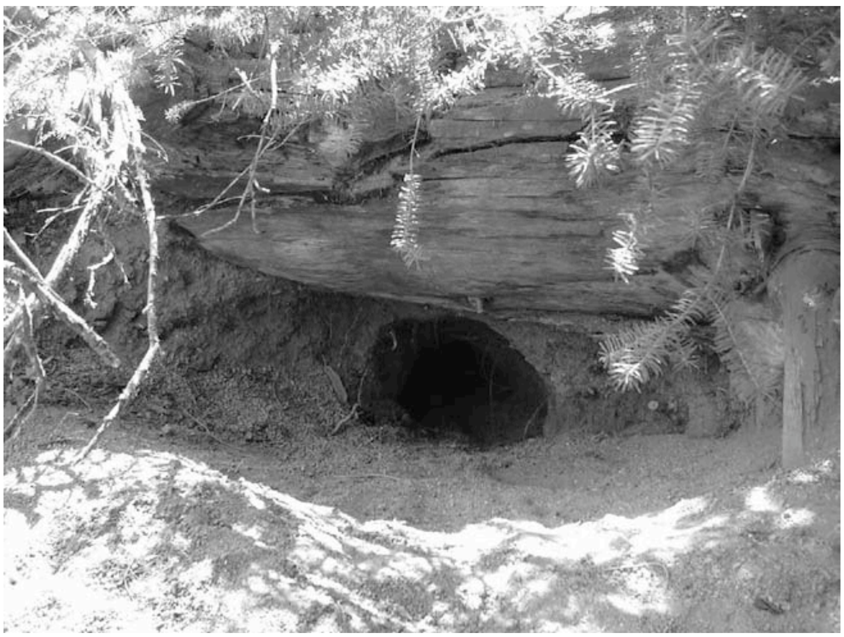
WOLF DEN SITE SELECTION AND CHARACTERISTICS
IN THE NORTHERN ROCKY MOUNTAINS:
A MULTI-SCALE ANALYSIS



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May 2004

WOLF DEN SITE SELECTION AND CHARACTERISTICS
IN THE NORTHERN ROCKY MOUNTAINS: A MULTI-SCALE ANALYSIS

A Thesis
By
Jon R. Trapp

Submitted in partial fulfillment of the
requirements for the degree of
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Environmental Studies – Conservation Biology

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ABSTRACT

Reproductive success is key to survival and persistence in any species. Gaining a better understanding of wolf (*Canis lupus*) den site selection and characteristics can help in the future management of wolves in the Northern Rocky Mountains (NRM) of the United States and elsewhere. I studied fine-scale denning habitat selection by comparing field-measured characteristics of 22 dens in Idaho, Montana, and Canada to paired random contrast sites within the pack home range. In order of importance, wolves denned in areas that had greater canopy cover, hiding cover, herbaceous ground cover, and woody debris, and were closer to water than paired random sites. Logistic regression models using these as candidate variables identified proximity to water, canopy cover, herbaceous ground cover, and small woody debris as the most important variables, and successfully categorized >81% of dens and >86 % of paired contrast sites. At a coarse-scale (using GIS data layers), 35 wolf dens did not differ from 35 paired random contrast sites in Idaho, Montana, and Yellowstone National Park with respect to elevation, slope, coniferous forest cover, solar radiation, land ownership, distance to water, and distance to roads. However, a GIS model based on the Mahalanobis distance (with slope, elevation, coniferous forest cover, and solar radiation as habitat variables) suggests that >85% of dens will occur in potential denning habitat that occupies <12% in the NRM.

ACKNOWLEDGEMENTS

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I also thank Joe Fontaine, Tom Meier, and Steve Fritts, of the USFWS. Doug Smith and Deb Guernsey of the Yellowstone Wolf Project provided insight and data that helped to shape this project. Thanks to John Waller with Glacier National Park for gathering a search party and allowing access to dens. Finding dens in Idaho was made easier by the hard work of the Nez Perce Wolf Project biologists Jim Holyan, Isaac Babcock, Kent Laudon, Adam

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And thank you to the small school with a big heart. Prescott College faculty members and staff have provided continual support and guidance through this process. I especially want to thank Lyn Chenier, Linda Butterworth, and Norma Mazur for their outstanding work in the library.

DEDICATION

This is dedicated to my wife Barbara, who is always there to bring me up when I am down, and to celebrate the victories with me. Her support, patience, and understanding have been an inspiration. I also dedicate this to my parents, Ted and Jackie, who have always supported the tough decisions in my life – especially the one to leave the Air Force to become a wildlife biologist.

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INTRODUCTION

Wolves are one of the most studied mammals in the world. Multiple studies have focused on wolf reproduction and denning (e.g., Mech 1970; Ballard and Dau 1983; Fuller 1989; Ciucii and Mech 1992; Matteson 1992; Unger 2003), but den site selection in forested ecosystems is not completely understood (Norris et al. 2002). Because most pup mortality occurs within the first 6 months, site selection and activity around the den affect reproductive success of the pack (Harrington and Mech 1982). This study is the first to examine wolf den site selection in the NRM since the reintroductions in central Idaho and Yellowstone National Park in 1995-96, and is based on a larger number of dens than any previous study of den site selection.

The purpose of this research is to better understand wolf den site selection and characteristics to support effective, long-term conservation and management of wolves. The objectives are threefold: 1) to determine wolf den site characteristics; 2) to investigate factors influencing den site selection at fine and course scales; and 3) to develop a predictive denning habitat model utilizing a Geographic Information System (GIS).

LITERATURE REVIEW

Wolves are social animals that form family groups called packs, ranging in size from 2 to more than 30 individuals. A wolf pack usually consists of the dominant pair (usually the parents) and their subordinate young (Mech 1970). Wolves generally establish territories that can cover as much as 2,500 km^2 (Mech et al. 1998), but average 579 km^2 in Idaho, 554 km^2 in the Greater Yellowstone Area, and 298 km^2 in northwest Montana (USFWS et al. 2001). Territories are defended passively and actively from other packs.

The breeding season is from January to April, depending upon latitude (Mech 1970). Usually, only the dominant pair breeds (Paquet and Carbyn 2003). Gestation lasts 62-63 days with parturition generally in some sort of sheltered area (Mech 1970). The average whelping date is 11 April for pregnant wolves in Yellowstone National Park (Thurston 2002). Litter size can range from one to 11, and averages 6 (Paquet and Carbyn 2003). Pups generally remain at the den site for 8 to 10 weeks before moving to their first rendezvous site (Murie 1944; Peterson 1977). Other pack members may assist in the pup rearing by providing defense (Mech 2000), feeding the nursing mother (Mech et al. 1999), or regurgitating food when the pups are older.

Denning habitat for tundra wolves may be a limiting factor (McLoughlin et al. 2004). In the tundra, esker habitat, which comprised only 1-2% of the landscape, was the preferred denning habitat. Wolves in Algonquin Provincial Park, Canada, prefer to den in pine forests (Norris et al. 2002). However, these pine forests are frequently and extensively logged, removing potential denning habitat. Repeated use of dens by wolves (Ballard and Dau 1983;

Mech and Packard 1990) suggests they are valuable habitat elements, and perhaps at times a limiting factor.

Techniques and results of the following studies guided the design and evaluation of this study. Studies of wolf dens have examined site location within home ranges (Ciucci and Mech 1992; Unger 1999), location in relation to prey availability (Banfield 1954; Carbyn 1975; Boertje and Stephenson 1992), effects of human disturbance (Mech 1989; Thiel et al.1998), and micro-habitat variables (Matteson 1992; Norris et al. 2002). GIS studies evaluated habitat variables involved in territory selection (Haight et al. 1998; Mladenoff et al. 1999; Houts 2001; Oakleaf 2002; Carrol et al. 2003), effects of road density on habitat suitability (Wydeven et al. 2001), and the Mahalanobis distance (Clark et al. 1993; Corsi et al. 1999; Podruzny et al. 2002; Farber and Kadmon 2003). A transect method for evaluating physical and vegetative characteristics at bobcat (*lynx rufus*) rest sites used by Kolowski and Woolf (2002) was modified for this study.

This study adds to Matteson's (1992) evaluation of dens (n = 15) in northern Montana and southern Canada. She found that wolves selected sites at lower elevations (e.g., valley bottoms and lower slopes) with less percent slope. Dens were also closer to hiking and horse packing trails than contrast locations. Variables found by Matteson (1992) to be insignificant included canopy cover, hiding cover, ecotype, structural class, solar radiation, and distance to water. A study of 13 dens by Unger (1999) in northwest Wisconsin and east-central Minnesota found steep slope, sandy soil, lower road density, and close proximity to water to be significant variables. Insignificant variables included canopy cover and hiding cover.

GIS analyses of wolf dens were completed by Unger (1999) and Norris et al. (2002). Unger's (1999) GIS analysis focused on the den site location within the Minimum Convex

Polygon (MCP) home range. He found that dens tended to be in the inner core of the MCP. This contradicts a study by Ciucci and Mech (1992), which found dens located randomly throughout home ranges. In Algonquin Provincial Park Norris et al. (2002) found dens (n = 16) to be in areas with a high proportion of pine forests. They also found that dens were at lower elevations and near water. Studies by Clark et al. (1993) and Podruzny et al. (2002) applied GIS and the Mahalanobis distance statistic to model bear habitat and den sites.

METHODS

Study Area

This study was focused in the 3 United States Northern Rocky Mountains (NRM) wolf recovery areas: northwestern Montana, central Idaho, and the Greater Yellowstone area (Fig. 1). At the end of 2003, there were an estimated 368 wolves in the central Idaho recovery area, 301 in the Greater Yellowstone area, and 92 in northwestern Montana (USFWS et al. 2004). Den sites were visited in Idaho, Montana, and southern Canada to examine wolf den characteristics and fine-scale habitat selection. Additional den sites from Yellowstone National Park were included in the course-scale habitat selection and GIS modeling analyses (Fig. 2).

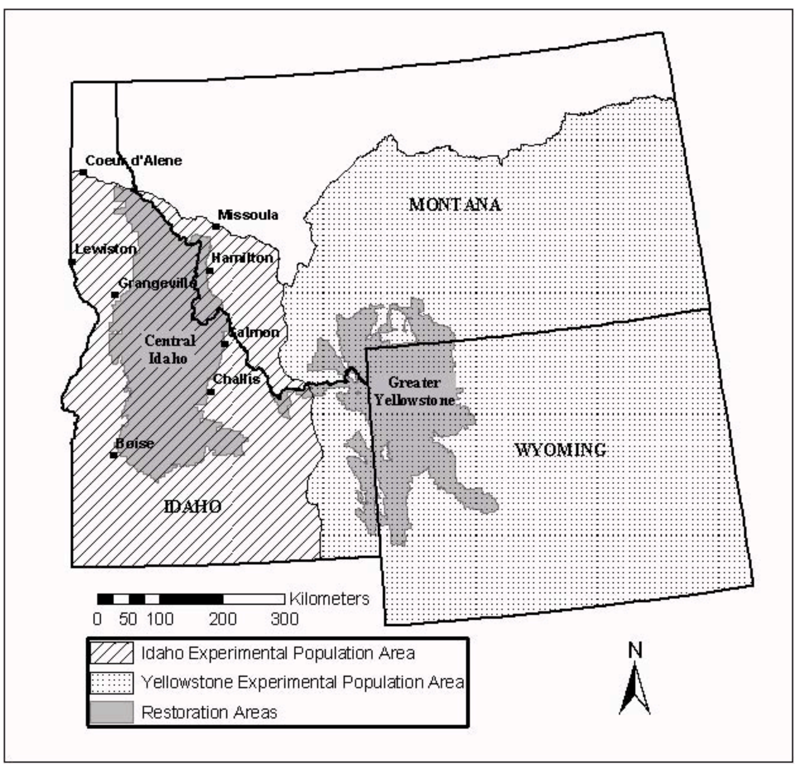

Figure 1. Northern Rocky Mountain gray wolf experimental population areas: northwest Montana (non-shaded area), Greater Yellowstone (dotted area), and central Idaho (hatched area). The areas in dark gray represent the core restoration areas.

The NRM extend from the Salt River and Wind River ranges in Wyoming to the northern borders of western Montana and Idaho. This mountain range is bounded by the Great Plains to the east and the Columbia Plateau and Great Basin to the west. The major factor in the formation of these mountains has been volcanic activity (Kershaw et al. 1998). Receding glaciers have smoothed plains, cut broad valleys, and formed dramatic peaks in other areas. Some of the highest peaks include Gannett Peak (4,183 m) in Wyoming, Granite Peak (3,878 m) in Montana, and Borah Peak (3,837 m) in Idaho.

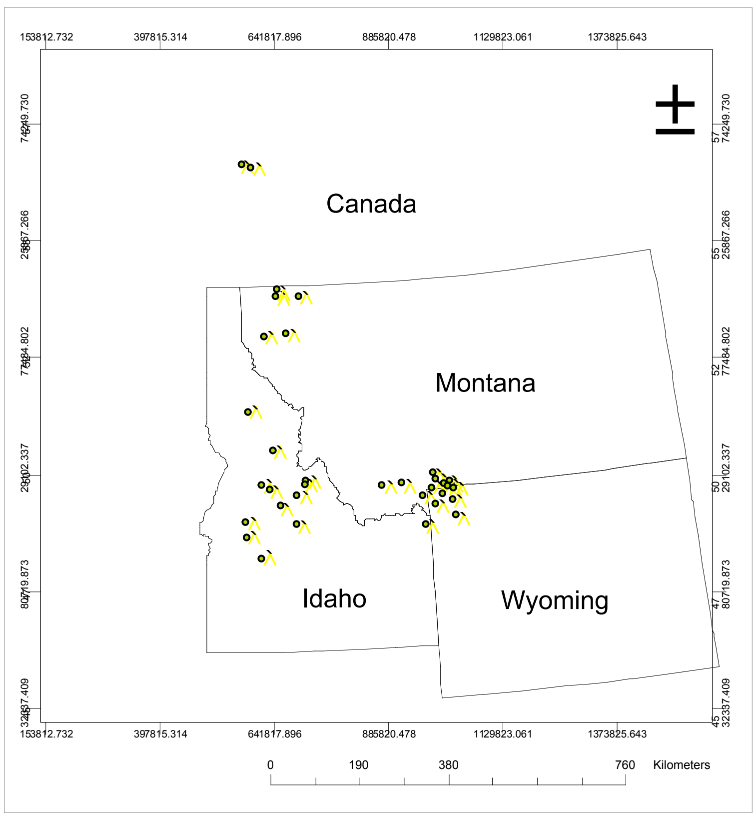

Figure 2. Den sites (*n* = 37) for both fine and course-scale analysis included in this study.

Because of the dramatic change in elevations and latitude, climate varies widely in the study area. Each of the 3 recovery areas exceeds 50,000 km^2 and is comprised primarily of public lands. The main ungulate prey of wolves in this region are elk (*Cervus elaphus*), white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), and moose (*Alces alces*).

Wolf Den Characteristics and Fine-scale Habitat Selection

Thirty-two dens were visited between June and October 2003. Known and suspected den site locations were provided by the Nez Perce Tribe in Idaho, USFWS in Montana, and Banff National Park in Alberta. Some dens were found by evaluating aerial telemetry locations of collared wolves during the denning season (April-June). I gave priority to dens used since 2000. To minimize impact to wolves, data collection at the den sites did not start until June, when packs start moving away from their dens (Haber 1968). Aerial and ground telemetry of collared wolves confirmed when they had moved away. In case uncollared pups were in dens, we moved into den areas quietly and slowly. Data collection began after confirming that the pack had departed the den. The field crew hiked to the derived coordinates utilizing a Global Positioning System (GPS). If the den was not found immediately, the crew split up and searched likely locations. When these search methods failed to locate the den, a grid search pattern was conducted.

Because wolves often use the same den in subsequent years (Ballard and Dau 1983; Mech and Packard 1990), we took precautions not to modify the den site. If the entrance dimensions did not allow entry to the main chamber to take measurements, we did not modify the entrance, and estimated dimensions visually. Because wolves are known to visit the dens throughout the year (Peterson 1977), precautions were taken to minimize our scent in the area (e.g., when necessary, urinating >150 m from the den).

Not all dens were suitable for analysis. Some dens were excluded for the following reasons: 1) last used prior to the year 2000; 2) uncertainty of site being the natal den; and 3) habitat modification since use (e.g., logging). We collected complete data at 25 dens (15 in Idaho, 8 in Montana, and 2 in Banff National Park, Canada).

Field data were collected at 5 locations per site: the den hole (center plot) and at 50 meters in each cardinal direction (50-m plots) (Fig. 3). Data collected at the center plot were used to characterize the "site," whereas the 50-m plots and the center plot were used to describe the "area." Three 20-m transects were placed perpendicular to the aspect of the hill and spaced 10 m apart at each plot. Plots covered a 20 x 20 m area.

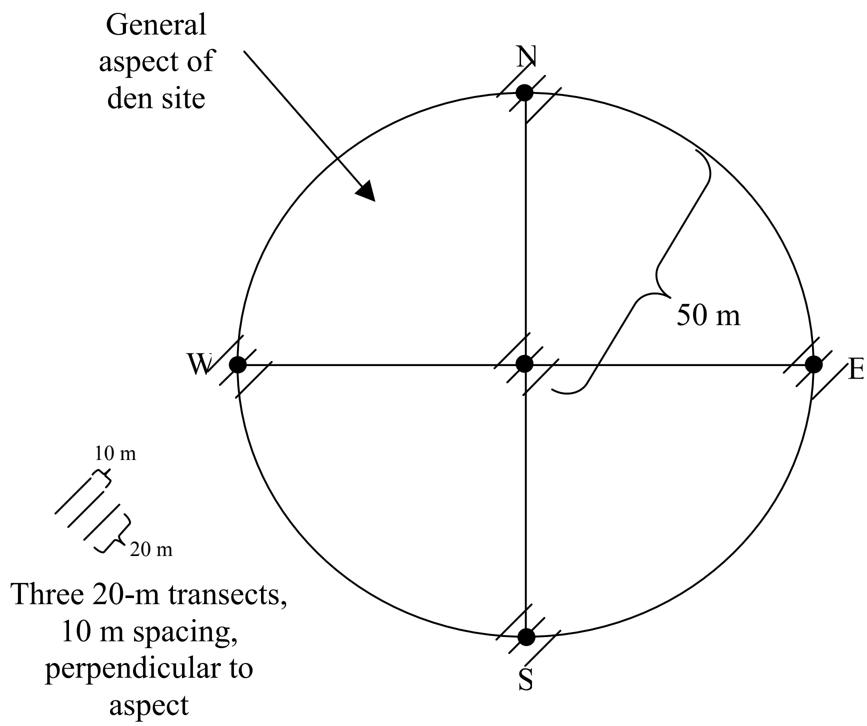

Figure 3. Plot layout for fine-scale denning habitat analysis. For each den area or contrast area, there was a center plot (the "den site"), and 4 satellite plots at 50 m in the 4 cardinal directions. Three 20-m transects were associated with each of the 5 plots. The term "den area" refers to the combined measurements across the 5 plots.

For each den, a random contrast location was chosen by placing a grid over the wolf pack home range polygon, and generating 2 random numbers between 0-100 on the X and Y axes. Home range boundaries were provided in the form of Minimum Convex Polygons (MCP) by the Idaho and Montana wolf projects, and Banff National Park. In some cases, telemetry data used to define the MCP spanned several years due to low numbers of locations (Ballard et al. 1987). These MCP home ranges were only acceptable if the pack had not significantly changed territory in the selected time frame.

Each random contrast location: 1) was within the home range of that pack; 2) >1 km from the actual den site; 3) had a slope <75 %; 4) was not in a town or lake; and 5) was on public land or private property with landowner consent for our research. In 4 cases where no home range data were available, contrast locations were established 1 km away in a random compass direction.

The following variables were measured at the center plot of each den area. Except as noted below, these variables were also measured at the center plot of each contrast location. Acronyms for the variables used in the logistic regression analysis are given in upper case within parentheses after each variable name. Field forms are presented in Appendix 1.

***Location*:** Den and contrast site coordinates were determined using a GPS unit (Garmin ™ eTrex Summit) and recorded in Universal Transverse Mercator (UTM) format referenced to North American Datum, 1927. Coordinates were not locked into the GPS until the estimated accuracy was <10 m.

Elevation (ELEVATION) was recorded in meters determined from the GPS unit.

***Den Type Description and Measurements*:** We categorized den type as hillside excavation, tree root crown, boulder pile, or as a combination (e.g., hillside excavation in root crown). Height and width of entrance and interior chamber, as well as depth, were recorded when possible. We also sketched the den site (Appendix 1). These data were only collected at the den site.

Slope Position was recorded at the den site as flat (< 2% slope), short slope (small hill in an otherwise flat landscape), valley bottom (lowest point in immediate landscape), lower 1/3 of hillside, middle 1/3, or upper 1/3. Slope position was not recorded at contrast sites.

Opening Aspect was obtained using a compass, with the observer's back towards the den opening. This data was only collected at the den site.

General Aspect was obtained using a compass, with the recorder faced down the predominant slope before obtaining the bearing.

***Presence of Water within 100 m (WATER)*:** We recorded presence or absence of standing water, permanent or ephemeral streams of any size, or lakes of any size, within 100 m as measured in the field.

***Presence of Roads or Trails within 100 m*:** Type of road or trail was noted (e.g., foot trail, 2WD dirt road, 4WD dirt road, etc.) and seasonal/closure information (e.g., road closed from November-May, road permanently closed, rarely used, often used, etc.), if available.

Presence of Meadow or other Opening within 100 m was recorded in any portion of a non-forested area at least 40 m wide and 100 m long, including recent clearcuts, but excluding roads.

Presence of Human Habitation/Disturbance within 100 m. We included mining, active logging operations, and human structures within 100 m of the site.

Presence of Rock Outcrop within 100 m of the den or contrast site.

***Structural Class*:** We recorded the dominant vegetation class within the 20 x 20 m plot delineated by the transect grid as: non-vegetated, herbaceous, shrub, sapling, pole/sapling, young/mature, old-growth.

***Soil Composition*:** Samples were taken from inside the den-hole and collected in a plastic bag labeled with the pack name and year used. Soil type (e.g., sand, loam, silt, clay, etc.) was analyzed using the "Texture-by-feel" method (Thien 1979). Soil samples were not taken at contrast sites.

Habitat Type was determined using U.S. Forest Service documents: *Forest Habitat Types of Central Idaho* (Steele et al. 1981), *Forest Habitat Types of Northern Idaho* (Cooper et al. 1991), and *Forest Habitat Types of Montana* (Pfister et al. 1977).

The following variables were measured at each of the 5 plots in both den areas and contrast areas:

Slope (SLOPE) percentage was determined using a clinometer. We averaged the slope along the fall line 10 m upslope and downslope from each point.

Hiding Cover (COVER) was recorded as the average percent obscured of a 2 m high cover pole observed from 10 m away in each cardinal direction (Griffith and Youtie 1988). The observer viewed the pole from a crouched position in the center of the plot. The cover pole was divided into 20 1-decimeter (dm) sections. Data were recorded as a percentage of 1-dm sections obscured by vegetative or structural (e.g., boulders, hillside) cover.

Canopy Density (CANOPY) was estimated using a spherical densiometer (Lemon 1957), because it is more likely to reflect an animal's perception of cover than point-intercept measures of cover (Nuttle 1997). We averaged the readings taken in 4 cardinal directions at each of 5 plots.

***Major Tree and Shrub Species*:** We recorded each tree species with at least 10 individuals within the 20 x 20 m plot, and each shrub that covered at least 10% of the ground within the plot.

Ground Cover*:** At each 1-m interval along the 3 transects (Figure 3), we assigned one ground cover category, and converted counts to percentage by dividing by the 63 (number of possible hits). The categories were: **Herbaceous** (HERB***, including shrubs <20 cm tall); **Leaf/Needle Litter** (***LITTER***, including woody material <5 cm in diameter); **Shrub** (***SHRUB***, plants 20 to 200 cm tall); **Small Wood** (***SMALL WOOD***, 5-15 cm diameter at midpoint); **Log** (***LOG***, >15 cm diameter); **Rock** (***ROCK***, >1" diameter); **Soil** (***SOIL***), or **Tree** (***TREE***, touching tape, including exposed root system, >200 cm tall).

Index of Tree Diameter: We measured diameter of each tree >2" DBH touching the transect tape, and tallied smaller trees (using 1" as a diameter in calculating means). Because the transect tape is deflected by larger trees and the crowns of saplings, this method may undersample medium-sized trees. Therefore, it was used only to compare den and contrast sites and areas. We did not record diameters separately by species.

Additional Observations**:** This category was used to record any other potentially useful information. Data recorded included observations on other predator activity, bones, wolf scats and daybeds, trails, etc.

To describe wolf den sites I created frequency distributions of structural class, tree species, shrub species, and habitat type. Soil composition was analyzed and described at the den sites only. I compared number of den and contrast sites within 100 m of roads/trails, meadow/opening, human disturbance, and rock outcrop, and tested for significant differences using Chi-square tests. I calculated mean and standard deviation (SD) for elevation, slope, hiding cover, canopy density, tree diameter index, and 8 ground cover classes at both den and contrast sites. I created a radar graph to depict frequency distributions of general aspects at den and contrast sites.

I excluded 3 of the 15 dens in Idaho from the fine-scale univariate analysis, because contrast site data were not obtained. The Wilcoxon's signed-ranks test (Zar 1999) was used to compare den and contrast areas and sites with respect to 13 variables: ELEVATION, SLOPE, COVER, CANOPY, WATER, and 8 ground cover categories (HERB, LITTER, SHRUB, SMALL WOOD, LOG, ROCK, SOIL, and TREE).

I created forward entry logistic regression models at the site (1-plot) and area (5-plot) scales. Variables significantly different (Wilcoxon's signed-ranks test, $\alpha = 0.10$) between den and contrast sites or areas were evaluated for multicollinearity. If Pearson Correlation (Zar 1999) coefficients indicated correlation ($|r| > 0.50$), variables with lower *P*-values were removed from the list of candidate variables. The criteria for variables to enter and remain in the logistic regression model was $P < 0.20$ (Hosmer and Lemeshow 2000), using *P*-values associated with each variable's R statistic.

Because univariate methods (e.g., Wilcoxon's signed-ranks test) can fail to address confounding of highly correlated variables, I also used Principal Component Analysis (PCA) (Ramsey and Schafer 1997) to characterize den sites and areas. I used the same 13 variables to derive the principal components. Principle components with initial eigenvalues >1 were used as candidate variables in a forward-entry logistic regression model. The criteria for components was $P \leq 0.05$ to enter, and $P \geq 0.1$ for removal (Hosmer and Lemeshow 2000), using *P*-values associated with each component's R statistic.

All statistical analyses were completed using SPSS (SPSS 8.0 1997).

Coarse-scale Habitat Selection and GIS Modeling

I excluded 2 dens in Canada due to lack of comparable GIS data, and added 15 den locations and MCP home ranges from Yellowstone National Park (YNP), for a total of 35 dens in the 3 NRM recovery areas. To examine habitat selection contrast locations were created for the new YNP dens using the random point generator in the Animal Movement Extension (Hooge et al. 1999) of ArcView 3.2 (ESRI 1992). Seven coarse-scale variables were generated within ArcView (Table 1).

Table 1. GIS variables used in analyses of coarse-scale habitat selection.

Variable	Units	Resolution	Data Source
Distance to Roads	m	1:100,000	USGS DLG (1983) [1,3] TIGER (2002) [2]
Distance to Water	m	1:100,000	USGS DLG (1983) [1,2] TIGER (2002) [3]
Land Ownership	n/a	30 m	GAP
Coniferous Forest	0/1	30 m	NLCD
Elevation	m	30 m	USGS NED
Slope	°	30 m	USGS NED
Direct Solar Radiation	W/m^2	30 m	Based on NED, Calculated with SolarFlux [4]

[1] Idaho
[2] Montana
[3] Yellowstone NP
[4] April 15, 0900-1500

Direct solar radiation was estimated with SOLARFLUX (Rich and Hetrick 1994), a GIS-based computer program (running under ARC/INFO with Digital Elevation Models) that models incoming solar radiation based on slope, aspect, solar azimuth and zenith, time of year, topographic features, elevation, and atmospheric conditions. I used April 15th as an average date for parturition in the NRM (C. Mack, personal communication). Because wolf home ranges and dens have been found primarily in coniferous forests (Matteson 1992; Oakleaf 2002), a coniferous forest GIS layer was derived from National Land Cover Data.

Coniferous forest layer was developed as a percentage of forested cells within 100 m of the den or contrast site. Elevation and slope were derived from National Elevation Data (NED). I determined land ownership with Gap Analysis Program (GAP) land ownership layers (USGS 2002). Road and water data were derived from USGS Digital Line Graphs (DLG) and Topologically Integrated Geographic Encoding and Referencing system (TIGER) (USSB 2002). Distances from dens to water and roads were calculated with distance functions in ArcView. In my analyses I did not distinguish among 4 TIGER road classes (primary highways with limited access, primary roads without limited access, secondary and connecting roads, and local, neighborhood and rural roads).

Habitat Selection. Variables significantly different (Wilcoxon's signed-ranks test, $\alpha = 0.10$) between den sites and contrast sites were evaluated for multicollinearity as measured by Pearson Correlation coefficients. If there was a correlation ($|r| > 0.50$), then variables with lower T-statistics were removed. The remaining variables were then used as candidate variables in a forward stepwise logistic regression. The criteria for variables to enter and remain in the logistic regression model was $P < 0.20$ (Hosmer and Lemeshow 2000), using *P*-values associated with each variable's R statistic.

To determine if wolves selected core areas for den sites I examined the location of each den within the home range. Fixed kernel home range estimators (Powell et al. 1997; Seaman et al. 1999) were generated using ArcView 3.2 (ESRI 1992) and the Animal Movement Extension (Hooge et al. 1999). The 50% polygon was used to represent a core area, and the 95% polygon to represent the home range exclusive of outliers. Telemetry locations taken from August 1 of the previous year to July 31 of the year the den was used were used to calculate home ranges for this analysis. Although Seaman et al. (1999)

suggested a minimum of 30 telemetry locations to generate a fixed kernel home range, 3 packs with 20-28 locations were included. To eliminate collection bias, if >25% of locations for a home range were obtained during the denning period (April-June), points were randomly removed so that this period provided 25% of the locations. Because not all packs were collared and some collared packs were not monitored for several months during the year, only 8 Idaho dens and 4 Montana dens could be evaluated. Road densities (km/km^2) in the core and home polygons were evaluated with ArcView.

GIS Modeling. I used Mahalanobis Distance (Krzanowski 1988, Farber and Kadmon 2003, Podruzny et al. 2002) to model potential den sites across the NRM (Fig. 4). This measure of dissimilarity is the squared distance between the vector of habitat variables measured at any location in the landscape and the mean vector for all den sites (*n* = 35). Mean vector and covariance values were generated from dens in the 3 recovery areas. I used elevation, slope, solar radiation, and coniferous forest cover as variables based on previous studies that suggested their importance (Mech 1970, Matteson 1992, Unger 1999). Using an ArcView extension (Jenness 2003), the Mahalanobis distances are calculated using matrix algebra as:

$$D^2 = (x-m)^T C^{-1}(x-m)$$

Where:

D^2 = Mahalanobis distance

x = Vector of data

m = Vector of mean values of independent variables

C = Covariance matrix of independent variables

T = Indicates vector should be transposed

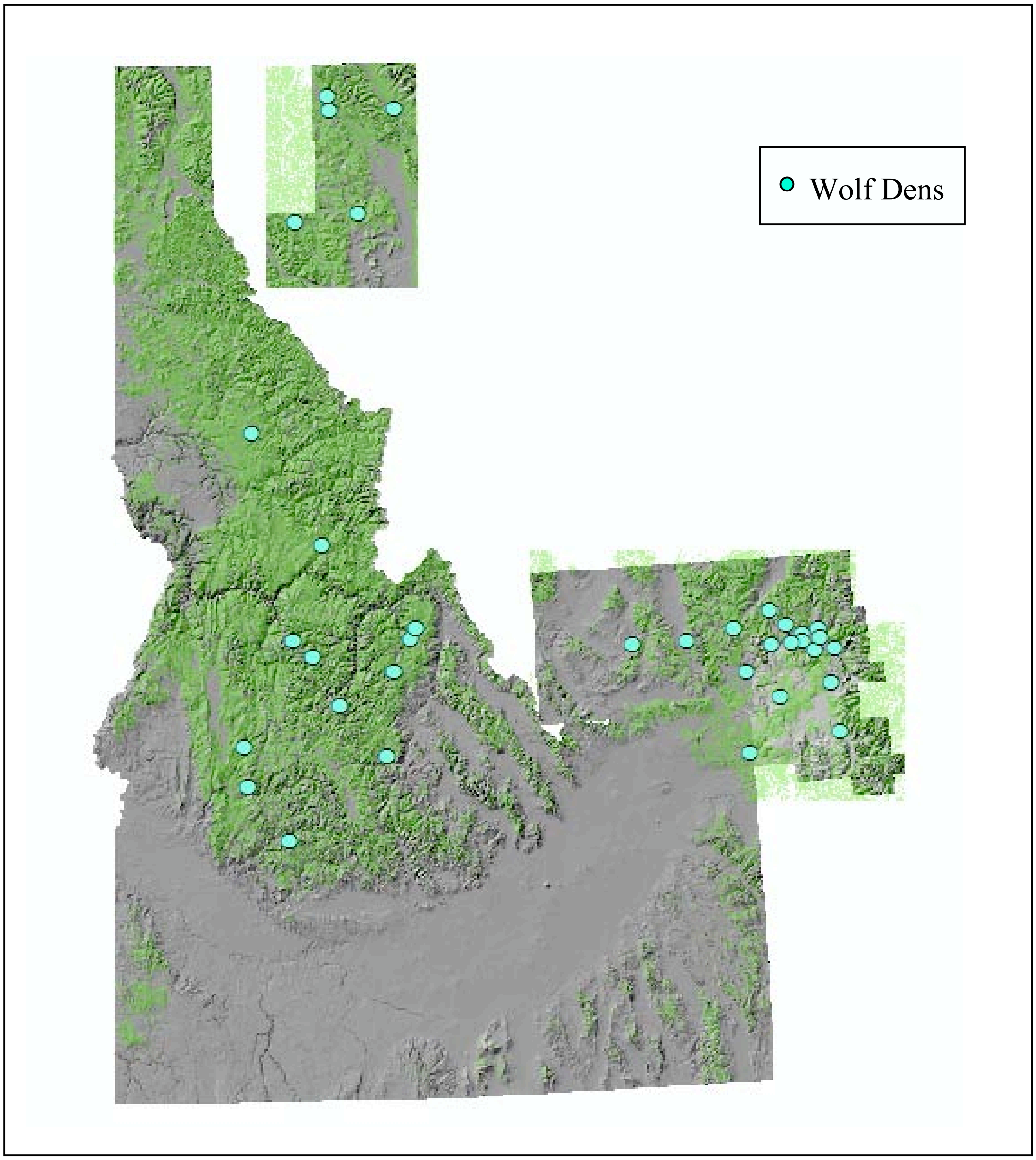

Figure 4. Area included for Mahalanobis analysis with dens used to generate mean vector and covariance data.

Because Mahalanobis distances have no upper limit, the values were converted to X^2 *P*-values where *P*-values close to 0 reflect a high Mahalanobis distance and high dissimilarity to observed den habitat. *P*-values close to 1 are similar to den sites. Each threshold *P*-value defines a habitat model. I evaluated models by calculating the percentage of wolf dens and percentage of the landscape that exceeded various threshold P-values. I considered a model helpful if it encompassed >85% of dens within suitable habitat that comprised < 25% of the landscape.

RESULTS

Wolf Den Characteristics and Fine-scale Habitat Selection

Den Characteristics. Twenty three of 25 dens were hillside excavations with an average slope of 26.9 $\pm$ 16.1 (SD) % (Fig. 5). Twelve of the hillside excavations were categorized as "open," since they were not directly under a tree; ten were under trees, and one was under a downed tree. One den was inside a fallen 200+ year old western red cedar (*Thuja plicata*). The cedar had suffered from a fire more than one hundred years ago and eventually fell. The core of the tree was hollow and extended back over 8 meters. Another den was in the base of an old-growth subalpine fir snag, *Abies lasiocarpa*, with 61.5" diameter at breast height. Based on telemetry locations and wolf sign one den area in Montana was in a forested wetland. In this case, the natal den could not be pinpointed because there were 5 excavations within 120 m, all of which appeared to be expanded beaver lodges.

Figure 5. Hillside excavation wolf den.

Most dens were clean and dry with hair in the soil and hanging from the roof. Average height and width of entrances were 43.9 $\pm$ 18 cm and 48.3 $\pm$ 15 cm, respectively. Average depth of the excavations was 282 $\pm$ 139.9 cm. Most den holes descended with 30-90% slope for approximately one meter before leveling or slightly climbing to an enlarged birthing/nursing chamber. Interior measurements averaged 50.5 $\pm$ 25.9 cm for height and 90.3 $\pm$ 38.3 cm for width. Land ownership was: US Forest Service (68%), National Park Service (12%), Bureau of Land Management (8%), private (8%) and state (4%). Contrast locations had a nearly identical ownership distribution.

Slope positions varied widely with 2 dens on short slopes, 6 on the lower third, 10 mid-slope, and 7 on the upper third. Dens were surrounded by 1-6 day beds, typically beside and above the dens with a clear view of the den hole. Chewed items around the dens included bones, sticks, bottle caps, drinking straw, plastic bags/containers, aluminum cans, and a French fry container. Trails going in and out of the dens often formed a star pattern with the den in the center. These trails became significantly more noticeable within 50 m of the den (Fig. 6). See Appendix 3 for a method to map patterns around den sites.

Figure 6. Wolf trail leading to den site.

Major shrub species occurring at den sites, from most to least common included: snowberry (*Symphoricarpos albus* and *S. oreophilus*), rose (*Rosa sp.*), grouseberry (*Vaccinium scoparium*), creeping Oregon-grape (*Berberis repens*), mountain huckleberry (*Vaccinium globulare*), saskatoon (*Amelanchier alnifolia*), common juniper (*Juniperus communis*), birch-leaved spiraea (*Spiraea betulifolia*), big sagebrush (*Artemisia tridentata*). Nineteen species of shrubs were at contrast sites, with only 4 species present at more than one site: green alder (*Alnus viridis*, n = 4), snowberry (*Symphoricarpos albus*, n = 3), big sagebrush (*Artemisia tridentate*, n = 3), and black huckleberry (*Vaccinium membranaceum*, n = 3).

Most dens (75%) occurred in mixed-age forest stands; 16% of dens occurred in shrubland, and 8% in old-growth forest. This was similar to structural stages at contrast sites: 64% young-mature, 18% shrubland, 14% herbaceous, and 4% old-growth. The most common tree species at den sites was Douglas-fir (*Pseudotsuga menziesii*), followed in order of occurrence by Engelmann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta*), trembling aspen (*Populus tremuloides*), grand fir (*Abies grandes*), western larch (*Larix occidentalis*), and limber pine (*Pinus flexilis*). The most common tree at contrast sites was also Douglas-fir, but it occurred less frequently than at the dens (Table 2). The most common forest habitat types included Douglas-fir as the dominant species at dens (n = 9) and contrast sites (n = 4) (Table 3). The tree/shrub association of *Pseudotsuga menziesii/ Symphoricarpos albus* appeared most frequently with 3 occurrences.

Table 2. Occurrence of tree species at den and contrast sites.

Den Sites			Contrast Sites		
Common Name	Latin Name	#	Common Name	Latin Name	#
Douglas-Fir	*Pseudotsuga menziesii*	14	Douglas-Fir	*Pseudotsuga menziesii*	8
Engelmann Spruce	*Picea engelmannii*	6	Engelmann Spruce	*Picea engelmannii*	5
Lodgepole Pine	*Pinus contorta*	6	Lodgepole Pine	*Pinus contorta*	4
Trembling Aspen	*Populus tremuloides*	5	Grand Fir	*Abies grandes*	4
Grand Fir	*Abies grandes*	3	Trembling Aspen	*Populus tremuloides*	2
Western Larch	*Larix occidentalis*	3	Subapline Fir	*Abies bifolia*	2
Limber Pine	*Pinus flexilis*	2	Ponderosa Pine	*Pinus ponderosa*	1
Ponderosa Pine	*Pinus ponderosa*	1	Western Larch	*Larix occidentalis*	1
Western Red Cedar	*Thuja plicata*	1	W. White Pine	*Pinus monticola*	1
Subapline Fir	*Abies bifolia*	1			
Rocky Mountain Juniper	*Juniperus scopulorum*	1			

Table 3. Habitat types for wolf den and contrast sites surveyed in Idaho and Montana.

State and Habitat Type	Den Occurrences	Contrast Occurrences
Idaho[1]		
Abies grandis/ Vaccinium globulare	0	1
Abies lasiocarpa/ Menziesia ferruginea	1	0
Abies lasiocarpa/ Streptopus amplexifolius	0	1
Abies lasiocarpa/ Vaccinium caespitosum	0	1
Abies lasiocarpa/ Vaccinium globulare-scoparium	1	0
Flood Plain	1	0
Grass/ Shrub	1	3
Herbaceous	0	1
Picea engelmannii/ Equisetum arvense	1	0
Pseudotsuga menziesii/ Arnica cordifolia	1	0
Pseudotsuga menziesii/ Calamagrostis rubescens	2	1
Pseudotsuga menziesii/ Cercocarpus ledifolius	0	1
Pseudotsuga menziesii/ Physocarpus malvaceus	1	0
Pseudotsuga menziesii/ Spiraea betulifolia	1	0
Pseudotsuga menziesii/ Symphoricarpos albus	1	2
Thuja plicata/ Athyrium filix-femina [2]	1	0
Montana[3]		
Abies grandis/ Clintonia uniflora	1	0
Abies lasiocarpa/ Menziesia ferruginea	0	2
Abies lasiocarpa/ Vaccinium scoparium	0	1
Abies grandis/ Xerophyllum tenax	0	1
Grass/ Shrub	1	1
Picea/ Clintonia uniflora	1	0
Picea/ Linnaea borealis	1	0
Pinus albicaulis/ Abies lasiocarpa	0	1
Pinus flexilis/ Agropyron spicatum	1	0
Pinus ponderosa/ Festuca idahoensis	0	1
Pseudotsuga menziesii/ Festuca Idahoensis	1	0
Pseudotsuga menziesii/ Symphoricarpos albus	2	0

[1] Steele et al. 1981

[2] Cooper et al. 1991

[3] Pfister et al. 1977

Soil samples were categorized using the soil texture triangle (Fig. 7) and flow chart (Appendix 2), as Sandy Loam (n = 9), Silt Loam (n = 8), Loam (n = 4), Sandy Clay Loam (n = 2), and Silt Clay Loam (n = 1). Percentage of clay, which helps to hold structure when dry, ranged from 8-30% and averaged 14.4%. Ten of the soil samples contained less than 10% course fragments (>2 mm), with the remainder averaging 41%.

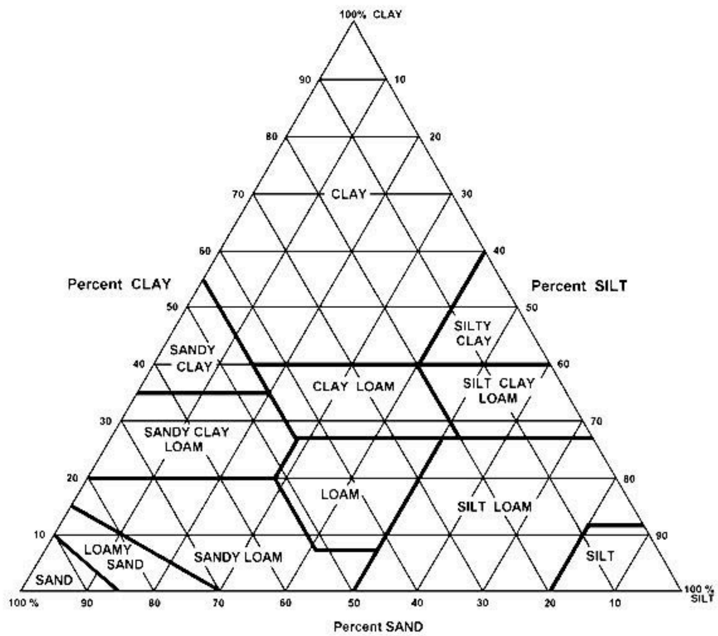

Figure 7. Soil texture triangle

Compared to contrast sites, wolf dens were more likely to be <100 m from water, and showed statistically non-significant tendencies to be >100 m from roads and rock outcrops (Table 4). There was no difference between den and contrast sites in terms of probability of being within 100 m of an opening. Ninety-two percent of den locations were on public lands.

The general aspects of den sites, as well as contrast sites, displayed no significant pattern (Fig. 8). Eleven dens faced generally North, while 9 of the dens faced generally South. In most cases (n = 16, 73%) the den opening aspect was within 20 degrees of the general aspect.

Table 4. Number of sites (out of 22 den sites and 22 contrast sites) within 100 m of various features. *P*-value is that of a Chi-squared test of a 2x2 contingency table. Significant values ($\alpha = 0.05$) are bolded.

Feature	Number of den sites	Notes	Number of contrast sites	Notes	P
Water	15		7		**.017**
Road/Trail	5	4x4 road (3), ATV trail (1), footpath (1)	9	4x4 road (3), ATV trail (2), footpath (2), major highway (1), closed dirt road (1)	.17
Meadow/Opening	11	Meadow (5), sagebrush (4), clear cuts (2)	10	sage brush (3), clear cuts (3), scree/rock (2), grassland (2)	.5
Human Disturbance	0		3	active logging, highway, active ATV course	.12
Rock Outcrop	2		7		.066

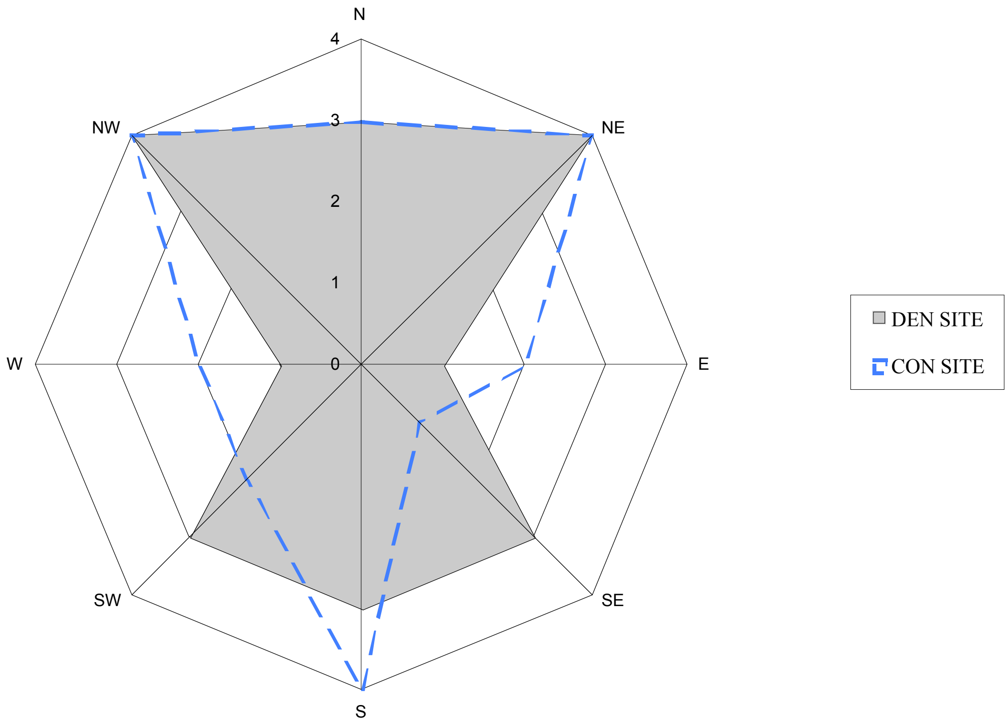

Figure 8. General aspects of den and contrast sites; octagons indicate number of dens (e.g., 4 dens with a NW aspect). Dens are depicted by solid gray and contrast sites by the dashed line.

Compared to contrast sites, den sites had greater canopy closure, hiding cover, herbaceous ground cover, woody debris, but less rock (Table 5). Average hiding cover was 82 $\pm$ 21 % from 0-1 m above ground level, and 61 $\pm$ 26 % from 1-2 m above ground level for a combined total of 72 $\pm$ 24 %. Den areas had greater hiding cover, more herbaceous ground cover, but less leaf and pine litter than contrast areas (Table 5).

Table 5. Mean and standard deviation of variables measured at the den and contrast sites (center 20x20 m plot) and in den and contrast areas (5 20x20 m plots). *P*-value is that of a Wilcoxon's signed-ranks test. Significant variables (α = 0.1) are bolded.

Variable (units)	Site			Area		
	Den	Contrast	*P*	Den	Contrast	*P*
ELEVATION (m)	1672 ± 397	1756 ± 323	0.25	n/a	n/a	n/a
SLOPE (%)	27 ± 16	23 ± 14	0.27	27 ± 17	26 ± 16	0.69
Index of Tree Diameter (")	7.4 ± 8.5	5.8 ± 4.2	0.17	5.8 ± 6.4	7.1 ± 6.1	0.16
CANOPY (%)	88 ± 22	59 ± 36	**0.009**	65 ± 34	60 ± 36	0.19
COVER (%)	72 ± 24	47 ± 30	**0.007**	57 ± 23	49 ± 29	**0.026**
HERB (%)	40 ± 15	30 ± 17	**0.020**	42 ± 18	31 ± 18	**<0.0005**
LITTER (%)	28 ± 13	29 ± 18	0.88	26 ± 15	30 ± 19	**0.1**
SHRUB (%)	12 ± 8	18 ± 16	0.14	15 ± 12	16 ± 16	0.80
S. WOOD (%)	5 ± 4	2 ± 2	**0.046**	4 ± 4	3 ± 4	0.56
LOG (%)	4 ± 6	4 ± 6	0.61	3 ± 4	3 ± 4	0.47
SOIL (%)	6 + 4	8 ± 10	0.98	5 ± 6	7 ± 10	**0.025**
ROCK (%)	1 ± 2	5 ± 15	**0.066**	2 ± 7	5 ± 16	**0.038**
TREE (%)	5 ± 5	5 ± 6	0.36	4 ± 5	5 ± 7	0.82

Den Site Regression Analysis. Five of 13 habitat variables differed between den and contrast sites (α = 0.10) and were candidates in logistic regression: COVER, CANOPY, HERB, SMALL WOOD, and ROCK (Table 5). Presence of WATER was also a candidate (Table 4). CANOPY and COVER were highly correlated ($|r|$ = 0.53), so COVER was removed because it had a lower significance. The final model (Table 6) included WATER, CANOPY, HERB, and SMALL WOOD; and accurately classified 86.4% of the contrast sites and 81.8% of the den sites for a combined accuracy of 84.1%.

Table 6. Results of the final logistic regression model predicting wolf den site locations vs. contrast site locations.

Variable	Coefficient	SE	Coefficient/SE	*P*-value	R
WATER	1.39	0.85	1.64	0.099	0.11
CANOPY	0.042	0.018	2.33	0.018	0.24
HERB	0.078	0.035	2.23	0.024	0.23
S. WOOD	0.21	0.13	1.62	0.11	0.094
Constant	-7.12	2.34	-3.04	0.002	

Using the same 22 den and contrast sites and 13 habitat variables, PCA was used to define 5 components with initial eigenvalues >1 accounting for more than 72% of the variance (Table 7). The sixth component accounted for 6.3% of the variance, which was less than any one of the original variables with eigenvalues >1.

Table 7. Total variance explained through Principal Component Analysis.

	Initial Eigenvalues		
Component	Total	% Variance	Cumulative %
1	3.28	25.2	25.2
2	2.09	16.1	41.3
3	1.61	12.4	53.7
4	1.44	11.1	64.8
5	1.01	7.7	72.6

In light of the correlation of each variable with each of the 5 axes (Table 8), each principle component axis can be described as follows:

1. More hiding cover, canopy cover, trees, shrubs, water; lower elevation; exposed soil; little or no rocks and herbs.
2. Greater slope, canopy cover, litter, and small logs; little or no water and shrubs.
3. More herbs, water, and small logs; little or no rocks and shrubs.
4. Higher elevation and greater slope; more trees, rocks and small logs; little or no litter and large logs.
5. More large logs and rocks; little or no shrubs and exposed soil.

Table 8. Five principal components derived from analysis of physical features at den sites (*n*=22).

	Component				
Variable	1	2	3	4	5
ELEVATION	-0.532	-0.234	-0.073	0.595	0.060
SLOPE	-0.172	0.605	-0.094	0.490	-0.110
WATER	0.553	-0.417	0.302	0.081	0.071
COVER	0.804	-0.158	0.079	0.278	-0.206
CANOPY	0.637	0.494	0.172	0.280	-0.154
HERB	-0.335	-0.187	0.866	-0.048	-0.034
LITTER	0.075	0.757	-0.289	-0.378	-0.086
SHRUB	0.526	-0.386	-0.468	0.054	-0.413
S WOOD	0.107	0.595	0.302	0.374	0.321
LOG	0.456	-0.088	-0.046	-0.323	0.585
ROCK	-0.392	-0.250	-0.554	0.342	0.407
SOIL	-0.699	-0.131	0.147	0.091	-0.320
TREE	0.693	-0.178	0.033	0.411	0.144

The 5 principal components were then used as candidate variables in a logistic regression model with forward stepwise entry. The final model (Table 9) included Components 1, 2, 3, and 5 and accurately classified 95.5% of the contrast sites and 77.3% of the den sites for a combined accuracy of 86.4%. A graph of den and contrast sites with respect to the 2 most important axes shows that a den site is more likely to be at a lower elevation, with diverse vegetation that provides hiding and canopy cover (Fig. 9). The den site would also have many small logs and be located near water.

Table 9. Results of the final logistic regression model predicting wolf den site locations with Principle Component Analysis

Variable	Coefficient	SE	Coefficient/SE	*P*-value	R
PC 1	2.08	0.82	2.54	0.011	0.27
PC 2	1.63	0.71	2.30	0.021	0.23
PC 3	4.26	1.55	2.75	0.0058	0.3
PC 5	-1.81	0.91	-1.99	0.047	-0.18
Constant	-0.41	0.47	-0.87	0.39	

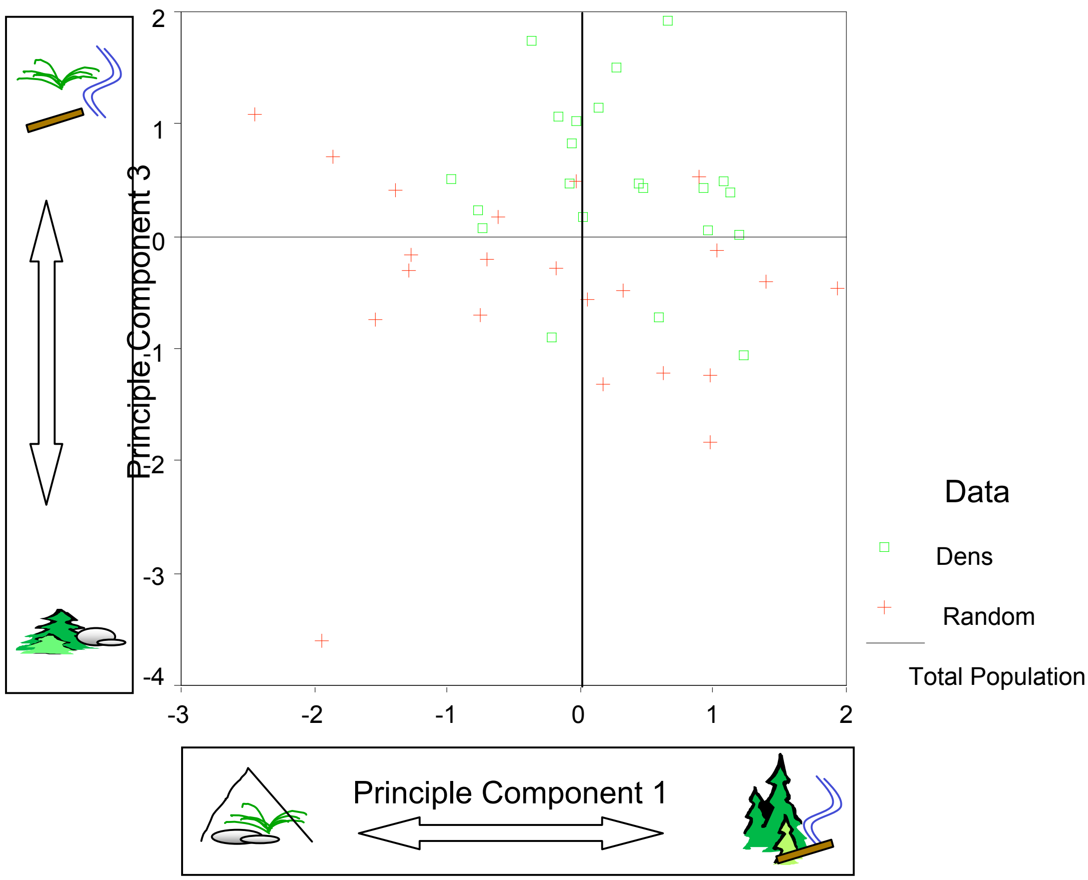

Figure 9. Plot of principal component 3 (corresponding to increasing herbaceous cover and small logs, greater probability of water within 100m, and fewer rocks and shrubs) and principal component 1 (corresponding to more hiding cover, canopy cover, trees, shrubs, water; lower elevation, and exposed soil).

Den Area Regression Analysis. The same variables were examined with the exception of ELEVATION, which was only recorded at the site (center plot). After univariate analysis (Wilcoxon's signed-ranks test) of the 12 habitat variables, 6 showed significance ($\alpha = 0.10$) and were retained: WATER, COVER, HERB, LITTER, SOIL and ROCK, none of which exhibited multicollinearity. The final model (Table 10) included

COVER, HERB, LITTER, and WATER and accurately classified 74.3 % of the contrast areas and 67.9 % of the den areas for a combined accuracy of 71.1 %.

Table 10. Results of the final logistic regression model predicting wolf den area locations vs. contrast area locations.

Variable	Coefficient	SE	Coefficient/SE	*P*-value	R
COVER	0.014	0.007	2.03	0.049	0.08
HERB	0.04	0.01	4.17	<0.0005	0.22
LITTER	0.025	0.011	2.23	0.0666	0.23
WATER	1.31	0.33	3.97	0.0001	0.21
Constant	-2.73	0.6	-4.55	0	

Coarse-scale Habitat Selection and GIS Modeling

Distance to water, distance to roads, slope, elevation, and solar radiation did not differ between den and contrast sites (Table 11). Land ownership was the same as reported earlier. Because there were no significant univariate differences, I did not create a logistic regression model at this scale.

Table 11. Mean and standard deviation of variables measured at the den (n = 35) and contrast sites (n = 35) with GIS. *P*-value is that of a Wilcoxon's signed-ranks test.

Variable	Dens	Contrasts	*P*
Distance to Roads (m)	2654 $\pm$ 3432	3039 $\pm$ 4855	0.86
Distance to Water (m)	412 $\pm$ 311	533 $\pm$ 483	0.41
Coniferous Forest (%)	59 $\pm$ 44	54 $\pm$ 44	0.48
Elevation (m)	1916 $\pm$ 404	2011 $\pm$ 389	0.104
Slope (degree)	19 $\pm$ 16	20 $\pm$ 16	0.54
Solar Radiation (W/m^2)	5822696 $\pm$ 1351423	5642444 $\pm$ 1500068	.54

Location of dens in home range. Seven of 8 Idaho dens, and all 4 Montana dens used for this analysis fell in the core 50% kernel (e.g., Fig. 10). The kernel estimator identified more than one core area for 5 territories. In these cases, the 50% core area was comprised of 2-3 discontinuous areas, and dens mostly fell in the largest 50% core area. The 50% kernel average size (147.9 $\pm$ 196.6 km^2) was approximately 18% of the 95% kernel size that averaged 760.9 $\pm$ 653 km^2. MCP home range size averaged 585.3 $\pm$ 453.2 km^2. Only 45% of the locations within the 50% kernel were from the denning period (Apr-Jun). Road densities in the core and home ranges (0.39 km/km^2 and 0.30 km/km^2, respectively) were not significantly different.

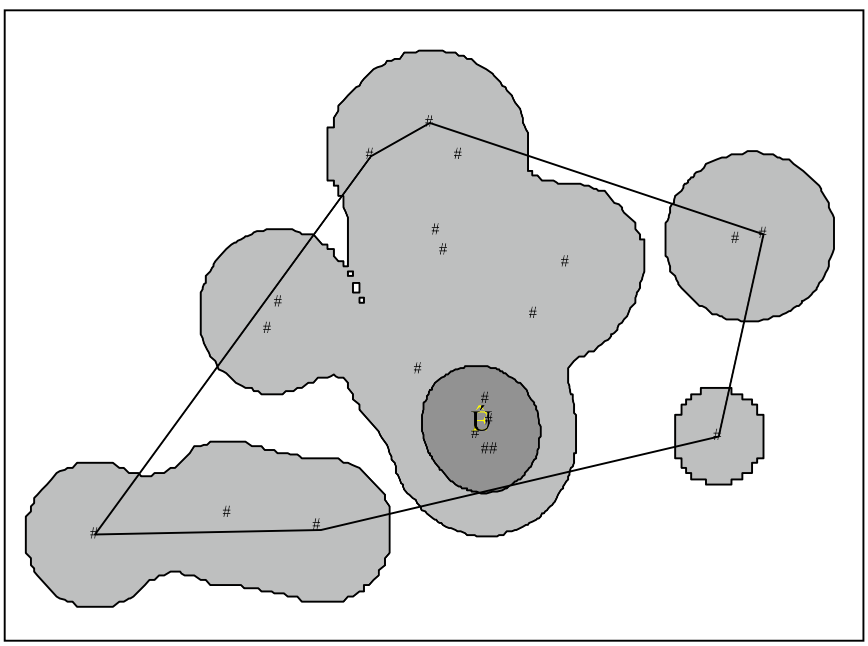

Figure 10. Example of den site, telemetry locations, fixed kernel home ranges (95 and 50%), and the MCP home range. The larger light polygons are part of the 95% kernel home range, and the small dark polygon is the core 50% kernel. The telemetry locations are the dots and the star is the den. The hollow polygon with the straight lines is the MCP home range.

Most wolf dens had habitat characteristics dissimilar to the mean habitat vector for 35 wolf dens (Mahalanobis $P \leq 0.40$ for 70% of dens – Fig. 12). This indicates considerable variation among wolf dens with respect to these habitat characteristics. But most of the landscape was even more dissimilar to the mean habitat vector, with > 80% of the study area having Mahalanobis $P < 0.10$) (Fig. 11). The 12% of the landscape that most resembled mean den habitat encompassed 89% of the wolf dens, and the 18% of the landscape most similar to the mean encompassed 91% of the dens (Figure 12). Thus Mahalanobis models with threshold P values of 0.10 to 0.20 are useful to managers, who can expect that about 90% of dens will occur within < 20% of the landscape.

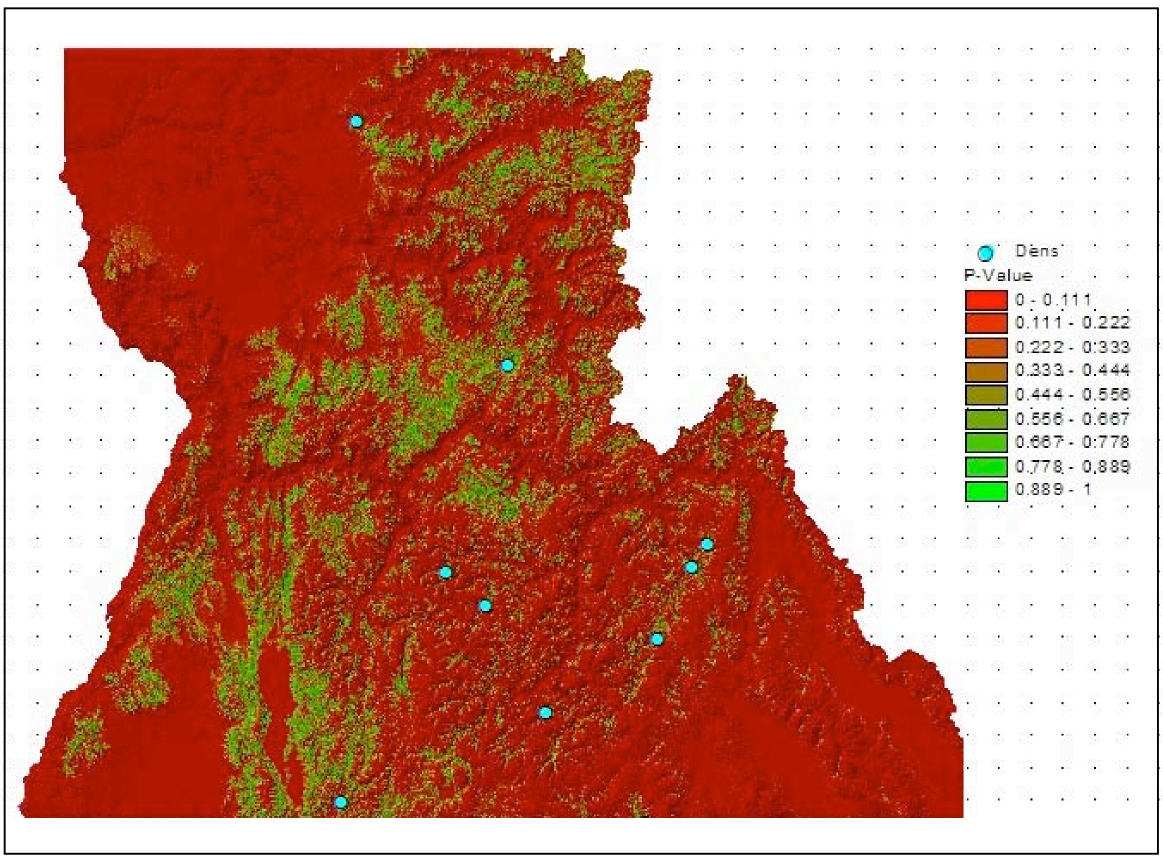

Figure 11. Example of Mahalanobis output for central Idaho with den sites.

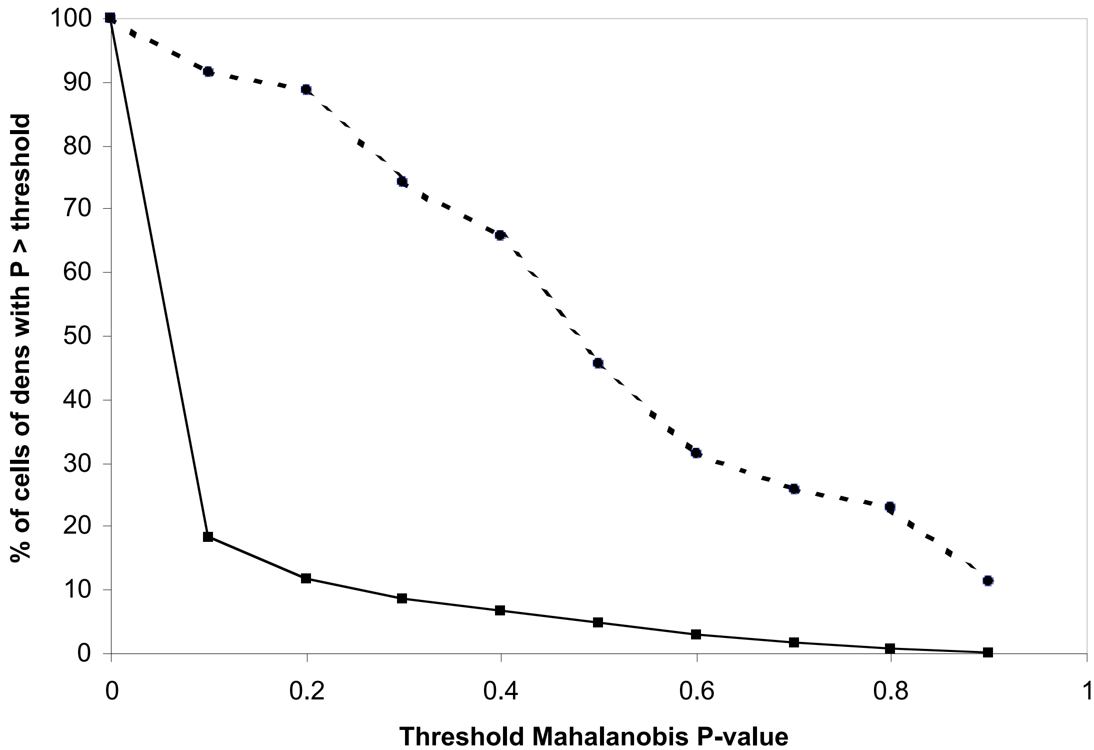

Figure 12. Percent of dens (dashed line) or cells (solid line) with Mahalanobis-*P* greater than or equal to threshold value. Higher values along the x-axis indicate greater similarity to the mean vector of habitat measurements at 35 wolf dens.

DISCUSSION

Although both univariate and multivariate techniques are commonly used to describe habitat selection, the univariate methods (e.g., Wilcoxon's signed-ranks test) can fail to address confounding of highly correlated variables.   The removal of hiding cover from the regression analysis due to its correlation with canopy cover to be problematic. Both canopy and hiding cover were highly significant. PCA eliminated the problem of covariance, but produced a characterization of dens that was not as clearly related to the measured habitat variables. Each of the 13 habitat variables were significant in at least 2 of the 5 principal components. Overall, univariate and multivariate techniques produced similar results and suggest that water within 100 m, canopy cover, herbaceous ground cover, small logs, and rocks are the most important factors influencing selection of den sites at the fine-scale.

Finding den sites near water was an expected outcome. Dens are often near water, probably due to the lactating female's increased need for hydration (Mech 1970; Peterson 1977, Norris et al. 2002). In south-central Alaska, Ballard and Dau (1983) found the average distance from den sites to a water source was 257 $\pm$ 263 meters.

I found dense cover near dens, which is consistent with the fact that dens were often difficult to find and could rarely be seen from >20 meters. Previous studies in Montana (Matteson 1992) and Wisconsin-Minnesota (Unger 1999) did not find a significant cover difference between den and contrast locations. Matteson (1992) measured cover at 30.5 and 61 m (compared to 15 m in this study); at these distances, Matteson found dense cover values at dens with 66.1 $\pm$ 27.3% and 91 $\pm$ 17.3, respectively. I believe Matteson measured cover at inappropriately long distances from the center of den and contrast sites, which could have reduced the power to detect differences. Unger (1999) collected data at 16 m, but used a 1 m high cover board compared to the 2-m cover pole used in this study. Unger (1999) found average hiding cover at dens to be 70 ± 24%, which is comparable to my results (72 ± 24%). Perhaps the vegetative structure in northwest Wisconsin and east-central Minnesota is not as diverse and more dense than in the NRM.

Canopy cover was also considered to be insignificant by Matteson (1992) and Unger (1999). The average canopy cover reported by Unger (1999) was 43.3 ± 8.8%, and 18.9 ± 21.3% by Matteson (1992), which is much less than the 87.6 ± 21.8% I observed. These differences could be explained by the different collection methods. Matteson (1992) visually estimated canopy cover whereas Unger (1999) used a point-intercept method. Nuttle (1997) suggested that point-intercept methods may not reflect an animal's perception of canopy cover. Although Matteson's study did not show statistical significance for canopy and hiding cover, she believed they played an important role within a 100-m radius of the den.

My fine-scale analysis did not identify elevation as an important variable. However, Matteson (1992) found dens at lower elevation than contrast locations, and called elevation the "overriding factor" for den site selection. Matteson (1992) found an average elevation of 1352 ± 221 m at dens, compared to my mean of 1672 ± 397. However, mean elevation was 1209 ± 176 m) for the subset of my dens that fall in Matteson's (1992) study area (i.e., northwest Montana and southern Canada). In my study average elevations were 1216 ± 170 m and 2065 ± 240 m north and south of the 46th parallel, respectively. Stephenson (1974) found an average elevation of 635 m for dens in the Brooks Range of Alaska. While these data suggest a trend, additional research would be required to determine if wolves are actually selecting lower elevations for den sites at higher latitudes and vice versa.

Unger (1999) found steeper slopes at dens versus contrast sites. Although I did not identify slope as a selected den site attribute, my average slope of 27% was similar to Unger's 25% (1999). Matteson (1992) found average slopes of 16 $\pm$ 19%. Stephenson (1974) found a much higher average slope of 65% in the Brooks Range of Alaska. Using elevation and slope measured in a GIS, Oakleaf (2002) found core areas of pack home ranges in the NRM at lower elevations with gentler slopes. While I found that most dens were located within home range core areas, I found no significant correlation between den sites and elevation or slope.

Variables that displayed significance at both site and area scale included hiding cover, herbaceous ground cover, and rock cover. At the area scale increased bare soil at the contrast locations was significantly different from the dens. Increased canopy cover and small woody debris was significant at the site level, suggesting that wolves respond to these 2 factors only in the area immediately surrounding the den hole. The increased canopy cover at the den hole could suggest that wolves select an area with more vertical protection, or this could be an artifact of site selection near tree roots for increased structural integrity. Although small woody material may provide little structural defense from ground predators, it may provide visual obscurity. Golden Eagles (*Aquila chrysaetos*) have been known to take fox (*Vulpes vulpes*) pups nears den sites (C. McIntyre, personal communication), so it is possible that woody debris and canopy cover may provide some protection from raptors.

Approximately half of the dens in my study were associated with trees and their root systems. This is consistent with Matteson's (1992) results of 8 of 15 dens at the base of trees, framed by roots. Perhaps den selection under trees and in their root structure is particular to wolves in the Northern Rockies. My measurements of den size and shape were similar to previous studies. Most dens had distinct, enlarged terminal chambers, consistent with the findings of Ballard and Dau (1983). However, Unger (1999) did not find dens with distinct birthing chambers. I found soil composition similar to that in previous studies. Wolves usually dig dens in stable, sandy soil, probably due to easy digging and good drainage (Mech 1970, Peterson 1977; Ballard and Dau 1983; Unger 1999). Matteson (1992) found the most frequent texture type to be loam.

Wolves apparently did not select any one aspect for den sites. Unger (1999) found similar results, but Matteson (1992) found a moderate preference by wolves for south and east facing slopes. Solar radiation at dens does not appear to be a factor in selection.

Unger (1999) called the area within 50 m of the den a "heavy use" area. I also found a significant increase in sign (e.g., day beds, scats, trails) within 50 m of the den. Wolf trails were characterized by their width and "softness," as compared to ungulate trails which are often more "harsh" because of their sharp hooves. J. Young and M. Elbroch (Shikari Tracking Guild, unpublished data, Appendix 3) measured direct register trot impressions in the trails and calculated a stride length of 28 inches, similar to Elbroch's (2003) range of 22-34", with a trail width of 4-9_". Tracks and other sign around the dens can help to determine how recently a den was used and differentiate between wolf and other canid dens.

Road and water GIS layers at the 1:100,000 resolution were inaccurate. In the field, I found most dens to be within 100 m of water, although GIS data only revealed 3 water sources within that distance. Several roads were depicted as within 30 m of dens, but I found no such roads in the field. These inaccuracies probably contributed to the lack of significant differences (Table 11) and my inability to construct a coarse-scale model of den selection.

Eleven of 12 den locations tested fell within the core home range (50% fixed kernel) polygon. Unger (1999) found that dens tended to be in the central part of the MCP, but Ciucci and Mech (1992) found wolf dens located randomly throughout the MCP home ranges. However, these findings could be a result of different methods in the analysis. Ciucci and Mech (1992) examined wolf den locations by calculating the mean radius for each territory as the average of the radii from the center to the vertices of the polygon. Unger (1999) characterized the core area by simply reducing the same dimensions of the 100% MCP by 75%. Both of these studies examined den location as either being centrally or peripherally located in the MCP home range. Fifty percent fixed kernel estimators examine the intensity of use in the home range, and therefore are a better predictor of denning areas.

In my study only 45% of the locations within the 50% kernel were from the denning period (Apr-Jun). This supports the theory that wolves use the denning area throughout the year. Road densities were not significantly different between core and home range kernels, which is consistent with Oakleaf's (2002) results.

Although there was considerable variation among wolf dens with respect to elevation, slope, solar radiation, and coniferous forest cover, I identified several useful Mahalanobis distance models using these GIS data layers. By combining Mahalanobis modeling with fixed kernel home ranges and core use areas, potential denning habitat can be identified.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Den site selection appears strongest within about 15 m of the den hole, but was also apparent (but less pronounced) within a 50-m radius of the den. That den sites had more hiding cover, canopy cover, and woody debris than random sites suggests that wolves select denning habitat for its added protective value. The den structure itself with a narrow tunnel leading to a larger birthing chamber may also be related to protection. Although elevation was not found to be significantly different between dens and random contrast locations, average elevation of dens decreased as latitude increased. Close proximity to water is also a significant factor. To help standardize den site data collection in the NRM, I have included a recommended den data collection form (Appendix 4).

More than 90% of the dens fell within the 50% fixed kernel core use area of the pack, which corresponds to a mean of 147.9 ± 196.6 km^2. Because these core areas are visited by the wolves throughout the year, managers may want to consider actions that would limit human disturbance year round in these areas. One-kilometer closure areas around den sites, which have been used in the Yellowstone and Mexican wolf (*Canis lupus baileyii*) recovery areas, may be too small to adequately protect wolves from detrimental effects of human disturbance. The 50% kernel would be a better closure perimeter for 2 reasons: 1) it represents a less arbitrary boundary of the important wolf area around the dens, and 2) it makes finding dens by inquisitive citizens more difficult, because the closed area is larger and dens are often not in the geographic center of the kernel. However, the large closure size delineated by 50% kernel would not be socially acceptable in many cases. The size and shape of the closures should be contingent on the potential for human disturbance during that period.

Minimum Convex Polygons are the standard method for delineating wolf home ranges in the NRM, and several studies have examined den site locations within 100% MCP home ranges. However, 100% MCP home ranges do not consider intensity of use, which should be considered when examining core use areas and wolf dens. When managers are attempting to identify potential core wolf habitat, I recommend the use of the 50% fixed kernel estimator which accounts for intensity of use.

Once dens are located, efforts could be made to protect these areas from human disturbance, development, and habitat alterations because wolves often reuse the same den in subsequent years. Additionally, the core areas should be protected because the availability of suitable den sites may limit the overall carrying capacity of regional habitats for wolves. If human disturbance does take place near or in the core areas, managers should monitor to determine if a shift in the core area takes place over the following year.

Although some GIS-derived data layers were accurate (e.g., elevation, slope, aspect), other data layers (e.g., roads and water) were highly inaccurate compared to site-specific data measured in the field. As GIS use becomes more prevalent, managers should be aware of some of its potential limitations. Layers used in modeling habitat should be sufficiently accurate for the level of analysis desired.

Mahalanobis models can help managers identify suitable den habitat (defined by $P > 0.20$). Managers can use these models to limit human disturbance in potential denning areas, or to evaluate the amount of denning habitat in existing wolf populations or proposed reintroduction sites. Because 80-90% of dens occur in suitable denning habitat that comprises only 12-18% of the recovery area, denning habitat may be a limiting factor. The modeling area can be further refined by calculating Mahalanobis distances within pack home range or core territories.

Further study should be focused on den site location in relation to ungulate distribution. In the Artic, wolves have located their dens in the migration route of the caribou (*C. Rangifer*) (Walton et al. 2001). I would expect to see a pattern emerging in the NRM with respect to elk calving grounds and ungulate winter and summer ranges. Additionally, this analysis could also be applied to rendezvous sites. Future research should investigate whether pup survival is related to den site characteristics, available prey, and human disturbance.

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APPENDIX 1 – Data Collection Forms

DATA SHEET: ____ of ____
SAMPLE SITE: ____________

Data entered into database: ________ (initials)

WOLF DEN/RENDEZVOUS

DATA SHEET

(circle one)
OFFICIAL DEN/REND. NAME: ________________________ PERSONNEL __________________________

PACK: _______________ BREEDING FEMALE (if known): ______ SAMPLE DATE: ___/____/_______

UTM: ZONE: _____ EASTING: _____________ NORTHING: ______________ DATUM: ___________
(**NAD 27**; NAD 83, WGS 84, etc)

GPS WAYPOINT ID: _____________ ELEVATION: __________ LAND OWNER ___________________
GENERAL LOCATION: ____(Quad) ____________________
DEN USED THIS YEAR: Y or N YEARS ACTIVE: ____
NO. OF ENTRANCE(S): _____ ENTRANCE : HEIGHT _______ cm WIDTH _____ cm
INTERIOR: HEIGHT _______ cm WIDTH _____ cm EST. DEPTH: _______cm

EST. DATES USED: ______________ TO _______________ COLLECT HAIR SAMPLE: Y / N ID______
DEN TYPE DESCRIPTION (tree, rock, hillside excavation, etc.): ____
PERCENT SLOPE: (Up)_____(Dn)_____ SLOPE POSITION: _____________ GENERAL ASPECT: _______
Avg _____ (e.g.,-upper, mid, lower, etc) OPENING ASPECT: ________

DISTANCE TO WATER: ___________m WATER TYPE (pond, creek, etc.): ______________________________
DISTANCE TO ROAD/TRAIL: ______m TYPE OF ROAD/TRAIL:_________________________________
DISTANCE TO MEADOW/OPENNING: _______ m TYPE: _____________________________________
DISTANCE TO HUMAN DISTURBANCE: ______ m TYPE: ___________________________________
DISTANCE TO ROCK OUTCROP: ______ m DESCRIPTION: ___________________________________

SOIL COMPOSITION: Inside _____________ Outside _____________ COLLECT SOIL SAMPLE? Y or N
(e.g., sand, loam, silt, etc) Inside # ________ Outside # __________

VEGETATION:

	N	E	S	W	
HIGH VEG COVER:	________	________	________	________	Mean: __________________
LOW VEG COVER:	________	________	________	________	Mean: __________________
DENSIOMETER:	________	________	________	________	Mean: __________________
MOOSEHORN: (c)____	____,____	____,___	___,____	___,_____	Mean:__________________

	Upper	Middle	Lower		
HERB GROUND COVER:	________	__________	__________	=	________________________
LEAF/PINE LITTER:	________	__________	__________	=	________________________
SHRUB COVER:	________	__________	__________	=	________________________
LOG-WOOD COVER (1):	________	__________	__________	=	________________________
LOG-WOOD COVER (2):	________	__________	__________	=	________________________
ROCK COVER:	________	__________	__________	=	________________________
SOIL:	________	__________	__________	=	________________________
WATER:	________	__________	__________	=	________________________
TREE COVER:	________	__________	__________	=	________________________
DBH AVERAGE:	________	__________	__________	=	________________________

HABITAT TYPE: ____________________________ STRUCTURAL CLASS: ____
MAJOR TREE SPP: ___________________________ MAJOR SHRUB SPP: ____
DISTANCE TO EDGE: _______ m

PHOTOS TAKEN: Y or N EXPOSURE NUMBERS: FROM _____________ to ____________________
DIGITAL: Y or N

PREY OBSERVATIONS: ____

____

ADDITIONAL OBSERVATIONS (Remains, scats, day beds, trails, etc): ________________________________

____

____

____

DEN SITE SKETCH

DATA SHEET: ____ of ____
SAMPLE SITE: ____________

Data entered into database: ________ (initials)

DEN/CONTRAST CENTER PLOT CHECK SHEET

✓ CHECK SHEET:

	Upper	Middle	Lower
HERB:			
LITTER:			
SHRUB:			
LOG (1):			
LOG (2):			
ROCK:			
SOIL:			
WATER:			
TREE:			
DBH:			

ADDITIONAL COMMENTS (prey observations, remains, pup holes, trails, etc):________________________

____

____

____

____

____

DATA SHEET: ____ of ____ SAMPLE SITE: ____________	Data entered into database: ________ (initials)

ADDITIONAL DATA SHEET
DEN/CONTRAST

SAMPLE SITE: Direction _________ Distance _____________

VEGETATION:	N	E	S	W	
HIGH VEG COVER:	_________	_________	_________	_________	Mean: _______________
LOW VEG COVER:	_________	_________	_________	_________	Mean: _______________
DENSIOMETER:	_________	_________	_________	_________	Mean: _______________
MOOSEHORN: (c)_____	_____,____	_____,_____	____,_____	_____,_____	Mean: _______________

PERCENT SLOPE: (Up)________(Dn)________ Avg _______ ASPECT: ___________________
MAJOR TREE SPP: ________________________ MAJOR SHRUB SPP: ________________________________

✓ CHECK SHEET:

	Upper	Middle	Lower
HERB:			
LITTER:			
SHRUB:			
LOG (1):			
LOG (2):			
ROCK:			
SOIL:			
WATER:			
TREE:			
DBH:			

ADDITIONAL COMMENTS (prey observations, remains, pup holes, trails, etc):________________________

____

____

TOTALS:

	Upper	Middle	Lower		
HERB GROUND COVER:	________	__________	__________	=	________________________
LEAF/PINE LITTER:	________	__________	__________	=	________________________
SHRUB COVER:	________	__________	__________	=	________________________
LOG-WOOD COVER (1):	________	__________	__________	=	________________________
LOG-WOOD COVER (2):	________	__________	__________	=	________________________
ROCK COVER:	________	__________	__________	=	________________________
SOIL:	________	__________	__________	=	________________________
WATER:	________	__________	__________	=	________________________
TREE COVER:	________	__________	__________	=	________________________
DBH AVERAGE:	________	__________	__________	=	________________________

RANDOM CONTRAST
DATA SHEET

NAME: _________________ DATE: ___________ PERSONNEL: ____
UTM: ZONE: ________ EASTING: __________________ NORTHING: ___________________ DATUM: ________________
(**NAD 27**; NAD 83, WGS 84, etc)
GPS WAYPOINT ID: _________________ ELEVATION: _______________ LAND OWNER ____________________________
GENERAL LOCATION: ____(Quad) __________________________
MAJOR TREE SPP: ______________________________ MAJOR SHRUB SPP: ____
HABITAT TYPE: ________________________________ STRUCTURAL CLASS: _______________________________________
PERCENT SLOPE: (Up)________(Dn)________ Avg _______ ASPECT: ___________________

VEGETATION:	N	E	S	W	
HIGH VEG COVER:	__________	__________	__________	__________	Mean: _________________
LOW VEG COVER:	__________	__________	__________	__________	Mean: ________________
DENSIOMETER:	__________	__________	__________	__________	Mean: ________________
MOOSEHORN: (c)_____	_____,____	_____,_____	____,_____	_____,_____	Mean: ________________

✓ CHECK SHEET:

	Upper	Middle	Lower
HERB:			
LITTER:			
SHRUB:			
LOG (1):			
LOG (2):			
ROCK:			
SOIL:			
WATER:			
TREE:			
DBH:			

DISTANCE TO WATER: ___________m WATER TYPE (pond, creek, etc.): ____
DISTANCE TO ROAD/TRAIL: ______m TYPE OF ROAD/TRAIL:____
DISTANCE TO MEADOW/OPENNING: _______ m TYPE: ____
DISTANCE TO HUMAN DISTURBANCE: ______ m TYPE: ____
DISTANCE TO ROCK OUTCROP: ______ m DESCRIPTION: ____

COMMENTS (prey observations, remains, pup holes, trails, etc):____

____

____

RANDOM CONTRAST
DATA SHEET

NAME: ________________ DATE: __________ PERSONNEL: ____

TOTALS:

	Upper	Middle	Lower		
HERB GROUND COVER:	________	__________	__________	=	________________________
LEAF/PINE LITTER:	________	__________	__________	=	________________________
SHRUB COVER:	________	__________	__________	=	________________________
LOG-WOOD COVER (1):	________	__________	__________	=	________________________
LOG-WOOD COVER (2):	________	__________	__________	=	________________________
ROCK COVER:	________	__________	__________	=	________________________
SOIL:	________	__________	__________	=	________________________
WATER:	________	__________	__________	=	________________________
TREE COVER:	________	__________	__________	=	________________________
DBH AVERAGE:	________	__________	__________	=	________________________

APPENDIX 2 – Soil Texture-By-Feel

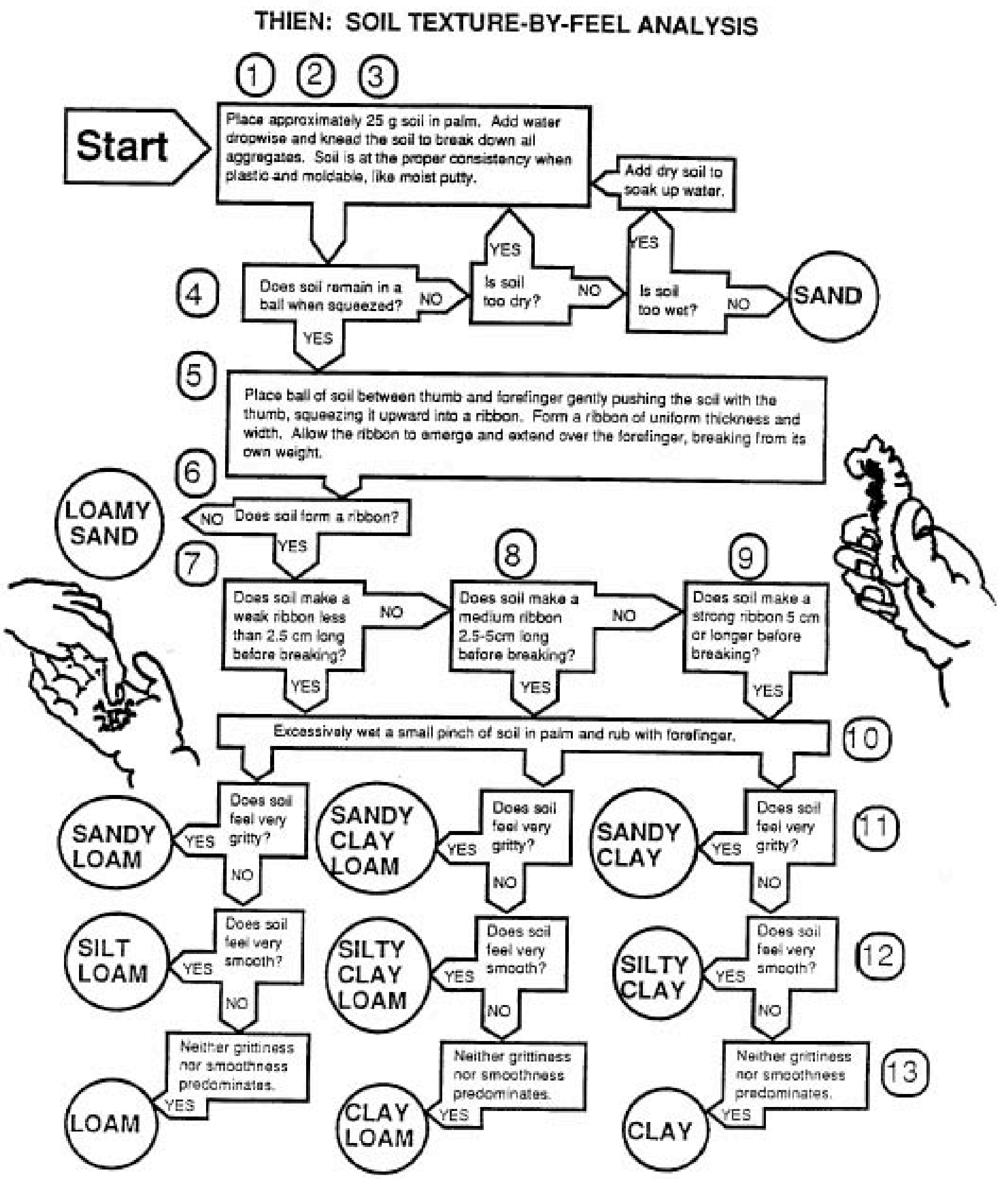

Fig. 12. Flow chart for determining soil texture by feel. Adapted from Thien, S. J., 1979, "A Flow Diagram for Teaching Texture-by-Feel Analysis," Journal of Agronomic Education, Vol. 8:54-55 by permission of the American Society of Agronomy.

APPENDIX 3 – CyberTracker Use at Dens

This section was added to show an additional method to gather data at den sites. During a portion of the field season, we were joined by Jon Young and several professional trackers from the Shikari Tracking Guild (www.Shikari.org). Jon Young, BS Environmental Science, is a professional wildlife inventory consultant and has been tracking for more than 30 years. Young brought with him new technology and ideas for gathering data around den sites. Young and his trackers used CyberTracker software loaded in a Personal Data Assistant (PDA), linked with a Magellan ™ Companion GPS unit. Young used the CyberTracker to collect data at 2 den sites in Idaho: Jureano Mountain and Wolf Fang. Below is an image of CyberTracker data collected at the Jureano Mountain Den. However, it must be pointed out that no specific collection protocol had been determined and time was a limiting factor.

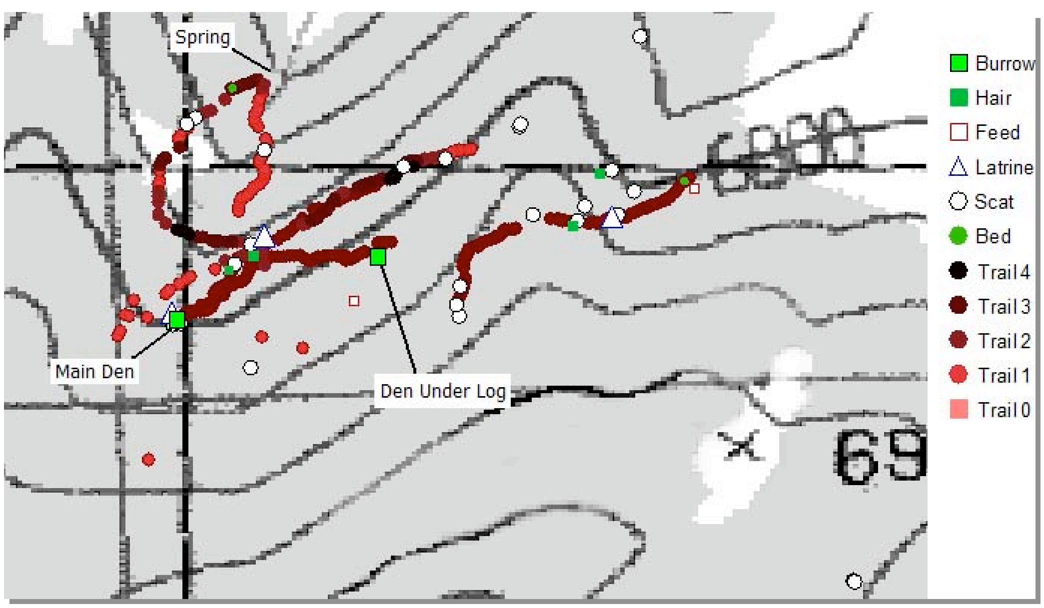

Figure A-2. CyberTracker data collected at den site

Figure A-2 depicts 5 different types of trails (Trail 0 – Trail 4). Young has a method for determining trail usage, with the heaviest use rating a "4". A latrine is an area with multiple scats. By following tacks and sign, Young located the spring where the wolves had been drinking during the denning season. Again, more data was available for collection, but time constraints prevented a complete survey.

I include this information, because I feel that a more in-depth picture of den site ecology could be gained by using this technology. With a developed collection protocol and trained personnel, CyberTracker equipment could expand on current knowledge of den site use, trail patterns, day bed locations, and more. CyberTracker data could also be combined with existing GIS layers for further analysis.

APPENDIX 4 – Suggested Den Data Collection Form

DATA SHEET: ____ of ____
SAMPLE SITE: ____________

Data entered into database: ________ (initials)

WOLF DEN/RENDEZVOUS
DATA SHEET

(circle one)
DEN/REND. NAME: _________________________ PERSONNEL _______________________________

PACK: ____________________ BREEDING FEMALE (if known): ______ DATE: ___/____/_______

UTM: ZONE: _____ EASTING: ____________ NORTHING: ____________ DATUM: ___________
(**NAD 27**; NAD 83, WGS 84, etc)

SOURCE (e.g., aerial average, GPS): _________________________ GPS WAYPOINT: _______________

ELEVATION (m): __________ LAND OWNER ____

GENERAL LOCATION: ____(Quad) ____________________

DEN USED THIS YEAR: Y or N YEARS ACTIVE: ______ EST. DATES USED: ________________

NO. OF ENTRANCE(S): _____ ENTRANCE : HEIGHT ______ cm WIDTH _____ cm
INTERIOR: HEIGHT ______ cm WIDTH _____ cm EST. DEPTH: ______cm

DEN TYPE DESCRIPTION (e.g., hillside excavation under tree) ____

NUMBER OF PUPS BORN: ____________ NUMBER STILL ALIVE BY 31 DEC _________________

PERCENT SLOPE: (Up)_____(Dn)_____ SLOPE POSITION: ___________ GENERAL ASPECT: _______
Avg _____ (e.g.,-upper, mid, lower, etc) OPENING ASPECT: _______

DISTANCE TO WATER: _________m TYPE (pond, creek, etc.):_____________________________________

DISTANCE TO ROAD/TRAIL: _____m TYPE: ____

DISTANCE TO MEADOW/OPENNING: ______ m TYPE: _______________________________________

DISTANCE TO HUMAN DISTURBANCE: _____ m TYPE: _____________________________________

SOIL SAMPLE COLLECTED? Y or N COMPOSITION (e.g., sand, loam, silt, etc): _________________

HAIR SAMPLE COLLECTED? Y or N SOIL SAMPLE # __________ HAIR SAMPLE # _________

	N	E	S	W		
HIDING COVER:	_______	_______	_______	_______	Mean:	________________
CANOPY COVER:	_______	_______	_______	_______	Mean:	________________

HABITAT TYPE: ____________________________ STRUCTURAL CLASS: ____

MAJOR TREE SPP: ____

MAJOR SHRUB SPP: ____

PHOTOS TAKEN: Y or N EXPOSURE NUMBERS: _____ to ______ DIGITAL: Y or N

OBSERVATIONS (e.g., trails, day beds, bones, scats, ground cover):________________________________
____
____
____
____
____

DEN SITE SKETCH

Sketch interior shape (note measurements)