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Burn Severities, Fire Intensities, and Impacts to Major Vegetation Types from the Cerro Grande Fire

Los Alamos
NATIONAL LABORATORY
EST. 1943

The World's Greatest Science Protecting America

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CONTENTS

Abstract......1
Introduction......2
Objectives......3
The Cerro Grande Fire......4
Methods......4
Acreage Estimates for Burn Severity......10
Acreage Estimates for Fire Intensity......11
Frequency Distribution of Polygon Size Classes......12
Accuracy Estimates......12
Results......16
Acreage Estimates for Burn Severity......16
Acreage Estimates for Fire Intensity......17
Frequency Distribution of Polygon Size Classes......19
Accuracy Estimates......21
Discussion......22
Acknowledgments......25
Literature Cited......25
Appendix A: Maps analyzed as part of the project......31
Appendix B: Scanned photos of plots representing typical fire behaviors in prominent vegetation types of the Los Alamos region......39
Appendix C: Acreages of the Cerro Grande Fire and percents of the total; by burn severity or by fire intensity and by land cover type......53
Appendix D: Frequency distribution of polygon size classes for burn severity and fire intensity......61
Appendix E: Frequency histograms of polygon size classes for burn severity and fire intensity......69
Appendix F: Accuracy assessments of maps and spatial themes used in this project......77

LIST OF TABLES

Table B-1. Descriptive information for the scanned photos that follow in this appendix......41

Table C-1. Burn severity versus land cover type for the entire Cerro Grande Fire......55

Table C-2. Burn severity versus land cover type for the portion of the Cerro Grande Fire that burned on LANL property......56

Table C-3. Burn severity versus land cover type for the portion of the Cerro Grande Fire that burned on lands owned or managed by agencies other than LANL......57

Table C-4. Fire intensity versus land cover type for the entire Cerro Grande Fire......58

Table C-5. Fire intensity versus land cover type for the portion of the Cerro Grande Fire that burned on LANL property......59

Table C-6. Fire intensity versus land cover type for the portion of the Cerro Grande Fire that burned on lands owned or managed by agencies other than LANL......60

Table D-1. Frequency distribution of burn severity polygon sizes....63
Table D-2. Frequency distribution of fire intensity (percent mortality) polygon sizes for piñon-juniper vegetation....64
Table D-3. Frequency distribution of fire intensity (percent mortality) polygon sizes for ponderosa pine vegetation....65
Table D-4. Frequency distribution of fire intensity (percent mortality) polygon sizes for mixed conifer and white fir vegetation....66
Table D-5. Frequency distribution of fire intensity (percent mortality) polygon sizes for aspen vegetation....67
Table F-1. Accuracy assessment for the burn severity map developed by the BAER Team (BAER 2000)....79
Table F-2. Accuracy assessment for the fire intensity map developed by the BAER Team (BAER 2000)....80
Table F-3. Accuracy assessment for the land cover map developed for wildlife habitat management (Koch et al. 1997)....81
Table F-4. Accuracy assessment for the land cover map developed for fuel assessments (Yool et al. 2000)....82
Table F-5. Accuracy assessment for the land cover map developed with the GENIE classification system (Brumby et al. 2002)....83

LIST OF FIGURES

Figure 1. Perimeter of the Cerro Grande Fire (BAER 2000) and its extent within the boundaries of major landowners....5
Figure 2. Major geographic features in the vicinity of the Cerro Grande Fire. The perimeter of the fire is provided by the BAER Team (BAER 2000)....6
Figure 3. Daily perimeter and progression of the Cerro Grande Fire (BAER 2000)....7
Figure 4. Daily perimeter and progression of the Cerro Grande Fire (Cerro Grande Fire, Incident Command 2000)....8
Figure A-1. Burn severity map for the Cerro Grande Fire (BAER 2000)....33
Figure A-2. Fire intensity map for the Cerro Grande Fire (BAER 2000)....34
Figure A-3. Land cover map for wildlife habitat management (Koch et al. 1997)....35
Figure A-4. Land cover map for fuel risk assessments (Yool et al. 2000)....36
Figure A-5. Land cover map developed by the application of the GENIE computation software, showing the original classification scheme (Brumby et al. 2002)....37
Figure A-6. Land cover map developed by the application of the GENIE computation software (Brumby et al. 2002), showing the aggregated classification scheme used in the accuracy analysis....38

Figure B-1. High burn severity and high fire intensity in ponderosa pine forests...........42
Figure B-2. High burn severity and high fire intensity in mixed conifer forests.............43
Figure B-3. High burn severity and high fire intensity in aspen forests. 45
Figure B-4. Low burn severity and moderate fire intensity in ponderosa pine forests.....46
Figure B-5. Moderate or low burn severity and moderate fire intensity in mixed conifer forests. 47
Figure B-6. Low burn severity and low fire intensity in ponderosa pine forests. 48
Figure B-7. Low burn severity and low fire intensity in mixed conifer forests. 50
Figure B-8. Low burn severity and low fire intensity in aspen forests. 52
Figure E-1. Frequency histogram of burn severity polygons for the entire Cerro Grande Fire. 71
Figure E-2. Frequency histogram of fire intensity polygons for all areas classified by the BAER Team as piñon-juniper vegetation. 72
Figure E-3. Frequency histogram of fire intensity polygons for all areas classified by the BAER Team as ponderosa pine vegetation...73
Figure E-4. Frequency histogram of fire intensity polygons for all areas classified by the BAER Team as mixed conifer or white fir vegetation. 74
Figure E-5. Frequency histogram of fire intensity polygons for all areas classified by the BAER Team as aspen vegetation. 75

BURN SEVERITIES, FIRE INTENSITIES, AND IMPACTS TO MAJOR VEGETATION TYPES FROM THE CERRO GRANDE FIRE

by

Randy G. Balice, Kathryn D. Bennett, and Marjorie A. Wright

Abstract

The Cerro Grande Fire resulted in major impacts and changes to the ecosystems that were burned. To partially document these effects, we estimated the acreage of major vegetation types that were burned at selected burn severity levels and fire intensity levels. To accomplish this, we adopted independently developed burn severity and fire intensity maps, in combination with a land cover map developed for habitat management purposes, as a basis for the analysis. To provide a measure of confidence in the acreage estimates, the accuracies of these maps were also assessed. In addition, two other maps of comparable quality were assessed for accuracy: one that was developed for mapping fuel risk and a second map that resulted from a preliminary application of an evolutionary computation software system, called GENIE.

According to the burn severity map and the fire intensity map, the Cerro Grande Fire is estimated to have covered 42,885.4 acres and 42,854.7 acres, respectively. Of this, 57.0 percent was burned at low severity and 34.7 percent was burned at high severity. Similarly, 40.0 percent of the Cerro Grande Fire burned at high fire intensity, greater than 70 percent mortality, while 33.1 percent burned at moderately low intensity, 10 to 40 percent mortality. The most frequently burned cover types over the entire Cerro Grande Fire were ponderosa pine forest and mixed conifer forest, at approximately 43 percent each. However, portions of the fire that burned on Los Alamos National Laboratory (LANL) property were predominantly in ponderosa pine forests, whereas the Cerro Grande Fire burned primarily in mixed conifer forests on lands managed by other agencies.

Some of the polygons of burn severities and fire intensities were extensive. The two largest burn severity polygons were 10,111 acres and 10,903 acres and these were burned at low severity. The next two largest polygons were 8999 acres (14 square miles) and 1551 acres (2.4 square miles) and both of these polygons were burned at high severity. The largest fire-intensity polygon represents 2512 acres (3.9 square miles) of ponderosa pine forest that burned at 70 percent to100 percent mortality.

The accuracies of the burn severity map, the map developed for habitat management purposes, the map developed for fuels risk assessments, the fire intensity map, and the preliminary map developed through the GENIE process were 80.4 percent, 74.5 percent, 74.4 percent, 63.0 percent, and 54.2 percent, respectively.

Introduction

The Cerro Grande Fire burned a large part of the eastern Jemez Mountains from May 4 to June 6 of 2000 (Site-Wide Issues Program Office 2000). On lands that were undeveloped during that time period, the fire burned in a variety of vegetation types and at a range of burn severities and fire intensities. As a result of the Cerro Grande Fire, extensive and sometimes dramatic changes occurred to the ecosystems of the Los Alamos region. The results of the fire had immediate, as well as long-term, effects to the residual wildfire hazards, the vegetation compositions and structures, the potential for soil erosion and contaminant transport, the status of wildlife habitat, and other ecosystem functions.

In addition to impacting the ecosystems of the Los Alamos region, the Cerro Grande Fire had important implications to management capabilities of the affected landowners. Many of our technical capabilities and resources for management and planning were made obsolete. These include the reduced usefulness of previously developed land cover maps, as a result of major changes and alterations to land cover types and distributions. In addition, spatial data layers used in wildfire behavior modeling and forest growth modeling and databases of fuels and fire hazards in forests and woodlands were also severely affected. To meet the scientific and management challenges presented by these changes, it is important to know the extent and intensity to which the Cerro Grande Fire burned and the amounts of the major vegetation types that were impacted by this fire.

Several independent estimates of the acreage burned by the Cerro Grande Fire have been reported. One of the early investigations of the fire estimated "as of May 17 the fire was uncontrolled and approaching over 45,000 acres" (Fire Investigation Team 2000; page 1). Another early estimate of the size of this fire stated that by May 17, 2000, approximately 47,000 acres had burned (DeClay et al. 2000). A Los Alamos National Laboratory (LANL) report estimated that the "total acreage burned was about 43,000 acres…" (Site-Wide Issues Program Office 2000, page 14). A statement prepared for the U.S. Senate offered the following estimate: "in the end about 48,000 acres were burned" by the Cerro Grande Fire (Hill 2000; page 1). Moreover, a report to study the implementation of Federal wildland fire policy quoted that the Cerro Grande Fire "burned 47,650 acres" (Panel of the National Academy of Public Administration 2000, page 1). The Interagency Cerro Grande Fire Burned Area Evaluation and Rehabilitation (BAER) Team estimated that the Cerro Grande Fire burned 42,878 acres in their final report (BAER 2000). Finally, a report to assess the impacts associated with emergency activities conducted at LANL in response to the Cerro Grande Fire indicated that a total of 43,150 acres were burned (DOE/LAAO 2000). There may be other estimates of the overall acreage covered by the Cerro Grande Fire that were not available at the time of writing this report. There are also no assumptions regarding the relative accuracies of the estimates quoted here. Regardless, there is a range of estimates of the size of the Cerro Grande Fire. In addition to the overall size of the Cerro Grande Fire, the relative impacts of the fire to individual ecosystem types have not been documented.

Objectives

The primary objective of this document is to report calculations of the overall extent of the Cerro Grande Fire, the extent of various burn conditions, and the effects on selected vegetation types. First, we calculated the number of acres covered by the entire fire. Next, we estimated the number of acres covered by the fire at specific burn severity levels, fire intensity levels, and for individual vegetation types.

To accomplish these objectives, we used the burn severity map and the fire intensity map produced by the Cerro Grande Fire BAER Team (BAER 2000). These fire maps were individually analyzed in combination with the land cover map that had been produced by the Ecology Group at LANL for habitat management purposes (Koch et al. 1997). This land cover map had been developed to assist in the location of habitat for threatened and endangered species and for other habitat management purposes. The fire maps and the land cover map were overlayed in a geographic information system (GIS) to estimate the acreages for each vegetation class within the various burn severity or fire intensity classes. This estimate was completed for each of the two fire maps. The process was also completed for two subsets of each fire map, the first representing all of the areas burned on LANL property and the second including all non-LANL lands.

As a second objective, we also calculated the frequency distribution of polygon size classes for fire intensity and burn severity. This was done by estimating the number of acres for each polygon, ordering them by acreage, and constructing frequency histograms of the size distributions.

The third objective of this report is to provide a measure of confidence in these acreage estimates produced during the completion of the first objective. This was done by estimating the level of accuracies for the two fire maps (BAER 2000) and for the land cover map (Koch et al. 1997). Data collected at permanent and temporary plots on the ground were compared with the assigned class at the corresponding map location. The results of these comparisons were summarized in the form of confusion matrices.

To provide a broader, comparative perspective of these accuracy assessments, similar methods were used to compute the accuracies of two other, independently produced, land cover maps. One of these maps had been developed for mapping fuel risks and fire hazards (Yool et al. 2000). The second map is a preliminary product that had been produced with an experimental, computer classification algorithm, called GENIE (Brumby et al. 2002). GENIE is an evolutionary computation software system that uses a genetic algorithm to assemble image-processing algorithms from a collection of image processing operators. GENIE generates a random population of image processing algorithms and assesses the fitness of each one based on its success with training data. After fitness has been assigned, reproduction among the population elements follows with modification to the most fit population members using evolutionary operators; mutation, crossover, and selection. The sequence of fitness evaluation and evolution is repeated until a stopping condition is satisfied.

The Cerro Grande Fire

The Cerro Grande Fire was initiated on May 4, 2000, and was fully contained by June 6, 2000 (Site-Wide Issues Program Office 2000). During the course of this fire, it burned on lands owned and managed by several agencies and organizations. The approximate boundaries of most of these ownership entities are shown in Figure 1. Figure 1 also shows the perimeter of the Cerro Grande Fire, as documented by the Cerro Grande BAER Team (BAER 2000).

Most of the Cerro Grande Fire burned on the Española Ranger District of the Santa Fe National Forest, LANL (LANL/DOE in Figure 1), and the Santa Clara Pueblo (Figure 1). Additional areas that were burned include those administered by the Bandelier National Monument, Pajarito Mountain Ski Area (not shown in Figure 1), San Ildefonso Pueblo, private lands in the Los Alamos town site, Department of Energy lands in Rendija Canyon (LANL/DOE in Figure 1), and other private entities. To the west, the Cerro Grande Fire also burned on portions of formerly private lands that are now owned by the United States Federal Government and managed as the Valles Caldera National Preserve. Note that the ownership boundaries in Figure 1, as adapted from the Facility Information Management, Analysis, and Display Database at LANL, are approximate and inaccuracies may exist. Major geographic features in the vicinity of the Cerro Grande Fire are shown in Figure 2.

Although the Cerro Grande Fire was classified as an active fire for more than a month, the majority of this fire burned in a matter of a few days. This is depicted by the daily perimeters of the fire as they were estimated and mapped by the Cerro Grande Fire BAER Team (BAER 2000) and by the Cerro Grande Fire, Incident Command Team (Cerro Grande Fire, Incident Command 2000). The map of the daily perimeter and fire progression developed by the BAER Team is shown in Figure 3. The Incident Command fire perimeter map required a one-day correction of the dates to match the time of the actual burn before the final map could be produced (Figure 4). In both cases, the days with the most extensive burn or the greatest relative increase include May 7, May 10, May 11, and May 13. Significant acreages were also burned on May 12.

Methods

Burn severity and fire intensity are technical terms to describe the behavior of wildfires, including their responses to the available fuels, local weather conditions, and topography, and their impacts on ecosystems (DeBano et al. 1998). Burn severity and fire intensity are related concepts but do not maintain a one-to-one correspondence (Hartford and Frandsen 1992). Burn severity, also known as fire severity, describes ecosystem responses to fire (Simard 1991). It can be used to describe the effects of fire on soil and water systems, flora and fauna, and society. In a more narrow sense, burn severity reflects the relative impact of fire on ground resources such as soil, duff, litter, and surface vegetation. Burn severity can be classified as follows (DeBano et al. 1998, BAER 2000):

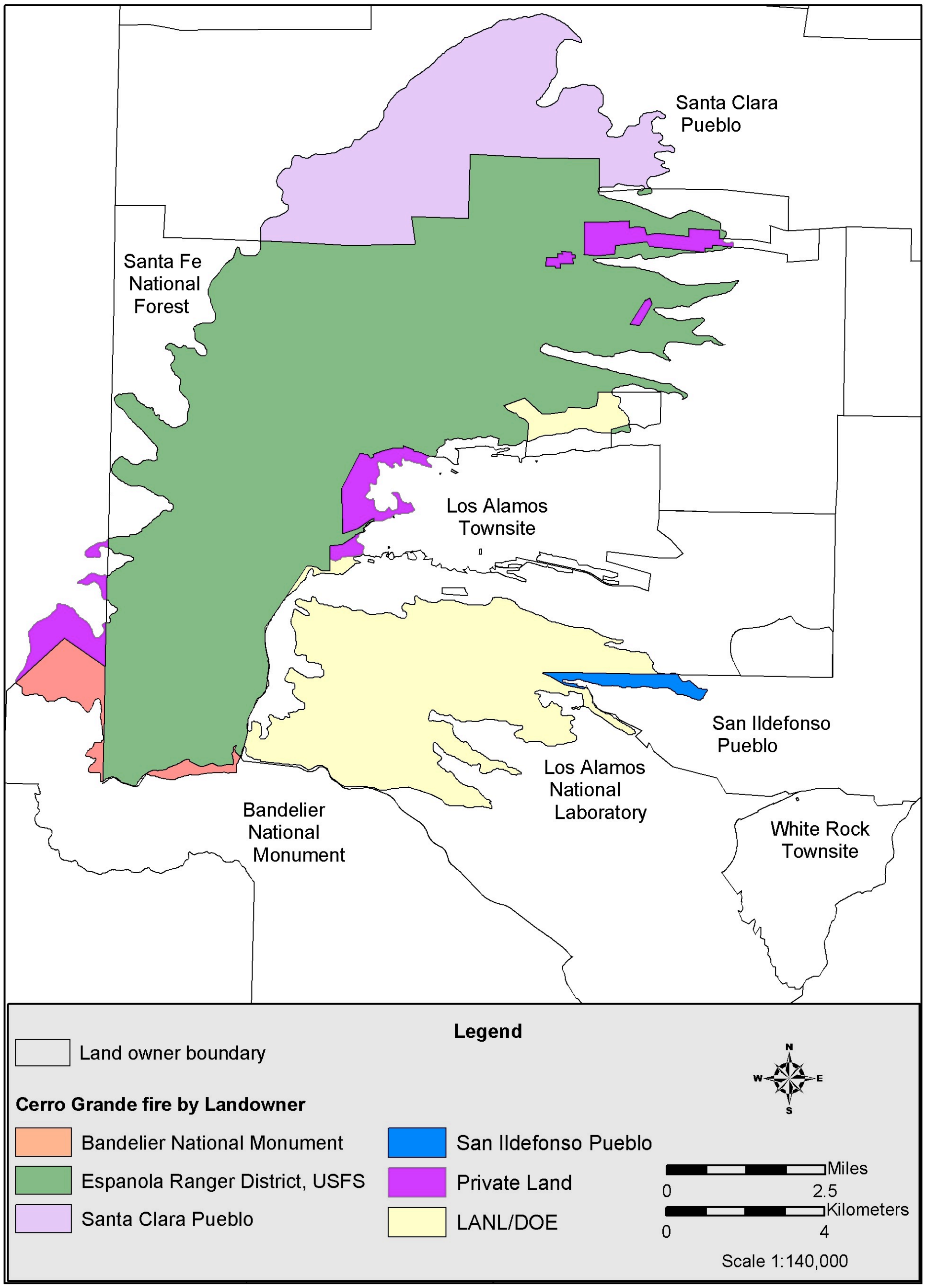

Figure 1. Perimeter of the Cerro Grande Fire (BAER 2000) and its extent within the boundaries of major landowners.

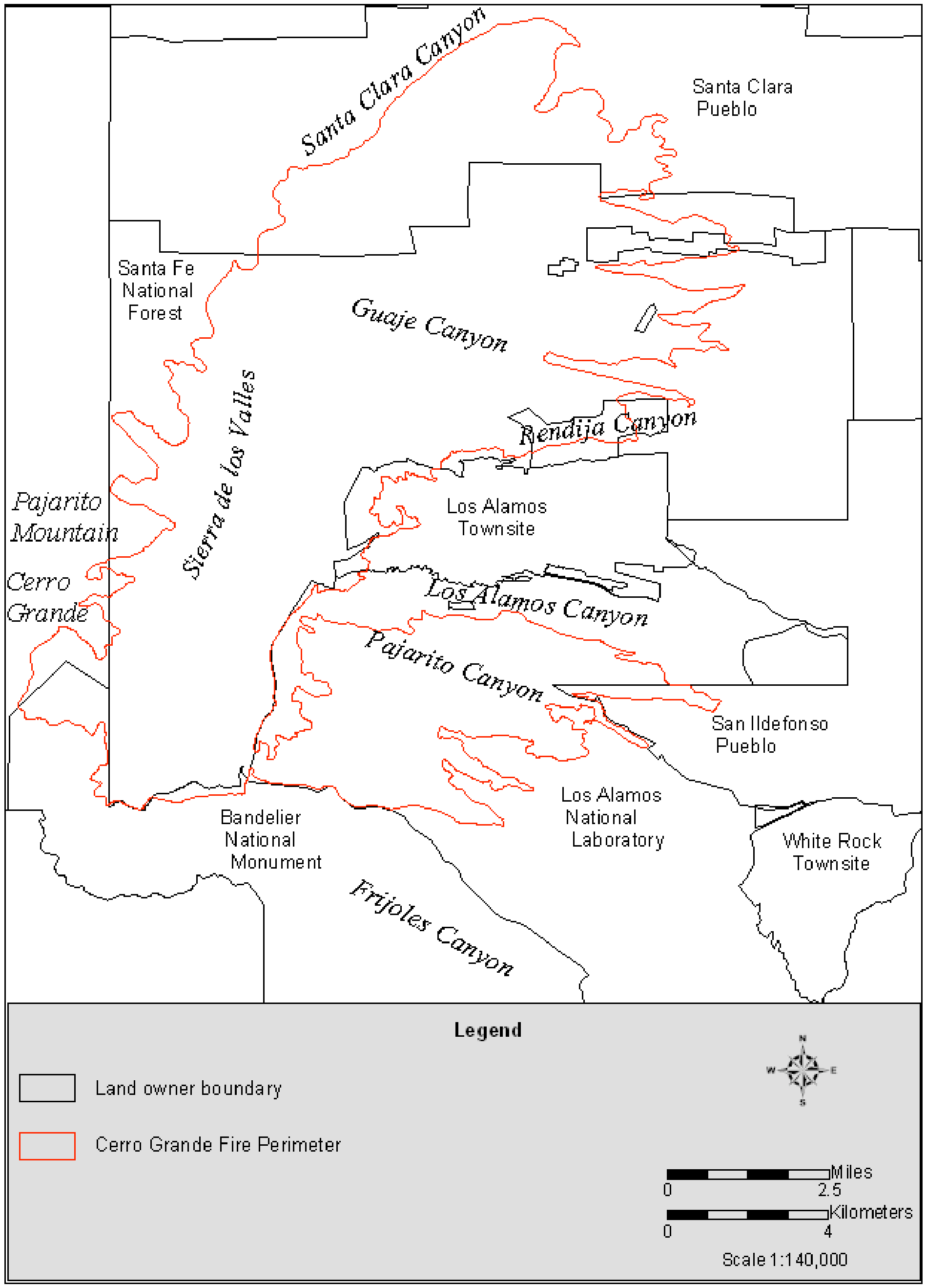

Figure 2. Major geographic features in the vicinity of the Cerro Grande Fire. The perimeter of the fire is provided by the BAER Team (BAER 2000).

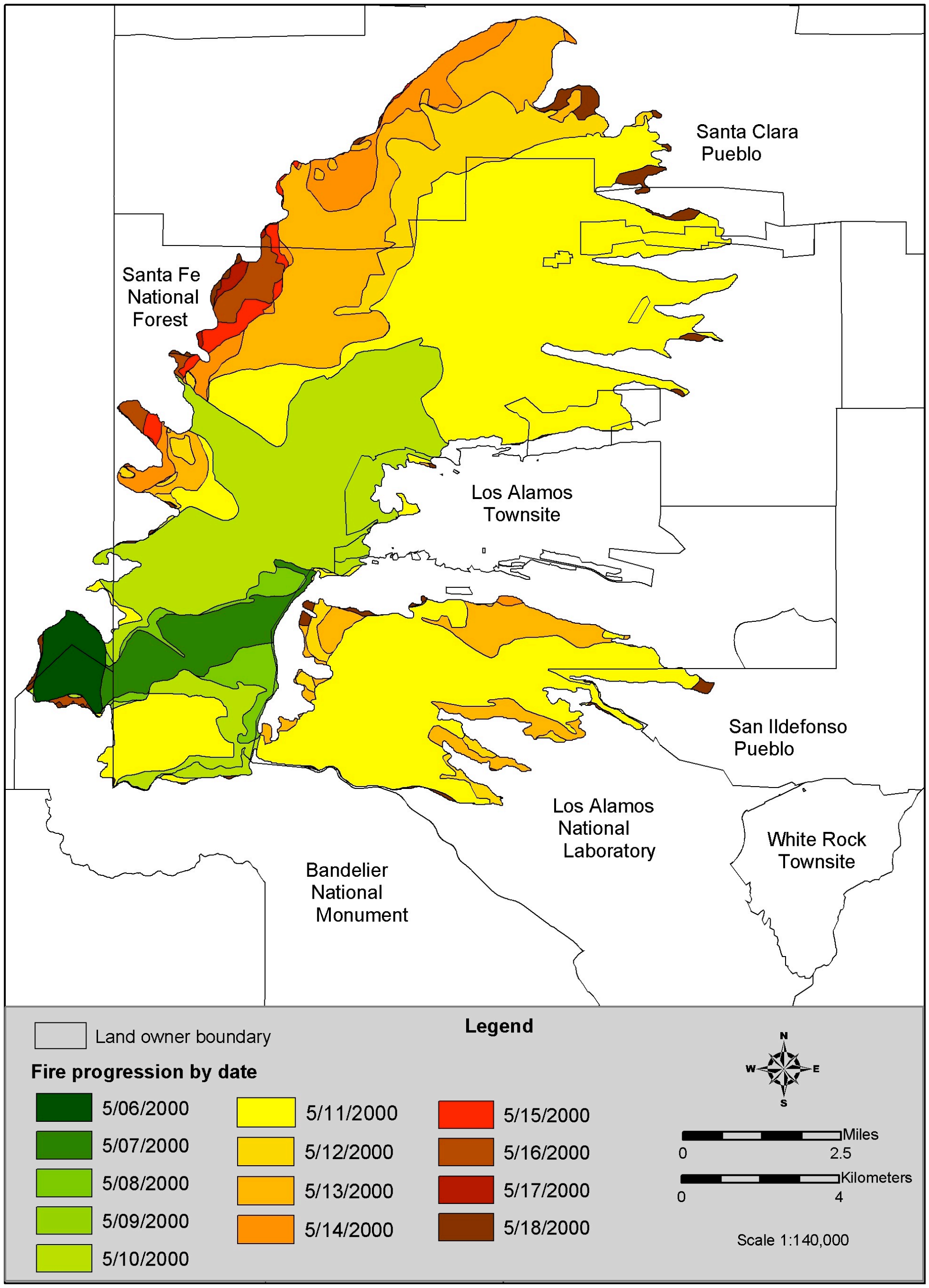

Figure 3. Daily perimeter and progression of the Cerro Grande Fire (BAER 2000).

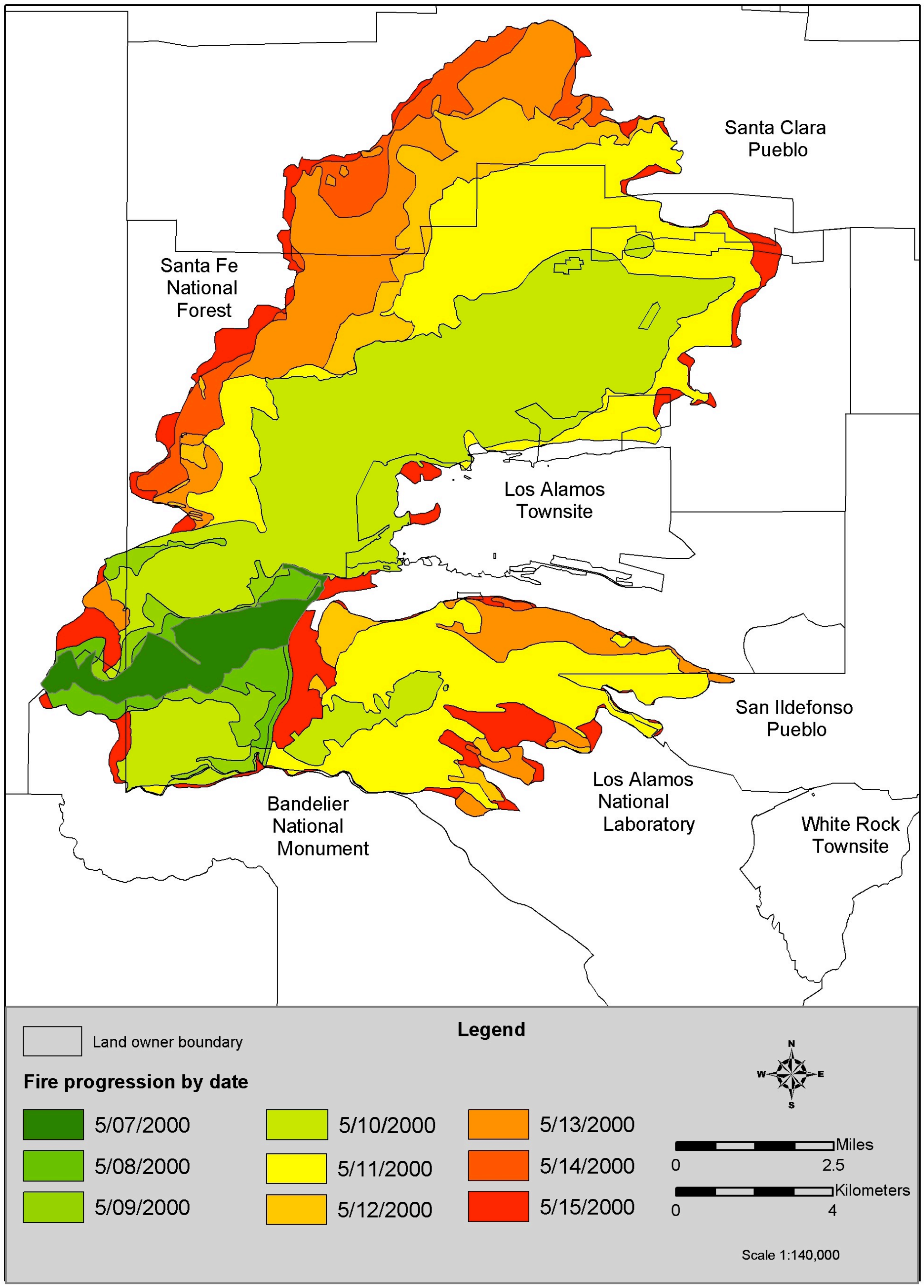

Figure 4. Daily perimeter and progression of the Cerro Grande Fire (Cerro Grande Fire, Incident Command 2000).

Low burn severity: The fire causes low soil heating, or light ground char. The litter is scorched, charred, or consumed, but the duff is left largely intact, although it can be charred or scorched on the surface. Woody debris is partially consumed or charred. Mineral soil is unchanged. Soil temperatures at 1 cm are less than 50 degrees C, and lethal temperatures to soil organisms do not extend below this level.

Moderate burn severity: The fire causes moderate soil heating, or moderate ground char. The litter on the forest floor is consumed and the duff is deeply charred or consumed but the underlying mineral soil surface is not visibly altered. Light colored ash is present. Woody debris is mostly consumed, except for logs, which are charred. Soil temperatures at 1 cm in depth can range from 100 to 200 degrees C. Lethal temperatures can occur to depths of 3 to 5 cm.

High burn severity: The fire causes high soil heating, or deep ground char. The duff is completely consumed and the top of the mineral soil is visibly altered to a depth of 1 cm or more. The top of the soil is reddish or orange where slash concentrations or logs burned intensely. Below 1 cm, the soil is darker or charred from consumed organic matter. The texture of soils can change and fusion of pedicels may be evident. Logs can be totally consumed or deeply charred. Soil temperatures at 1 cm can exceed 250 degrees C. Lethal temperatures can occur to depths of 9 to 16 cm.

The BAER Team initially assessed burn severity by performing aerial surveys during and immediately after the Cerro Grande Fire (BAER 2000). The resulting preliminary map of burn severity polygons was then checked for accuracy and updated through extensive ground surveys. As a result of this, the final map was edited, produced, and distributed. For the purposes of this report, we adopted the burn severity map to conform to the following classes (Figure A-1):

- high burn severity,
- moderate burn severity, or
- low burn severity.

The BAER Team's original classification of low burn severity was more inclusive in that it also included unburned sections. However, very little of the area within the perimeter of the Cerro Grande Fire was unburned. Therefore, all the areas that were originally classified by the BAER Team as low/unburned were considered to be low burn severity during the analyses in this report. In addition, all areas that are outside of the burn severity spatial theme are classified as unburned.

Fire intensity is the rate at which a fire produces thermal energy (Whelan 1995, Pyne et al. 1996). It is most commonly expressed in terms of fire line intensity, or the rate of heat release in the flaming front per unit length of the fire front (Byram 1959). Fire intensity is influenced by the amount of fuel available for burning, local weather conditions before and at the time of the fire, and topographic conditions (DeBano et al.

1998). The limiting factor in fire intensity is the amount of energy stored in the fuel. Although fire intensity was originally developed as a measure of fire behavior on the ground surface, it has been extended to the characterization of fires in the overstory canopies of forests (van Wagner 1977, Scott and Reinhardt 2001).

The fire intensity map for the Cerro Grande Fire was produced in much the same manner as the burn severity map (BAER 2000). The BAER Team established fire intensity classes according to the percent mortality in the forest overstory (Figure A-2). These mortality and fire intensity levels can also be referred to respectively as low, moderately low, moderately high, and high. The fire intensity classes adopted from the BAER Team and used for the purposes of this project are as follows

- 0 percent to 10 percent overstory mortality or low fire intensity,
- 10 percent to 40 percent overstory mortality or moderately low fire intensity,
- 40 percent to 70 percent overstory mortality or moderately high fire intensity, or
- 70 percent to 100 percent overstory mortality or high fire intensity.

Fire intensity can also be described in terms of the amount of canopy fire that is in evidence (Scott and Reinhardt 2001). High fire intensity can be thought of as a continuous canopy fire. Moderate fire intensity is in evidence when a fire burns with intermittent crowning and torching. Low fire intensity refers to fires that burn on the ground surface, without entering the overstory canopy. As for the burn severity theme, all areas outside of the collective fire intensity perimeter are considered to be unburned (Figure A-2).

Scanned photos showing a variety of fire behaviors exhibited by the Cerro Grande Fire in several vegetation types are included as Appendix B. These include typical examples of high, moderate, and low burn severities/fire intensities. Examples for ponderosa pine forests, mixed conifer forests, and aspen forests are provided, where available. Descriptive notes for each photo, including the plot number, the date of the photo, the level of burn severity and fire intensity, percent crown scorch, and height of bole scorch, are also tabulated (Table B-1).

Acreage Estimates for Burn Severity

To assess the number of acres burned in the Cerro Grande Fire, by burn severity and by vegetation type, the Cerro Grande burn severity spatial theme (BAER 2000) was used in conjunction with the Ecology Group's land cover map (Koch et al. 1997). All spatial themes were processed in ArcView (ESRI 2002a) using the Xtools extension (DeLaune 2001). Xtools is a GIS extension used for vector spatial analysis, shape conversions, and table management.

To perform the acreage assessment by burn severity, each severity class was converted to individual spatial themes (Figure A-1). The total number of acres of each severity class was then determined and these were summed to estimate the acreage of the entire area that was burned. Next, the spatial themes for high, moderate, and low burn severities were individually combined with the land cover map that had been developed for wildlife habitat management purposes (Koch et al. 1997). The land cover classes on this map are as follows (Figure A-3)

- aspen/other deciduous,
- mixed conifer forest,
- ponderosa pine forest,
- piñon-juniper woodland,
- juniper savannah,
- grassland,
- developed,
- unvegetated land,
- water (including shadows), and
- unclassified.

The mixed conifer forest class includes mid-elevation forests dominated by *Abies concolor* and *Pseudotsuga menziesii*, as well as high-elevation spruce-fir forests dominated by *Picea engelmannii* and *Abies bifolia*. For the purposes of this study, water/shadows, unvegetated, and unclassified polygons are combined in an "other" category. This map coverage includes much of the eastern Jemez Mountains, including all of Los Alamos County except for the extreme eastern portions of the County that are in White Rock Canyon near White Rock.

Finally, the collection of polygons corresponding to each of the combined burn severity/land cover types were clipped, the acreage of each polygon was calculated, and the acreages were summed over all polygons to estimate the total acreages for each combination of burn severity class and land cover type.

This analysis of acreages was first completed for the entire burn severity map. However, because the Cerro Grande Fire was highly variable in space, these calculations were also repeated for two subsets of the fire. The first subset included all of the burned areas on LANL property. The second subset consisted of all burned areas that were owned and managed by agencies and organizations other than LANL. Throughout this analysis and all the analyses that follow, English units of measure were used.

Acreage Estimates for Fire Intensity

To assess the number of acres burned in the Cerro Grande Fire, by fire intensity and by vegetation type, the Cerro Grande Fire intensity spatial theme (Figure A-2) was used in place of the burn severity spatial theme (BAER 2000). Then, the methods described above for acreage estimates of the burn severity spatial theme were repeated. As before, the land cover map developed for wildlife habitat management purposes (Figure A-3; Koch et al. 1997) was used to calculate the acreages for land cover types.

Frequency Distribution of Polygon Size Classes

The size distributions of the individual polygons were calculated for both the burn severity map and for the fire intensity map. For the burn severity map (Figure A-1), the acreages were estimated for each polygon. Then the polygons were ordered by burn severity level and then by size. These results were used to construct frequency histograms, by burn severity level, in 50-acre classes.

The analysis for the fire intensity map (Figure A-2) was performed in a manner similar to that for the burn severity map. However, the process in this case was more difficult because the fire intensity map produced by the BAER Team consists of a combined fire intensity and land cover classification system (BAER 2000). The land cover classes that were imbedded in the fire intensity classes include aspen, grass, grass-shrub, piñon-juniper, ponderosa pine, mixed conifer, meadow, oak, riparian-evergreen, rock-agriculture-developed, white fir, and unclassified. Because of GIS constraints, it was not possible to eliminate the land cover classes and combine adjacent fire intensity polygons that are of identical mortality or fire intensity levels. Therefore, it was decided to select individual land cover types and construct frequency histograms of polygon sizes for each type. This was done for piñon-juniper, ponderosa pine, mixed conifer, white fir, and aspen. The mixed conifer and white fire vegetation categories were combined for the purposes of this analysis. Size classes of 25 acres were used to construct the final histograms.

Accuracy Estimates

To provide a partial measure of the confidence in the acreage estimates for the burn severity classes (Figure A-1) and for the fire intensity classes (Figure A-2), by land cover type (Figure A-3), we estimated the accuracy of the data layers that were used to calculate these acreages. This consisted of independent accuracy estimates for the burn severity map (BAER 2000), the fire intensity map (BAER 2000), and the land cover map (Koch et al. 1997). To provide a basis for further comparisons with existing maps, we also conducted accuracy estimates for a land cover map produced for fuel risk assessments (Figure A-4; Yool et al. 2000) and for a preliminary land cover map developed using the GENIE algorithm (Figure A-5; Brumby et al. 2002).

The cover types used to classify the fuel risk map (Yool et al. 2000) are as follows:

- clouds,
- unvegetated land,
- mixed conifer forest,
- aspen,
- ponderosa pine forest,
- piñon-juniper woodland,
- shrubs,
- grassland, and

- developed.

In a manner similar to the habitat management land cover map, the fuel risk map combined mixed conifer and spruce-fir forests into one class. The coverage of this map includes much of the Jemez Mountains and most of Los Alamos County. The eastern boundary of this map is the north-south line along the eastern extremity of the lands in Rendija Canyon managed by the U.S. Department of Energy and continuing southward to the western extent of the San Ildefonso Pueblo. Eastern portions of this map that correspond to the Los Alamos region are shown in Figure A-4.

The preliminary cover types that arose from the application of the GENIE software system and were also used to map the Los Alamos region (Brumby et al. 2002) are listed as follows:

- grassland/piñon-juniper/shrubs,
- aspen/mixed conifer forest,
- mixed conifer forest,
- unvegetated,
- unvegetated/piñon-juniper/trees,
- unclassified/cloud/shadows,
- grasslands,
- unvegetated/piñon-juniper/shrubs,
- trees/shrubs/grassland,
- mixed conifer forest,
- ponderosa pine, and
- sparse grasslands.

Although there are two mixed conifer forest classes, either of these will also include the spruce-fir cover type. The coverage of this map includes much of the Jemez Mountains, including all of Los Alamos County. The segment of this map that corresponds to Los Alamos County and the area burned by the Cerro Grande Fire is shown in Figure A-5.

The general methods for this accuracy assessment consist of developing a mutual correspondence between each map and data that had been collected in the field. Then, specific points on the thematic map layers (prediction) to corresponding classification data that had been collected at the same location on the ground (actual) were compared. The results were organized into confusion matrices for analysis.

Ground sample data (actual) had been collected from 1997 to 2000 as part of an ongoing survey of vegetation conditions at temporary and permanent plots to assess fuels and fire hazards in the Los Alamos region and were utilized for this study. Methods varied somewhat from year to year, but were generally as described in (Balice et al. 1999, 2000). The relevant field methods employed at the selected plots are as follows. First, the plot centers were located in the field and confirmed as being homogeneous for at least 30 meters (98 feet) in all directions. Next, the coordinates of these plot centers were recorded with a global positioning system, with post-differential correction. Among the types of data that were recorded for each plot, the dominance type was categorized as piñon-juniper woodland, juniper woodland, shrubland, ponderosa pine forest, mixed conifer forest, aspen forest, grassland, or spruce-fir forest. The habitat type was also documented, as were the dominant tree, shrub, forb and graminoid species.

Immediately after the Cerro Grande Fire during the summer of 2000, each of the previously sampled plots was revisited to assess the impacts of the fire, and new plots were also qualitatively sampled to assess the effects of the fire. Many of the methods used for sampling previous to the Cerro Grande Fire were employed, as described above. Additional methods were also incorporated as part of the post-fire field sampling process. In particular, the area of each plot was classified according to its burn severity and fire intensity. Burn severity classes could either be unburned, low severity, moderate severity, or high severity. Burn severity was classified using the criteria outlined in DeBano et al. (1998). Fire intensity classes could be unburned, low intensity, moderate intensity, or high intensity. Fire intensity was classified according to the relative amount of crowning that had occurred during the Cerro Grande Fire at the sample location. Low fire intensity was indicated where the fire burned on the ground without entering the overstory canopy, although some crown scorch and bole scorch could occur. Moderate fire intensity resulted when the Cerro Grande Fire exhibited intermittent crowning in one or more forest patches ranging from a few to several neighboring trees. The burned forest was classified as high fire intensity if the entire overstory canopy was consumed during the fire, and there was apparently 100 percent overstory mortality.

There was a one-to-one correspondence between the map classes for burn severity (predicted) and the ground sample classes (actual). As a result, the accuracy of the burn severity map (Figure A-1) was conducted using the original unmodified classes, as described above. However, this approach was not possible for the fire intensity map (Figure A-2). The field data used to assess the accuracy of the fire intensity map were gathered using the following classification scheme: unburned, low fire intensity, moderate fire intensity, and high fire intensity; whereas, the BAER Team divided moderate fire intensity into moderately low and moderately high (BAER 2000). To facilitate the analysis, the moderately low fire intensity class and the moderately high class used by the BAER Team were combined into one moderate fire intensity class, for accuracy assessment purposes.

For the most part, there was perfect correspondence between the land cover classes from the field plots and from the map that was being analyzed. Where this assumption was not satisfied, modifications to the original field data sets (actual) or to the map classes (predicted) were required. For the land cover map developed for fuel risk assessments (Yool et al. 2000), none of the ground samples (actual) corresponded to the cloud, developed, or unvegetated land map classes. As a result, these classes were not considered further in the analysis of this map (predicted). In addition, a juniper woodland plot was disregarded because the map developed by Yool et al. (2000) did not contain a juniper woodland category. Similarly, for the land cover map developed for habitat management purposes, a shrubland category was not included (Koch et al. 1997).

Moreover, areas that were developed, unclassified (other), water/shadows (other), or unvegetated (other) were not sampled in the field (actual). As a result, shrubland plots were deleted from the field plot data set during the accuracy assessment for this map, and the unsampled classes were not considered further. Finally, the plots with mixed conifer forest and plots with spruce-fir forest were combined into a single mixed-conifer forest class, to conform with the classifications used in each of the maps.

The preliminary map developed from the GENIE experimental algorithm (Brumby et al. 2002) required more extensive modifications to make it compatible with the available ground data for accuracy assessment purposes. First, the class consisting of unclassified/clouds/shadow was not included in this analysis. Second, the land classification system that resulted from the GENIE algorithm was more general than the classes used for land cover identification at the field plots. In an effort to create a more direct correspondence between the ground sampling (actual) and the GENIE land cover classes (predicted), the map classes were combined or reclassified as follows:

- the two mixed conifer classes were combined into one class,
- the sparse grassland class was combined with grassland,
- the aspen/mixed conifer map class corresponds to the aspen ground class,
- the grasslands/pinon-juniper/shrubs map class corresponds to the grassland ground class,
- the trees/shrubs/grassland class corresponds to the ponderosa pine ground class,
- the unvegetated/piñon-juniper/shrubs corresponds to the piñon-juniper ground class, and
- the unvegetated/piñon-juniper/trees class corresponds to the piñon-juniper ground class.

The portion of the reclassified version of the map developed by the GENIE process that corresponds to Los Alamos County and the Cerro Grande Fire is shown in Figure A-6.

For each land cover map, the resulting point locations on the ground, with their burn severity and fire intensity attributes, and their land cover classes, were converted into ArcInfo coverage format (ESRI 2002b). Next, an intersection analysis was conducted between the ground locations and each of the mapped polygon spatial themes. The results of the intersection analysis were new point themes that contained attributes of both the ground conditions and the mapped conditions. These data were then exported from ArcInfo into VisiRex (CorMac Technologies, Inc. 2001). VisiRex was used to create a confusion matrix. A confusion matrix contains information about ground (actual) and mapped (predicted) classifications. In this matrix, all the rows represent the predicted classes, and thus a piece of data belongs to the row if it is classified on the map as belonging to this class. The columns represent the actual classes, and a piece of data is thus represented in a particular column if it is determined on the ground as belonging to the corresponding class. A perfect classification thus results in a matrix with zeroes everywhere but on the main diagonal.

Results

Acreage Estimates for Burn Severity

The estimates of the areal coverage for the entire Cerro Grande burn severity map (BAER 2000), which is based on a breakdown of land cover types in the map developed by Koch et al. (1997), are displayed in Table C-1. The units of the estimates are in acres and in percents of the total acreage. According to this analysis, the total acreage of the fire is 42,646.7 acres. However, this value is a slight underestimation that resulted from a slight lack of correspondence between land cover map (Figure A-3) and the burn severity map (Figure A-1). The upper limits of the land cover map did not extend over the entire burn severity map. This area in the northernmost extent of the Cerro Grande Fire that was not covered by the land cover map was calculated to be approximately 238.7 acres. The sum of these two estimates equals 42,885.4 acres for the entire Cerro Grande Fire, based on the burn severity map.

Over the entire Cerro Grande Fire burn severity map (Figure A-1), excluding the area in the northernmost extent of the fire that had no correspondence with the land cover map, 57.0 percent (24,303.1 acres) was burned at low severity (Table C-1). Another 34.7 percent (14,793.3 acres) was burned at high severity. Only 8.3 percent (3,550.3 acres) of the area covered by the Cerro Grande Fire was burned at moderate severity.

Of the cover types analyzed in this study, ponderosa pine forests and mixed conifer forests were burned more extensively than any other cover type throughout the entire Cerro Grande Fire (Table C-1). Each of these cover types accounted for approximately 43.0 percent (18,343 acres) of the entire fire. Of these, nearly 25 percent (10,572.0 acres) was ponderosa pine forest and low burn severity and another 21.5 percent (9151.8 acres) was mixed conifer forest at low burn severity. The next most abundant classes were mixed conifer forest at high burn severity and ponderosa pine forest at high burn severity, at 19.5 percent (8301.5 acres) and 13.7 percent (5846.0 acres), respectively. Piñon-juniper woodlands contributed 2648.3 acres (6.2 percent) to the Cerro Grande Fire. Nearly 5 percent (2122.0 acres) of this was at low burn severity. No other land cover class or combination of burn severity/land cover type contributed as much as 5 percent during the fire.

The estimates of the acreages and percentages of the total acres that were burned by the Cerro Grande Fire on LANL property are shown in Table C-2. Approximately 7651.1 acres, or 17.8 percent of the entire Cerro Grande Fire, burned on LANL. Nearly all of this, 88 percent or 6756.9 acres, was of low burn severity. Approximately 11 percent (844.1 acres) was of moderate burn severity, and less than 1 percent (50.1 acres) was burned at high severity.

The most commonly burned cover type on LANL property, at 61.7 percent (4718.4 acres), was ponderosa pine forest (Table C-2). The next most commonly burned cover type was piñon-juniper woodlands, at 16.9 percent (1289.7 acres). Large amounts of grassland on LANL property, 10.3 percent or 788.7 acres, were also burned by the

Cerro Grande Fire. Mixed conifer forest on LANL contributed to 6.8 percent (522.7 acres) of the fire.

Of the combinations of burn severities and cover types on LANL property caused by the Cerro Grande Fire, five exceeded 5 percent (Table C-2). Of these the most common combination was ponderosa pine forest and low burn severity, at 54.2 percent (4150.9 acres). Piñon-juniper woodlands and low burn severity was the second most common combination, at 15.0 percent (1150.0 acres). Grasslands on LANL, at low burn severity, contributed to 8.4 percent (644.7 acres) of the area burned by the Cerro Grande Fire. Within the ponderosa pine cover type, an additional 7.0 percent (536.0 acres) was burned at moderate severity. Finally, approximately 6.4 percent (488.9 acres) of the mixed conifer forest on LANL was also burned at low severity.

Excluding the northernmost portion of the Cerro Grande Fire that was not analyzed as part of this project because of the lack of correspondence with the land cover map, approximately 34,994.8 acres were burned on lands managed by agencies other than LANL (Table C-3). If the northernmost 238.7 acres are included in this estimate, this estimate becomes 35,233.5 acres, or about 82.2 percent of the total area covered by the fire. This acreage was somewhat evenly divided between low burn severity and high burn severity, at 50.1 percent (17,546.8 acres) and 42.1 percent (14,743.7 acres), respectively.

Mixed conifer forest, at 50.9 percent (17,821.3 acres), was the most commonly burned cover type by the Cerro Grande Fire outside of LANL property (Table C-3). Ponderosa pine forest, at 38.9 percent (13,623.7 acres), was the second most commonly burned cover type. Piñon-juniper woodland and aspen were burned with much less frequency, at approximately 3.8 percent each or about 1330 acres.

Of the mixed conifer forests that were burned by the Cerro Grande Fire on lands managed by agencies other than LANL, 24.8 percent (8662.8 acres) were burned at low severity and 23.7 percent (8283.2 acres) were burned at high severity (Table C-3). Ponderosa pine forests burned at similar proportions, with regard to low severity and high severity. Respectively, these are 18.4 percent (6421.1 acres) and 16.6 percent (5814.9 acres). None of the other combinations of cover type and burn severity equaled or exceeded 5 percent of the total acres.

Acreage Estimates for Fire Intensity

The entire fire intensity thematic layer covered 42,854.7 acres, including the 238.7 acres that were outside the limits of the land cover map (Table C-4). Approximately 40 percent (17,061.2 acres) of the analyzed total was at high fire intensity (greater than 70 percent mortality). An additional 33.1 percent (14,101.8 acres) and 19.7 percent (8393.3 acres) was burned at moderately low fire intensity (10 to 40 percent mortality) and moderately high fire intensity (40 to 70 percent mortality), respectively. Only 7.2 percent (3059.7 acres) of the Cerro Grande Fire burned at low fire intensity (less than 10 percent mortality).

In a fashion that was similar to burn severity, the majority of the Cerro Grande Fire burned in either ponderosa pine forests or mixed conifer forests, with relatively large amounts of the fire also occurring in the piñon-juniper woodlands (Table C-4). The majority of the mixed conifer forest that was burned (23.1 percent or 9845.4 acres) was at high fire intensity. The ponderosa pine forests that were burned were evenly divided among the moderately low (16.7 percent or 7121.2 acres), high (14.3 percent or 6105.1 acres), and moderately high (11.8 percent or 5045.2 acres) fire intensity classes. In contrast to the burn severity results, relatively larger amounts of the mixed conifer forests were burned at moderate fire intensities, with lesser amounts in the low fire intensity class.

On LANL property, 88.7 percent (6837.1 acres) of the Cerro Grande Fire burned at moderately low fire intensity, whereas none of the fire was observed to burn at low fire intensity (Table C-5). An additional 10.3 percent (792.0 acres) were burned at moderately high fire intensities. The moderately high and high fire intensity classes occurred in proportions similar to that observed for the burn severity data layer.

Of the major cover types on LANL, 54.6 percent (4209.2 acres) of the Cerro Grande Fire occurred in ponderosa pine forest at moderately low fire intensity (Table C-5). An additional 6.6 percent (513.0 acres) of the ponderosa pine forest was burned at moderately high fire intensity. Similarly, 15.3 percent (1181.7 acres) of the land was piñon-juniper woodland burned at moderately low fire intensity. An additional 8.3 percent (639.5 acres) was grassland burned at moderately low fire intensity. Finally, 6.3 percent (488.5 percent) of the area burned on LANL was mixed conifer forest at moderately low fire intensity.

On lands managed by agencies other than LANL, 48.6 percent (16,984.6 acres) of the Cerro Grande Fire burned at high fire intensity (Table C-6). An additional 42.6 percent (14,866.0 acres) of the land burned at either moderately high fire intensity or moderately low fire intensity. Only 8.8 percent of the land (3059.7 acres) was burned at low fire intensity.

The proportions of the major cover types burned at the various severity levels are similar to the results for the burn severity acreage estimates. Within these major cover types, 28.1 percent (9815.2 acres) of the landscape was occupied by mixed conifer forest and burned at high fire intensity (Table C-6). The remainder of the mixed conifer forests that were burned was relatively evenly distributed among the moderately high, moderately low, and low fire intensity classes. Most of the ponderosa pine forests that were burned were either in the high fire intensity class (17.4 percent or 6059.1 acres) or in the moderately high class (13.0 percent or 4532.2 acres). An additional 8.3 percent (2912.0 acres) of the total area was ponderosa pine forest burned at moderately low fire intensity. None of the other combinations of cover type and fire intensity exceeded 5 percent of the total acres.

Frequency Distribution of Polygon Size Classes

The frequency distribution of polygon size classes for burn severity is shown in tabular form in Table D-1 and is presented graphically in Figure E-1. The burn severity map included a total of 132 polygons. Approximately 49.2 percent of these polygons (65) were burned at high severity. Of the total number of polygons, 64 (48.5 percent) were less than 25 acres, 83 (62.9 percent) were less than 50 acres, and 103 (78.0 percent) were less than 100 acres. The majority of the polygons, 125 or 94.7 percent, were less than 500 acres.

Within the burn severity spatial theme, 5.3 percent of the polygons (7) were greater than 950 acres and these represent a total of 35,077.7 acres (Table D-1). This is 82.3 percent of the entire portion of the Cerro Grande Fire that was analyzed as part of this project. The burn severity of three of these polygons is high, while the remaining four polygons were burned at low severity. Of the total collection of polygons, 29 (22.0 percent) were greater than 100 acres. At 500 acres or less, these polygons were predominantly high (6) or moderately burned (9). However, the largest moderately burned polygon was 432.7 acres.

The two largest burn severity polygons were 10,110.7 acres and 10,902.9 acres, and these were burned at low severity (Table D-1 and Figure E-1). These represent 23.7 percent and 25.6 percent of the entire Cerro Grande Fire, respectively. They cover a total of 15.8 and 17.0 square miles, respectively. The first of these polygons covers a large portion of the southern Cerro Grande Fire. This begins at the Cerro Grande, extends eastward across the southern Sierra de los Valles, and continues to the eastern areas of LANL (Figure A-1). The second largest polygon is the large, irregular area of low burn severity in the northernmost region of the Cerro Grande Fire. The next two largest polygons were 1551.3 acres (2.4 square miles or 3.6 percent of the fire) and 8999.4 acres (14.1 square miles or 21.1 percent of the fire). Both of these polygons were burned at high severity. The first of these polygons is the large area of high severity burn near the northern boundary of the Cerro Grande Fire. The second polygon is the irregular area of conterminous high burn severity in the central section of the fire extending from the base of Pajarito Mountain, across Los Alamos Canyon, and continuing in a northeastward direction to the eastern extent of the fire.

The fire intensity map consisted of four fire intensity levels that were imbedded with a land cover classification (BAER 2000). As a result of the cross-classification between the fire intensity types and land cover types, the acreage distributions of fire intensity polygons were analyzed individually for selected vegetation types. These vegetation types of interest include piñon-juniper, ponderosa pine, mixed conifer, white fir, and aspen. The mixed conifer and white fir vegetation polygons were combined for the purposes of this analysis.

Within the piñon-juniper cover type, there were a total of 269 fire intensity polygons (Table D-2 and Figure E-2). Most of these (233 or 86.6 percent) were less than 25 acres. Moreover, 196 polygons (72.9 percent) are less than 10 acres in size. However, there were 12 polygons (4.5 percent) of at least 100 acres. Most of the polygons (111 or

41.3 percent) were of the moderately low fire intensity category, with 10 percent to 40 percent mortality.

The largest fire intensity polygon that was classified as piñon-juniper occupied 835.9 acres (1.3 square miles) and this was burned at high fire intensity or greater than 70 percent mortality (Table D-2 and Figure E-2). This polygon is located on the extreme eastern portion of the large area of high intensity burn that dominates the central portion of the Cerro Grande Fire (Figure A-2). In order of decreasing size, the next four polygons, from 165 acres to 425 acres, were burned at moderately low fire intensities. The next two polygons, 158.2 acres and 161.6 acres, were burned at moderately high intensities, and a polygon of 139.2 acres was burned at moderately low fire intensity. The next largest two polygons, 115.2 acres and 121.4 acres were burned at high fire intensities.

Within the fire intensity map, there are 597 polygons that are classified as ponderosa pine (Table D-3 and Figure E-3). Most of these (210 or 35.2 percent) were within the moderately low fire intensity category, characterized by 10 percent to 40 percent mortality. Of these 597 polygons, 485 (81.2 percent) were less than 25 acres and 429 (71.9 percent) were less than 10 acres. A total of 42 polygons (7.0 percent) were greater than 100 acres.

The largest fire intensity polygon within the ponderosa pine vegetation type was 3842.7 acres (6.0 square miles or 9.0 percent of the entire fire) and this polygon burned at high fire intensity, or greater than 70 percent mortality (Table D-3 and Figure E-3). This polygon is located in the central portion of the Cerro Grande Fire, extending from Los Alamos Canyon north past the western boundary of Los Alamos and continuing northeastward until it merges with the largest fire intensity polygon of piñon-juniper vegetation that was discussed previously (Figure A-2). Of the polygons that were greater than 100 acres, 15 (35.7 percent) burned at high fire intensity, eight (19.0 percent) burned at moderately high fire intensity, 17 (40.5 percent) burned at moderately low intensity, and two (4.8 percent) burned at low fire intensity.

Within the Cerro Grande Fire intensity theme, there were 377 polygons that were classified by the BAER Team as either mixed conifer or white fir (Table D-4 and Figure E-4). In contrast to the previous cover types, the most prominent polygon type was the high fire intensity category, or 70 percent to 100 percent mortality, at 148 or 39.3 percent of the total. A total of 246 of the 377 polygons (65.2 percent) were less than 10 acres, and 306 polygons (81.2 percent) were less than 25 acres. Moreover, 349 polygons (92.6 percent) were less than 100 acres.

The largest polygon of this combined type was 929.3 acres (1.5 square miles or 2.2 percent of the Cerro Grande Fire) and this polygon was burned at low fire intensity, or 0 to 10 percent mortality (Table D-4 and Figure E-4). This polygon is located at the northernmost boundary of the Cerro Grande Fire that borders Santa Clara Canyon (Figure A-2). The next five largest polygons were burned at high fire intensity, or 70 percent to 100 percent mortality. The largest of these (593.4 acres or 0.9 square miles) contributes to the western portion of the largest conterminous area of high fire intensity in the central portions of the Cerro Grande Fire. This polygon is near the headwaters of Rendija and Guaje Canyons.

A total of 94 fire intensity polygons were classified as aspen (Table D-5 and Figure E-5). A total of 37 of these polygons (39.4 percent) were classified as high fire intensity. Sixty-three of these polygons (67.0 percent) were less than 10 acres, 78 polygons (83.0 percent) were less than 25 acres, and 89 polygons (94.7 percent) were less than 50 acres. Only two of these polygons (2.1 percent) were greater than 100 acres. These were 127.7 acres and 157.5 acres in size and were both burned at high fire intensity. The largest of these polygons was located at the south-facing slope at the base of Pajarito Mountain and at the headwaters of Pajarito Canyon (Figure A-2). The second largest polygon was located at the higher elevations near the western boundary of the Cerro Grande Fire, to the northwest of the Los Alamos town site, and near the headwaters of Rendija Canyon. This polygon was also part of the large conterminous block of high fire intensity areas that dominates the central portions of the Cerro Grande Fire.

Accuracy Estimates

For the Cerro Grande Fire burn severity map (BAER 2000), a total of 92 ground points were available to conduct the accuracy assessment. These had been collected from June to October of 2000, during a reconnaissance survey of the Cerro Grande Fire. From the analysis of these points, the overall accuracy of the burn severity map was 80.4 percent (Table F-1). The map representations of low and high burn severities were the most accurate cover types, with respective accuracy estimates of 82.9 percent and 84.4 percent accuracies. The moderate burn severity class was the least accurate. However, there were only five total sample points in the burn severity type that were available for the accuracy assessment. Moreover, ground sample points that were classified as moderate or low range from unburned to high burn severity on the burn severity map. In general, the error was spread evenly over the classes on the burn severity map.

The same number of sample points (92) was used to evaluate the accuracy of the fire intensity map (BAER 2000). The overall accuracy of the fire intensity theme was approximately 63.0 percent (Table F-2). The moderate fire intensity class was the least accurate, with only 25.6 percent of the ground sites accurately predicted on the map. Conversely, the high fire intensity class was accurately predicted 96.8 percent of the time and low fire intensity was predicted with 100 percent accuracy. Ground sites that were identified as low fire intensity were most frequently mapped as moderate fire intensity, but could be mapped with any of the available classes.

A total of 149 ground-point locations were available to assess the accuracy of the land cover map developed for wildlife habitat management purposes (Koch et al. 1997). The overall accuracy of this map was 74.5 percent (Table F-3). Juniper woodland, with one sample, was predicted with 100 percent accuracy. Among the remaining classes, aspen was the most accurate, at 90.0 percent, and the piñon-juniper woodland cover type was the least accurate, at 61.5 percent. Mixed conifer forests had the highest fidelity of any of the cover types, at 84.6 percent, being confused with only ponderosa pine forest. Grasslands and aspen had the lowest fidelity, ranging from 60.0 to 61.5 percent. The largest source of error on this map was between ponderosa pine forests and mixed conifer forests, with significant contributions from the aspen class.

Survey plots from 156 field locations were used to assess the accuracy of the land cover map developed for fuels risk assessments (Yool et al. 2000). The overall accuracy of this map was 74.4 percent (Table F-4). The most accurate class was shrubland, although there was only one sample point available to evaluate this class. Of the remaining classes, mixed conifer forests were the most accurately mapped, at 86.7 percent. Piñon-juniper woodlands were the least accurately mapped, at 50.0 percent. Sites classified on the ground as aspen were mapped with 100 percent accuracy. Shrublands were classified with the least fidelity, at 7.7 percent. Ponderosa pine forests and mixed conifer forests were significant sources of error.

Ground conditions at 155 locations were used to assess the accuracy of the preliminary map developed with the GENIE computer software system (Brumby et al. 2002). The overall accuracy of this map was 54.2 percent (Table F-5). Shrublands and grasslands were the most accurately mapped cover type, but had the lowest fidelity of plots that were identified as grasslands or shrublands on the ground. Of the remaining classes, aspen was the most accurately mapped, at 80.0 percent. Piñon-juniper woodlands were the least accurately mapped, at 44.4 percent. Mixed conifer forests had the greatest fidelity, at 92.2 percent, being confused only with ponderosa pine forest. Grasslands and shrublands had the least fidelity, respectively at 7.7 percent and 18.2 percent. The largest source of error on this map resulted from sites identified on the ground as ponderosa pine forest to be classified on the map as mixed conifer forest.

Discussion

The Cerro Grande Fire was one of the largest recorded fires in New Mexico and the Southwest. The behavior of this fire was highly variable in space and time. Although the fire was active for more than one month, the bulk of the acreage that was burned occurred in a matter of a few days. Moreover, the fire burned large acres at low severity/intensity, large acres of high severity/intensity, and large acres of a mixture of interspersed severity/intensity levels. The ecological implications of these fire behaviors are equally diverse. The impacts of high severity fire were profound in that forest vegetation was reduced to conditions that will result in reforested areas only after protracted recovery that will resemble primary succession. Conversely, in many areas that were lightly burned, the effects of the fire are largely unrecognizable after a matter of months. Moderately burned areas are intermediate in their vegetation responses and in their recovery processes. However, the Cerro Grande Fire was largely characterized by polar fire behaviors. The fire tended to burn with either high severity/intensity levels or low severity/intensity levels. Intermediate or moderate levels, especially with regard to burn severities, occurred with less frequency.

The ponderosa pine and mixed conifer vegetation types were the most dramatically impacted ecosystems within the perimeter of the Cerro Grande Fire. At higher elevations, large areas of land were burned with high burn severity and high fire intensity. The third largest polygon of burn severities was a nearly continuous area of high severity burn that covered 14.1 square miles or 21.1 percent of the entire Cerro Grande Fire (Figure A-1). Most of this polygon was created in a single day of burning, May 10 (see Figures 3 and 4).

The dramatic impact of the portion of the Cerro Grande Fire that burned on May 10 is also demonstrated by the fire intensity theme (Figure A-2). With regard to high fire intensity polygons, the largest polygon in the piñon-juniper woodlands, the largest polygon in the ponderosa pine vegetation type, the second largest polygon within the mixed conifer and white fir vegetation types, and both the largest and the second largest polygons of the aspen vegetation type all contribute to the large area of high intensity fire in the central portion of the Cerro Grande Fire. If the vegetation types are disregarded throughout this area of high severity burn, the sum of the polygons of high intensity fire north of Los Alamos Canyon equals 10,275.35 acres (16.06 square miles or 24.1 percent of the entire Cerro Grande Fire). To the south of the Los Alamos Canyon, this large polygon continues with an additional 1342.91 acres (2.12 square miles or 3.2 percent of the fire). Together, these subsets combine to include 18.18 square miles or 27.3 percent of the fire.

These large areas of continuous high fire intensity have profound impacts on the affected ecosystems. Seed sources for natural reforestation of the original mixed conifer and ponderosa pine forests are all but eliminated. Assuming that soil conditions will support the germination of ponderosa pine and Douglas fir seed, extensive areas of up to two miles across will have to undergo growth and development of forest vegetation. This will not be a simple process, as outlined below.

Seed dispersal of ponderosa pine is mostly within 60 to 130 feet of the parent tree (Curtis and Foiles 1961). Most of the seed would fall within a distance of one to two times the tree height (Fowells and Schubert 1956). Ponderosa pine bears cones as early as 16 years; it will continue to produce good seed when 350 years old (Curtis 1955). Seed from trees 60 to 160 years old possess greater viability than that from younger or older trees. Seed dissemination from mature ponderosa pine can result in 125,000 to 350,000 seeds per acre (Squillace and Adams 1950, Curtis and Foiles 1961). In Arizona, typical ponderosa pine forests grow from 40 to 100 feet in the first 100 years after germination (Minor 1964).

Douglas fir may bear seed as early as 20 years (Frothingham 1909). Douglas fir is rated a prolific seeder (Frothingham 1909, Koch and Cunningham 1927). In New Mexico, Douglas fir produce 290,000 seeds per acre; white fir produces even more; other species produce less (Krauch 1945). For trees 100 feet tall, effective seeding distance is about 250 feet (Boe 1953). The approximate radius of reproduction from open-grown trees on level land has been set at 300 to 600 feet (Frothingham 1909). In New Mexico, Douglas fir trees grow to 18 inches in diameter and 150 feet tall in 100 to 150 years (Frothingham 1909).

Using this information, one can conclude that ponderosa pine and Douglas fir will generally achieve optimal seed development and dispersal height, 80 feet, in approximately 80 years. Ponderosa pine seed dispersal is within approximately 100 feet of the parent tree, and Douglas fir seed dispersal may extend to an average of 250 feet. Using these assumptions and ignoring the dispersal of seed from trees of lower heights, the calculated time required for reforestation of two miles of severely burned areas with either ponderosa pine or Douglas fir, is 8448 years and 3379 years, respectively.

Interpretations of the acreage estimates presented in this report should consider the potential differences between burn severities and fire intensities. Burn severity is a measure of the fire effects to soils and the ground surface. Fire intensity is a measure of the fire effects to above-ground vegetation. The result is that low severity burn and moderate severity burn can sometimes be accompanied with high fire intensities that consume the entire forest or woodland overstory. For the Cerro Grande Fire, this combination of low to moderate burn severity and high fire intensity frequently occurred at lower elevations in the piñon-juniper woodlands, in Gambel oak shrublands, and on north-facing slopes with mixed conifer forests.

The accuracy estimates presented in this report are developed without the benefit of an accepted standard for comparison. This is partially a result of the difficult challenges that are presented in the development of robust accuracy assessment methods for the validation of land cover maps (Lunetta and Lyon 2004). Typical standards of accuracy range between 75 percent and 85 percent. However, achieving these accuracy standards is increasingly elusive as sensors evolve to supply smaller pixel sizes, which increases the intra-class variability and compromises accurate pattern recognition (Yool 2004).

The accuracy estimates for the burn severity map, the fire intensity map, and each of the land cover maps may be conservative. One of the potential causes for this may be due to the manual establishment of the boundaries on the burn severity map and the fire intensity map during airplane and helicopter aerial surveys. Moreover, the BAER mapping of low burn severity areas included unburned areas that were not incorporated into this analysis. In addition, the methods used to determine severity/intensity levels are not always consistent between the Forest Service survey teams and the LANL field team. However, the low fire intensity category is a conspicuous example of this inconsistency, but this fact was not reflected in the accuracy matrix. Given the LANL team classified low fire intensity as fires that did not enter the overstory canopy, and given that the Forest Service Team classified forests with as much as 10 percent mortality as low fire intensity, it would be expected forests classified on the ground as moderate would be classified as low by the Forest Service, but the opposite case was true. Finally, for each of the three land cover maps, reclassification of the cover types was necessary to create a direct correspondence between the map classes and the field sampling classes. To the extent that this was not possible, the accuracy estimates will suffer. This is probably an important consideration to the accuracy estimate for the GENIE map.

Alternative techniques for mapping burn severity and fire intensity are being investigated (Miller and Yool 2002). Multitemporal LANDSAT imagery, in combination with previous land cover classification maps, have produced promising representations of burn severity and fire intensity with accuracies that are consistent with those presented in this report, reducing the need to produce these fire behavior maps through laborious aerial reconnaissance and ground sampling techniques, which are often conducted while the fire is still active. However, the approach investigated by Miller and Yool (2002) requires the availability of accurate land cover maps for the burned area of interest, in conjunction with a postfire overflight of the LANDSAT satellite to produce results in a timely manner.

With regard to map accuracy, another point of comparison was completed in the aftermath of the Cerro Grande Fire. A new map was produced from LANDSAT data in 2001 to partially resolve the dramatic land use changes that were created by the Cerro Grande Fire (McKown et al. 2003). One of the versions of this map product, using a quarter-hectare minimum mapping unit and a taxonomic approach to characterize the land cover types, achieved an accuracy assessment of 74.8 percent. As a result, this map and the two other land cover maps analyzed in this report, created by LANDSAT imagery for different purposes, each achieved accuracy levels of about 75 percent.

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Literature Cited

BAER. 2000. Cerro Grande Fire Burned Area Emergency Rehabilitation (BAER) Plan. U.S. Interagency Burned Area Emergency Rehabilitation Team (June 9), National Park Service.

Balice, R.G., B.P. Oswald, and C. Martin. 1999. Fuels inventories in the Los Alamos National Laboratory Region; 1997. LA-13572-MS, Los Alamos National Laboratory, Los Alamos, NM.

Balice, R.G., J.D. Miller, B.P. Oswald, C. Edminster, and S.R. Yool. 2000. Forest surveys and wildfire assessment in the Los Alamos region: 1998–1999. LA-13714-MS, Los Alamos National Laboratory, Los Alamos, NM.

Boe, K.N. 1953. Western larch and Douglas-fir seed dispersal into clear-cuttings. Research Note 129, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Brumby, S.P., S.W. Koch, and L.A. Hansen. 2002. Evolutionary computation and post-wildfire land-cover mapping with multispectral imagery. Pages 174–183 in *Proceedings SPIE, Volume 4545 Remote Sensing for Environmental Monitoring, GIS Applications, and Geology* (Editor: M. Ehlers), University of Vechta, Germany.

Byram, G.M. 1959. Combustion of forest fuels. Pages 61–89 in *Forest fire: control and use, second edition*. McGraw-Hill, New York.

Cerro Grande Fire, Incident Command. 2000. Cerro Grande Fire (NM-SNF-043), Fire Behavior and Weather Documentation CD (May 6–24, 2000). Compiled by Kelly Close, Poudre Fire Authority, Fort Collins, CO.

CorMac Technologies, Inc. 2001. VisiRex 2.1 for Windows. CorMac Technologies, Inc., Thunder Bay, Ontario, Canada.

Curtis, J.D. 1955. Effects of origin and storage method on the germinative capacity of ponderosa pine seed. Research Note 26, U.S. Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Curtis, J.D. and M.W. Foiles. 1961. Ponderosa pine seed dissemination into group clearcuttings. *Journal of Forestry* 59:766–767.

DeBano, L.F., D.G. Neary, and P.F. Ffolliott. 1998. *Fire's effects on ecosystems*. John Wiley and Sons, Inc., New York.

DeClay, Jr., P., L. Laverty, M. Long, and E. Zielinski. 2000. Cerro Grande Prescribed Fire. Independent Review Board Report (May 6, 2000) to Secretary of the Interior, Bruce Babbitt. State of Forestry, Division of Forestry, USDI Bureau of Land Management, USDA Forest Service, White Mountain Apache Tribe.

DeLaune, M.G. 2001. XTools ArcView extension (Version 6/1/2001). Website (http://www.odf.state.or.us/DIVISIONS/management/state_forests/GIShome.asp) maintained by the State Forest Management Program, Oregon Department of Forestry, Salem, OR.

DOE/LAAO. 2000. Special environmental analysis for the Department of Energy/National Nuclear Security Agency: Actions taken in response to the Cerro Grande Fire at Los Alamos National Laboratory, Los Alamos, New Mexico. DOE/SEA-003, U.S. Department of Energy, Los Alamos Area Office, Los Alamos, NM.

ESRI. 2002a. ArcView (Version 3.3) GIS and mapping software. Environmental Systems Research Institute (ESRI), Inc., Redlands, CA.

ESRI. 2002b. ArcDoc (Version 8.2). Environmental Systems Research Institute (ESRI), Inc., Redlands, CA.

Fire Investigation Team. 2000. Cerro Grande Prescribed Fire, May 4–8, 2000. Investigation report (May 18), National Interagency Fire Center, Boise, ID.

Fowells, H.A. and G.H. Schubert. 1956. Seed crops of forest trees in the pine region of California. Technical Bulletin 1150, U.S. Department of Agriculture, Washington, D.C.

Frothingham, E.H. 1909. Doulgas fir: A study of the Pacific Coast and Rocky Mountain forms. Circular 150, U.S. Forest Service, Washington, D.C.

Hartford, RA. and W.J. Frandsen. 1992. When it's hot, it's hot... or maybe it's not! *International Journal of Wildland Fire* 2:139–144.

Hill, B.T. 2000. Lessons learned from the Cerro Grande (Los Alamos) Fire. Statement from the Associate Director for Energy, Resources and Science Issues; Resources, Community and Economic Development Division (GAO/T-RECD-00-257), U.S. General Accounting Office, Washington, D.C.

Koch, E. and R.N. Cunningham. 1927. Timber growing and logging practice in the western white pine and larch-fir forests of the northern Rocky Mountains. Bulletin 1494, U.S. Department of Agriculture, Washington, D.C.

Koch, S.W., T.K. Budge, and R.G. Balice. 1997. Development of a land cover map for Los Alamos National Lab and vicinity. LA-UR-97-4628, Los Alamos National Laboratory, Los Alamos, NM.

Krauch, H. 1945. Some factors influencing Douglas-fir reproduction in the southwest. *Journal of Forestry* 34:601–608.

Lunetta, R.S. and J.G. Lyon. 2004. *Remote sensing and GIS accuracy assessment*. CRC Press, Boca Raton, Florida.

McKown, B., S.W. Koch, R.G. Balice, and P. Neville. 2003. Land cover map for the eastern Jemez region. LA-14029, Los Alamos National Laboratory, Los Alamos, NM.

Miller, J.D. and S.R. Yool. 2002. Mapping forest post-fire canopy consumption in several overstory types using multi-temporal Landsat ET and ETM data. *Remote Sensing of Environment* 82:481–496.

Minor, C.O. 1964. Site-index curves for young-growth ponderosa pine in northern Arizona. Research Note RM-37, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Panel of the National Academy of Public Administration. 2000. Study of the implementation of Federal wildland fire policy. Phase I report, Perspectives on Cerro Grande and recommended issues for further study. Report for the U.S. Department of Interior (Frank Fairbanks, Chair). National Academy of Public Administration, Washington, D.C.

Pyne, S.J., P.L. Andrews, and R.D. Laven. 1996. *Introduction to wildland fire*. John Wiley and Sons, Inc., New York.

Scott, J.H. and E.D. Reinhardt. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. Research Paper RMRS-RP-29, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Simard, A.J. 1991. Fire severity, changing scales, and how things hang together. *International Journal of Wildland Fire* 1:23–34.

Site-Wide Issues Program Office. 2000. A special edition of the SWEIS Yearbook: Wildfire 2000. LA-UR-00-3471, Site-Wide Issues Program Office, Los Alamos National Laboratory, Los Alamos, NM.

Squillace, A.E. and L. Adams. 1950. Dispersal and survival of the seed in a partially cut ponderosa pine stand. Research Note 79, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

van Wagner, C.E. 1977. Conditions for the start and spread of crown fire. *Canadian Journal of Forest Research* 7:23–34.

Whelan, R.J. 1995. The ecology of fire. Cambridge University Press, Cambridge, England.

Yool, S.R. 2004. Personal email communication, December 8, 2004.

Yool, S.R., J.D. Miller, R.G. Balice, B.P. Oswald, and C. Edminster. 2000. Mapping fuel risk at the Los Alamos urban-wildland interface. Pages 228–234 in *Proceedings of* *the Crossing the Millennium: Integrating Spatial Technologies and Ecological Principles for a New Age in Fire Management Conference and Workshop, Volume I* (Technical Editors: L.F. Neuenschwander and K.C. Ryan). University of Idaho and International Association of Wildland Fire, Moscow, ID.

Appendix A:

Maps analyzed as part of this project

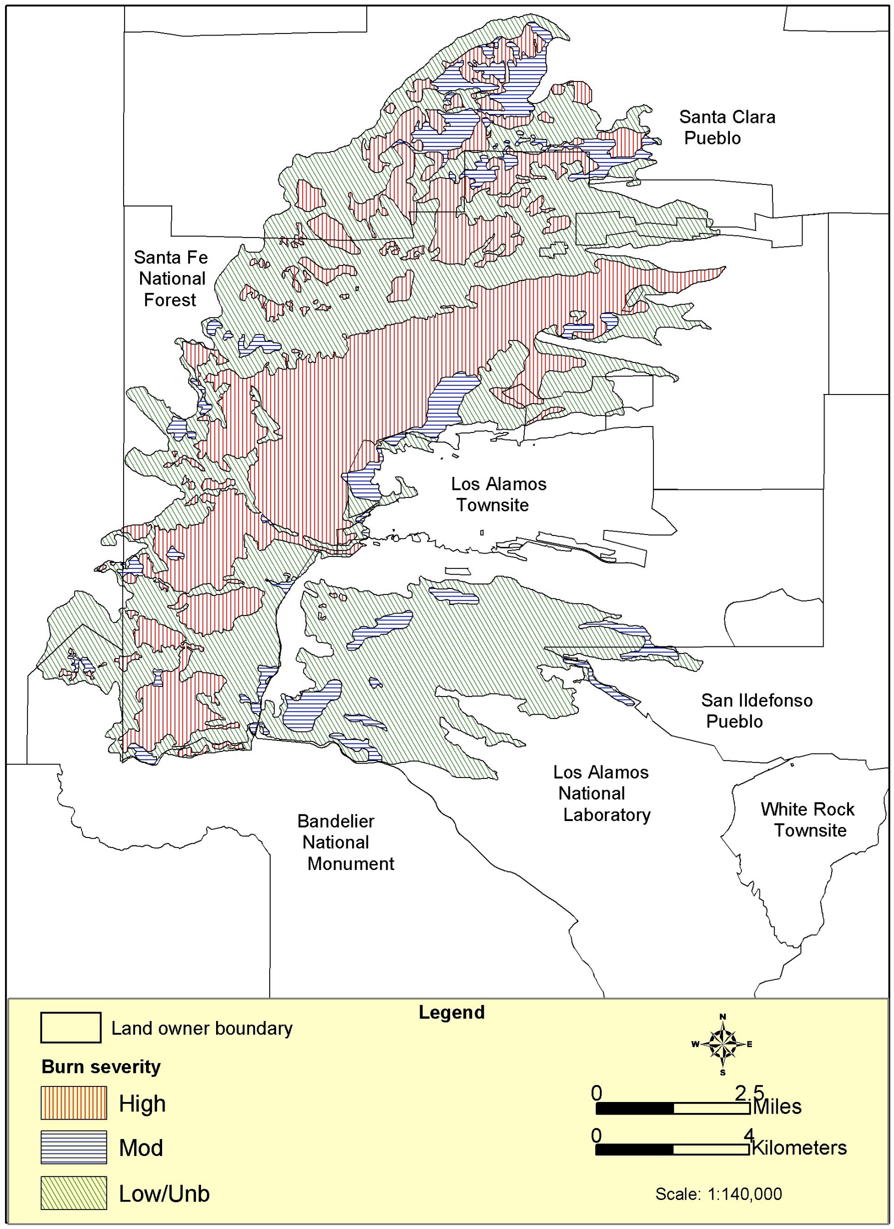

Figure A-1. Burn severity map for the Cerro Grande Fire (BAER 2000).

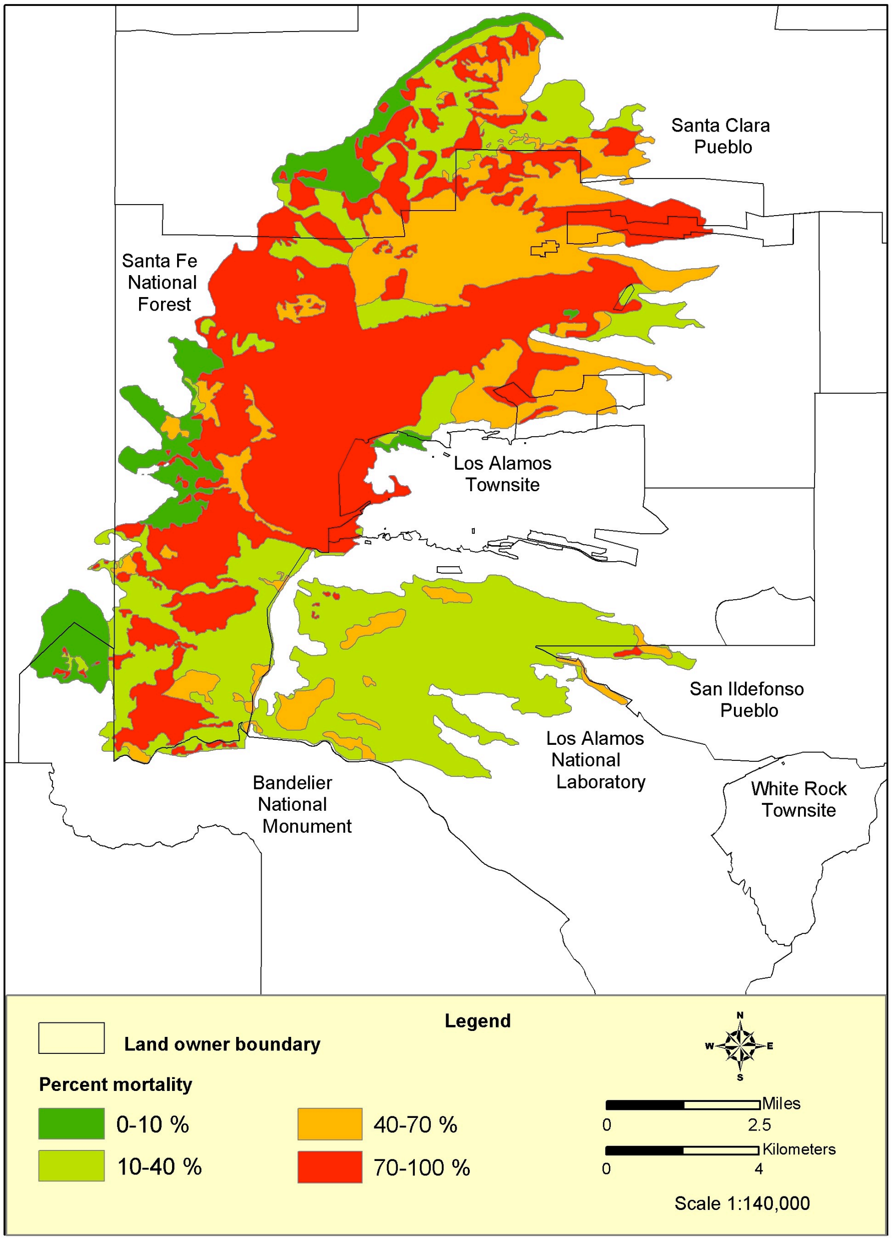

Figure A-2. Fire intensity map for the Cerro Grande Fire (BAER 2000).

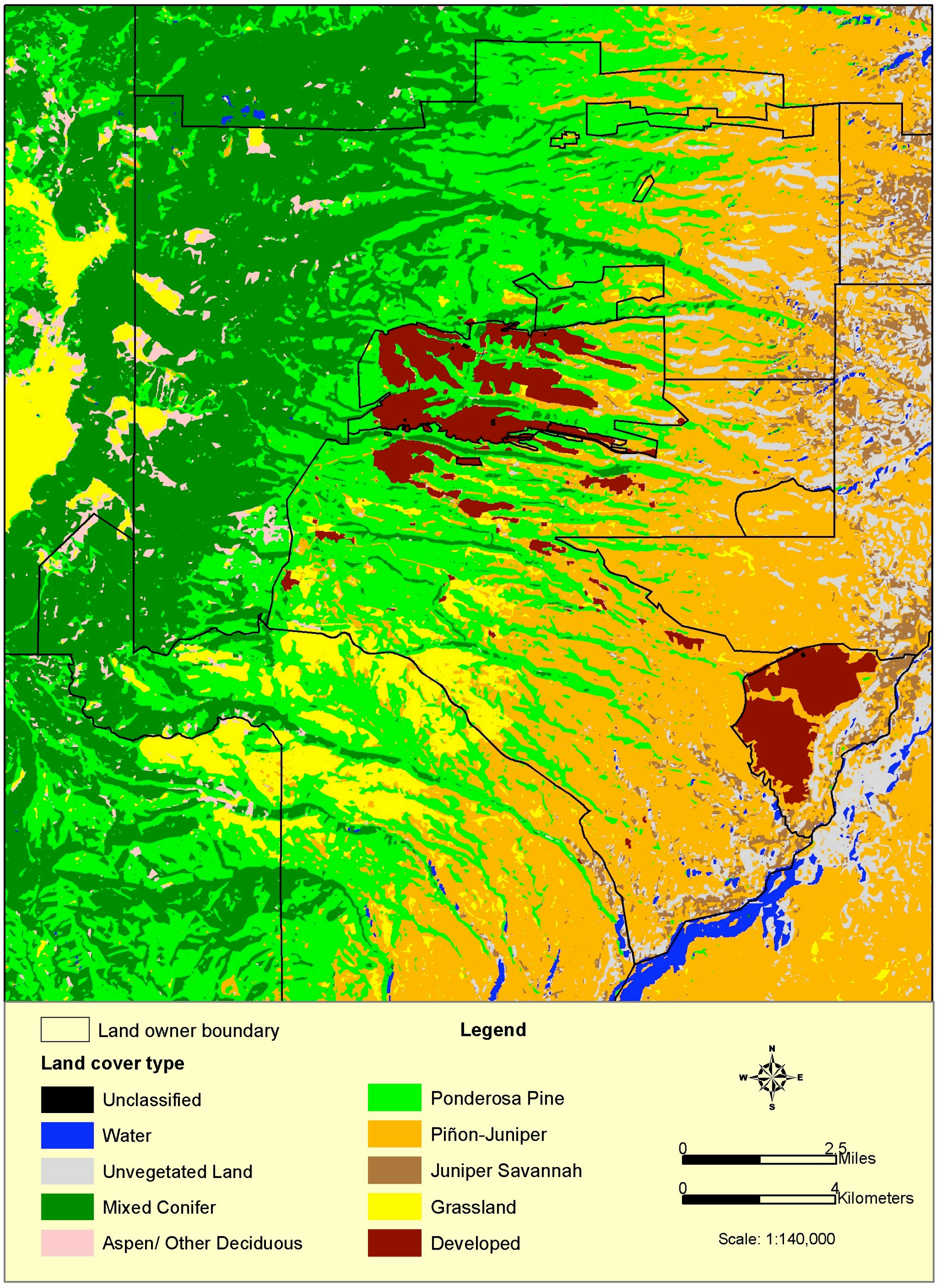

Figure A-3. Land cover map for wildlife habitat management (Koch et al. 1997).

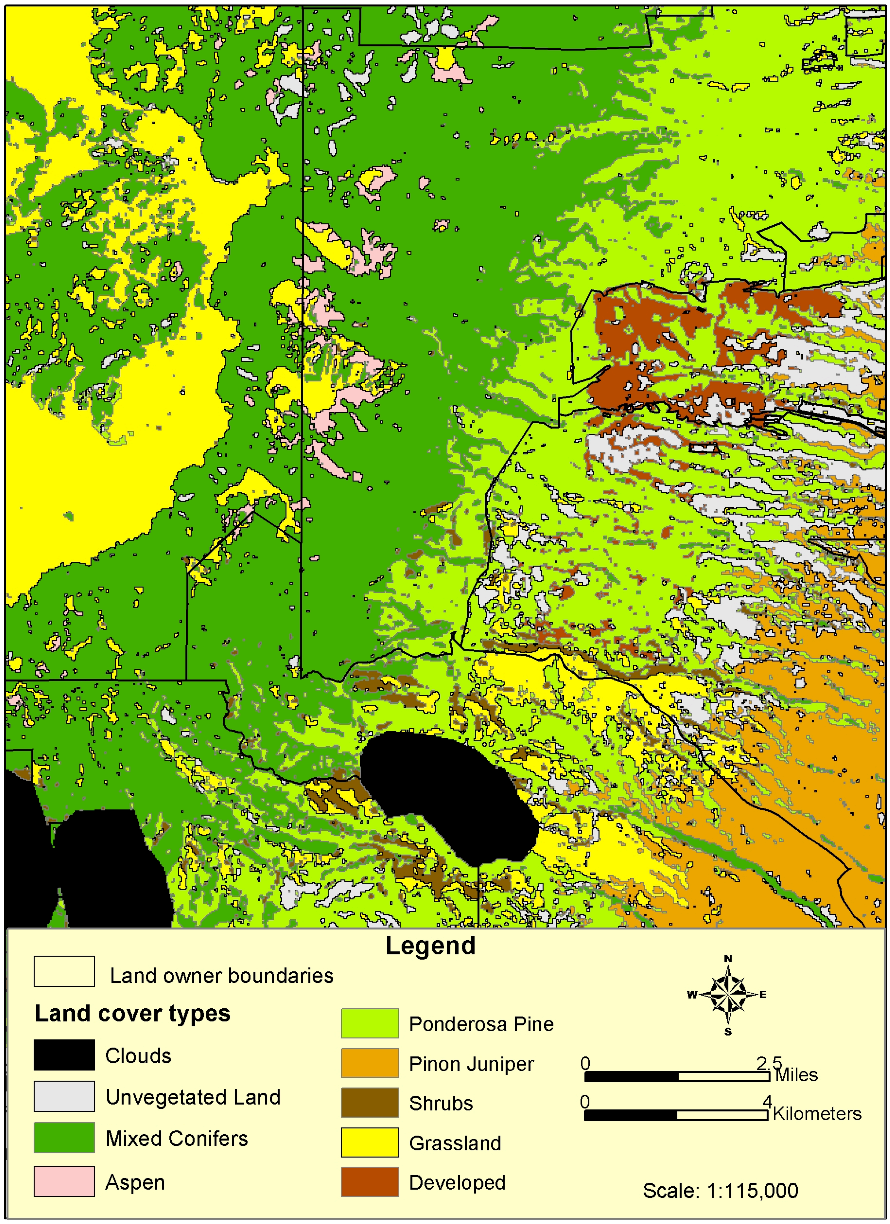

Figure A-4. Land cover map for fuel risk assessments (Yool et al. 2000).

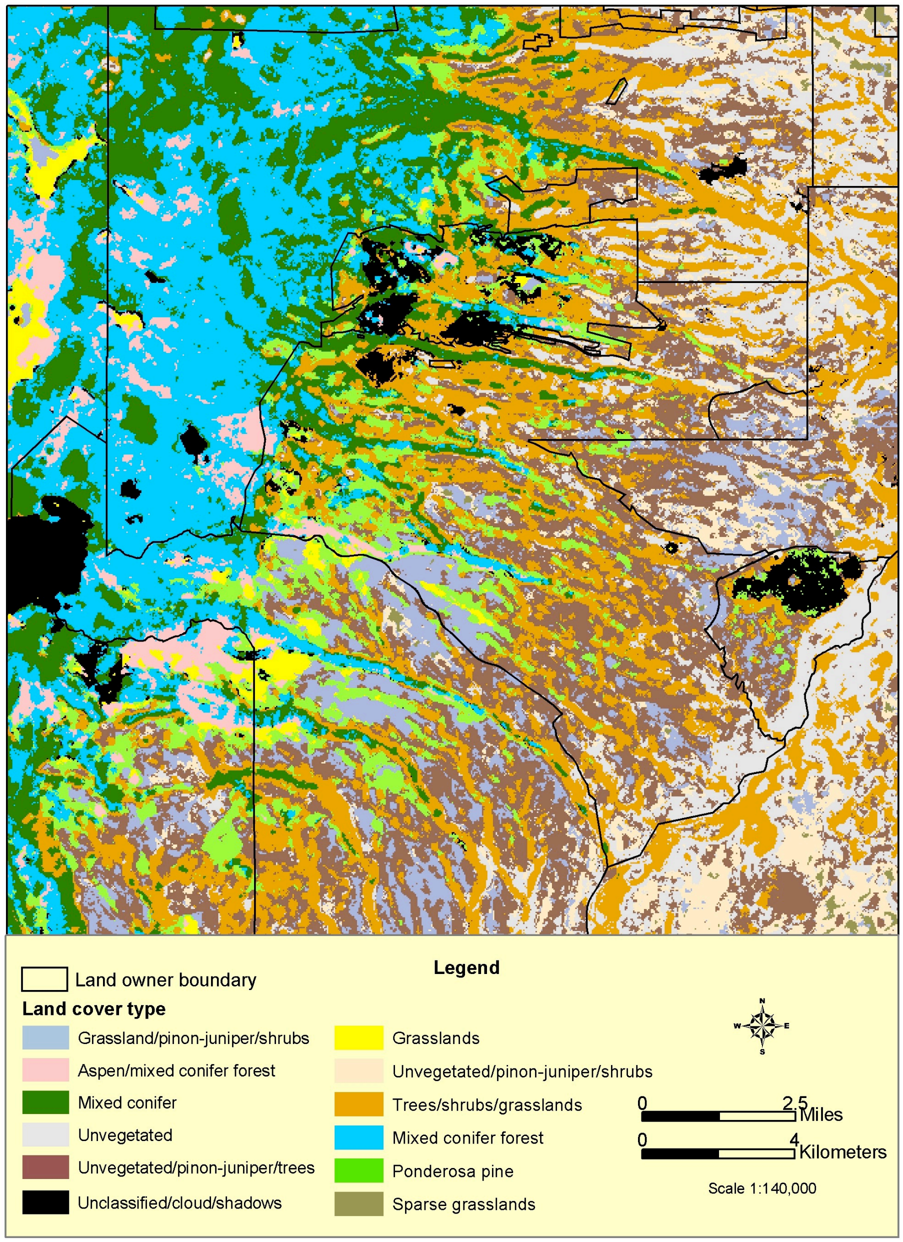

Figure A-5. Land cover map developed by the application of the GENIE computation software, showing the original classification scheme (Brumby et al. 2002).

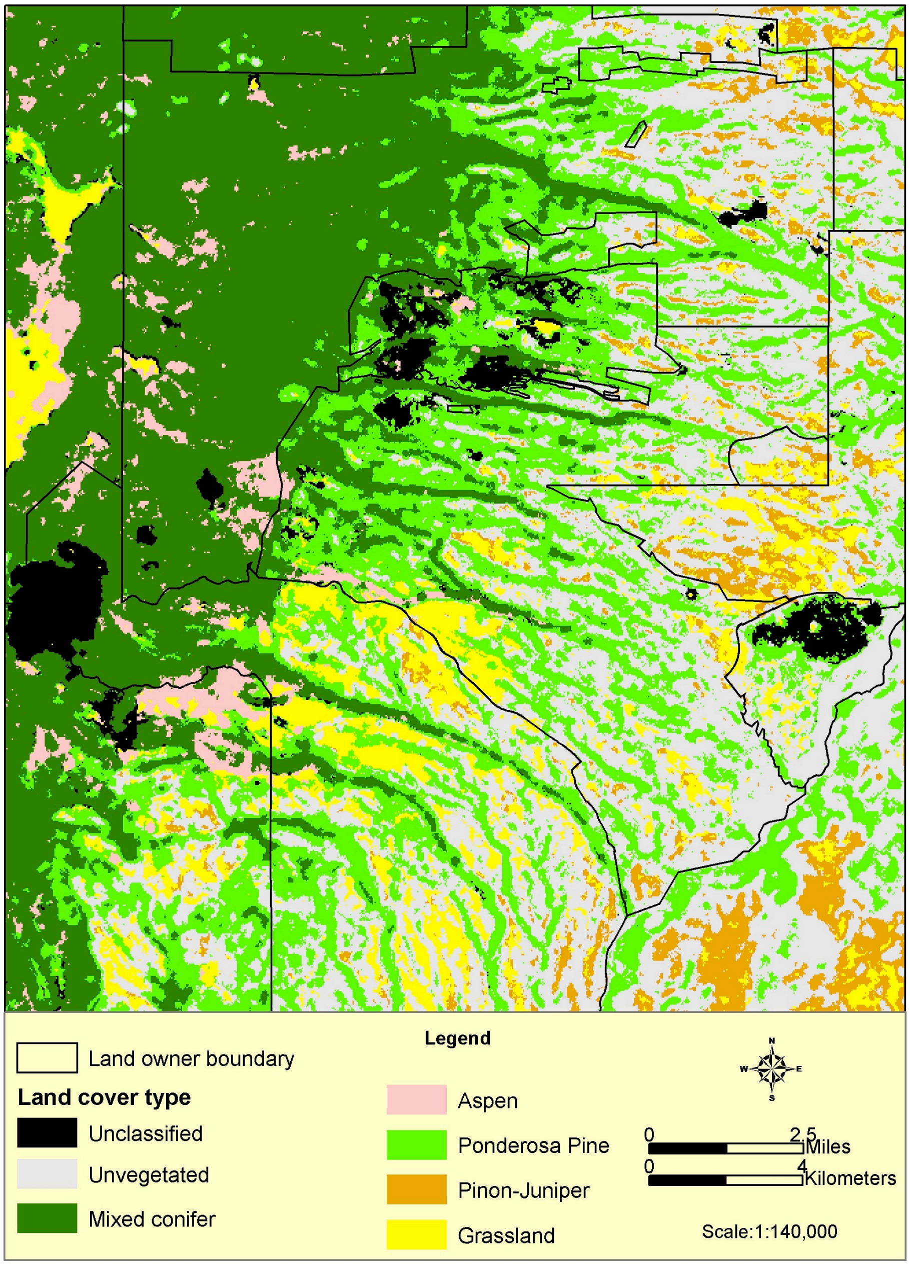

Figure A-6. Land cover map developed by the application of the GENIE computation software (Brumby et al. 2002), showing the aggregated classification scheme used in the accuracy analysis.

Appendix B:

Scanned photos of plots representing typical fire behaviors in prominent vegetation types of the Los Alamos region

Table B-1. Descriptive information for the scanned photos that follow in this appendix.

Figure	Plot	Date	Dom	HT	Slope	Aspect	Elevation	Intensity	Severity	Can cov	Crn Con	B scorch
B-1-A	TC25	6/8/2000	PP	Pipo/Quga	15	170	7583	H	H	0	100	35
B-1-B	TF05D	6/15/2000	PP	Psme/Aruv	12	100	7879	H	H	0	100	68
B-2-A	TF05C	6/15/2000	MC	Abco/Quga	14	50	7998	H	H	0	100	75
B-2-B	CF01	6/26/2000	MC	Abco/Quga	30	163	8710	H	H	0	100	50
B-2-C	NF22	7/10/2000	MC	Abco/Quga	15	245	8659	H	H	0	100	60
B-3	AF0409	7/24/2000	AS	Potr/Feth	39	151	9853	H	H	0	100	47
B-4-A	AF0906	8/10/2000	PP	Pipo/Quga	21	76	7750	M	L	16.1	40	15
B-4-B	TF02B	7/3/2000	PP	Pipo/Quga	4	135	8109	M	L	6.0	75	27.5
B-5-A	NL51	8/2/2000	MC	Abco/Quga	58	355	7308	M	M	28.4	60	24
B-5-B	AB0701	7/13/2000	MC	Abco/Quga	36	91	9410	M	L	30.7	50	17
B-6-A	TB01	8/16/2000	PP	Pipo/Quga	17	101	7606	L	L	61.6	2.5	4
B-6-B	AL0609	8/1/2000	PP	Pipo/Quga	13	16	7535	L	L	65.3	20	14
B-6-C	TF02A	7/3/2000	PP	Pipo/Quga	1	180	8087	L	L	50.3	15	20
B-7-A	AF0310	7/17/2000	MC	Abco/Erex	7	354	9120	L	L	81.6	10	3.5
B-7-B	AB0402	7/20/2000	MC	Psme/Quga	30	241	9530	L	L	73.2	10	2.5
B-7-C	CF18	9/13/2000	MC	Abco/Quga	5	335	8138	L	L	43.1	20	11
B-8-A	AF0808	7/24/2000	AS	Potr/Feth	36	184	9876	L	L	78.1	4	1
B-8-B	TF13	8/17/2000	AS	Potr/Feth	47	186	9664	L	L	89.9	0.5	1.5

This table gives descriptive information, including the plot number and the date of the sample, for the photos that follow in this appendix.

Dom = Dominance type (PP = ponderosa pine, MC = mixed conifer, AS = aspen)

HT = Habitat type (Pipo/Quga = Ponderosa pine/Gambel oak, Psme/Aruv = Douglas fir/Kinnikinnik, Abco/Quga = White fir/Gambel oak, Potr/Feth = Aspen/Thurber fescue, Psme/Quga = Douglas fir/Gambel oak, Abco/Erex = White fir/mountain fleabane)

Slope = Slope percent

Aspect = Aspect of the slope in degrees from true north

Elevation = Feet above sea level

Intensity = Fire intensity

Severity = Burn severity

Can cov = Percent canopy cover

Crn con = Average consumption of the tree crowns resulting from the fire, in percent

B scorch = Average height of the bole scorch, in feet

A

B

Figure B-1. High burn severity and high fire intensity in ponderosa pine forests.

A

B

Figure B-2. High burn severity and high fire intensity in mixed conifer forests

C

Figure B-2 (Continued). High burn severity and high fire intensity in mixed conifer forests

Figure B-3. High burn severity and high fire intensity in aspen forest.

A

B

Figure B-4. Low burn severity and moderate fire intensity in ponderosa pine forests.

A

B

Figure B-5. Moderate or low burn severity and moderate fire intensity in mixed conifer forests.


A


B

Figure B-6. Low burn severity and low fire intensity in ponderosa pine forests.

C

Figure B-6 (Continued). Low burn severity and low fire intensity in ponderosa pine forests.


A


B

Figure B-7. Low burn severity and low fire intensity in mixed conifer forests.

C
Figure B-7 (Continued). Low burn severity and low fire intensity in mixed conifer forests.

A

B

Figure B-8. Low burn severity and low fire intensity in aspen forests.

Appendix C:

Acreages of the Cerro Grande Fire and percents of the total; by burn severity or by fire intensity and by land cover type

Table C-1. Burn severity versus land cover type for the entire Cerro Grande Fire (A = acres, B = percents of the total). Legend: JUMO = Juniper woodlands and savannas, P-J = Piñon-juniper woodland, PIPO = Ponderosa pine forest, MC = Mixed conifer forest, POTR = Aspen forests and woodlands, Nonveg = Unvegetated lands with bare rock or bare soil, and Unclass = Unclassified lands.

A

Burn Severity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Nonveg	Unclass	Totals
High	0.044	194.425	5845.975	8301.480	295.853	114.683	40.585	0.043	0.207	14793.295
Moderate	3.417	331.886	1923.867	890.545	111.342	205.310	72.411	11.487	0	3550.265
Low	18.102	2122.001	10572.000	9151.763	929.589	1122.142	330.500	55.142	1.900	24303.139
Totals	21.563	2648.312	18341.842	18343.788	1336.784	1442.135	443.496	66.672	2.107	42646.699

B

Burn Severity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Nonveg	Unclass	Totals
High	0.00	0.46	13.71	19.47	0.69	0.27	0.10	0.00	0.00	34.69
Moderate	0.01	0.78	4.51	2.09	0.26	0.48	0.17	0.03	0	8.32
Low	0.04	4.98	24.79	21.46	2.18	2.63	0.77	0.13	0.00	56.99
Totals	0.05	6.21	43.01	43.01	3.13	3.38	1.04	0.16	0.00	100.00

Table C-2. Burn severity versus land cover type for the portion of the Cerro Grande Fire that burned on LANL property (A = acres, B = percents of the total). Legend: JUMO = Juniper woodlands and savannas, P-J = Piñon-juniper woodland, PIPO = Ponderosa pine forest, MC = Mixed conifer forest, POTR = Aspen forests and woodlands, and Nonveg = Unvegetated lands with bare rock or bare soil.

A

Burn Severity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Nonveg	Totals
High	0	0.189	31.570	18.309	0	0	0	0	50.068
Moderate	0.530	139.500	536.000	15.500	1.600	144.000	2.000	5.000	844.130
Low	13.627	1149.983	4150.864	488.925	31.915	644.652	236.079	40.811	6756.856
Totals	14.157	1289.672	4718.434	522.734	33.515	788.652	238.079	45.811	7651.054

B

Burn Severity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Nonveg	Totals
High	0	0.00	0.41	0.24	0	0	0	0	0.65
Moderate	0.01	1.82	7.01	0.20	0.02	1.88	0.03	0.07	11.03
Low	0.18	15.03	54.25	6.39	0.42	8.43	3.09	0.53	88.31
Totals	0.19	16.86	61.67	6.83	0.44	10.31	3.11	0.60	100

Table C-3. Burn severity versus land cover type for the portion of the Cerro Grande Fire that burned on lands owned or managed by agencies other than LANL (A = acres, B = percents of the total). Legend: JUMO = Juniper woodlands and savannas, P-J = Piñon-juniper woodland, PIPO = Ponderosa pine forest, MC = Mixed conifer forest, POTR = Aspen forests and woodlands, Nonveg = Unvegetated lands with bare rock or bare soil, and Unclass = Unclassified lands.

A

Burn Severity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Nonveg	Unclass	Totals
High	0.044	194.235	5814.901	8283.173	295.853	114.684	40.585	0.043	0.207	14743.725
Moderate	2.886	192.337	1387.623	875.309	109.656	60.588	69.949	5.907	0	2704.255
Low	4.475	972.516	6421.137	8662.841	897.676	477.490	94.421	14.331	1.900	17546.787
Totals	7.405	1359.088	13623.661	17821.323	1303.185	652.762	204.955	20.281	2.107	34994.767

B

Burn Severity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Nonveg	Unclass	Totals
High	0.00	0.56	16.62	23.67	0.85	0.33	0.12	0.00	0.00	42.13
Moderate	0.01	0.55	3.97	2.50	0.31	0.17	0.20	0.02	0	7.73
Low	0.01	2.78	18.35	24.75	2.57	1.36	0.27	0.04	0.01	50.14
Totals	0.02	3.88	38.93	50.93	3.72	1.87	0.59	0.06	0.01	100.00

Table C-4. Fire intensity versus land cover type for the entire Cerro Grande Fire (A = acres, B = percents of the total). Legend: JUMO = Juniper woodlands and savannas, P-J = Piñon-juniper woodland, PIPO = Ponderosa pine forest, MC = Mixed conifer forest, POTR = Aspen forests and woodlands, and Unclass = Unclassified lands.

A

Fire Intensity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Unclass	Totals
High, >70%	3.296	514.544	6105.099	9845.436	317.677	148.179	121.218	5.727	17061.176
Mod High, 40% to 70%	5.489	666.566	5045.239	2296.165	107.589	246.317	10.141	15.805	8393.311
Mod Low, 10% to 40%	12.856	1515.435	7121.229	3855.16	490.278	795.961	266.576	44.329	14101.824
Low, 0 to 10%	0.019	11.794	196.413	2136.646	408.021	241.522	63.450	1.826	3059.691
Totals	21.660	2708.339	18467.980	18133.407	1323.565	1431.979	461.385	67.687	42616.002

B

Fire Intensity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Unclass	Totals
High, >70%	0.01	1.21	14.33	23.10	0.75	0.35	0.28	0.01	40.03
Mod High, 40% to 70%	0.01	1.56	11.84	5.39	0.25	0.58	0.02	0.04	19.70
Mod Low, 10% to 40%	0.03	3.56	16.71	9.05	1.15	1.87	0.63	0.10	33.09
Low, 0 to 10%	0.00	0.03	0.46	5.01	0.96	0.57	0.15	0.00	7.18
Totals	0.05	6.36	43.34	42.55	3.11	3.36	1.08	0.16	100.00

Table C-5. Fire intensity versus land cover type for the portion of the Cerro Grande Fire that burned on LANL property (A = acres, B = percents of the total). Legend: JUMO = Juniper woodlands and savannas, P-J = Piñon-juniper woodland, PIPO = Ponderosa pine forest, MC = Mixed conifer forest, POTR = Aspen forests and woodlands, and Unclass = Unclassified lands.

A

Fire Intensity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Unclass	Totals
High, >70%	0	0.009	45.994	30.224	0.207	0	0.096	0	76.53
Mod High, 40% to 70%	0.719	110.412	513.015	16.261	2.001	140.881	2.697	5.991	791.977
Mod Low, 10% to 40%	12.461	1181.670	4209.221	488.537	35.536	639.485	230.947	39.249	6837.106
Low, 0 to 10%	0	0	0	0	0	0	0	0	0
Totals	13.180	1292.091	4768.230	535.022	37.744	780.366	233.740	45.240	7705.613

B

Fire Intensity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Unclass	Totals
High, >70%	0	0.00	0.60	0.39	0.00	0	0.00	0	0.99
Mod High, 40% to 70%	0.01	1.43	6.66	0.21	0.03	1.83	0.04	0.08	10.28
Mod Low, 10% to 40%	0.16	15.34	54.63	6.34	0.46	8.30	3.00	0.51	88.73
Low, 0 to 10%	0	0	0	0	0	0	0	0	0
Totals	0.17	16.77	61.88	6.94	0.49	10.13	3.03	0.59	100

Table C-6. Fire intensity versus land cover type for the portion of the Cerro Grande Fire that burned on lands owned or managed by agencies other than LANL (A = acres, B = percents of the total). Legend: JUMO = Juniper woodlands and savannas, P-J = Piñon-juniper woodland, PIPO = Ponderosa pine forest, MC = Mixed conifer forest, POTR = Aspen forests and woodlands, and Unclass = Unclassified lands.

A

Fire Intensity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Unclass	Totals
High, >70%	3.296	514.534	6059.109	9815.210	317.475	148.179	121.123	5.727	16984.653
Mod High, 40% to 70%	4.770	556.157	4532.231	2279.900	105.589	105.435	7.444	9.814	7601.340
Mod Low, 10% to 40%	0.395	333.766	2912.007	3366.622	454.743	156.473	35.629	5.080	7264.715
Low, 0 to 10%	0.019	11.794	196.412	2136.645	408.021	241.522	63.450	1.826	3059.689
Totals	8.480	1416.251	13699.759	17598.377	1285.828	651.609	227.646	22.447	34910.397

B

Fire Intensity	JUMO	P-J	PIPO	MC	POTR	Grassland	Developed	Unclass	Totals
High, >70%	0.01	1.47	17.36	28.12	0.91	0.42	0.35	0.02	48.65
Mod High, 40% to 70%	0.01	1.59	12.98	6.53	0.30	0.30	0.02	0.03	21.77
Mod Low, 10% to 40%	0.00	0.96	8.34	9.64	1.30	0.45	0.10	0.01	20.81
Low, 0 to 10%	0.00	0.03	0.56	6.12	1.17	0.69	0.18	0.01	8.76
Totals	0.02	4.06	39.24	50.41	3.68	1.87	0.65	0.06	100.00

Appendix D:

Frequency distribution of polygon size classes for burn severity and fire intensity

Table D-1. Frequency distribution of burn severity polygon sizes.

Acreage class	Total	High	Mod	Low
0-50	83	44	29	10
50-100	20	9	10	1
100-150	5	3		2
150-200	7	3	4	
200-250	2		1	1
250-300	2	1	1	
300-350	1		1	
350-400	2	1	1	
400-450	2		1	1
450-500	1	1		
500-550				
550-600				
600-650				
650-700				
700-750				
750-800				
800-850				
850-900				
900-950				
950-1000	1			1
1000-1050				
1050-1100				
1100-1150	1	1		
1150-1200				
1200-1250				
1250-1300				
1300-1350				
1350-1400				
1400-1450	1			1
1450-1500				
1500-1550				
1550-1600	1	1		
8950-9000	1	1		
10100-10150	1			1
10900-10950	1			1
Total	132	65	48	19

Table D-2. Frequency distribution of fire intensity (percent mortality) polygon sizes for piñon-juniper vegetation.

Acreage class	Total	0-10%	10-40%	40-70%	70-100%	Unclassified
0-25	233	6	97	54	50	26
25-50	14		5	5	4	
50-75	6	1	1	2	2	
75-100	4		3	1		
100-125	4			2	2	
125-150	1		1			
150-175	3		1	2		
175-200						
200-225						
225-250						
250-275	1		1			
275-300	1		1			
300-325						
325-350						
350-375						
375-400						
400-425	1		1			
425-450						
450-475						
475-500						
500-525						
525-550						
550-575						
575-600						
600-625						
625-650						
650-675						
675-700						
700-725						
725-750						
750-775						
775-800						
800-825						
825-850	1				1	
850-900						
900-925						
925-950						
950-975						
975-1000						
Total	269	7	111	66	59	26

Table D-3. Frequency distribution of fire intensity (percent mortality) polygon sizes for ponderosa pine vegetation.

Acreage class	Total	0-10%	10-40%	40-70%	70-100%	Unclassified
0-25	485	23	171	115	111	65
25-50	40	3	13	14	10	
50-75	16		4	4	8	
75-100	14		5	5	4	
100-125	5	1	3		1	
125-150	8		4		4	
150-175	6		1	3	2	
175-200	1		1			
200-225	1		1			
225-250	4		2		2	
250-275	2			1	1	
275-300						
300-325						
325-350						
350-375	1			1		
375-400	2				2	
400-425	1				1	
425-450	1		1			
450-475	1				1	
475-500	2	1	1			
500-525	1		1			
525-550	1			1		
550-575						
575-600	1		1			
600-625	1			1		
625-650						
650-675						
675-700						
1175-1200						
1200-1225						
1225-1250	1		1			
1250-1275						
1275-1300	1			1		
1300-1325						
1325-1350						
1350-1375						
1375-1400						
3825-3850	1				1	
Total	597	28	210	146	148	65

Table D-4. Frequency distribution of fire intensity (percent mortality) polygon sizes for mixed conifer and white fir vegetation.

Acreage class	Total	0-10%	10-40%	40-70%	70-100%	Unclassified
0-25	306	30	63	67	112	34
25-50	20	2	1	5	12	
50-75	17	2	5	3	7	
75-100	6	1	2	3		
100-125	7		2		5	
125-150	3	1			2	
150-175	5	1	1		3	
175-200	2		1		1	
200-225	1			1		
225-250	1				1	
250-275	2		2			
275-300	1		1			
300-325						
325-350						
350-375	1				1	
375-400	2				2	
400-425	1				1	
425-450						
450-475						
475-500						
500-525						
525-550						
550-575						
575-600	1				1	
600-625						
625-650						
650-675						
675-700						
700-725						
725-750						
750-775						
775-800						
800-825						
825-850						
850-900						
900-925						
925-950	1	1				
950-975						
975-1000						
Total	377	38	78	79	148	34

Table D-5. Frequency distribution of fire intensity (percent mortality) polygon sizes for aspen vegetation.

Acreage class	Total	0-10%	10-40%	40-70%	70-100%	Unclassified
0-25	78	27	13	1	32	5
25-50	11	2	4	3	2	
50-75	1				1	
75-100	2	1	1			
100-125						
125-150	1				1	
150-175	1				1	
175-200						
Total	94	30	18	4	37	5

Appendix E:

Frequency histograms of polygon size classes for burn severity and fire intensity

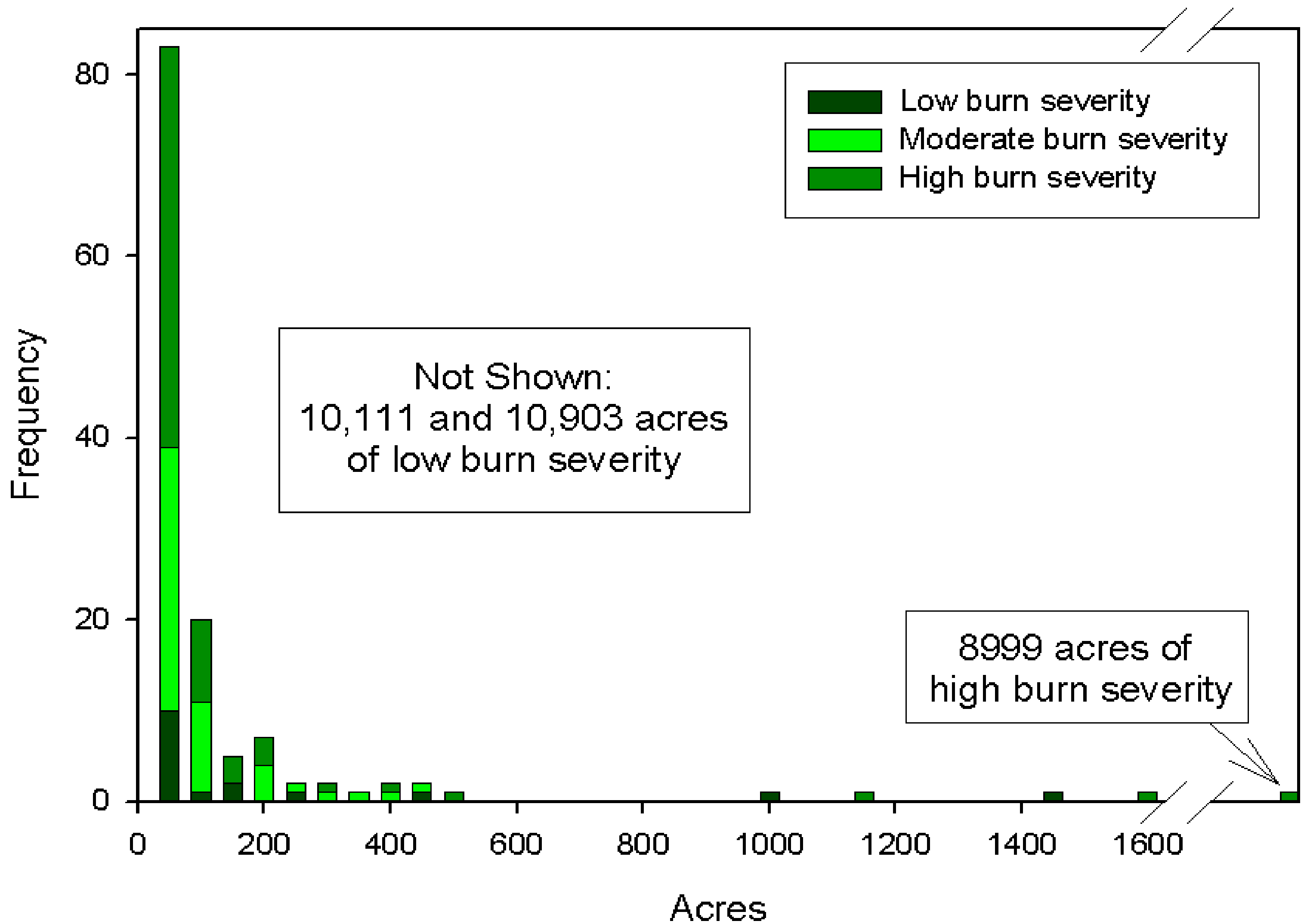

Figure E-1. Frequency histogram of burn severity polygons for the entire Cerro Grande Fire.

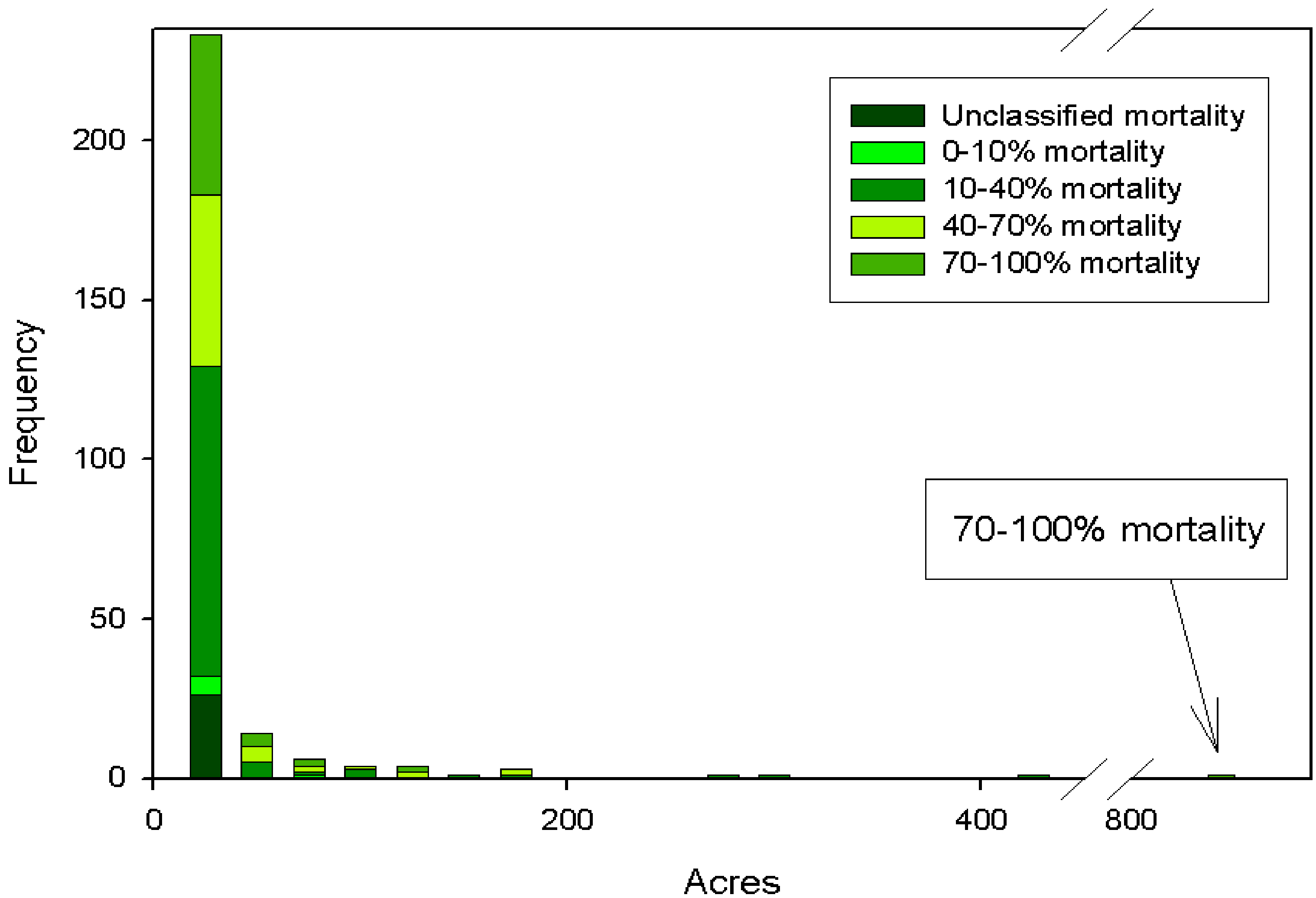

Figure E-2. Frequency histogram of fire intensity polygons for all areas classified by the BAER Team as piñon-juniper vegetation.

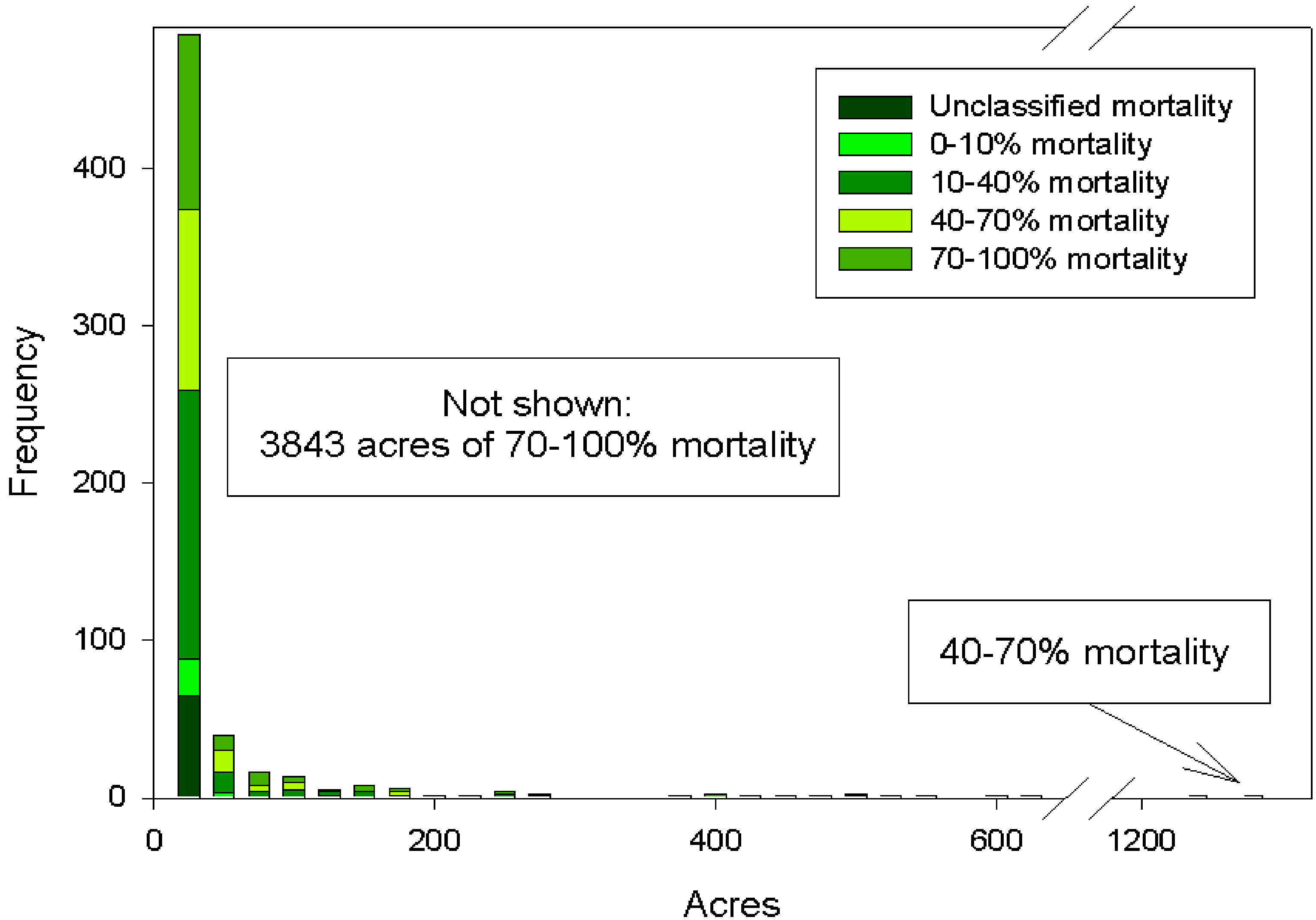

Figure E-3. Frequency histogram of fire intensity polygons for all areas classified by the BAER Team as ponderosa pine vegetation.

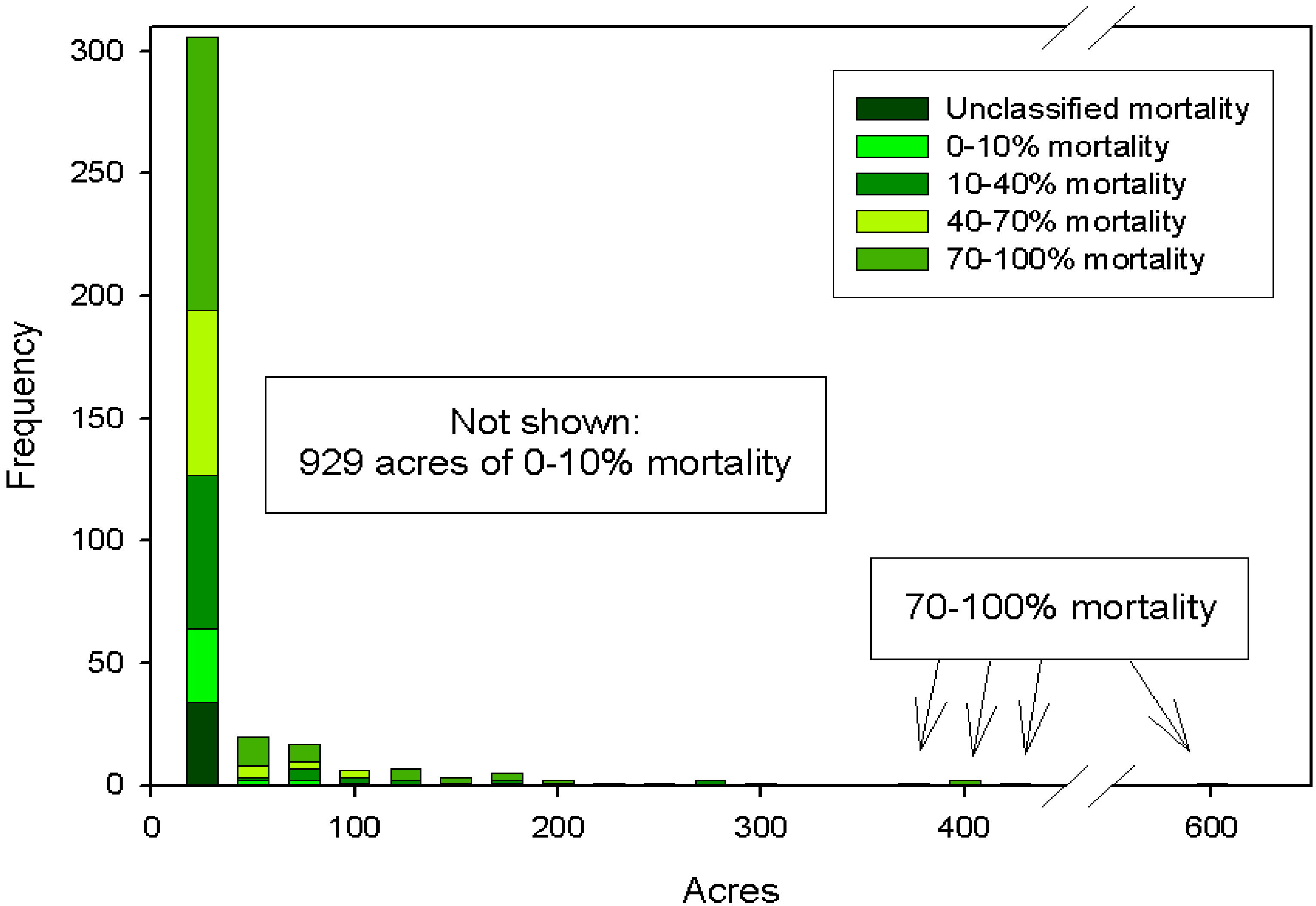

Figure E-4. Frequency histogram of fire intensity polygons for all areas classified by the BAER Team as mixed conifer or white fir vegetation.

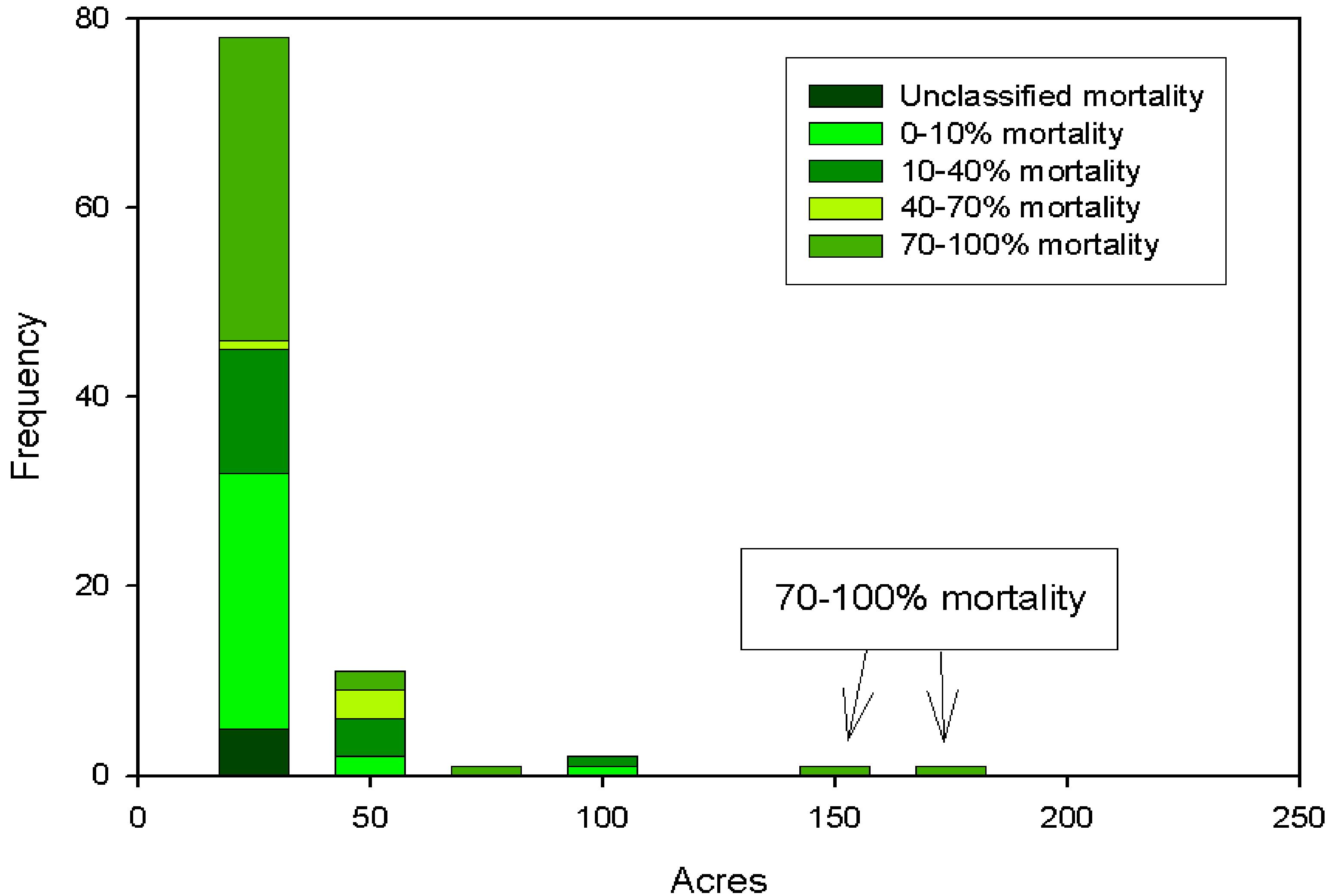

Figure E-5. Frequency histogram of fire intensity polygons for all areas classified by the BAER Team as aspen vegetation.

Appendix F:

Accuracy assessments of maps and spatial themes used in this project

Table F-1. Accuracy assessment for the burn severity map developed by the BAER Team (BAER 2000).

PREDICTION		ACTUAL: High	ACTUAL: Moderate	ACTUAL: Low	ACTUAL: Unburned	Prediction Totals	Prediction Error
	High	27	3	2	0	32	15.63%
	Moderate		3	2	0	5	40.00%
	Low	3	2	34	2	41	17.07%
	Unburned		1	3	10	14	28.57%
	Actual Totals	30	9	41	12	92	19.57%
	Actual Error	10.00%	66.67%	17.07%	16.67%	19.57%	

Table F-2. Accuracy assessment for the fire intensity map developed by the BAER Team (BAER 2000).

PREDICTION	ACTUAL					
	High	Moderate	Low	Unburned	**Prediction Totals**	**Prediction Error (%)**
High	29	1	1	0	31	3.23
Moderate	5	10	24	0	39	74.36
Low	0	0	8	0	8	0.00
Unburned	0	0	3	11	14	21.43
Actual Totals	34	11	36	11	92	36.96
Actual Error (%)	14.71	9.09	77.78	0.00	36.96	

Table F-3. Accuracy assessment for the land cover map developed for wildlife habitat management (Koch et al. 1997).

		ACTUAL							
		Aspen	Grassland	Juniper Woodland	Mixed Conifers	Piñon-Juniper	Ponderosa Pine	**Prediction Totals**	**Prediction Error**
PREDICTION	Aspen	9	1	0	0	0	0	10	10.00 %
	Grassland	2	8	0	0	1	0	11	27.27%
	Juniper Woodland	0	0	1	0	0	0	1	0.00 %
	Mixed Conifers	2	0	0	44	0	13	59	25.42 %
	Piñon-Juniper	0	2	0	0	8	3	13	38.46 %
	Ponderosa Pine	2	2	0	8	2	41	55	25.45 %
	Actual Totals	15	13	1	52	11	57	149	25.50 %
	Actual Error	40.0 %	38.46 %	0.00 %	15.38 %	27.27 %	28.07 %	25.50%	

Table F-4. Accuracy assessment for the land cover map developed for fuels risk assessments (Yool et al. 2000).

	ACTUAL							
PREDICTION	Aspen	Grassland	Mixed Conifers	Piñon-Juniper	Ponderosa Pine	Shrubland	**Prediction Totals**	**Prediction Error**
Aspen	10	0	3	0	0	0	13	23.08 %
Grassland	0	7	2	1	0	3	13	46.15 %
Mixed Conifers	0	1	39	0	5	0	45	13.33 %
Piñon-Juniper	0	4	0	10	3	3	20	50.00 %
Ponderosa Pine	0	1	8	0	49	6	64	23.44 %
Shrubland	0	0	0	0	0	1	1	0.00 %
Actual Totals	10	13	52	11	57	13	156	25.64 %
Actual Error	00.0 %	46.15 %	25.00 %	9.09 %	14.04 %	92.31%	25.64 %	

Table F-5. Accuracy assessment for the land cover map developed with the GENIE classification system (Brumby et al. 2002).

		ACTUAL							
		Aspen	Grassland	Mixed Conifers	Piñon-Juniper	Ponderosa Pine	Shrubland	**Prediction Totals**	**Prediction Error**
PREDICTION	Aspen	4	0	0	0	0	1	5	20.00%
	Grassland	0	1	0	0	0	0	1	0.00%
	Mixed Conifers	8	4	47	0	31	1	91	48.35%
	Piñon-Juniper	0	5	0	8	3	2	18	55.56%
	Ponderosa Pine	0	3	4	4	22	5	38	42.11%
	Shrubland	0	0	0	0	0	2	2	0.00%
	Actual Totals	12	13	51	12	56	11	155	45.81%
	Actual Error	66.67%	92.31%	7.84%	33.33%	60.71%	81.82%	45.81%	

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