elk sedge-sparse serviceberry-sparse snowberry	Aspen	7	20.389	0.10%	0	0.00%
Aspen-common juniper-snowberry-sparse serviceberry	Aspen	40	153.518	0.74%	9	1.56%
Aspen-rose-sparse serviceberry-elk sedge-brome	Aspen	11	22.079	0.11%	0	0.00%
Aspen-Saskatoon serviceberry	Aspen	22	68.038	0.33%	0	0.00%
Aspen-serviceberry-common juniper-snowberry-bedstraw	Aspen	2	0.908	0.00%	0	0.00%
Aspen-snowberry-wheatgrass	Aspen	12	57.072	0.27%	0	0.00%
Baltic rush-dandelion-yarrow-sparse willows	Other	1	0.583	0.00%	0	0.00%
Big sagebrusg-bitterbrush-muttongrass-pine needlegrass	Big Sagebrush	2	9.538	0.05%	0	0.00%
Big sagebrush muttongrass-sparse snowberry	Big Sagebrush	46	216.799	1.04%	7	1.21%
Big sagebrush sparse Utah serviceberry-rabbitbrush-sparse snowberry-Indian ricegrass	Big Sagebrush	117	418.348	2.01%	1	0.17%
Big sagebrush/Muttonrass-dark soils, 8,000-10,200ft	Big Sagebrush	3	41.682	0.20%	4	0.69%
Big sagebrush-Arizona fescue-junegrass	Big Sagebrush	3	10.836	0.05%	0	0.00%
Big sagebrush-bitterbrush-grasses	Big Sagebrush	51	211.465	1.02%	2	0.35%
Big sagebrush-bitterbrush-muttongrass	Big Sagebrush	34	199.157	0.96%	10	1.73%
Big sagebrush-black sagebrush-muttongrass-Arizona fescue	Big Sagebrush	1	3.067	0.01%	0	0.00%
Big sagebrush-grasses	Big Sagebrush	155	956.925	4.59%	46	7.96%
Big sagebrush-grasses-sparse bitterbrush <10% bitterbrush cover	Big Sagebrush	38	182.032	0.87%	0	0.00%
Big sagebrush-grasses-sparse snowberry-sparse bitterbrush <10% bitterbrush cover	Big Sagebrush	243	1402.77	6.73%	18	3.11%
Big sagebrush-Kentucky bluegrass-yarrow-dandelion	Big Sagebrush	3	4.756	0.02%	1	0.17%
Big sagebrush-muttongrass	Big Sagebrush	1	13.832	0.07%	0	0.00%
Big sagebrush-muttongrass-pine needlegrass	Big Sagebrush	64	368.561	1.77%	16	2.77%
Big sagebrush-oak-snowberry-sparse serviceberry	Big Sagebrush	77	397.575	1.91%	0	0.00%
Big sagebrush-oak-sparse grasses	Big Sagebrush	43	129.672	0.62%	1	0.17%
Big sagebrush-pine needlegrass-grasses	Big Sagebrush	174	1020.81	4.90%	41	7.09%
Big sagebrush-prairie junegrass-serviceberry absent to sparse	Big Sagebrush	1	2.024	0.01%	0	0.00%
Big sagebrush-quackgrass-Baltic rush-Ketucky bluegrass-dandelion	Big Sagebrush	1	0.967	0.00%	0	0.00%
Big sagebrush-serviceberry-bitterbrush-green needlegrass-pine needlegrass	Big Sagebrush	1	2.705	0.01%	0	0.00%
Big sagebrush-snowberry-dryland sedge-Utah serviceberry	Big Sagebrush	13	40.413	0.19%	5	0.87%
Big sagebrush-sparse bitterbrush <10% bitterbrush cover	Big Sagebrush	104	498.994	2.40%	34	5.88%
Big sagebrush-sparse serviceberry-muttongrass-spike fescue	Big Sagebrush	1	1.465	0.01%	0	0.00%
Big sagebrush-sparse Utah serviceberry-pine needlegrass-sparse snowberry	Big Sagebrush	176	940.36	4.51%	9	1.56%
Big sagebrush-sparse Utah serviceberry-rabbitbrush-sparse snowberry	Big Sagebrush	279	2456.842	11.80%	28	4.84%

Appendix 1.1. Classification of habitat polygons mapped to date (see Figure 1.2), and classification of habitat of sage grouse relocations.

		Available Habitat			Used habitat	
Common Name	Category	# polygons	acres	%	# relocations	%
Bitterbrush-big sagebrush-muttongrass	Other	12	21.323	0.10%	3	0.52%
Bitterbrush-big sagebrush-muttongrass-Arizona fescue	Other	1	0.574	0.00%	0	0.00%
Bitterbrush-big sagebrush-muttongrass-grasses	Other	9	20.607	0.10%	0	0.00%
Bitterbrush-sagebrush/Needlegrasss-dark coarse soils, <9,700ft	Other	6	11.89	0.06%	0	0.00%
Black sagebrush-big sagebrush-bottlebrush	Black sagebrush	52	260.167	1.25%	26	4.50%
Black sagebrush-bottlebrush-pine needlegrass	Black sagebrush	20	189.999	0.91%	0	0.00%
Black sagebrush-pine needlegrass	Black sagebrush	4	25.328	0.12%	0	0.00%
Black sagebrush-rabbitbrush-sparse	Black sagebrush	19	72.433	0.35%	0	0.00%
Black sagebrush-Sandberg bluegrass-Arizona fescue	Black sagebrush	2	6.08	0.03%	0	0.00%
Black sagebrush-sparse	Black sagebrush	40	202.301	0.97%	1	0.17%
Cheatgrass-black sagebrush	Other	2	20.237	0.10%	0	0.00%
Cottonwood/Willow-Water-layered soils-floodplains, <9,400ft	Willow/Cottonwood	5	16.84	0.08%	0	0.00%
Cottonwood-Pacfic willow-alder-swamp bluegrass	Willow/Cottonwood	1	16.406	0.08%	0	0.00%
Cottonwood-rose-Kentucky bluegrass-bedstraw	Willow/Cottonwood	7	93.349	0.45%	2	0.35%
Cottonwood-rose-snowberry-western wheatgrass	Willow/Cottonwood	10	60.229	0.29%	0	0.00%
Douglas-Fir/Serviceberry-Steep Northerly, 7,900-10,000ft	Douglas-Fir	1	3.846	0.02%	0	0.00%
Douglas-Fir/wax currant-Arizona Fescue-Coarse Thin Dark Soils-Steep	Douglas-Fir	1	1.162	0.01%	0	0.00%
Douglas-fir-aspen-common juniper-serviceberr-Thurber fescue-elk sedge	Douglas-Fir	15	55.569	0.27%	0	0.00%
Douglas-fir-maple-rose-snowberry	Douglas-Fir	1	0.95	0.00%	0	0.00%
Douglas-fir-serviceberry-snowberry-muttongrass	Douglas-Fir	11	36.993	0.18%	3	0.52%
Douglas-fir-sparse Arizona fescue	Douglas-Fir	2	12.125	0.06%	0	0.00%
Douglas-fir-sparse serviceberry-elk sedge-Oregon grape	Douglas-Fir	9	45.3	0.22%	0	0.00%
Douglas-fir-sparse serviceberry-Oregon grape-sparse snowberry	Douglas-Fir	23	142.938	0.69%	1	0.17%
Douglas-fir-sparse wax currant	Douglas-Fir	14	89.011	0.43%	0	0.00%
Douglas-fir-sparse wax currant-grasses	Douglas-Fir	12	99.741	0.48%	0	0.00%
Douglas-fir-tree juniper-Wheeler bluegrass-sparse wax currant	Douglas-Fir	29	191.124	0.92%	0	0.00%
Douglas-fir-wax currant-sagebrush-Arizona fescue	Douglas-Fir	2	4.048	0.02%	0	0.00%
Forbs-big sagebrush-sedges-rabbitbrush	Other	24	145.857	0.70%	8	1.38%
Geyer willow-beaked sedge	Willow	1	63.543	0.31%	19	3.29%
Geyer willow-Kentucky bluegrass, dandelion	Willow	4	34.776	0.17%	11	1.90%
Grasses-big sagebrush-rabbitbrush	Other	10	220.395	1.06%	52	9.00%
Indian Ricegrass/Needle-and-Thread-Aridic soils-Windswept ridge shoulders, > 9,000ft	Other	20	58.616	0.28%	2	0.35%
Kentucky bluegrass-Baltic Rush-Dry grasses	Other	1	0.392	0.00%	0	0.00%
Kentucky bluegrass-sagebrush-cinquefoil	Other	1	1.927	0.01%	0	0.00%
Kentucky bluegrass-western wheatgrass-bluegrass	Other	2	0.732	0.00%	0	0.00%
Mixed Rocky Tall Shrublands	Other	31	84.35	0.40%	0	0.00%

Appendix 1.1. Classification of habitat polygons mapped to date (see Figure 1.2), and classification of habitat of sage grouse relocations.

		Available Habitat			Used habitat	
Common Name	Category	# polygons	acres	%	# relocations	%
Mountain Mahogany-sagebrush-muttongrass-sparse Utah serviceberry	Mountain Mahogany	78	423.615	2.03%	1	0.17%
Mountain Mahogany-Utah serviceberry-big sagebrush-snowberry	Mountain Mahogany	82	641.472	3.08%	1	0.17%
Mountain Mahogany-Utah serviceberry-big sagebrush-snowberry-muttongrass	Mountain Mahogany	16	86.021	0.41%	0	0.00%
Needle-and-thread-blue grama-Wyoming sagebrush	Needle-and-Thread	17	32.696	0.16%	0	0.00%
Needle-and-thread-sedge-Sandberg bluegrass-sparse Indian ricegrass	Needle-and-Thread	9	19.981	0.10%	1	0.17%
Needle-and-thread-sparse	Needle-and-Thread	118	818.85	3.93%	13	2.25%
Needle-and-thread-winterfat-western wheat	Needle-and-Thread	4	27.024	0.13%	0	0.00%
Oak-big sagebrush-snowberry-muttongrass	Oak	58	260.231	1.25%	0	0.00%
Oak-serviceberry-snowberry-bedstraw	Oak	45	253.542	1.22%	0	0.00%
Saskatoon Serviceberry-big sagebrush-snowberry-muttongrass-elk sedge	Other	5	10.717	0.05%	0	0.00%
Serviceberry-Oak-Dark Clay Soils-Protected, 7,600-8,600ft	Other	4	18.1	0.09%	0	0.00%
Serviceberry-snowberry-mountain mahogany-green needlegrass	Other	1	17.264	0.08%	0	0.00%
Shrubby cinquefoil-sparse cottonwood-Kentucky bluegrass-Baltic Rush	Other	4	11.105	0.05%	0	0.00%
Snakeweed-pine needlegrass-needle-and-thread-blue grama	Other	4	24.826	0.12%	0	0.00%
Snowberry-big sagebrush-dry sagebrush-dry grasses	Other	3	6.028	0.03%	1	0.17%
Snowberry-big sagebrush-muttongrass-green needlegrass	Other	2	7.917	0.04%	0	0.00%
Tree juniper-blue grama-sagebrush	Juniper	46	219.588	1.05%	2	0.35%
Tree Juniper-Coarse Dark Soils-Steep Southerly, 8,300-9,300ft	Juniper	1	3.667	0.02%	0	0.00%
Tree juniper-muttongrass-littleseed ricegrass	Juniper	4	2.064	0.01%	0	0.00%
Tree juniper-sagebrush-Indian ricegrass	Juniper	21	60.742	0.29%	2	0.35%
Unassigned-see comments	Other	33	209.268	1.00%	0	0.00%
Utah Serviceberry/Sedge-dark clay soils-leeward, < 9,100ft	Other	3	2.911	0.01%	0	0.00%
Utah Serviceberry-Mountain Mahogany/Sedge-Dark Clay Soils-Protected, <8,700ft	Other	1	0.706	0.00%	0	0.00%
Utah Serviceberry-Mountain Mahogany-snowberry-dryland sedge	Other	12	71.494	0.34%	0	0.00%
Utah serviceberry-snowberry-sunsedge	Other	3	7.364	0.04%	0	0.00%
Utah serviceberry-sparse	Other	29	93.283	0.45%	1	0.17%
Wyoming big sagebrush/Indian ricegrass-Aridic soils, <9,000ft	Wyoming Sagebrush	6	20.823	0.10%	2	0.35%
Wyoming sagebrush-Hood's phlox	Wyoming Sagebrush	227	2369.874	11.38%	50	8.65%
Wyoming sagebrush-muttongrass-needle-and-thread	Wyoming Sagebrush	85	613.948	2.95%	32	5.54%
Wyoming sagebrush-rabbitbrush-muttongrass-pine needlegrass	Wyoming Sagebrush	12	64.802	0.31%	4	0.69%
Wyoming sagebrush-sparse	Wyoming Sagebrush	135	823.043	3.95%	39	6.75%
Wyoming sagebrush-sparse Indian ricegrass	Wyoming Sagebrush	155	1393.27	6.69%	69	11.94%
Yellow willow-deep alluvial soils-concave bottoms and swales, 7,800-9,700ft	Willow/Cottonwood	2	3.925	0.02%	0	0.00%
Yellow willow-Geyer willow-other willows-beaked sedge	Willow/Cottonwood	1	1.321	0.01%	0	0.00%
Yellow willow-other willows-moist to dry grasses and forbs	Willow/Cottonwood	1	3.432	0.02%	0	0.00%
Total			20828.506	100.00%	578	100.00%

Appendix 1.2. List of radio-telemetered sage grouse, gender and number of relocations for birds from the three main leks.

Sex	NPS_#	# relocations
Female	0207	80
Female	0107	66
Female	0205	44
Female	0206	39
Female	0513	36
Female	0006	31
Female	0002	23
Female	0306	21
Female	0501	19
Female	0514	18
Female	0519	17
Female	0004	16
Female	0005	16
Female	0504	16
Female	0521	16
Female	0210	14
Female	0511	14
Female	0520	14
Female	0308	13
Female	0003	12
Female	0118	9
Female	0517	8
Female	0526	7
Female	0011	6
Female	0303	6
Female	0015	5
Female	0110	5
Female	0506	5
Female	0522	5
	0013	2
Female	0008	2
Female	0204	1
Female	0407	1
Male	0013	70
Male	0209	67
Male	0108	52
Male	0307	50
Male	0103	45
Male	0405	44
Male	0211	34
Male	0010	33
Male	0112	29
Male	0009	27
Male	0116	24
Male	0117	24
Male	0106	18
Male	0111	18
Male	0115	18

Sex	NPS_#	# relocations
Male	0017	16
Male	0502	12
Male	0508	12
Male	0505	11
Male	0201	9
Male	0403	8
Male	0113	7
Male	0401	7
Male	0406	7
Male	0102	5
Male	0114	5
Male	0301	5
Male	0402	5
Male	0404	5
Male	0515	5
Male	0525	5
Male	0510	4
Male	0109	3
Male	0208	3
Male	0304	3
Male	0503	3
Male	0518	3
Male	0523	3
Male	0012	2
Male	0202	2
Male	0203	2
Male	0512	2
Male	0524	2
Male	0105	1
Male	0302	1
Male	0507	1
Male	0509	1
unknown	0536	9