DEVELOPMENT AND EVALUATION OF MOVEMENT CORRIDORS USED BY ROCKY MOUNTAIN ELK WITHIN THE VICINITY OF LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NEW MEXICO

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DEVELOPMENT OF ROCKY MOUNTAIN ELK MOVEMENT CORRIDORS

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Abstract

This research was undertaken to develop, through a spatial modeling process, major seasonal Rocky Mountain elk movement paths to determine how elk move on and off Los Alamos National Laboratory (LANL) lands. These paths were developed for three time periods, late 1990s, the early 2000s and 5-10 years in the future (using two different future scenarios). The development of these paths was conducted to address two specific questions; 1) Have predicted seasonal movement paths changed between time periods? 2) What are the likely factors contributing to the detected change? The methodology used in this research integrated a habitat suitability model, developed through logistic regression with a least-cost path modeling process to predict seasonal elk movements. Movement source locations were located on LANL lands and movement destinations areas were located on lands adjacent to LANL. Results of this study indicated that movement paths did change between time periods. Generally, the 1990s showed a lower travel cost for most paths predicted. However, there were some general trends in movement paths across all the time periods. The analysis of change indicated that the

majority of the differences in paths seen were directly related to the habitat suitability model. However, barrier features such as buildings, structures, and security fencing also had an impact on how paths were generated. The development of new high impedance barrier features has the potential to obstruct movements on and off laboratory lands if unmanaged.

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I want to thank the Ecology Group of Los Alamos National Laboratory for their support of this thesis, providing data resources and funding. I especially would like to acknowledge Dr. Yi-Hwa Wu for all of her encouragement and efforts assisting me through the thesis process. In addition, I am extremely grateful for the support of my husband and close friends that provided moral support, technical editing, and provided assistance with the final thesis formatting.

LIST OF ABBREVIATIONS

BNM	Bandelier National Monument
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
ETM	Enhanced Thematic Mapper
GIS	Geographic Information System
GPS	Global Positioning System
HS	Habitat Suitability
LANL	Los Alamos National Laboratory
LSCV	Least Squares Cross Validation
NMDGF	New Mexico Department of Game and Fish
NWI	National Wetland Inventory
TM	Thematic Mapper
UD	Utilization Distribution
VCNP	Valles Caldera National Preserve

CHAPTER 1

INTRODUCTION

It is estimated that over 1800 elk inhabit the Pajarito Plateau, primarily on Bandelier National Monument (BNM) and Los Alamos National Laboratory (LANL, a Department of Energy facility) lands in north-central New Mexico. White (1981) investigated movement patterns and population characteristics of elk inhabiting the Pajarito Plateau and portions of the east Jemez Mountains during the time of 1978 to 1980. Since that time, few studies have looked at movement patterns and corridors of elk.

Over the last five years numerous changes have occurred on the Pajarito Plateau that have the potential to influence how elk move across the landscape. Some of the changes include a catastrophic wildfire (Cerro Grande fire, 2000), regional drought, bark beetle infestation of pinon-juniper woodland, and new development and land management practices (tree clearing and tree thinning) at LANL. Recently, concerns were raised by neighboring natural resource trustee, San Ildefonso Pueblo, that LANL operations have resulted in creating barriers or altered "normal" elk movement paths in such a way that elk are no longer moving onto adjacent Native American lands (Hansen 2005). Elk are an important resource to the neighboring Pueblo. Native Americans of San Ildefonso Pueblo utilize elk as a food source and in other traditional ways. This research will try to address the concern expressed by San Ildefonso Pueblo.

In addition to the concerns raised by San Ildefonso Pueblo, prior to the last five years adverse elk-human interactions (traffic accidents, nuisance animals, and habitat destruction) appeared to be on the increase but have leveled off in the last few years. The change in these interactions may be the result of a regional drought condition causing elk to stay at higher elevations. However, as regional weather patterns change back toward normal precipitation, elk may utilize more of the lower elevation areas. When this occurs, increased elk-human interactions are likely. With this in mind, predicting how elk are moving within LANL and how LANL operations affect these movements may be a useful tool for minimizing adverse interactions.

1.0 Research Background

The scientific name for Rocky Mountain elk is *Cervus elaphus nelsoni*. They are native to north-central New Mexico, including the study area of this research. Elk are one of the largest ungulates of the deer family with height at the shoulders around 4 to 5 feet and an average weight between 600 to 700 pounds. However, large bulls (males) can weigh as much as 1200 pounds (New Mexico Department of Game and Fish 2004). Elk can be identified by their reddish-brown coloring and their distinguishing pale patch on their rump and buttock. The head, neck, and legs are usually darker than the rest of their body. Females (cows) are more evenly colored than males. Bulls may show a larger amount of contrasting color on the neck and have a dense mane and antlers whereas cows do not (Figure 1).

Figure 1. Photographs taken near the Valles Caldera National Preserve, showing a small herd of Rocky Mountain elk. The photograph shows both bulls (with antlers) and cows (without antlers). Photographs courtesy of Phill Noll of LANL.

Elk favor mixed habitat types and are frequently found in forest mountain meadows and grasslands, but they are also found in pinon-juniper woodlands and sagebrush communities. Elk rely on their habitat to provide food, water, space, and cover. Grass is the preferred food for elk but elk will also consume forbs and browse on woody vegetation. Elk use the habitat differently during different times of the year based on a variety of factors including forage material availability, forage quality, and cover characteristics (New Mexico Department of Game and Fish 2004). Changes in habitat use are commonly seen during different seasons. For elk, there are five distinct seasons

(Biggs *et al*. 1999): winter (November-February), spring (March-April), calving (May-June), summer (July-August), and fall (September-October).

Within each season, elk tend to forage for food, water, and take cover in defined areas. These areas are typically referred to as home ranges. Biggs *et al*. (1999) found that the home ranges for elk in the Jemez Mountains area were the largest in the fall (5736 ha) and the smallest in the spring (2270 ha). The remainder of the seasons had very similar sized home ranges.

Rocky Mountain elk, even though native to north-central New Mexico, were extirpated from the area in 1909 (Findley *et al*. 1975). The extirpation occurred because of the enormous amount of hunting pressure the elk population experienced. After the Civil War, many ranchers, miners, rail workers and soldiers occupied New Mexico and extensive elk hunting was conducted to feed these individuals (New Mexico Department of Game and Fish 1999). A series of re-introductions of elk occurred from 1911 to the mid 1960's (Allen 1995; New Mexico Department of Game and Fish 1999; and White 1981). After the mid 1960's, the elk population became established and their numbers in the Jemez Mountains and in the area around LANL began to grow at an extremely fast rate (Allen 1995). A major wildfire, La Mesa, consumed over 6,000 hectares of forest and transformed the area into graze lands in 1977. This change in habitat was favorable for elk and the wintering elk population on BNM increased from less than 100 to near 300 animals within a little over one year (Allen 1995). Elk population continued to increase and estimates of the wintering elk population on BNM and LANL rose to between 1,000 to 2,000 elk by 1989 (Allen 1995). Prior to the 1990s elk typically migrated west of BNM and LANL to the Valle Grande Baca Ranch, at the time a privately owned ranch but now federally owned (Valles Caldera National Preserve, VCNP), where they would have their calves and spend the majority of the summer. However, Biggs *et al*. (1999) showed that a large number of elk inhabit BNM, LANL, and surrounding lands on a year-round basis. The number on LANL was estimated to be as high as 200 animals (Fresquez *et al*. 1998). At the same time, Allen (1995) estimated that the elk wintering population on BNM was 1500 animals with an annual population growth of 21.3% representing a 3.6-year doubling time. Currently, data are not available to determine if this rate of increase is still being experienced within the population. In addition, very little information is available as to the number of elk wintering or resident on adjacent San Ildefonso Pueblo lands.

Rocky Mountain elk that occur in New Mexico are considered property and resource of the State, and the New Mexico Department of Game and Fish (NMDGF) is responsible for their management. NMDGF defines the hunting season and the numbers of takes allowed for each year as well as issuing hunting licenses (licensing for hunting on public lands is conducted through a lottery system). Elk hunting is allowed on private, public and tribal lands, but not all public lands allow hunting. BNM as part of the National Park system does not allow hunting within their boundaries nor does LANL. Even though NMDGF manages elk within New Mexico, they do not manage elk that are within the boundaries of Native American lands and Pueblos. Each Pueblo or Reservation develops their own game management plan and sets their own policies, hunts, and licensing process. NMDGF has no jurisdiction on tribal lands (New Mexico Department of Game and Fish 1999). Hunting season is generally from late September to November on both NMDGF managed areas and tribal lands. However, tribal lands may also have additional hunts or takes allowed at other times of the year to support ceremonies or other traditional aspects of their culture.

2.0 Study Area

LANL is located in north-central New Mexico on the Pajarito Plateau, approximately 120 km (80 mi) north of Albuquerque and 40 km (25 mi) west of Santa Fe (Figure. 2). The Laboratory is bounded to the east by the Pueblo of San Ildefonso, U.S. Forest Service property to the west and north, and BNM to the south. The Plateau is an apron of volcanic rock stretching 33 to 40 km (20 to 25 mi) in a north-south direction and 8 to 16 km (5 to 10 mi) from east to west. The average elevation of the Plateau is 2286 m (7500 ft). It slopes gradually eastward from the edge of the Jemez Mountains, a complex pile of volcanic rock situated along the northwest margin of the Rio Grande rift. From an elevation of approximately 1890 meters (6200 ft) at White Rock, N.M., the Plateau scarp drops to 1646 meters (5400ft) at the Rio Grande. Intermittent streams flowing southeastward have dissected the Plateau into a number of finger-like narrow mesas separated by deep, narrow canyons.

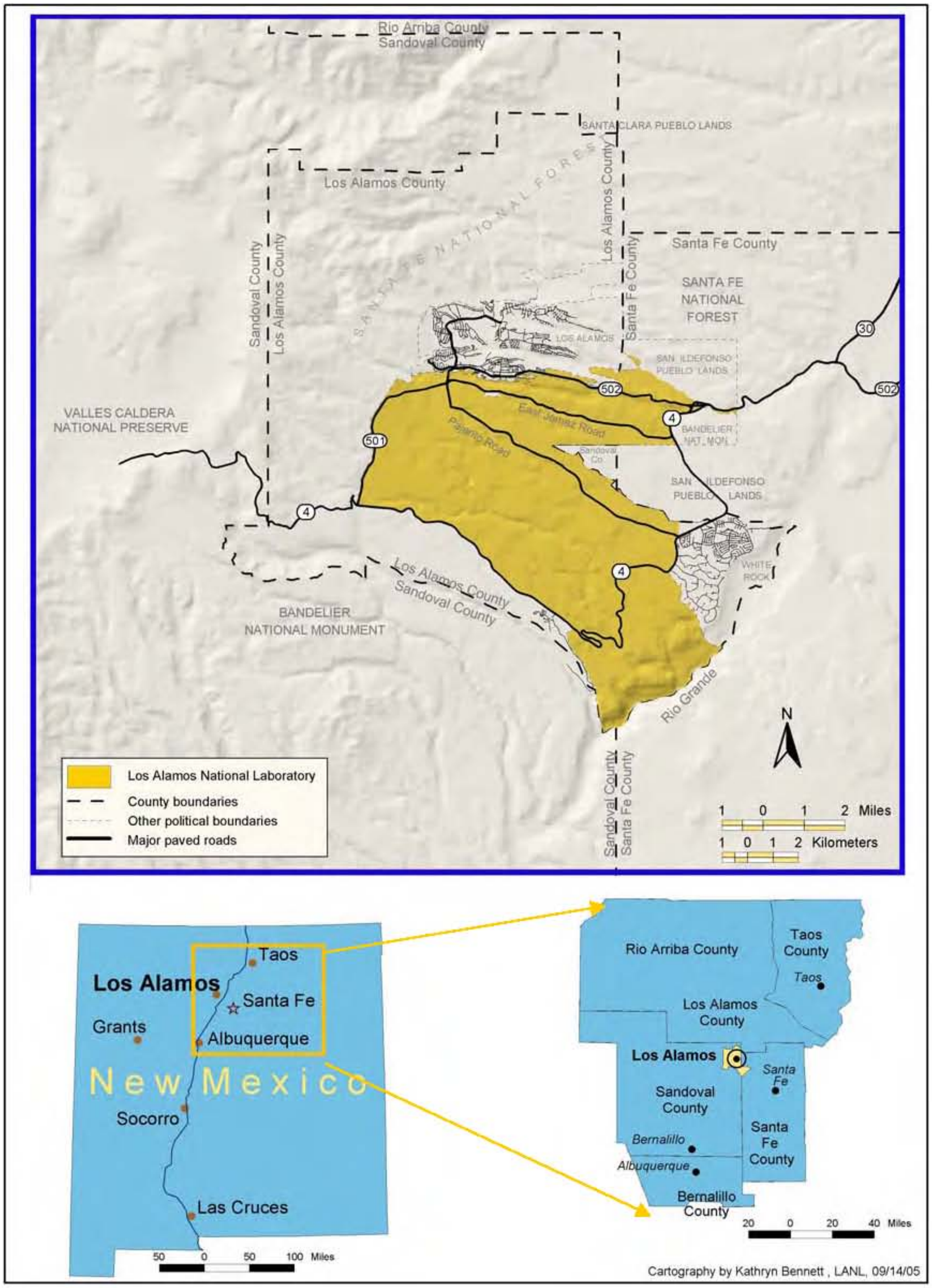


Figure 2. Study area.

There is a large diversity of ecosystems because of the elevational gradient from the Jemez Mountains down to the Rio Grande. Studies conducted by Foxx and Tierney (1984) show that six general plant communities are found on LANL and surrounding areas. The predominant vegetation types within the LANL boundary are ponderosa pine and pinon pine-one seed juniper (Foxx and Tierney 1984). Even though most of the streams are intermittent, permanent water flow from springs and LANL facilities has resulted in a number of permanent or near-permanent water sources and wetlands. Recent LANL operations have focused on reducing LANL discharges that may be seen on the landscape in the reduction of water sources and wetlands.

Wildfire has changed the landscape of the Pajarito Plateau on numerous occasions. Since 1977, there have been three major wildfires on the Plateau: La Mesa fire, the Dome fire, and the most recent and largest the Cerro Grande fire that occurred in 2000. Recovery of these severely burned areas has resulted and will continue to result in changes on the landscape through successional processes.

3.0 Research Objective

The objective of this research was to develop, through a spatial modeling process, major seasonal Rocky Mountain elk movement paths to determine how elk move on and off LANL lands. These paths were developed for three time periods, late 1990s, the early 2000s and 5-10 years in the future. The development of these paths was conducted to address two specific questions: 1) Have predicted seasonal movement paths changed between time periods? 2) What are the likely factors contributing to the detected change?

To address these questions, a research methodology was designed that integrated habitat suitability modeling through logistic regression with least-cost path modeling and the development of a barrier model to predict elk movement.

4.0 Research Framework

This research utilized a habitat suitability model along with a barrier model to construct a cost surface that estimates the cost of impedance to elk as they move across the landscape. Figure 3 illustrates the general research framework. The habitat suitability model defined how elk used resources within the study area by analyzing elk telemetry data to access habitat use within the animal's home ranges and comparing that to availability of resources defined by random points. A predictive habitat suitability equation was developed through a logistic regression.

The barrier model was developed to model features that act as a physical barrier to elk movement. These barriers impede movement completely or partially and included features like buildings/structures, fences (security and industrial), roads, steep slopes, and major water features. These features were weighted based on the amount of impedance they impose on movement.

The habitat suitability model and barrier model were combined to produce a cost surface. The cost surface represented a relative cost per cell to elk movement, with low cost cells facilitating movement and high cost cells impeding movement.

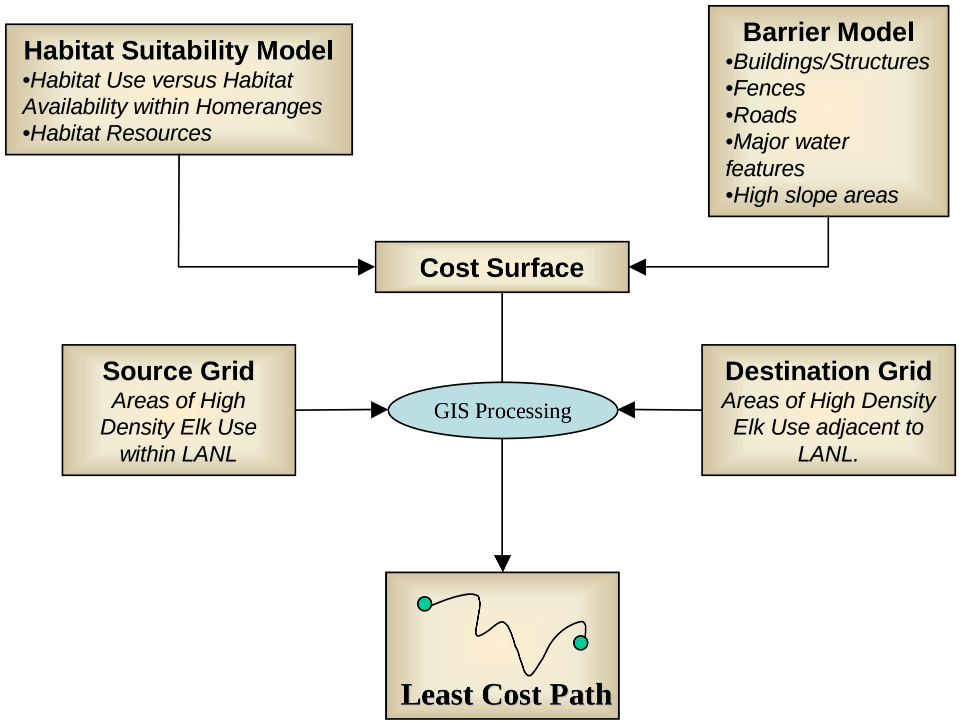


Figure 3. Research framework.

Actual elk movement paths or corridors were developed using seasonal cost surfaces and defining source and destinations areas. Source and destinations were defined by evaluating elk location point density information. The results of the modeling process were compared for each time period to evaluate change. Change evaluation was conducted for the final predicated movement pathways as well as for the habitat suitability models and barrier models.

This research is limited to the study area surrounding LANL. The relationships and model parameters may not be valid in other geographic areas. The results of this work have applications for resource management and LANL facility planning and may not be directly applicable for other purposes.

CHAPTER 2

LITERATURE REVIEW

Wildlife managers have sought to understand the factors that influence the selection of habitat for a species as well as the impact human activities have on the habitat and the movement paths a species uses to access different habitat patches. With the use of GIS, the development of spatially explicit models are possible that can combine both habitat resource components in a habitat suitability model and human activity barriers to construct least-cost path models that predict the path of least resistance for animal movement. In addition, statistical methodologies have been applied to habitat suitability models that provide a quantitative approach. The following literature review focuses on the use of least-cost path models in natural resource and wildlife studies and the development of habitat suitability models. This literature provided the basis for the development of the methodology utilized for this research.

1.0 Least-cost Path Model

Least-cost path modeling has become a familiar tool in addressing routing and movement pathways issues. Common examples can be found in the transportation and utility industries where least-cost path modeling is used to find the potential routes for a new road or transmission line (Gilbrook 1998 and Glasgow 2004). In addition, least-cost path modeling has also become a popular technique field of ecology (Adriaensen *et al*. 2003; Walker and Craighead 1997; and Halpin and Bunn 2000). Halpin and Bunn (2000) used least-cost path modeling to assess connectivity of landscape patches in terrestrial and marine environments. This approach not only includes information about where patches are located and the proximity of patches, but also the environment found in between the patches. In landscape ecology, least-cost path modeling allows both the structural connectivity (characteristics of the landscape) and the functional connectivity (mobility of an organism) to be considered when evaluating landscape fragmentation and connectivity (Adriaensen *et al*. 2003).

The heart of the least-cost path process is the development of a cost surface. The cost surface contains a measure of the facilitating or hindering effects of movement (ESRI 2004). How the cost surface is constructed and resistance values assigned is the most important step in the process (Adriaensen *et al*. 2003). In many ecological cases, the assignment of resistance values is based on expert opinion and information available in previous research (Walker and Craighead 1997; and Schadt *et al*. 2002). Other researchers use field data to provide an estimate for resistance values. For example, Ferreras (2001) on the Iberian lynx assigned resistance values by inversely relating them to habitat suitability that was derived from collared animals. Most wildlife applications of least-cost path models use some methods to assign habitat suitability/preference while very little research has focused on integrating a habitat suitability model (constructed within a statistical framework) into the least-cost path modeling process.

2.0. Habitat Suitability Models

The aim of a habitat suitability model is to model the habitat preference of a species. Garshelis (2000) defines preference as the likelihood that a habitat resource will be chosen for use by the animal when offered at an equal basis with other resources. This definition implies that a habitat suitability model contains some evaluation of habitat use and availability. He also reviewed habitat suitability studies published in the literature over a ten-year time span and found that 58% of that literature used some type of use-availability design. Biggs *et al*. (1999) looked at use and availability of habitat by Rocky Mountain elk using pooled telemetry data from collared animals. They used a very common methodology of comparing the frequency of used resources to the availability of the resource using Chi-square analysis. This study stopped short of actually constructing a habitat suitability model from the use-availability analysis. Huber (1992) also looked at relative landcover use by elk but evaluated the data by individual animal as well as pooled data. Both of these studies evaluated use-availability within animal home ranges.

In northeastern Oregon, the Starkey Project developed a GIS-based habitat suitability model using an index approach. The index score ranged from 0 (not suitable) to 1 (highly suitable) and the scoring was based on information published in the literature. The project utilized relocation data from collared elk to provide a means for model verification and refinement (Rowland *et al*. 1998 and Benkobi *et al*. 2004). Data from the Starkey project was also used to evaluate daily and seasonal resource use patterns by elk. Researchers allocated resources based on relocation data and analyzed the data using regression (Ager *et al*. 2003).

Studies conducted on grizzly bear habitat in western Montana went one step further and developed a habitat suitability model using a logistic regression on seasonal telemetry data. Relocation data was pooled and used to model resource use and an equal number of random locations were generated within the study area to model the resource availability component (Mace *et al*. 1999). The logistic model equation was then applied within a GIS.

Similar methods were used on Eld's deer in a forest in Southeast Asia. Instead of using telemetry data, sighting data was used and all available habitats were examined. Resources within 1-km^2 blocks where Eld's deer were sighted were compared to resources present in 1-km^2 blocks where no Eld's deer were found. The model was validated by utilizing data collected in Cambodia in a suitable forest where a large game survey was conducted and Eld's deer were detected during the survey (McShea *et al*. 2005). This model was also applied within a GIS.

Another example of a GIS-based habitat model was developed for mountain goats using logistic regression. This research was similar to the Eld's deer study. The researchers used sighting data and compared areas of "presence" to areas of "absence" to evaluate use and availability of resources (Gross *et al*. 2002).

The type of data collected and the methodology used for collection drives how researchers use logistic regression modeling in developing habitat suitability models. Manly *et al*. (2002) describes different study design methodologies used in habitat preference studies and then demonstrates through examples and theory how statistical modeling procedures could be applied to different design types. Design I types are those studies similar to the mountain goat (Gross *et al*. 2002) and the Eld's deer (McShea *et al*. 2005) research where "presence" is compared to "absence". Design II types are typically based on animal capture and relocation data like the study on grizzly bears in Montana (Mace *et al*. 1999).

Erickson *et al*. (2001) discussed the use of a Design II methodology with logistic regression when inference to the population is needed. Even though researchers pool relocation data, for example the grizzly bear study conducted by Mace at al. (1999), Erickson et al. (2001) discussed the statistical assumptions that are violated when data are pooled and inference is then made to the population. Using pooled data across all animals in logistic regression results in pseudo replication and violates the assumption of independence. Instead, the authors recommend allocating resource use and availability within home ranges of individual elk, applying the logistic regression and then averaging the coefficients across the set of sampled animals. However, the authors admit that sample size is a critical factor when attempting to apply logistic regression across a set of animals and sometimes pooling data is the only alternative when sample size is small.

The research reviewed focused on the use of least-cost path modeling in ecological studies and emphasized the importance in the development of the cost surface component. In wildlife studies, cost surfaces usually incorporated some assessment of habitat use or preference. Habitat use is frequently analyzed in the development of habitat suitability models but little research was found that actually integrated the development of a statistical-based habitat suitability model into the least-cost path process. However, many examples were found in the literature on the development of habitat suitability models utilizing different methodologies. Research conducted by Manly et al. (2002) and Erickson et al. (2001) provided important insight into a valid statistical methodology that could be applied to this research.

This research builds on the current literature by integrating a logistic regression based habitat suitability model with the least-cost path process to predict movement pathways of elk. The integration process developed in this research is applicable to other wildlife studies especially ones utilizing relocation data from tracked animals. In addition, this research may provide important information to local researchers that are managing elk populations in the Jemez Mountains area of New Mexico.

CHAPTER 3

METHODOLOGY

1.0. Description of Data

Most of the data used in this research were managed and maintained by LANL, US Geological Survey, or VCNP and were provided or projected into New Mexico State Plane Coordinated System, Central Zone with units in feet in the North America Datum of 1983. All raster layers created had a common grid cell size of 30 by 30 meters and a spatial extent equivalent to the LANL 1990s landcover map.

Relocation data of elk captured were available for the time period of 1996 – 2003. Data were maintained and managed by LANL. The data consisted of over 75,000 elk relocations from sixty-three animals and the dataset contained relocation coordinates, with date, time, and animal identification numbers. Of the sixty-three animals represented in the dataset, only twelve were from the 1990s time period. In addition, relocation data were not available for all animals for each season. Approximately 22 animals from the 2000s were within the study area extent.

A Digital Elevation Model (DEM) of the extent of the study area was used for elevation and to develop aspect and slope rasters. A 10-meter DEM from the US Geological Survey was used.

LANL infrastructure and water source data for the 1990s and 2000s were used in this research. This included shapefiles of:

- paved roads and dirt roads
- buildings and above ground structures
- security fences and standard industrial fences (4 to 5 strand barb-wire fence)
- wetlands, springs, and drainages

Paved roads not represented in the LANL infrastructure data were obtained from the County of Los Alamos, and VCNP. In addition, dirt road data in the form of shapefiles occurring on VCNP were acquired from data collected in 1981 from the Valles Caldera Trust. Roads occurring on Santa Fe National Forest were obtained from Santa Fe National Forest.

The data published in 1990 from the US Fish and Wildlife Service's National Wetland Inventory (NWI) was used to determine water sources from non-LANL or Los Alamos County areas. This dataset contains attribute information about the wetland type and was used to evaluate potential water sources. In addition, water source information in terms of springs and livestock watering tanks that occur on the VCNP was obtained from the Valles Caldera Trust in the form of shapefiles.

Automobile accident locations involving Rocky Mountain elk in Los Alamos County were used in this research. The dataset contained information from 1990 through 2002. The dataset contained a shapefile of accident locations and attribute information of accident details. This information was obtained from Los Alamos County Police Department and NMGF but compiled and managed by LANL.

Two different landcover maps were used for this research - one for each time period. A 15-meter landcover raster of LANL and surrounding area was produced in 2002 using a Landsat ETM+ satellite scene obtained in June 2001. This landcover map was used to represent the early 2000 landcover. The second landcover map with a resolution of 30 meters was developed in 1997 by LANL from a Landsat TM image (September, 1992 date). The resolution of the map was 30 m. This landcover information was used to represent the late 1990 landcover.

This research utilized information available in the LANL Site Development Plan and the Biological Resource Management Plan to create layers of proposed future development. Two layers were developed from this information that represent a minimum development strategy (projects that are expected to be developed) and a maximum development strategy based on zones that have been allocated for future LANL growth. Future development information utilized in this research safeguarded any security or data sensitivities issues.

2.0. General Methodology

Movement paths were developed for three time periods (late 1990s, early 2000s, and 5-10 years into the future) within the study area of the Pajarito Plateau (Figure 2). These movement paths were developed for each season (winter, spring, calving, summer, and fall). Elk often use the habitat differently at different times of the year (Biggs *et al*. 1999) as their needs for food and cover change. The movement paths were compared over the time periods to see if changes had occurred and to evaluate the possible reasons that might have influenced change. The construction of these pathways utilized least-cost path modeling, available in ArcGIS 9.0 (ESRI 2004), where the movement across the landscape is predicted by finding the travel route with the lowest cost or impedance to travel. The least-cost path modeling process involves the assignment of source grids, destination grids, and a cost surface. Next, the CostDistance function was used to generate an accumulation grid (least accumulative cost distance to the nearest source) and a backlink grid (direction along the least accumulative cost path). Figure 4 shows the framework of the least-cost path model.

There were two major components used to create the cost surface: habitat suitability (HS) model, and a barrier raster. The HS model defines how elk are using resources within the study area by looking at resources used by individual elk within their home ranges and comparing that to the availability of resources from randomly generated points in the home range areas and then applying a logistic regression. Results from individual logistic regressions were averaged (where there was sufficient sample) to create a mathematical model that predicted how the population of elk within the study area used the habitat. Figure 5 shows the HS model process.

The second component of the cost surface was the development of a barrier grid. The barrier grid was comprised of features that act as a physical barrier to elk movement either by totally preventing movement or greatly increasing the amount of energy

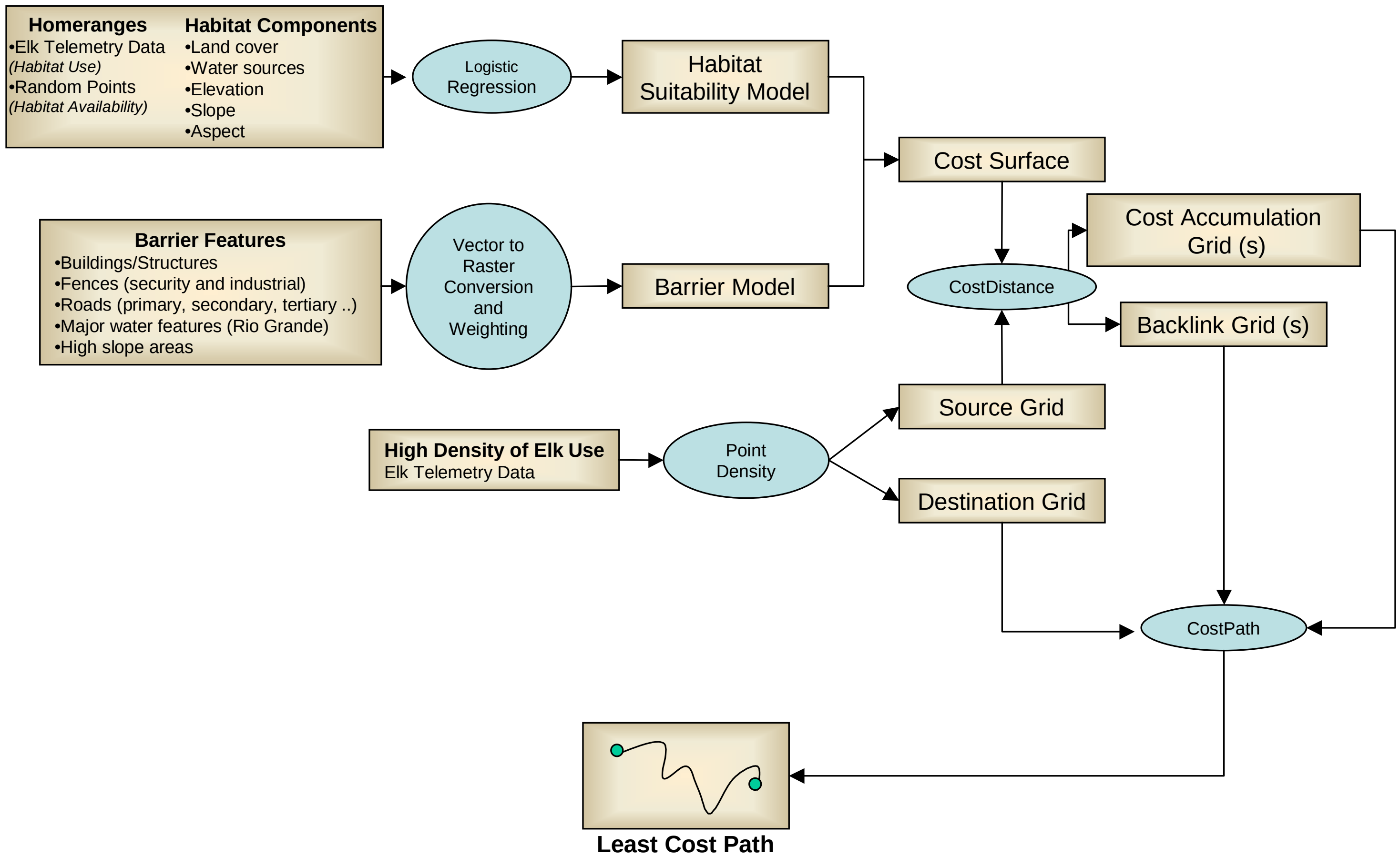


Figure 4. Framework of the least-cost path model.

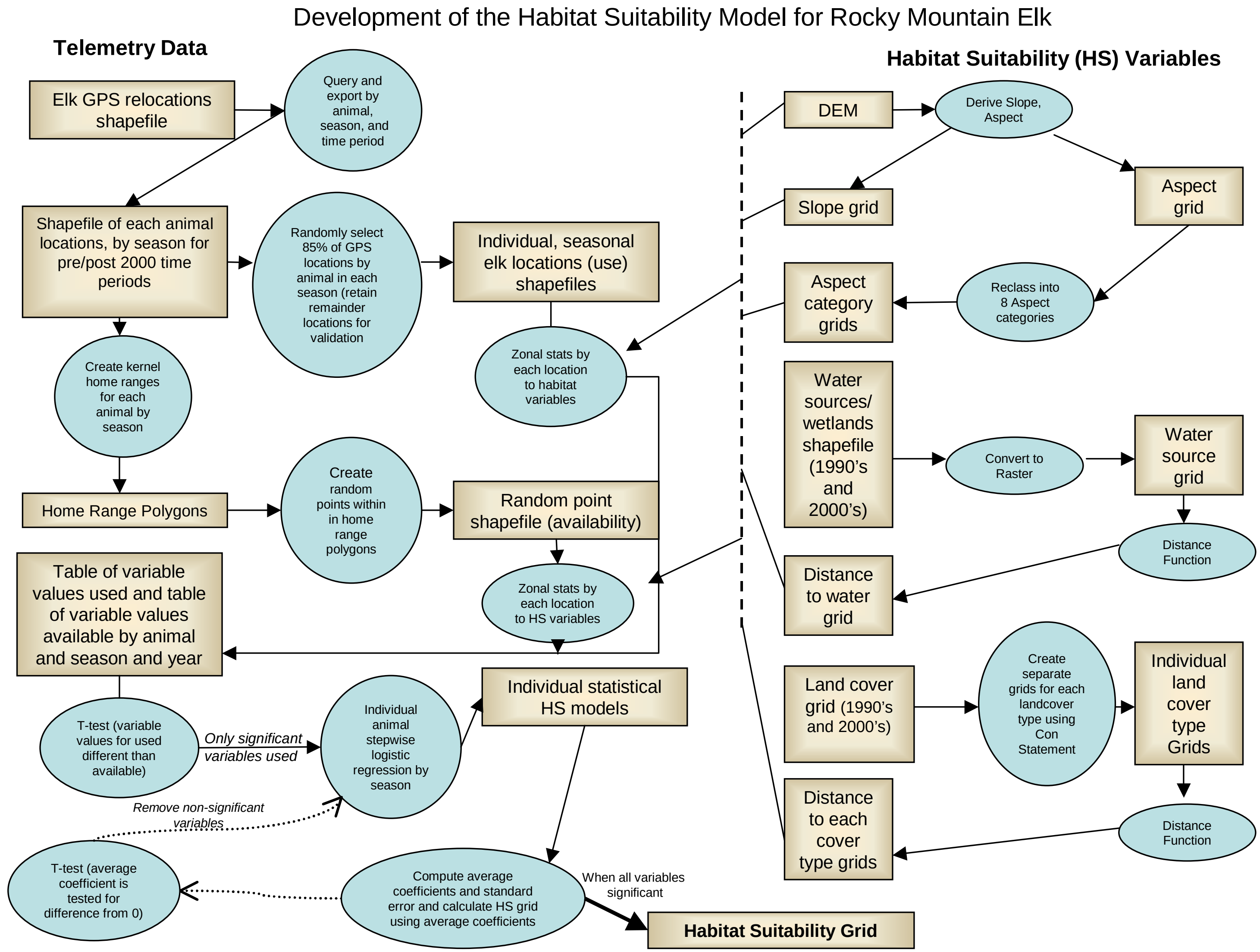


Figure 5. The development of Habitat Suitability Model for Rocky Mountain elk.

required by elk to cross the barrier. Barrier features included buildings, structures, fences, roads, extreme slope, and major water bodies.

The final step involved in creating the least-cost path was the execution of the CostPath function (ESRI 2004). This function created a single pixel wide path (the cost path) associated with the path of least travel cost.

3.0. Constructing the Seasonal least-cost Path

The least-cost path modeling process involved the assignment of source grids, destination grids, and a cost surface. The process utilitized ArcGIS CostDistance function to generate an accumulation grid and a backlink grid based on the input of a source grid and a cost surface (ESRI 2004).

3.1. Source Grids

The source grid represents the starting points of the pathways or corridors. The source grids were constructed by developing a point density surface of elk locations and creating polygons at the densest areas (defined as the upper 25% of the generated density values). Three source areas were constructed for each season. The number of source areas were chosen because the visual inspection of the raw data prior to analysis indicated that the seasonal data typically exhibited around three natural clustering areas. Although a larger number of source areas would identify additional pathways, working with three source areas would focus the analysis on major pathways. Typically, three distinct source areas were identified when selecting the upper 25% of the density values. However, some seasons (fall and calving) had less than three sources identified using this method. In these cases, overlapping homeranges and elk relocation data were further evaluated to determine if additional source areas were needed that would represent important areas of potential movement that had not been adequately represented. Areas of homerange overlap that showed the presence of elk relocation points were then added by on-screen digitizing. This study concentrated on source areas within LANL lands.

3.2. Cost Surface

The cost surface was developed to model the cost or impedance of travel by elk across the study area. The cost surface had two major components, the HS model and the barrier surface.

3.3. HS Model

The HS model is a probability model that gives the probability or likelihood of an elk utilizing an area. The habitat suitability model was constructed by following the general methodology described by Erickson *et al*. (2001). The model was constructed initially based on evaluating habitat components within individual animal home ranges and initially constructing suitability models at the individual animal level and then averaging all the animals' models to make an inference about the elk population. This method was successfully implemented for the time period of the early 2000s but was not implemented fully for the late 1990s data because of sample size and within-animal and among-animal variability. This issue will be discussed in further detail later on in the methodology. The construction of the model required the following inputs: individual elk relocations, home-range polygons (seasonally based), randomly generated points within home ranges, and habitat components layers.

3.3.1. Elk Radio Telemetry and Relocation Data

From 1996 – 2003, the elk trapped on LANL, BNM, and US Forest Service lands were fitted with a Global Positioning System (GPS) collar and then released. The collars collected relocation data on the elks' movement based on a variety of relocation schedules programmed into the collars. Programming of the collars was not the same across the dataset. Some collars collected locations several times a day while others collected locations only once per day. Data collected from the collar included at a minimum (data dependent on make and model of the collar) collar identification number (animal identification), date, time, error code, longitude, and latitude for each relocation. All data collected were entered into an Microsoft Access database and coordinate information was used to create a ESRI shapefile in the projection of New Mexico State Plane, Central Zone.

The elk relocation data were the foundation for building the habitat suitability model. They were used to determine how elk are using habitat components on the Pajarito Plateau. Individual animal datafiles and shapefiles based on a query of animal identification number, season, and time period (late 1990s or early 2000s) were created. In order to minimize the dependent nature of relocation data (Erickson *et al*. 2001), the assumption was made that relocations from the same animal were independent if they were separated in time for more than 23-24 hours. Therefore, all relocations from the same elk that were not at least 23-24 hours apart were removed from the analysis. The 23-24 hour assumption was used because the 1990s relocation data were only collected once every 23 hours but the 2000s data were collected six to eight times a day for each animal. The home range seasonal polygons were constructed using this subset of data for each animal.

Initially, fifty percent of the points used to create the subset of data described above and used to create home range polygons (discussed below), were randomly selected to represent habitat use locations of an individual elk. However, this percent was increased to 85 percent to increase sample size in an attempt to provide sufficient data for model creation. Sample size became a limiting factor for the 1990 time period. The same numbers of random points were generated within the individual home ranges to represent the habitat availability. These locations were used to assign values of the habitat components.

3.3.2. Home Range Polygons

Individual animal home range polygons were developed by calculating a fixed kernel home range utilization distribution (UD) based on the relocation data. UD is the relative frequency distribution of animal relocations over a set time period (Seaman and Powell 1996). The kernel–based home range method created a 3-D "hill" representing a kernel probability density (Worton 1987). Initially, these home ranges were developed as a probability surface but converted to polygon shapefiles by specifying a probability level of UD (Worton 1987). ESRI ArcView 3.3 with the Animal Movement Extension

(Hooge and Eichenlaub 1997) was used to develop the home ranges. A fixed kernel with a least squares cross validation (LSCV) option was chosen. LSCV gives the lowest mean integrated square error for the density estimate and is recommended (Seaman and Powell 1996). Several different probabilities levels were evaluated to determine which level would produce a home range estimate that would include sufficient geographical extent to adequately represent the areas that an animal used but also contain habitat components that are available for selection. If the home range was defined too restrictively then available resources were not adequately evaluated. Garshelis (2000) discusses the difficulty in defining the geographical extent that defines the actual resources that are available to individual animals. A 95% and a 99% UD were created. The 99% UD produced improved home range polygons in which to evaluate use versus availability. This study also evaluated the use of a minimum convex polygon method to create home ranges. The method creates the minimum polygon that encompasses the relocation data. However, the 99% UD proved to provide better and more realistic results and was used to estimate all homeranges and bound the assignment of availability.

3.3.3. Habitat Components

There are four basic components to elk habitat: cover, space, food, and water (Skovlin 1982). Three of the four components (cover, food, and space) can be estimated by landcover types. Landcover maps developed in 1997 and 2001 at LANL were used to represent these components for the two time periods. The landcover maps were developed from Landsat Thematic Mapper images and show the major vegetation type of the area. No cover information is explicitly given in the classification. The landcover map from the 1990s has the lowest resolution (30-meter by 30-meter) and was used to set the resolution of the entire model. For the habitat suitability model, individual rasters representing a single landcover type, such as ponderosa pine, were created for the two time periods from the two landcover maps. The objective was to create raster layers of cover types to be used in the development of distance grids so elk proximity to individual cover types could be determined. Elk are frequently found in transitional zones or on the edges between covertypes. Knowing proximity to a landcover type provides more information than just what landcover type a relocation falls within. Once individual rasters were created, the ArcGIS EucDistance function was used to construct covertype distance grids, and zonal statistics were performed on the elk use and availability points to determine the proximity to each covertype. Each individual elk use and availability point was assigned a unique identifier. The unique identifier was used to establish the zones used in zonal statistics. Therefore, each point represented a single zone. When zonal statistics were performed a new table was generated that contained the zone unique identifier and descriptive statistics such as the mean, maximum, and minimum distance values. Because only one point represented a zone, the mean, maximum, and minimum values were all the same. The summary zonal statistics tables were joined back to the original elk use and availability tables using the unique zone identifier as the join field. New fields were created in the original elk use and availability tables to store the distance values calculated from zonal statistics. The calculation function was then utilized to calculate the distance value from the zonal table back into the original table. The maximum distance field in the zonal table was used to perform the calculation. However, mean or minimum could have also been used because all values were equal (n = 1).

The forth component of elk habitat is water. The water covertype contained within the landcover maps underestimates the available water within the study area. Therefore, water source information available from springs, wetlands, livestock water tanks, and stream shapefiles were used to represent the water sources. These features were converted from their vector format to raster and the EucDistance function used to create distance to water sources. The elk usage and availability points were assigned a proximity to water using the same procedures as described with the landcover types. Water availability was assumed to be constant throughout all time periods because water flow and water storage data were not available to determine actual availability from time period to time period.

There are other important habitat components not specifically addressed in the four components discussed by Skovlin (1982). These components are topographical and include elevation, aspect, and slope. Researchers have found that these variables influence elk habitat by influencing thermal stress, local climate (precipitation and snow depth), vegetation types, and energetics of the animal (Ager *et al*. 2003 and Biggs *et al*. 1999). This study used a 10-meter resolution U.S. Geological Survey DEM to represent the elevation of the area and to calculate slope and aspect. Because aspects are circular and not linear, aspect was reclassed into 9 classes of north, northeast, east, southeast, south, southwest, west, northwest, and flat. Proximity to the aspect classes was also determined as previously described for landcover and water. Elevation and slope were determined for each usage and availability point using zonal statistics.

3.3.4. t-test and Logistic Regression

The logistic regression was used to create the individual animal HS models (by season and time period) and the final HS model. The habitat components selected for use in the HS Model were selected based on information in the literature. However, it is possible that elk within the study area used habitat in a slightly different manner so that the mean usage of a variable is not statistically different than the mean availability. In this case, the variable would not be a good predictor for habitat suitability and should be removed prior to input into the logistic regression (Erickson *et al*. 2001). Therefore, *t*-tests, available in SAS statistical software version 8 (SAS 2000), were used to compare usage and availability of each coefficient. Non-significant coefficients were removed from further inclusion into the model.

A backward elimination stepwise logistic regression was used (SAS 2000) with the remaining coefficients to produce the individual animal HS models. The backward elimination stepwise logistic regression starts out utilizing all coefficients in the model then in a stepwise fashion removes coefficients that are above the probability criterion until all coefficients are significant (SAS 1995). A logistic regression results in an equation that defines the probability (p_i) of use as equation (1) (Manly et al. 2002):

$$p_i = \frac{\exp(\alpha + \beta_1 x_{i1} + \beta_2 x_{i2} + ... + \beta_k x_{ik})}{1 + \exp(\alpha + \beta_1 x_{i1} + \beta_2 x_{i2} + ... + \beta_k x_{ik})} \quad (1)$$

where α and β_1 to β_k are constants that are estimated from the use and available data, x_i to x_k are the model variables, and exp is the exponential function equivalent to e^x.

The final seasonal model developed for the 2000 time period was based on the average of the coefficient as equation (2):

$$\beta_{-j} = \sum_{i=1}^{n} \beta_{ij} \div n \qquad (2)$$

where $ß_{ij}$ is the logistic regression coefficient for the $_i$th animal for the $_j$th variable and n is the number of animals. The standard error of the estimate was calculated by equation (3) (Erickson *et al*. 2001):

$$se(\beta_{-j}) = \sqrt{\sum_{i-1}^{n} (\beta_{ij} - \beta_j)^2 / (n-1) / n} \qquad (3)$$

After all logistic regressions were run for each animal for each season and time period, then a *t*-test was used to determine if each average coefficient is statistically different than zero. Non-significant coefficients were removed and the model was refit (by re-running each individual animal logistic regression with coefficient(s) removed) until each average coefficient was statistically different than zero. These significant variables resulted in developing the final model that was based on the average coefficient.

However, the 1990 dataset had sufficient variability between animals and within animals' relocations that no variables remained after conducting the *t*-test. All coefficients were deemed not statistically different than zero. The sample size for most seasons was just six animals and relocations for each animal was typically around 30. Therefore, in order to develop seasonal models for this time period all of the 1990 data for each season was pooled and logistic regression was performed on pooled data. This resulted in the development of a single model for each season instead of an average model for each season that was produced for the 2000 data.

The HS model raster had values that ranged from 0 to 1, reflecting the probability or likelihood of an elk using an area. In order to use this model in the least-cost path analysis, the values were altered so that low values referred to low impedance areas (high habitat suitability) and high values referred to high resistance (low habitat suitability). The HS raster was recoded by subtracting the HS value from one and then multiplying the layer by 100.

3.3.5. HS Model Validation

Fifteen percent of the relocation points that were retained from use in the development of the HS model were used in model validation. These relocations were overlaid on the HS model and descriptive statistics used to describe how well the model reflects the habitat at these locations.

3.4. Barrier Raster

Only one barrier raster was created for each time period. It was assumed that barrier features do not change with season. The barrier raster was developed by converting vector layers to raster, applying impedance values and then compositing the rasters to form a single barrier layer. The vectors layers used to represent barrier features (from the late 1990s and early 2000s) were buildings/structures, fences (security and industrial), extreme slope (cliffs), and large water bodies (Rio Grande). Some of these barrier features imposed a total impedance to elk movement such as buildings/structures, security fences, and cliffs (extreme slopes). These features were initially assigned a high impedance value of 100. However, this value was too low and resulted in paths being predicted that went through buildings and security fences. Through trial and error the weighting was re-scaled to 10,000. This extremely high impedance value prevented buildings and security fences from being crossed unless there was no other possible solution.

Large bodies of water impede the movement of elk even though elk are good swimmers. Elk expend more energy crossing these large water bodies. The coding for the Rio Grande was given a moderate impedance of 50 to account for this higher energy cost to elk.

Not all roads have the same or equal impedance to elk movement. Most elk avoid roadways but the avoidance factor is based on the amount of traffic the roadway receives as well as if they have been used traditionally by elk (Walker and Craighead 1997; and Tressler 2003). Research on the Oregon coast range found that elk avoided primary roads at twice the distance of secondary roads (Tressler 2003) but the avoidance was not as much as researchers thought. Therefore, the road shapefiles was assigned an impedance value based on road type and their relative avoidance by elk. Primary roads received an impedance value of 75, for moderately high impedance and secondary roads received a value of 35 for moderately low impedance. These values were altered if along a segment of a primary or secondary road there was information about the historical usage. This information was obtained by evaluating vehicle collision hot spots. Dirt roads were also included into the barrier layer, and were coded values of half of secondary roads.

3.5. Final Cost Surface

The final cost surface was created by combining the HS raster and the barrier raster. The two rasters were combined to retain the highest impedance of the two input rasters.

The integrity of the cost surfaces (cost surface for each season and time period) was evaluated by identifying if there are “cracks” within the surface. Cracks can occur in a cost surface when linear features are converted from vector to raster. In some cases, the linear feature only connects on the diagonal and if it is a barrier, movement can still occur across the features at the diagonal points (Rothley 2005). Using Avenue scripts discussed by Rothley (2005), “cracks” were filled in the barrier layer before the cost surface was created so that linear features were corrected.

3.6. Destination Grid

The destination grid was comprised of areas (cells) that represent where the elk move to. For this study, destination points included locations on neighboring lands where elk density points indicate their usage. Destinations areas were concentrated on Santa Fe National Forest, Bandelier National Monument, and San Ildefonso Pueblo lands because these areas were immediately adjacent to LANL where the impacts of LANL development would have the greatest effect. An attempt was made to have at least one destination located on each of these landowners property. In some cases, one destination overlapped onto the property of two landowners. Therefore, additional destinations were not created unless elk density data indicated more destinations were needed. The destination grids were constructed by developing a point density surface of elk locations and creating polygons at the densest areas (defined as the upper 25% of the generated density values). In addition, overlapping homeranges and elk relocation data were further evaluated to determine if additional source areas were needed that would represent important areas of potential movement that had not been adequately represented. Areas of homerange overlap that showed the presence of elk relocation points were then added by on-screen digitizing. In some cases, destination areas were not constructed for every landowner. In these cases, relocation data did not indicate major movements onto these properties during that season.

3.7. Least-Cost Path

The least-cost paths were generated for each season and time period. Accumulation cost surfaces and a backlink grid were developed for each source of each season and time period. The actual paths were generated using the ArcGIS CostPath function where the destination areas, accumulation, and backlink grids were used as the inputs. The use of the corridor analysis was evaluated. The function provides a surface of travel cost values, allowing the definition of a multi-cell path connecting two areas based on a user-defined maximum allowable travel cost (ESRI 2004). However, after the evaluation it was determined to utilize the single cost paths instead of corridors. The single-wide paths allowed for easier interpretation and comparisons between time periods.

3.8. Future Development

In order to evaluate the possible impacts from future development, this study assumes that development that occurred in the 2000s would remain developed unless the LANL future development plan called for its decommissioning. Therefore, the buildings/structures and fencing layer from the 2000s was used to form the base for future barriers. Additional barriers were added by digitizing from conceptual drawings areas of new projects. In addition, the landcover map was updated to indicate vegetation succession that would be evident within the Cerro Grande burn area 10 years from now (low slope areas [≤15%] of severe burn converted to grasslands and high slope areas [>15%] converted to shrubs). Initially, it was thought that impacts associated with LANL thinning operations and bark beetle infestation could be incorporated into the future model, however, these factors result in a reduction in covertype and not the complete replacement of a covertype. The landcover data available for this study only indicated the type of cover and not the amount. There was no information available about the actual canopy closure or percent cover for the 1990's and 2000's landcover layer. Therefore a comparison of change in percent canopy or cover could not be included in this analysis .

Sensitivity and security issues concerning future development at LANL was addressed by developing two future models, one showing minimal development (development expected to occur) and maximum development where zones were defined where new development at LANL would be confined. The zones of maximum development were given the highest impedance value to represent a worst case scenario.

Two future cost surfaces were generated using the updated barrier layer from the two future development scenarios and the projected landcover. The 2000s logistic model by season was applied to the updated layers and the least-cost path model was re-run using the same source and destination grids.

3.9. Change Detection

To assess change in movement paths, changes in the model coefficients, the HS model, barrier surfaces, and actual least cost paths were evaluated. The evaluation was performed for each season. The model coefficients and equations were compared descriptively between the two time periods (1990s and 2000s [future condition utilizes same equations as 2000s]). To evaluate change in HS, a *t*-test was performed on HS values assigned to approximately 5000 random points overlaid on the 1990s and 2000s HS layers for each season. The *t*-test tested the difference in the mean HS value between time periods. This analysis checks to see if the mean values were different but does not provided any information as to the similarities or difference in spatial distribution. In order to evaluate the difference in the spatial distribution, a difference operation was used to identify locations in the 2000s HS model that had suitability values that were different from the late 1990s HS model. In order for an area to be considered different, there was at least a 10 percent difference detected. This difference operation was also applied to the cost surface, comparing the early 2000s with that that of the late 1990s by season. Changes in barrier information were evaluated by comparing the number of grid cells within each barrier category between the time periods (1990s, 2000s and future scenarios). Changes in barrier directly related to the change in LANL development and operations. The last change detection process evaluated the actual paths or corridors that have been delineated. Descriptive statistics were used to compare the pathways and a visual overlay was used to show differences. Analysis of differences detected in coefficients, HS model, cost surface, and barrier rasters provided some insight to what factor(s) are responsible for the change.

This same process was used to assess differences in the future paths and corridors with the early 2000s and late 1990s paths with one exception. Because there was no data for future relocations, *t*-test evaluation of the HS covariates was not valid. However, change detection in the HS raster and cost surface was appropriate as well as evaluating the predicted paths with descriptive statistics and visual overlays.

CHAPTER 4

RESULTS AND DISCUSSION

1.0. HS Models

1.1. Homeranges

Habitat Suitability (HS) models were developed for each season within the late 1990s and 2000s as well as a projected HS model for 5-10 years in the future. The HS models were developed by evaluating use and availability within a 99% utilization distribution defining homeranges. Homerange estimates were developed for each animal. For comparative purposes, a homerange extent was developed for the 1990s and 2000s showing the spatial extent of pooled homeranges. Figures 6 through 10 show these homerange extents for the 1990s and 2000s by season as well as the number of individual animal homeranges used to create the pooled extent. Sample size (number of animals) was greater in the 2000s for all seasons compared to the 1990s. In general, the 1990s homerange extents were centered within LANL while the 2000s homerange extents were centered further west and north of LANL. These differences in homeranges appeared to be influenced by the animal's tendency to be a LANL resident or a migratory animal. The 1990s data seemed to be taken from mostly resident animals while the 2000s data appeared to be dominated by more migratory animals. Also, homeranges of the 2000s represented a much larger geographical area, which resulted in a larger area for defining resource availability than homeranges represented in the 1990s (Table 1). In fact the pooled homeranges of the 2000s had a total (sum of all five seasons) aerial extent of

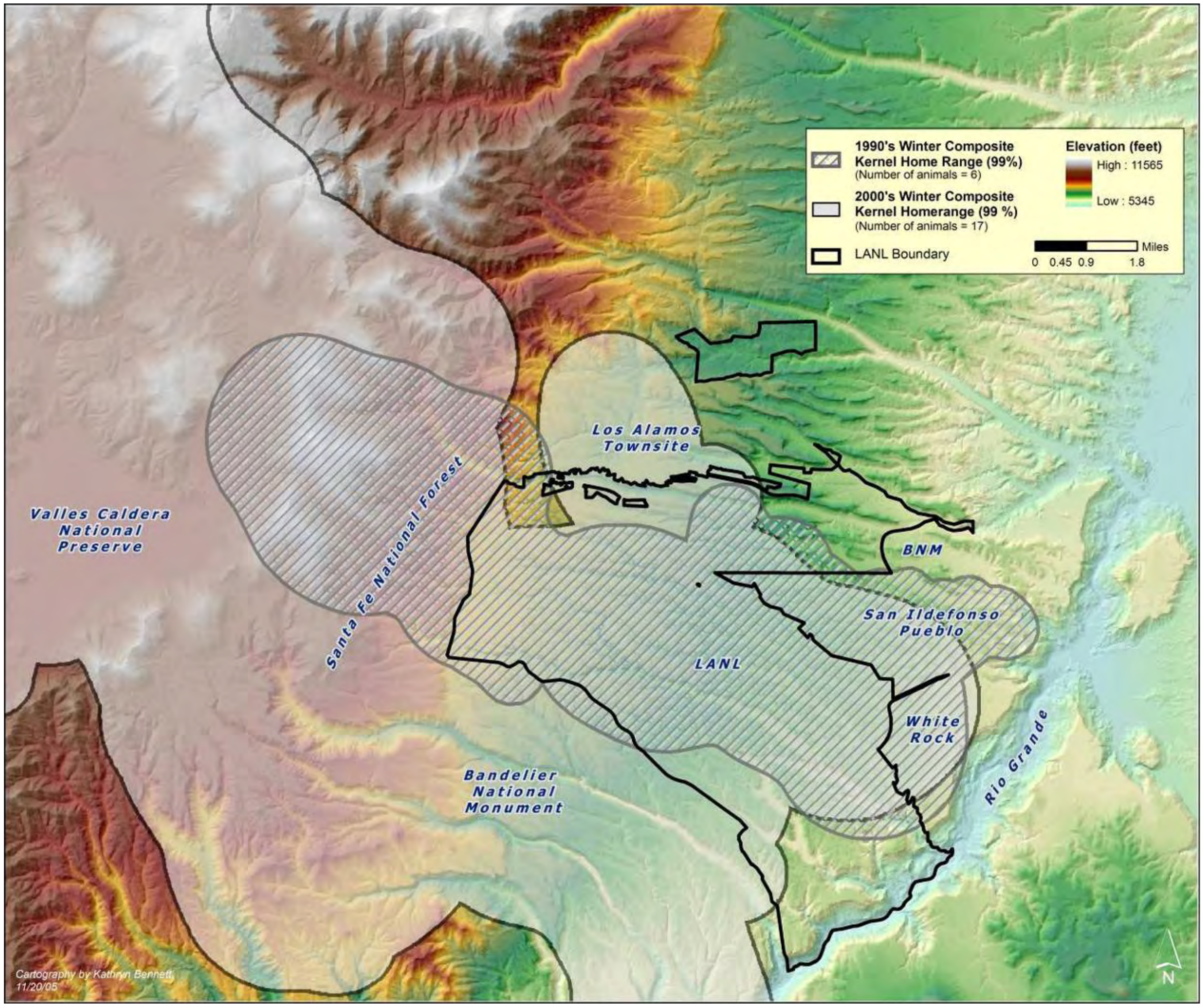


Figure 6. The pooled homerange extents for the winter season during 1990s and 2000s

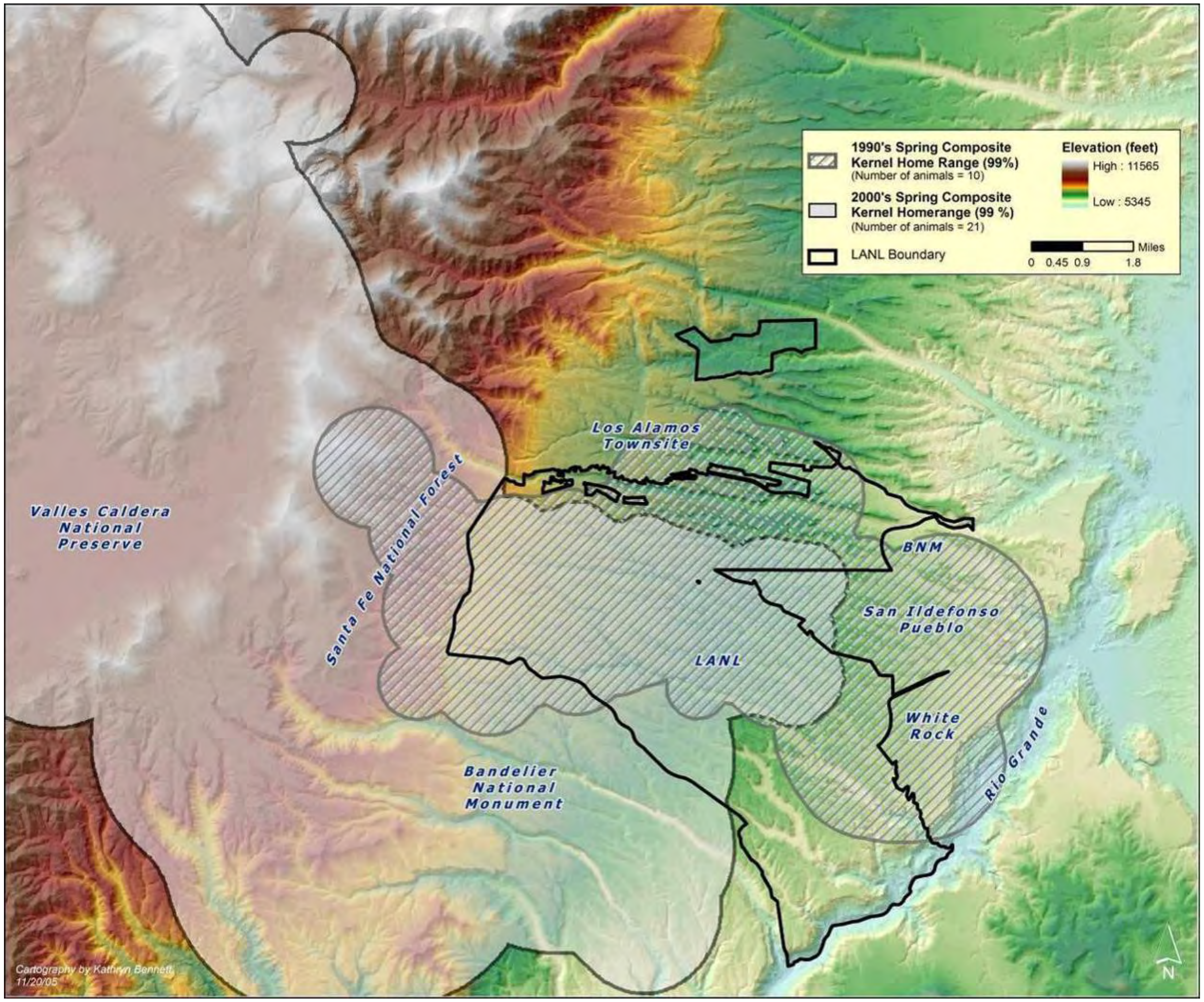


Figure 7. The pooled homerange extents for the spring season during the 1990s and 2000s.

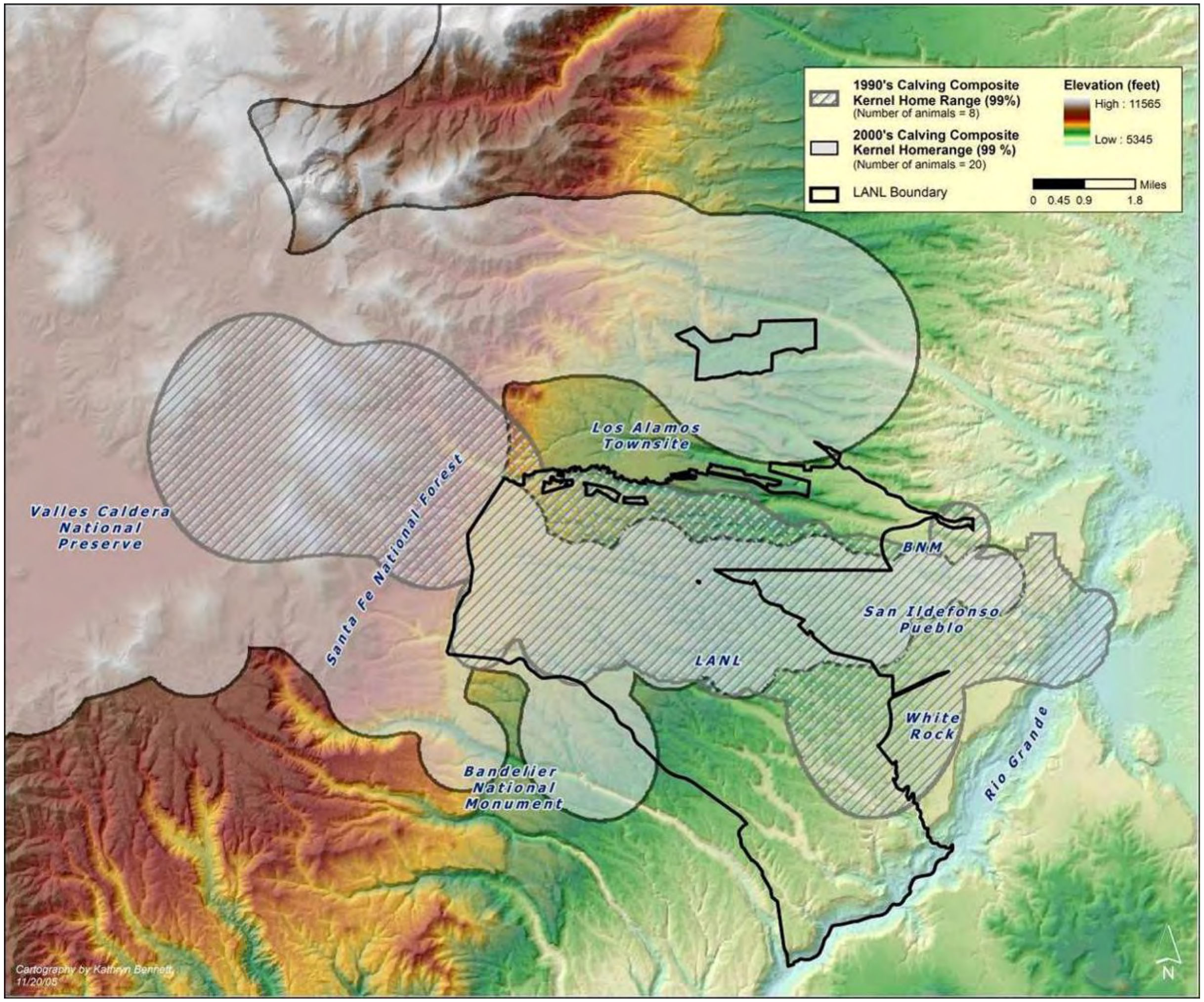


Figure 8. The pooled homerange extents for the calving season during the 1990s and 2000s.

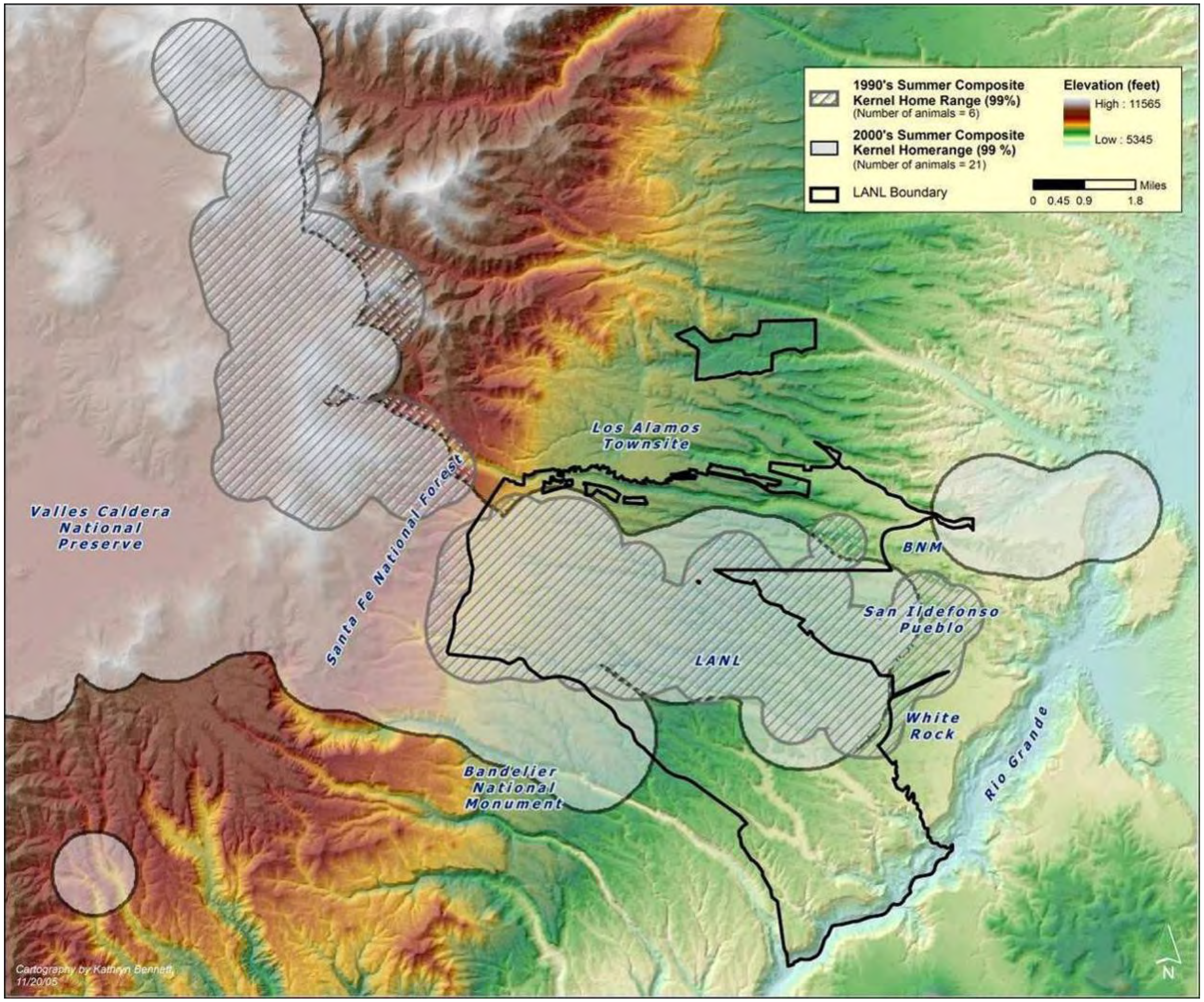


Figure 9. The pooled homerange extents for the summer season during the 1990s and 2000s.

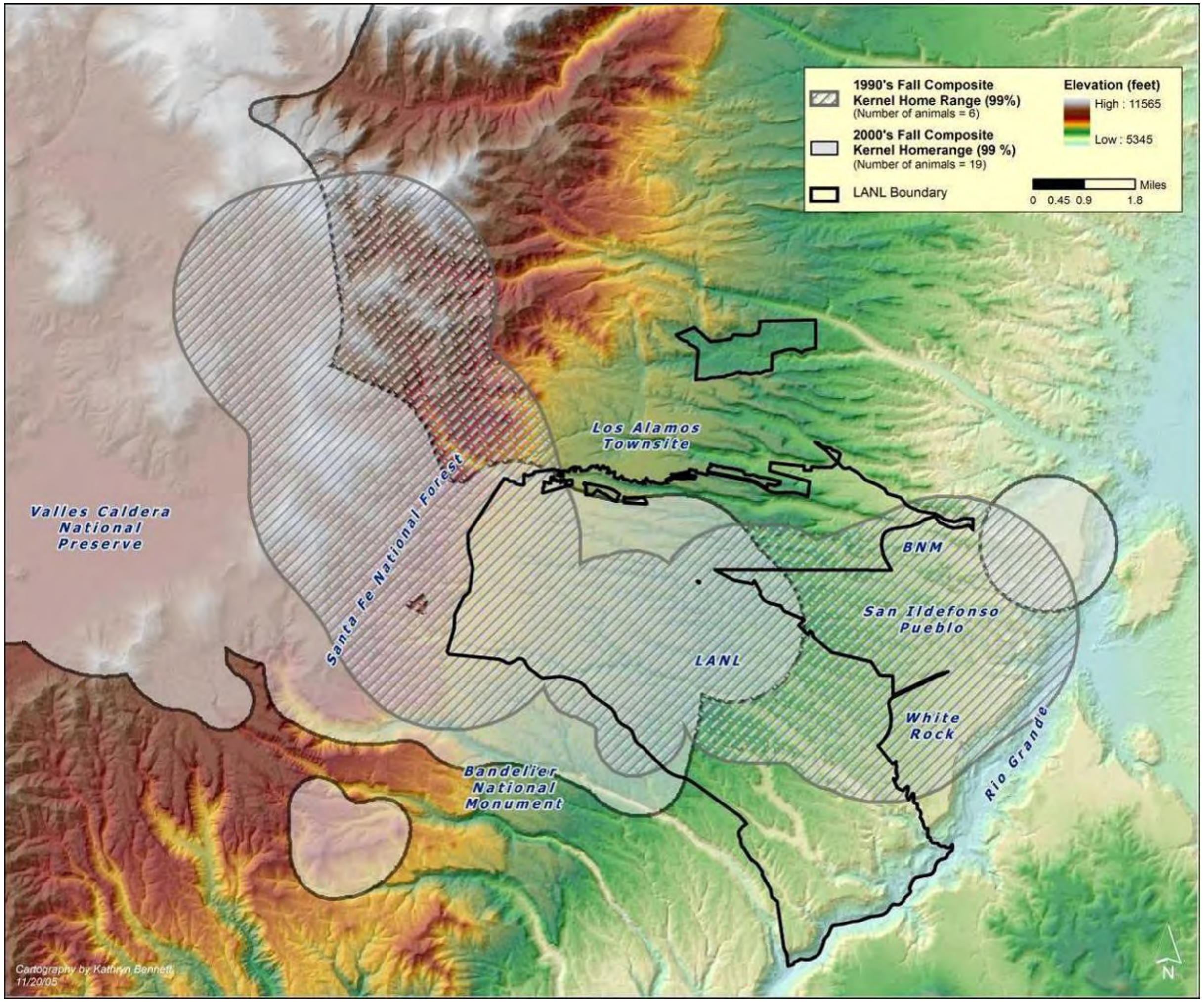


Figure 10. The pooled homerange extents for the fall season during the 1990s and 2000s.

Table 1. Pooled homerange extents area estimates for the 1990s and 2000s.

	Area in Hectares	
Season	**(1990s)**	**(2000s)**
Winter	15450	78013
Spring	15044	66963
Calving	16198	63478
Summer	13723	56096
Fall	21875	48151
Yearly Mean	16458	62540
Yearly Sum	82290	312701

over 300,000 ha compared to only 82,290 ha of the 1990s. In 2000s the winter season had the largest pooled homerange and the fall season had the smallest. However, this trend was not seen in the 1990s data, where fall had the largest extent and summer the smallest.

1.2. *t*-test and Logistic Regression Equations

A *t*-test was used to determine if there was a difference in the seasonal mean value of habitat components between those actually used by elk and those that were available within the seasonal homeranges. These results are shown in Tables 2 through 6 for 1990s and Tables 7 through 11 for the 2000s. Only those variables that were significantly different ($\alpha = 0.05$) were evaluated in the logistic regression. For the 1990s time period, a total of 22 variables were evaluated. Of the 22 variables tested, 20 variables were significant for winter, 19 for spring, 6 for calving, 8 for summer and 13 for fall. There were only 21 initial variables evaluated for the 2000s season. The difference in the number of initial variables between the 1990s and 2000s was due to the slight differences in landcover classification. The 2000s landcover had one less landcover class. The

Table 2. Results of *t*-test comparing use and availability of variables during the winter season in the 1990s time period (grayed shaded variables were significant, α = 0.05).

WINTER		
Variable	***t* Value**	**Probability**
Distance to Unclassified Areas	-1.67	0.0953
Distance to Developed Areas	10.95	< 0.0001
Distance to Grassland	7.25	< 0.0001
Distance to Juniper Woodland	10.39	< 0.0001
Distance to Pinon-Juniper Woodland	12.47	< 0.0001
Distance to Ponderosa Pine	-2.99	0.0028
Distance to Aspen	-6.53	< 0.0001
Distance to Mixed Conifer	-8.83	< 0.0001
Distance to Unvegetated Areas	12.61	< 0.0001
Distance to Landcover Water Features	12.76	< 0.0001
Distance to Additional Water Features (tanks, wetlands, etc.)	0.62	0.5330
Elevation	11.57	< 0.0001
Slope (degrees)	-2.93	0.0034
Distance to Flat areas	8.05	< 0.0001
Distance to North Facing Slopes	4.90	< 0.0001
Distance to Northeast Facing Slopes	4.13	< 0.0001
Distance to East Facing Slopes	3.00	0.0028
Distance to Southeast Facing Slopes	3.23	0.0013
Distance to South Facing Slopes	2.74	0.0062
Distance to Southwest Facing Slopes	4.28	< 0.0001
Distance to West Facing Slopes	5.00	< 0.0001
Distance to Northwest Facing Slopes	2.84	0.0046

Table 3. Results of *t*-test comparing use and availability of variables during the spring season in the 1990s time period (grayed shaded variables were significant, α = 0.05).

SPRING		
Variable	***t* Value**	**Probability**
Distance to Unclassified Areas	-4.01	< 0.0001
Distance to Developed Areas	11.77	< 0.0001
Distance to Grassland	10.41	< 0.0001
Distance to Juniper Woodland	8.80	< 0.0001
Distance to Pinon-Juniper Woodland	7.54	< 0.0001
Distance to Ponderosa Pine	3.04	0.0024
Distance to Aspen	3.58	0.0004
Distance to Mixed Conifer	0.71	0.4788
Distance to Unvegetated Areas	-14.20	< 0.0001
Distance to Landcover Water Features	-0.26	0.7917
Distance to Additional Water Features (tanks, wetlands, etc.)	6.96	< 0.0001
Elevation	2.40	0.0166
Slope (degrees)	1.37	0.1709
Distance to flat areas	4.31	< 0.0001
Distance to North Facing Slopes	-2.03	0.0423
Distance to Northeast Facing Slopes	-2.83	0.0047
Distance to East Facing Slopes	1.65	0.0997
Distance to Southeast Facing Slopes	4.28	< 0.0001
Distance to South Facing Slopes	3.46	0.0006
Distance to Southwest Facing Slopes	3.74	0.0002
Distance to West Facing Slopes	5.05	< 0.0001
Distance to Northwest Facing Slopes	3.20	0.0014

Table 4. Results of *t*-test comparing use and availability of variables during the calving season in the 1990s time period (grayed shaded variables were significnat, α = 0.05).

CALVING		
Variable	***t* Value**	**Probability**
Distance to Unclassified Areas	1.19	0.2358
Distance to Developed Areas	-1.54	0.1237
Distance to Grassland	2.25	0.0249
Distance to Juniper Woodland	0.55	0.5831
Distance to Pinon-Juniper Woodland	2.09	0.0365
Distance to Ponderosa Pine	2.71	0.0069
Distance to Aspen	0.79	0.4280
Distance to Mixed Conifer	-0.89	0.3716
Distance to Unvegetated Areas	1.86	0.0629
Distance to Landcover Water Features	-0.96	0.3356
Distance to Additional Water Features (tanks, wetlands, etc.)	-0.46	0.6464
Elevation	-0.83	0.4041
Slope (degrees)	-0.01	0.9940
Distance to F-lat areas	1.20	0.2318
Distance to North Facing Slopes	-0.14	0.8883
Distance to Northeast Facing Slopes	-1.49	0.1354
Distance to East Facing Slopes	-2.19	0.0287
Distance to Southeast Facing Slopes	1.11	0.2659
Distance to South Facing Slopes	-3.70	0.0002
Distance to Southwest Facing Slopes	0.26	0.7952
Distance to West Facing Slopes	-2.49	0.0131
Distance to Northwest Facing Slopes	-1.24	0.2169

Table 5. Results of *t*-test comparing use and availability of variables during the summer season in the 1990s time period (grayed shaded variables were significant, α = 0.05).

SUMMER		
Variable	***t* Value**	**Probability**
Distance to Unclassified Areas	0.59	0.5532
Distance to Developed Areas	1.37	0.1715
Distance to Grassland	3.43	0.0007
Distance to Juniper Woodland	0.98	0.3292
Distance to Pinon-Juniper Woodland	3.55	0.0004
Distance to Ponderosa Pine	-2.93	0.0341
Distance to Aspen	-3.09	0.0021
Distance to Mixed Conifer	-4.10	< 0.0001
Distance to Unvegetated Areas	-4.16	< 0.0001
Distance to Landcover Water Features	3.76	0.0002
Distance to Additional Water Features (tanks, wetlands, etc.)	1.10	0.2707
Elevation	2.41	0.0165
Slope (degrees)	1.45	0.1481
Distance to Flat areas	-0.57	0.5697
Distance to North Facing Slopes	-0.31	0.7593
Distance to Northeast Facing Slopes	-0.20	0.8384
Distance to East Facing Slopes	0.55	0.5812
Distance to Southeast Facing Slopes	0.83	0.4086
Distance to South Facing Slopes	1.59	0.1117
Distance to Southwest Facing Slopes	0.81	0.4191
Distance to West Facing Slopes	1.54	0.1248
Distance to Northwest Facing Slopes	-0.51	0.6138

Table 6. Results of *t*-test comparing use and availability of variables during the fall season in the 1990s time period (grayed shaded variables were significant, α = 0.05).

FALL		
Variable	***t* Value**	**Probability**
Distance to Unclassified Areas	-4.16	<0.0001
Distance to Developed Areas	4.62	< 0.0001
Distance to Grassland	3.89	< 0.0001
Distance to Juniper Woodland	1.60	0.1103
Distance to Pinon-Juniper Woodland	3.88	< 0.0001
Distance to Ponderosa Pine	2.67	0.0079
Distance to Aspen	2.77	0.0060
Distance to Mixed Conifer	1.27	0.2060
Distance to Unvegetated Areas	3.95	< 0.0001
Distance to Landcover Water Features	2.05	0.0410
Distance to Additional Water Features (tanks, wetlands, etc.)	1.14	0.2556
Elevation	0.65	0.5150
Slope (degrees)	2.04	0.0426
Distance to Flat areas	-1.28	0.2008
Distance to North Facing Slopes	0.2	0.8403
Distance to Northeast Facing Slopes	1.62	0.1073
Distance to East Facing Slopes	1.90	0.0581
Distance to Southeast Facing Slopes	2.05	0.0411
Distance to South Facing Slopes	-0.15	0.8831
Distance to Southwest Facing Slopes	-2.85	0.0048
Distance to West Facing Slopes	-3.51	0.0005
Distance to Northwest Facing Slopes	-4.06	< 0.0001

Table 7. Results of *t*-test comparing use and availability of variables during the winter season in the 2000s time period (grayed shaded variables were significant, α = 0.05).

WINTER		
Variable	**t Value**	**Probability**
Distance to Cerro Grande Fire High Burn Severity Areas	3.09	0.002
Distance to Developed Areas	-6.01	<.0001
Distance to Grassland	17.44	<.0001
Distance to Shrub species	-5.36	<.0001
Distance to Pinon-Juniper Woodland	0.57	0.57
Distance to Ponderosa Pine	-13.82	<.0001
Distance to Aspen	-17.04	<.0001
Distance to Mixed Conifer	-17.75	<.0001
Distance to Landcover Water Features	-0.71	0.477
Distance to Additional Water Features (tanks, wetlands, etc.)	8.22	<.0001
Elevation	1.8	0.0713
Slope (degrees)	15.56	<.0001
Distance to Flat areas	2.89	0.0039
Distance to North Facing Slopes	-6.04	<.0001
Distance to Northeast Facing Slopes	0.05	0.958
Distance to East Facing Slopes	5.6	<.0001
Distance to Southeast Facing Slopes	11.21	<.0001
Distance to South Facing Slopes	10.21	<.0001
Distance to Southwest Facing Slopes	14.93	<.0001
Distance to West Facing Slopes	1	0.3167
Distance to Northwest Facing Slopes	-3.64	0.0003

Table 8. Results of *t*-test comparing use and availability of variables during the spring season in the 2000s time period (grayed shaded variables were significant, α = 0.05).

SPRING		
Variable	**t Value**	**Probability**
Distance to Cerro Grande Fire High Burn Severity Areas	3.33	0.0009
Distance to Developed Areas	-4.17	<.0001
Distance to Grassland	13.98	<.0001
Distance to Shrub species	2.28	0.0226
Distance to Pinon-Juniper Woodland	-0.61	0.5401
Distance to Ponderosa Pine	-5.46	<.0001
Distance to Aspen	-10.52	<.0001
Distance to Mixed Conifer	-13.19	<.0001
Distance to Landcover Water Features	4.44	<.0001
Distance to Additional Water Features (tanks, wetlands, etc.)	2.91	0.0037
Elevation	5.47	<.0001
Slope (degrees)	11.77	<.0001
Distance to Flat areas	-2.76	0.0057
Distance to North Facing Slopes	-7.62	<.0001
Distance to Northeast Facing Slopes	-0.71	0.4795
Distance to East Facing Slopes	6.09	<.0001
Distance to Southeast Facing Slopes	8.73	<.0001
Distance to South Facing Slopes	0.83	0.408
Distance to Southwest Facing Slopes	7.25	<.0001
Distance to West Facing Slopes	-4.06	<.0001
Distance to Northwest Facing Slopes	-7.22	<.0001

Table 9. Results of *t*-test comparing use and availability of variables during the calving season in the 2000s time period (grayed shaded variables were significant, $\alpha = 0.05$).

CALVING		
Variable	**t Value**	**Probability**
Distance to Cerro Grande Fire High Burn Severity Areas	-1.05	0.2938
Distance to Developed Areas	0.7	0.4864
Distance to Grassland	19.98	<.0001
Distance to Shrub species	8.02	<.0001
Distance to Pinon-Juniper Woodland	-1.58	0.1135
Distance to Ponderosa Pine	-3.31	0.001
Distance to Aspen	-7.62	<.0001
Distance to Mixed Conifer	-8.64	<.0001
Distance to Landcover Water Features	1.48	0.1392
Distance to Additional Water Features (tanks, wetlands, etc.)	5.46	<.0001
Elevation	8.52	<.0001
Slope (degrees)	8.28	<.0001
Distance to Flat areas	2.95	0.0032
Distance to North Facing Slopes	-0.97	0.3328
Distance to Northeast Facing Slopes	0.39	0.6931
Distance to East Facing Slopes	2.17	0.0303
Distance to Southeast Facing Slopes	-0.36	0.7213
Distance to South Facing Slopes	0.15	0.8838
Distance to Southwest Facing Slopes	-1.13	0.2581
Distance to West Facing Slopes	0.51	0.6113
Distance to Northwest Facing Slopes	-0.19	0.8503

Table 10. Results of *t*-test comparing use and availability of variables during the summer season in the 2000s time period (grayed shaded variables were significant, α = 0.05).

SUMMER		
Variable	**t Value**	**Probability**
Distance to Cerro Grande Fire High Burn Severity Areas	-0.7	0.4854
Distance to Developed Areas	-0.71	0.4766
Distance to Grassland	12.57	<.0001
Distance to Shrub species	2.49	0.0129
Distance to Pinon-Juniper Woodland	-0.01	0.9914
Distance to Ponderosa Pine	-7.41	<.0001
Distance to Aspen	-9.42	<.0001
Distance to Mixed Conifer	-9.47	<.0001
Distance to Landcover Water Features	-0.26	0.7913
Distance to Additional Water Features (tanks, wetlands, etc.)	3.2	0.0014
Elevation	5.71	<.0001
Slope (degrees)	7.83	<.0001
Distance to Flat areas	4.43	<.0001
Distance to North Facing Slopes	0.33	0.7439
Distance to Northeast Facing Slopes	0.98	0.3272
Distance to East Facing Slopes	2.97	0.003
Distance to Southeast Facing Slopes	2.34	0.0192
Distance to South Facing Slopes	1.28	0.2002
Distance to Southwest Facing Slopes	1.36	0.1736
Distance to West Facing Slopes	1.65	0.0989
Distance to Northwest Facing Slopes	1.16	0.2481

Table 11. Results of *t*-test comparing use and availability of variables during the fall season in the 2000s time period (grayed shaded variables were significant, α = 0.05).

FALL		
Variable	**t Value**	**Probability**
Distance to Cerro Grande Fire High Burn Severity Areas	-0.74	0.4605
Distance to Developed Areas	-2.11	0.0348
Distance to Grassland	16.63	<.0001
Distance to Shrub species	4.74	<.0001
Distance to Pinon-Juniper Woodland	1.23	0.2179
Distance to Ponderosa Pine	-9.05	<.0001
Distance to Aspen	-11.42	<.0001
Distance to Mixed Conifer	-12.94	<.0001
Distance to Landcover Water Features	1.38	0.1662
Distance to Additional Water Features (tanks, wetlands, etc.)	4.9	<.0001
Elevation	7.15	<.0001
Slope (degrees)	10.52	<.0001
Distance to Flat areas	4.88	<.0001
Distance to North Facing Slopes	-0.56	0.576
Distance to Northeast Facing Slopes	1.68	0.0938
Distance to East Facing Slopes	4.65	<.0001
Distance to Southeast Facing Slopes	5.02	<.0001
Distance to South Facing Slopes	1.03	0.3023
Distance to Southwest Facing Slopes	1.91	0.0564
Distance to West Facing Slopes	0.65	0.5142
Distance to Northwest Facing Slopes	-0.45	0.6497

classification system used for the 1990s and 2000s landcover map were similar but not exactly the same. For the time period of 2000s, spring had the largest number of significant variables (18), followed by winter at 16 significant variables. The lowest number of significant variables was the calving season (10). Summer had 11 significant variables and fall had 12. These significant variables were the initial variables utilized in the logistic regression.

In both time periods, winter and spring had the highest number of significant variables while summer and calving had the lowest number. This pattern may be the result of elk foraging practices. During the winter and spring, forage material is reduced and elk must forage in a greater number of habitats to acquire sufficient forage material. In addition, during the spring and winter elk may forage on more woody material instead of solely concentrating on grasslands (New Mexico Department of Game and Fish 2004) and therefore visit an increased diversity of habitats. In the calving and summer seasons, grass is more abundant and elk may not have to forage and visit as many different habitat patches. This change in forage practices between these seasons may account for the differences in the number of significant variables being detected.

Because of sample size issues with the 1990s data, all data for each animal by season were pooled in the logistic regression to formulate a habitat suitability model. Pooling the 1990s data was the only way to develop a valid model for each season. This research utilized the HS model as a means to weighting resource use or avoidance for input in the development of the cost surface. The aspect of pooling data was not ideal but still allowed for a means for assigning weights to resources. Table 12 contains the final 1990s seasonal models obtained by the stepwise logistic regression. The table provides the estimate of the coefficient of each variable as well as the standard error, Wald Chi-Square, and probability that the coefficient is equal to zero. There was sufficient data to create valid average logistic regression equations for each season within the 2000s time period. Table 13 contains the final 2000s seasonal models obtained by the stepwise process (logistic regression by animal, testing mean coefficient through *t*-test). The table

Table 12. Results of the logistic regression for the time period of the late 1990s using pooled data from all animals.

FALL 1990s				
Coefficient	*Estimate*	*Standard Error*	*Chi-Square*	*p*
Intercept	0.9655	0.3146	9.4163	0.0022
Distance to Developed Areas	-0.00007 (use decreases as distance increases)	0.000024	8.9692	0.0027
Distance to Grasslands	-0.00036 (use decreases as distance increases)	0.000129	7.6837	0.0056
Distance to Aspen	-0.00008 (use decreases as distance increases)	0.000023	13.7564	0.0002
Distance to Unvegetated Areas	-0.00024 (use decreases as distance increases)	0.0000068	12.1183	0.0005
Distance to Northwest Facing Slopes	0.00118 (use increases as distance increases)	0.000259	20.7674	< 0.0001
SUMMER 1990s				
Coefficient	*Estimate*	*Standard Error*	*Chi-Square*	*p*
Intercept	-4.7465	1.5477	9.4049	0.0022
Distance to Aspen	-0.00029 (use decreases as distance increases)	0.000088	10.8282	0.0010
Distance to Mixed Conifer	0.000355 (use decreases as distance increases)	0.000096	13.8245	0.0002
Distance to Unvegetated Areas	-0.00016 (use decreases as distance increases)	0.000065	6.1123	0.0134
Distance to Water Features in Landcover	-0.00004 (use decreases as distance increases)	0.000015	7.3155	0.0068
Elevation	0.000880 (use decreases as elevation decreases)	0.000265	11.0230	0.0009

Table 12 (continued). Results of the logistic regression for the time period of the late 1990s using pooled data from all animals.

WINTER 1990s				
Coefficient	*Estimate*	*Standard Error*	*Chi-Square*	*p*
Intercept	-21.8900	3.1335	48.8000	< 0.0001
Distance to Developed Areas	-0.00029 (use decreases as distance increases)	0.000049	34.7448	< 0.0001
Distance to Grasslands	-0.00023 (use decreases as distance increases)	0.000113	4.2318	0.0397
Distance to Pinon-Juniper	-0.00079 (use decreases as distance increases)	0.000316	6.2198	0.0126
Distance to Aspen	-0.00030 (use decreases as distance increases)	0.000050	36.3241	< 0.0001
Distance Mixed Conifer	-0.000165 (use decreases as distance increases)	0.000045	13.6451	0.0002
Distance to Unvegetated Areas	-0.00032 (use decreases as distance increases)	0.000118	7.5357	0.0060
Distance to Water Features in Landcover	-0.00025 (use decreases as distance increases)	0.000030	65.2785	< 0.0001
Elevation	0.00428 (use decreases as elevation decreases)	0.000558	58.9667	< 0.0001
Slope	0.0459 (use decreases as slope decreases)	0.0114	16.1178	< 0.0001
Distance to Northwest Facing Slopes	0.000560 (use decreases as distance decreases)	0.000225	6.1768	0.0129
Distance to Southeast Facing Slopes	0.00162 (use decreases as distance decreases)	0.000481	11.3201	0.0008

Table 12 (continued). Results of the logistic regression for the time period of the late 1990s using pooled data from all animals.

SPRING 1990s				
Coefficient	*Estimate*	*Standard Error*	*Chi-Square*	*p*
Intercept	1.9941	0.3233	38.0434	< 0.0001
Distance to Developed Areas	-0.00055 (use decreases as distance increases)	0.000103	28.3058	< 0.0001
Distance to Grasslands	-0.00069 (use decreases as distance increases)	0.000243	8.0973	0.0044
Distance to Juniper Woodland	-0.00073 (use decreases as distance increases)	0.000116	39.2778	< 0.0001
Distance to Pinon-Juinper	-0.00099 (use decreases as distance increases)	0.000273	13.2289	< 0.0001
Distance to Aspen	-0.00055 (use decreases as distance increases)	0.000096	32.4442	< 0.0001
Distance to Unvegetated Areas	0.00124 (use increases as distance increases)	0.000109	129.1914	< 0.0001
Distance to Water Features	-0.00032 (use decreases as distance increases)	0.000089	12.7376	0.00004
Distance to North Facing Slopes	0.00134 (use increases as distance increases)	0.000377	12.7437	0.0004
CALVING 1990s				
Coefficient	*Estimate*	*Standard Error*	*Chi-Square*	*p*
Intercept	-0.2303	0.1220	3.5615	0.591
Distance to Grasslands	-0.00014 (use decreases as distance increases)	0.000071	3.8763	0.0490
Distance to Pinon-Juinper	-0.00014 (use decreases as distance increases)	0.000046	9.2272	0.0024
Distance to South Facing Slopes	0.000718 (use decreases as distance decreases)	0.000198	13.1432	0.0003
Distance to West Facing Slopes	0.000418 (use decreases as distance decreases)	0.000119	12.3863	0.0004

Table 13. Results of the logistic regression process for the time period of the early 2000s.

FALL 2000s (n = 19)				
Coefficient	*Estimate*	*Standard Error*	*t*	*p*
Intercept	0.6460158	0.3146	6.05	< 0.0001
Distance to Grasslands	-0.0058695 (use decreases as distance increases)	0.0015708	-3.74	0.0015
Slope	-0.0585368 (use increases as slope decrease)	0.0211629	-2.77	0.00127
WINTER 2000s (n = 17)				
Coefficient	*Estimate*	*Standard Error*	*t*	*p*
Intercept	-0.9107573	0.1542874	5.90	< 0.0001
Distance to Cerro Grande Severe Burn	-0.000054045 (use decreases as distance increases)	0.000019063	-2.84	0.0099
Distance to Grasslands	-0.000968045 (use decreases as distance increases)	0.000273713	-3.54	0.0020
Slope	-0.0869273 (use decreases as slope increases)	0.0275657	-3.15	0.0048
Distance to South Facing Slopes	-0.000624182 (use decreases as distance increases)	0.000131837	-4.73	0.0001
SPRING 2000s (n = 21)				
Coefficient	*Estimate*	*Standard Error*	*t*	*p*
Intercept	0.3114960	0.1424715	2.19	0.0415
Distance to Grasslands	-0.000685050 (use decreases as distance increases)	0.000182967	-3.74	0.0014
Distance to Mixed Conifer	0.000376450 (use decreases as distance decrease)	0.000099255	3.79	0.0012
Distance to Ponderosa Pine	-0.00054050 (use decreases as distance increases)	0.000200455	-2.70	0.0143
Slope	-0.0459170 (use decreases as slope increases)	0.0104958	-4.37	0.0003
CALVING 2000s (n = 20)				
Coefficient	*Estimate*	*Standard Error*	*t*	*p*
Intercept	0.4750345	0.1213612	3.91	0.0009
Distance to Grasslands	-0.0030215 (use decreases as distance increases)	0.000776082	- 3.89	0.0010
Slope	-0.0278700 (use decreases as slope increases)	0.0115561	- 2.41	0.0262
SUMMER 2000s (n = 21)				
Coefficient	*Estimate*	*Standard Error*	*t*	*p*
Intercept	6.8072524	2.7030535	2.52	0.0204
Distance to Grasslands	-0.0040501 (use decreases as distance increase)	0.0015730	- 2.57	0.0181
Elevation	-0.000738476 (use decreases as elevation increases)	0.000305466	- 2.42	0.0253

provides the mean coefficient, standard error, *t* value, and the probability that the coefficient equals zero.

Models developed for the 1990s showed some variability in the variables and coefficients selected between seasons. However, there were two variables that were utilized in almost all seasons, distance to aspen and distance to grasslands. Summer 1990s was the only model where distance to grasslands was not included in the final model, and the calving model did not include distance to aspen. The general directional relationship of these two variables remained the same in the 1990s model. Both coefficients were negative values which resulted in a higher probability of use as the distance to the feature decreased.

The 2000s models showed a greater consistency between seasons. Distance to grasslands was a significant variable in all seasons and the directional relationship was negative for all seasons. Slope was also a significant variable for all seasons with the exception of summer. Models indicated as slope increased, use of the area decreased.

In general, the 1990s model contained more of the initial variables than the 2000s models and a lot of variation was seen between the seasonal models of the two time periods. However, there was one consistent factor among the 1990s and 2000s model. Both time periods found distance to grasslands to be an important variable in the majority of the models and the relationship was the same (probability of use increased as distance to grassland decreased). In other cases where common variables were identified in seasonal models of the two time periods, the relationship was opposite. For example, in summer

1990s the model includes the variable elevation with a positive relationship (probability of use increased as elevation increased), but in 2000s the relationship was found to be negative (probability of use increased as elevation decreased).

Some of the differences in the logistic regression equations developed for the 1990s and 2000s may be influenced by a larger portion of migratory animals in the 2000s data. Migratory animals may have utilized resources somewhat differently than resident animals. In addition, the small sample size with the 1990s data affected the modeling process. Average logistic regression could not be developed because of an increased variability within and among animals. This would most likely have some effect on the model developed.

1.3. HS Layers

The HS layers were developed using the seasonal model equations for the 1990s and 2000s time period. Figures 11 through 20 show the seasonal HS maps indicating the probability of elk use. Theoretically, the probability of use ranged from 0 to 1. However, not all models predicted areas of suitability near 1. Most of the models developed for the 1990s time period had probability values that ranged from near zero to greater than 0.9, but this was not the case for the 2000s models. Many of the models predicted for the 2000s had probability values that ranged from near zero to near 0.6. Models with maximum values below one may indicate that there were other unexplored variables that could further explain habitat use. Seasons below 0.9 probability included fall (0.656),

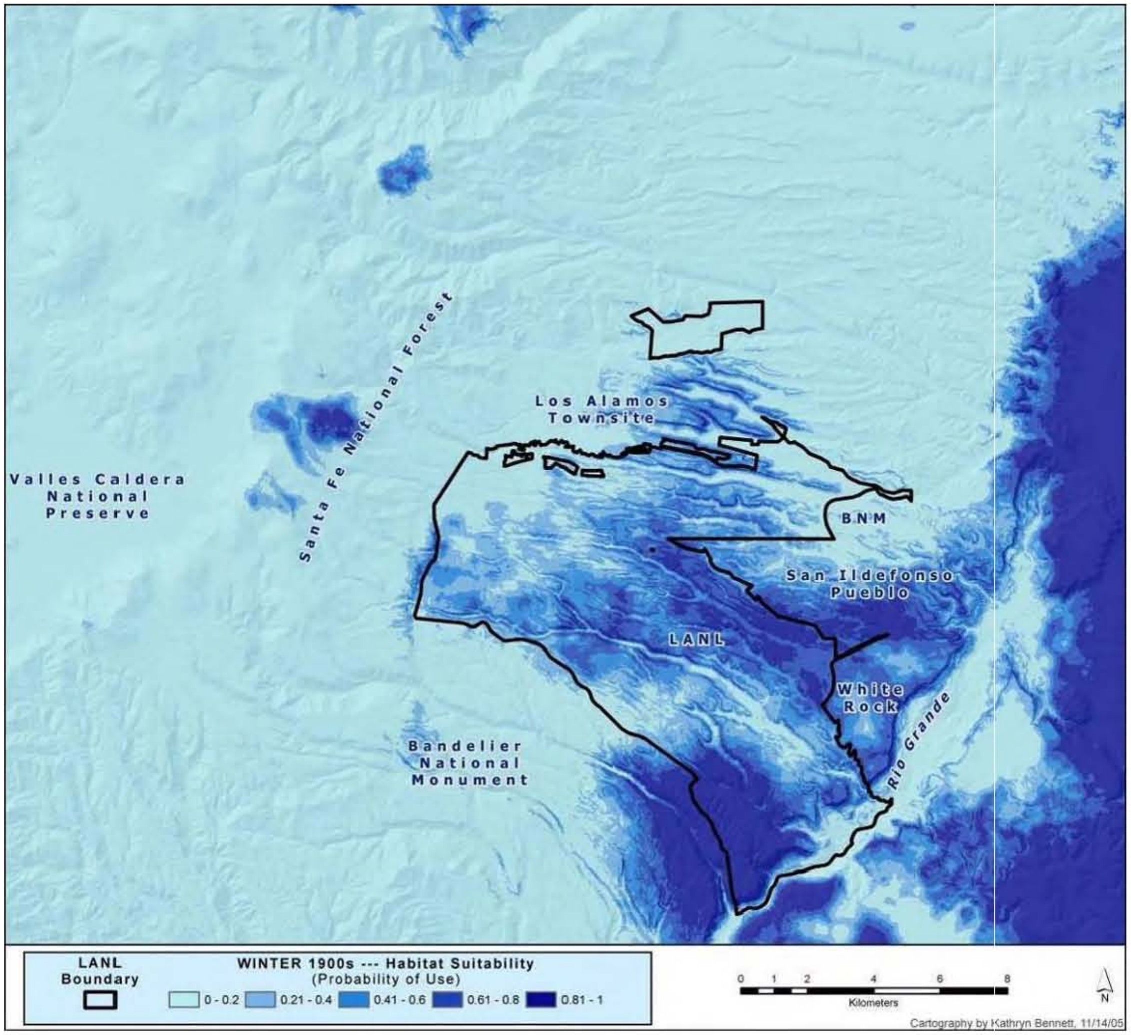


Figure 11. The 1990s winter habitat suitability layer developed from logistic regression of pooled animal data.

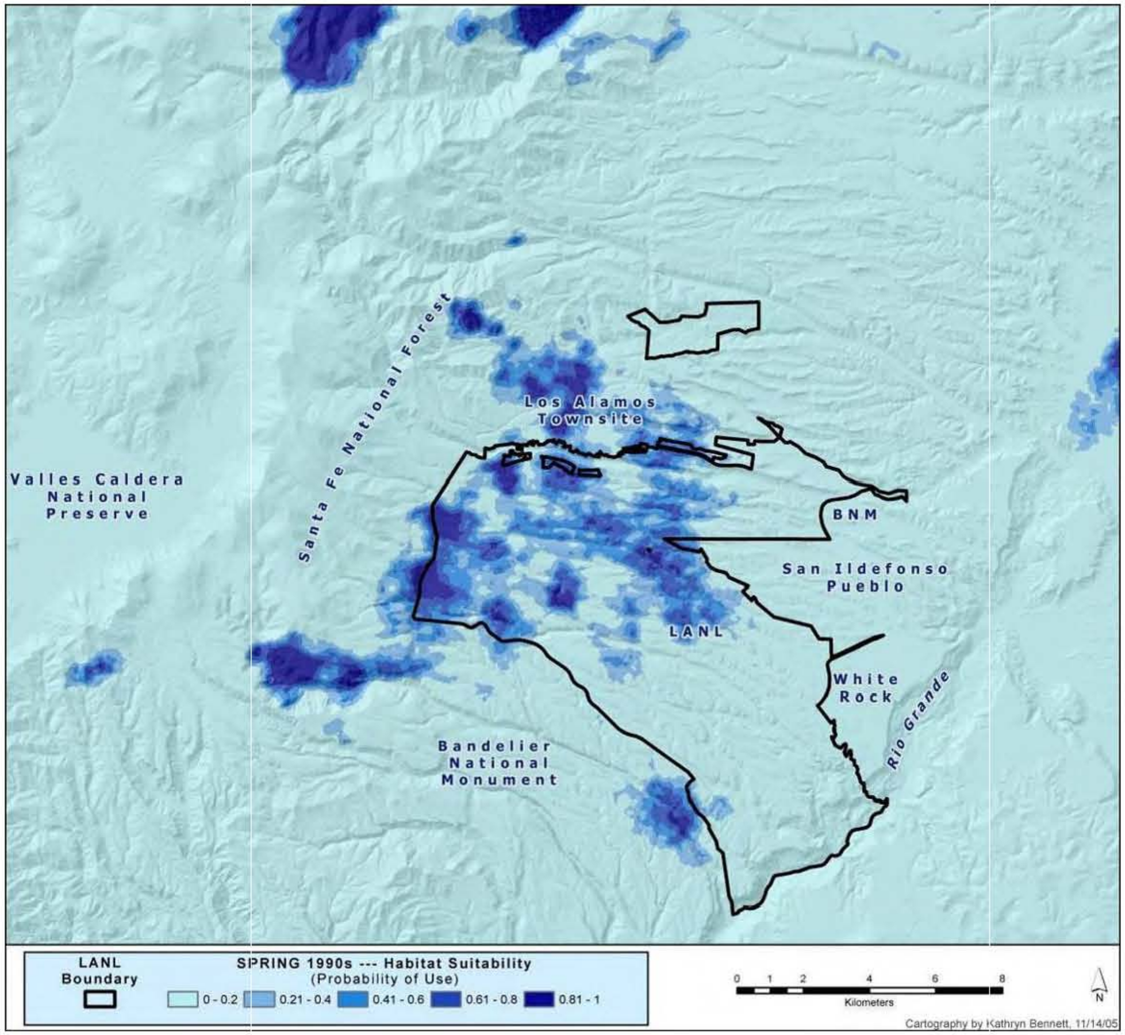


Figure 12. The 1990s spring habitat suitability layer developed from logistic regression of pooled animal data.

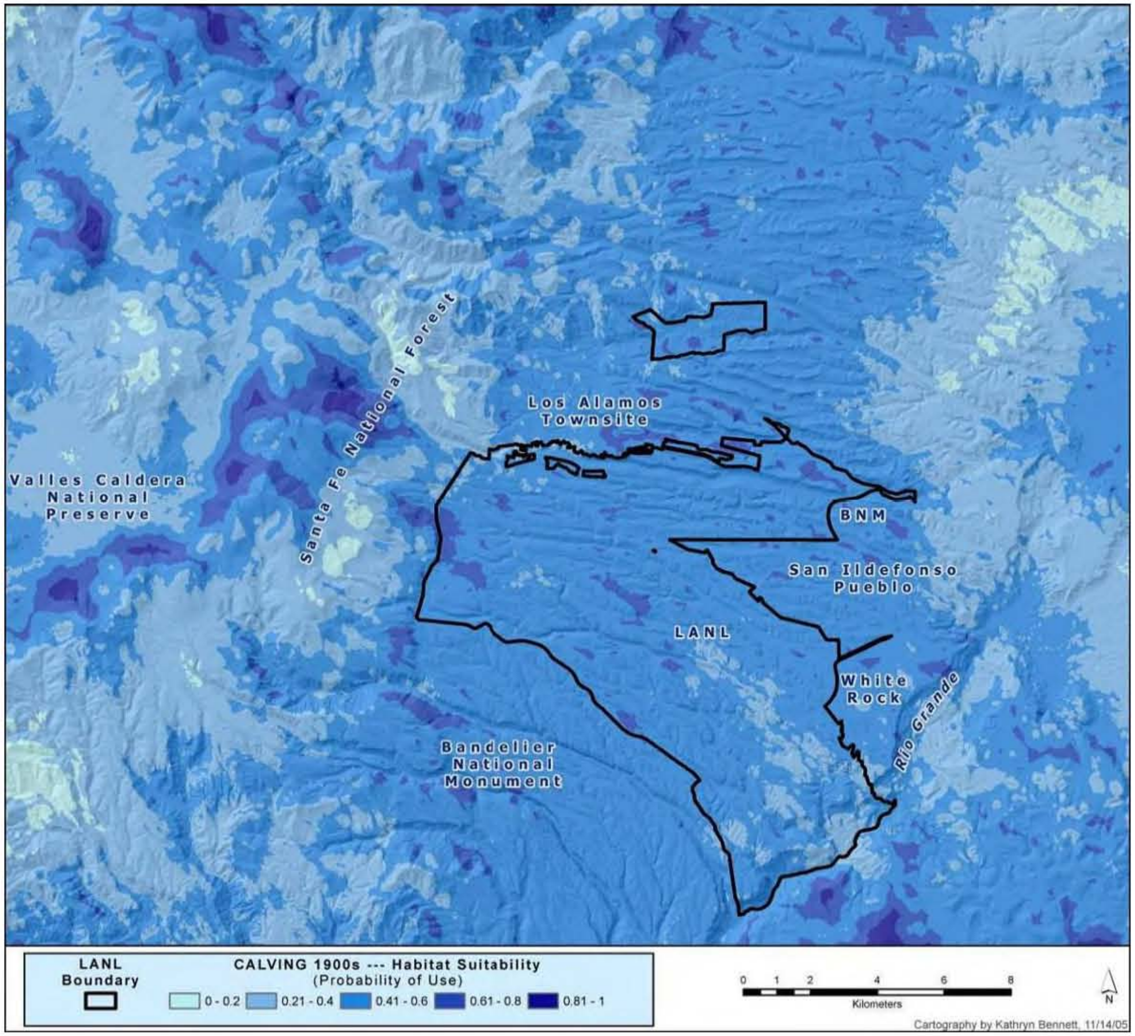


Figure 13. The 1990s calving habitat suitability layer developed from logistic regression of pooled animal data.

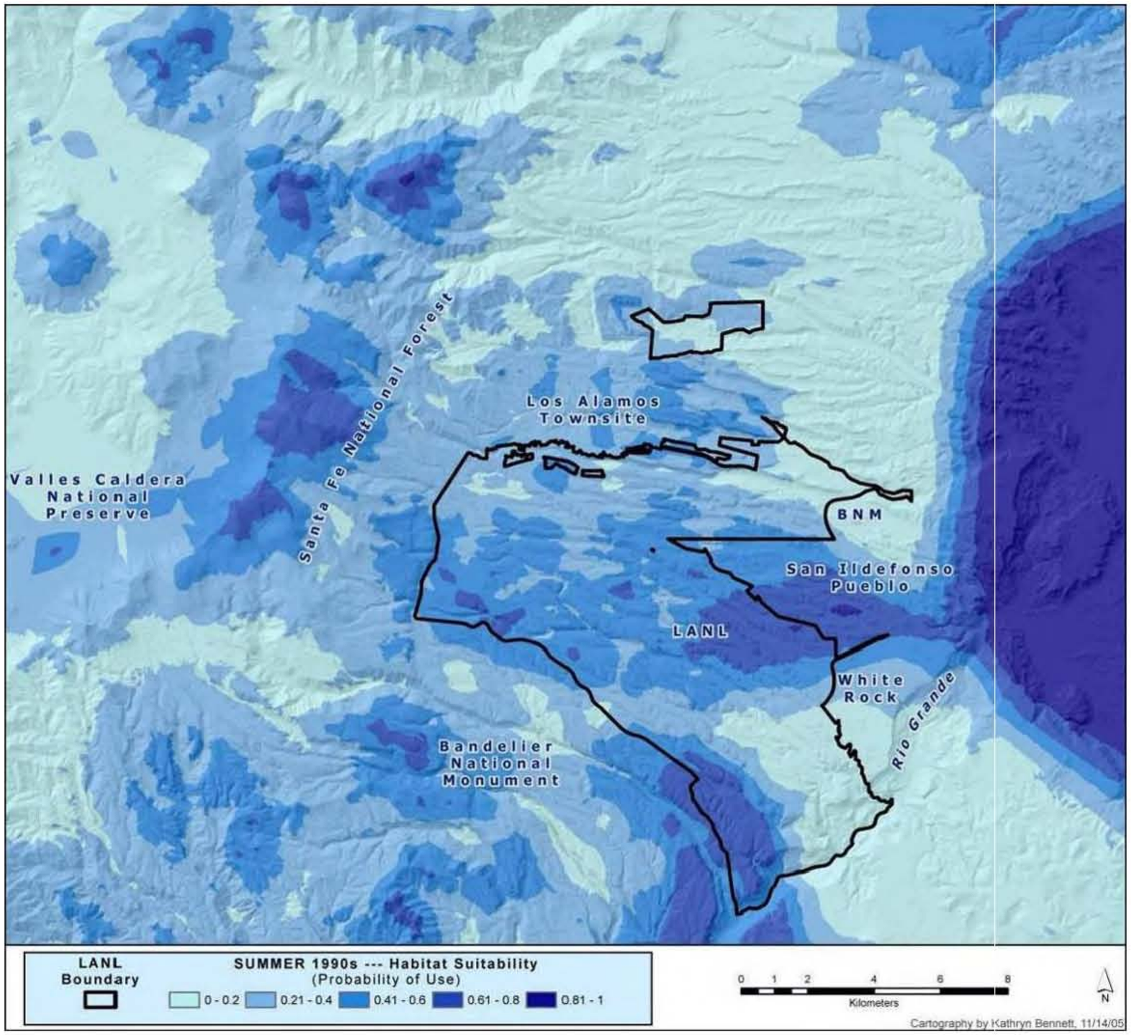


Figure 14. The 1990s summer habitat suitability layer developed from logistic regression of pooled animal data.

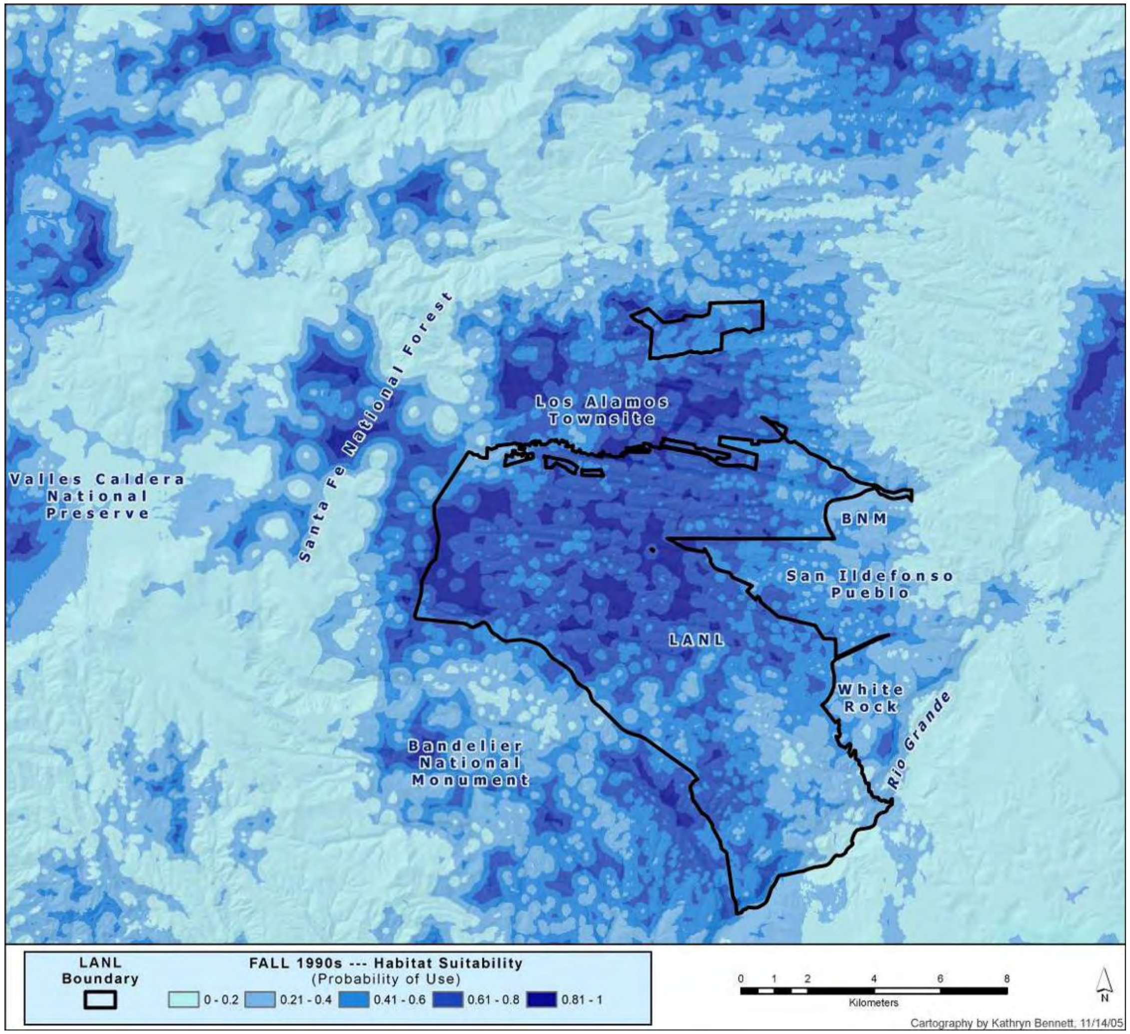


Figure 15. The 1990s fall habitat suitability layer developed from logistic regression of pooled animal data.

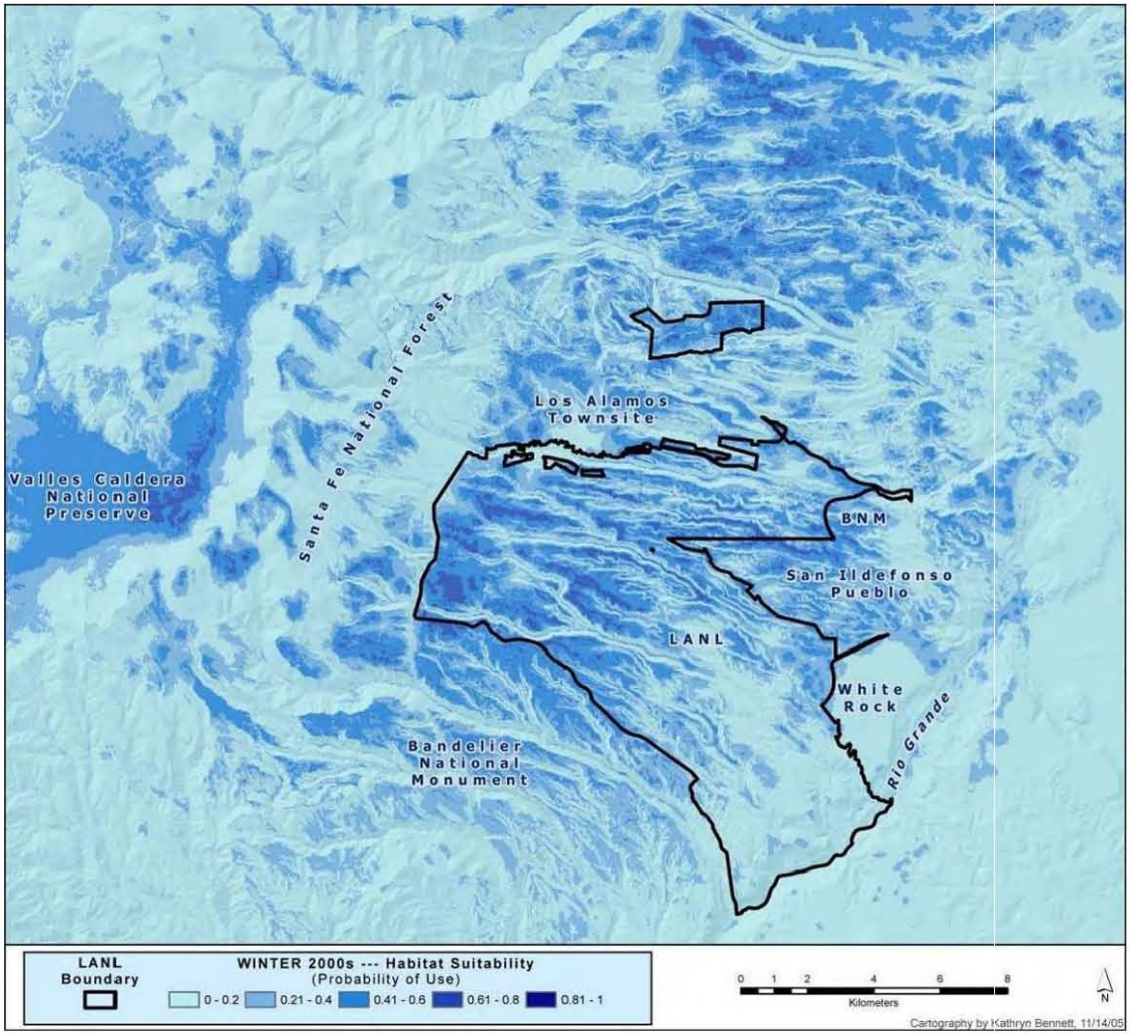


Figure 16. The 2000s winter suitability layer developed from logistic regression of animal data.

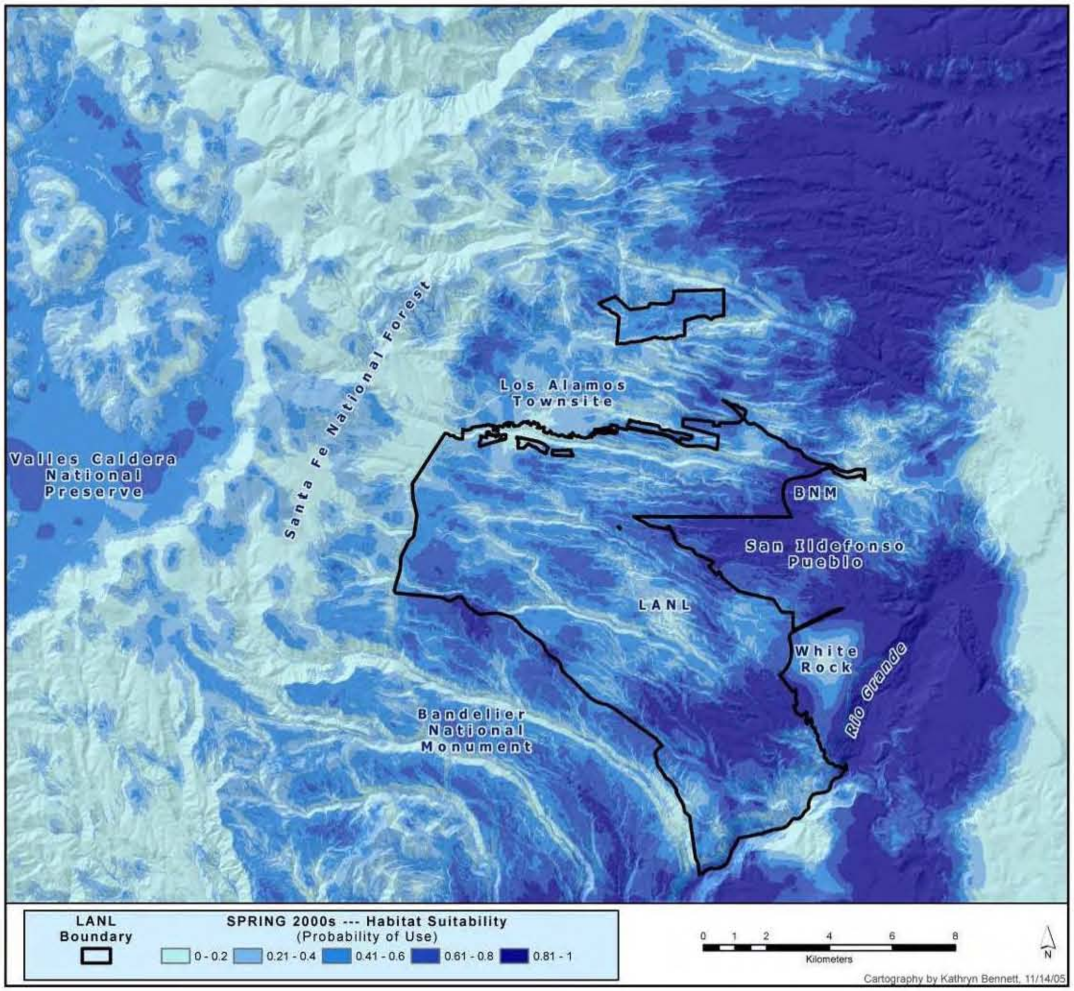


Figure 17. The 2000s spring habitat suitability layer developed from logistic regression of animal data.

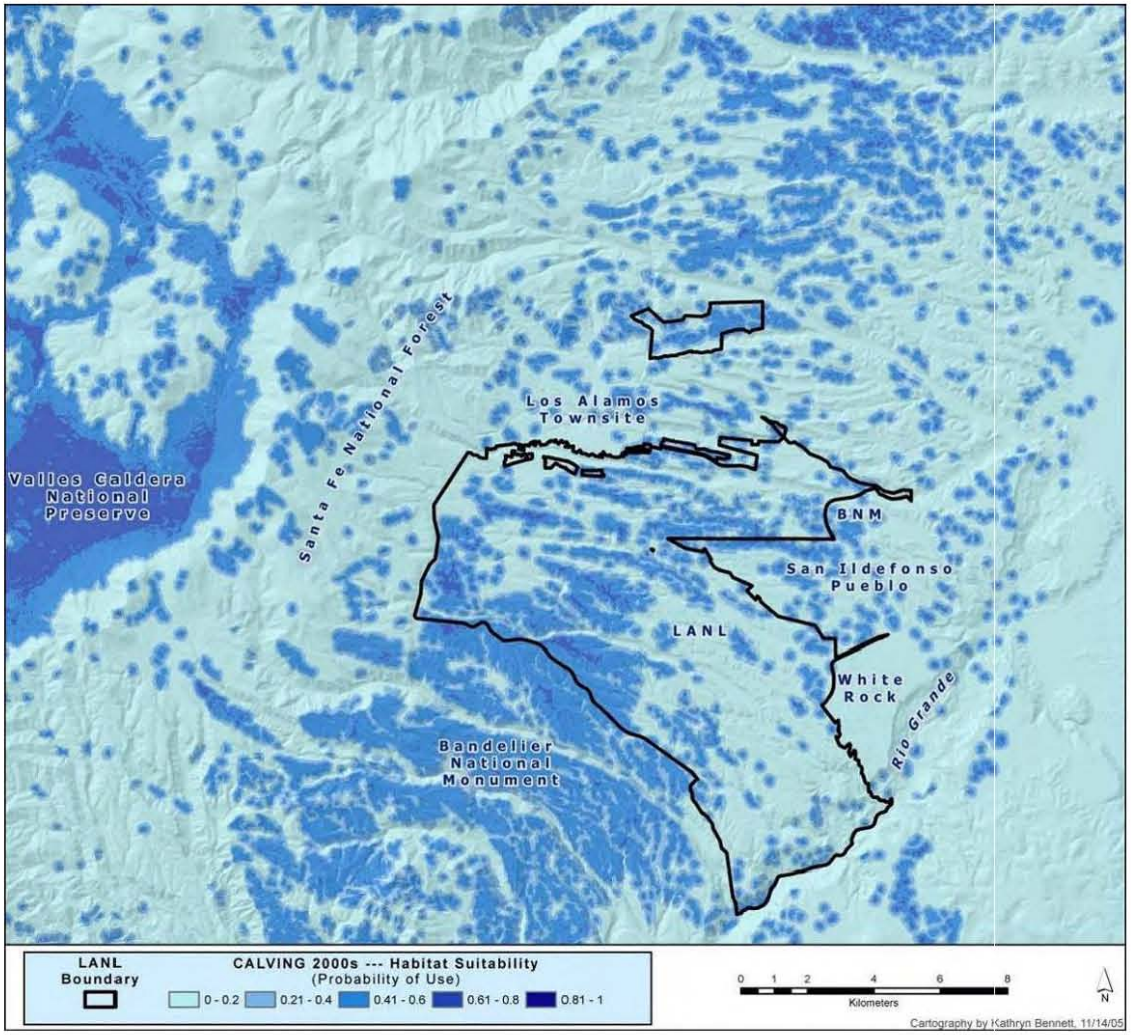


Figure 18. The 2000s calving habitat suitability layer developed from logistic regression of animal data.

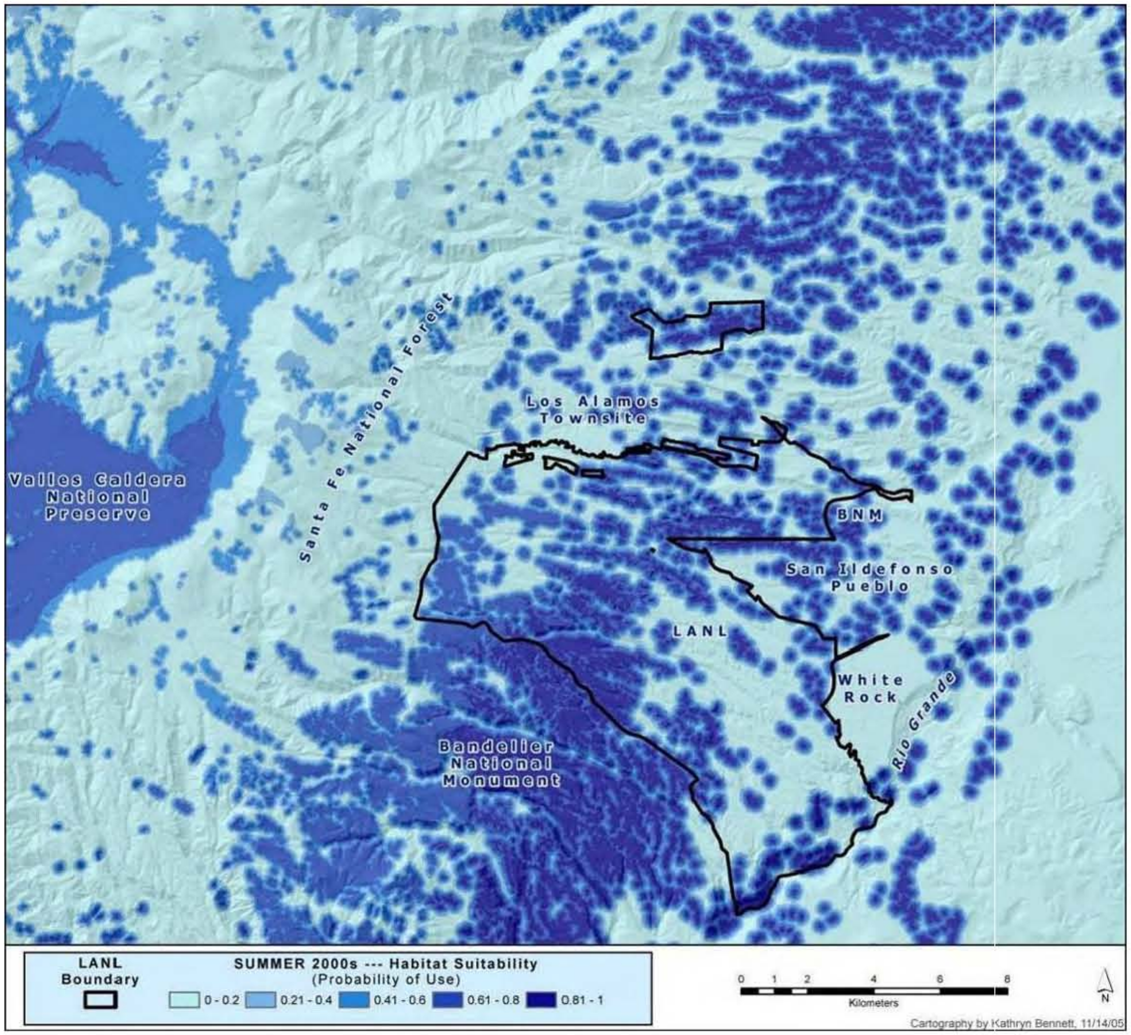


Figure 19. The 2000s summer habitat suitability layer developed from logistic regression of animal data.

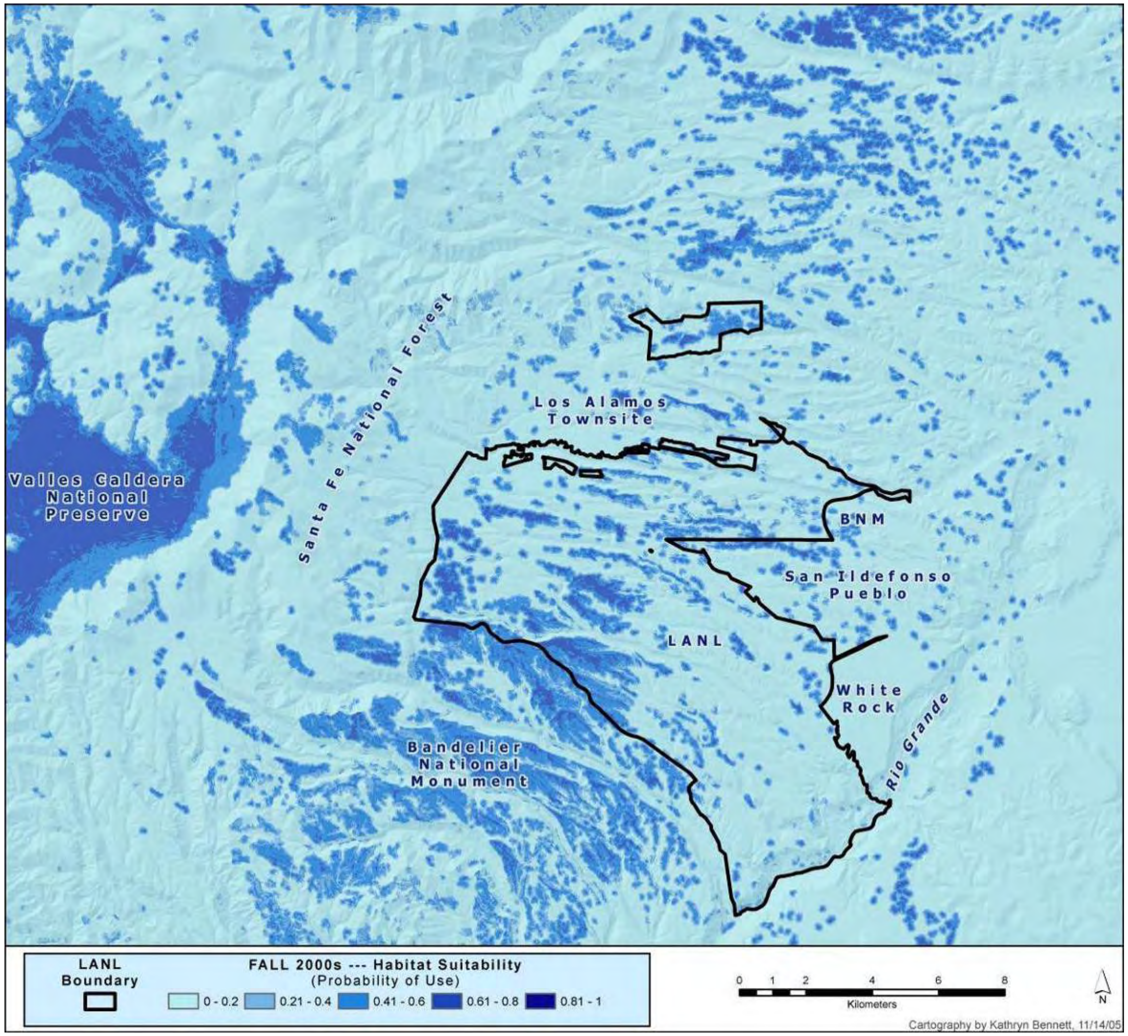


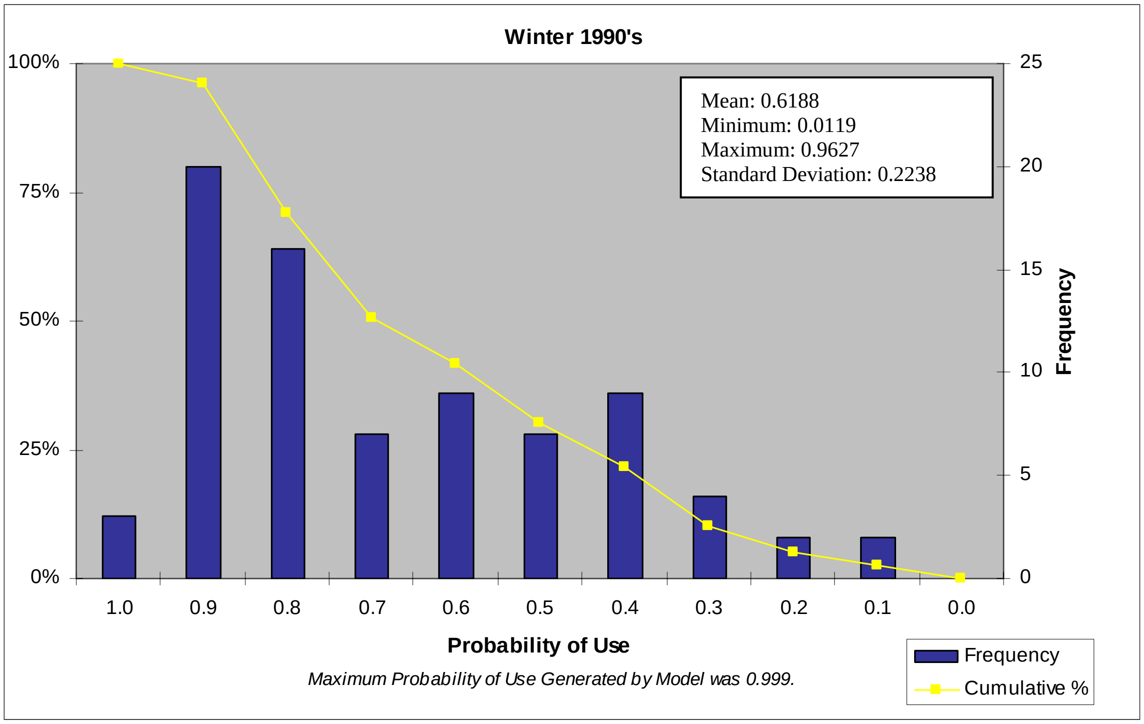
Figure 20. The 2000s fall habitat suitability layer developed from logistic regression of animal data.

winter (0.707), and calving (0.656). From the HS maps for the 2000s (Figures 16 through 20), the variables of slope and distance to grassland are evident. Areas within grasslands and low slopes area have the highest probabilities. High probabilities of use areas were located within the meadows of the VCNP and on mesa tops of grassland within and adjacent to LANL. HS maps of the 1990s appear differently than those of the 2000s. Because of the increased variables in the development of the 1990s HS layer, clear influences of one or two variables were more difficult to visually detect. In general, higher probability of use areas were found within or near LANL.

The habitat suitability layers for the future conditions were developed by modifying the landcover map by converting the Cerro Grande Burn Area into grassland and shrub depending on slope and utilizing the same equations that were developed for the 2000s time period. The habitat suitability models developed for this time period were very similar to those shown for the 2000s. For the winter future condition, the HS layer was not altered from the 2000s because the model utilized the landcover of the Cerro Grande burn. For fall, spring, calving, and summer the future HS models had expansion of higher probability of use in flat areas of the Cerro Grande burn.

1.4. HS Verification

The uncertainties of the HS models were evaluated by analyzing the HS values assigned to elk relocation data that were reserved (15% of the relocations) for the verification process and were not used in the logistic regression modeling process. Figures 21 through 25 shows histograms of each season’s verification data for the 1990s and 2000s.



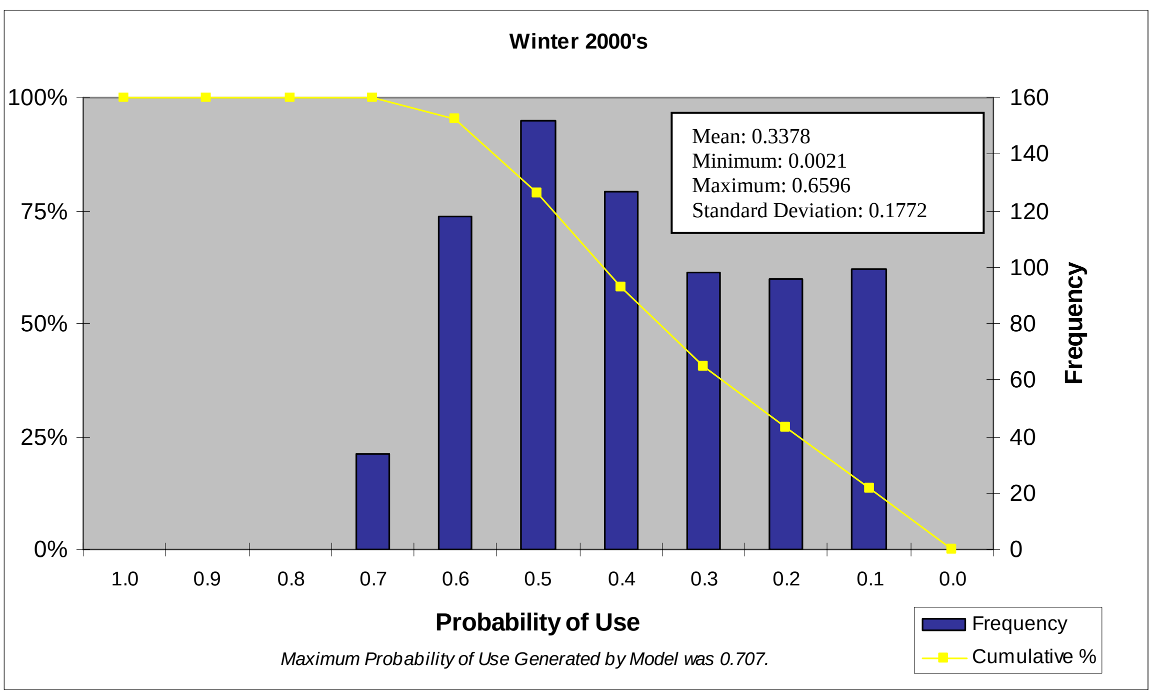
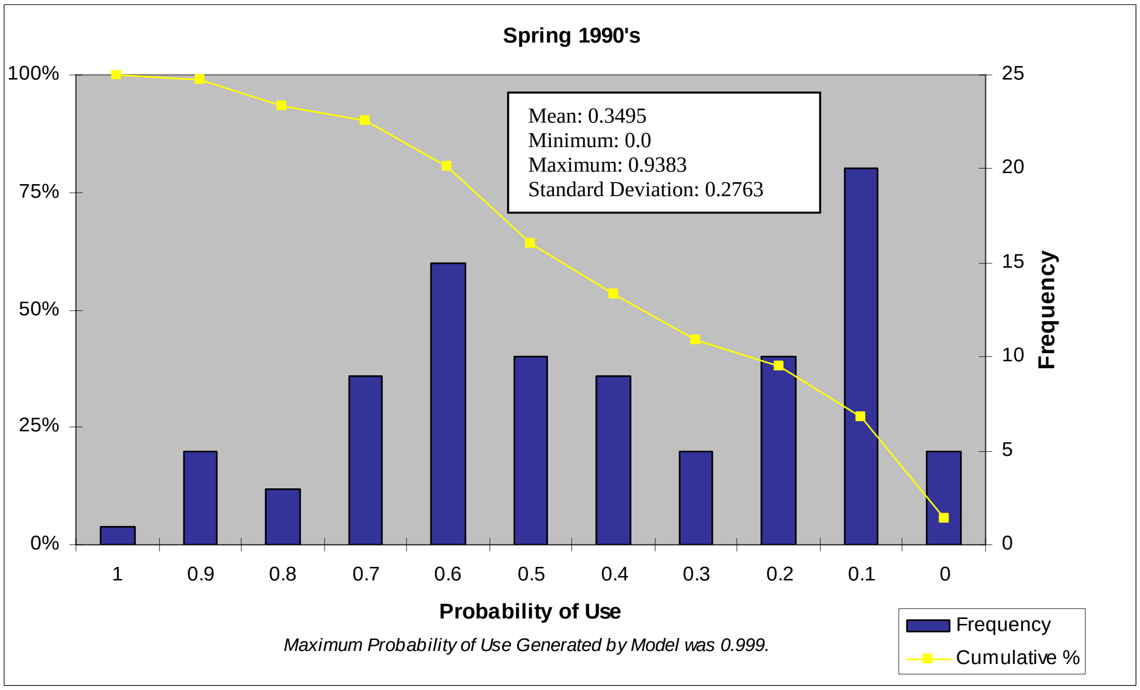


Figure 21. Histograms of probability of use for the relocation verification data for the habitat suitability models developed for the winter season in 1990s and 2000s.



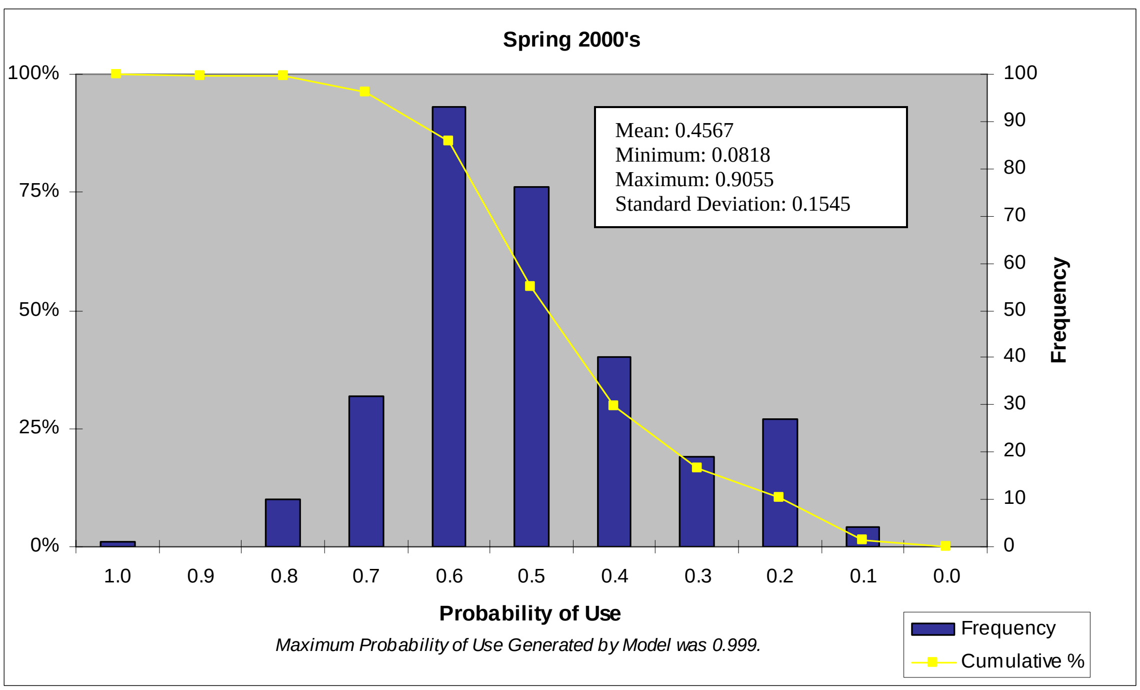
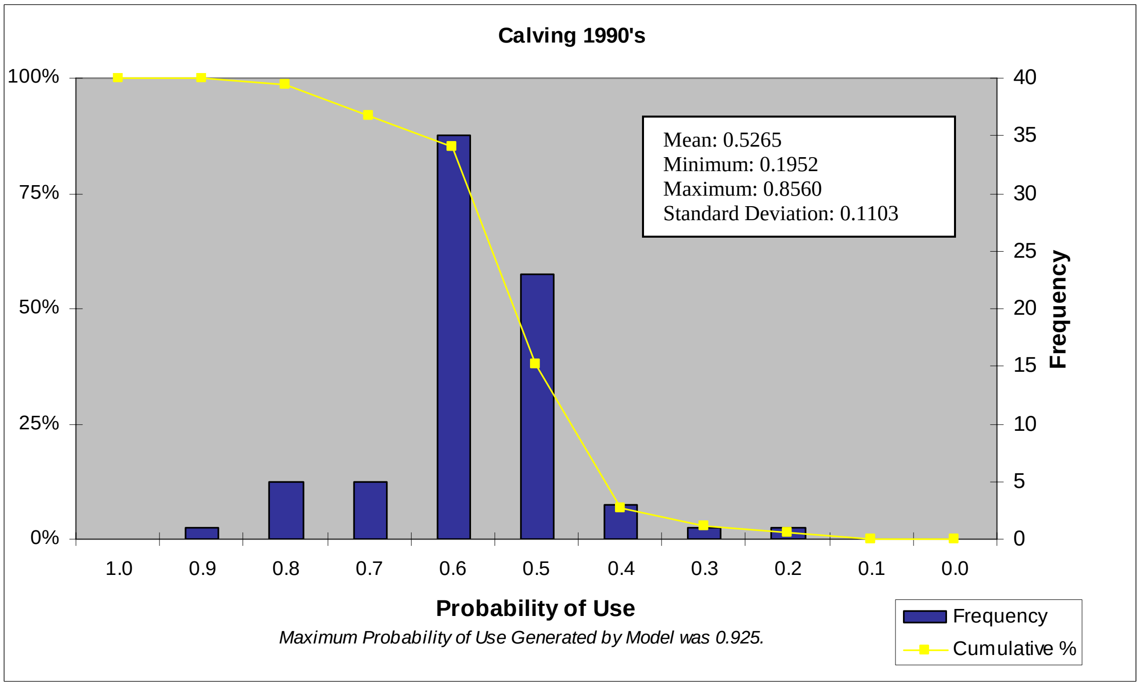


Figure 22. Histograms of probability of use for the relocation verification data for the habitat suitability models developed for the spring season in 1990s and 2000s.



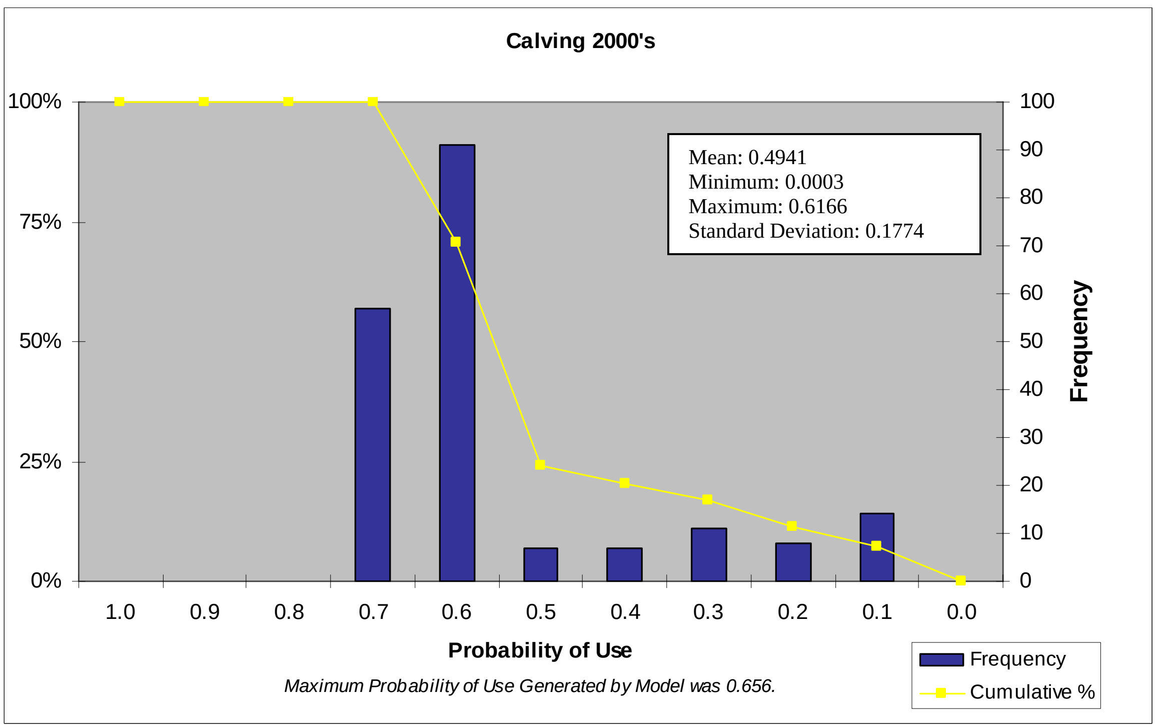
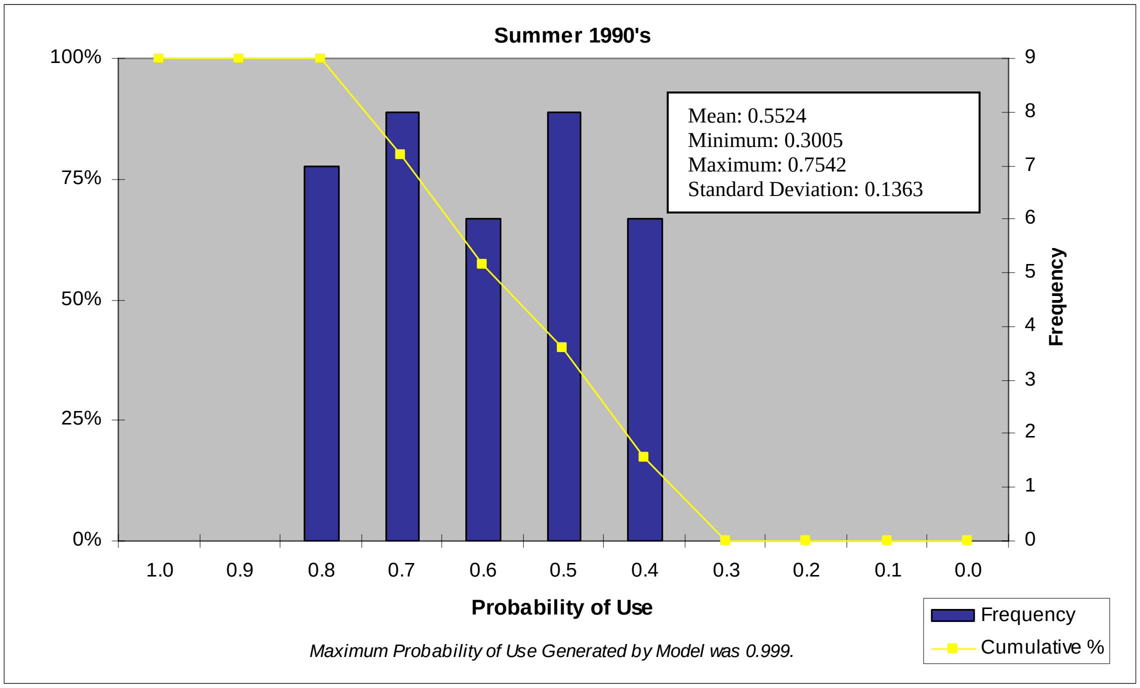


Figure 23. Histograms of probability of use for the relocation verification data for the habitat suitability models developed for the calving season in 1990s and 2000s.



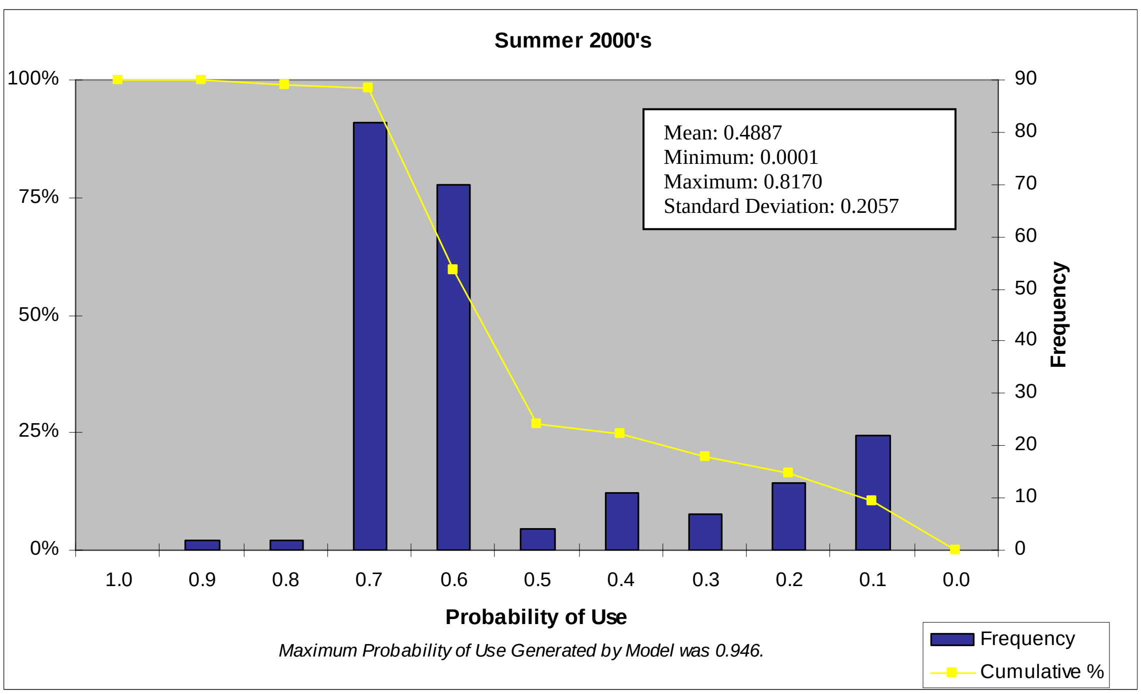
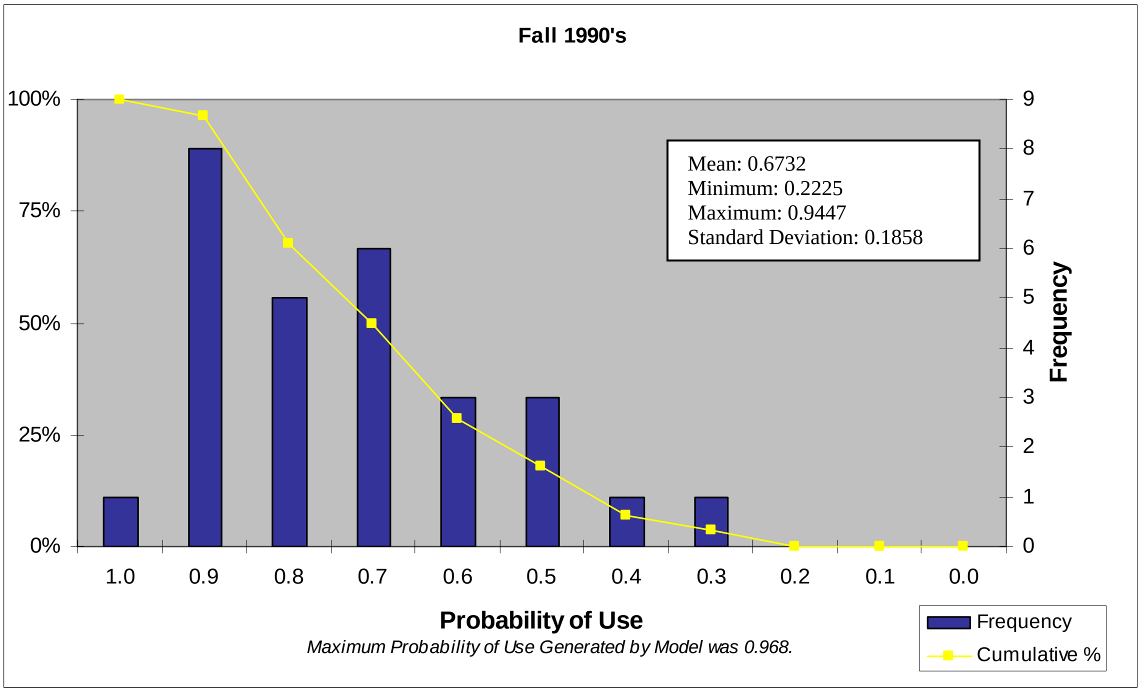


Figure 24. Histograms of probability of use for the relocation verification data for the habitat suitability models developed for the summer season in 1990s and 2000s.



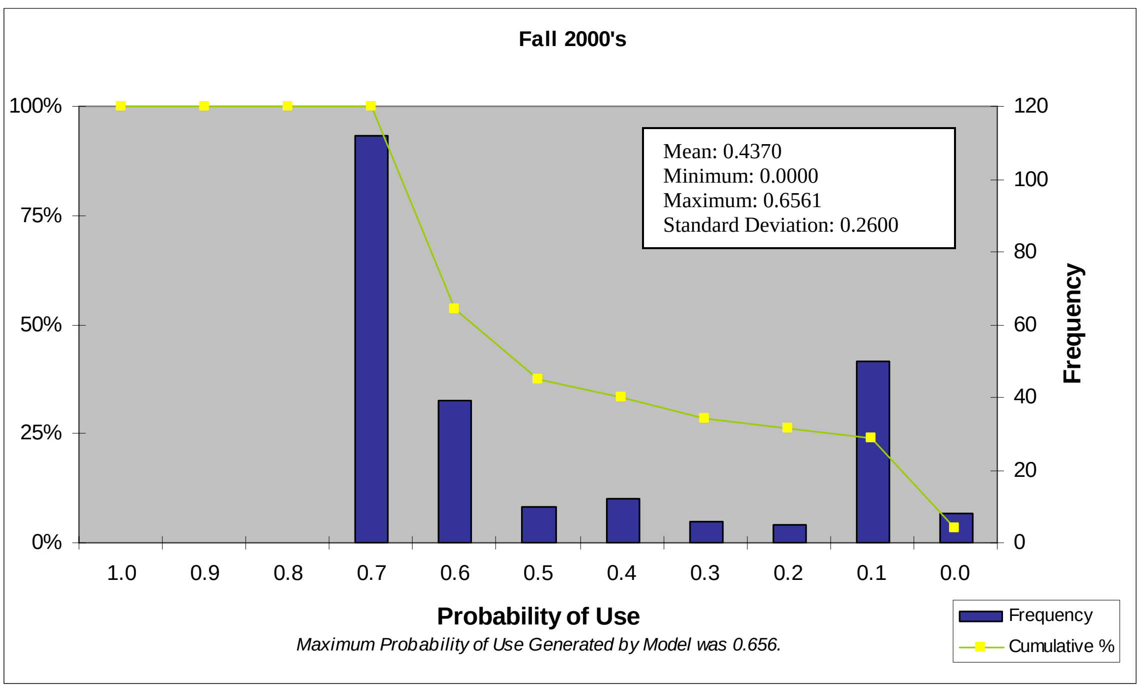


Figure 25. Histograms of probability of use for the relocation verification data for the habitat suitability models developed for the fall season in 1990s and 2000s.

Each histogram shows the frequency of relocations that were within a probability range, cumulative percent, and descriptive statistics.

In this study, model verification is being used to understand the amount of uncertainty related to each model. Models with a higher mean value and a higher proportion of values in the upper limits of the model, equate to a higher level of verification and a lower amount of uncertainty. All seasonal HS models produced were statistically significant ($\alpha = 0.05$). However, these models still do not have perfect agreement with ground data. The amount of agreement between the models and ground data provide a mechanism to evaluate how much uncertainty is associated with the models. Because elk may utilize areas of lower probability of use while moving from location to location, model thresholds were not set to validate a model, rather verification information was analyzed in a comparative format with the understanding that higher model agreement with elk relocation points provides higher confidence in the model but a lower agreement may not necessarily mean the model is invalid. Additional studies will be needed to address the threshold levels in which to invalidate HS models.

Taking into account that some of the 2000s models had values much less than one, the 2000s verification data seemed to have a slightly higher agreement with the models produced. Conversely, the 1990s data had a slightly lower agreement. This may be due to the smaller sample of verification points compared to the number of verifications points available during the 2000s. In addition, the 2000s models were developed by the averaging coefficients from individual animal models where the 1990s models used pooled data. However, all models showed a fair agreement between the HS values and the verification points. With only a couple exceptions (spring 1990s and spring 2000s), models had over 50% of the verification points in the upper 40% of the HS modeled values (based on the highest theoretical value produced by the model). The calving 2000s model showed the highest level of agreement with 83% of the verification points within the upper 40% of the model and spring 1990 had the lowest agreement with only 36% within the upper 40%. Spring 2000s was near the 50% level with 46% of its points in the upper 40%.

1.4.1. Winter

The mean probability of use for verification points in the winter 1990s HS model was 0.6188 with a maximum value of 0.9627 (Figure 21). The maximum probability value predicted by the model was 0.999. Approximately 50% of all relocations occurred in areas where probability of use was greater than 0.60. For the winter 2000s model, the maximum probability of use predicted by the model was 0.707 and the maximum value given to a verification point was 0.6596. The mean value was 0.3378. Over 50% of the verification points had probabilities of 0.4 or higher.

1.4.2. Spring

The mean probability of use for 1990s spring verification points was 0.3495 with a maximum value of 0.9383 (Figure 22). The maximum value predicted by the model was 0.999. Approximately 36% of the verification points were found in areas of 0.6 or greater. The maximum probability of use value generated by the spring 2000s model was

0.999 and the maximum value obtained by a verification point was 0.9055. The mean 2000s value was 0.4567. Forty-six percent of the verification points had probability values greater than 0.6. However, over 70% of the points were greater than 0.4.

1.4.3. Calving

The 1990s calving verification points had a mean probability of use of 0.5265 with a maximum value of 0.8560 (Figure 23). The maximum value predicted by the model was 0.925. Less than 15% of the verification points had values greater than 0.6. However, over 90% of the points had values greater than 0.4. The probability range of 0.6 had the largest number of verification points. The 2000s calving model had a maximum predicted value of 0.656 and over 75% of the verification points were above 0.4. The mean verification probability of use value was 0.4941 with a maximum value of 0.6163.

1.4.4. Summer

The majority (roughly 80%) of the verification points for the summer 1990s HS model fell into the range of 0.4 to 0.8 (Figure 24). Very few points were found at the high end of the probability levels or at the low end. The maximum value predicted by the model was 0.925 and the maximum value assigned to a verification point was 0.7542. The mean verification value was 0.5524. Over 40% of the 2000s verification points were above 0.6 and approximately 75% of the points were above 0.4. The maximum value predicted by the model was 0.946 and the maximum value assigned to a verification point was 0.8170. The mean value was 0.4887.

1.4.5. Fall

The mean probability of use value for fall 1990s was 0.6732 with a maximum value of 0.9447 (Figure 25). This mean value was the highest mean generated for all of the seasons. Over 72% of the verification points had a probability of 0.6 or greater and 100% of the data had values greater than 0.2. Of all the seasonal models, fall 1990s had the highest mean value. The 2000s fall model generated a maximum value of 0.656 and the maximum probability value assigned to a verification point was 0.656. Over 45% of the verification data had values of 0.6 or greater and over 65% of the data had values greater than 0.4. The mean value was 0.4370. The mean probability for the fall 1990s season was 0.6732 with a maximum value of 0.9447. Approximately 71% of the verification points occurred in habitat with probability of use greater than 0.6.

2.0. Cost Surface

Cost surfaces for each time period were developed from combining the HS models with the barriers the same time period. The HS models were re-coded so that high suitability areas received low impedance or resistant values. The cost surfaces for each season and time periods are shown in Figures 26 through 45. Low areas of impedance are shown in shades of blue and high impedance values are shown in shades of orange to reds. Extremely high impedance areas (buildings, some types of fences, and extreme slopes) are shown in a dark red and received an impedance value of 10,000. The 1990s

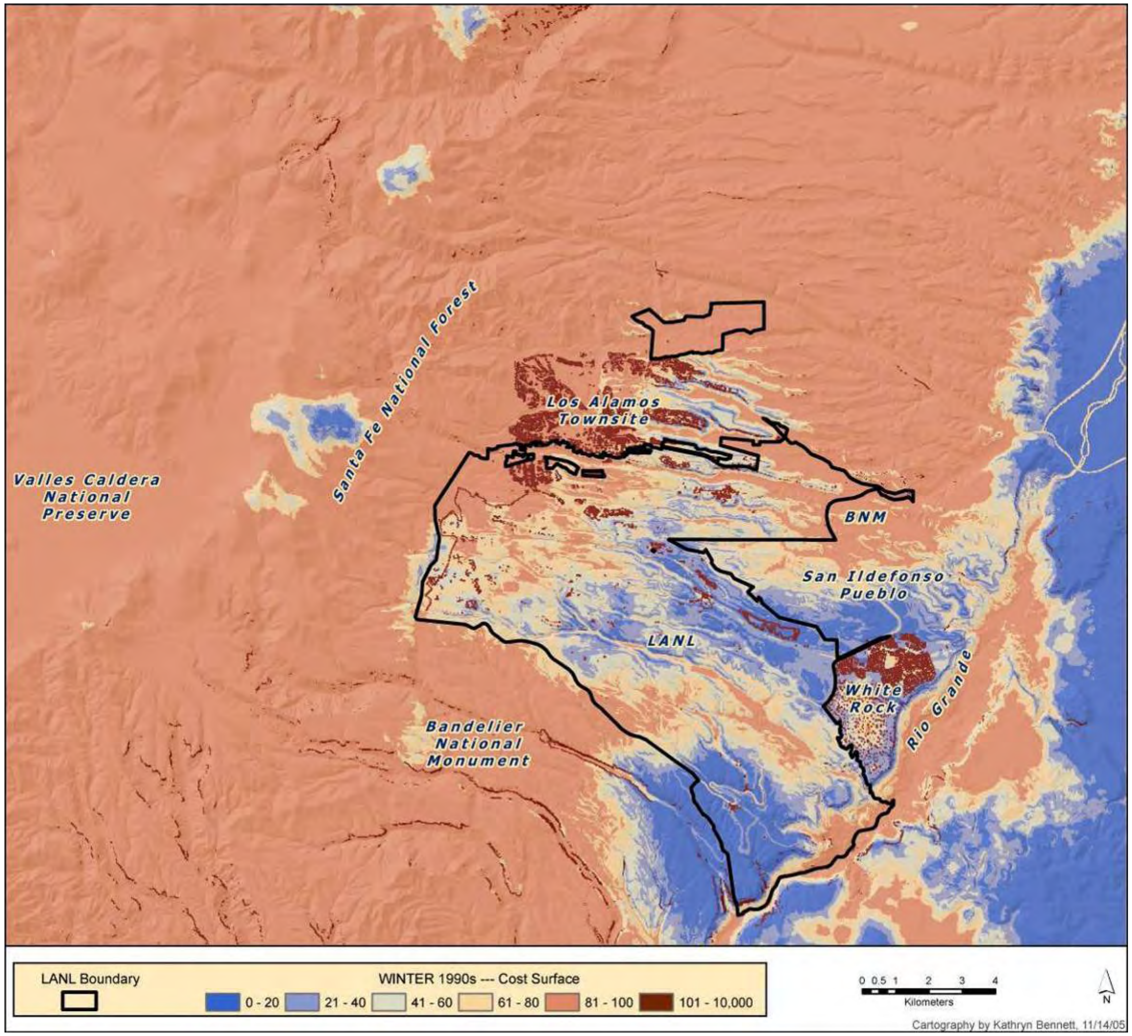


Figure 26. The winter 1990s cost surface.

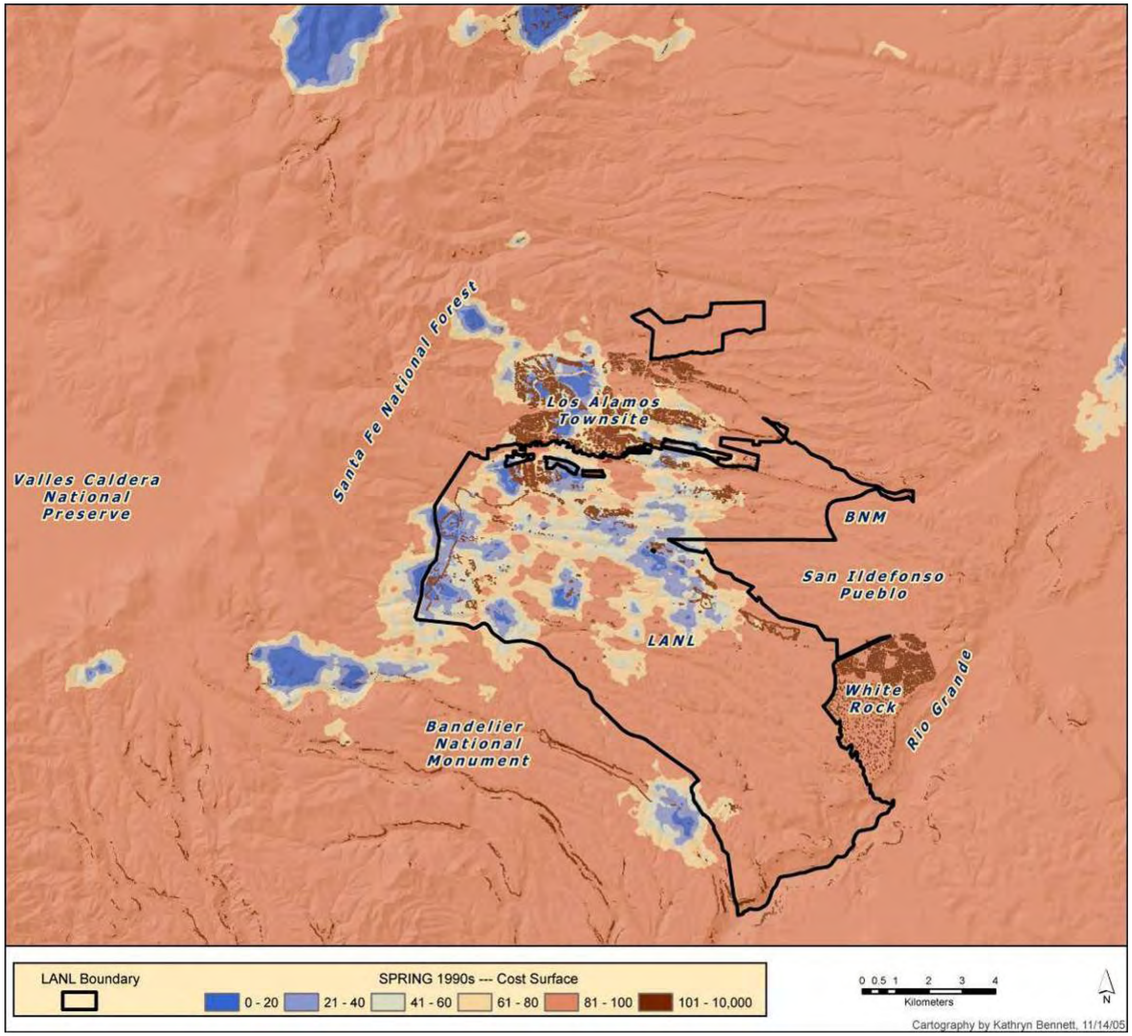


Figure 27. The spring 1990s cost surface.

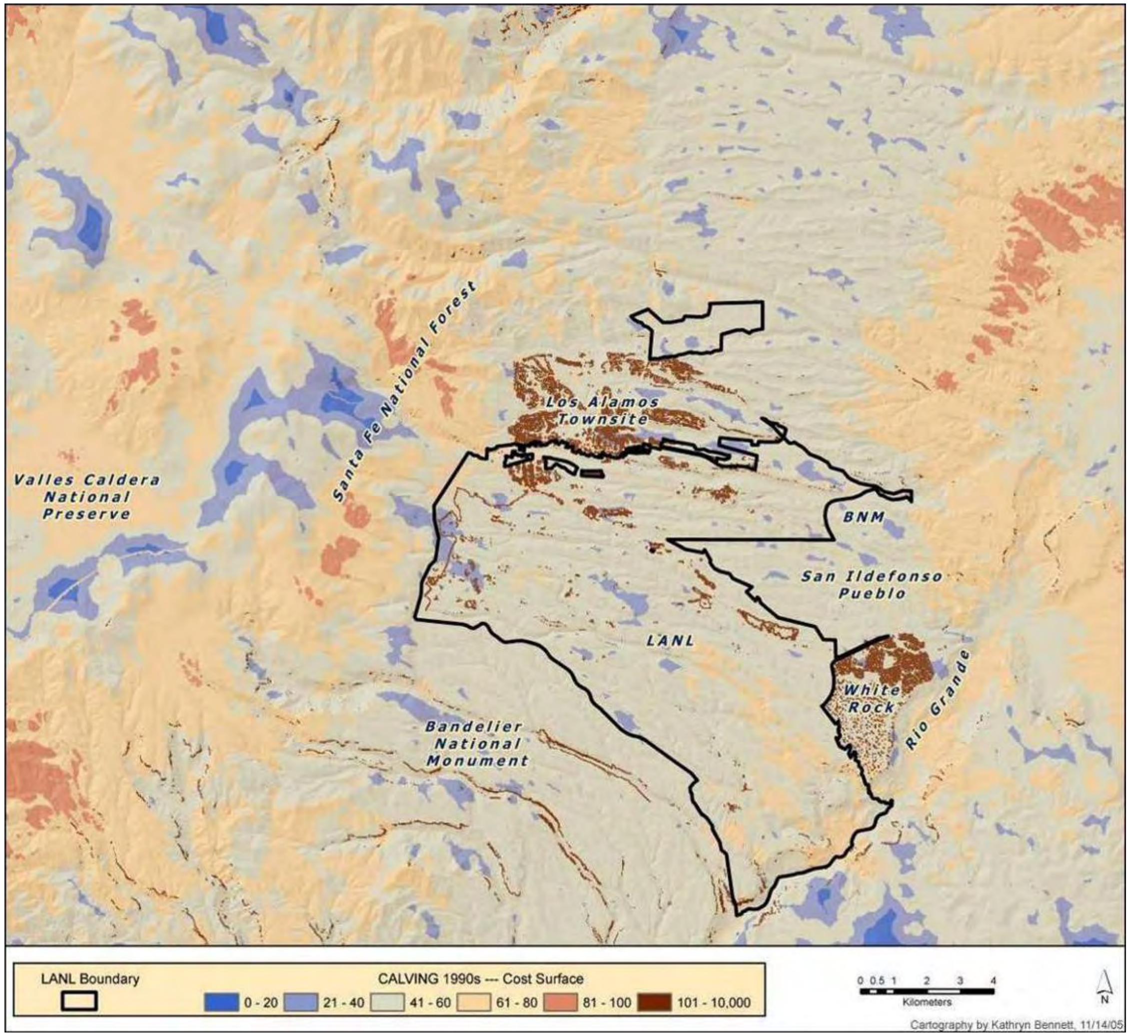


Figure 28. The calving 1990s cost surface

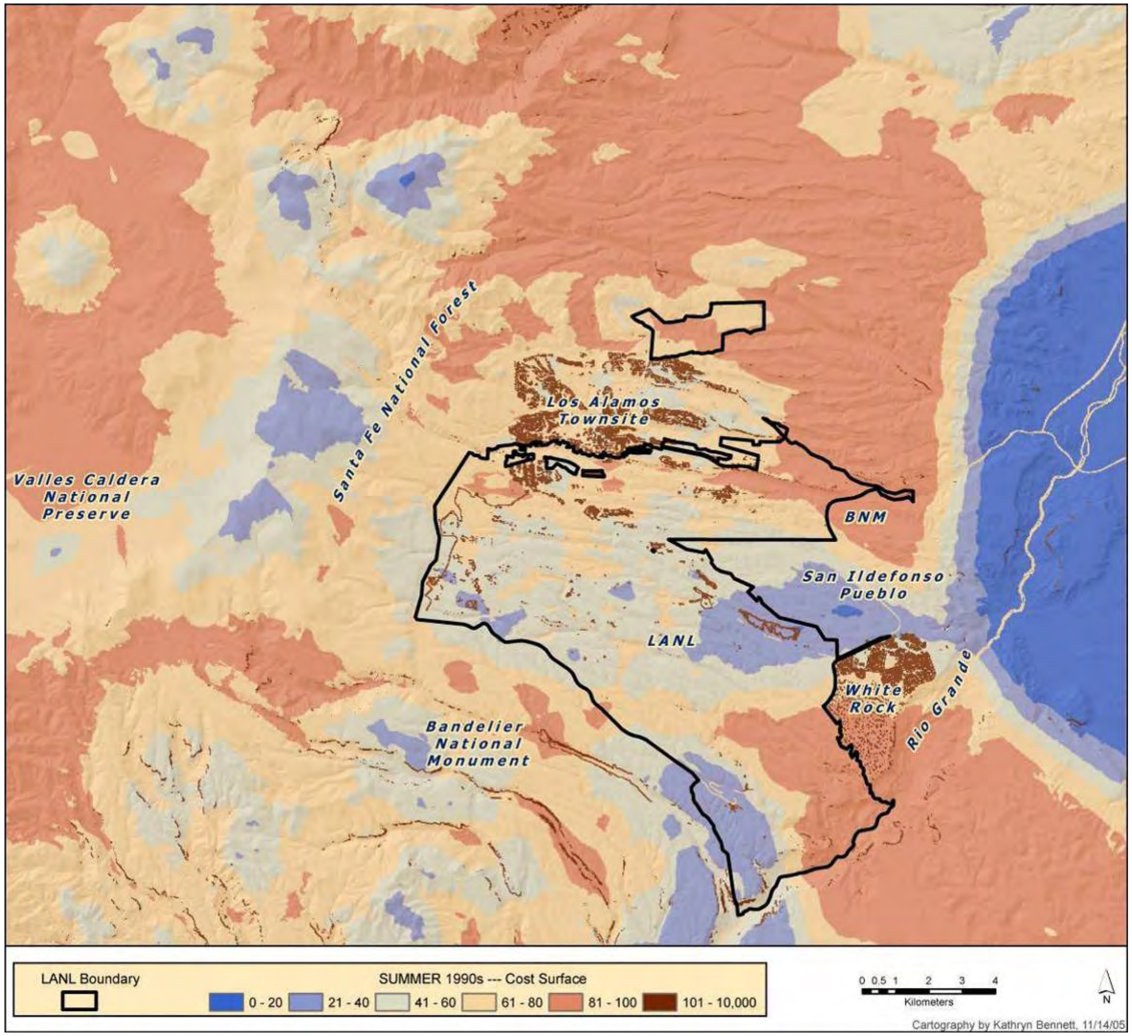


Figure 29. The summer 1990s cost surface

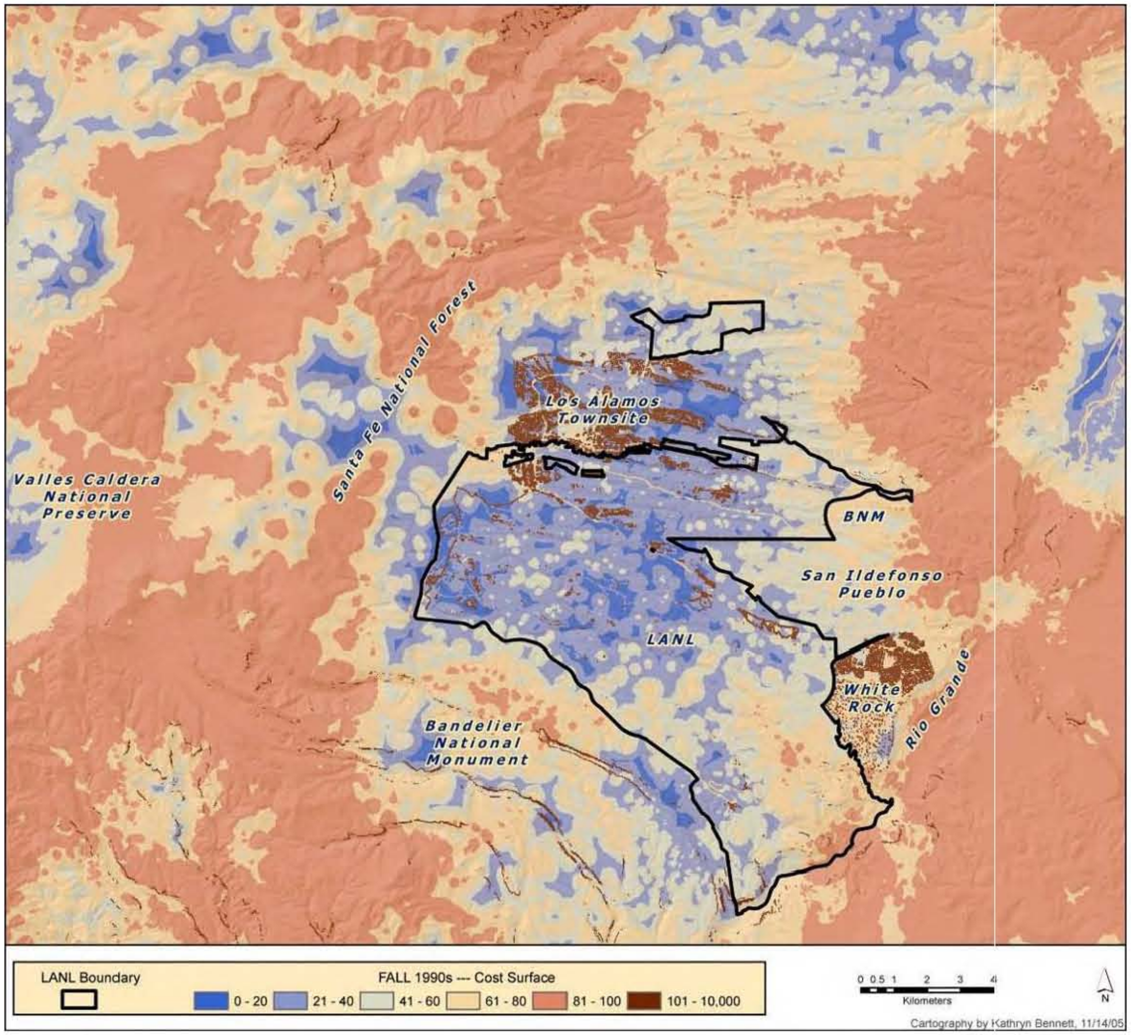


Figure 30. The fall 1990s cost surface.

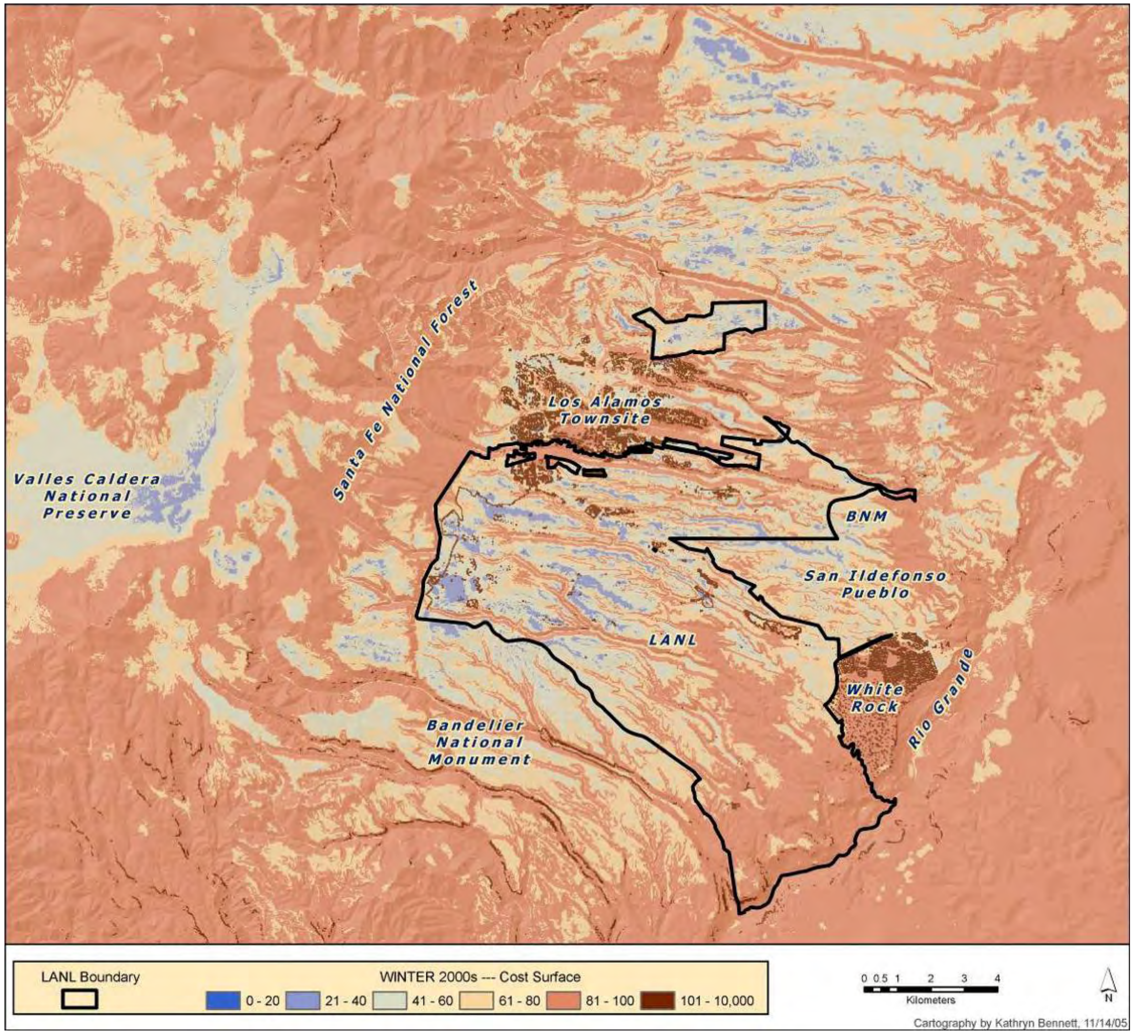


Figure 31. The winter 2000s cost surface.

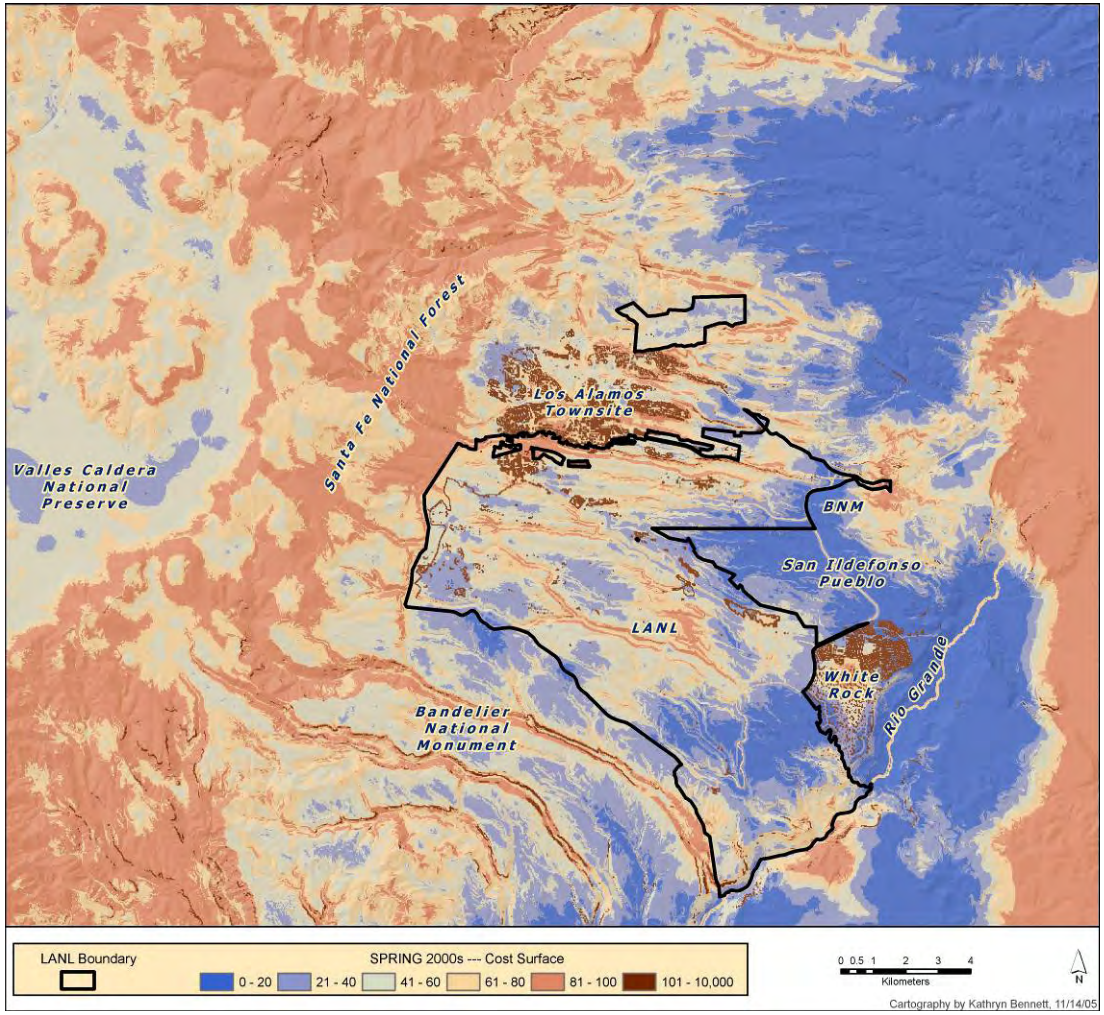


Figure 32. The spring 2000s cost surface.

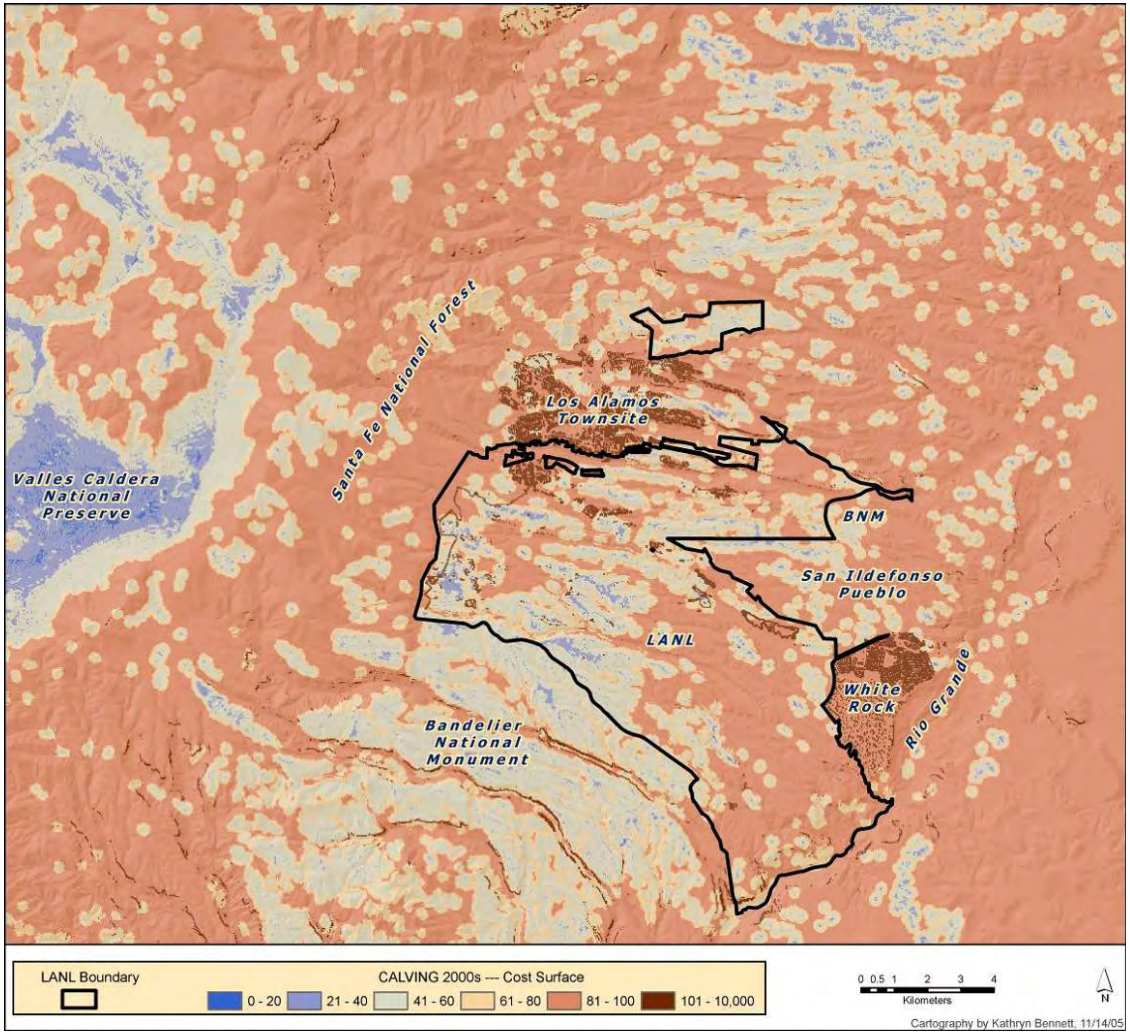


Figure 33. The calving 2000s cost surface.

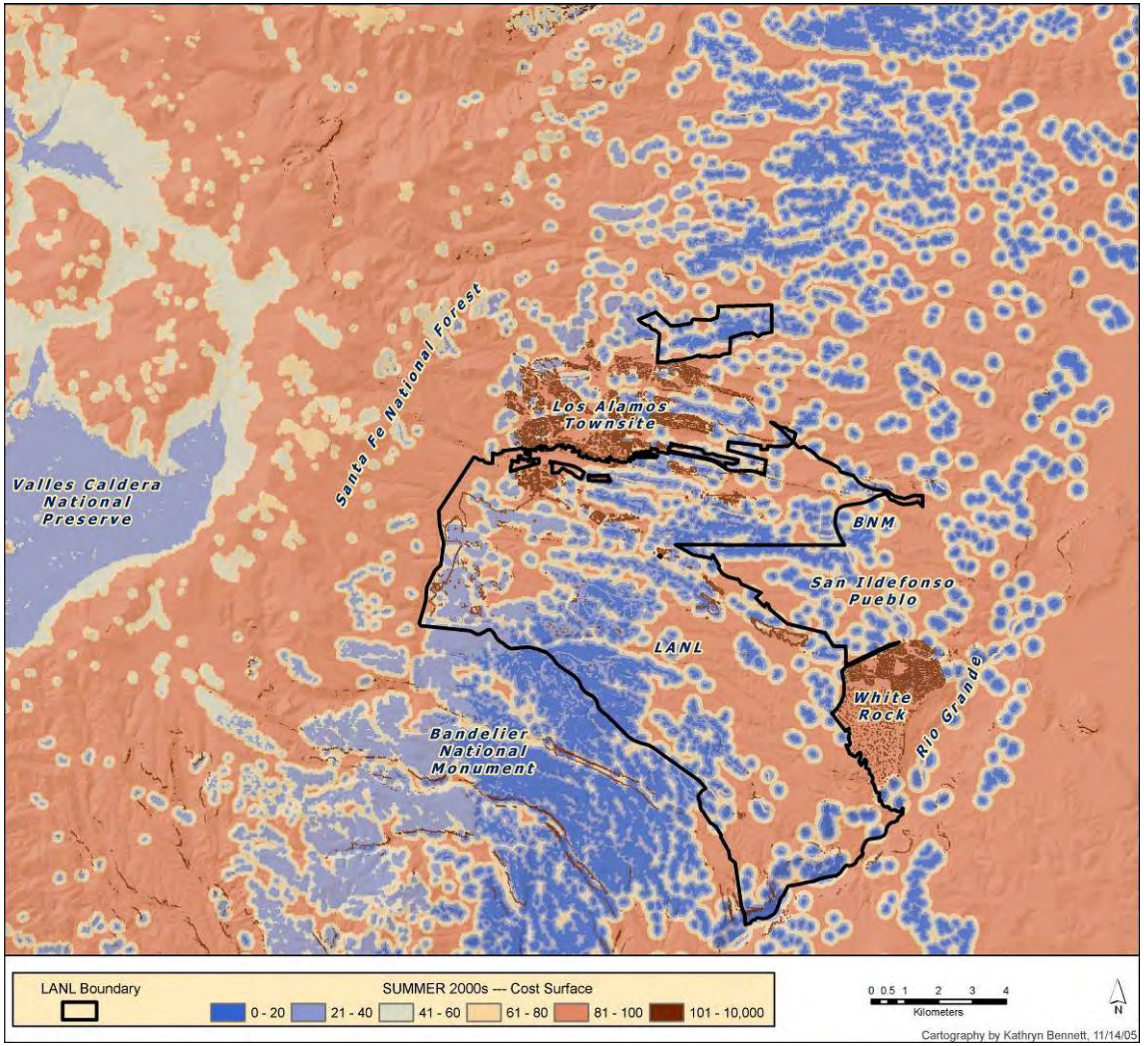


Figure 34. The summer 2000s cost surface.

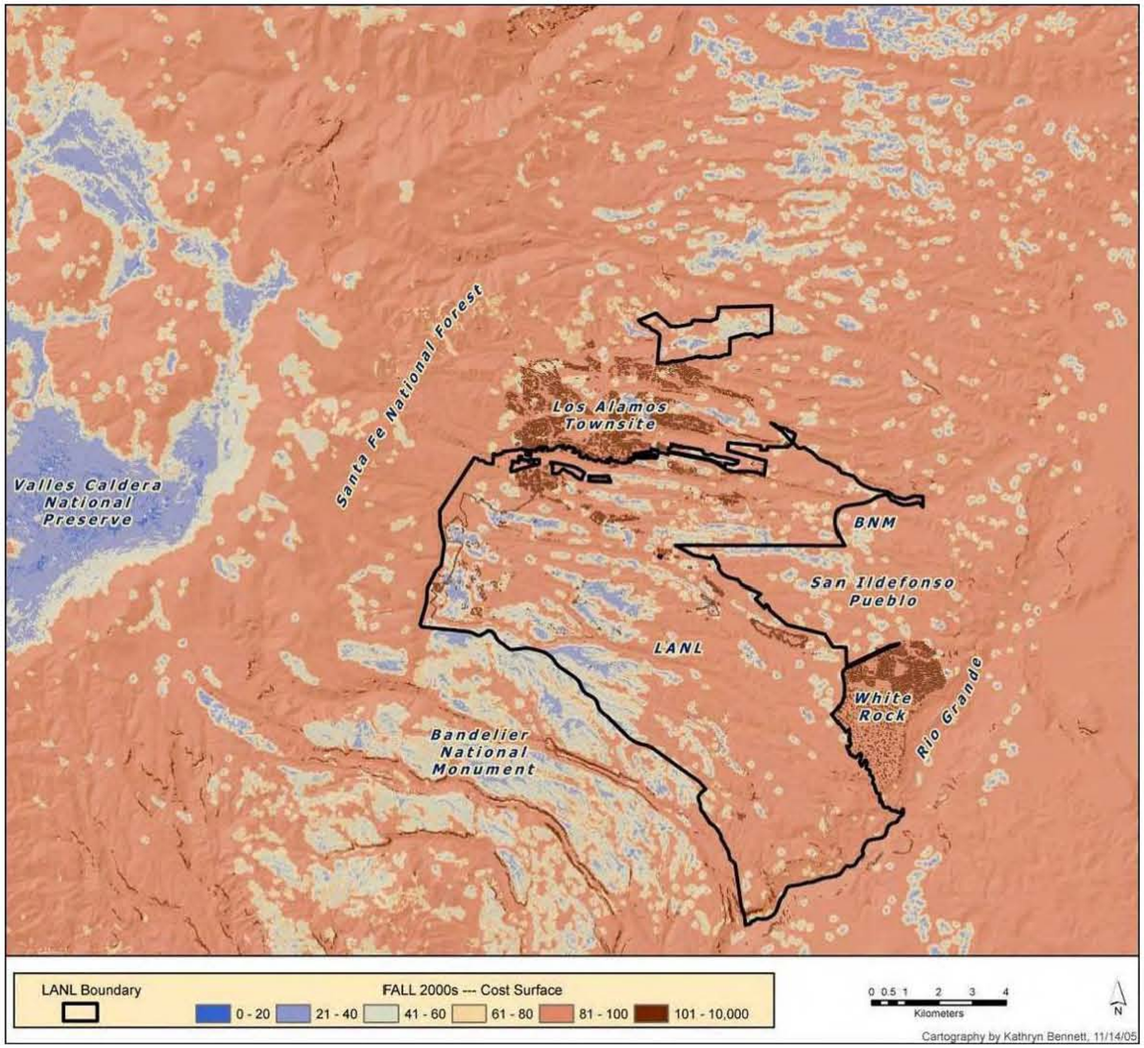


Figure 35. The fall 2000s cost surface.

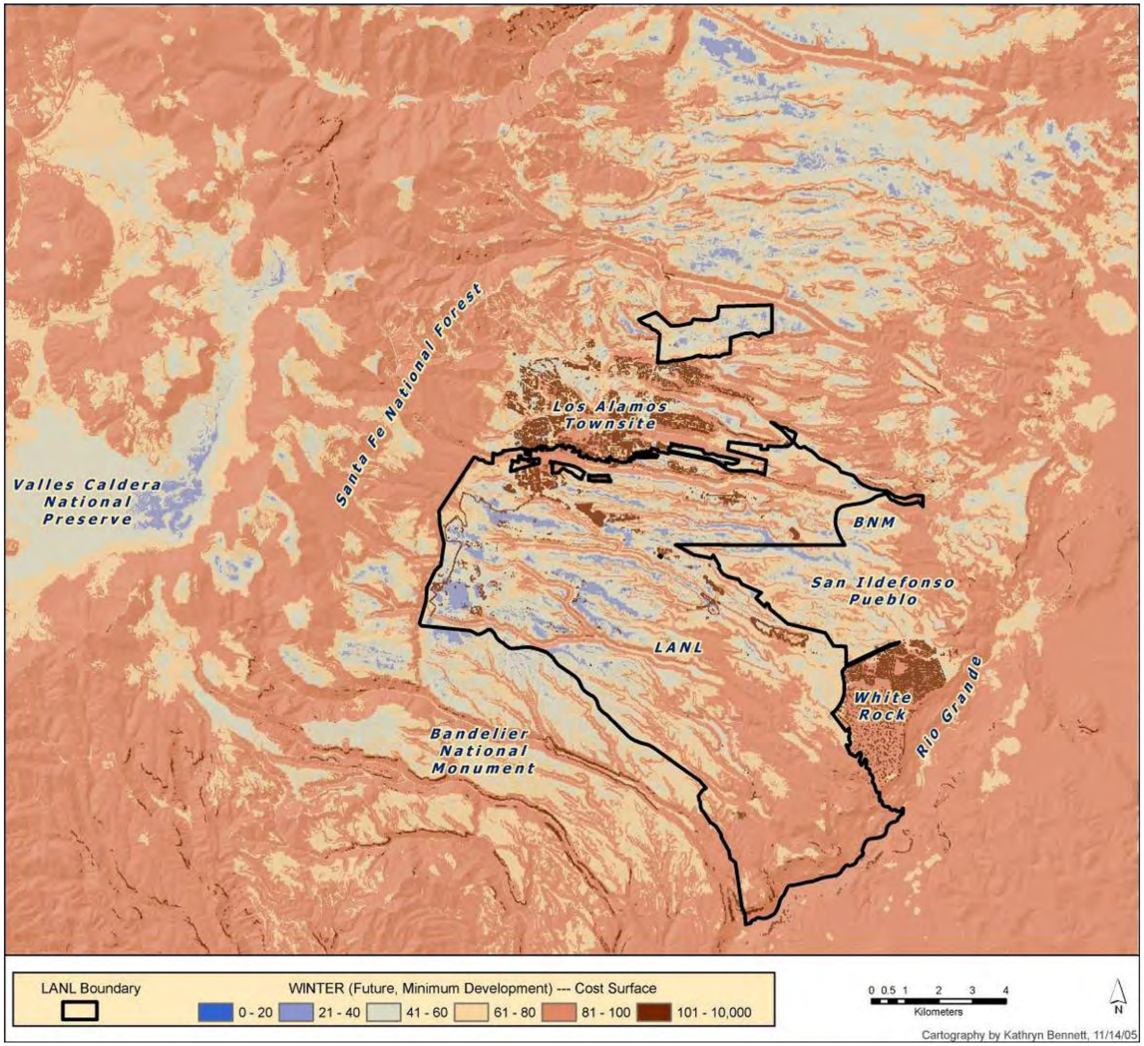


Figure 36. The future winter cost surface with minimum development.

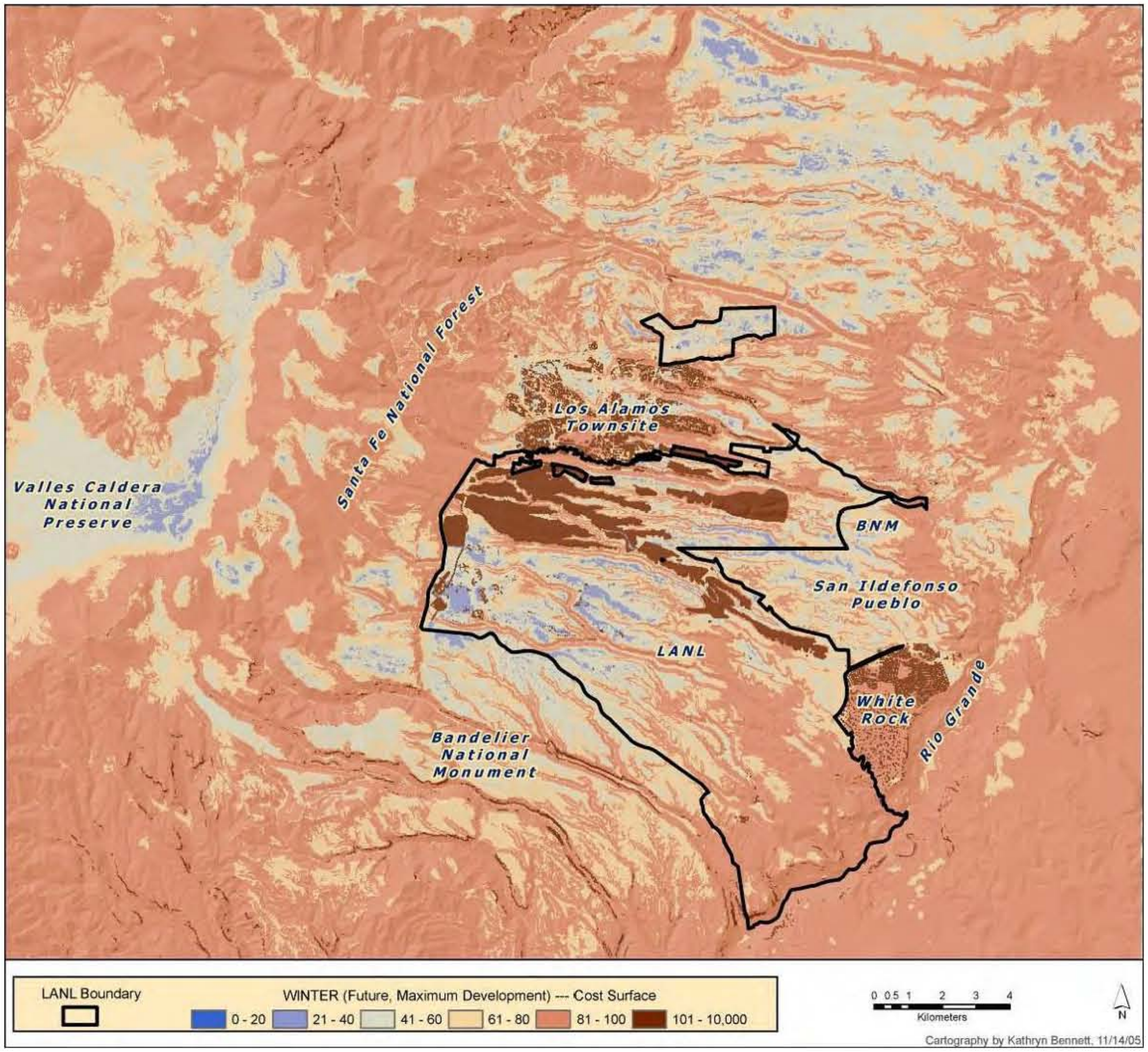


Figure 37. The future winter cost surface with maximum development.

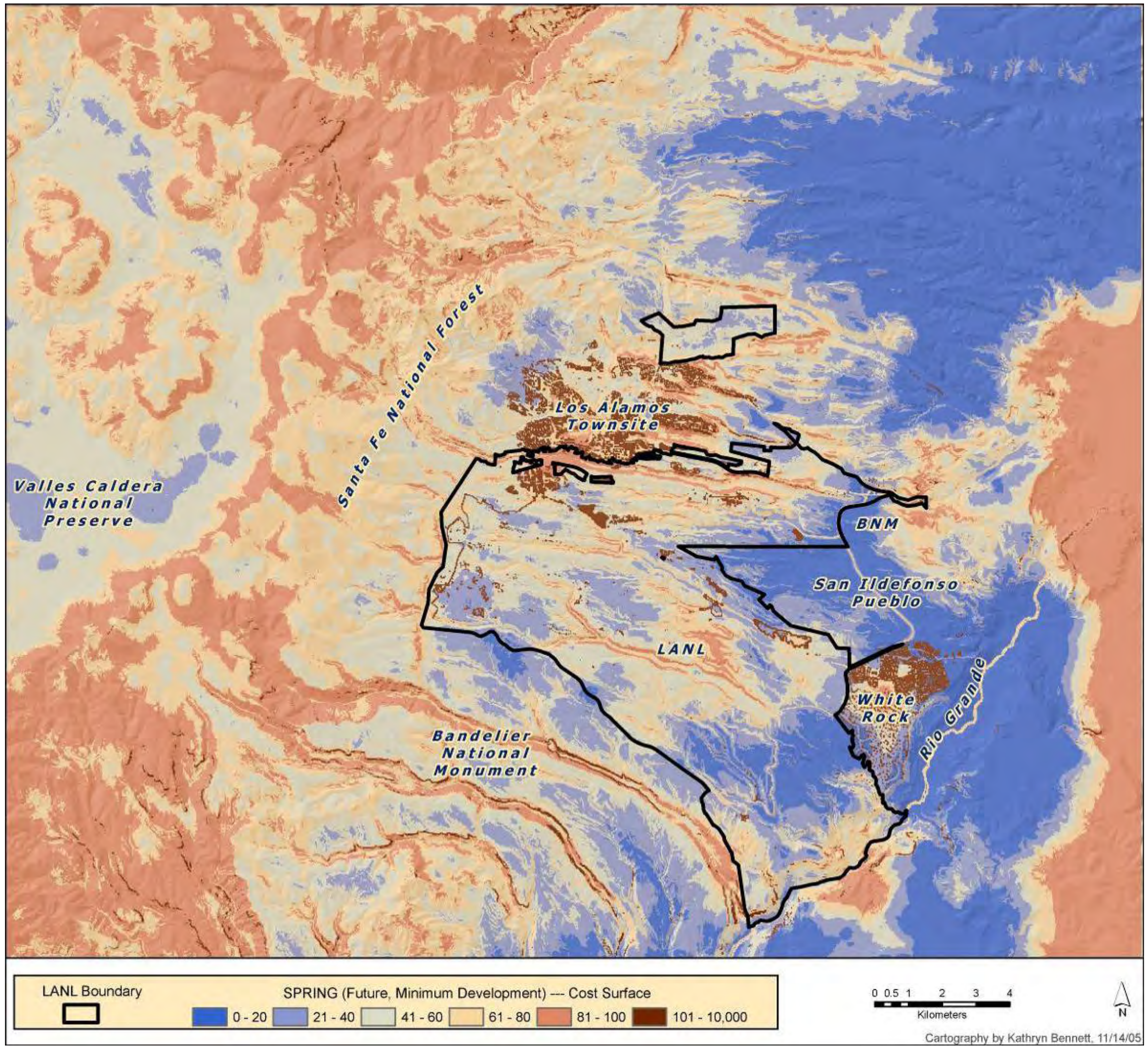


Figure 38. The future spring cost surface with minimum development.

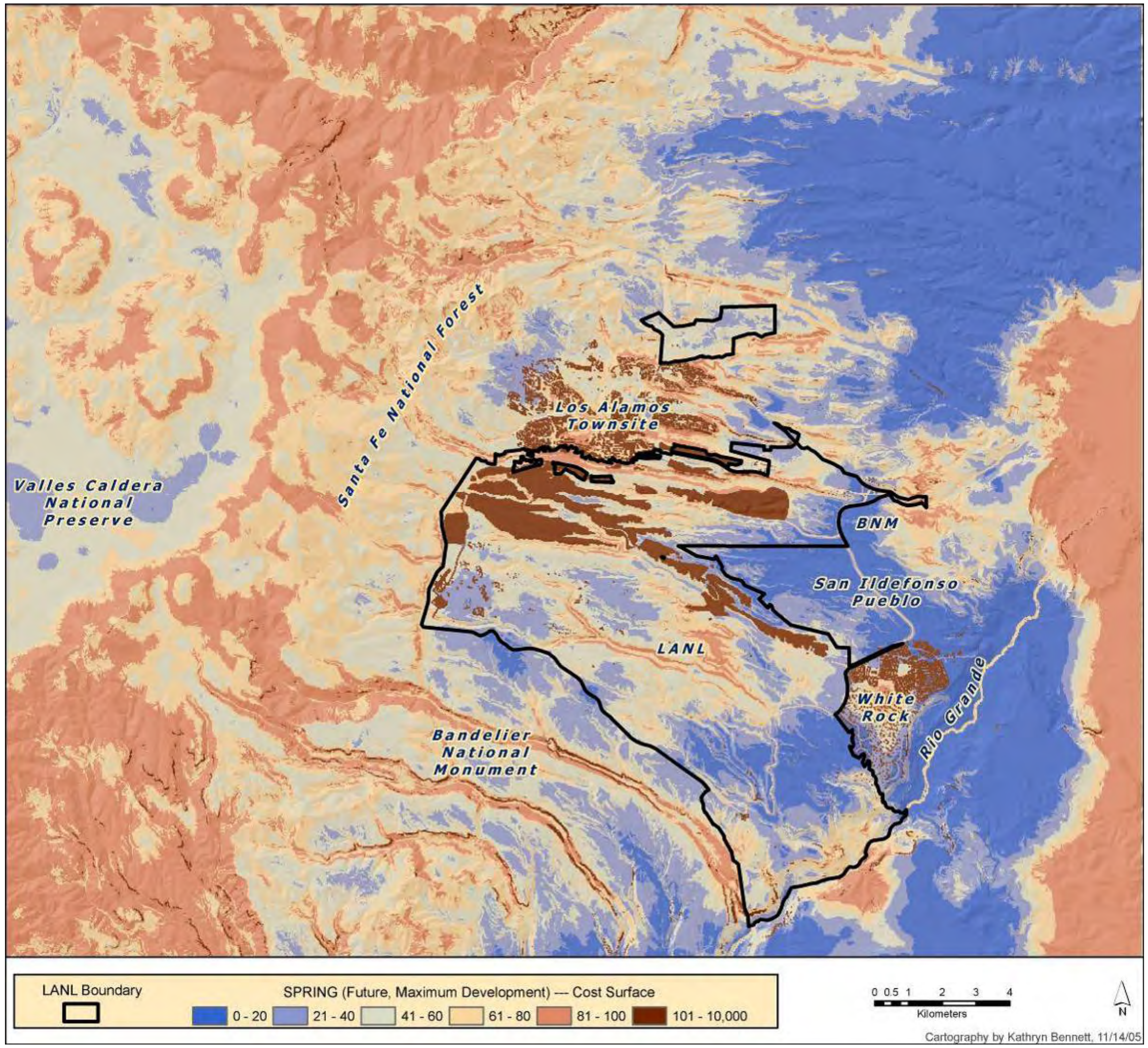


Figure 39. The future spring cost surface with maximum development.

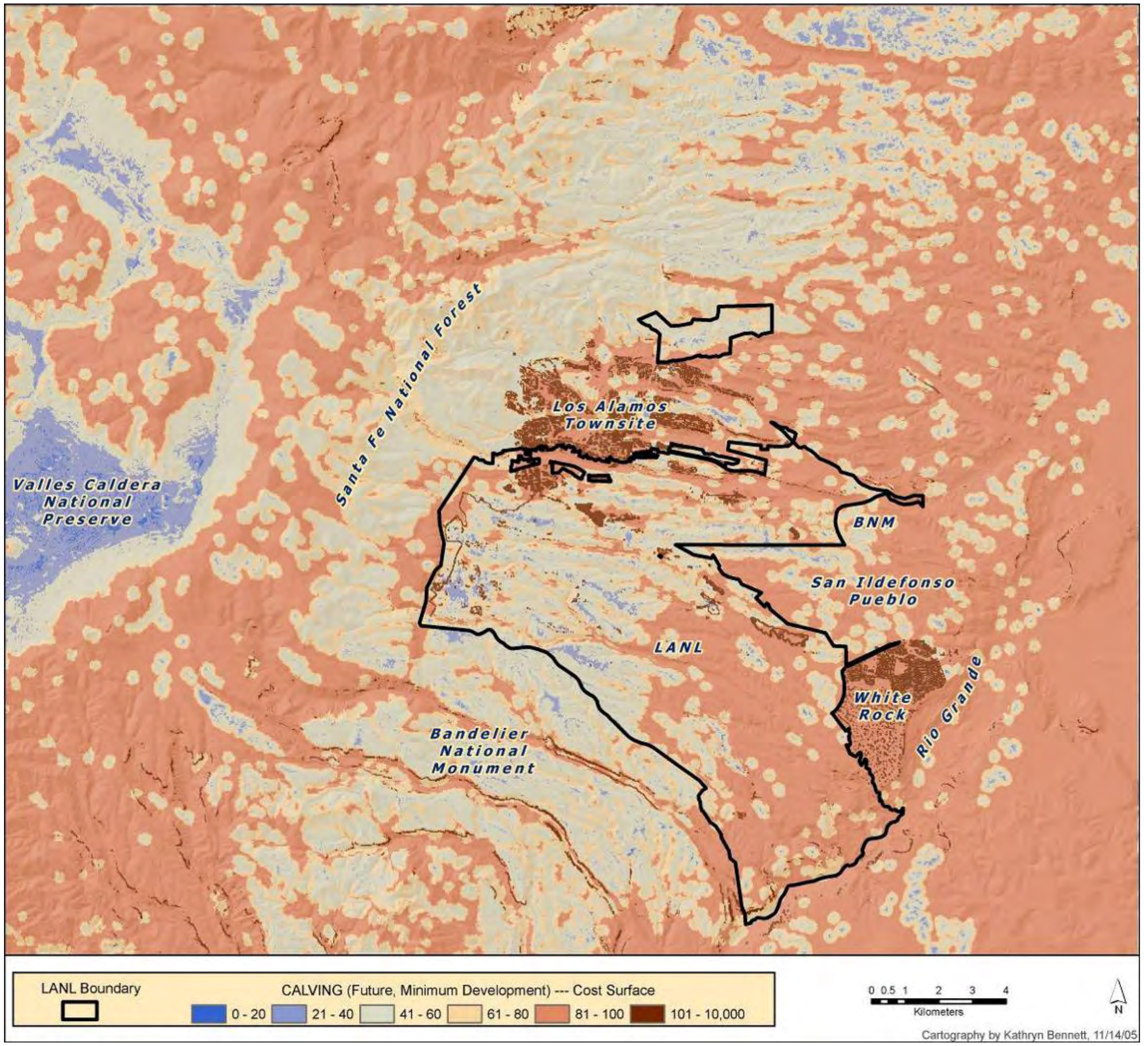


Figure 40. The future calving cost surface with minimum development.

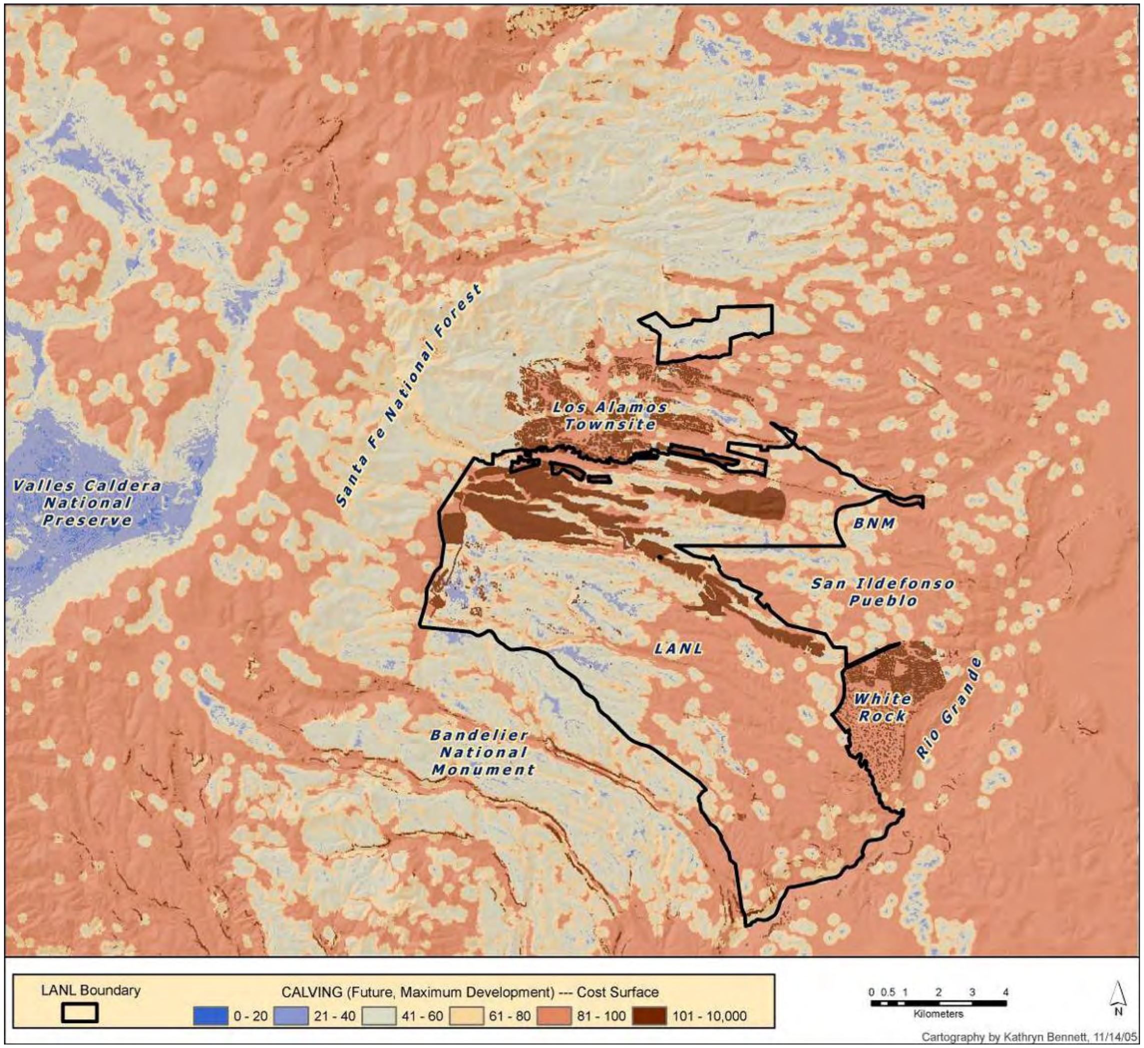


Figure 41. The future calving cost surface with maximum development.

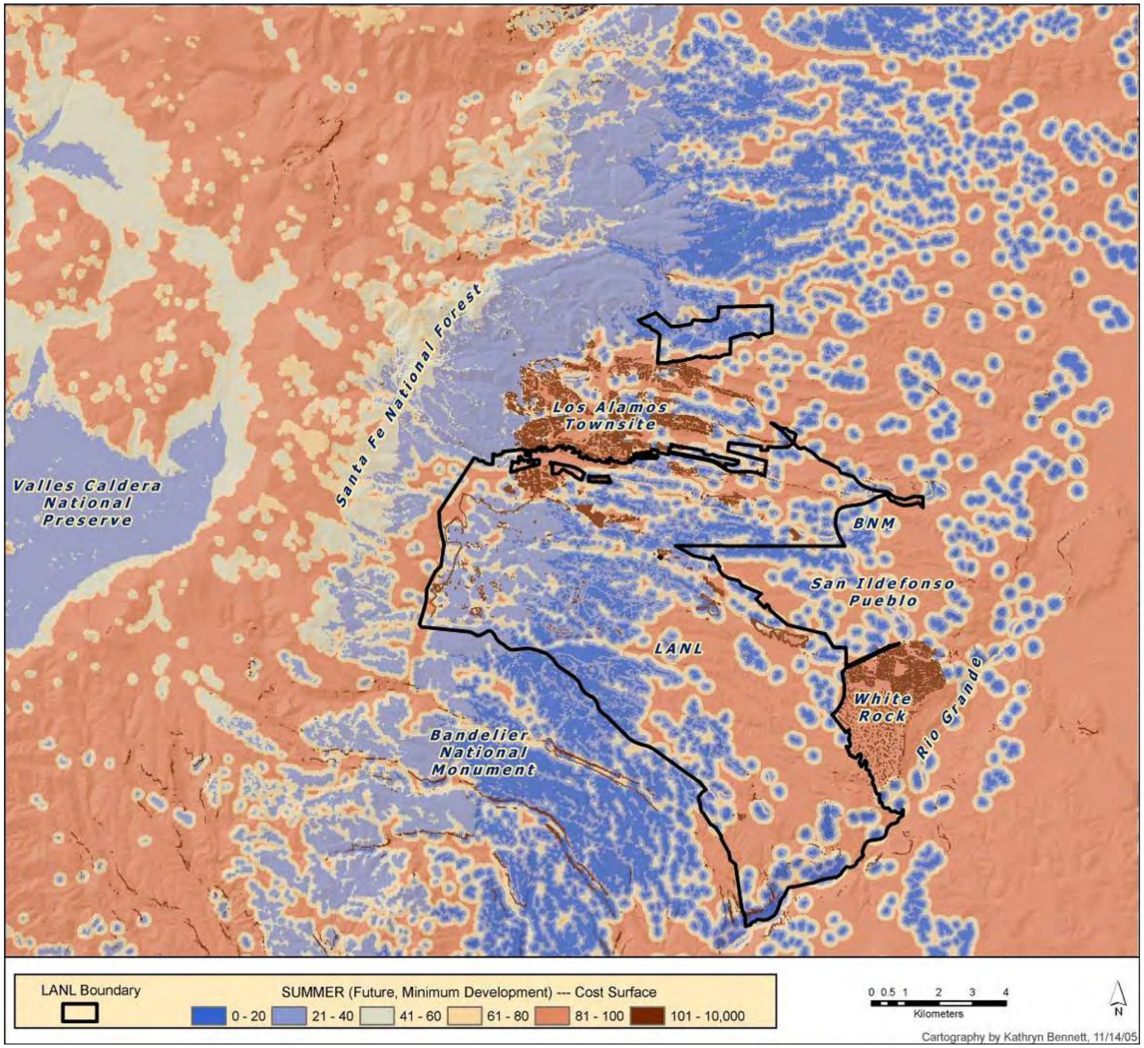


Figure 42. The future summer cost surface with minimum development.

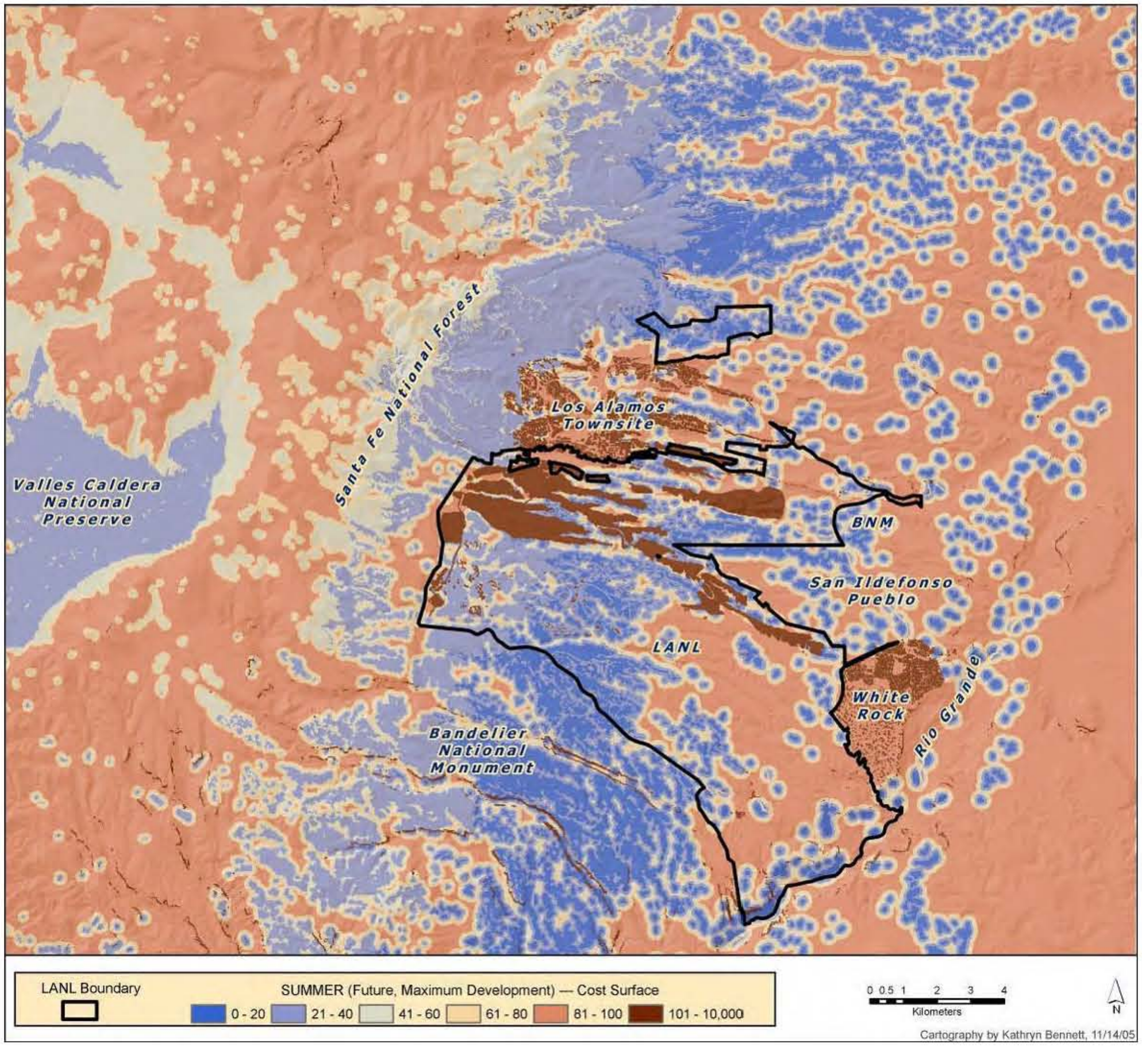


Figure 43. The future summer cost surface with maximum development.

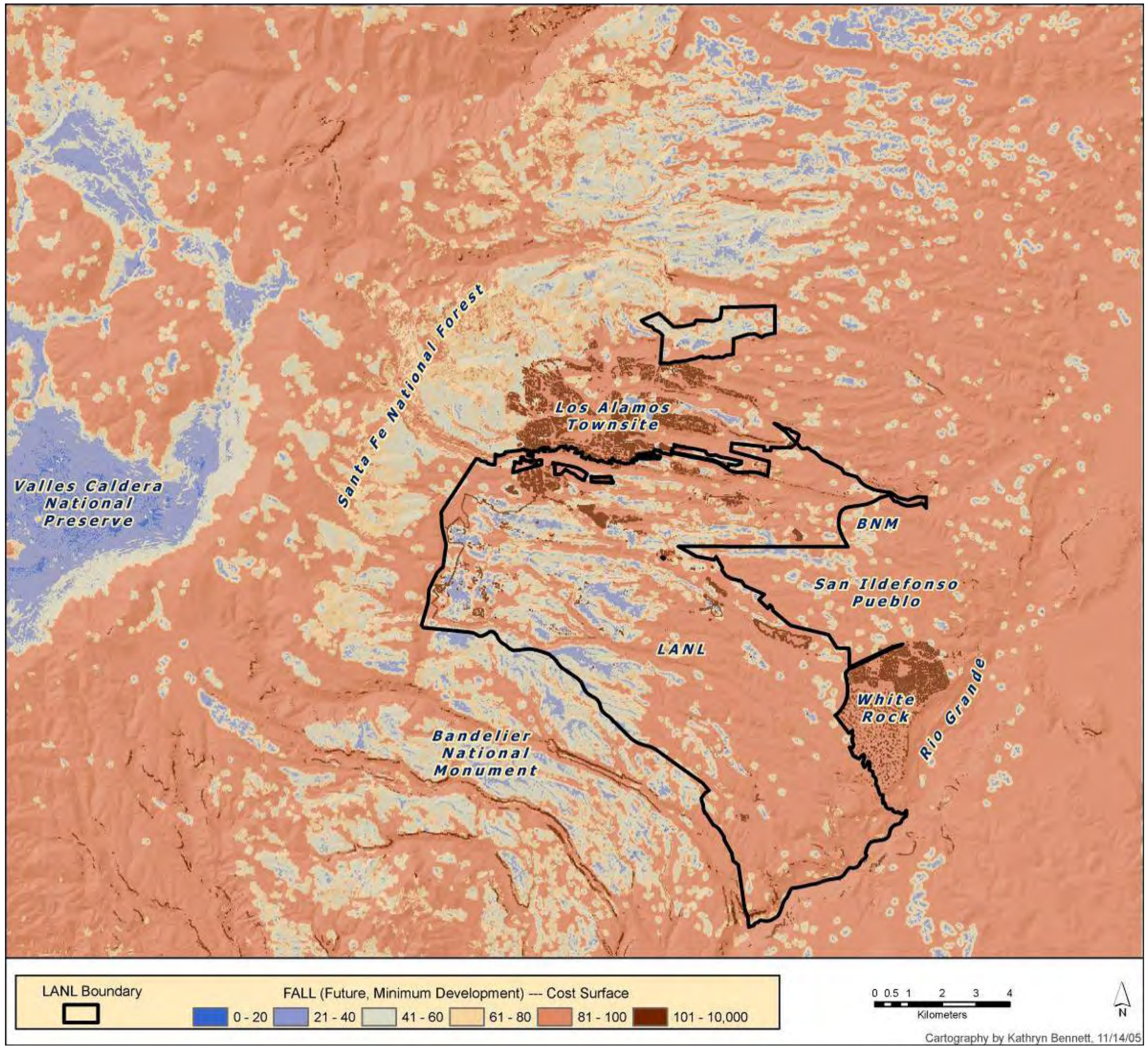


Figure 44. The future fall cost surface with minimum development.

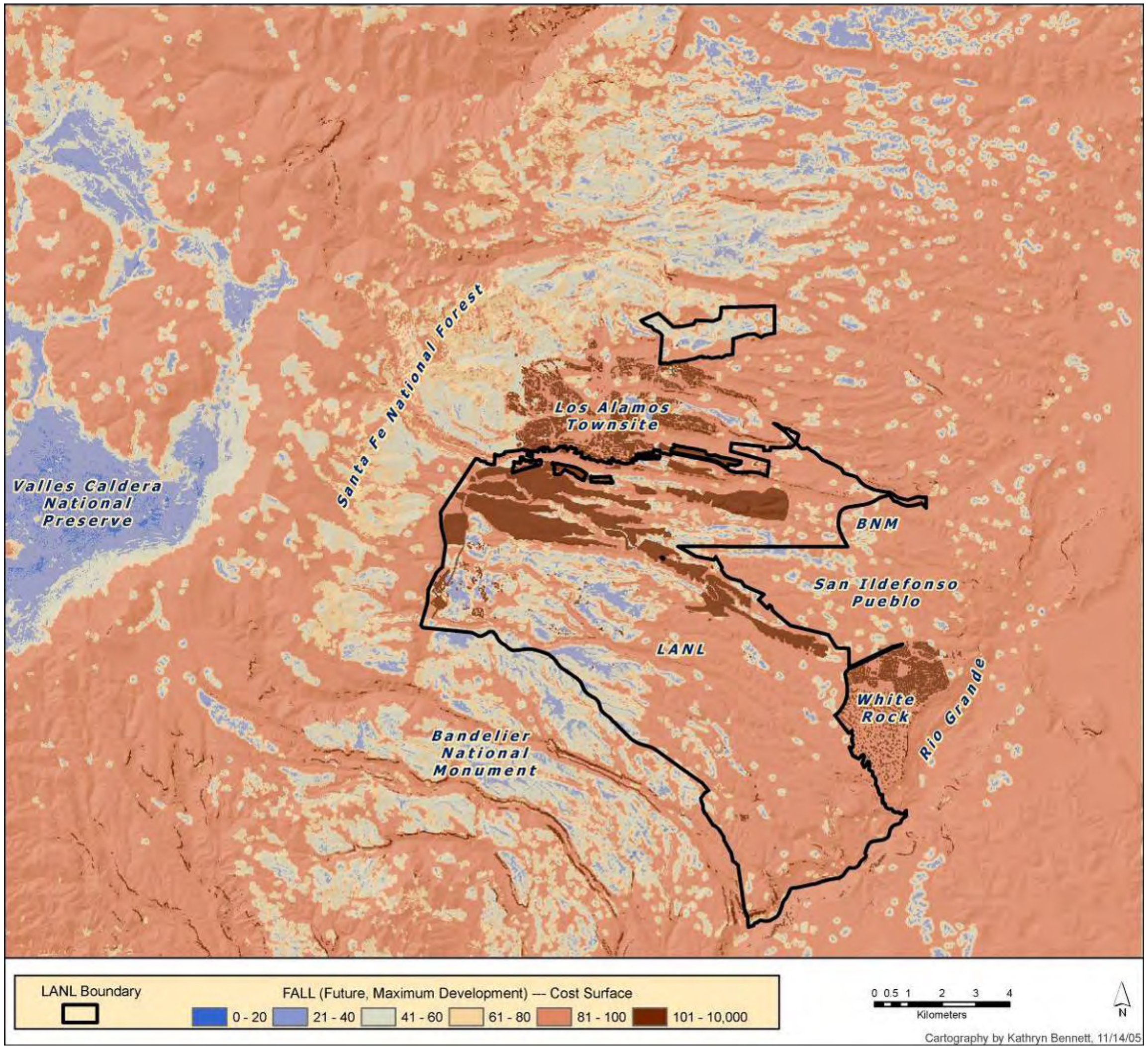


Figure 45. The future fall cost surface with maximum development

and 2000s cost surface look fairly similar to the HS model with the exception of the dark red barrier features (Figures 26 through 35). Extreme barrier features are very similar from 1990s to 2000s. Close visual inspection showed a decrease in extreme barrier features in the western portion of LANL and the northwest portion of Los Alamos townsite in the 2000s time period. This decrease in extreme barrier features was due to the loss of buildings and structures as the result of the Cerro Grande wildfire. Dark blue areas in the HS model that represented high suitability areas are shown in dark blue in the cost surface indicating low impedance.

The future cost surface includes both a minimum development and a maximum development cost surface (Figures 36 through 45). There are slight differences between the future minimum cost surfaces of each season to those developed for the 2000s. The major difference between the two is the decrease in impedance in areas in the western portion of LANL and northwest of LANL. These areas represent portions of the Cerro Grande burn. This decrease in impedance was seen in all future seasonal maps except for winter (future winter HS model is unchanged from the 2000s model). In addition, there were a few additional high barrier features located in the northwest and north central portions of LANL. The maximum development scenario has both the decrease in impedance due to Cerro Grande fire and the increase in impedance due to new development areas. The majority of these high impedance areas are located in the north portion of the LANL.

3.0. Least-cost Paths

Least-cost paths were developed by utilizing the cost surfaces created for each season, source, and destination areas. Sources and destinations areas were developed from seasonal elk relocation point density surfaces with source areas being defined within LANL boundaries and destinations in neighboring areas. Figures 46 through 65 show the seasonal least-cost paths by time period overlaid on the seasonal cost surface. Source areas were designated numerically (1,2,3...) and destinations alphabetically (A,B,C...). Destinations points were defined in areas of US Forest Service (west of LANL), BNM (southwest of LANL) and San Ildefonso (east of LANL). The size of the destination areas were directly related to the extent of the high density areas. The majority of all source locations were developed in the western, central, and southeastern portions of LANL.

The effects of extreme barrier features were seen in the paths selected. A linear extreme barrier feature paralleled the LANL boundary on the west for some distance. Predicted paths did not cross this barrier but instead were routed around it either to the southwest or northwest. This routing resulted in two critical areas being formed. Without these two areas, major changes in movement might occur and a complete movement barrier on to or off of LANL might be created. In general, paths did not cross extreme barrier features unless there was no other route with lower cost available. Crossing extreme barrier features was seen in some paths generated for the future maximum development scenario. In these scenarios, the future development resulted in a very large extreme barrier feature being formed from west to east in the central portion of LANL and the model could not

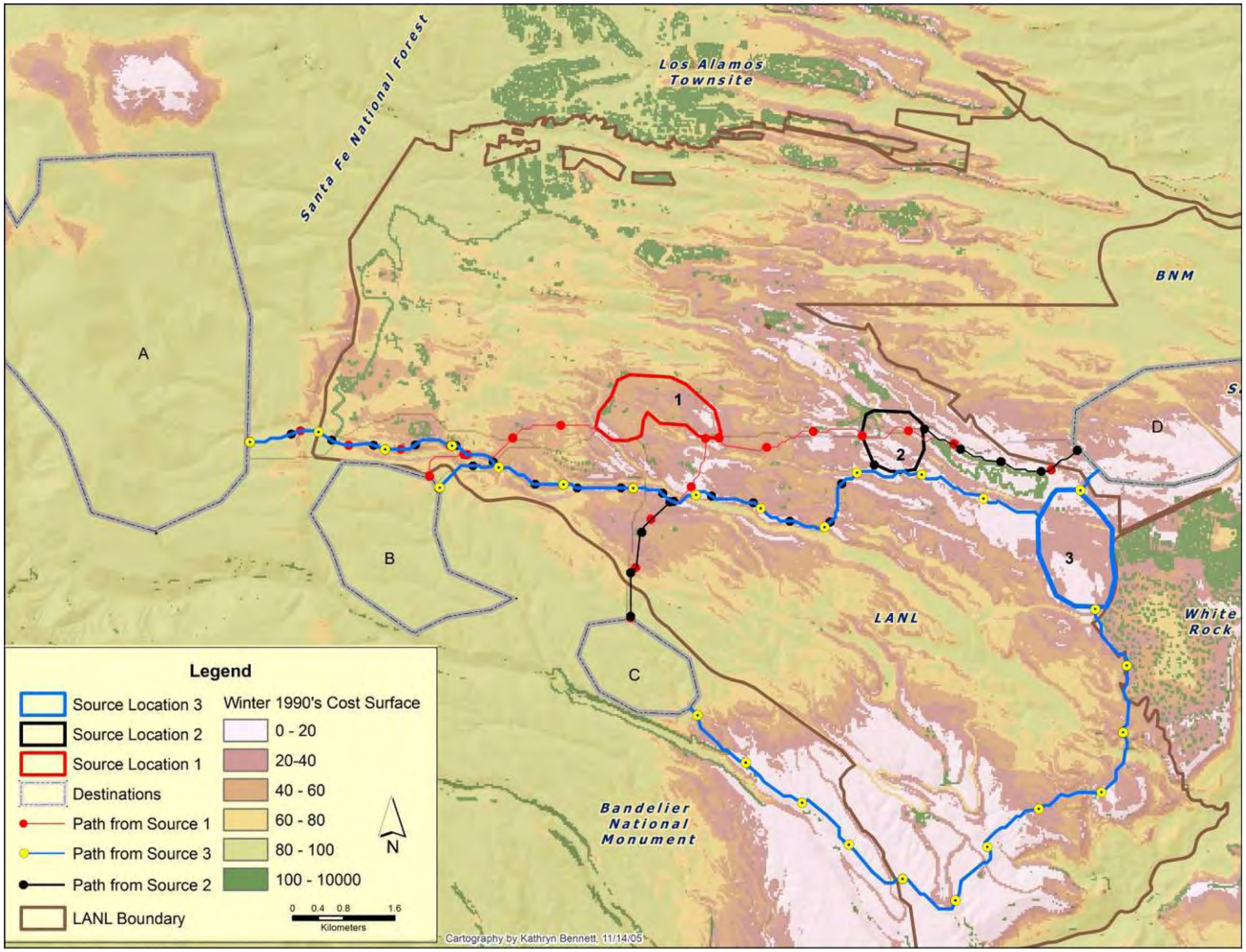


Figure 46. The winter least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for 1990s.

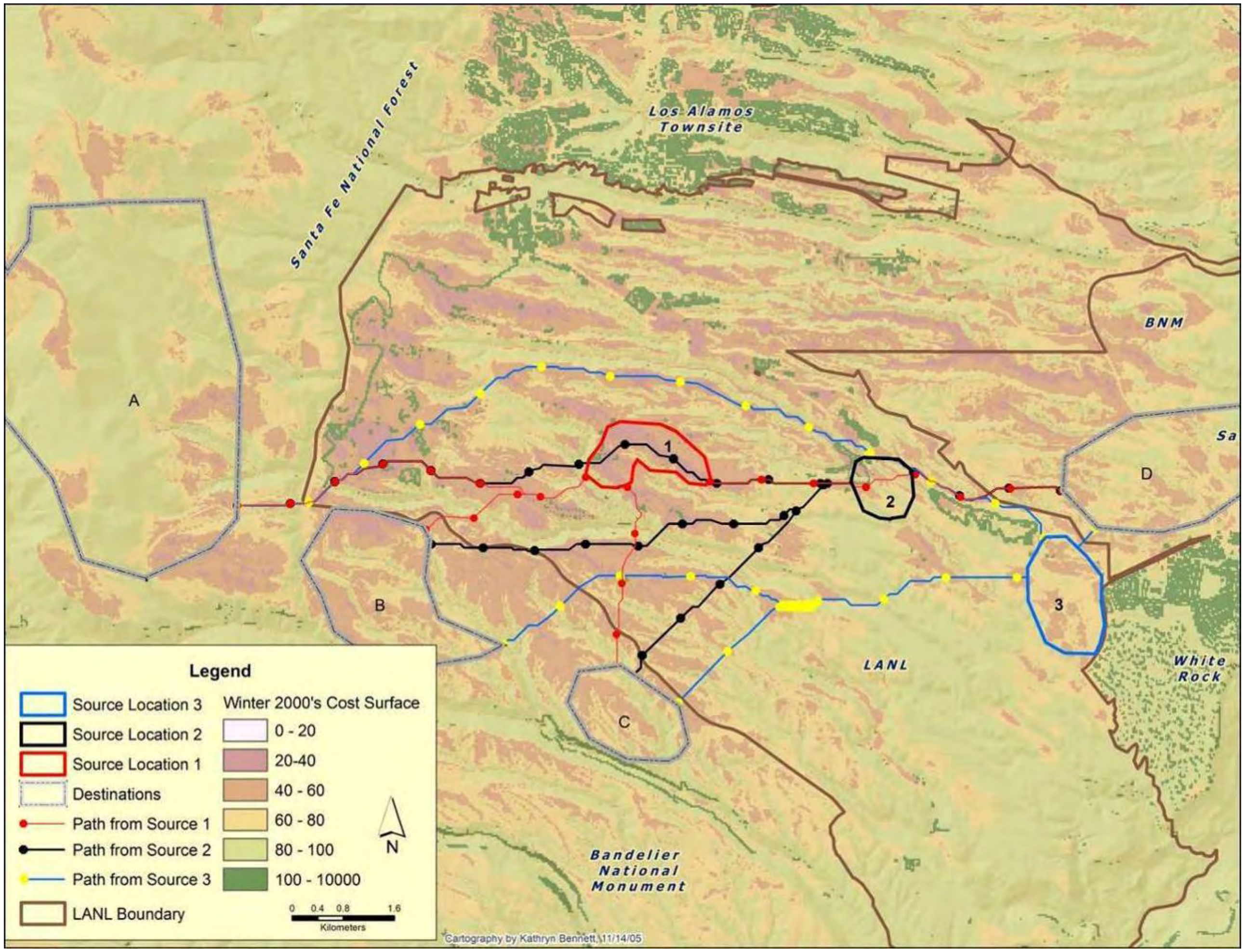


Figure 47. The winter least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for 2000s.

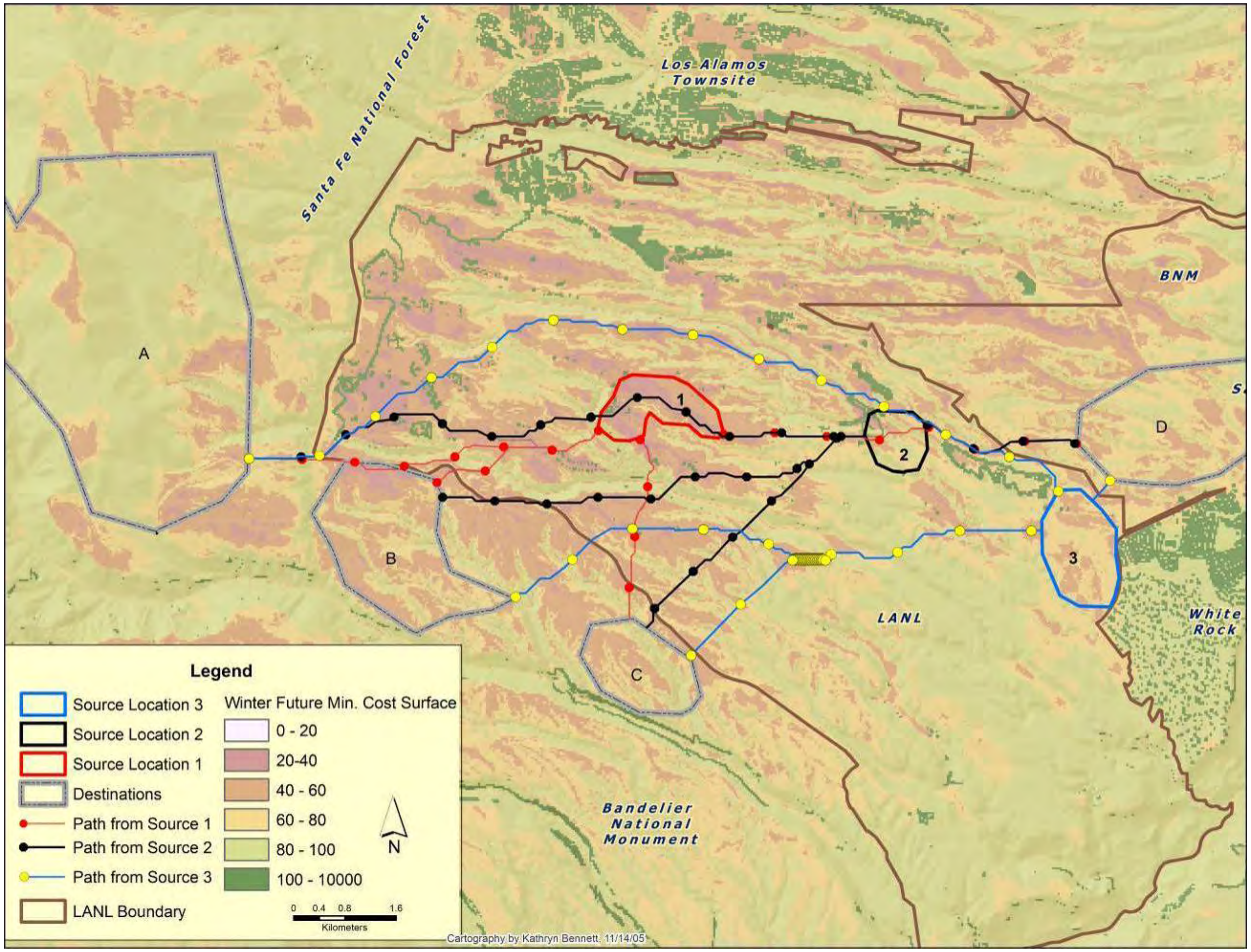


Figure 48. The winter least-cost paths generated from source areas (numbered to destinations (labeled with letters) for the future scenario with minimal development.

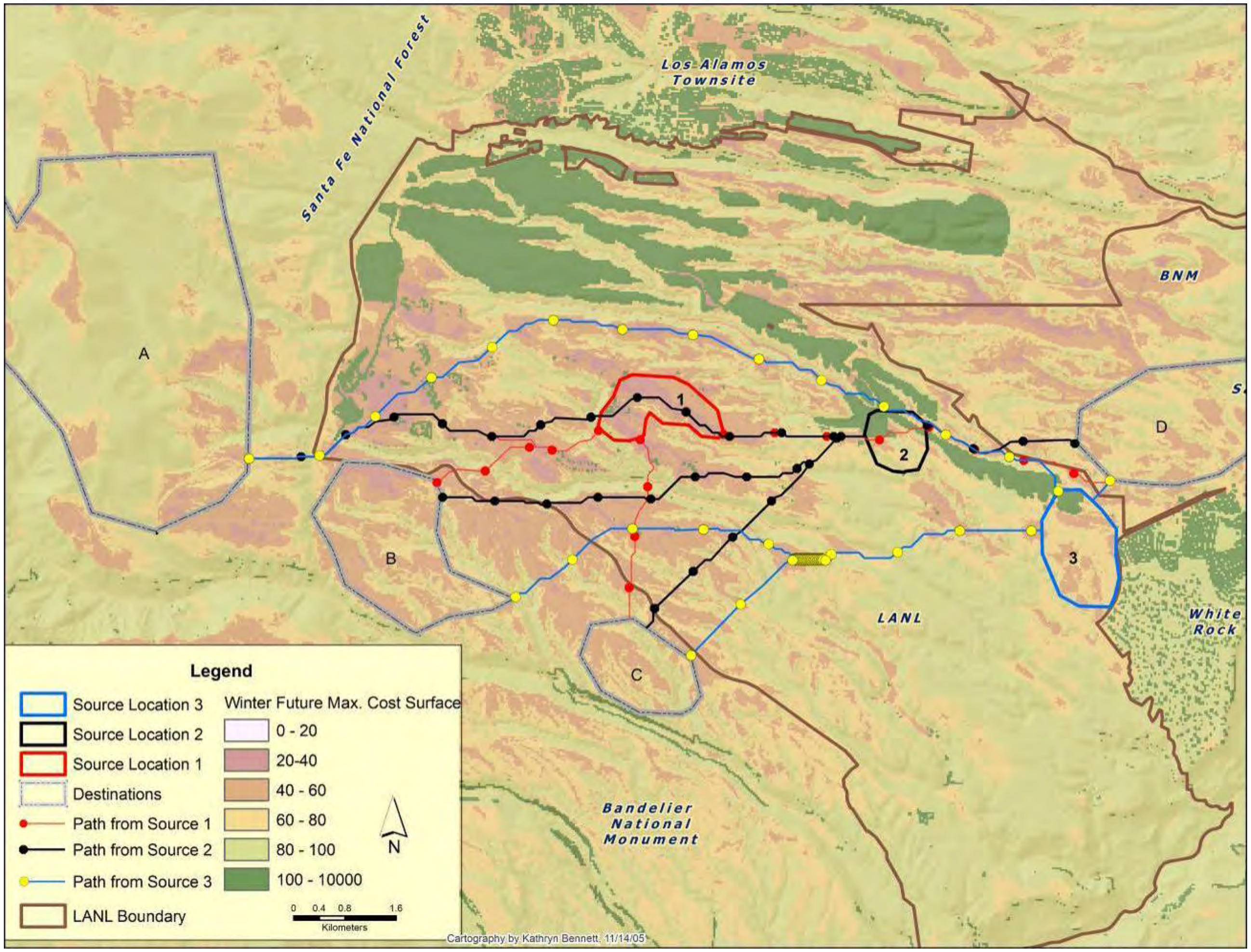


Figure 49. The winter least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for the future scenario with maximum development.

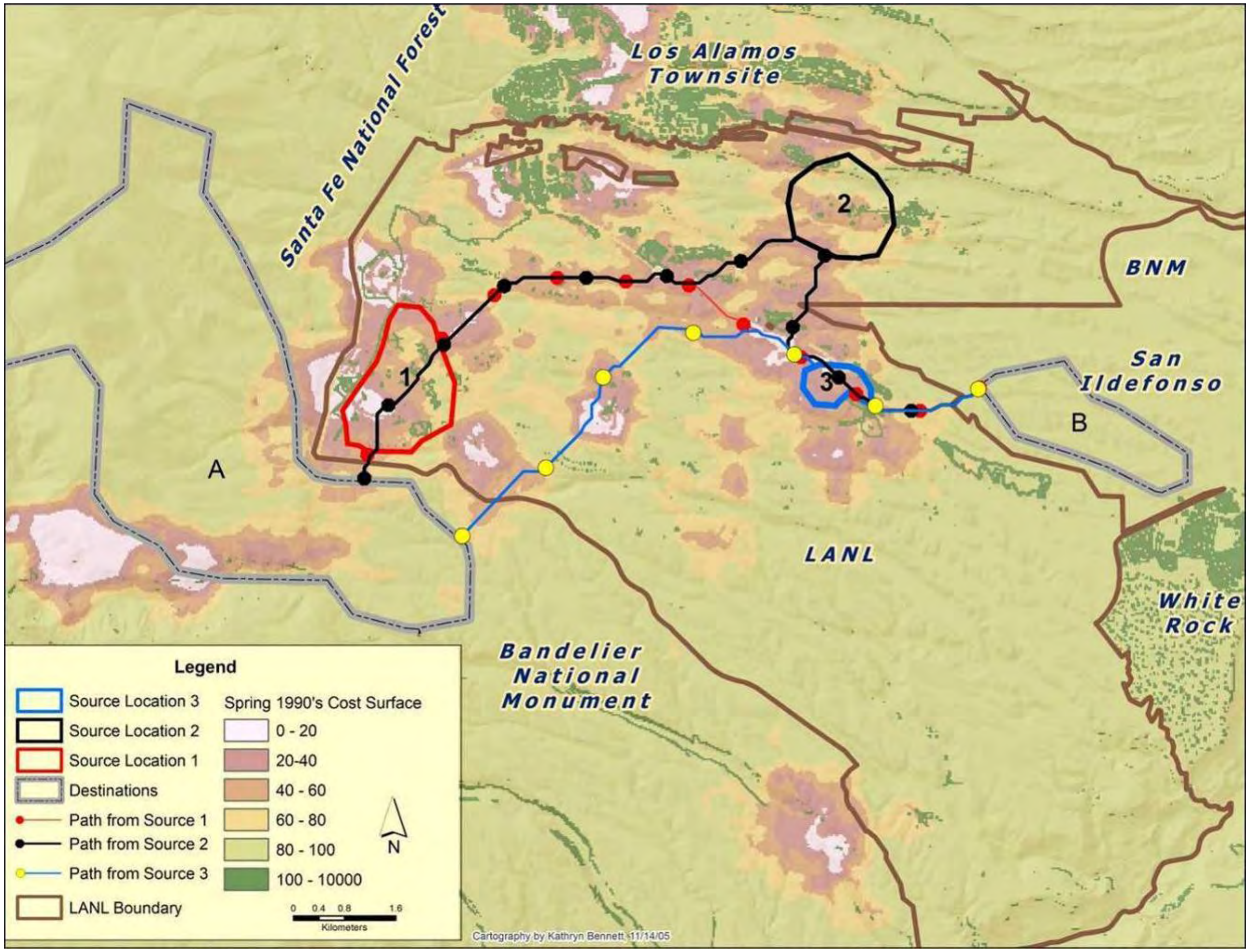


Figure 50. The spring least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for 1990s.

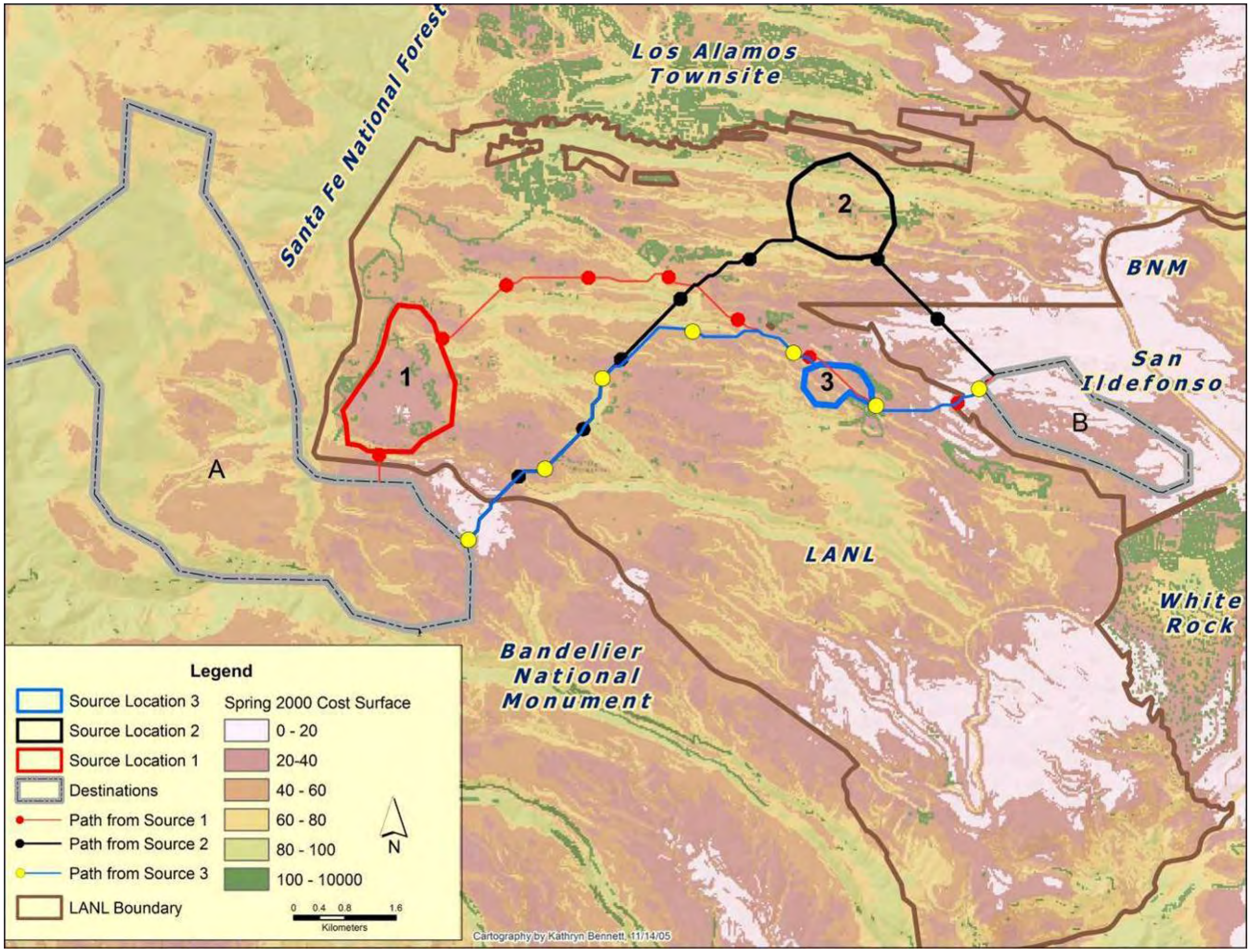


Figure 51. The spring least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for 2000s.

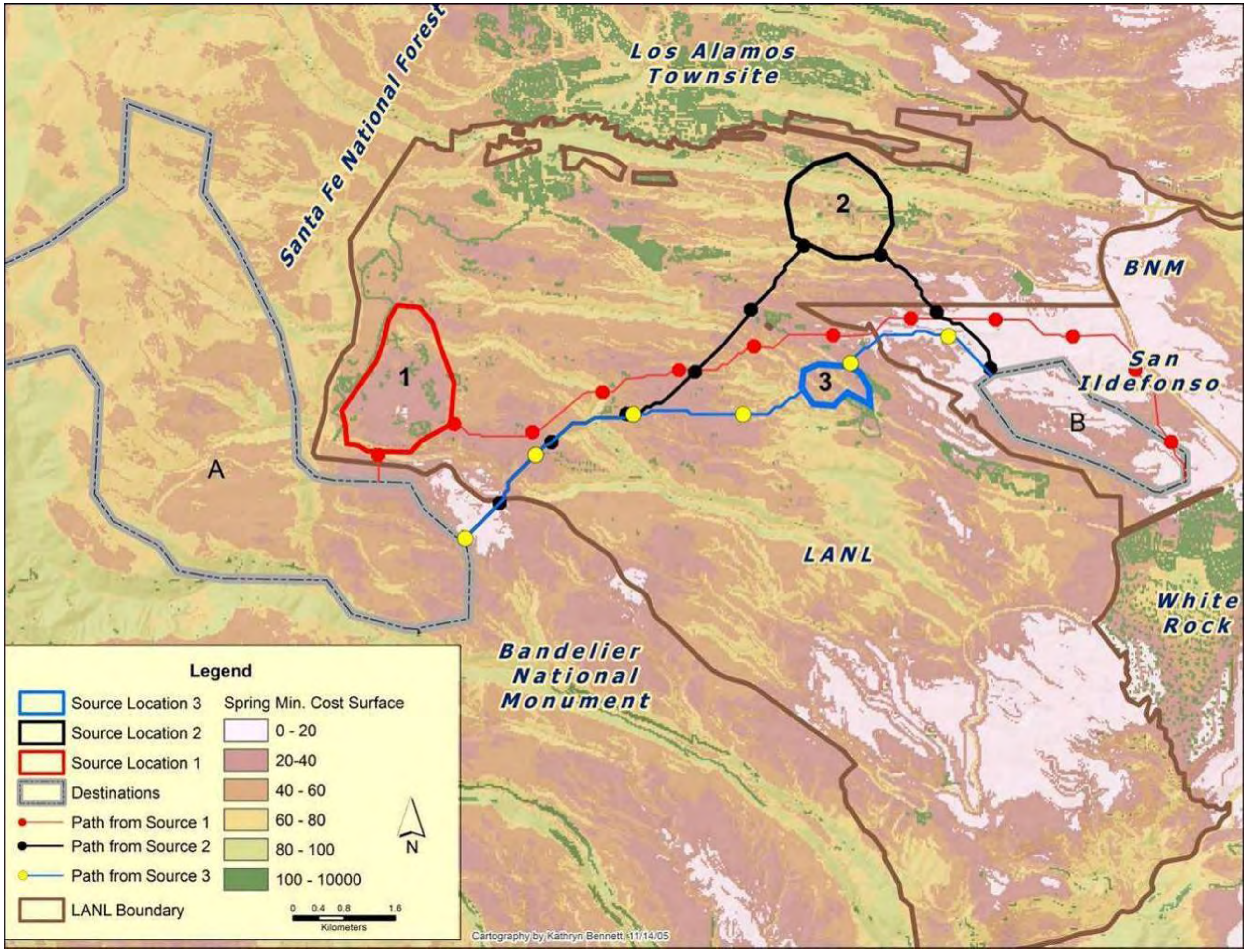


Figure 52. The spring least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for the future scenario with minimum development.

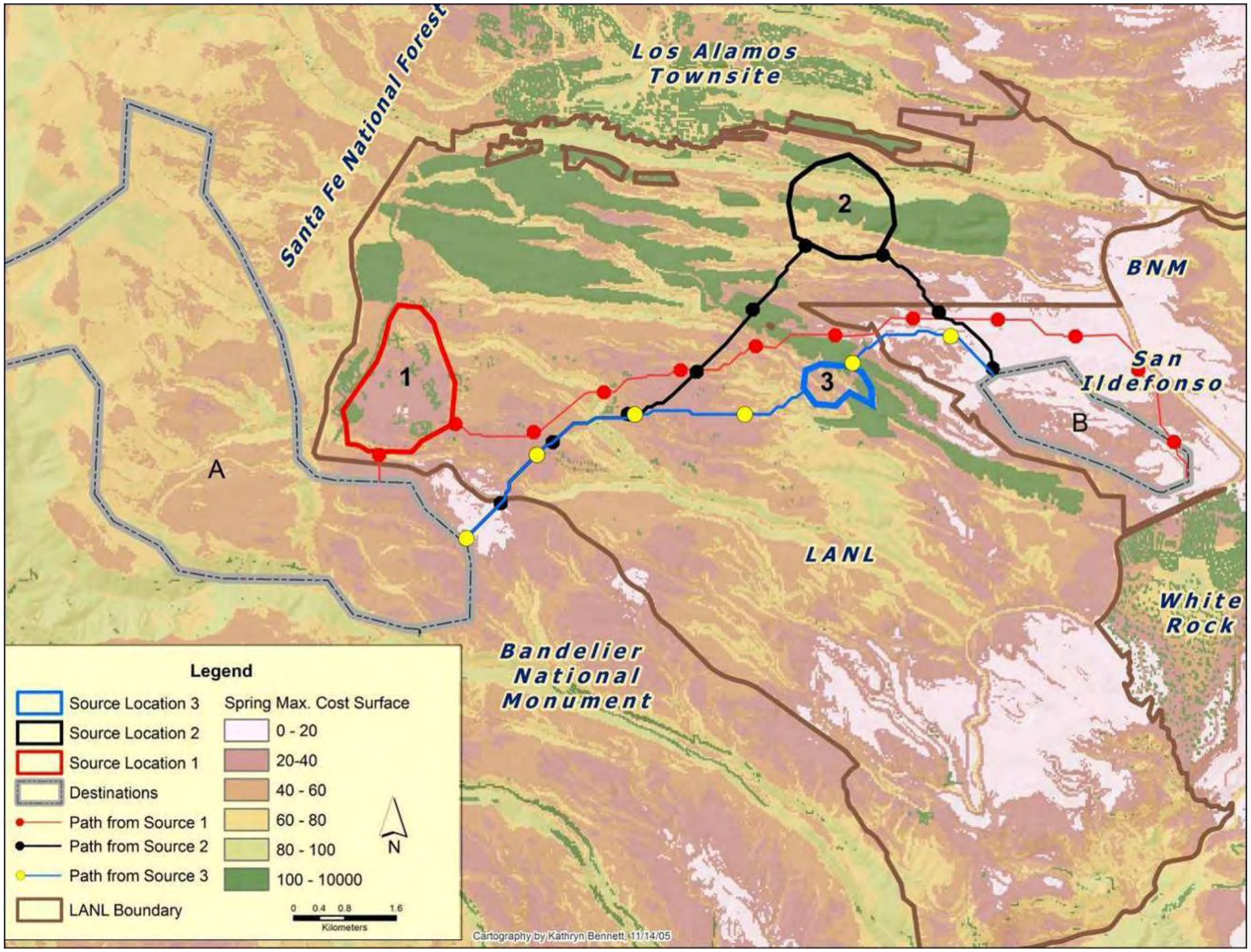


Figure 53. The spring least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for the future scenario with maximum development.

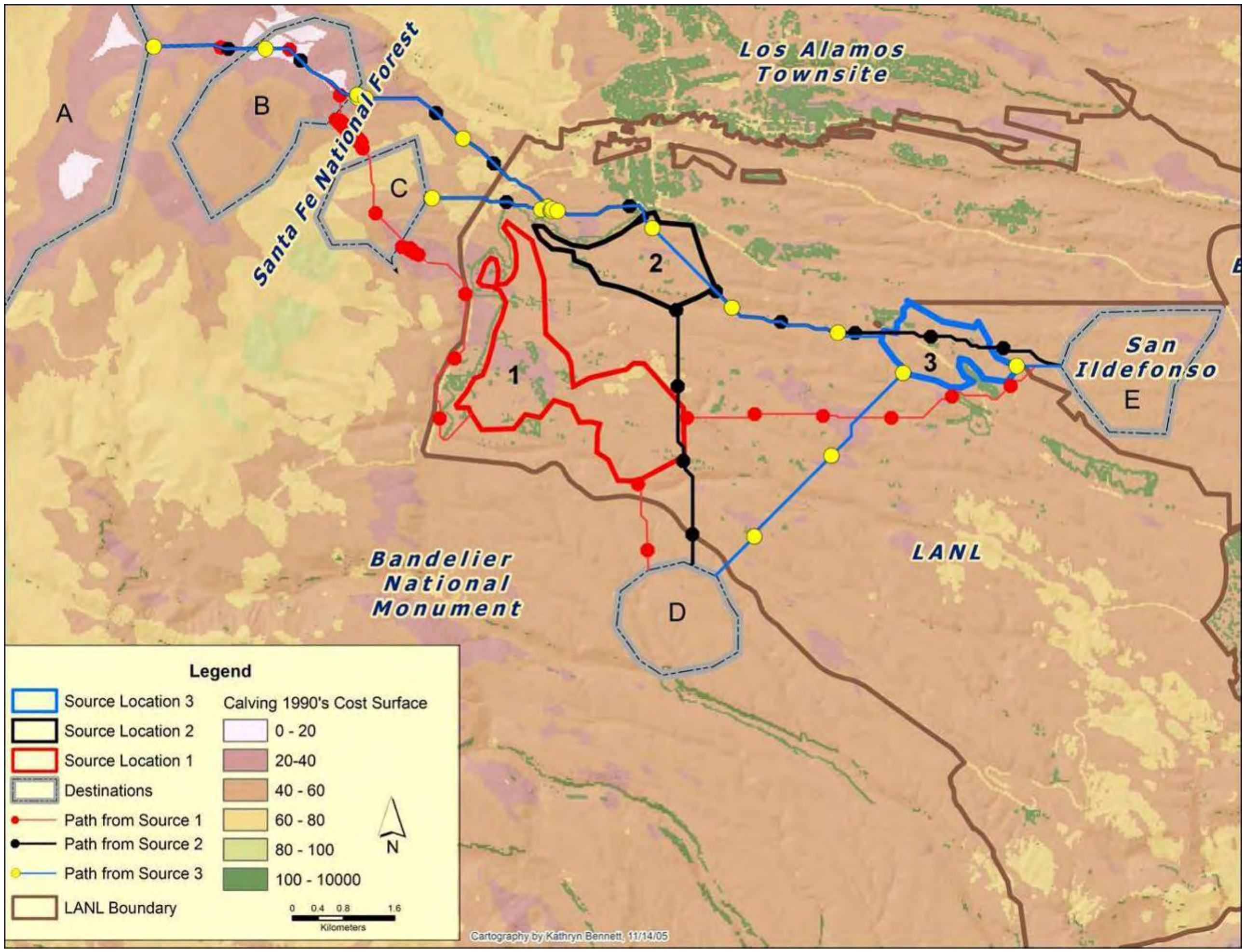


Figure 54. The calving least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for 1990s.

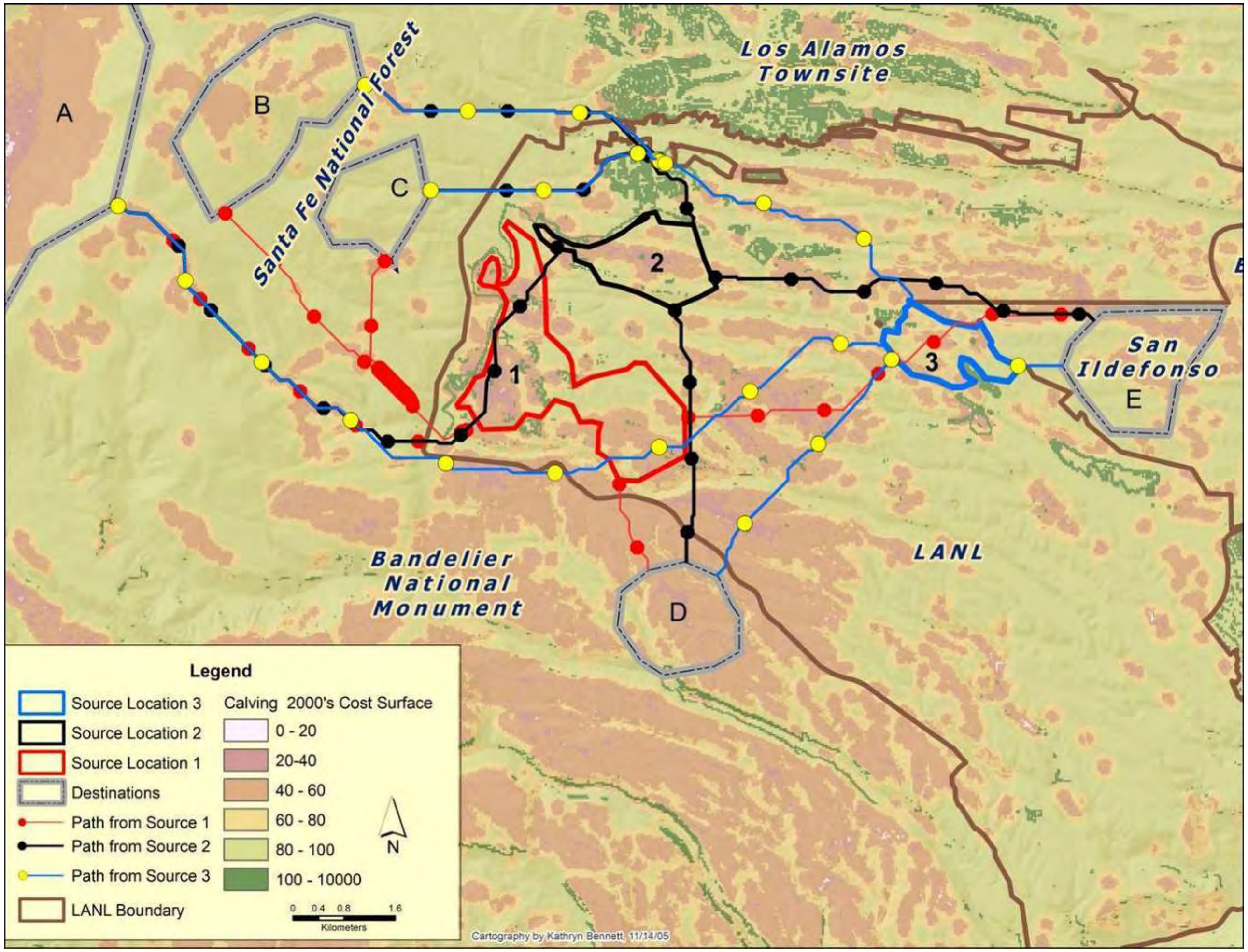


Figure 55. The calving least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for 2000s.

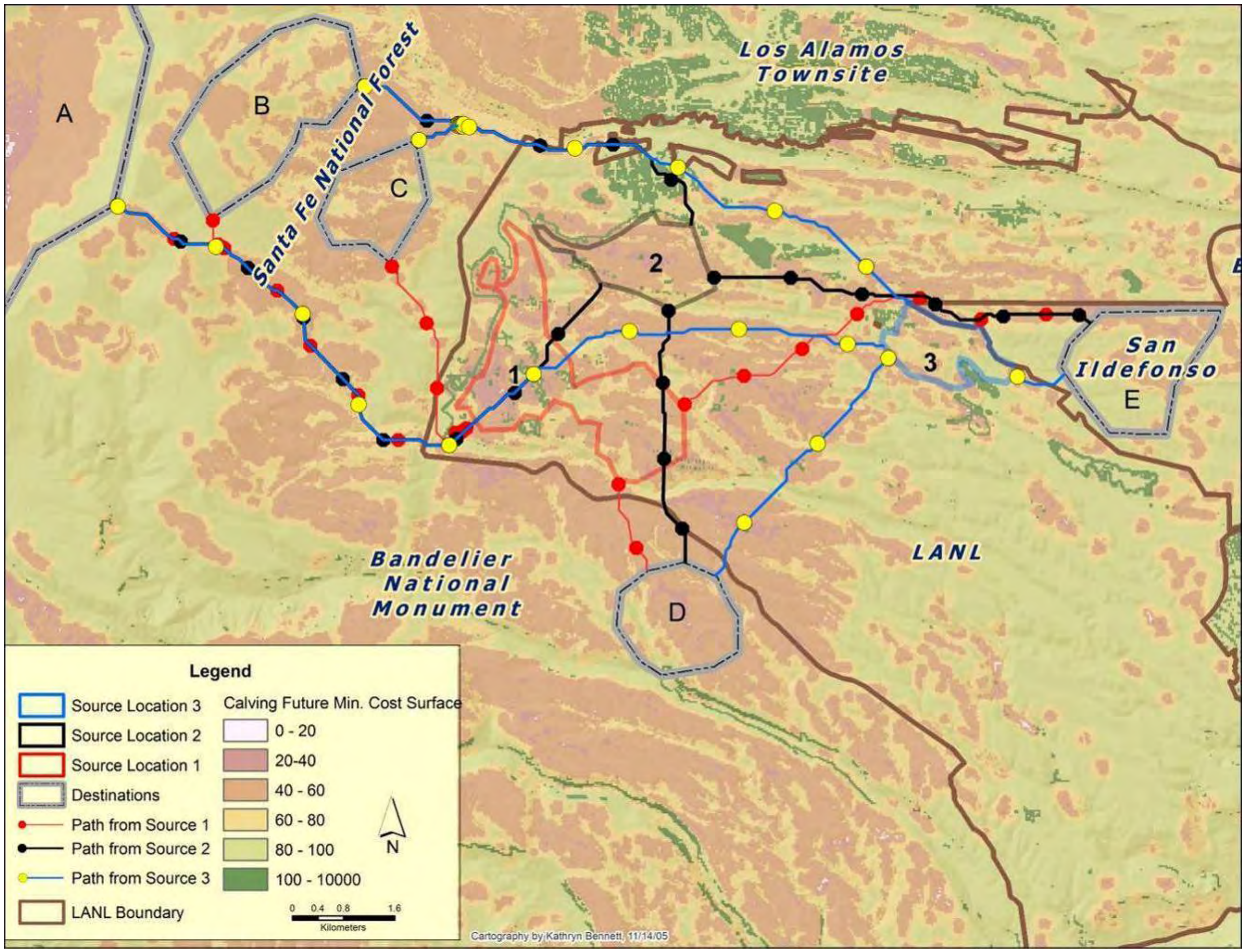


Figure 56. The calving least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for the future scenario with minimum development.

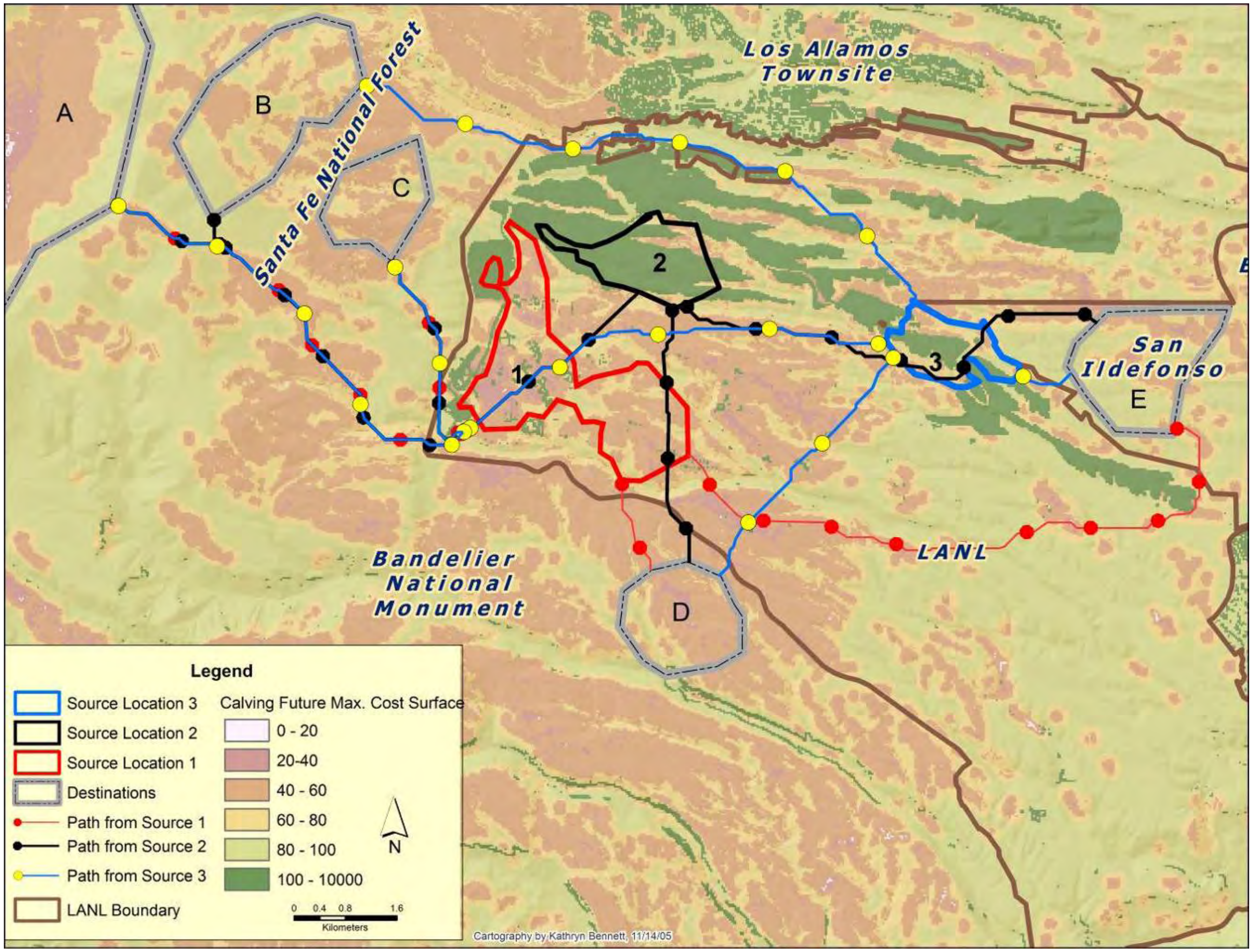


Figure 57. The calving least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for the future scenario with maximum development.

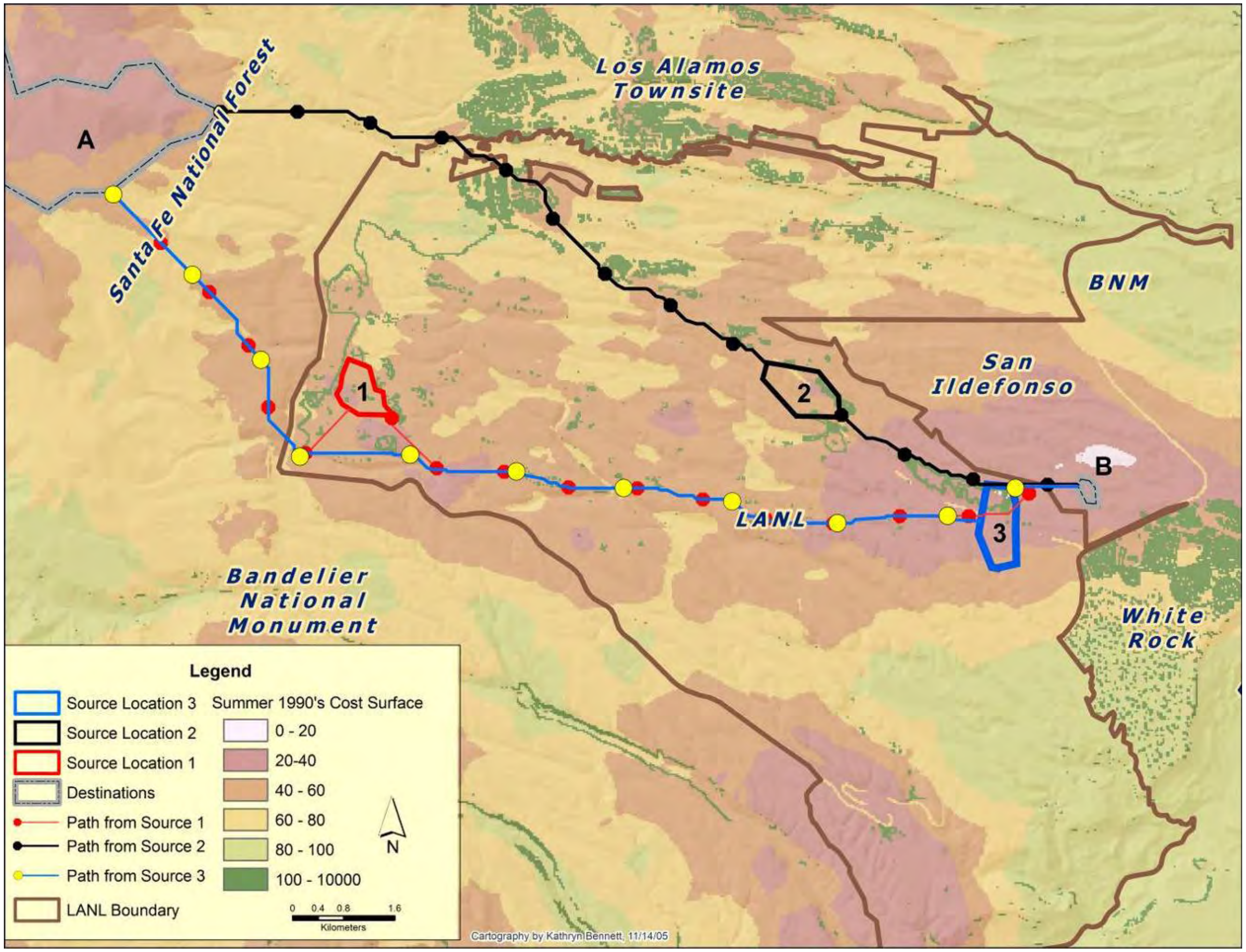


Figure 58. The summer least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for 1990s.

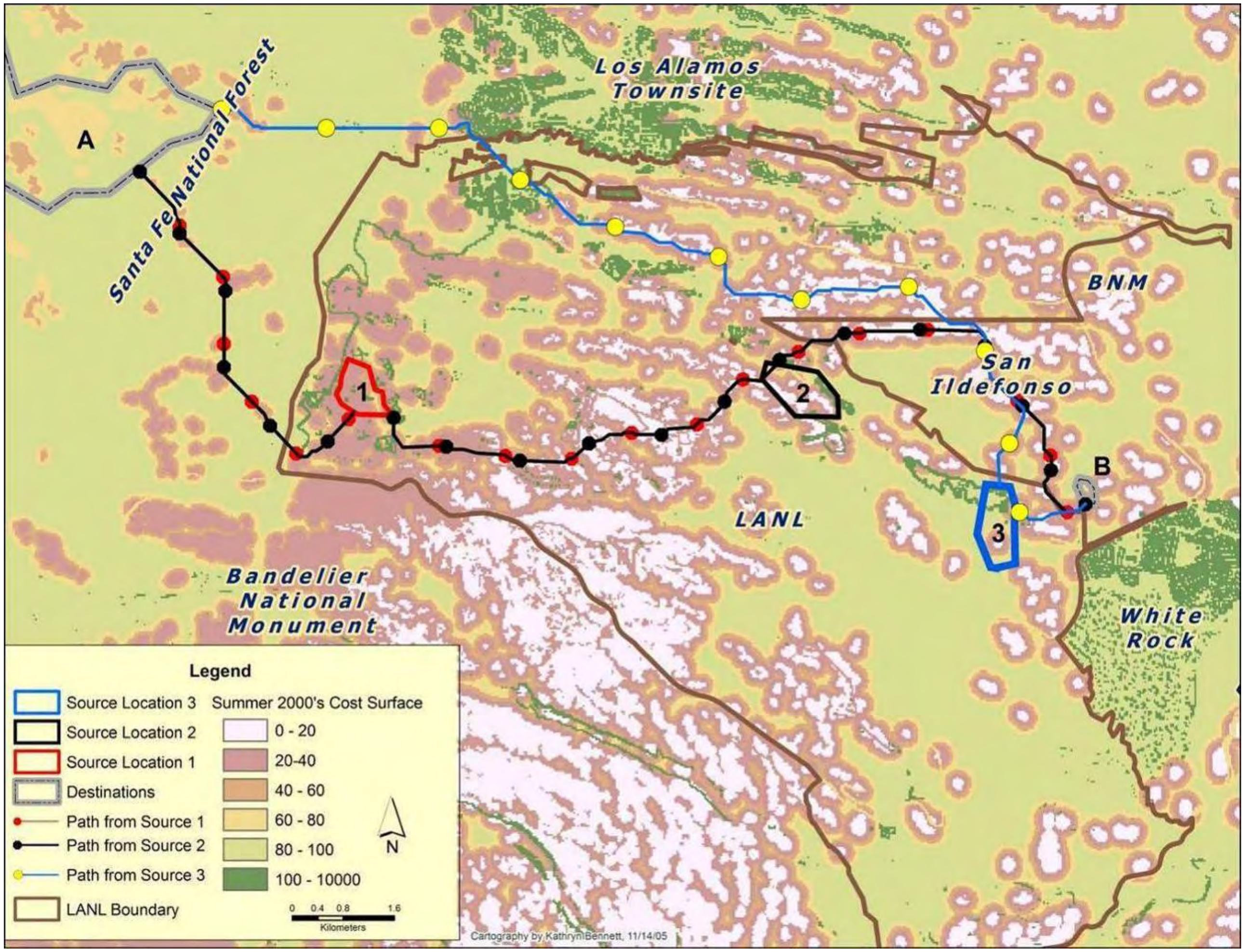


Figure 59. The summer least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for 2000s

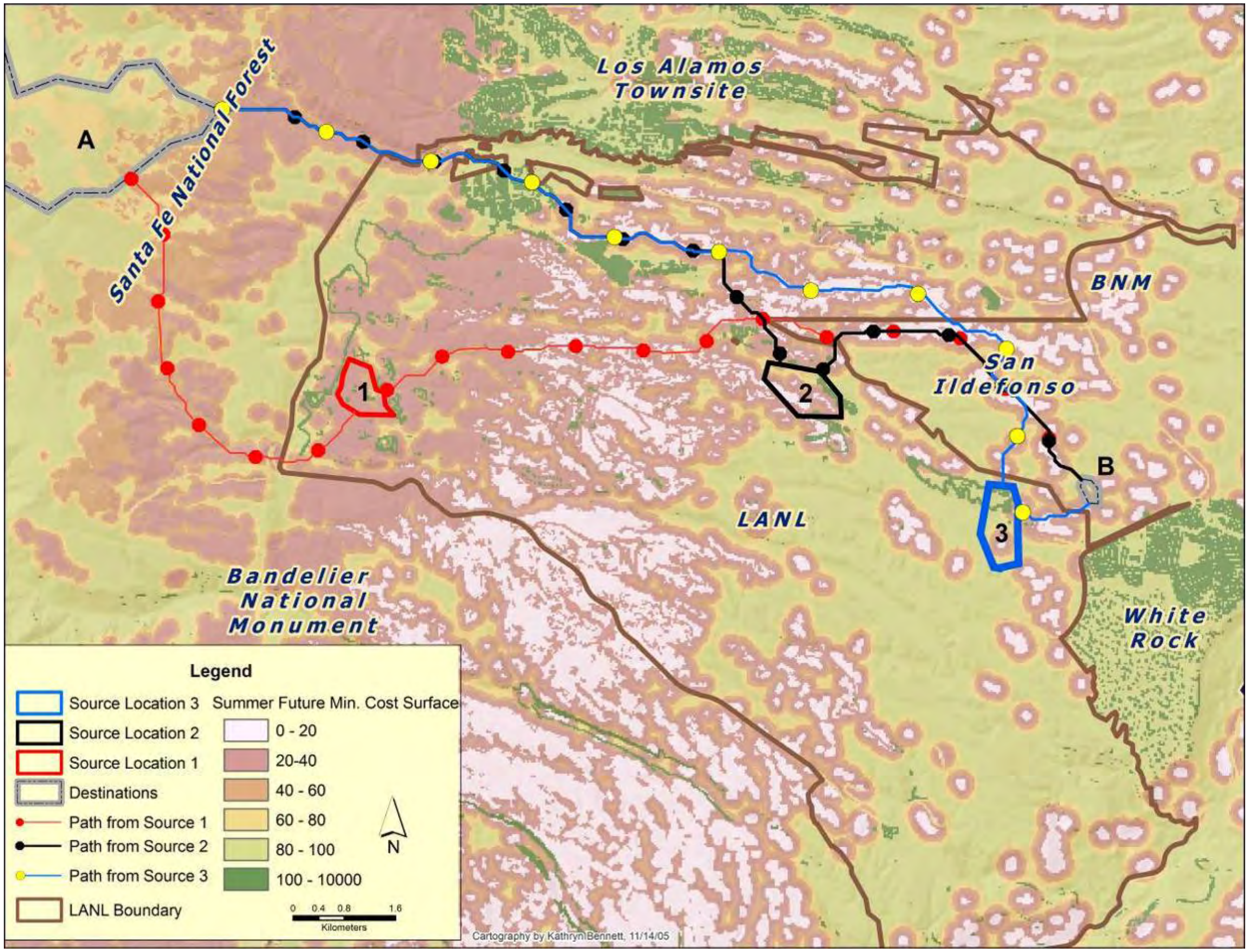


Figure 60. The summer least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for the future scenario with minimum development.

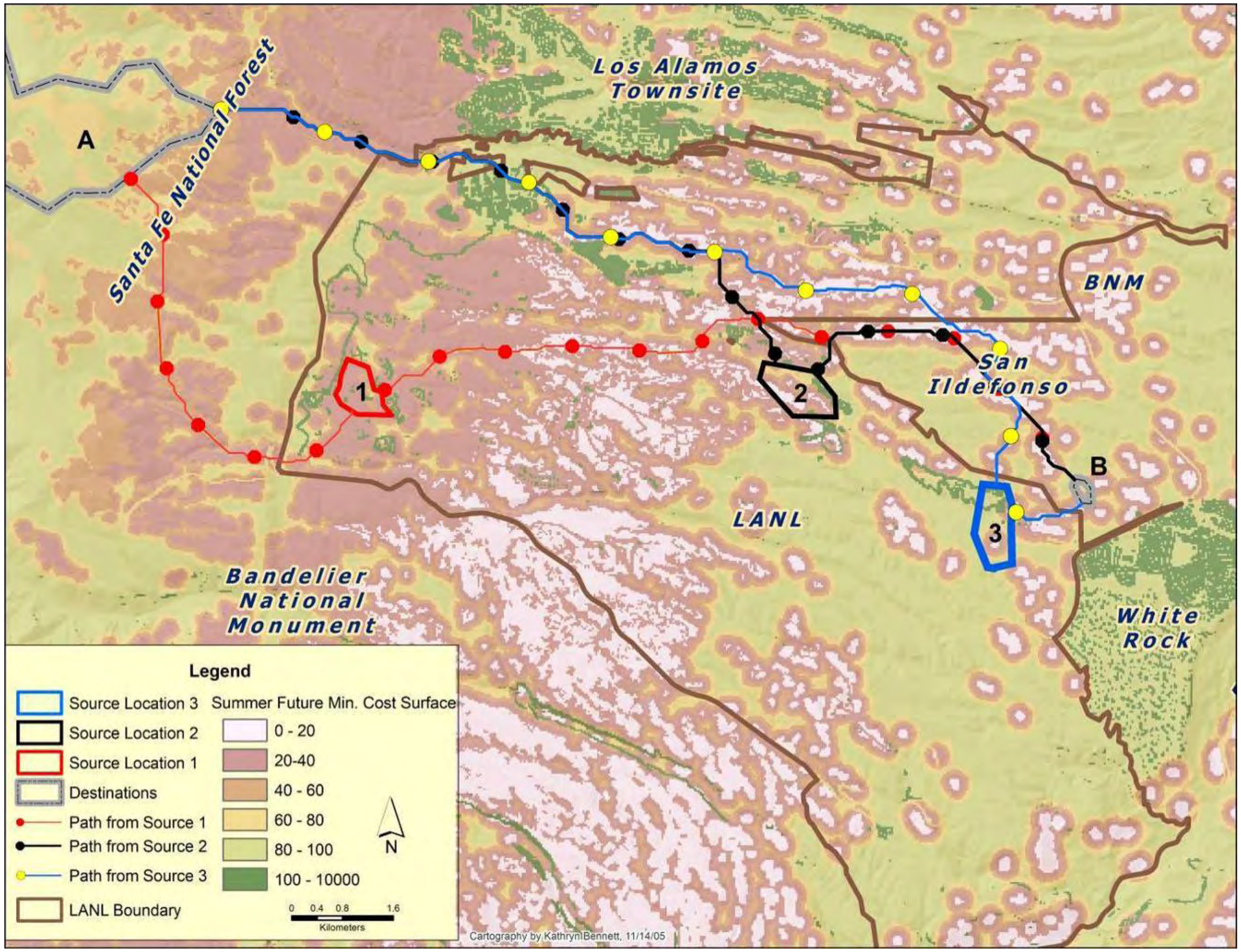


Figure 61. The summer least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for the future scenario with maximum development.

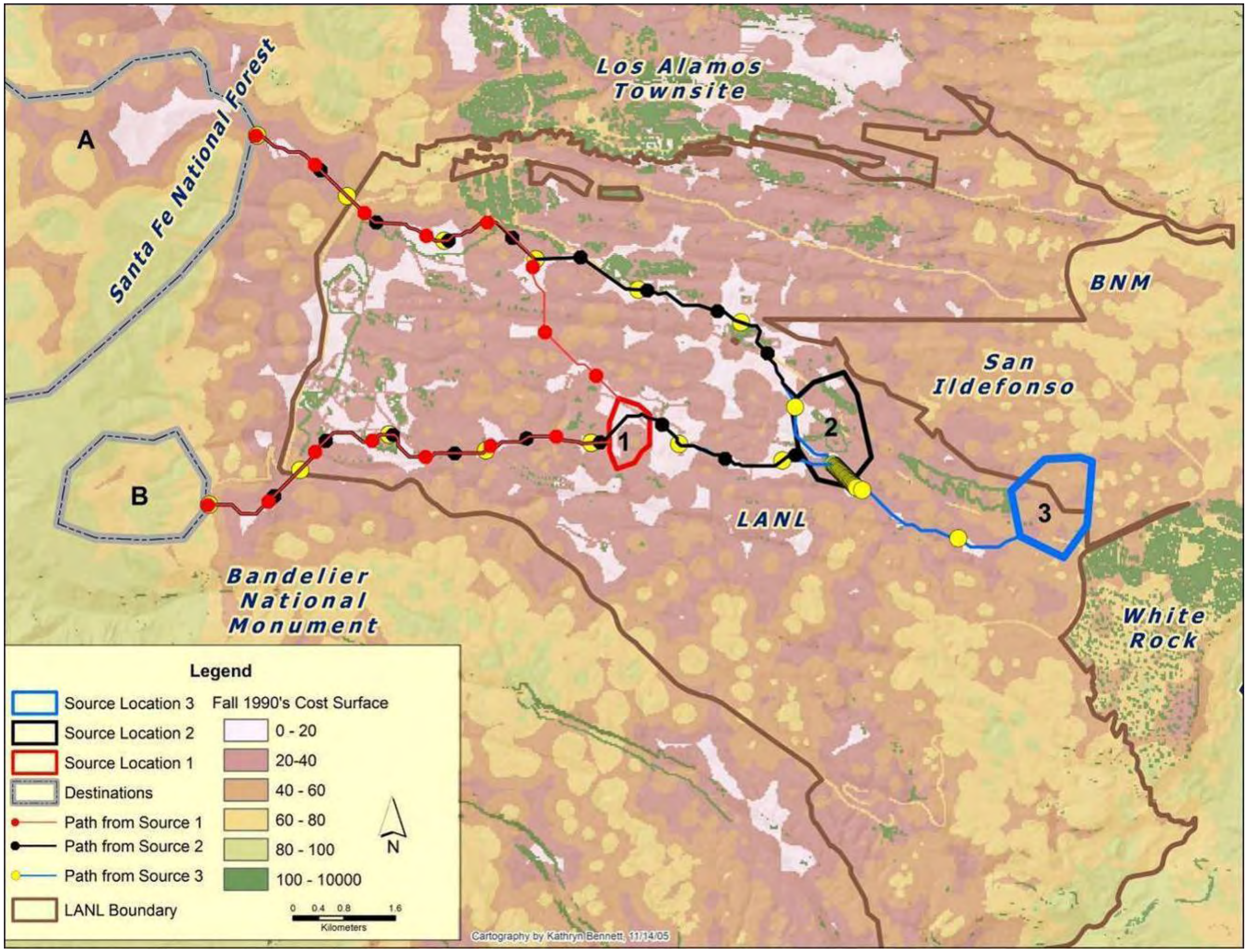


Figure 62. The fall least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for 1990s.

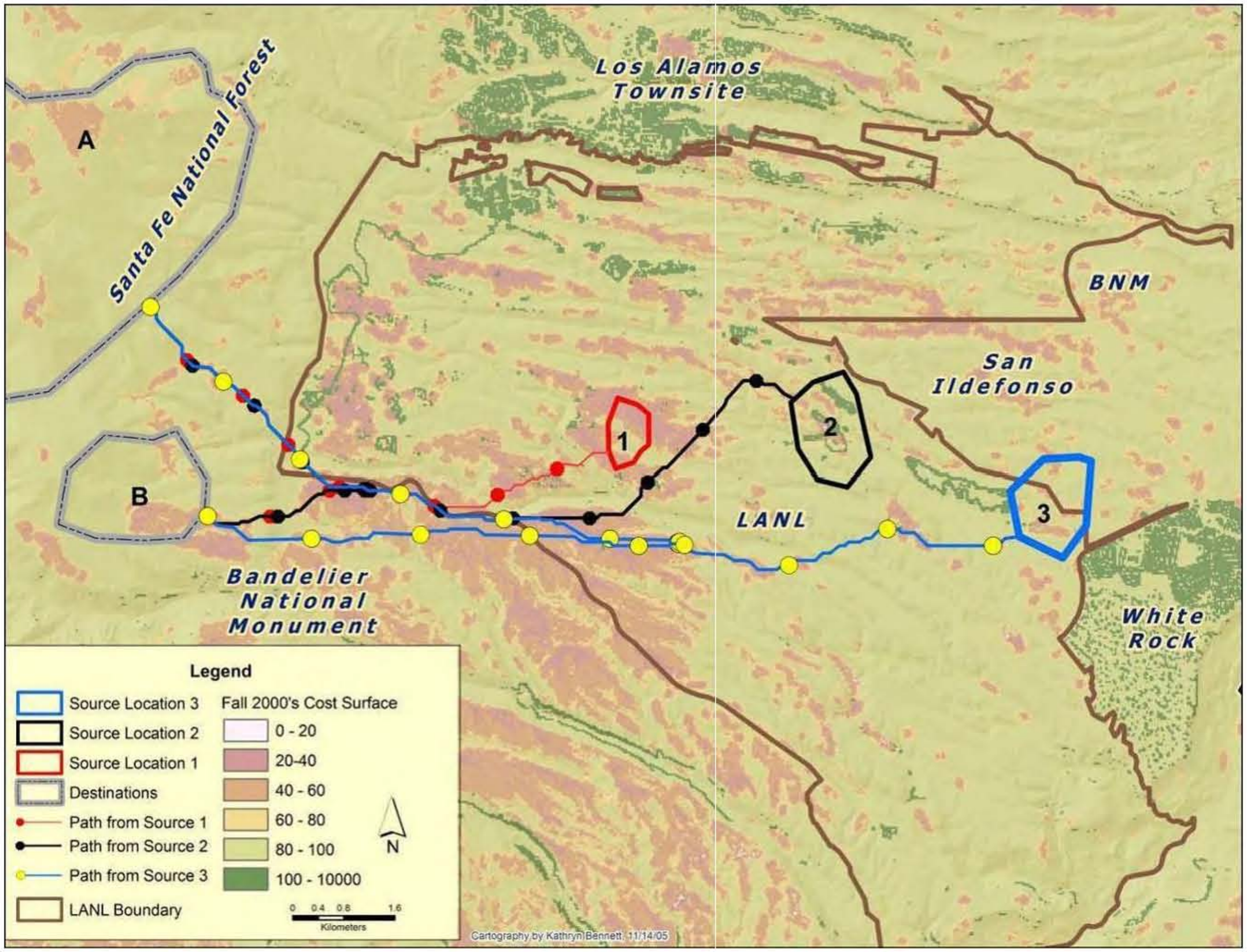


Figure 63. The fall least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for 2000s

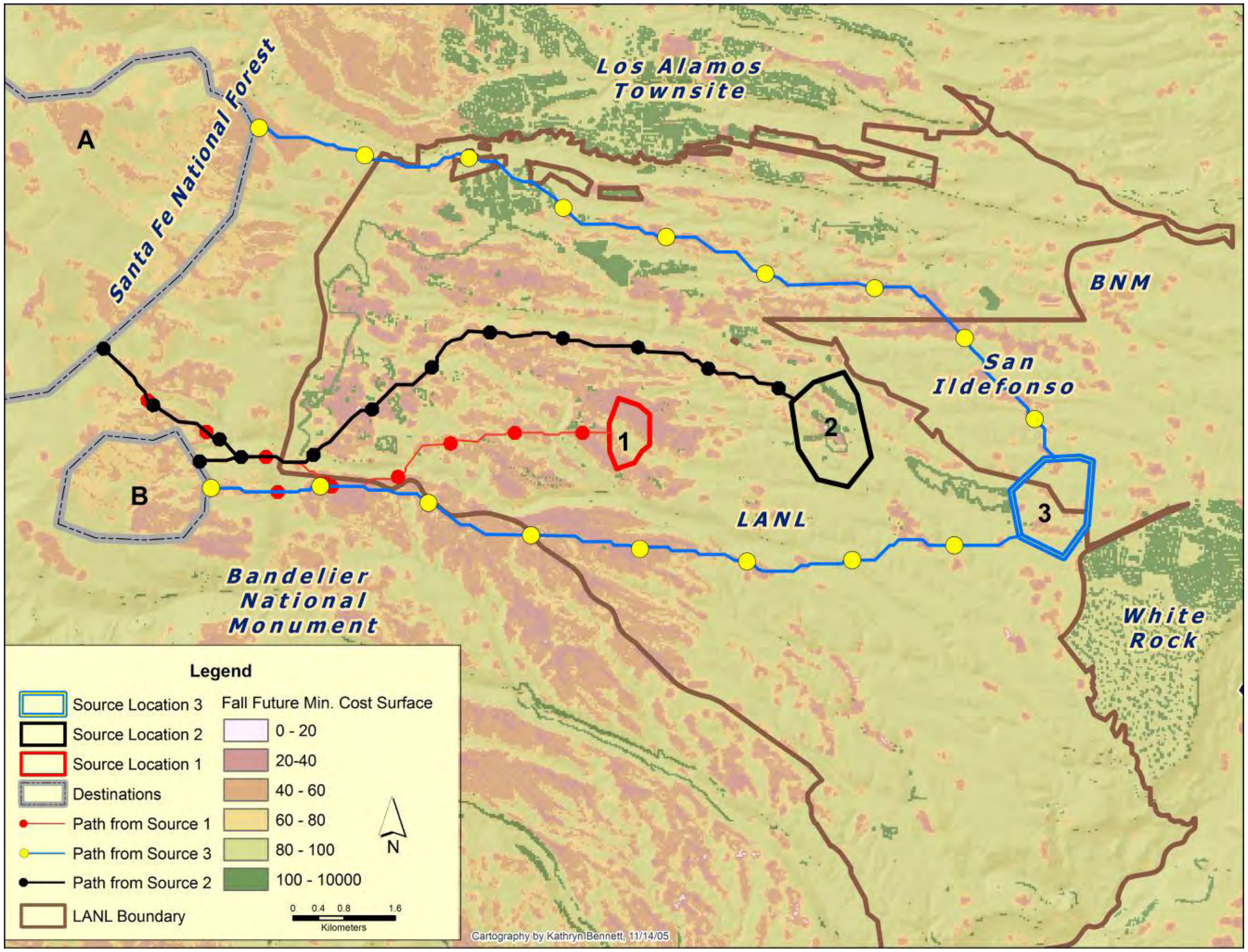


Figure 64. The fall least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for the future scenario with minimum development.

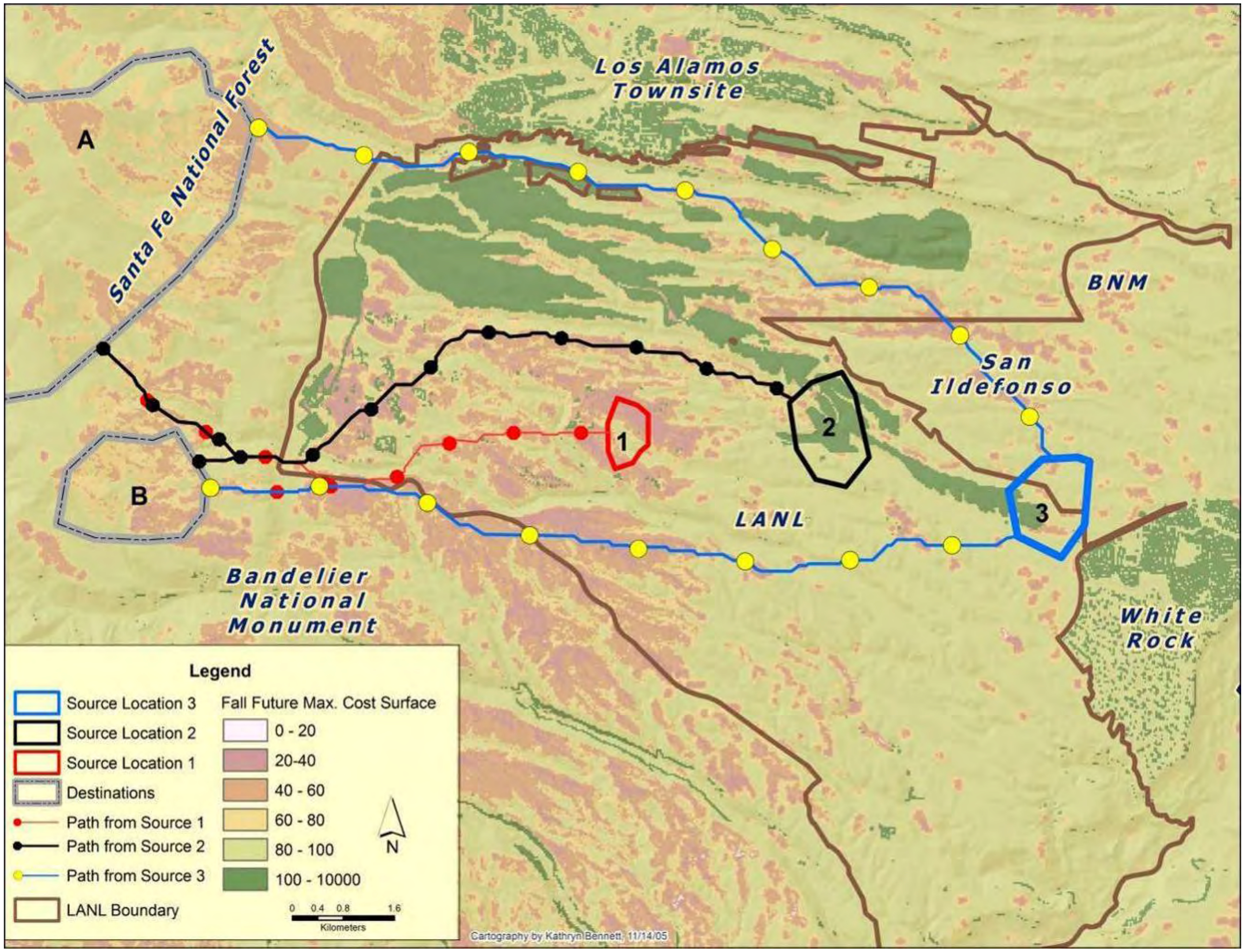


Figure 65. The fall least-cost paths generated from source areas (numbered) to destinations (labeled with letters) for the future scenario with maximum development

find a lower cost path to select. These crossings would actually not occur and a movement barrier would be formed. This barrier could cause significant issues with neighboring San Ildefonso if it were to occur.

The majority of the paths generated for all time periods transversed the lab from east to west crossing the central part of LANL. Development along the central and western portions of LANL, most affected these movement paths. Roadways that intersect these paths could result in an increased risk of animal-vehicle collisions and facilities near paths or sources could experience an increase in adverse elk-human interactions.

3.1. Winter

Three source areas and four destination areas were defined for the winter season based on density of elk relocations. Figure 46 through 49 shows the winter least-cost paths generated for the 1990s, 2000s, future minimum development, and future maximum development, and Table 14 shows the travel cost associated with each path. In general, all least-cost paths generated passed through the central portion of LANL with the exception of one path generated for 1990s (going from Source 3 to Destination C) that took a southern route.

3.2. Spring

Three source areas were defined within LANL for the spring season. These areas were located in the western, northern, and central portions of LANL Two destinations were defined, one on BNM that overlapped onto Santa Fe National Forest, and another on San

Table 14. The winter travel cost from LANL sources to destinations near LANL.

Time Period	Source Number	Destination Letter	Travel Cost
1990s	1	A	911002
2000s	1	A	959179
Future Minimum	1	A	959336
Future Maximum	1	A	959336
1990s	1	B	457648
2000s	1	B	483151
Future Minimum	1	B	483151
Future Maximum	1	B	483151
1990s	1	C	424568
2000s	1	C	550642
Future Minimum	1	C	550642
Future Maximum	1	C	550642
1990s	1	D	351075
2000s	1	D	1066349
Future Minimum	1	D	1066349
Future Maximum	1	D	1347885
1990s	2	A	1184443
2000s	2	A	1678475
Future Minimum	2	A	1679148
Future Maximum	2	A	1679148
1990s	2	B	729264
2000s	2	B	1175530
Future Minimum	2	B	1175530
Future Maximum	2	B	1175530
1990s	2	C	602657
2000s	2	C	964200
Future Minimum	2	C	964200
Future Maximum	2	C	964200
1990s	2	D	92471
2000s	2	D	436849
Future Minimum	2	D	436849
Future Maximum	2	D	436849
1990s	3	A	1268236
2000s	3	A	2260668
Future Minimum	3	A	2261342
Future Maximum	3	A	2273153
1990s	3	B	813057
2000s	3	B	1744843
Future Minimum	3	B	1744843
Future Maximum	3	B	1744843
1990s	3	C	603443
2000s	3	C	1392033
Future Minimum	3	C	1392033
Future Maximum	3	C	1392033
1990s	3	D	92471
2000s	3	D	95755
Future Minimum	3	D	95755
Future Maximum	3	D	95755

Ildefonso. Table 15 shows the total travel cost for each path and the paths can be seen in Figures 50 through 53. For the 1990s and 2000s, the predicted paths transversed the upper third of LANL going from north to south–southwest to BNM and Forest Service lands and with a easterly path to San Ildefonso. However, in the two future scenarios the paths were shifted slightly more to the south. In some cases, the 1990s had the highest cost of travel (Path 1 to all destinations) but there were other paths (path 2 to destination A) where the future maximum development had the highest cost. There was at least one case (path 3 to destination A) where a decrease in travel cost was seen in both future scenarios.

Table 15. The spring travel cost from LANL sources to destinations near LANL.

Time Period	Source Number	Destination Letter	Travel Cost
1990s	1	A	87651
2000s	1	A	59983
Future Minimum	1	A	60186
Future Maximum	1	A	60186
1990s	1	B	1298286
2000s	1	B	974955
Future Minimum	1	B	954469
Future Maximum	1	B	1146980
1990s	2	A	1132878
2000s	2	A	987850
Future Minimum	2	A	960075
Future Maximum	2	A	1287721
1990s	2	B	751267
2000s	2	B	176068
Future Minimum	2	B	177640
Future Maximum	2	B	177640
1990s	3	A	1094944
2000s	3	A	813782
Future Minimum	3	A	796598
Future Maximum	3	A	796598
1990s	3	B	458212
2000s	3	B	145119
Future Minimum	3	B	145166
Future Maximum	3	B	153109

3.3. Calving

The calving cost paths were generated for five destinations and three sources. Three of the destinations were on Forest Service lands, one on BNM, and one on San Ildefonso. The source areas were located in the western, west-central, and central portions of LANL. Figures 54 through 57 show the cost paths that were generated, and Table 16 shows the total travel cost. The majority of the paths transversed through the central and northwest portions of LANL. For the 2000s time period and both future scenarios, northerly paths just south of the Los Alamos townsite were predicted for travel to Destinations B and C from all source areas except Source 1, while in 1990s, the paths were shifted slightly to the south. In general, the paths predicted for the 1990s had the lowest travel cost and the paths for the 2000s had the highest.

3.4. Summer

There were two destination areas developed for the summer season. One of the destinations was on Santa Fe National Forest and the other much smaller destination was on San Ildefonso lands. Three source areas were developed on LANL (west, central, and southeast). Table 17 gives the total travel cost for each path predicted for the summer season and the predicted paths are shown in Figures 58 through 61. The 2000s and future scenario maps show that paths to the Forest Service lands from source 3 were shifted more to the north than those predicted in the 1990s. In addition, these paths go through a larger portion of San Ildefonso Pueblo lands than the 1990s pathway. The 2000s and future scenario maps also show an increase of movement pathways on San Ildefonso lands when movements transverse from source 1 or 2 to San Ildefonso lands. The 1990s

Table 16. The calving travel cost from LANL sources to destinations near LANL.

Time Period	Source Number	Destination Letter	Travel Cost
1990s	1	A	1233338
2000s	1	A	1702102
Future Minimum	1	A	1370818
Future Maximum	1	A	1370818
1990s	1	B	985602
2000s	1	B	1478444
Future Minimum	1	B	1120710
Future Maximum	1	B	1120710
1990s	1	C	605501
2000s	1	C	954516
Future Minimum	1	C	645696
Future Maximum	1	C	845696
1990s	1	D	239744
2000s	1	D	220916
Future Minimum	1	D	220958
Future Maximum	1	D	220958
1990s	1	E	992525
2000s	1	E	1181252
Future Minimum	1	E	1138438
Future Maximum	1	E	2067030
1990s	2	A	1063760
2000s	2	A	2206262
Future Minimum	2	A	1827383
Future Maximum	2	A	1886057
1990s	2	B	828483
2000s	2	B	1767559
Future Minimum	2	B	1320941
Future Maximum	2	B	1635949
1990s	2	C	624333
2000s	2	C	1449059
Future Minimum	2	C	1762923
Future Maximum	2	C	1360936
1990s	2	D	664205
2000s	2	D	739722
Future Minimum	2	D	684681
Future Maximum	2	D	684681
1990s	2	E	919136
2000s	2	E	1039422
Future Minimum	2	E	965345
Future Maximum	2	E	2143580
1990s	3	A	1747622
2000s	3	A	2832210
Future Minimum	3	A	2430476
Future Maximum	3	A	2430476
1990s	3	B	1512336
2000s	3	B	2358950
Future Minimum	3	B	1896427
Future Maximum	3	B	2076451

Table 16 (continued). The calving travel cost from LANL sources to destinations near LANL.

Time Period	Source Number	Destination Letter	Travel Cost
1990s	3	C	1308186
2000s	3	C	2042305
Future Minimum	3	C	1762923
Future Maximum	3	C	1905356
1990s	3	D	652398
2000s	3	D	746984
Future Minimum	3	D	758083
Future Maximum	3	D	758083
1990s	3	E	139661
2000s	3	E	253974
Future Minimum	3	E	199084
Future Maximum	3	E	199084

Table 17. The summer travel cost from LANL sources to destinations near LANL.

Time Period	Source Number	Destination Letter	Travel Cost
1990s	1	A	1163030
2000s	1	A	1483019
Future Minimum	1	A	972426
Future Maximum	1	A	972426
1990s	1	B	1473653
2000s	1	B	1096244
Future Minimum	1	B	973762
Future Maximum	1	B	1357777
1990s	2	A	2078685
2000s	2	A	1992715
Future Minimum	2	A	1317866
Future Maximum	2	A	1465481
1990s	2	B	383158
2000s	2	B	461280
Future Minimum	2	B	461945
Future Maximum	2	B	461945
1990s	3	A	2491244
2000s	3	A	2394996
Future Minimum	3	A	1691114
Future Maximum	3	A	1886078
1990s	3	B	75317
2000s	3	B	90537
Future Minimum	3	B	95829
Future Maximum	3	B	109954

data did not show this characteristic. Fifty percent of the predicted paths had the highest cost in the 1990s time period and one third of the paths had the highest cost in the future maximum scenario.

3.5. Fall

Two destination areas were defined for the fall season. One of these destinations was on Forest Service lands and another in the upper BNM area. Three sources were defined, within LANL, central, east-central, and southeast. The southeast source overlapped onto San Ildefonso Pueblo lands. Table 18 contains the total travel cost for each path and Figures 62 through 65 show the cost paths. The paths predicted for the 1990s and the future scenarios were fairly similar. However, the paths predicted for the future scenarios that led to the Forest Service destination A from source 3 were shifted more to the north. The 2000s time period had cost paths that were most dissimilar to the other time periods. These paths were shifted more to the south. The 1990s had the lowest travel cost of all of the seasons and the 2000s time period had the highest cost.

4.0. Change Detection

4.1. Habitat Suitability

The seasonal habitat suitability models appeared very different between the 1990s and the 2000s. A *t*-test was used to test the difference between the two HS models. Approximately 5000 random points were overlaid on the 1990s and 2000s HS models and their HS values compared. Table 19 shows the results of the *t*-test. There were statistical differences ($\alpha = 0.05$) between the 1990s HS values and the 2000s. The winter season was the only season where the mean HS value was not found to be statistically

Table 18. The fall travel cost from LANL sources to destinations near LANL.

Time Period	Source Number	Destination Letter	Travel Cost
1990s	1	A	681829
2000s	1	A	1837614
Future Minimum	1	A	1653391
Future Maximum	1	A	1653391
1990s	1	B	543128
2000s	1	B	1223731
Future Minimum	1	B	1184188
Future Maximum	1	B	1184188
1990s	2	A	766049
2000s	2	A	2409513
Future Minimum	2	A	2127238
Future Maximum	2	A	2127238
1990s	2	B	713413
2000s	2	B	1795630
Future Minimum	2	B	1689693
Future Maximum	2	B	1689693
1990s	3	A	1131044
2000s	3	A	3216301
Future Minimum	3	A	2852479
Future Maximum	3	A	3017089
1990s	3	B	1042689
2000s	3	B	2598753
Future Minimum	3	B	2577505
Future Maximum	3	B	2577505

Table 19. Results of an independent t-test comparing HS values from the 1990s to the 2000s.

FALL	*2000s*	*1990s*
Mean	0.1324	0.3013
Variance	0.0418	0.0528
Observations	4994	4994
df	9854	
t Stat	-38.8270	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9602	
WINTER	*2000s*	*1990s*
Mean	0.1879	0.1821
Variance	0.0312	0.0906
Observations	4994	4994
df	8068	
t Stat	1.1881	
P(T<=t) two-tail	0.2348	
t Critical two-tail	1.9603	
SPRING	*2000s*	*1990s*
Mean	0.4433	0.0560
Variance	0.0893	0.0261
Observations	4994	4994
df	7678	
t Stat	80.59581	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9603	
CALVING	*2000s*	*1990s*
Mean	0.1964	0.4314
Variance	0.0435	0.0127
Observations	4994	4994
df	7686	
t Stat	-70.009	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9603	
SUMMER	*2000s*	*1990s*
Mean	0.2937	0.3307
Variance	0.0919	0.0557
Observations	4994	4994
df	9420	
t Stat	-6.79037	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9602	

different. The differences in the HS models were further evaluated by comparing the HS raster through a difference operation. Areas were identified as similar if they were within 10 percent of each other. All seasonal HS values were found to have considerable differences (greater than + 10% or less than -10%).

Table 20 shows the number of grid cells and percentage of values that were within 10%. The winter season had the highest amount of agreement (approximately 34%) between the 1990s and the 2000s time period and spring had the lowest amount of agreement (13.5%). Figures 66 through 70 show the areas of differences and similarities between the two time periods. Areas that were similar are shown in white. Areas that were greater than 10% of the 1990 values are shown in dark blue and areas where the 2000 HS values were less than -10% of the 1990s values are shown in green.

General differences detected during the HS change detection process were influenced by the different maximum values predicted by the seasonal models of each time period. For the winter, calving, and fall season of the 2000s time period, the maximum probability of use values were much less than one while the 1990s had values approaching one.

Table 20. The number of cells within the 2000s habitat suitability model that were within 10% of the values in the 1990s habitat suitability model.

Season	Number of Cells Within 10%	Total Number of Cells	Percent Within 10%
Fall	276997	1143675	24.22
Winter	386289	1143675	33.78
Spring	160703	1143675	14.052
Calving	154289	1143675	13.49
Summer	235978	1143675	20.63

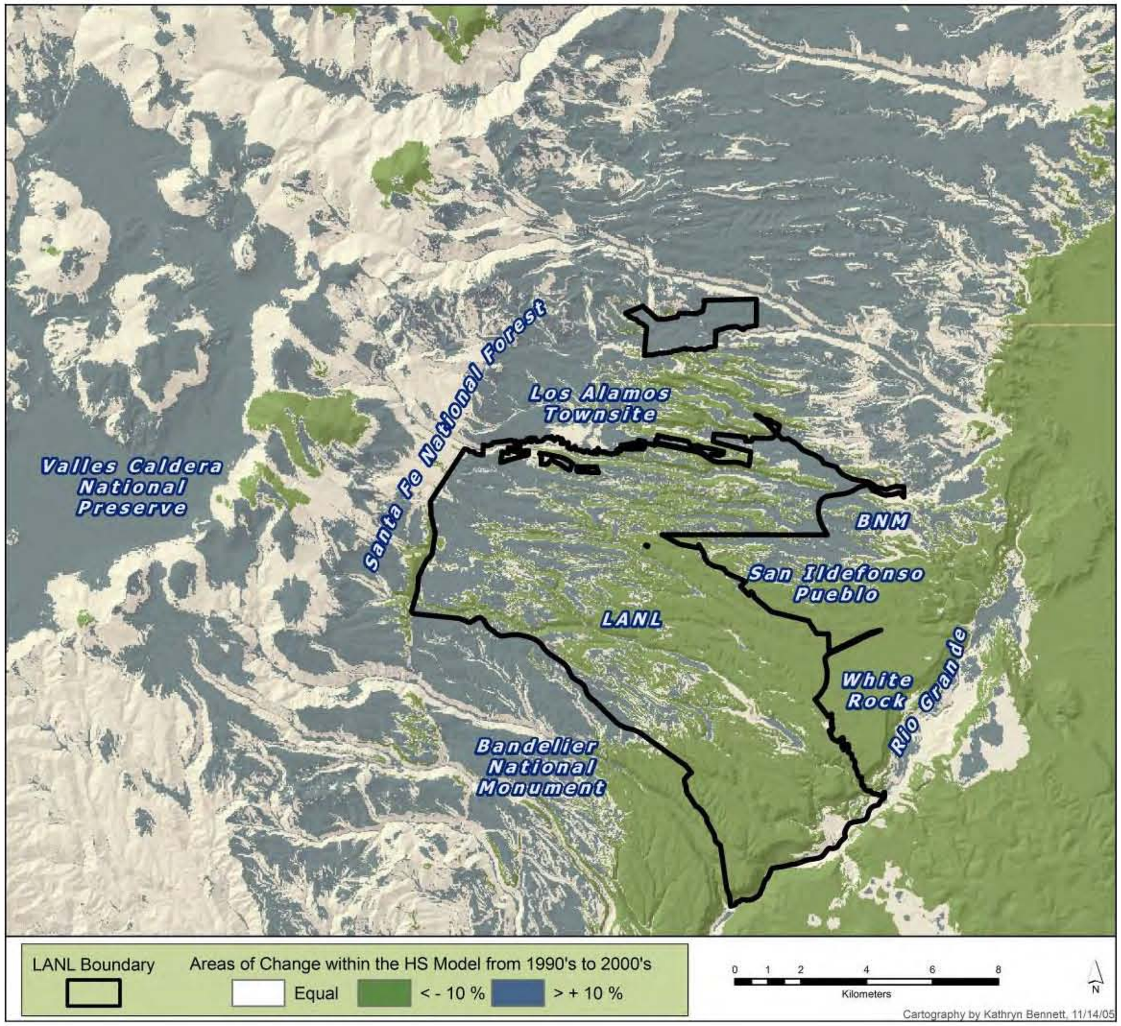


Figure 66. Map showing the areas of differences between the 1990s HS model and the 2000s model for the winter season.

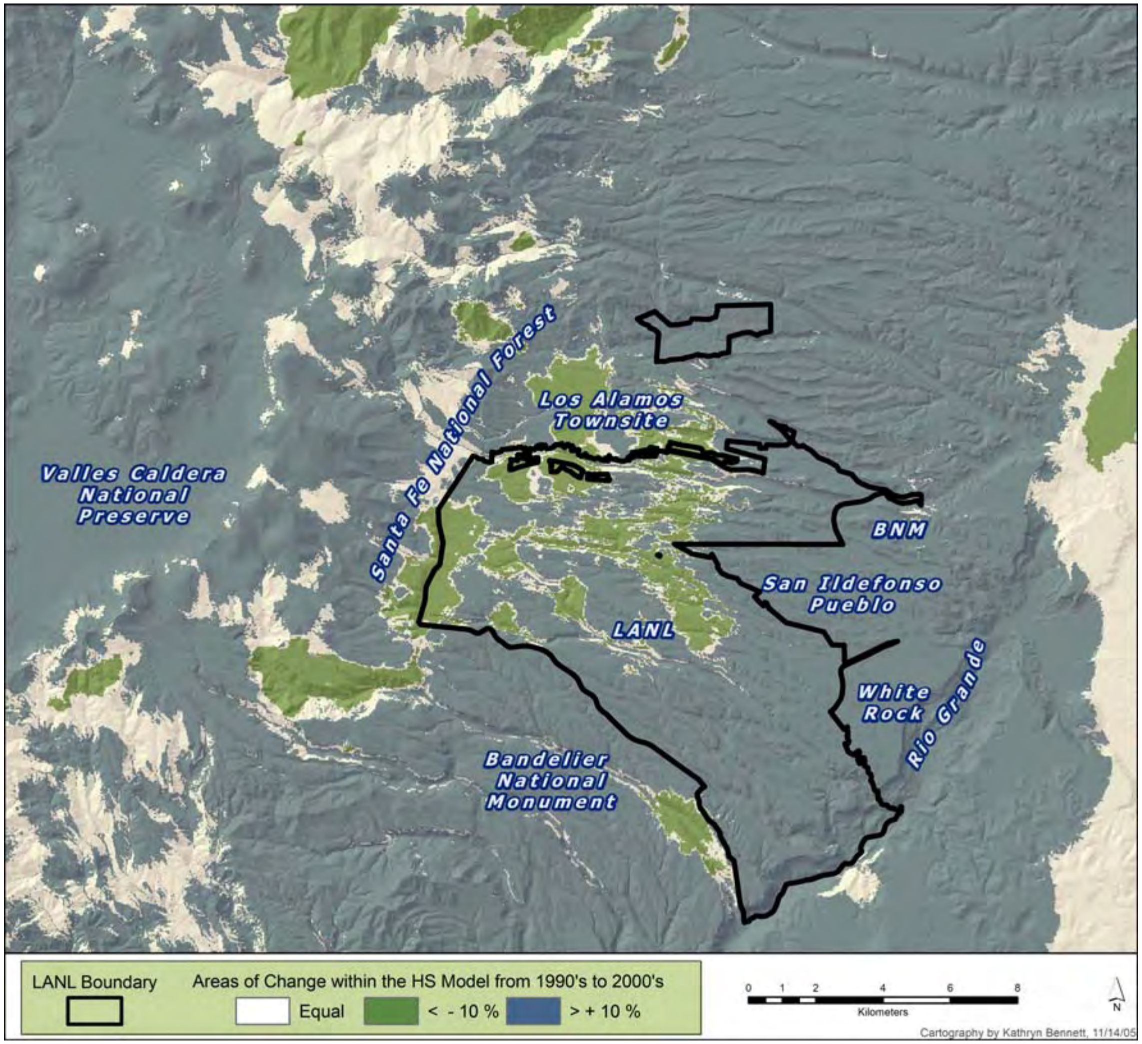


Figure 67. Map showing the areas of differences between the 1990s HS model and the 2000s model for the spring season.

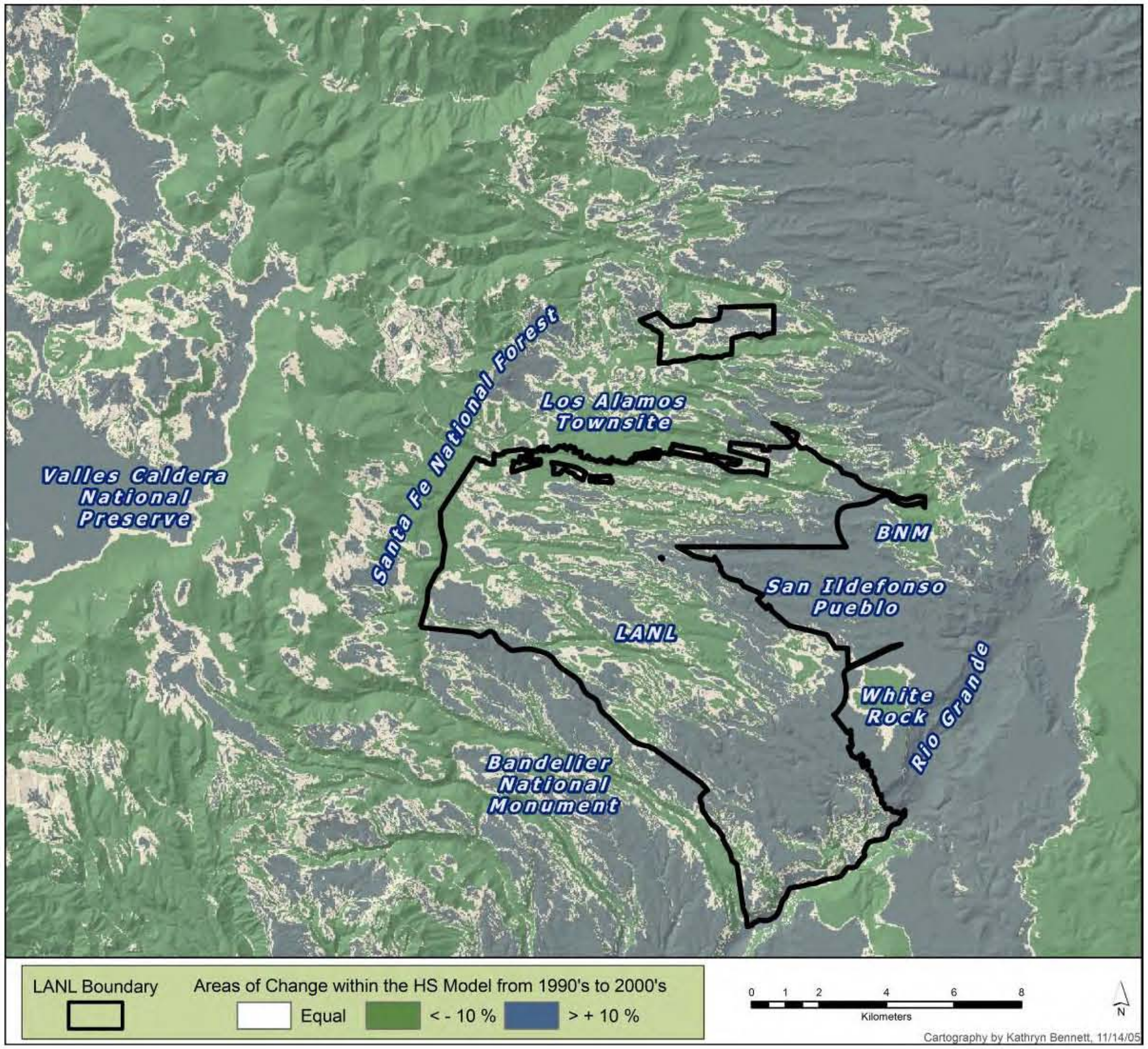


Figure 68. Map showing the areas of differences between the 1990s HS model and the 2000s model for the calving season.

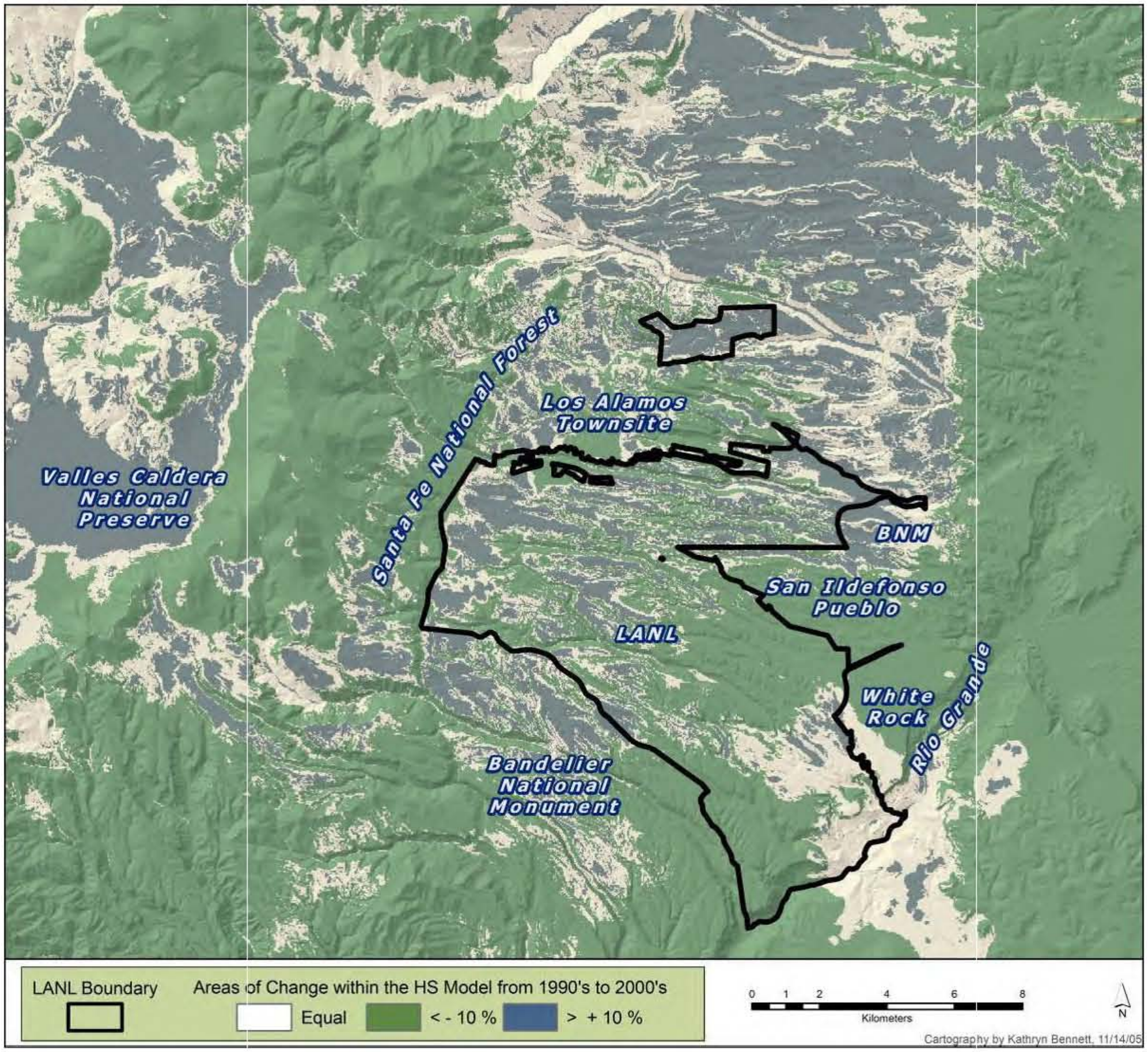


Figure 69. Map showing the areas of differences between the 1990s HS model and the 2000s model for the summer season.

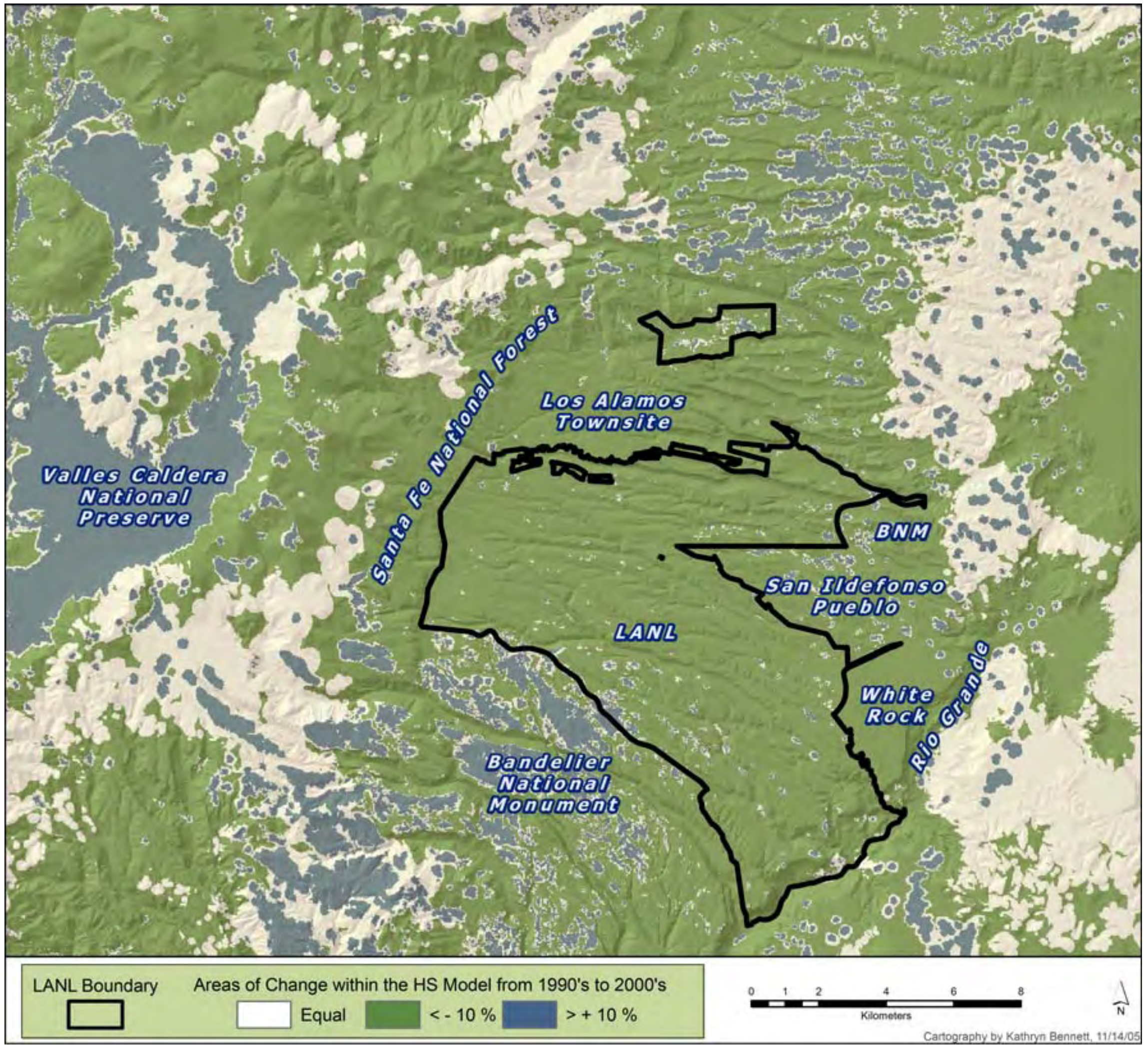


Figure 70. Map showing the areas of differences are shown between the 1990s HS model and the 2000s model for the fall season.

This difference in maximum values influenced change detection. If the 2000s model were improved or re-scaled to near one, then agreement between these two time periods would increase. In cases where the maximum HS values were near one for the 2000s time period, the 2000s predicated paths generally had the lowest travel cost.

4.1.1. Winter

The 2000s HS model showed areas that were greater than the 1990s HS model in a large portion of the Valles Caldera and lower HS values for much of the area of central LANL and the lower elevations near Rio Grande. Similarities were seen in areas to the extreme southwest portion of the study area and along the mountainous areas to the west and northwest of LANL (Figure 66). These areas that had a lower HS values were also the areas where much of the movement paths were generated for this season. The 1990s movement paths had a consistently lower movement cost than those of the other time periods. This is consistent with the HS values or lower impedance values seen in the 1990s.

4.1.2. Spring

Generally, the 2000s HS model had higher values (greater than 10%) than the 1990s HS model for a large portion of the study area. However, there were areas within the 2000s HS model that had values less than the 1990's HS model. These lower HS values were within the western and central portions of LANL, primarily on mesa tops (Figure 67). The spring travel paths showed that the 2000s generally had the lowest travel cost. This low travel cost was due to the high HS values that existed between the sources and destinations.

4.1.3. Calving

The 2000s HS model showed areas that were greater than 10% of the 1990's HS model in areas of the Valles Caldera and in lower elevation areas near the Rio Grande, San Ildefonso and north of San Ildefonso. Lower values occurred within the mountainous areas west of LANL and the far east of LANL. In addition, lower HS values were also found within the canyon system within LANL and BNM. Similarities between the two HS models were scattered throughout the study area (Figure 68). The cost paths that were generated indicated that the paths generated for the calving season in the 1990s usually had a lower cost of travel than that of the 2000s. This is mostly likely due to the lower HS values within the travel path. However, it is difficult to clearly see the relationship due to the mixture of high and low values through the areas of movement.

4.1.4. Summer

Areas with greater than 10% differences between the 2000s and 1990s HS model were found in areas of the Valles Caldera and the western mesa tops within LANL and north of LANL. Areas of lower values were found throughout the central portions of LANL, mountainous area to the west of LANL, and within BNM. Areas of similarities were scattered throughout the study area with one large concentration of similar areas located in the southeast portion of LANL and across the Rio Grande (Figure 69). The cost paths that were generated for this season indicated that approximately 50% of the time the 1990s predicted paths had a higher associated cost than the other time periods. These paths transversed much of the western mesa top locations where HS values in the 2000s were high.

4.1.5. Fall

The 2000s HS model had higher HS values compared to the 1990s model in areas of the Valles Caldera and portions of BNM. The majority of the area within LANL had lower values. Areas of similarities are concentrated in the east and northeast portion of the study area and in the upper elevations of BNM near the rim of the Caldera (Figure 70). The 1990s had the lowest cost of travel during the fall. The travel paths crossed the areas where the change detection indicated a lower HS value for the 2000s and conversely a higher HS (lower impedance) value for the 1990s.

4.1.6. Future Scenarios

The future scenarios HS models showed a similar trend to the 2000s HS model, with one exception. Areas of change between 2000s and future scenarios occurred in areas of the Cerro Grande severe burn on low slopes because of the conversion from burned areas to grassland. There was approximately 45% increase in grasslands in the future scenarios expanding the higher suitability values associated with grasslands. These areas received an increase in HS values and areas in close proximity to these areas also received an increase in HS values. Figure 71 shows the area of the conversion to grassland. The effect of the increase in HS values due to grassland was seen in the movement paths predicted in some of the future scenarios. In some of these cases, the travel cost predicted for the future cases was actually lower than that predicted for the 2000s.

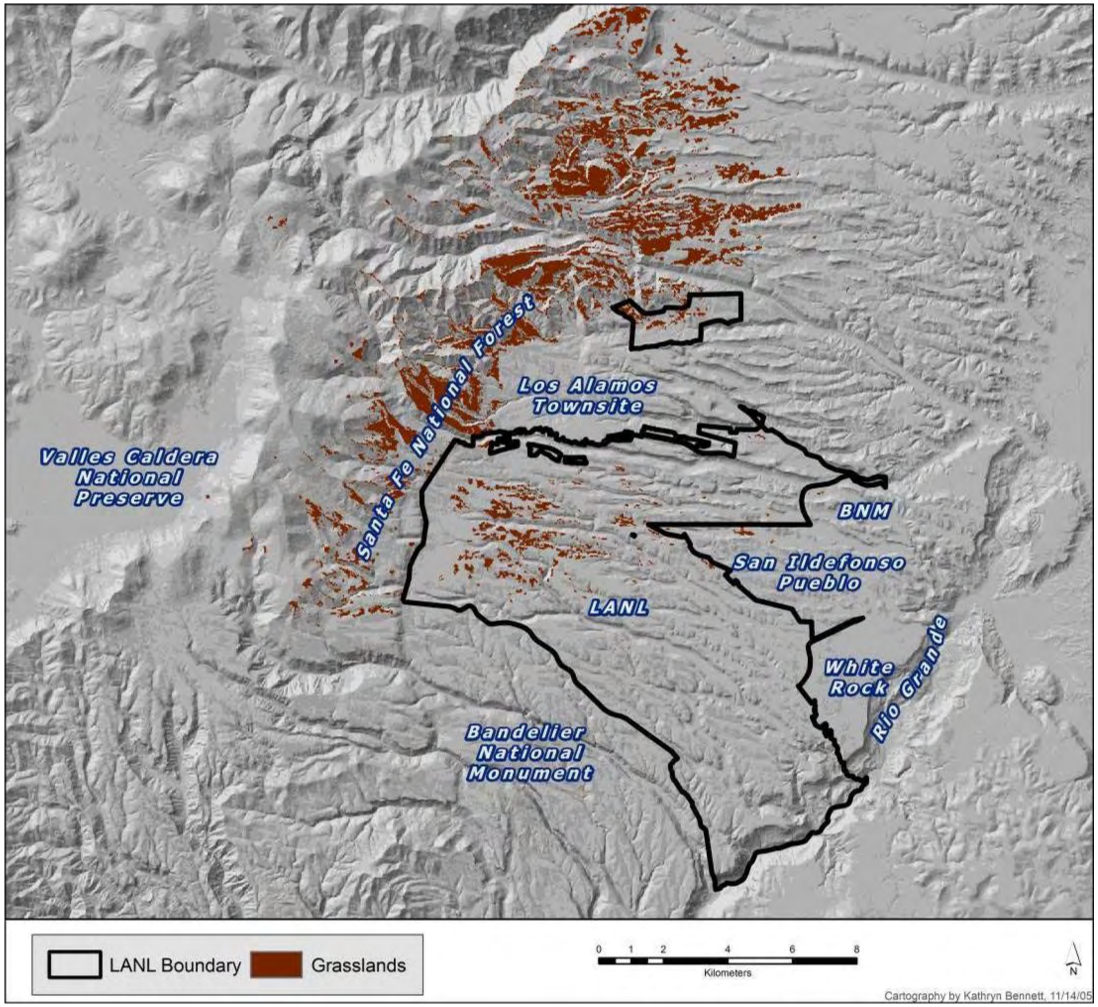


Figure 71. Map showing the areas of grassland conversion within the Cerro Grande severe burn.

4.2. Barrier

Very similar barrier layers were developed for the 1990s and 2000s. The differences detected were very slight and did not seem to be a major factor regulating movement. The differences that did occur were associated with development. Table 21 shows the percent of each barrier type for each time period. The 1990s time period had a slightly higher percent of extreme barrier features such as buildings/structures and security fences than the 2000s. However, both future scenarios had an increase in this highest barrier class with the maximum future development scenario resulting in a 41% increase of extreme barrier features. In addition, there was a decrease in the number of dirt roads from the 1990s to 2000s. Some of the differences between the 1990s and 2000s may be the result of the accuracy of the initial layers used. During the 2000s, LANL as well as Los Alamos County revised their infrastructure data using survey-grade GPS. The 1990s data was an accumulation of data collected from a variety of sources and methodology and the general accuracy was considered to be lower than the 2000s. In the 2000s, the barrier model and the number of dirt roads seemed to decrease. This was most likely caused by the inaccuracies or incompleteness of the 1990s or 2000s data.

Table 21. Comparison of the 1990s barrier layer to the 2000s barrier layer.

Cell Values	Number of Grid Cells in 1990s (percent of total)	Number of Grid Cells in 2000s (percent of total)	Number of Grid Cells in Future Minimum (percent of total)	Number of Grid Cells in Future Maximum (percent of total)
0 (no barriers)	1059436 (92.63%)	1086112 (94.97%)	1083603 (94.74%)	1075663 (94.05%)
18.75 (dirt roads)	39699 (3.47%)	12922 (1.13%)	13147 (1.15%)	11206 (0.98%)
25 (industrial fences)	8144 (0.71%)	8421 (0.74%)	8580 (0.75%)	7308 (0.64%)
37.5 (secondary roads)	8066 (0.71%)	8339 (0.73%)	8399 (0.73%)	7068 (0.62%)
75 (major roads and water features)	7684 (0.65%)	7383 (0.67%)	7915 (0.69%)	7542 (0.66%)
10000 (buildings, security fences, etc)	20646 (1.81%)	20498 (1.79%)	22032 (1.93%)	34888 (3.05%)

CHAPTER 5

CONCLUSION

The objective of this research was to develop, through a spatial modeling process, major seasonal Rocky Mountain elk movement paths to determine how elk move on and off LANL lands. These paths were developed for three time periods, late 1990s, the early 2000s and 5-10 years in the future (using two different future scenarios). The development of these paths was conducted to address two specific questions; 1) Have predicted seasonal movement paths changed between time periods? 2) What are the likely factors contributing to the detected change?

This research integrated a habitat suitability model with a least-cost path modeling process to predict seasonal elk movements from source areas of high density elk use to destinations of high density elk use. Source areas were located on LANL lands and destinations areas were located on adjacent lands.

Results of this study showed that movement paths did change between time periods. Generally, the 1990s showed a lower travel cost for most paths predicted. Although, the spring season of 1990s had a consistently higher travel cost than those predicted for the 2000s. There were some general trends in movement paths across all the time periods. The analysis of change indicated that the majority of the differences in paths were directly related to the HS model. Barrier features also had an impact on how paths were generated. In all time periods, movement paths were routed to either side of a linear barrier feature running along the western LANL boundary. This resulted in a reduced number of movement options. These pinch point areas would be critical for management. If barriers were placed in these areas then movement off or onto LANL could be compromised. In addition, the maximum future scenario could also result in movement barriers being formed preventing access to San Ildefonso. However, movement paths created for the 1990s and 2000s indicated there has not been any development of a barrier feature that prevented movement onto neighboring lands.

The movement paths that were generated have LANL facility management implications. Many of the sources of these paths were near areas of high development, and the paths crossed primary and secondary roads within LANL. If elk populations continue to increase in the area and an increase in LANL resident animals is seen, then increases in adverse animal-human interactions are possible. However, if proactive management is initiated, then these impacts could be minimized. This research should provide a framework for the development of an elk corridor protection plan at LANL providing information to resource and facility planners concerning elk movement and LANL operations.

The HS model substantially contributed to the differences in movement paths that were seen between time periods. Some of the differences seen could be a result of the modeling process, and actions taken to improve the process could result in higher confidence of predicted movement patterns. However, basic relationships and trends would probably not change dramatically.

There were several areas that were identified in the HS modeling process that could be evaluated for future improvement. These areas included defining the optimal extent to extract habitat availability information and inclusion of additional local variables that might prove to be important to elk habitat use and movement within the study area. The development of the habitat suitability model required the development of individual animal home ranges. These home ranges defined the geographical extent for the extraction of resource availability information. The general assumption was that elk selectively use resources within their homeranges, and not all resources within this area were used the same. However, the homerange estimates themselves were selectively defining the area based on where elk were found, and the homerange extent may be too restrictive in which to define habitat availability. This was seen in this research when the initial homeranges of 95% UD were created and valid models could not be constructed. Later, the UD's were re-calculated to 99%, which increased the size of the homerange and effectively increased the boundaries to extract availability information. This greatly improved the ability to assess the differences between resource use and availability for the 2000s data, but did not improve the ability to generate an average logistic regression model for the 1990s data. However, sample size might have been the controlling factor with the 1990s data. There still may be other methods of defining resource availability that might lead to model improvement. Garshelis (2000) suggests several different methodologies to address the difficulty in assessing habitat availability. However, he states the issue is problematic and there is no perfect solution. Each method has its own set of shortcomings. Future studies analyzing different methods of assigning resource availability and selecting the most appropriate method for this study might lead to model improvement with a stronger relationship being defined between use and availability of habitat resources. In addition, a stronger relationship might result in more variables being selected in the final averaged logistic regression. This might raise the maximum probability of use assigned by the model and increase the predictive power and accuracy of the model.

The model variables used in the HS models are not all inclusive. Additional variables may need to be included in the model evaluation. Including additional variables may increase both the predictive ability of the models as well as increasing the accuracy and resulting in a higher agreement between the models and verification data. This model does not account directly for the amount of cover, only the type of cover. The amount of cover may be an important factor to consider. The analysis of the impact on forest thinning and the deforestation due to bark beetle infestation was not analyzed with this model and may have important implications to elk movement.

The relationship of forage quality was not evaluated in the seasonal HS models. During the early 2000s the study area experienced drought conditions. These drought conditions could directly affect forage quality within a landcover type. The quality of forage may result in elk differentially selecting habitat within the same covertype.

The process of verification of the HS models needs to be further evaluated. Additional verification data are needed to assist in evaluating appropriate threshold levels in which to validate or verify the model. Because elk may utilize lower suitability areas while moving to patch to patch some distribution of lower suitability areas is highly likely. Therefore, it is important to assess what a valid distribution of verification points looks like.

The results of the study indicated that movement paths of Rocky Mountain elk are dynamic and change in time in response to environmental factors that influence habitat suitability and man-induced impedance factors. While habitat suitability was found to be the major factor influencing elk movements, man-induced impedance features have the potential to become barriers to elk movement. Utilizing this information in LANL facility planning has the potential to minimize possible adverse human-elk interactions but at the same time allow for elk movements to occur on and off LANL lands with minimum impedance.

This research may also be useful to adjacent landowners to assess movement pathways on their lands and provide information on corridor management. In addition, the methodology used in this thesis could be applied to the Jemez Mountains region utilizing telemetry data collected by many state and federal agencies to predict regional movement patterns and provide useful information in the development of an interagency elk corridor management plan.

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