# USING LOGISTIC REGRESSION TO MODEL WOLF HABITAT SUITABILITY IN THE NORTHERN ROCKY MOUNTAINS

MICHAEL E. HOUTS, Kansas Applied Remote Sensing Program, Kansas Biological Survey, University of Kansas, 2101 Constant Avenue, Lawrence, KS 66045-7612
phone 785-864-1515; fax 785-864-1534; e-mail mhouts@ku.edu

***Abstract***: The sixty six wolves that were reintroduced into Yellowstone National Park and Central Idaho in 1995 and 1996 have prospered to over 663 wolves in Yellowstone, Idaho, and Montana as of 2002. With the wolf population and occupied territory expanding so rapidly, being able to know where the wolves will go next would help wildlife managers and policy makers with proactive planning. In 1999 a geographic information system (GIS) was developed to model wolf habitat suitability using road density and land cover data from a subset of Idaho, Montana, and Wyoming. Now, results from this model are re-assessed using 2001 wolf pack locations, and the study area has been enlarged to include all of Idaho, Montana, and Wyoming, plus Washington and Oregon. The model was tested using data from the entire study area and 2001 wolf pack locations for out-of-sample validation. Results indicated that the model created in 1999 was able to successfully predict suitable wolf habitat, and areas of future wolf occupation with a 91% overall accuracy (2001 pack locations). The resulting habitat suitability maps can assist management agencies in the identification of potential wolf habitat, areas where human/wolf conflicts are likely to occur, and areas that should be considered critical wolf habitat..

**Key words**: wolves, habitat, modeling, logistic regression

## Introduction

The reintroduction of wolves into the Northern Rocky Mountains has been a success, so far. The 66 reintroduced wolves in 1995 have quickly adapted to their new locations, and by the end of 2002, had prospered to a population of approximately 271 wolves throughout the Yellowstone area, as well as an estimated 284 wolves in Idaho and about 108 wolves in Montana (USFWS 2003). According to the current reintroduction plan, the wolves will be removed from the Endangered Species Act and managed as Threatened species when there are greater than 30 breeding wolf packs distributed throughout the three states for three consecutive years. Currently, 2000, 2001, and 2002 have met these requirements, however, the question of how to manage the wolves still remains unclear. This project was designed to assist in answering that question. A map-based conservation plan could help facilitate human-wolf coexistence by identifying areas where human development trends may create potential conflicts with wolves (Mladenoff et al. 1995, Mladenoff et al. 1997). This research expands on research conducted by Houts (1999), and attempts to map suitable wolf habitat across the northern Rocky Mountains (NRM) and the Pacific Northwest to identify where wolves may disperse to in the future and to assist with pro-active management planning.

The two variables used in this analysis, road density and land cover, were identified by Houts (1999) as being critical variables for predicting wolf habitat in the (NRM). Roads, by increasing human contact, have been documented to negatively affect wolf populations at both local and regional scales (Fuller 1989, Thurber et al. 1994, Mladenoff et al. 1995, Mech et al. 1988). The mean road density in areas occupied by wolves is generally lower than in areas not occupied by wolves. Studies in Wisconsin showed that wolves were concentrated in areas with a mean road density less than 0.23 km/sq km, and tolerated areas as high as 0.45 km/sq km; as opposed to a mean road density of 0.74 km from random non-pack areas (Mladenoff et al.1995). Similarly, most (75%) of the wolves in the NRM were found in areas with a mean road density less than 0.54 km per sq km (Houts 1999). Additionally, studies also indicate wolves respond to vegetation type. In Minnesota, wolves territories had a higher proportion of conifer and conifer mixed woodlands than non wolf areas, and occupied areas had a lower percentage of agricultural and deciduous forest than unoccupied land (Mladenoff et al. 1995). Previous analysis of the NRM wolves also found that wolves were found more commonly in coniferous forests and mixed conifer/deciduous forests (Houts 1999).

**Study Area**

This study focused on predicting wolf habitat in the Northern Rocky Mountains (NRM) and the Pacific Northwest; specifically, Idaho, Montana, Wyoming, Oregon and Washington (Figure 1). These states were selected because they either already had wolves , or are nearby neighbors that could possibly receive dispersing wolves in the future. This large area contains a wide range of topography, precipitation, and vegetation types that can be generalized into the following course geographic regions: the northern Rocky Mountains (NRM), the northern great plains and Columbia and Snake River Basins, and the Cascade, Sierra Nevada and coastal Mountains.

The Northern portion of the United States Rock Mountains are the central focus of the study area. This area includes the western portions of Montana and Wyoming as well as northern Idaho and the northeast corner of Washington. Included in this large and diverse area are the Greater Yellowstone Ecosystem (GYE), the Selway-Bitterroot Wilderness area, and the Frank Church River of no Return Wilderness Area among others.

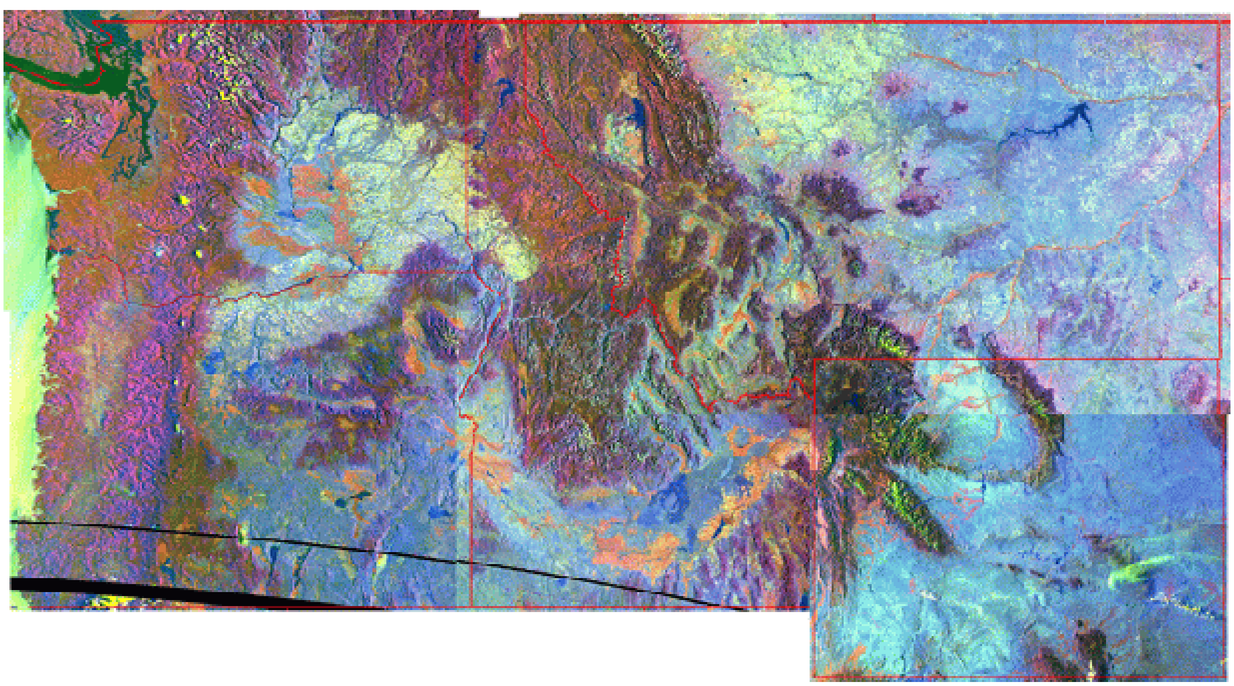

Figure 1. Advanced Very High Resolution Radiometer (AVHRR) satellite image of the study area. Forested areas are shown as shades of red, while grass and shrublands are shown in shades of light blue.

Precipitation varies greatly in response to elevation change, with slightly higher rates in the higher elevations and during the winter months. These factors work together to create a landscape that is characterized by western temperate coniferous forests in the upper, wetter, elevations, and sagebrush steppes in the lower, drier, elevations (Marston 1991). In the lowest elevations, grasses include wheat grasses from the genus *"Agropyron*", needle grasses from the genus "*Stipa"*, Idaho fescue "*Festuca idahoensis*", and various bluegrasses from the genus "*Poa*", among others. Shrub steppes are commonly dominated by big sagebrush "*Artemisia tridentata"*, with other species such as threetip sagebrush *"Artemisia tripartita"* and rabbit brush "*Chrysothamnus*" frequently occurring. The lower elevation forests are largely comprised of Douglas fir "*Pseudotsuga menziesii*" which give way to extensive lodgepole pine "*Pinus contorta*" forests in the middle elevations. As elevation continues to increase, the lodgepole pine communities become intermixed with subalpine forest species such as the Engelmann spruce "*Picea engelmannii*", subalpine fir "*Abies lasiocarpa*", and whitebark pine *"Pinus- albicaulis*".

Surrounding the NRM are the Northern Great Plains to the east and the Columbia Basin and Snake River Basin to the west. These areas can be roughly characterized as grasslands or shrub-steppe environments with vegetation similar to the lower elevations of the NRM. Grasses such as wheat grasses, needle grasses, Idaho fescue, and various bluegrasses frequently occur in wetter areas and big sagebrush, threetip sagebrush, and rabbit brush occur in dryer environments. Agriculture and grazing are the primary land uses in the grasslands and shrub steppes surrounding the mountains.

The western edge of Oregon and Washington are comprised of the Cascade, Sierra Nevada, and Costal mountain ranges, with the Puget lowland and Willamette Valley occurring between the Cascade and Coastal ranges. This western quarter is generally much wetter than the rest of the study area, making for a mostly forested landscape. Ponderosa Pine "*Pinus ponderosa*", Big leaf Maple "*Acer macrophyllum*", Douglas Fir "*Pseudotsuga menziesii*", and Pacific Silver fir "*Abies amabilis*" are common in the interior mountains, while Sitka Spruce "Picea sitchensis", Western Hemlock "Tsuga heterophylla", and Shore Pine "Pinus contorta" dominate the coastal locations. Forestry is a major land use throughout the forested lands of the NRM and the Pacific Northwest.

**Methodology**

In an attempt to predict suitable wolf habitat for five states in the north-western United States, two variables (majority land cover and road density) were analyzed using a 30x30 km grid. The grid was constructed in MAPINFO by applying the "Gridmakr" and "Cookie" extensions to a boundary coverage of the five state area. Once completed, the grid was imported into ARCINFO as a polygon coverage containing 1591 grid cells. Majority land cover was derived from 30-meter landcover maps generated from Landsat Thematic Mapper imagery as part of the Multi-Resolution Land Characteristics (MRLC) data set. The data was processed using ERDAS IMAGINE 8.5 software using the "majority" option in *Zonal Attributes*. The 30km vector coverage was intersected with the MRLC raster data; the results of the "majority" analysis resulted in 13 land cover classes: residential, commercial, bare rock, transitional, deciduous forest, evergreen forest, mixed forest, shrub land, grasslands, pasture, row crops, small grains crops, and fallow.

Road density data was calculated from 1998 Tiger line files for each of the states. The road coverages were then intersected with the grid coverage and then the summation function in ArcView was used to calculate the sum of the road length attributes that occurred within each grid cell. Grid cells that intersected with wolf pack locations from 1999 were used to identify and define suitable wolf habitat. Wolf packs locations were the same as used in Houts (1999) and were digitized from Maughan (1999). Grid cells were labeled with a "one" for presence, or a "zero" for absence. The 1999 pack location data was used so that predicted habitat suitability could be compared to current wolf pack locations as delineated by USFWS (2002) for out-of-sample model validation, and to examine the models ability to predict future occupied areas.

A subset of the five state area containing 153 of the 1591 original grid cells was created to generate the logistic regression model (Figure 2). This was done to increase the frequency that suitable wolf habitat was represented (61 of 153 cells labeled as having wolves). Using SPSS software, the land cover and road density variables were tested for normality and significant differences between wolf and non-wolf cells. For the logistic regression, the wolf presence/ absence was entered as the dependent variable, and majority land cover and road density were entered into the model with the land cover variable specified as categorical. The results of the regression produced variable coefficients that were then applied to the subset area and the entire five state data set to produce an indicator of habitat suitability ranging from zero to one, where values greater than 0.5 were considered to be suitable for wolves.

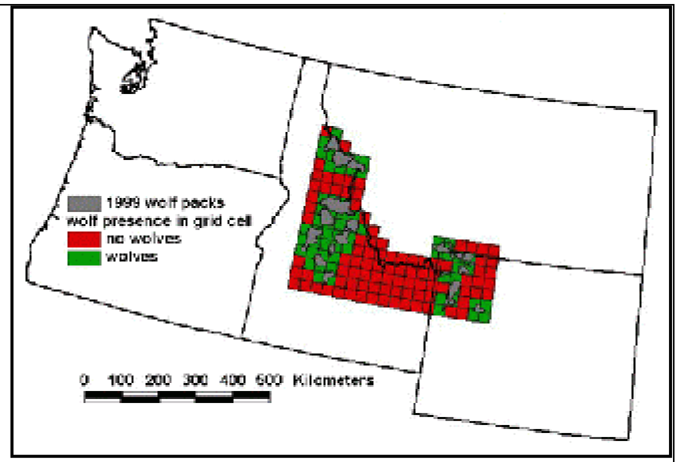


Figure 2. Subset of the study area used to generate the logistic regression model. Shown are the 1999 wolf pack locations, and the 30km by x30 km grid cells used for the analysis.

It was hypothesized that the models ability to predict where wolves may disperse to would be better assessed by building the model using historical wolf locations and testing it against current wolf locations. To do this, the model was first evaluated by creating a confusion matrix from the 1999 wolf pack data to compare observed wolf presence/absence against the predicted suitable/unsuitable habitat. The model was then further scrutinized by comparing its predicted suitable habitat with current wolf pack locations from 2001. By doing this, the accuracy of areas predicted as suitable but absent from wolves in 1999 could be better evaluated. This is important because, since this is a new and expanding population, the absence of wolves from an area does not necessarily indicate unsuitable wolf habitat.

**Results**

The results suggest that wolf habitat can be successfully modeled using road density and land cover when mapped at a resolution nearly equal to the average pack territory size. The regression formula generated using data from the subset and 1999 wolf locations data produced satisfactory results when applied to the larger five state area and tested against wolf locations from 2001.

Analysis of the road density and land cover data showed that there was a difference between wolf and non-wolf coded grid cells. Road density values for grid cells within the subset area showed that the data were normally distributed and an Analysis of Variance test showed that there was a significant difference between cells labeled as wolf (1) and non wolf (0) ($P = 0.001$). Wolf occupied cells had a mean road density of 0.5820 km/sq km., with 79% having a road density less than 0.50 km/sq km, while non-wolf cells had a mean road density of 0.903 km/sq km.(Figure 3). Similarly, analysis of the majority land cover data using a chi square test showed that wolves were more likely to occupy areas dominated by coniferous forest than other cover types (P<0.005) (Table 1).

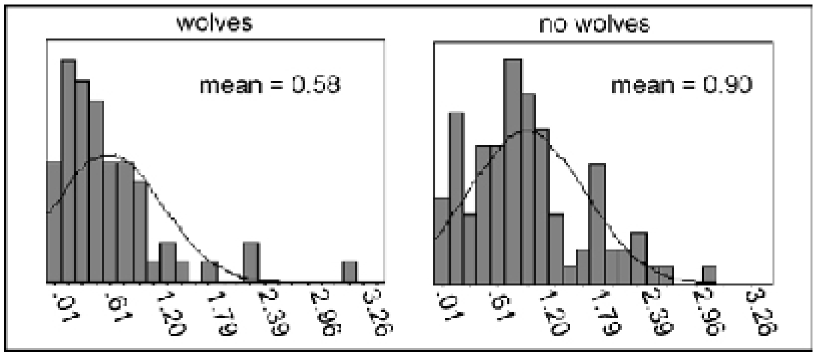


Figure 3. Graph of road density for wolf and non-wolf occupied grid cells.

| Cover | entire subset (n= 153) | wolves (n=61) | no wolves (n=92) |
|---|---|---|---|
| Con. forest | 66% | 90% | 50% |
| Shrub land | 26% | 8% | 38% |
| Grass land | 6% | 2% | 9% |
| Crop land | 2% | - | 3% |

Table 1. Proportion of "majority land cover" values for grid cells within the subset area. Each cover type was then further examined to examine where wolf vs. non-wolf areas were located.

When the logistic regression was performed on the subset data using the 1999 wolf pack territories, the resulting coefficients (forest B = 6.0884, shrub land B = 4.1491, grass land B = 3.9212, agriculture B = -0.8921, road density B = -0.5777 and a constant of -5.5378) were used to generate a model that correctly identified 48 of the 61 (78.7%) known wolf grid cells and had on overall accuracy of 71.9% (Figure4A). To further test the model, predicted suitability was compared to current wolf locations from winter 2001. Results showed that the model was able to correctly identify 52 of the 76 (68.4%) cells known to be occupied by wolves, nd had an overall accuracy of 67.3% (Figure4B).

The model was then applied to the larger five state area to examine the full extent of potentially suitable wolf habitat. The model visually showed a reasonable pattern of predicted suitability across the study area. When the model results were analyzed using known wolf locations form 2001, the model was able to correctly identify 70 of the 121 (57.9%) known wolf grid cells, and had on overall accuracy of 90.7% (Figure 5). Many of the incorrectly predicted unsuitable habitat cells fell just short of the 0.5 probability cut-off. If the cut-off point for predicted suitable habitat were placed at 0.4, the model would have correctly identified 91 out of 121 grid cells (74% vs 58%) which would then include most of the mis-classified wolf cells in northwest Montana.

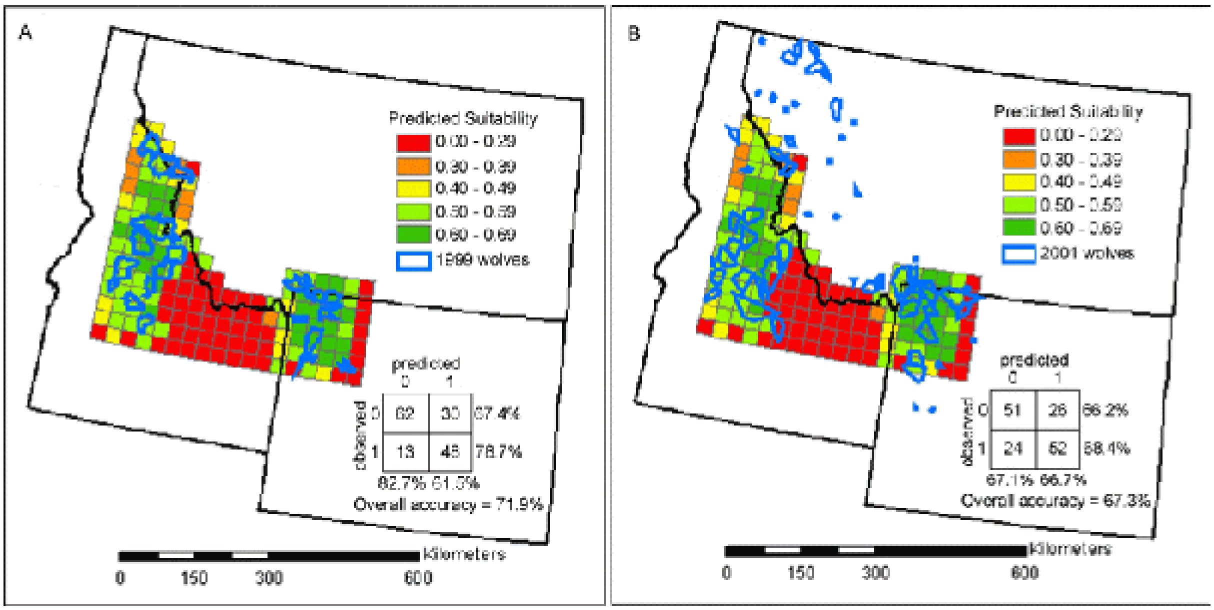


Figure 4. Logistic regression results depicting wolf habitat suitability with values greater than or equal to 0.5 representing suitable habitat. Predictions are compared to known wolf pack locations from 1999 (map A) and 2001 (map B).

**Discussion**

As the wolf population grows, there will probably be a proportional increase in human-wolf conflicts, and since humans are the leading cause of wolf mortality, public support of the wolves is crucial to their recovery. The regions of Idaho, Montana, and Wyoming that wolves currently occupy are a complex mixture of national parks, national forests, public land, and private property. The neighboring states of Washington and Oregon also contain suitable wolf habitat according to this model, and dispersing wolves have already been found in eastern Washington. With the success of the wolf reintroduction, the de-listing of the wolves is eminent in the very near future, and it is important that each state in this region have a clear management plan in place before any actions are taken.

Identifying suitable wolf habitat is an important step in managing wolf populations throughout the region. By identifying areas of suitable habitat, areas of potential conflict can be identified, and population sources/sinks can be considered. To successfully manage wildlife populations in this complex mosaic of land uses, there will probably need to be an equally complex management strategy. The creation of management zones allows for different management strategies to be created for different areas depending on the priority use of that area (Carbyn, L.N. et al. 1995 p534). The creation of management zones may be a key strategy to maintain a balance between wildlife conservation and human land use practices. Hopefully, the results of this research can help wildlife managers gain a better idea of where wolves may disperse to as populations increase in the future, and assist with the creation of management zones and pro-active planning.

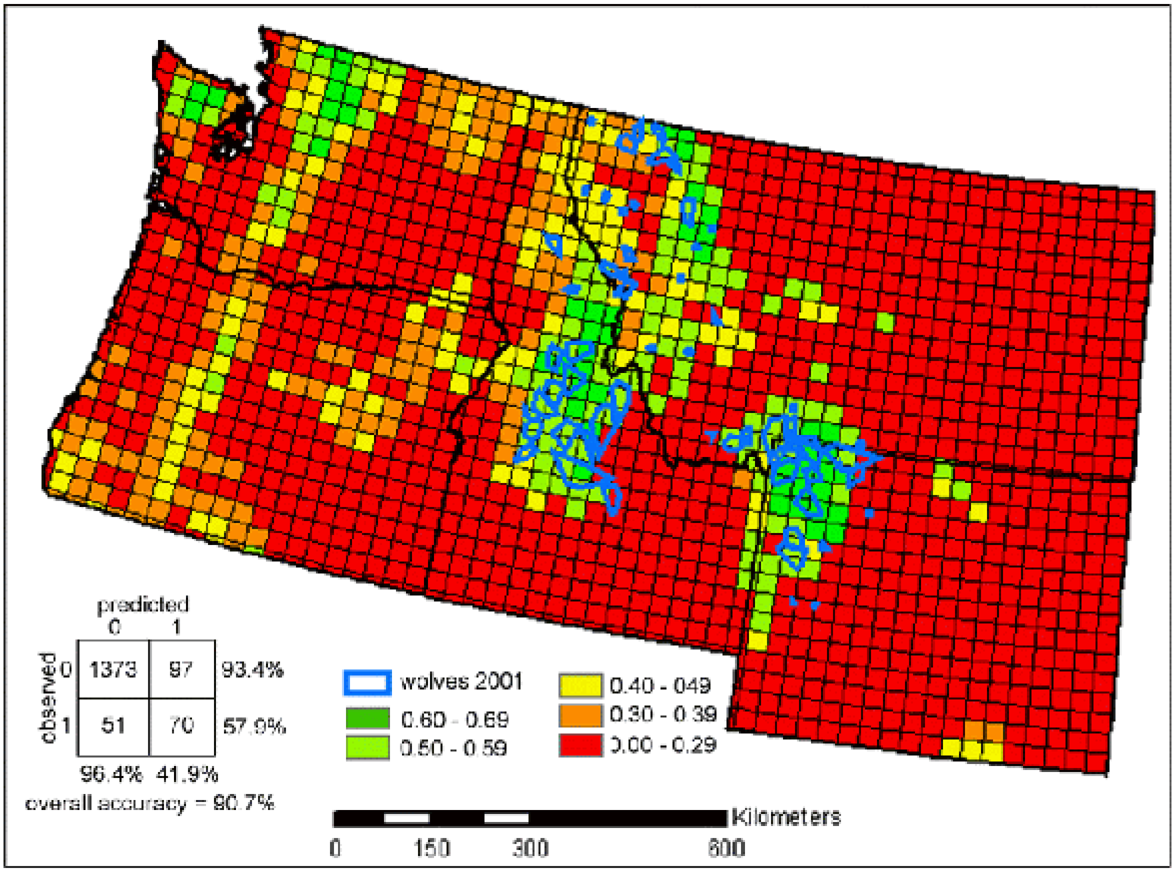


Figure 5. Logistic regression results depicting wolf habitat suitability with values greater than 0.5 representing suitable wolf habitat. Predictions are compared to known wolf pack territories from 2001. Visual analysis shows a reasonable pattern of prediction and good agreement with known wolf locations.

## Literature Cited

Fritts, S.H., E.E. Bangs, J.A. Fontaine, W.G. Brewster, J.F. Gore. 1995. Restoring the Wolf to the Northern Rocky Mountains of the United States. Pages 107-125 in L.N. Carbyn, S.H. Fritts, D.R. Seip. Eds. *Ecology and Conservation of Wolves in a Changing World*. Canadian Circumpolar Institute. Occasional Publication Number 35, University of Alberta, Edmonton.

Fuller, T. K. 1989. Population Dynamics of Wolves in North-Centeral Minnesota. *Wildlife Monographs*. 105:1-41.

Houts, Michael E. 1999. Masters Thesis, University of Kansas.

Marston, R.A., J.E. Anderson. 1991. Watersheds and Vegetation of the Greater Yellowstone Ecosystem. *Conservation Biology*.5(3):338-346.

Mech, L. D., S.H. Fritts, G.L. Radde, W.J. Paul. 1988. Wolf Distribution and Road Density in Minnesota. *Wildlife Society Bulletin* 16(1)

Mladenoff, D.J., T.A. Sickley, R.G. Haight, A.P. Wydeven. 1995. A regional Landscape Analysis and Prediction of Favorable Gray Wolf Habitat in the Northern Great Lakes Region. *Conservation Biology*. 9(2):279-294.

Mladenoff, D.J., R.G. Haight, T.A. Sickley, and A.P. Wydeven. 1997. Causes and Implications of Species Restoration in Altered Ecosystems: A Spatial Landscape Projection of Wolf Population Recovery. *Bioscience*. 47:21-31.

Thurber, J. M., R.O. Peterson, T.R. Drummer, S.A. Thomasma. 1994. Gray Wolf Response to Refuge Boundaries and Roads in Alaska. *Wildlife Society Bulletin*. 22:61-68.

U.S. Fish and Wildlife Service 2002. *Rocky Mountain Wolf Recovery 2001 Annual Report.*

U.S. Fish and Wildlife Service 2003. *Rocky Mountain Wolf Recovery 2002 Annual Report.*