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Forest Surveys and Wildfire Assessment in the Los Alamos Region; 1998–1999

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threat of catastrophic wildfire has not decreased. In fact, this threat increases with the new growth that is added to the forests each year.

The only plausible means for reducing this threat is to reduce the amount of fuels in the forests (Graham et al. 1999, Stephens 1998). This can be accomplished in a number of ways, but each fuels-reduction method requires the commitment of financial and human resources for its implementation. The level of resource commitment for each method can vary considerably, depending on

1) the nature of the specific methods under consideration,
2) the amount of fuels that need removal to reduce the wildfire hazard to acceptable levels,
3) the topographic characteristics of the site to be treated, and
4) the accessibility of the site to equipment and people.

Purpose of This Study

LANL's Ecology Group, in collaboration with the U.S. Forest Service's Rocky Mountain Research Station (RMRS), the University of Arizona, and Stephen F. Austin State University, has initiated a program to

1) survey the fuels in the forests and woodlands of the Los Alamos region and
2) understand the spatial distribution of these fuels and forest structures.

The Los Alamos County and the Bandelier National Monument have also participated as cooperators in this program. This project was begun on an exploratory basis in 1997. In 1998, we expanded the scope to 1) include more detailed sampling protocols, 2) emphasize landscapes that are known to support the greatest amounts of fuels, and 3) provide inputs to remote sensing and geographic information system (GIS) techniques that extrapolate the plot-based results to larger landscapes. The 1997 results were reported by Balice et al. (1999). This report contains the results of the surveys conducted in 1998 and 1999 and discusses the results of preliminary spatial analyses.

Environmental Setting

LANL covers 112 sq km (43 sq mi) of land. It is located on the eastern slopes of the Jemez Mountains, approximately 120 km (80 mi) north of Albuquerque and 40 km (25 mi) northwest of Santa Fe (Figure 1). LANL is largely but not completely circumscribed by Los Alamos County. In addition to LANL and County administered parcels, a significant portion of Los Alamos County is under the management of the U.S. Forest Service. LANL is also bordered on the south by the Bandelier National Monument and on the east by the San Ildefonso Pueblo. Two populated areas, Los Alamos townsite and White Rock townsite, are adjacent to LANL on the north and southeast, respectively.

Los Alamos County and its surroundings span an elevational gradient that ranges from approximately 1,631 m (5,350 ft), adjacent to the Rio Grande, to 3,199 m (10,496 ft) at

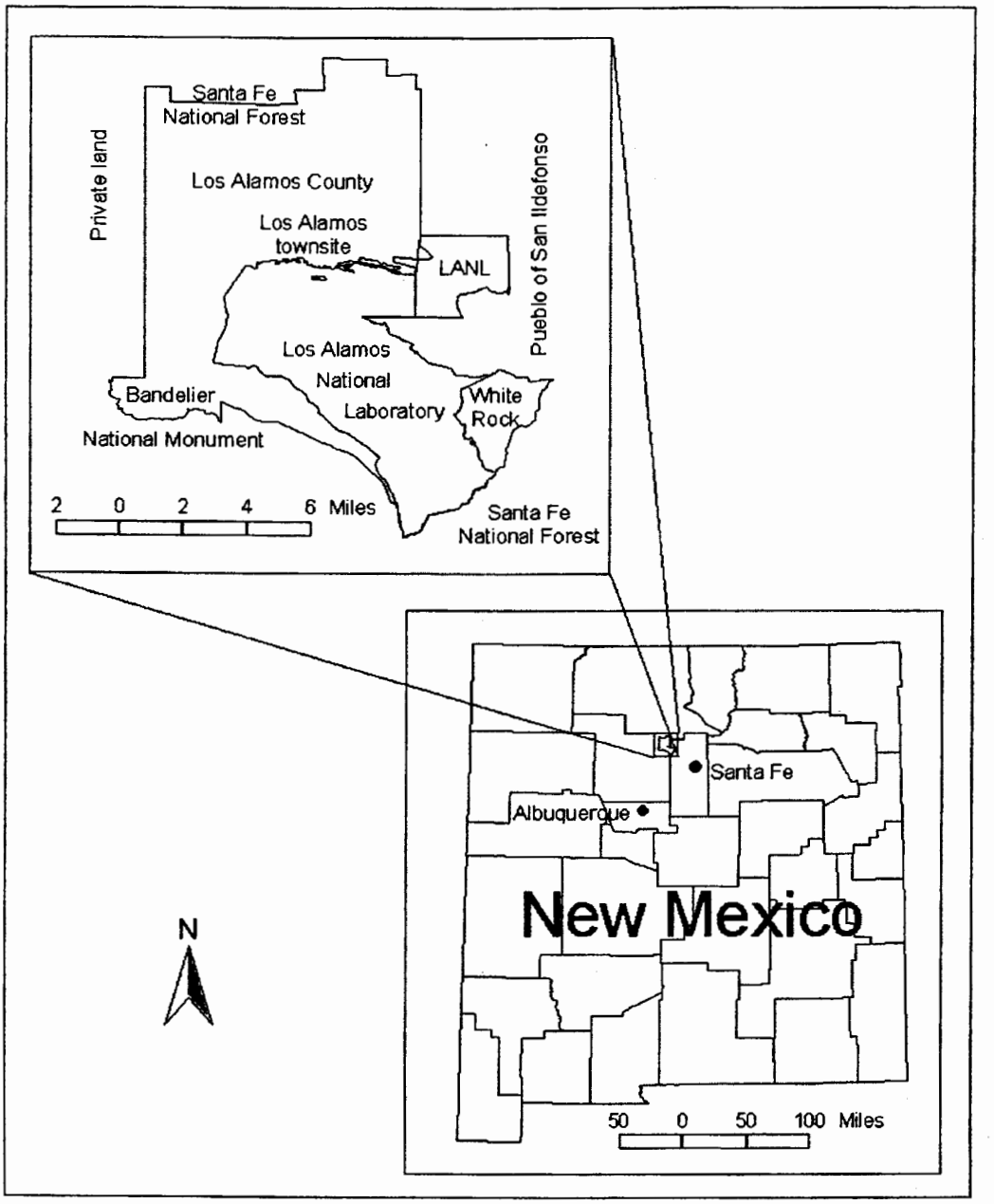

Figure 1. Location of the Los Alamos region and selected major landowners.

the crest of the Sierra de los Valles (Figure 2). Located in the western portions of Los Alamos County, the Sierra is a string of peaks, including, from south to north, Cerro Grande, Pajarito Mountain, and Cerro Rubio. Further to the west, the Sierra borders the Valle Grande, an ancient caldera.

The elevational gradient in the Los Alamos County and its surroundings encompasses several major cover types, including five vegetational zones (Figure 3). These are juniper savannas, piñon-juniper woodlands, ponderosa pine forests, mixed-conifer forests, and spruce-fir forests (Balice et al. 1997). Large acreages of grasslands and aspen forests are also found in the region. The elevational ranges of most of these major cover types are summarized in Figure 4. For further details see Balice et al. (1997) and Balice (1998).

Sample Site Selection

Scope of the Study

Within this environmental setting, the region of interest to this study was limited to forested and wooded areas at the middle and upper elevations of LANL property and in its immediate surroundings on Forest Service, Bandelier National Monument, and Los Alamos County lands (Figure 5). This consists primarily of forested or wooded mesas and canyons and mountain slopes above 2,134 m (7,000 ft), but also includes extensive acreages of grasslands. Specifically, the study area includes

1) the western 40% of LANL,
2) U.S. Forest Service land to the crest of the Sierra de los Valles and north to the Guaje Canyon area,
3) the western portions of Bandelier National Monument, including the upper sections of Frijoles Canyon,
4) the western and central portions of lands that surround the Los Alamos townsite and are administered by Los Alamos County, and
5) Department of Energy (DOE) lands that are located in Rendija Canyon.

This area is approximately 18.3 km (11.4 mi) long and 3.7 km (8.5 mi) wide: a total of 250.7 sq km (96.8 sq mi). The predominant vegetation types in this study area include ponderosa pine forests, mixed-conifer forests, spruce-fir forests, aspen forests, and grasslands.

Automatic Stratification Using Spectral and Spatial Data

Multi-spectral, remotely sensed, and digital elevation model (DEM) data were used to construct a stratified random sample of field sampling locations that represents environmental conditions within the study area (Yool et al. 2000). The DEM data were combined into a base map composed of single DEM scenes mosaicked together using digital processing techniques. In particular, a multistage convolution filter was used to

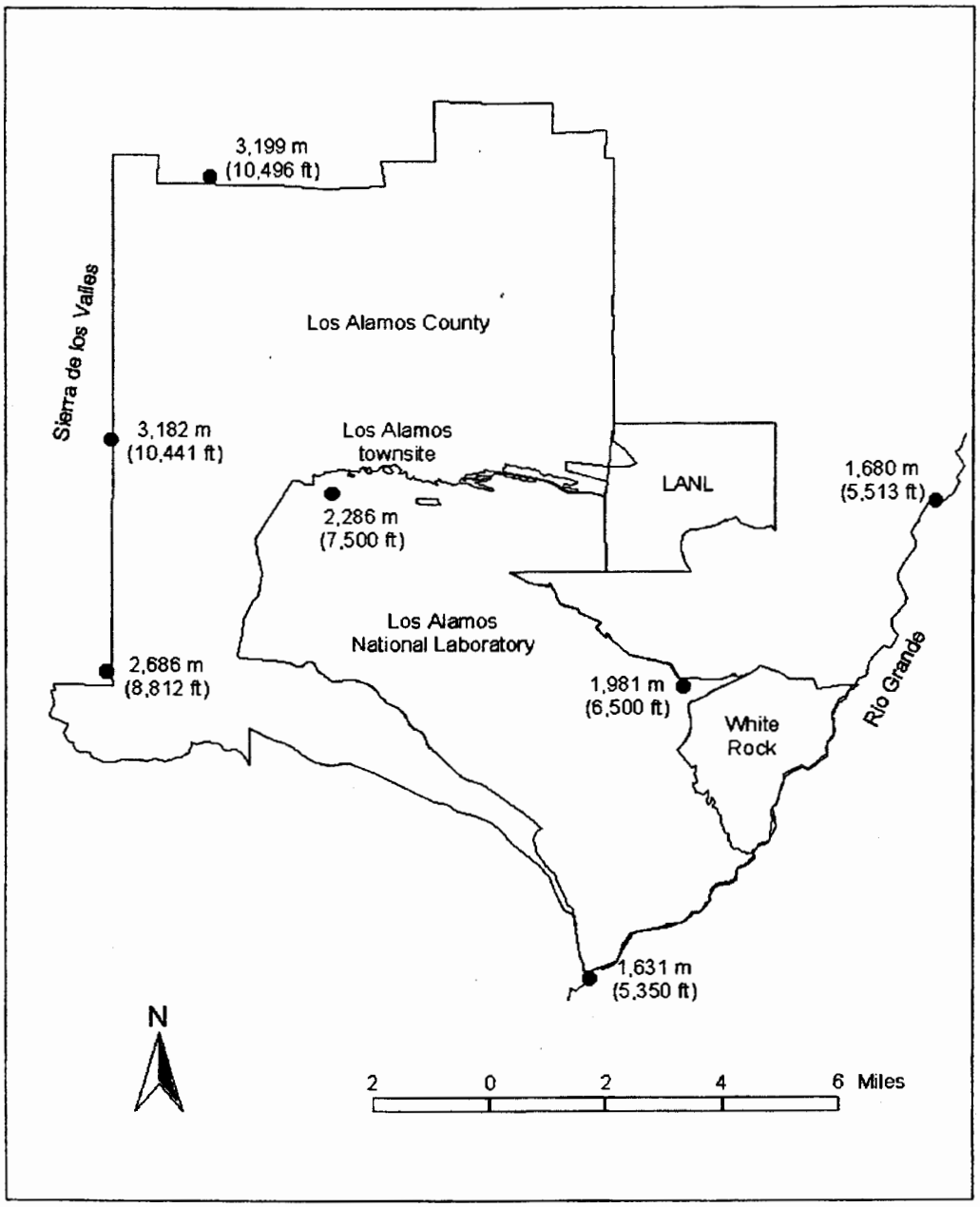

Figure 2. The elevation gradient of the Los Alamos region.

control for this project. Next, a Landsat Thematic Mapper (TM) image (July 3, 1997) was obtained and registered to the DEM base map.

Variables derived from digital terrain models were used to predict vegetation patterns and construct a random sample of potential sample sites (Davis and Goetz 1990). First, the TM-DEM data layers were stratified into combinations of overstory type and aspect categories. These include sixteen possible combinations of grass, ponderosa pine, mixed conifer, and aspen over aspect categories of north, south, east, and west. Then, one hundred possible sample points were randomly selected from each stratum. In the interest of safety, no points were chosen in areas with slopes of 56 percent or greater. In addition, each selected sample site was constrained to be spectrally and spatially homogeneous and at least 60 m by 60 m in size. This is equivalent to four 30-m by 30-m TM pixels.

Location of Sample Sites in the Field

From the collection of potential sample sites that had been identified through the automated stratification procedure, individual sites were selected for further analysis on the ground. First, each of the selected sites was located in the field, with the assistance of a Geo Explorer II™ global positioning system (GPS) unit (Trimble Navigation Ltd. 1996). Then, the site was checked to verify the homogeneity of topographic, soils, and vegetational conditions for a distance of 60 m (197 ft) in any direction. If these conditions were not met, the site was rejected and either a new randomly selected point was located in the field or the original point was replaced by the nearest homogeneous area of vegetation. Assuming that the registration error of the TM data could be plus or minus one 30-m pixel, the resulting minimum mapping unit is 60 m (197 ft) or four TM pixels.

In addition to providing a random sample of data points for detailed sampling, the results of the automated stratification process were also used to select clusters of paired, triplicate, or quadruplicate plots whenever possible. The purpose of this sampling sub-strategy was to provide a means for analyzing the spatial variability of fuels and vegetational structures within the same vegetation-topographic combination. First, a sample point was selected from the output of the automated stratification process. If the area was homogeneous, this point was sampled using the field procedures described in this document. Then, a second sample point was subjectively selected at a distance of approximately 120 m (394 ft) from the first point and on roughly the same topographic position as the first point. Finally, the second point was sampled according to the field methods described below. If a sufficiently large homogeneous area was available, this subjective selection process was repeated to generate a triplicate plot or a quadruplicate plot.

Field Methods

The field methods described below are generic in that they represent the minimum data collection procedures that were performed at each sample location. If time and resources were available, additional information was gathered and recorded. Since the sampling

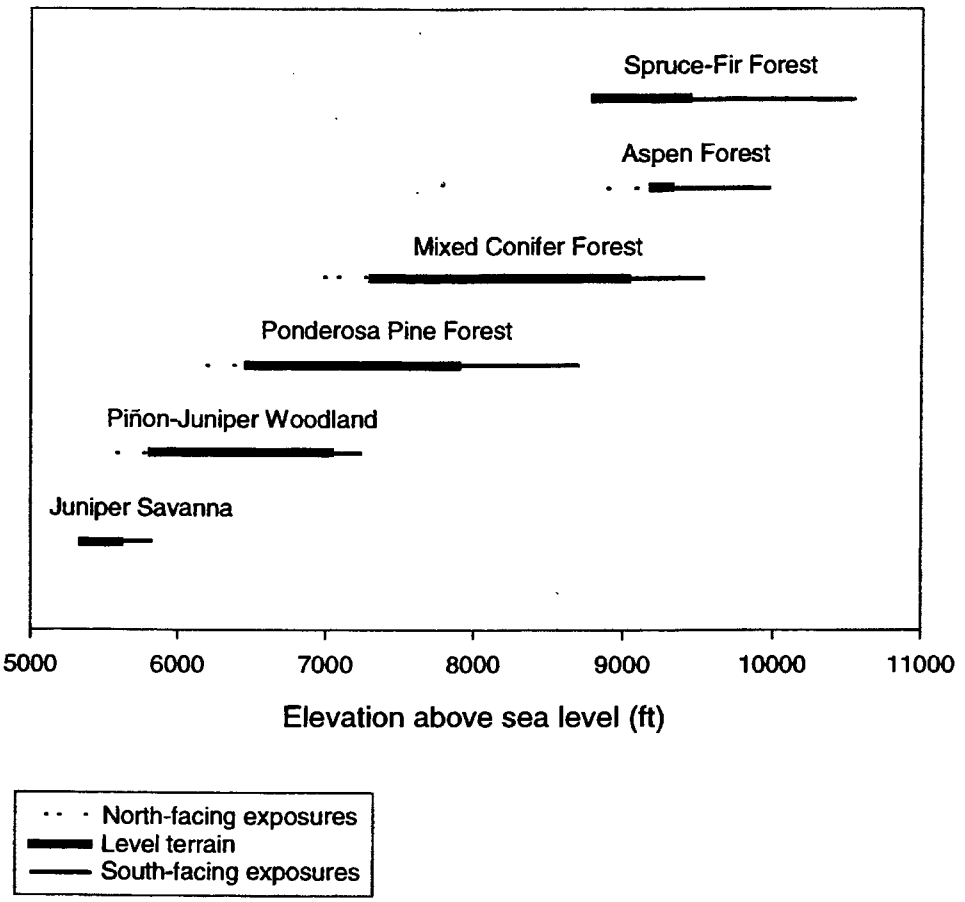

Figure 4. Elevational ranges of selected land cover types.

design used a nested approach, the collection of additional information was facilitated by merely repeating the sample process in a separate and additional subsample (i.e., subplot).

By convention, metric units were used during the plot layout procedure and for measurements made on the ground surface. English units were used for measurements made above the ground surface and for measurements of depths below the ground surface.

Appendix A includes examples of the field data forms used in this project. One Site Summary form and one Plot Layout form were used per macroplot. Since a nested design was used, all other forms were used in multiple quantities. Two Quad Summary forms and two Overstory Fuels, Complete Sample Forms were used. The remaining forms were used in multiples of four for each macroplot. That is, two subplots and six quads were sampled at some level within each macroplot.

Appendix B contains lists of all plant species that have been mentioned and discussed in this report. The plant species in these two lists are arranged in alphabetical order and by scientific name or four-letter code, respectively. A list of additional plant species encountered during the execution of this project can be found in Balice (1998).

Sample Site Summary Information

All of the data collected in the field were stored on field data forms and transferred to a computer database at the completion of each respective field season. In 1998, the sample sites were given alphanumeric plot numbers of the form TAXX-YYP. The actual values of the plot numbers reflect the

1) field team (T) that collected the data (Table 1),
2) agency (A) that owned or administered the land that was being sampled (Table 2),
3) remotely sensed topographic-vegetation combination (XX),
4) plot or cluster number (YY), and
5) sequence number within its respective cluster (P), where applicable.

The cluster number ranged from 1 to 16 and the sequence number was incremented sequentially beginning with 1. For paired plots, triplicate plots, etc., the cluster numbers (YY) were given alphabetical annotations (P) starting with "A" for the first, randomly selected plot in the cluster, and continuing with "B", "C", etc., respectively, for each additional plot in the cluster. In 1999, this alphanumeric system was simplified to the form TA-YYP. The remote sensing indicator number (XX) was dropped from the nomenclatural scheme.

The plot number, along with the date and the names of the field team members and information describing the directions to the plot, were recorded on the Site Summary data form. The GPS location was also collected, and the name of the GPS file and the time of its collection were recorded on the Site Summary data form. Descriptive notes pertaining to the vegetational conditions, including dominant species, disturbance history, plant

Table 1. Plot number coding conventions for the field team identifier (T).

Code	Year	Field team
A	1998	Forest Service, RMRS and Ecology Group, LANL
N	1999	Ecology Group, LANL
T	1999	Forest Service, RMRS

Table 2. Plot number coding conventions for the agency identifier (A).

Code	Land Management Agency
B	Bandelier National Monument
C	Los Alamos County
F	Española Ranger District, U.S. Forest Service
L	Los Alamos National Laboratory
P	Pajarito Ski Area – private
R	Los Alamos Area Office, U.S. Department of Energy

diseases, soil conditions, and topographic setting were also compiled on the Site Summary form. For coniferous forests, the habitat type, or plant community type, was recorded according to previous classifications by Balice et al. (1997), Balice (1998), or DeVelice et al. (1986). For aspen forests, community classifications developed in surrounding regions were used to determine the habitat type (Mueggler and Campbell 1986, Mueggler 1988, Komarkova et al. 1988). The U.S. Forest Service fuel model was also recorded (Anderson 1982). Whenever possible, the fuel model was also compared to the fuel photo series developed for Arizona and New Mexico (U.S. Forest Service, Southwestern Region, undated report). Finally, 35-mm photographs were obtained that portray the general site conditions. The roll and photo numbers, along with the compass direction of the camera view, were recorded on the Site Summary form.

Plot Layout and Sampling Conventions

A nested, randomized plot layout and sampling design was used to 1) allow for within-plot replication and measurement of statistical dispersion of fuel loads and other parameters and 2) provide a random sampling frame for statistical analyses of fuels and fire hazard variations at the pixel and subpixel level. This was accomplished by defining a macroplot about the plot center (O) that consisted of four subplots (Figure 6). The macroplot consisted of a square area, 60 m on each side, with each subplot being 30 m on a side. The macroplot and subplot margins were oriented along the slope contours, and the horizontal and vertical compass bearings of the macroplot axes were recorded on the Plot Layout form. The plot center (O) was permanently marked with rebar, and the four corners of the plot were also marked with flagging and spikes.

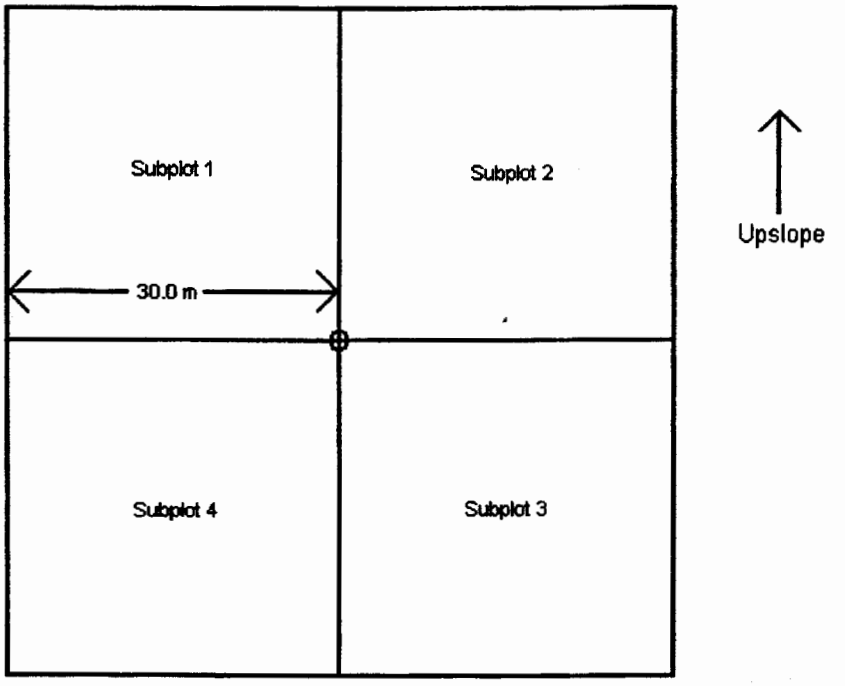

Figure 6. Macroplot layout and subplot numbering scheme. The macroplot scale is 60 m by 60 m. The subplots are numbered sequentially in clockwise direction about the plot center (O).

The subplots were numbered sequentially in a clockwise direction, with the subplot number 1 being arbitrarily located in the upper left corner of the macroplot. Then a subset of two subplots was randomly selected for further sampling, and their numbers were recorded on the Plot Layout form. The randomization was done using the Statistical Analysis Systems™ (SAS) programming language (SAS Institute Inc. 1988). Since the layout of each subplot was almost always associated with some error, this gap between the start and finish was also recorded to the nearest centimeter. This plot-layout error term allows for the estimation of the amount of variability for many of the parameters that were collected within the subplot.

Next, each of the two subplots that had been selected for sampling were further divided into quarters, or quads, that were 15 m on a side (Figure 7). The quads, within each subplot, were numbered 1 through 4 in a clockwise direction, with the upper left quarter being designated as quad number 1. Then, three of the four quads were randomly selected, and the numbers of the selected quads were recorded on the Plot Layout form. As before, the randomization was done using the SAS programming language (SAS Institute Inc. 1988).

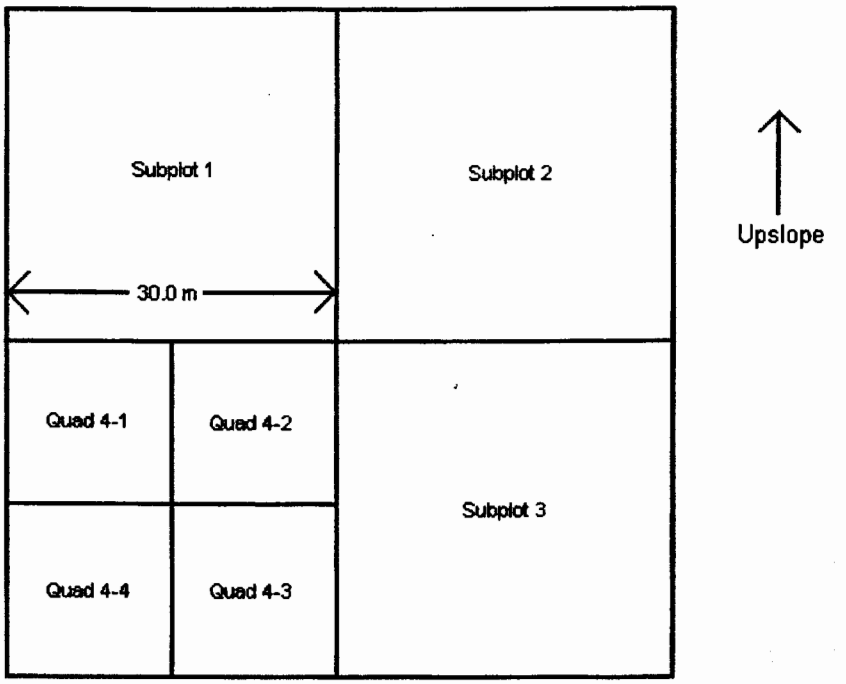

Figure 7. Plot layout with arrangement and numbering of quads shown for subplot four. The macroplot scale is 60 m and quad scale is 15 m.

In each selected subplot, two 3-m by 15-m strip plots were constructed within the first randomly selected quad (Figure 8). This was accomplished by selecting a random starting point (X) along the downhill border of the quad, where the lower left corner of the quad was arbitrarily defined to be the origin. This random starting point (X) marked the beginning of the strip plot system, where each subsequent step in the layout procedure was systematic. At the starting point (X), a 15-m line transect was constructed from the downhill border to the uphill border of the quad. A second 15-m line transect was constructed perpendicular to the first one, but separated by a distance of an additional 3 m from the origin. These two line transects defined a 3-m by 15-m strip plot (strip plot A).

This strip plot layout process was repeated to form a second 3-m by 15-m strip plot (strip plot B). However, the origination of strip plot B was exactly 7.5 meters from the randomly selected starting point (X). According to this randomized strip plot layout procedure, every point within the quad had equal chance of being selected. SAS was used to develop the randomization algorithm (SAS Institute Inc. 1988). By convention, the first line transect in each strip plot was denoted the vegetation transect and the second line transect in each strip plot was denoted the fuels transect.

modifications detailed below. According to this inventory procedure, woody fuels that were on or near the ground were counted or measured if they intercepted the plane of a sampling line.

To facilitate sampling and subsequent analyses of fire behaviors, these down woody fuels were subdivided into four size classes (Table 3). According to their size class, these woody fuels were sampled at varying positions along the lines. Tallies of 1-hour fuels and 10-hour fuels were completed in the first 2 m of each line. Tallies of 100-hour fuels were completed in the first 3 m of the lines. The 1000-hour fuels were sampled along the entire length of the lines, 15 m. The diameters of the 1000-hour fuels at the point of intercept were recorded to the nearest tenth of an inch. The condition of the 1000-hour fuels, sound or rotten, was also noted.

Duff depths and soil depths were also measured along the second transect of each strip plot. This was done at distances of 5 m and 10 m from the beginning of each transect. The duff depth was measured by inserting a ruler into the layer of duff and measuring its thickness to the nearest tenth of an inch. The soil depth was measured by inserting a soil probe into the soil and measuring its penetration to the nearest inch.

Litter-weight and Vegetation-weight Samples

Ground-surface fuels, in the form of litter and vegetation, were sampled within rectangular microplots. Four 1-ft by 2-ft rectangles were used for this purpose. The rectangles were located along each of the fuels transects at a starting point that was 7.5 m from the lower border of the quad. From this starting point, the rectangles were systematically arranged similarly to that described by Brown et al. (1982). The primary difference from the standard procedure was that the rectangles were offset from the line by a distance of 2 ft. Then, they were located in a rectangular fashion and separated from each other by distances of 2 ft. Once the rectangles were placed at their respective locations, they were used to sample the litter biomass and understory herbaceous and shrubby vegetation. For the purposes of this study, understory herbaceous and woody vegetation is defined as grasses, forbs, and low-growing shrubs. Low-growing shrubs are those, such as *Pachistima myrsinites* (mountain lover), that typically grow to heights of less than 0.30 m (1 ft).

Litter and understory vegetation were sampled independently within the system of rectangles, but using identical methods. The example that follows is for the litter, but the sampling of understory vegetation was the same. First, the rectangle with the greatest amount of litter was exhaustively sampled and the material was placed in a labeled bag for transport and processing. Next, the litter biomass within each of the remaining three rectangles was estimated as a percent of the total amount of litter contained in the sampled rectangle. Finally, these percentages were recorded on the Quad Summary and Surface Conditions form.

Table 3. Size classes of down woody fuels. The fuel type designation reflects the time required for the fuel moisture to equilibrate with ambient atmospheric conditions.

Fuel type	Size class
1-hour	Less than ¼ inch in diameter
10-hour	¼ inch to 1 inch in diameter
100-hour	1 inch to 3 inches in diameter
1000-hour	Greater than 3 inches in diameter

Understory Vegetation Sampling

The Surface Vegetation data form was used to record understory vegetation data and selected ground surface characteristics. The two vegetation transects were used for this purpose. The line intercept method was used to sample all herbs, graminoids, and shrubs (Canfield 1941, Bonham 1989, Elzinga et al. 1998). The intercept of each individual plant or group of plants was measured to the nearest centimeter and recorded by species and growth form. Intercepts of litter, duff, bare soil, moss, lichens, gravel, cobbles, stones, and boulders, and bedrock were also recorded. Finally, a complete list of plant species was compiled for the subplot.

Woody Midstory Sampling

The two 3-m by 15-m strip plots, strip plots A and B, were used to sample all trees and shrubs that met specific height criteria. These data were recorded on the Woody Midstory form and a two-part procedure was used. First, a 3-m by 3-m microplot was used to sample all trees and shrubs less than 2 ft tall. Information recorded for each individual included the species, live or dead status, basal diameter, total height, height to live crown, and crown width to the nearest tenth of a foot. Crown shapes were also classified as a rectangle, circle, triangle, inverse triangle, diamond, or flag. Multiple stemmed individuals were noted but only the number of stems and the basal diameter of the largest stem were recorded.

Second, the entire 3-m by 15-m strip plot was used to sample all shrubs and trees greater than or equal to 2 ft tall and less than 10 ft in height. These individuals were measured and recorded in a manner similar to that used in the 3-m by 3-m microplots. However appropriate adjustments were made to the units of measure. The total heights, crown widths, and heights to live crown were measured to the nearest foot, and the basal diameters were measured to the nearest tenth of an inch. In addition, any mistletoe infestations were rated and recorded according to a rating scheme developed by Hawksworth (1977). This was done by dividing the crown of each plant into three sections, the lower third, middle third, and upper third. Within each third, the presence of mistletoe was given a numerical rating of zero for "absence" of mistletoe, one for

moderately infested, and two for severely infested. Then the rating for each third was summed for a total value that can range from zero to six.

Overstory Sampling

For the purposes of this study, overstory trees and shrubs were defined as those that were at least 10 ft tall. Within each subplot, the forest overstory was sampled using two levels of detail. In the first randomly selected quad, a "complete" sample was obtained and recorded on the Overstory Fuels – Complete Sample form. In the remaining two randomly selected quads, a "reduced" sample was taken and the data were recorded on the Overstory Fuels – Reduced Sample form. In either case, all trees or shrubs that were in the respective quad and were greater than or equal to 10 ft tall were sampled

For the complete sample, each tree or shrub in the quad was recorded by species and by its live or dead status. For dead trees, diameters at breast height (*dbh*) and total heights were also recorded. For each live tree, the *dbh*, total heights, heights from the ground to the live crown, greatest crown widths, crown shapes, and mistletoe infestation ratings were recorded. The total heights, crown widths, and heights to live crown were measured to the nearest foot and the diameters were measured to the nearest tenth of an inch. Crown shapes were classified as a rectangle, circle, triangle, inverse triangle, diamond, or flag. The mistletoe infestation was rated and recorded according to the method developed by Hawksworth (1977). Multiple stems, forks, presence of disease or infestations, or other unusual conditions or deformities were also noted where applicable.

From the collection of live trees sampled in the first randomly selected quad, the complete sample, a dominant, intermediate, and suppressed tree were selected and noted on the Overstory Fuels – Complete Sample form. Increment cores were extracted from each of these trees. The approximate age of each tree, at breast height, was determined from its respective increment core and recorded on the form.

Finally, the overstory canopy coverage of the quad was estimated using the densiometer method (Lemmon 1956, Strickler 1959, Ganey and Block 1994). This was done in the approximate center of the quad and the measurement was repeated four times, once for each primary axis of the plot. According to the densiometer method, 96 possible points could be covered by green foliage in the forest overstory. For each of the four densiometer measurements, the actual number of covered points, up to 96, was recorded on the Overstory Fuels – Complete Sample form.

The methods for each of the two reduced samples, in the second and third randomly selected quads, were similar to the complete sample. All trees that were greater or equal to 10 ft tall were censused. However, the Overstory Fuels – Reduced Sample form was used for each reduced sample and the recorded data were limited to the species, live or dead status, and *dbh*. In addition, four densiometer measurements of the overstory canopy coverage were also obtained.

Office Methods and Database Development

The data forms were checked for completeness and accuracy before they were transported to the office. Once in the office, the data forms were stored in a secure area. Upon request, copies of the data forms were supplied to each of the collaborators and agency cooperators. As time became available, the data recorded on the paper forms were transferred to electronic spreadsheet versions of the data forms, by plot, and stored in a computer database.

The litter-weight and vegetation-weight samples were weighed, dried for 24 hours at 65° C, and weighed again. The wet weights and the dry weights were recorded on the Quad Summary and Surface Conditions data forms and in the electronic database.

The location information was also summarized and catalogued. The GPS data were corrected using ESH-20's GPS base station and Pathfinder™ software (Trimble Navigation Ltd. 1995). Then, the data for each plot were averaged and transformed from Latitude/Longitude, WGS 84, to State Plane coordinates, New Mexico Central Zone, and to UTM coordinates, NAD27 and NAD83 (ESRI Inc. 1994). Finally, the corrected, transformed GPS data points were labeled with the plot names and stored in an Arc/Info database. The 35-mm photographic exposures were developed and catalogued by sample plot and by date. Many of these photos were scanned and stored in an electronic folder in ESH-20's computer network.

Data Summarization

The data for each plot were summarized by subplot and by plot using appropriate transformations and units of measure. Then, the average values for each plot were entered into a plot summary spreadsheet for each plot. This was done according to the following procedures. Unless stated otherwise, it is assumed that the data were scaled up from the original strip transect, quad, or subplot levels to the plot level.

Topography and Site Classification

The two measurements of slope, in percent, and slope aspect, in degrees from true north, were averaged. Then, to adjust for downward biases in plot estimates that had been gathered on sloped terrain, the slope correction factor (*SCF*) was calculated as an intermediate result.

$$SCF = \sqrt{1 + \left(\frac{slope}{100}\right)^2} \qquad (1)$$

where *slope* = slope angle from level terrain (percent).

In addition, to partially assess the solar exposure that the sample site experiences during a growing season, the percent slope and slope aspect were entered into the following solar exposure (*SE*) function.

$$SE = slope \times \cos\left(\frac{\pi \times (aspect - 190)}{180}\right) \tag{2}$$

where *aspect* = slope aspect (degrees from true north).

This unitless relationship assumes that a site on a relatively steep slope and with an aspect of 190° from true north receives the greatest solar input. The cosine term ranges from –1 for aspects of 10° to 1 for aspects of 190°.

For each macroplot, the approximate elevation, in feet above mean sea level, was obtained by projecting its GPS location on Arc/Info elevation data layers, including 100-ft, 20-ft, 10-ft, and 2-ft contour databases. The elevation of the sample site was visually interpolated to the nearest foot. The elevation data were also converted to metric units. Using information recorded on the sample sheets and from mapped data, the topographic position of the macroplot was determined and recorded for each plot (Table 4). The dominant overstory species or the physiognomic structure of the macroplot was also recorded (Table 5). The habitat type that had been recorded in the field was also entered into the summary spreadsheet (Table 6).

Ground Surface Biomass and Fuels

The downed woody fuel weights ($DWFW_i$) for the *i*th size class (see Table 3), were calculated, in tons per acre, according to the following relationship adopted from Brown (1974) and Brown et al. (1982; page 16).

$$DWFW_i = \frac{m_i \times n_i \times SCF}{N \times l} \tag{3}$$

where m_i = conversion factors for the *i*th size class,
n_i = the total number of intercepts for the *i*th size class,
SCF = the slope correction factor,
N = number of lines, and
l = the length of each line (ft).

In this report, the downed woody fuel weights are reported by individual size classes and by two summary size classes. The first summary size class, the combined 1-hour to 100-hour fuels, summed over the 1-hour, 10-hour, and 100-hour down woody fuel classes. The second size class, the total 1000-hour fuels, summed over both of the 1000-hr fuel categories, sound and rotten.

Table 4. Topographic setting of the sampled plots and their data codes.

Code	Topographic Setting
CY	Canyon
MS	Mesa
MT	Mountain

Table 5. Database coding for overstory dominance.

Code	Dominant Overstory Species or Vegetation Type
AS	Aspen forest
GR	Grassland
MC	Mixed conifer forest
PP	Ponderosa pine forest
SB	Shrub-pine woodland
SF	Spruce-fir forest

Two independent methods for estimating duff weights appeared to give disparate results (Ffolliott et al. 1968, Wagtendonk et al. 1998). To resolve this, we obtained 19 duff samples from seven forested sites, representing *Pinus ponderosa* (ponderosa pine), *Pseudotsuga menziesii* (Douglas fir), and *Abies concolor* (white fir) vegetation. Drying and weighing of these samples resulted in bulk density estimates that were an order of magnitude lower than similar estimates from Wagtendonk et al. (1998), but within one standard deviation of the estimates for *Pinus ponderosa* forests reported by Ffolliott et al. (1968). For ponderosa pine duff, Ffolliot et al. (1968) would predict approximately 16.8 tons/acre, whereas the 95% confidence interval for the eight duff weights obtained from ponderosa pine forests in the study region returned a lower limit of 15.9 and an upper limit of 20.3 ($t_{7,0.025} = 2.365$). Therefore, conversion factors in Ffolliott et al. (1968) were used to estimate duff weights for this study.

Within each fuels transect, the average duff weight (*DW*) was calculated for the two duff depth measurements as

$$DW = 4.9 \times 3630 \times \frac{dd_1 + dd_2}{2 \times 2.54} \tag{4}$$

where dd_i = the *i*th depth measurement in the transect, where $i = 1$ and 2.
4.9 = weighted-average bulk density for ponderosa pine duff from Ffolliott et al. (1968),
3630 = conversion factor from Brown et al. (1982), and
2.54 = conversion from centimeters to inches.

Table 6. Habitat type or community type database coding. The vegetation types are separated into types according to the dominant overstory species or the dominant growth form.

Code	Habitat type or community type
Abla / Erex	Corkbark fir / Forest fleabane
Abla / Vamy	Corkbark fir / Whortleberry
Abco / Acgl	White fir / Mountain maple
Abco / Aruv	White fir / Kinnikinnik
Abco / Quga	White fir / Gambel oak
Abco / Erex	White fir / Forest fleabane
Abco / Rone	White fir / New Mexico locust
Mesagrass	Grassland on mesas below 8500 feet in elevation
Mtngrass	Grassland on mountains above 8500 feet in elevation
Pien / Erex	Engelmann spruce / Forest fleabane
Pipo / Bogr - Scsc	Ponderosa pine / Blue grama – Little blue stem
Pipo / Mumo	Ponderosa pine / Mountain muhly
Pipo / Quga	Ponderosa pine / Gambel oak
Potr / Feth	Aspen / Thurber fescue
Potr / Ptaq	Aspen / Bracken fern
Psme /Aruv	Douglas fir / Kinnikinnik
Psme / Mumo	Douglas fir / Mountain muhly
Psme / Quga	Douglas fir / Gambel oak

The dry weights for the litter and ground vegetation samples were combined with the estimated percentages of litter and vegetation in the three unsampled rectangles. These results were used to estimate the amount of both vegetation biomass (BW_1) and litter biomass (BW_2), in tons per acre, within each strip plot. Relationships developed by Brown et al. (1982) were adopted for this purpose.

$$BW_i = \frac{c_i \times SCF \times wt_i \left(1 + P_{i,1} + P_{i,2} + P_{i,3}\right)}{2000} \tag{5}$$

where i = indicator value: 1 = herbaceous vegetation and 2 = litter,
c_i = conversion factor: herbaceous vegetation = 12.39 and litter = 24.78,

SCF = slope correction factor,
wt_i = dry weight (g) from the sampled vegetation or litter, and
$P_{i,j}$ = the fraction of litter or vegetation in the jth rectangle, where j = 1, 2, and 3.

Woody Shrub Biomass and Fuels

The method for calculating the individual total aboveground weights of shrubs was adopted from Brown (1976). This was based on the generic equation for the shrub total weight ($STW_{i,j}$) for the ith individual in the jth shrub species, in grams, of the form

$$\ln(STW_{i,j}) = a_j + b_j \times \ln(dia_{i,j}) \tag{6}$$

where $dia_{i,j}$ = basal diameter (cm) for the ith shrub in the jth species,
a_j = first coefficient for the jth species, from Brown (1976; Table 1), and
b_j = second coefficient for the jth species, from Brown (1976; Table 1).

These results, in grams, were converted to tons/ac by multiplying by 0.0022.

A total of 25 species were listed in Brown (1976; Table 1), and 17 of these were the same species, such as *Acer glabrum* (mountain maple) or in the same genus, such as *Vaccinium* spp., as those encountered during the execution of this study. For those species, such as *Jamesia americana* (cliff bush), that had no counterpart in Brown (1976; Table 1), the coefficients, a = 3.580 and b = 2.853, that derived for combined medium-sized species were used. An exploratory data analysis indicated that these coefficients fit our data better than coefficients for low-growing or tall species. Finally, the estimates for total biomass of individual shrubs were summed for all shrubs and for all species in the strip plot and over all strip plots and quads. Then, these total shrub biomass estimates were converted from grams to tons/ac. The specific conversion factors depended on the size of the strip plot, 3 m by 3 m or 3 m by 15 m, and therefore the size of the plant, less than two ft in height or greater than or equal to 2 ft in height.

Brown (1976; Table 1) was also used to estimate the leaf weights for the shrubs sampled in the strip plots. These biomass estimates were used to partially evaluate the 1-hour fuels in the plot that are close to the ground, but not on the ground. As before, this was based on the generic equation for the shrub foliage weights ($SFW_{i,j}$) for the ith individual in the jth shrub species, in grams, of the form

$$\ln(SFW_{i,j}) = a_j + b_j \times \ln(dia_{i,j}) \tag{7}$$

where $dia_{i,j}$ = basal diameter (cm) for the ith shrub in the jth species,
a_j = first coefficient for the jth species, from Brown (1976; Table 1), and
b_j = second coefficient for the jth species, from Brown (1976; Table 1).

The remainder of the calculation procedure was identical to that used for total shrub biomass, as described above. For those shrubs that had no counterpart in Brown (1976;

Table 1), the coefficient values, $a = 1.945$ and $b = 2.363$, were used. The weights of dead shrubs were estimated by subtracting the foliage weight from the total shrub weight.

For calculation of total shrub biomass and shrub foliage biomass of *Quercus gambelii* (Gambel oak) in specified size ranges, a system of equations developed by Chojnacky (1988, 1992) was used. First, for those individual oaks where the diameters were measured at breast height (dbh_i), the diameters were converted to measures at the root crown or the base of the stem (DRC_i), according to

$$DRC_i = \frac{dbh_i - \beta_o}{\beta_1} \tag{8}$$

where $\beta_o = -0.5766$ and
$\beta_1 = 0.8841$.

Then, the diameter squared height (X_i) was calculated for the ith individual oak

$$X_i = \frac{DRC_i^2 \times ht_i}{1000} \tag{9}$$

where DRC_i = basal diameter (cm) for the ith individual oak and
ht_i = total height (ft) for the ith individual oak.

Acceptable size ranges include all *Q. gambelii* with basal diameters (*DRC*) greater than or equal to 2.0 in., otherwise the generic medium-sized shrub equations from Brown (1976) were used. Next, the diameter squared height (X_i) was used to calculate the gross, outside-bark bole volume ($V_{bd,i}$) for the ith Gambel oak according to the following relationships

$$V_{bd,i} = \beta_o + \beta_1 X_i + \beta_2 X_i^2 \qquad X_i \le 7.1046 \tag{10}$$

or

$$V_{bd,i} = \beta_o + \beta_1 X_i + \beta_2 \left(\frac{3X_o^2 - 2X_o^2}{X_i} \right) \qquad X_i > 7.1046 \tag{11}$$

where $\beta_o = -0.0534$,
$\beta_1 = 2.3077$, and
$\beta_2 = 0.0467$.

The gross, outside-bark bole volume ($V_{bd,i}$) for the ith Gambel oak was used to calculate the weight of outside bark, oven-dry bole and branches, greater than 3.8 inches in diameter ($W_{bd,i}$) as

Systems of equations for whole tree weights and foliage weights for *Populus tremuloides* (aspen) were not reported in Brown (1978). Therefore, data presented in Johnston and Bartos (1977) were investigated for this purpose. These data were subjected to regression and nonlinear modeling using SAS (SAS Institute Inc. 1988). However, the greatest R-square observed during this modeling exercise was 0.932 or less. In contrast, analyses of aspen data presented by Telfer (1969) resulted in R-squares for total weight and leaf weight of 0.988 and 0.956, respectively. Therefore, equations presented in Telfer (1969) were used for this purpose. For the total weight ($W_{qt,i}$) and the leaf weight ($W_{ql,i}$) of the *i*th aspen trees, these equations are

$$W_{qt,i} = \exp(-2.920 + 2.715 * \ln(bd_i)) \tag{15}$$

and

$$W_{ql,i} = \exp(-2.677 + 2.156 * \ln(bd_i)) \tag{16}$$

where bd_i = the basal diameter (mm) of the *i*th aspen.

The composite biomass data for shrubs and trees less than 10 ft tall were summarized into groups that represent their contribution to wildfire behaviors and entered into the database. These include

1) total shrub biomass,
2) total tree biomass,
3) total biomass for both shrubs and small trees,
4) shrub and small tree 1-hour fuels,
5) shrub and small tree 10-hour fuels, and
6) shrub and small tree 100-hour fuels.

A summary database category that consisted of all understory fuels was also created. This total understory fuel category included the fuel types

1) all size classes of down woody fuels,
2) duff biomass,
3) litter biomass,
4) herbaceous and small shrub biomass, and
5) total biomass for both shrubs and trees.

Forest Midstory and Overstory Characteristics

The data for trees and shrubs, greater than 10 ft tall, were incorporated into stand tables for each subplot, by species, by live or dead status, and by 4-in. diameter classes. Trees, less than 10 ft tall, which had been sampled in the strip plots were also entered into the stand tables by the height classes

1) less than 1 ft tall,

2) greater than or equal to 1 ft to 2 ft tall,
3) greater than or equal to 2 ft to 6 ft tall, and
4) greater than or equal to 6 ft to 10 ft tall.

The data were converted to numbers of stems per acre, summarized by subplot and by macroplot, and entered into the database by the following growth form-size classes

1) small trees: less than 2 ft tall,
2) shrubs: greater than or equal to 2 ft tall and less than 8 in. *dbh*,
3) ladder fuels: greater than or equal to 2 ft tall and less than 8 inches *dbh*, and
4) overstory fuels: greater than or equal to 8 inches *dbh*.

The densiometer measurements, 12 per subplot or 24 per macroplot, were converted to percent canopy cover, averaged for the macroplot, and entered into the database.

Analysis of Remotely Sensed Data

Spectral response patterns from spaceborne sensors are useful for characterizing the forest canopy using vegetation indices (e.g., Baret and Guyot 1991) and radiative transfer modeling (e.g., Ganapol et al. 1999). To assess the biophysical characteristics of the vegetation in the study region, we applied two Kauth-Thomas (KT) linear transformations to the TM data (Kauth and Thomas 1976). The KT greenness index contrasts the near-infrared band (TM4) with the three visible TM bands (TM1, TM2, and TM3). Similarly, the KT wetness index contrasts the mid-infrared bands (TM5 and TM7) with the visible and near-infrared bands.

These indices were calculated for a single TM pixel that overlaps the coordinates of the sample sites. A correction was applied to reduce the error introduced by atmospheric scattering. However, the image processing did not translate the digital numbers recorded by the on-satellite cameras to radiances or reflectances. The KT transform rotates the data in 3-space to align the axes with the greeness, brightness, and wetness structures of the vegetation and soil planes (Crist and Cicone 1984). Since the KT is a linear transformation, the resulting data remain unitless. The final KT greenness and wetness results were stored in the database.

Database Organization

The database for the forest surveys conducted in 1999 were combined with the summarized sample data that had been collected during the 1998 field season. The composite database contained results for a total of 29 variables in 76 macroplots. These were organized by dominant overstory structures, by plant community type, and in order of increasing elevations of the sample sites. Then for each overstory dominance-community type grouping, the average, standard deviation, standard error of the mean, and the percent coefficient of variation were calculated for each variable and added to the columns of the data base.

Spatial Data Analysis

A subset of the variables was defined and each of these variables was subjected to spatial analysis. GS+™ software was used for this purpose (Gamma Design Software 1998). The list of analyzed variables includes percent canopy coverage, trees per acre >8 in. *dbh*, trees per acre <8 in. *dbh*, total understory fuels, combined 1-hr to 100-hr fuels, and total 1000-hr fuels. To analyze the data in a distribution that was approximately normal, the square-root transformation was applied to the trees per acre <8 in. *dbh* data before analysis.

Each of these variables was analyzed for spatial autocorrelations by calculating the semivariance for all possible pairs of points in the data set (Goovaerts 1997). The general form of the semivariance, $\gamma(h)$, for the interval distance class (h) is

$$\gamma(h) = \frac{1}{2 * N(h)} \sum [z_i - z_{i+h}]^2 \tag{17}$$

where z_i = measured sample value at point i,
z_{i+h} = measured sample value at point $i+h$, and
$N(h)$ = total number of sample couples for interval distance class h.

The interval distance classes are defined by subdividing the range of distances between sample points into classes of equal distance.

These intermediate results were used to map each variable for the entire study region (Goovaerts 1997). The semivariogram results provided the variance estimates for interpolation from sampled sites to unsampled coordinates. This was done by producing regional variables through a family of least-square regression algorithms, known as kriging. In this case, block kriging was used. The three-dimensional kriging output was displayed graphically using Sigmaplot™ (SPSS Inc. 1998).

Results

From the original collection of 100 potential sample points in each of 16 spectral classes, a total of 76 macroplots were sampled during the two-year period of this study. The spatial distribution of these sample sites is shown in Figure 9. The original data for each of the 76 sampled macroplots are included in Appendices C–F. Each of these appendices is arranged into separate tables according to dominance type and community type. Within the dominance-community stratifications, the individual sample sites are listed in order of increasing elevation. The plot number is listed in each of the tables within each of the appendices. The entry order and brief descriptions for the remaining variables is given in Table 7.

The means, standard deviations, and standard errors of the means, for each numeric variable, are also given in Appendices C–F. Aspect (Asp) was the only variable without these summary statistics. Since aspect ranges from 0 degrees to 360 degrees, a mean and

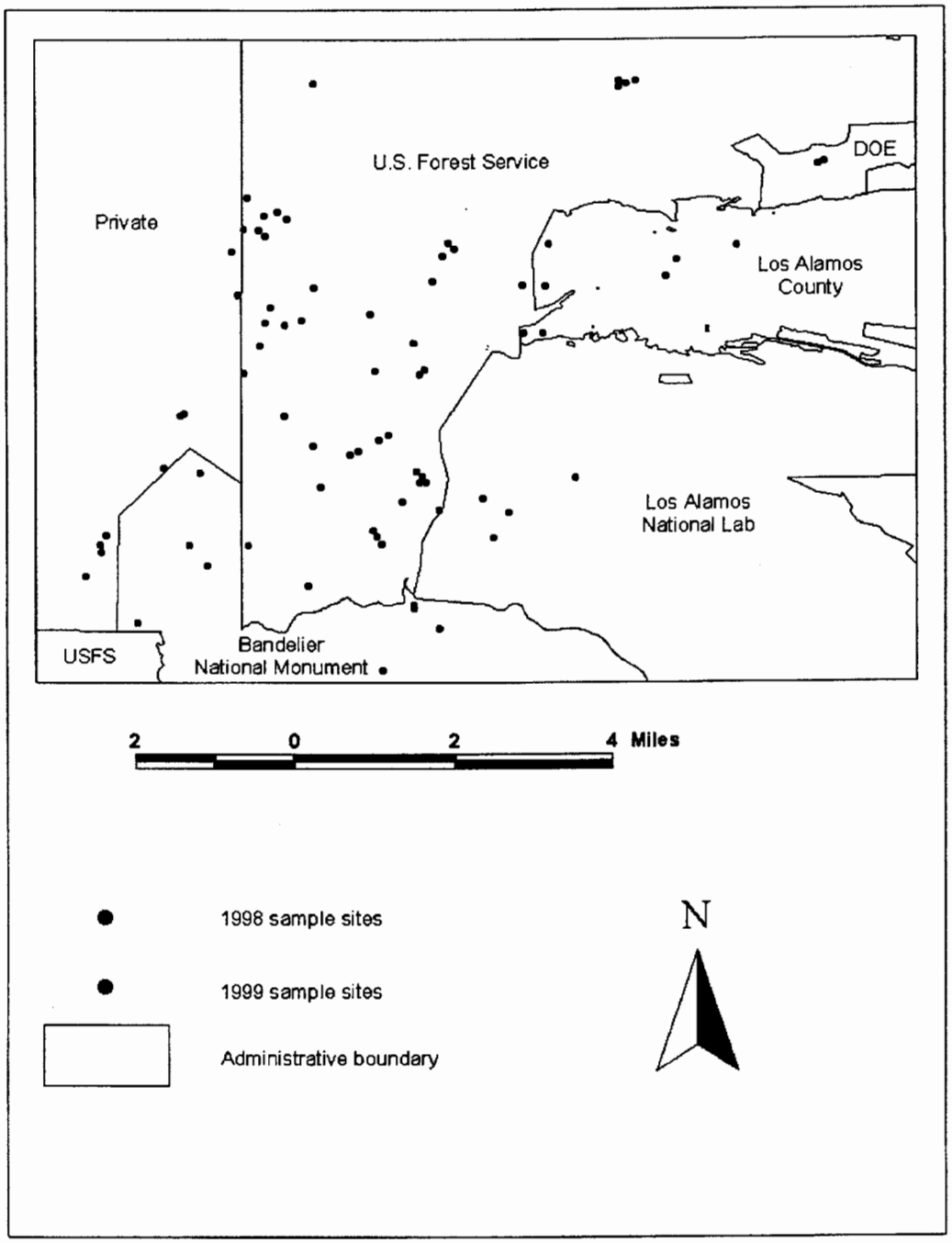

Figure 9. Distribution of sample sites. Major landowners include the U.S. Forest Service (USFS), Bandelier National Monument, Los Alamos National Lab, Los Alamos County, Department of Energy (DOE), and Baca Land and Cattle Company (Private).

Summary statistics for each of the kriged variables are shown in Table 8. Kriging resulted in interpolation for 3,685 coordinates. The average kriged value (mean), the average standard deviation for each of the kriged coordinates (Std Dev), and the percent coefficient of variation, which is the ratio of the mean to the standard deviation expressed as a percentage (CV %), are listed for each dependent variable. With the exception of the large tree component, where the CV % was very low, the approximate range of CV % values was from 20 to 75.

The first three mesh-plot figures in Appendix G show the results for kriging of overstory variables. The kriged results for percent canopy coverage (mean = 72.83) are relatively homogeneous throughout the study area (Figure G-2). The predicted canopy coverage values tend to increase to the north and the east and are the lowest in the grassland areas and where the 1954 fire occurred to the northwest of the South Gate.

Within the study area, the distribution of large trees, those greater than 8 in. *dbh*, shows a prominent tendency to increase with elevation (Figure G-3). Exceptions include the grasslands at the Pajarito Mountain and the Cerro Grande. However, these results are relative to the study area, since the overall average is approximately 120 trees per acre (Table 8). Large tree populations are still relatively dense at lower elevations. For instance, the densities of large trees in the ponderosa pine community type are approximately 106 trees per acre (Table F-1).

Table 8. Summary statistics for kriging results, by dependent variable.

Variable	Description	Mean	Std Dev	CV %
CC %	Canopy coverage	72.83	15.42	21.17
TPA >8"	Trees/acre, >8 in. *dbh*	119.95	0.25	0.21
TPA <8"	Trees/acre, <8 in. *dbh* – square root transformation	20.19	5.20	25.76
Ust Total	Total understory fuels	25.49	13.27	52.06
1-1C hr	Combined 1-100 hr woody fuels	3.28	2.17	66.16
1K-hr T	Total 1000-hour fuels	10.11	7.52	74.38

The opposite pattern was displayed by the kriging results of small trees, less than 8 in. *dbh* (Figure G-4). The analysis of the square-root transformed data indicated a tendency for the density of smaller trees to increase toward the north and the east within the study area. The smaller tree populations were particularly dense in Rendija Canyon, with relatively deep soils, and on exposed ridgeline positions, with relatively sparse soils. The populations of smaller trees were less dense in the area that was burned in 1954.

The last three figures in Appendix G show the kriging results for understory variables. In Figure G-5, the results of the kriging of total understory fuels (mean = 25.49) are shown. Although, there is a considerable amount of variation throughout the study area, there is a clear tendency for the total understory fuels to be the greatest at middle and upper elevations. Total fuels are less in the area that was burned in the 1954 fire and show an inverse relationship to the density of small trees in the overstory (Figure G-4).

This trend toward higher fuels at middle elevations, in contrast to lower amounts of fuels at lower elevations under dense overstories of smaller trees, is strengthened by the kriging results for smaller down woody fuels, the 1-hr to 100-hr fuels (Figure G-6). However, the highest elevations show relatively less amounts of smaller woody fuels. The area burned in 1954 is also sparse in these types of fuels.

The larger down woody fuels, both sound and rotten, also tend to increase with elevation and decrease under dense overstories of smaller trees and in the area that was burned in 1954 (Figure G-7). However, the overall spatial variability of the larger down woody fuels is greater than for the smaller down woody fuels (Figure G-6).

Discussion

The results of this study have increased our knowledge of the levels of fuels in the Los Alamos region and the wildfire hazards they represent. From previous results, it was determined that fuel levels generally increase with elevation (Balice et al. 1999). It was also thought that fuels tended to increase on steeper slopes and particularly on north-facing slopes. In contrast to this, Balice et al. (1999) learned that dense overstory canopies tended to be common at lower elevations in the Los Alamos region, those between 2,134 m (7,000 ft) and 2,438 m (8,000 ft) above mean sea level. However, the variability of the overstory structures at these lower elevations was generally greater than elsewhere.

These previous conclusions are still valid although the spatial distributions of specific fuel components were understood in more detail as a result of this study. First, it appears that some of the fuel categories, such as trees >8 in. *dbh*, do tend to increase linearly with elevation. In contrast, some of the fuel categories increase with elevation, but in a curvilinear manner. For instance, the 1-hr to 100-hr fuels category appears to be at a maximum at the approximate 2,743-m (9,000-ft) elevation level. As we develop predictive relationships for the spatial distributions of fuels, these relationships will undoubtedly prove to be of value (Yool et al. 2000).

The highest elevations in the Los Alamos region tend to support the greatest amounts of fuels, but the current study indicates that the relative fuel levels at these elevations also tend to vary by habitat type or community type. For instance, a perusal of the tables for aspen communities, that tend to occur on south-facing slopes, and spruce-fir communities, that tend to occur on north-facing slopes, suggests a contrast in fuel levels. The overstory densities tend to be greater in spruce-fir communities, whereas the understory fuels tend to be greater in aspen communities. A statistical analysis was not performed on this relationship. However, the opportunity arises for the reduction of fuels in aspen vegetation with the subsequent benefit that they would serve as a fuel break for the adjacent spruce-fir vegetation, while simultaneously increasing their productivity for wildlife habitat.

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Appendix A

Examples of Data Forms Used in This Study

Plot Layout and Subplot/Quad Arrangement

1-1	1-2	2-1	2-2
1-4	1-3	2-4	2-3
4-1	4-2	3-1	3-2
4-4	4-3	3-4	3-3

Plot	N -	Date	/ / 99
Plot Hor. Az/Back Az		Plot Vert. Az/Back Az	

First Subplot	Quad 1 - Full Sample	Quad 2 - Red. Sample	Quad 3 - Red. Sample
Subplot Closure			

Second Subplot	Quad 1 - Full Sample	Quad 2 - Red. Sample	Quad 3 - Red. Sample
Subplot Closure			
Notes, Comments:			

Quad Summary and Surface Conditions

Plot number	N -	Date	/ / 99
Subplot number		Quad number	
Slope		Aspect	
Elevation		Topo position	
Horiz. Config.		Vert. Config.	
Start distance (m)			

	Transect A	Transect B
Duff depth, 5m/10m		
Soil depth, 5m/10m		
1-hr fuels to 2m		
10-hr fuels to 2m		
100-hr fuels to 3m		
1000-hr fuels, sound		
1000-hr fuels, rotten		
Veg fuels, wet wt		
Veg fuels, dry wt		
First %		
Second %		
Third %		
Litter fuels, wet wt		
Litter fuels, dry wt		
First %		
Second %		
Third %		
Small trees, wet wt		
Small trees, dry wt		
First %		
Second %		
Third %		

Overstory Fuels, >10 ft tall – Complete sample

Plot	N -	Date	/ / 99		Page
Subplot		Quad			/

Dens.	#1		#2		#3		#4	
Age dom		Age int		Age sup			Av Dens	

Species	L/D	Diam	Tot. Ht.	HTLC	C Width	C Shape	M-toe	M-stems

Overstory Fuels, >10 ft tall – Reduced sample

Plot	N -	Date	/ / 99	Page	
Subplot		Quad			/

Dens.	#1		#2		#3		#4	

Species	L/D	Diam	Species	L/D	Diam	Species	L/D	Diam

Woody Midstory
Trees <2 ft (3mx3m) and Shrubs/Trees 2-10 ft (3mx15m)

Plot	N -	Date	/ / 99	Page	
Subplot		Quad	- A B		/

Species	L/D	Diam	Tot. Ht.	HTLC	C Width	C Shape	M-toe	M-stems

Appendix B

Plant Species Discussed in This Report

Plant Species Discussed in This Report
(by common name)

Common name	Scientific name	Code
Aspen	*Populus tremuloides*	Potr
Blue grama	*Bouteloua gracilis*	Bogr
Bracken fern	*Pteridium aquilinum*	Ptaq
Cliffbush	*Jamesia americana*	Jaam
Corkbark fir	*Abies lasiocarpa*	Abla
Douglas fir	*Pseudotsuga menziesii*	Psme
Engelmann spruce	*Picea engelmannii*	Pien
Forest fleabane	*Erigeron eximius*	Erex
Gambel oak	*Quercus gambelii*	Quga
Kinnikinnik	*Arctostaphylos uva-ursi*	Aruv
Little bluestem	*Schizachyrium scoparium*	Scsc
Mountain lover	*Pachistima myrsinites*	Pamy
Mountain maple	*Acer glabrum*	Acgl
Mountain muhly	*Muhlenbergia montana*	Mumo
New Mexico locust	*Robinia neomexicana*	Rone
Ponderosa pine	*Pinus ponderosa*	Pipo
White fir	*Abies concolor*	Abco
Whortleberry	*Vaccinium myrtillus*	Vamy

Plant Species Discussed in This Report
(by scientific name and four-letter code)

Common name	Scientific name	Code
White fir	*Abies concolor*	Abco
Corkbark fir	*Abies lasiocarpa*	Abla
Mountain maple	*Acer glabrum*	Acgl
Kinnikinnik	*Arctostaphylos uva-ursi*	Aruv
Blue grama	*Bouteloua gracilis*	Bogr
Forest fleabane	*Erigeron eximius*	Erex
Cliffbush	*Jamesia americana*	Jaam
Mountain muhly	*Muhlenbergia montana*	Mumo
Mountain lover	*Pachistima myrsinites*	Pamy
Engelmann spruce	*Picea engelmannii*	Pien
Ponderosa pine	*Pinus ponderosa*	Pipo
Aspen	*Populus tremuloides*	Potr
Douglas fir	*Pseudotsuga menziesii*	Psme
Bracken fern	*Pteridium aquilinum*	Ptaq
Gambel oak	*Quercus gambelii*	Quga
New Mexico locust	*Robinia neomexicana*	Rone
Little bluestem	*Schizachyrium scoparium*	Scsc
Whortleberry	*Vaccinium myrtillus*	Vamy

Appendix C

Site Summary Data for the Macroplots

Table C-1. Plot summary information for the ponderosa pine dominance type with ponderosa pine community types.

Plot	Year	Dom	Comm type	Topo	Slope	Asp	SE	Elev
NR01	1999	PP	Pipo/Bogr-S	CY	4.0	191	4.0	6859
NR03	1999	PP	Pipo/Bogr-S	CY	7.5	162	6.6	6860
AB0705	1998	PP	Pipo/Mumo	MT	20.8	173	19.8	7940
AC0603	1998	PP	Pipo/Quga	CY	8.0	288	-1.1	7161
AL0609	1998	PP	Pipo/Quga	MS	9.8	40	-8.4	7535
AL0709	1998	PP	Pipo/Quga	MS	3.5	3	-3.5	7540
AL0610	1998	PP	Pipo/Quga	MS	4.0	130	2.0	7575
TC25	1999	PP	Pipo/Quga	MS	15.0	170	14.1	7583
TB01	1999	PP	Pipo/Quga	MT	10.5	98	-0.4	7606
AB0109	1998	PP	Pipo/Quga	MS	8.8	123	3.4	7615
AF0906	1998	PP	Pipo/Quga	MT	30.5	96	-2.2	7750
TF03C	1999	PP	Pipo/Quga	MT	6.0	70	-3.0	8038
TF02A	1999	PP	Pipo/Quga	MT	1.0	180	1.0	8087
TF02B	1999	PP	Pipo/Quga	MT	4.0	135	2.3	8109
Mean					9.5		2.5	7590
Std. Dev.					7.9		7.3	404
Std. Err.					2.2		2.0	112

Table C-2. Plot summary information for the ponderosa pine dominance type with Douglas fir community types.

Plot	Year	Dom	Comm type	Topo	Slope	Asp	SE	Elev
TF06C	1999	PP	Psme/Aruv	MT	24.0	220	20.8	8542
TF06B	1999	PP	Psme/Aruv	MT	9.0	150	6.9	8494
AF1301	1998	PP	Psme/Aruv	MT	7.7	35	-6.9	8480
TF05A	1999	PP	Psme/Aruv	MT	12.0	100	0.0	7939
TF05D	1999	PP	Psme/Aruv	MT	12.0	100	0.0	7879
NF10	1999	PP	Psme/Aruv	MT	18.5	103	1.0	7809
AC0602	1998	PP	Psme/Mumo	MS	9.8	309	-4.8	7219
TC21	1999	PP	Psme/Mumo	CY	12.0	86	-2.9	7138
NF05	1999	PP	Psme/Quga	MT	8.0	100	0.0	8056
NC26	1999	PP	Psme/Quga	MS	17.5	101	0.3	7502
Mean					13.1		1.4	7906
Std. Dev.					5.3		7.7	510
Std. Err.					1.8		2.6	170

Table C-3. Plot summary information for the mixed conifer dominance type with Douglas fir community types.

Plot	Year	Dom	Comm type	Topo	Slope	Asp	SE	Elev
AF1302	1998	MC	Psme/Aruv	MT	3.7	54	-2.7	8280
NC52	1999	MC	Psme/Aruv	MT	11.0	102	0.4	7709
TC24	1999	MC	Psme/Aruv	MT	25.5	87	-5.7	7512
AB0402	1998	MC	Psme/Quga	MT	29.0	260	9.9	9530
Mean					17.3		0.5	8258
Std. Dev.					12.0		6.8	909
Std. Err.					6.9		3.9	525

Table C-4. Plot summary information for the mixed conifer dominance type with more xeric white fir community types.

Plot	Year	Dom	Comm type	Topo	Slope	Asp	SE	Elev
AB0501	1998	MC	Abco/Aruv	MT	4.8	50	-3.6	8780
TF08A	1999	MC	Abco/Aruv	MT	6.0	140	3.9	8435
AB0701	1998	MC	Abco/Quga	MT	45.0	94	-4.7	9410
AF0508	1998	MC	Abco/Quga	MT	30.3	114	7.3	8830
TF23	1999	MC	Abco/Quga	MT	26.0	218	23.0	8810
TF19	1999	MC	Abco/Quga	MT	36.5	246	20.4	8794
NF18	1999	MC	Abco/Quga	MT	48.5	129	23.5	8773
NF22	1999	MC	Abco/Quga	MT	15.0	256	6.1	8659
AF0210	1998	MC	Abco/Quga	MT	26.0	144	18.1	8610
TF17	1999	MC	Abco/Quga	MT	33.0	180	32.5	8579
TF06A	1999	MC	Abco/Quga	MT	13.0	220	11.3	8531
AF0301	1998	MC	Abco/Quga	MT	41.3	36	-37.2	8203
TF05B	1999	MC	Abco/Quga	MT	46.0	70	-23.0	8072
TF05C	1999	MC	Abco/Quga	MT	14.0	50	-10.7	7996
NL51	1999	MC	Abco/Quga	CY	63.5	359	-62.3	7308
AB0304	1998	MC	Abco/Rone	MT	22.0	284	-1.5	9010
Mean					29.4		0.2	8550
Std. Dev.					16.7		24.6	482
Std. Err.					4.3		6.3	125

Table C-5. Plot summary information for the shrub dominance type.

Plot	Year	Dom	Comm type	Topo	Slope	Asp	SE	Elev
TF03A	1999	SB	Pipo/Quga	MT	2.0	10	-2.0	8050
TF03B	1999	SB	Pipo/Quga	MT	6.0	70	-3.0	8019
NF02C	1999	SB	Psme/Quga	MT	8.0	118	2.5	8138
Mean					5.3		-0.8	8069
Std. Dev.					3.1		2.9	62
Std. Err.					2.2		2.1	44

Table C-6. Plot summary information for the mixed conifer dominance type with more mesic white fir community types.

Plot	Year	Dom	Comm type	Topo	Slope	Asp	SE	Elev
AB0302	1998	MC	Abco/Acgl	MT	20.5	150	15.7	9110
AF0507	1998	MC	Abco/Acgl	MT	35.5	30	-33.4	8430
TB10B	1999	MC	Abco/Acgl	MT	31.0	120	10.6	9024
TB10A	1999	MC	Abco/Acgl	MT	17.0	110	3.0	9003
TB10C	1999	MC	Abco/Acgl	MT	18.0	110	3.1	8968
TF20B	1999	MC	Abco/Acgl	MT	44.0	30	-41.3	8489
TF20A	1999	MC	Abco/Acgl	MT	26.5	4	-26.4	8365
NF04	1999	MC	Abco/Acgl	MT	64.0	11	-64.0	7990
AF0310	1998	MC	Abco/Erex	MT	7.8	360	-7.6	9120
AB0203	1998	MC	Abco/Erex	MT	30.8	290	-5.3	8780
Mean					29.5		-14.6	8728
Std. Dev.					16.0		25.7	387
Std. Err.					5.3		8.6	129

Table C-7. Plot summary information for the aspen dominance type.

Plot	Year	Dom	Comm type	Topo	Slope	Asp	SE	Elev
AF0808	1998	AS	Potr/Feth	MT	32.5	197	32.3	9876
AF0406	1998	AS	Potr/Feth	MT	26.5	75	-11.2	9874
AF0409	1998	AS	Potr/Feth	MT	38.0	145	26.9	9853
TF11	1999	AS	Potr/Feth	MT	40.5	230	31.0	9760
AF1305	1998	AS	Potr/Feth	MT	25.8	186	25.7	9675
TF13	1999	AS	Potr/Ptaq	MT	48.0	200	47.3	9664
Mean					35.2		25.3	9784
Std. Dev.					8.6		19.5	98
Std. Err.					3.9		8.7	44

Table C-8. Plot summary information for the spruce-fir dominance type.

Plot	Year	Dom	Comm type	Topo	Slope	Asp	SE	Elev
AF0305	1998	SF	Abla/Erex	MT	20.5	42	-17.4	9651
NP11	1999	SF	Abla/Vamy	MT	66.5	62	-40.9	10291
AF0807	1998	SF	Abla/Vamy	MT	31.0	353	-29.6	10215
TF15	1999	SF	Pien/Erex	MT	28.0	50	-21.4	9863
TF14	1999	SF	Pien/Erex	MT	41.0	30	-38.5	9821
TF12B	1999	SF	Pien/Erex	MT	34.0	40	-29.4	9496
TF12A	1999	SF	Pien/Erex	MT	28.5	45	-23.3	9404
TP16	1999	SF	Pien/Erex	MT	29.0	1	-28.6	9350
Mean					34.8		-28.7	9761
Std. Dev.					14.1		8.1	355
Std. Err.					5.0		2.9	125

Table C-9. Plot summary information for the grassland dominance type.

Plot	Year	Dom	Comm type	Topo	Slope	Asp	SE	Elev
AB1209	1998	GR	Mesagrass	MS	6.0	146	4.3	7520
AF1304	1998	GR	Mtngrass	MT	18.5	188	18.5	10145
NB09B	1999	GR	Mtngrass	MT	25.0	140	16.1	10067
TB09A	1999	GR	Mtngrass	MT	23.0	180	22.7	10054
TF07A	1999	GR	Mtngrass	MT	7.0	180	6.9	9851
Mean					15.9		13.7	9527
Std. Dev.					8.9		7.8	1127
Std. Err.					4.5		3.9	564

Appendix D

Surface Fuels for the Macroplots

Table D-8. Surface fuels for the spruce-fir dominance type.

Plot	1-hr	10-hr	100-hr	1-1C hr	1K-hr S	1K-hr R	1K-hr T	Duff	Litter
AF0305	0.71	1.42	5.03	7.16	3.04	5.02	8.07	21.62	0.95
NP11	0.27	0.75	0.88	1.90	4.74	22.71	27.45	14.41	0.29
AF0807	1.09	2.38	4.71	8.18	4.62	0.00	4.62	12.49	2.14
TF15	0.14	1.01	3.06	4.22	7.19	0.51	7.70	9.12	0.31
TF14	0.26	2.17	5.64	8.06	4.23	3.08	7.31	8.89	0.33
TF12B	0.16	1.47	3.12	4.75	10.27	5.78	16.06	14.56	0.10
TF12A	0.16	0.94	3.07	4.17	49.82	4.06	53.88	19.68	0.22
TP16	0.24	2.03	4.99	7.26	9.76	2.63	12.39	6.67	0.28
Mean	0.38	1.52	3.81	5.71	11.71	5.47	17.18	13.43	0.58
Std. Dev.	0.34	0.61	1.57	2.27	15.62	7.25	16.50	5.27	0.68
Std. Err.	0.12	0.22	0.55	0.80	5.52	2.56	5.83	1.86	0.24

Table D-9. Surface fuels for the grassland dominance type.

Plot	1-hr	10-hr	100-hr	1-1C hr	1K-hr S	1K-hr R	1K-hr T	Duff	Litter
AB1209	0.02	0.28	0.37	0.67	1.58	0.00	1.58	3.28	0.15
AF1304	0.01	0.00	0.00	0.01	0.00	0.00	0.00	2.45	0.69
NB09B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.23
TB09A	0.00	0.07	0.38	0.45	0.00	0.00	0.00	9.00	0.00
TF07A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.11	0.00
Mean	0.01	0.07	0.15	0.22	0.32	0.00	0.32	3.92	0.21
Std. Dev.	0.01	0.12	0.21	0.31	0.71	0.00	0.71	3.09	0.29
Std. Err.	0.00	0.06	0.10	0.16	0.35	0.00	0.35	1.55	0.14

Appendix E

Understory and Midstory Fuels for the Macroplots

Table E-1. Understory and midstory fuels for the ponderosa pine dominance type with ponderosa pine community types.

Plot	Veg	Shrubs	Tree 10	S&T Tot	Ust Tot	ST 1hr	ST 10hr	ST 1Chr
NR01	0.03	0.00	0.08	0.08	13.08	0.02	0.02	0.04
NR03	0.02	0.00	3.71	3.71	19.64	0.37	0.00	0.00
AB0705	0.00	0.00	0.00	0.00	19.02	0.00	0.00	0.00
AC0603	0.10	0.08	0.16	0.25	27.91	0.07	0.03	0.03
AL0609	0.01	0.00	0.00	0.00	18.46	0.00	0.00	0.00
AL0709	0.02	0.00	0.01	0.01	20.26	0.00	0.00	0.00
AL0610	0.05	0.00	0.08	0.08	12.85	0.01	0.00	0.00
TC25	0.01	1.07	0.35	1.43	14.28	0.22	0.11	0.19
TB01	0.01	0.33	0.00	0.33	29.96	0.02	0.00	0.00
AB0109	0.01	0.00	0.00	0.00	7.55	0.00	0.00	0.00
AF0906	0.01	0.37	0.00	0.37	17.66	0.04	0.00	0.00
TF03C	0.02	0.31	0.12	0.43	20.04	0.07	0.01	0.00
TF02A	0.20	1.96	0.01	1.97	25.59	0.21	0.00	0.00
TF02B	0.22	0.58	0.01	0.59	25.20	0.08	0.01	0.00
Mean	0.05	0.34	0.32	0.66	19.39	0.08	0.01	0.02
Std. Dev.	0.07	0.56	0.98	1.05	6.27	0.11	0.03	0.05
Std. Err.	0.02	0.16	0.27	0.29	1.74	0.03	0.01	0.01

Table E-2. Understory and midstory fuels for the ponderosa pine dominance type with Douglas fir community types.

Plot	Veg	Shrubs	Tree 10	S&T Tot	Ust Tot	ST 1hr	ST 10hr	ST 1Chr
TF06C	0.00	0.01	0.42	0.44	32.20	0.12	0.12	0.19
TF06B	0.17	0.00	1.73	1.73	51.80	0.45	0.52	0.79
AF1301	0.00	0.00	0.33	0.33	17.83	0.10	0.10	0.13
TF05A	0.00	1.55	1.34	2.89	20.87	0.51	0.40	0.66
TF05D	0.00	0.16	1.52	1.69	53.86	0.35	0.44	0.77
NF10	0.03	0.07	0.27	0.34	8.72	0.07	0.08	0.14
AC0602	0.00	0.09	0.20	0.30	20.25	0.10	0.06	0.06
TC21	0.00	0.06	0.17	0.24	23.68	0.05	0.06	0.08
NF05	0.30	0.70	0.06	0.76	15.35	0.11	0.02	0.03
NC26	0.05	0.01	0.15	0.16	9.39	0.03	0.03	0.05
Mean	0.06	0.27	0.62	0.89	25.40	0.19	0.18	0.29
Std. Dev.	0.10	0.50	0.64	0.91	15.97	0.18	0.19	0.32
Std. Err.	0.03	0.17	0.21	0.30	5.32	0.06	0.06	0.11

Table E-8. Understory and midstory fuels for the spruce-fir dominance type.

Plot	Veg	Shrubs	Tree 10	S&T Tot	Ust Tot	ST 1hr	ST 10hr	ST 1Chr
AF0305	0.03	0.00	0.16	0.16	38.00	0.09	0.03	0.04
NP11	0.04	0.08	0.22	0.30	44.37	0.15	0.04	0.05
AF0807	0.01	0.00	0.13	0.13	27.56	0.08	0.02	0.03
TF15	0.06	0.00	1.17	1.17	22.58	0.63	0.22	0.29
TF14	0.03	0.01	0.16	0.17	24.79	0.07	0.04	0.05
TF12B	0.14	0.00	1.27	1.28	36.89	0.67	0.24	0.37
TF12A	0.15	0.01	0.43	0.43	78.54	0.17	0.12	0.13
TP16	0.06	0.01	0.31	0.32	26.97	0.19	0.06	0.07
Mean	0.06	0.01	0.48	0.50	37.46	0.26	0.10	0.13
Std. Dev.	0.05	0.03	0.47	0.46	18.23	0.25	0.09	0.13
Std. Err.	0.02	0.01	0.17	0.16	6.44	0.09	0.03	0.05

Table E-9. Understory and midstory fuels for the grassland dominance type.

Plot	Veg	Shrubs	Tree 10	S&T Tot	Ust Tot	ST 1hr	ST 10hr	ST 1Chr
AB1209	0.31	0.00	0.34	0.34	6.33	0.16	0.10	0.08
AF1304	0.30	0.00	0.00	0.00	3.45	0.01	0.00	0.00
NB09B	0.47	0.00	0.00	0.00	1.49	0.00	0.00	0.00
TB09A	0.96	0.00	0.00	0.00	10.41	0.00	0.00	0.00
TF07A	0.61	0.00	0.00	0.00	4.72	0.00	0.00	0.00
Mean	0.53	0.00	0.07	0.07	5.28	0.03	0.02	0.02
Std. Dev.	0.27	0.00	0.15	0.15	3.37	0.07	0.04	0.04
Std. Err.	0.14	0.00	0.08	0.08	1.69	0.04	0.02	0.02

Appendix F

Overstory Fuels and Remote Sensing Results for the Macroplots

Table F-5. Overstory fuels and remote sensing results for the shrub dominance type.

Plot	TPA <2'	SPA <8"	TPA <8"	TPA >8"	CC %	KT W	KT G
TF03A	0.00	3758.00	334.00	42.00	62.92	-50.04	50.61
TF03B	112.00	1716.00	142.00	45.00	53.54	-43.91	49.81
NF02C	0.00	3026.00	24.00	81.00	56.86	-42.48	67.50
Mean	37.33	2833.33	166.67	56.00	57.77	-45.48	55.97
Std. Dev.	64.66	1034.54	156.47	21.70	4.75	4.02	9.99
Std. Err.	45.72	731.53	110.64	15.35	3.36	2.84	7.06

Table F-6. Overstory fuels and remote sensing results for the mixed conifer dominance type with more mesic white fir community types.

Plot	TPA <2'	SPA <8"	TPA <8"	TPA >8"	CC %	KT W	KT G
AB0302	1012.00	92.00	247.00	137.00	76.54	-21.76	48.01
AF0507	641.00	34.00	609.00	175.00	84.76	-12.88	49.43
TB10B	7532.00	85.00	470.00	99.00	90.63	-19.42	61.42
TB10A	4609.00	60.00	390.00	105.00	83.65	-15.00	55.90
TB10C	0.00	0.00	1032.00	75.00	81.46	-18.46	50.88
TF20B	337.00	0.00	320.00	132.00	83.85	-11.27	44.72
TF20A	1012.00	0.00	746.00	210.00	93.54	-14.40	46.47
NF04	337.00	1135.00	878.00	138.00	91.80	-11.47	54.58
AF0310	3572.00	0.00	876.00	198.00	91.68	-19.28	58.10
AB0203	5666.00	0.00	863.00	99.00	69.84	-22.21	36.67
Mean	2471.80	140.60	643.10	136.80	84.77	-16.62	50.62
Std. Dev.	2675.51	351.34	274.08	45.06	7.54	4.12	7.23
Std. Err.	891.84	117.11	91.36	15.02	2.51	1.37	2.41

Table F-7. Overstory fuels and remote sensing results for the aspen dominance type.

Plot	TPA <2'	SPA <8"	TPA <8"	TPA >8"	CC %	KT W	KT G
AF0808	0.00	0.00	49.00	115.00	66.66	-18.47	84.13
AF0406	1821.00	0.00	196.00	119.00	79.35	-20.54	73.99
AF0409	67.00	0.00	656.00	117.00	89.75	-22.63	68.85
TF11	1461.00	37.00	1344.00	255.00	80.52	-18.92	63.36
AF1305	270.00	0.00	214.00	292.00	79.30	-19.19	75.07
TF13	225.00	2125.00	2071.00	3.00	96.46	-21.77	80.82
Mean	640.67	360.33	755.00	150.17	82.01	-20.25	74.37
Std. Dev.	789.41	864.63	799.02	105.90	10.21	1.68	7.61
Std. Err.	353.04	386.68	357.33	47.36	4.56	0.75	3.40

Table F-8. Overstory fuels and remote sensing results for the spruce-fir dominance type.

Plot	TPA <2'	SPA <8"	TPA <8"	TPA >8"	CC %	KT W	KT G
AF0305	90.00	0.00	646.00	151.00	80.04	-15.27	57.87
NP11	112.00	382.00	325.00	216.00	90.23	-24.65	46.53
AF0807	101.00	0.00	1457.00	223.00	77.69		
TF15	112.00	0.00	950.00	252.00	90.73	-11.27	61.18
TF14	0.00	0.00	437.00	294.00	88.13	-23.15	51.31
TF12B	337.00	0.00	655.00	240.00	89.48	-17.05	62.16
TF12A	0.00	0.00	618.00	138.00	84.57	-19.28	57.10
TP16	450.00	0.00	580.00	270.00	93.65	-13.21	70.36
Mean	150.25	47.75	708.50	223.00	86.81	-17.70	58.07
Std. Dev.	159.85	135.06	352.71	54.56	5.56	4.97	7.72
Std. Err.	56.51	47.75	124.70	19.29	1.97	1.88	2.92

Table F-9. Overstory fuels and remote sensing results for the grassland dominance type.

Plot	TPA <2'	SPA <8"	TPA <8"	TPA >8"	CC %	KT W	KT G
AB1209	472.00	0.00	342.00	7.00	19.14	-78.93	29.65
AF1304	101.00	0.00	34.00	11.00	0.52	-49.19	55.83
NB09B	0.00	0.00	22.00	9.00	19.70	-57.32	70.54
TB09A	0.00	0.00	0.00	0.00	0.00	-52.98	60.24
TF07A	0.00	0.00	0.00	0.00	0.00	-42.38	73.98
Mean	114.60	0.00	79.60	5.40	7.87	-56.16	58.05
Std. Dev.	204.52	0.00	147.41	5.13	10.55	13.86	17.51
Std. Err.	102.26	0.00	73.71	2.56	5.27	6.93	8.75

Appendix G

Kriging Results for Selected Variables

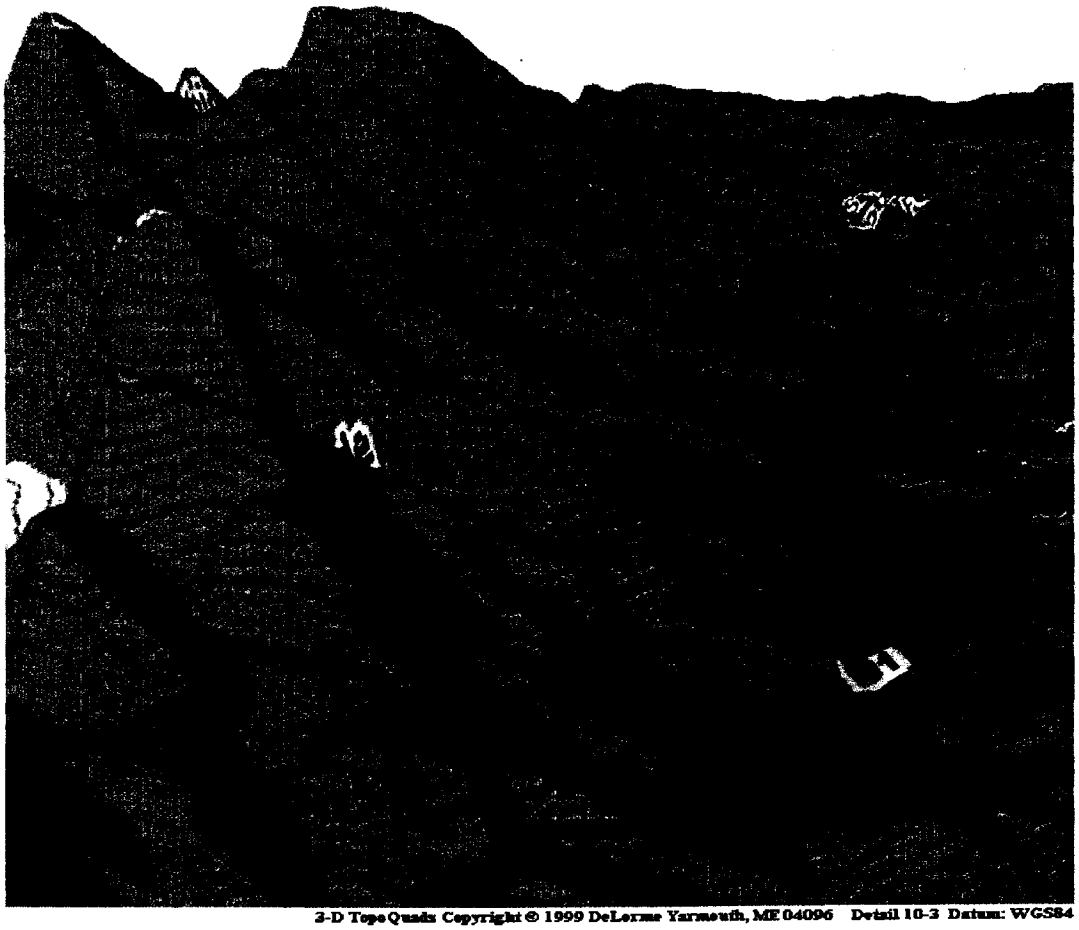

Figure G-1. Topographic perspective of the Los Alamos study region. This approximates the perspective of the kriging results that follow. The aspect of each of these views is 245 degrees from true north. State Highway 4 can be seen in the left foreground as it proceeds below Cerro Grande. The Valle Grande is in the upper left margin, and the South Gate is at the intersection of Highway 501 and Highway 4, in the lower right.

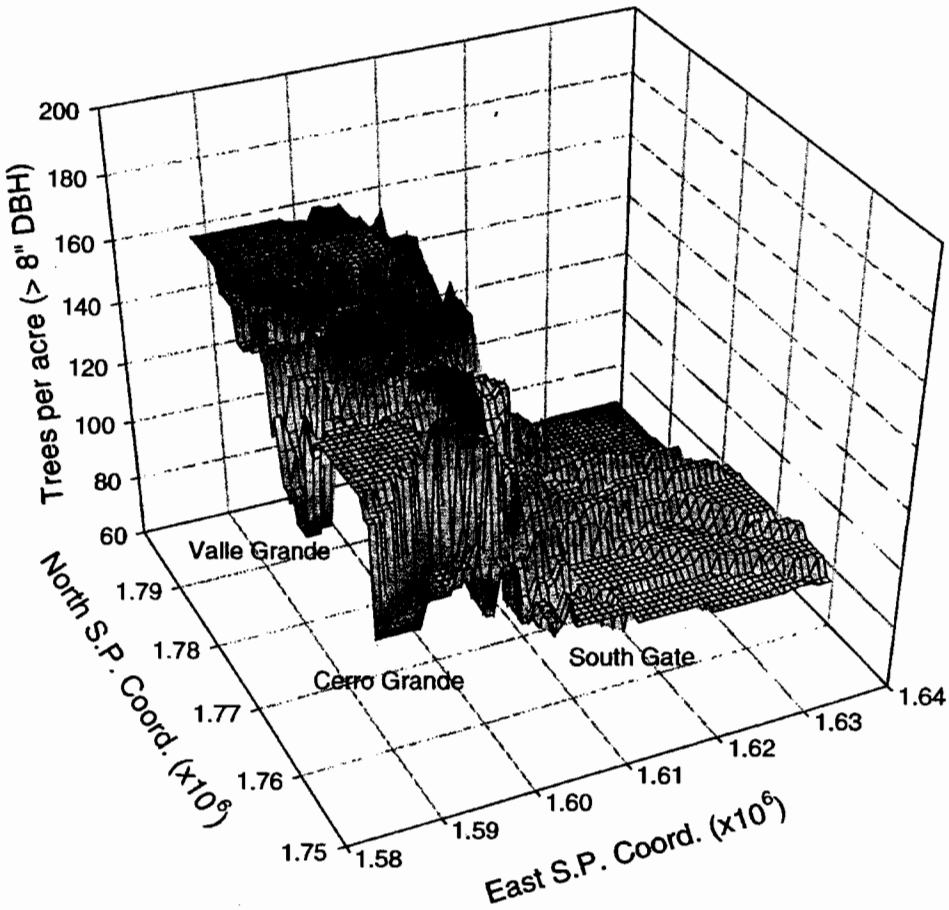

Figure G-3. Kriging results for number of trees per acre (>8 in. *dbh*).

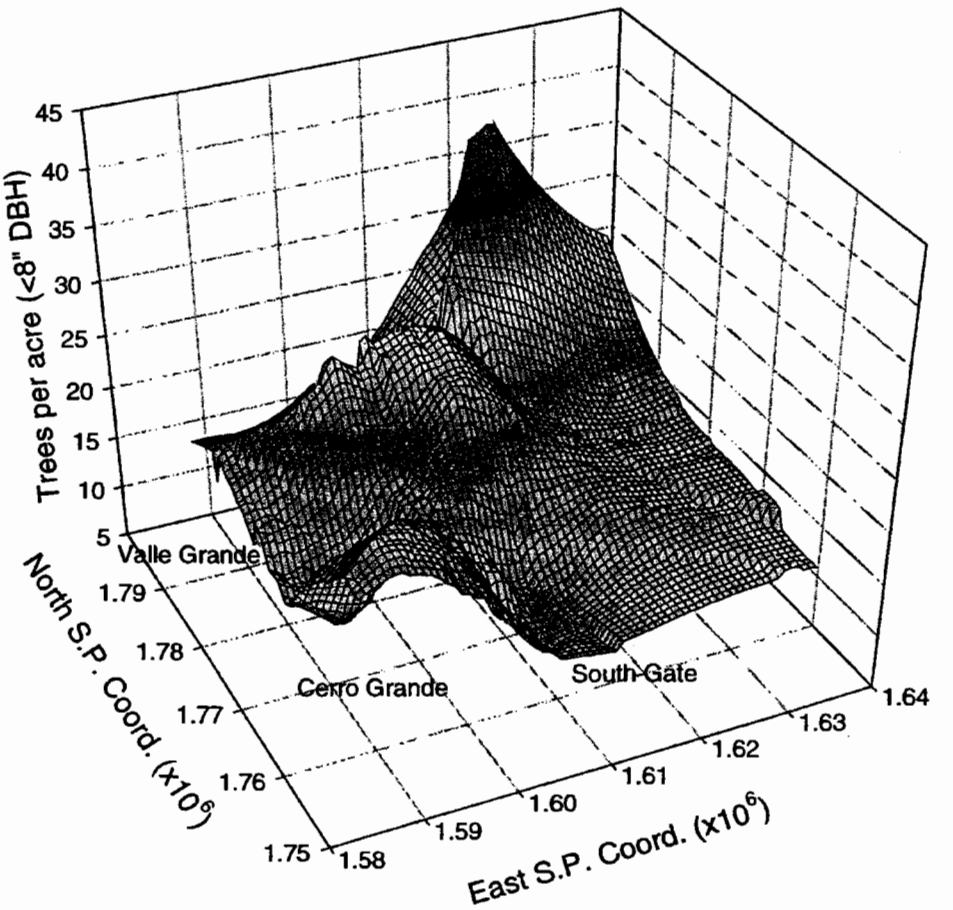

Figure G-4. Kriging results for number of trees per acre (<8 in. *dbh*).

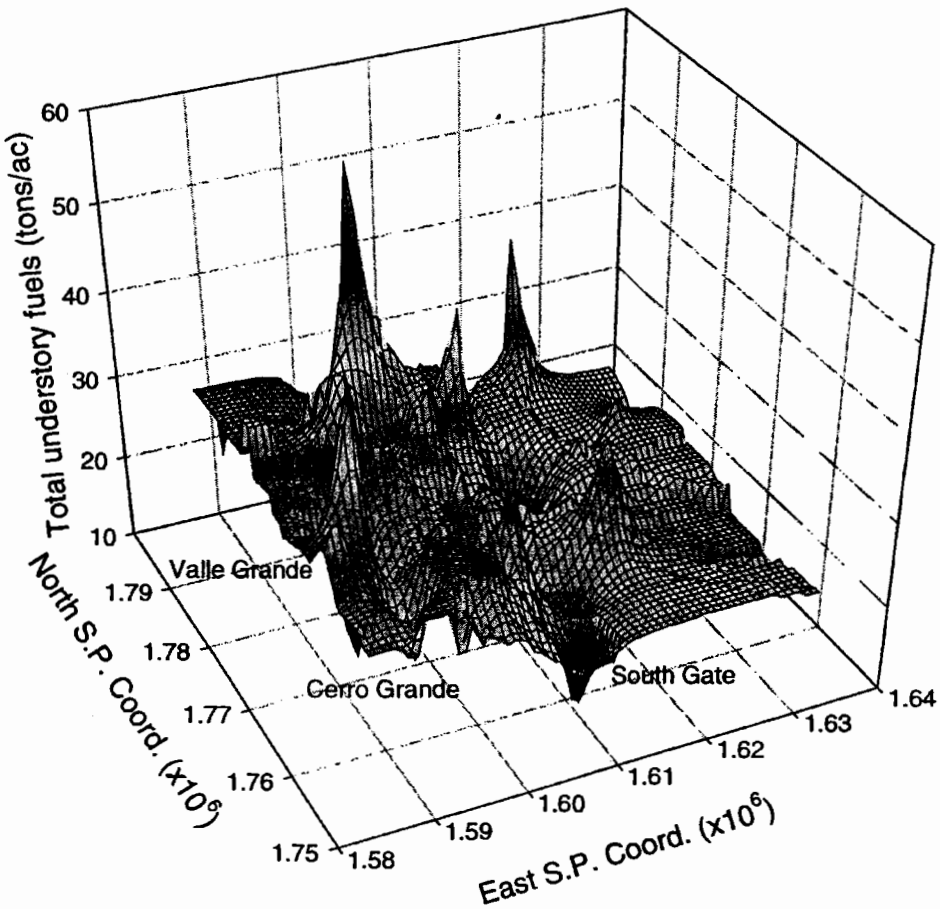

Figure G-5. Kriging results for total understory fuels (tons/acre).

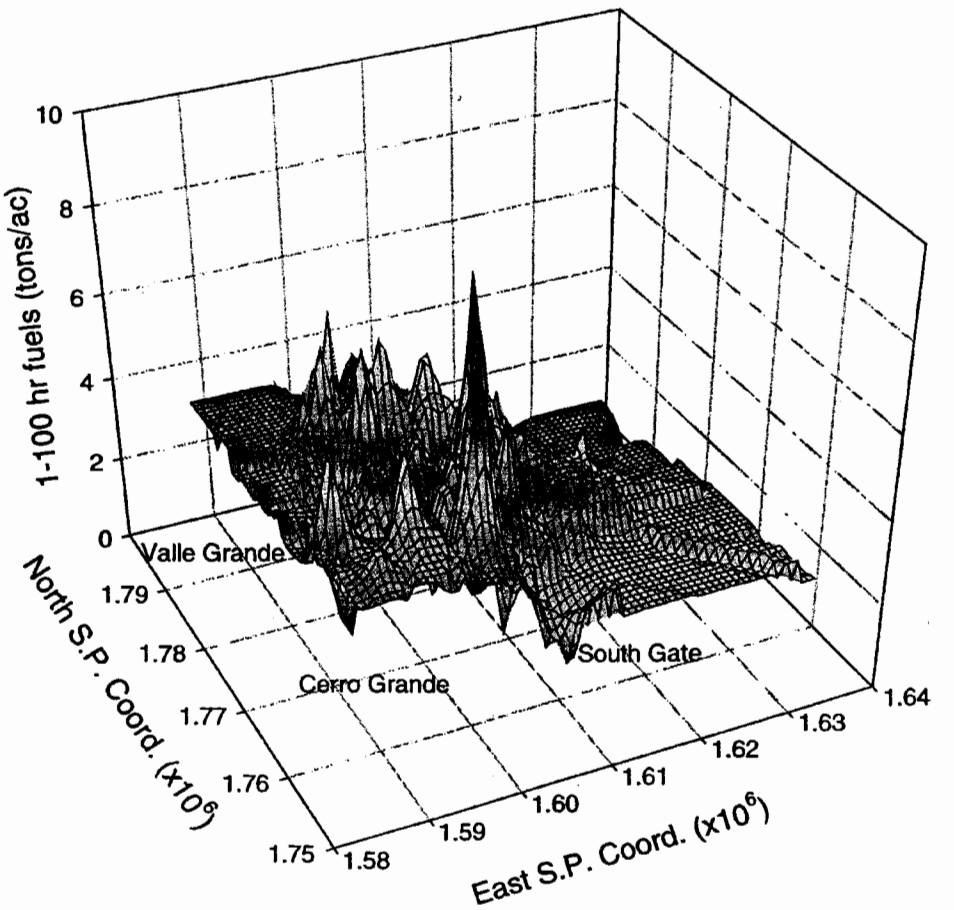

Figure G-6. Kriging results for 1-hr to 100-hr fuels (tons/acre).

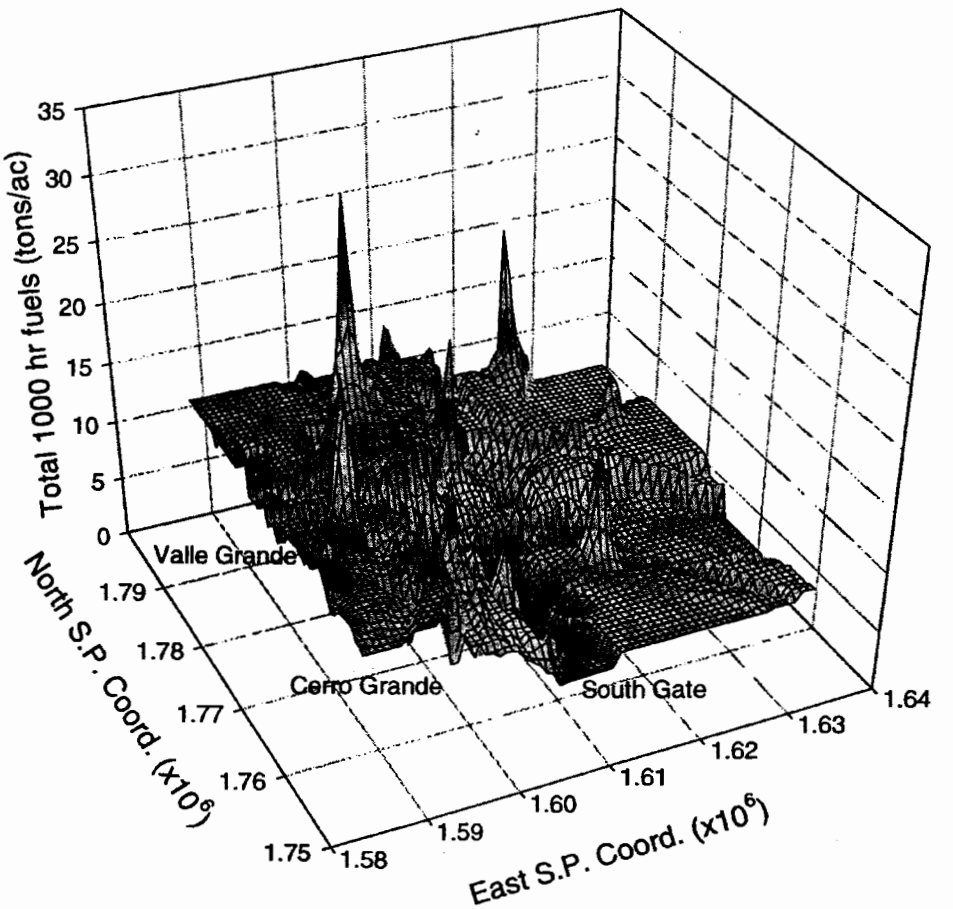

Figure G-7. Kriging results for 1000-hr fuels, both sound and rotten (tons/acre).

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