National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Lava Beds National Monument

Natural Resource Condition Assessment

Natural Resource Report NPS/NRSS/WRD/NRR—2013/726

ON THE COVER
View from Schonchin Butte north of Tule Lake Basin
Courtesy of Lava Beds National Monument

Lava Beds National Monument

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Natural Resource Report NPS/NRSS/WRD/NRR—2013/726

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Publisher's Note: This report deviates from the standard report outline established by the National Park Service for this report series. See Prologue (p. xiii) for more information.

Executive Summary

To characterize the condition and trends in priority natural resources in Lava Beds National Monument, we compiled existing data and information. This report and the spatial datasets provided with it is intended to inform and support park managers and scientists in developing recommendations for improving or maintaining natural resource conditions in the park. It also can assist park resource managers in meeting the reporting requirements of the Government Performance Results Act and Office of Management and Budget.

In attempts to describe the current condition and trends for each of the park's natural resources of concern, we followed generally the Environmental Protection Agency's "Framework for Assessing and Reporting on Ecological Condition" (Young and Sanzone 2002). Specifically, we first identified seven natural resource themes considered by this park's managers and scientists to be most important. They are:

- Changes in Climate and Microclimate (including ice and groundwater)
- Changes in Cave Geologic Features
- Changes in Cave-dependent Species
- Changes in Vegetation
- Changes in Aboveground Wildlife
- Changes in Air Quality
- Changes in Natural Quality of the Park Experience

We identified 21 indicators to evaluate these seven resource concerns. For each indicator we then attempted to define reference conditions to which we could compare present conditions. Making that comparison, we described the condition of each indicator as "Good," "Somewhat Concerning," "Significant Concern," or "Indeterminate." We described the indicator's trend as "Improving," "Somewhat Concerning," "Significant Concern," or "Indeterminate." In each instance where we applied these terms, we also described (as high, moderate, or low) the certainty associated with our estimate. Where reference conditions that were the basis for our comparisons lacked quantitative standards, we based the assessment on qualitative descriptions of least-altered resource conditions derived from historical accounts, scientific literature, and professional opinion.

Applying the 21 indicators, we determined that the condition of four indicators is of *Significant Concern* in this park. Two -- the spread of cheatgrass and the decline of sagebrush cover -- are interrelated. The reduced frequency of fire in some parts of the park has created conditions that are at the extreme end of the natural age distribution for the park's vegetation types. This can restrict the park's ability to effectively support the region's wildlife and plant diversity. In addition, increasing threats from other invasive plants and the complete loss of persistent ice from three caves (and decline of ice in many others) are considered Significant Concerns.

The condition and/or trend of ten indicators is *Somewhat Concerning*:

- Damage to cave geologic features
- Increasing cover of juniper

- Decreasing cover of bunchgrasses
- Loss of diversity of native terrestrial wildlife species
- Impaired connectivity and extent of important terrestrial habitats
- High ozone concentrations
- Diminished visibility
- Long-term changes in aboveground temperature and precipitation

Managers have limited capacity to influence the condition of the last three. However, NPS has had some success working with policy makers and regulators to enforce stricter standards when park data indicated air quality problems resulting from local sources.

Information sufficient to estimate *trends* was lacking for 14 of the 21 indicators, and none were considered to have a high degree of certainty. Information sufficient to estimate present *condition* was lacking for 5 of the 21 indicators.

Acknowledgments

For their steadfast interest in this assessment and helpful suggestions, we thank Daniel Sarr (NPS, Klamath Network I&M Program's Supervisory Ecologist) and Marsha Davis (NPS Pacific West Regional Office). For their useful input during preparation of this assessment, from Lava Beds National Monument we thank David Larson, Nancy Nordensten, Shane Fryer, Shawn Thomas, and Jason Mateljak. Overall guidance was provided by the NPS Project Managers—initially David Larson from Lava Beds, succeeded by Mac Brock from Crater Lake National Park.

Prologue

Publisher's Note: This report is part of an ongoing series of natural resource condition assessments in national park units. As a point of clarification, this document does not follow the standard report outline that the National Park Service (NPS) has established for the series. However, the condition assessment methodologies and reporting details found in chapter 4—the "core section" of the report—do conform to NPS guidelines.

Publisher's Note: This report deviates from the standard report outline established by the National Park Service for this report series. See Prologue (p. xiii) for more information.

1.0 NRCA Background

What is the current condition of natural resources in our nation's national parks? How has that condition changed in recent years? What might be the actual and potential causes of current and future change? This report, prepared under a National Park Service (NPS) agreement with Southern Oregon University (SOU), attempts to address these questions as they pertain to Lava Beds National Monument.

Addressing these questions is essential to the mission of the NPS. Thus, the NPS in 2003 initiated overview assessments of each of 270-plus parks which NPS deemed to have significant natural resources and related values. Those assessments, termed "Natural Resource Condition Assessments" (NRCAs), focus on compiling and interpreting existing data, and are intended to complement Inventory and Monitoring (I&M) programs and other efforts that feature the collection of new data. Both programs complement and help support each park's development of a Resource Stewardship Strategy (RSS)[1], which focuses instead on management targets and provides guidance on how to respond to and manage threats. NRCAs rely significantly on review and syntheses of existing data and maps, as contrasted with the NPS Vital Signs Program which mainly features the collection of new field data.

NRCAs evaluate current conditions for a subset of natural resources and resource indicators. NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue- and threat-based resource assessments. As distinguishing characteristics, NRCAs:

- are multi-disciplinary in scope;[2]
- employ hierarchical indicator frameworks;[3]
- identify or develop reference conditions/values for comparison against current conditions;[4]

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[1] formerly called a Resource Management Plan (RMP).

[2] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[3] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[4] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g., ecological thresholds or management "triggers").

- emphasize spatial evaluation of conditions and GIS (map) products;[5]
- summarize key findings by park areas; and[6]
- follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs are not required to report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. NRCAs can yield new insights about current park resource conditions but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision-making, planning, and partnership activities.

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[7] and help parks to report on government

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[5] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[6] In addition to reporting on indicator-level conditions, NRCAs attempt to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

[7] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

accountability measures.[8] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts. For more information on the NRCA program, visit http://nature.nps.gov/water/nrca/index.cfm

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[8] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of “resource condition status” reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

2.0 Introduction and Resource Setting

Lava Beds National Monument was established in 1925 by the presidential proclamation of President Calvin Coolidge. The unique landscape was set aside to protect and interpret volcanic and natural features of scientific interest, and evidence of prehistoric and historic human settlement, use, and conflict.

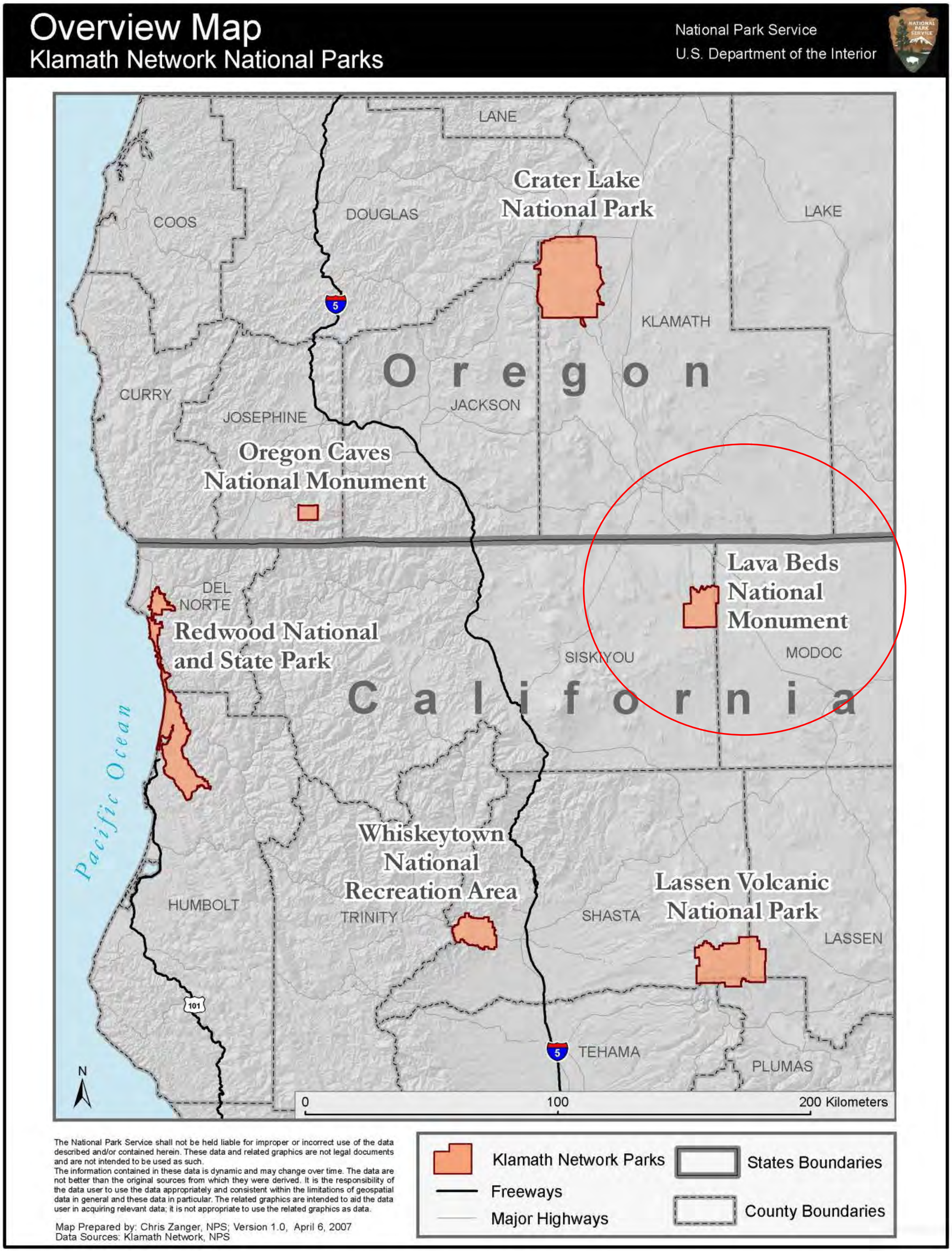
The 46,560 acre monument is located in northeastern California, approximately 155 miles northeast of Redding and 50 miles southeast of Klamath Falls, Oregon. Ninety-four percent of the monument lies within Siskiyou County in the 2nd Congressional District. The remaining six percent is in Modoc County in the 4th Congressional District. The monument boundary is bordered by Modoc National Forest, Klamath National Forest, the Lower Klamath Basin National Wildlife Refuges (Tulelake Refuge), Bureau of Reclamation land, and Bureau of Land Management land, as well as private lands.

The monument contains some of the most extensive and least impacted lava tube caves in the western United States (Figures 1-3). Regulated public access is allowed to about 22 of the monument's 700+ caves, and these are easily accessible from trails, roads, picnic areas, and off-trail areas. Many of the other caves are in remote, isolated areas and are not well known to the general public. The majority of the monument's primary visitor sites contain non-renewable geologic features. These include Fleener Chimneys, Black Crater, Petroglyph Point, Schonchin Butte, and Captain Jack's Stronghold. The monument is also distinctive because it occurs at the junction of the Sierra-Nevada, Cascade, and Great Basin geologic provinces. The monument contains a range of Great Basin vegetation communities, including ponderosa pine forest, mountain mahogany/juniper community, and Great Basin sagebrush/bunchgrass steppe community.

The monument also incorporates a portion of the Medicine Lake shield volcano, a 900-square-mile highland created by various types of volcanic eruptions. Over the last half-million years, eruptions on the Medicine Lake shield volcano have created a rugged wilderness landscape dotted with diverse volcanic features. These volcanic features, and the resultant habitats formed across the monument, encompass the significant natural resources the monument protects and manages:

- the largest concentration of lava tube caves in the contiguous U.S., along with unique environments and cave-dependent species,
- outstanding, diverse, abundant, and well preserved lava flows, cinder cones, spatter cones, maar volcanoes, and other volcanic features associated with the Medicine Lake shield volcano,
- wilderness in the unique volcanic landscape of the Great Basin and Cascade ecosystems, and
- native plant and animal species, their habitats, and the processes (such as fire) representative of the transition zone for Great Basin and Cascade ecosystems.

The effects of environmental degradation outside the monument (e.g., air pollution) undoubtedly extend into the monument. Conversely, significant benefits from the monument extend beyond the monument's boundaries. These include being a likely source area and refugium for local and regional populations of terrestrial animals, recharging groundwater that is important to high-volume irrigation wells just outside the monument's borders (Martin 2007), and helping support the local tourism economy. The monument supports a number of wildlife species that are rare or declining regionally or locally, as well as over 280 plant species and a relatively intact bunchgrass community.



Map Prepared by: Chris Zanger, NPS; Version 1.0, April 6, 2007
Data Sources: Klamath Network, NPS

Figure 1. Location map for Lava Beds National Monument.

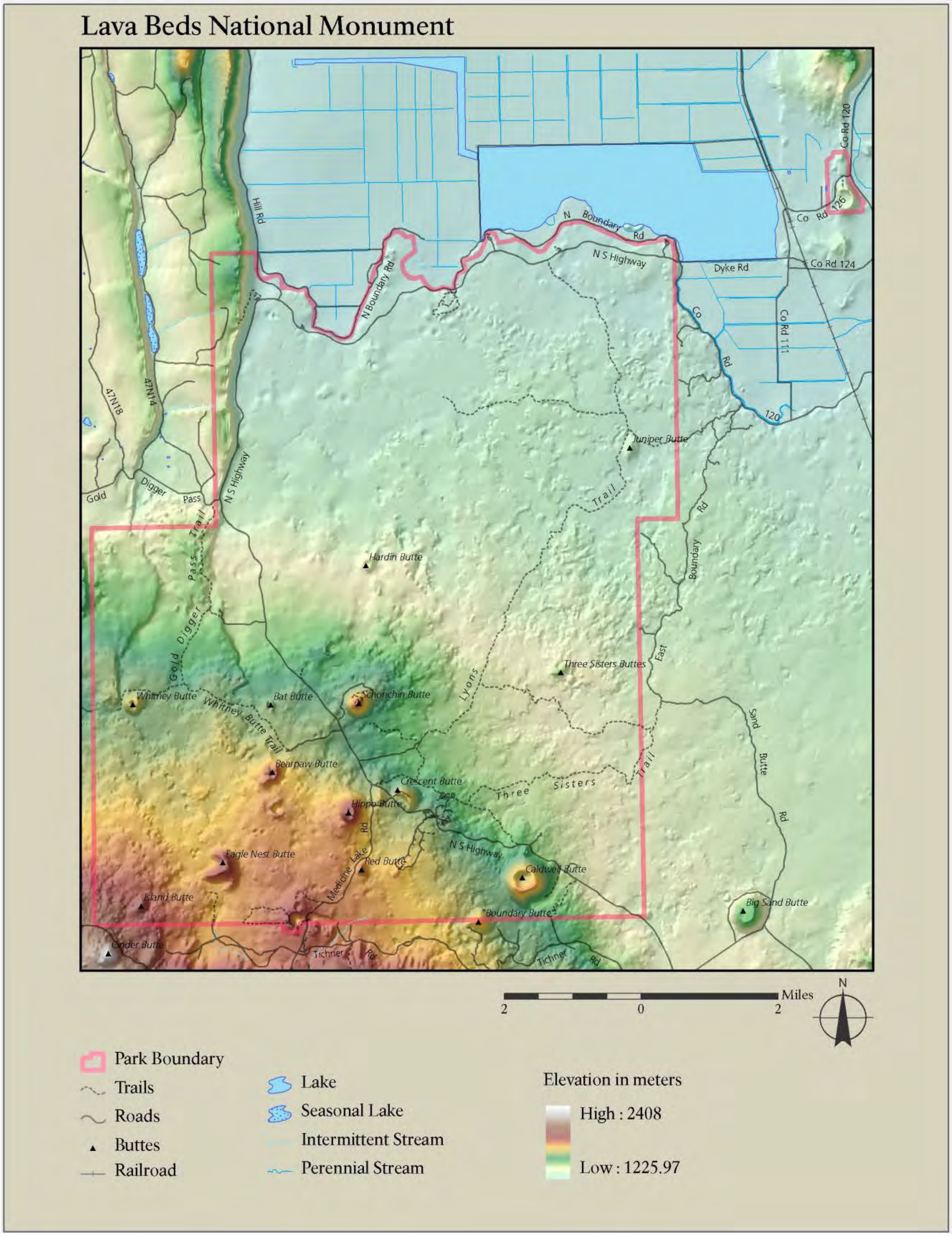


Figure 2. Base map for Lava Beds National Monument.

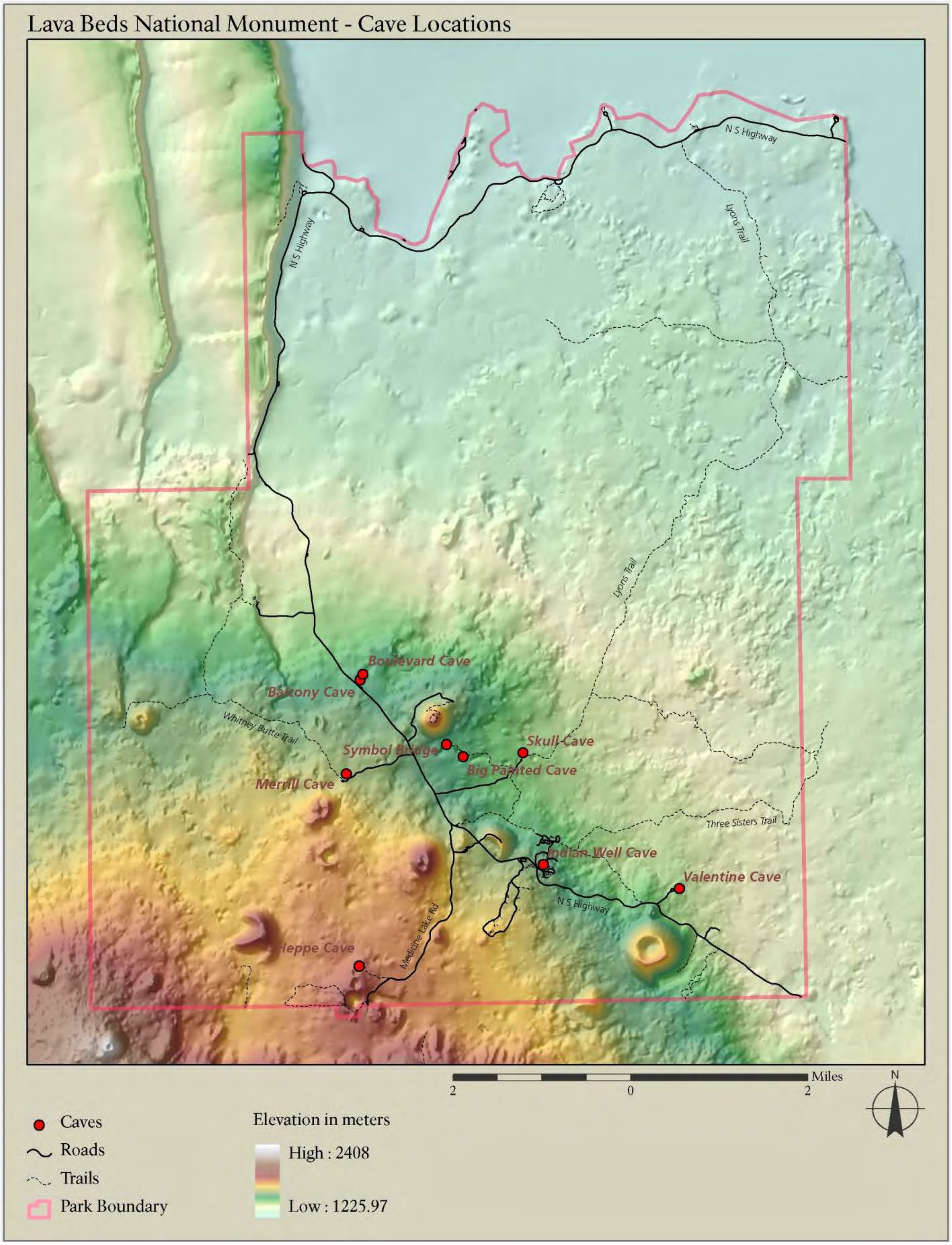


Figure 3. Locations of major visitor-accessible caves at Lava Beds National Monument.

3.0 Study Scoping, Design, and Implementation

3.1 Project Responsibilities

Co-investigators for this project were Dr. Greg Jones, climatologist, Southern Oregon University, and Dr. Paul Adamus, ecologist, Oregon State University. Dr. Jones administered the agreement and analyzed climatological data (section 2.1). Sections 2.2 (Cave Geologic Features) and 2.3 (Cave-dependent Species) were prepared mainly by Jean Krejca and other staff at Zara Environmental, LLC. Section 2.4 of this report (Vegetation) was written by Dennis Odion, Southern Oregon University. The rest of this report was written by Paul Adamus, who also served as overall editor. Spatial data were compiled and analyzed by Ryan Reid and Lorin Groshong (GIS specialists, Southern Oregon University) with substantial input from other members of the project team.

3.2 Preliminary Scoping, Framework and Information Gathering

This assessment is one of three NRCAs prepared under a single agreement with Southern Oregon University. The others pertain to Lassen Volcanic National Park (LAVO) and Crater Lake National Park (CRLA). The assessments began in October 2010 with a scoping workshop that included the SOU study team, most members of the NPS Project Oversight Committee[9], and other scientists from the three parks being assessed. Held at the monument headquarters near Tulelake, California, the session began with a background description of the NRCA process presented by Marsha Davis from the NPS Pacific West Regional Office, followed by presentations by the project co-principal investigators and others, and a group discussion focusing on project frameworks and strategy. Information gathering then began as the study team spent the remainder of the day conferring with several of the natural resource scientists at Lava Beds.

Natural resource issues at the monument had recently been prioritized by the monument's staff, using a structured input process, and that was a great help in focusing our efforts. In no particular order, the 19 "focal themes" that were ranked highest (3 on a scale of 0 to 3) from a list of 56 themes considered potentially applicable to the three Klamath Network parks that are the subject of this SOU agreement were:

- Cave processes
- Cave features
- Cave entrance ecology
- Cave flora and fauna
- Bats
- Ice monitoring
- Geologic resources and features

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[9] From the monument: David Larson (formerly, Chief of Resources and NRCA Project Manager), Jason Mateljak (Resource Management Specialist), Shane Fryer (Physical Scientist). From CRLA: Mac Brock (Chief of Resources), Jeff Runde (Resource Management Specialist and Data Manager), Chris Wayne (GIS Specialist). From Lassen: Louise Johnson (formerly, Chief of Resources), Nancy Nordensten (formerly, Resource Management Specialist; Biologist), Janet Coles (Plant Ecologist). From Pacific West Regional Office: Marsha Davis (Geologist).

- Areas of focal species
- Habitat for focal species
- Fire regimes
- Fire suppression and fuels management
- Invasive species (plants)
- Solitude and silence
- Recreation
- Road and trail development
- Social trails
- Wilderness
- Dark night sky
- Global warming

In addition, indicators of natural resource condition had recently been identified through the Klamath Network's Vital Signs planning process. Some of that information was used to target indicators pertinent to our NRCA effort.

Subsequently, all relevant documents from the parks were identified. This task was made easier by the Klamath Network having recently completed a "data mining" report. That report was accompanied by a bibliographic database of nearly all published and unpublished documents and maps for these parks, up to about 2007. We augmented that using online search engines (Web of Science, Google Scholar) to identify newer publications from the three parks, as well as relevant documents pertaining to the regions surrounding these parks, searching with phrases such as Southern Cascades. We obtained complete digital copies (PDFs) of many publications that reported relevant research results from the monument and surrounding region. We then indexed all digital documents in an Excel spreadsheet so they could be sorted by topic and year. The database and all the digital documents, as well as spatial data layers, were placed on a server computer at SOU that was accessible to the project team throughout this project.

We reviewed and considered several frameworks for organizing our NRCA effort. We decided to follow generally the Environmental Protection Agency's "Framework for Assessing and Reporting on Ecological Condition" (Young and Sanzone 2002). Specifically, for each priority resource we identified multiple *indicators* of resource condition and defined reference conditions that could be used as a basis for assessing these. An ecological indicator is any measurable attribute that provides insights into the state of the environment and provides information beyond its own measurement (Noon 2003). Indicators are usually surrogates for properties or system responses that are too difficult or costly to measure directly (Leibowitz et al. 1999). Indicators differ from estimators in that functional relationships between the indicator and the various ecological attributes are generally unknown (McKelvey and Pearson 2001). Not all indicators are equally informative—one of the key challenges of an NRCA is to select those attributes whose values (or trends) provide insights into ecological integrity at the scale of the ecosystem.

In developing the list of indicators and specific measures, we considered some basic criteria for useful ecological indicators as provided by Harwell et al. (1999). "Useful indicators need to be understandable to multiple audiences, including scientists, policy makers, managers and the public; they need to show status and/or condition over time; and there should be a clear, transparent scientific basis for the assigned condition." Indicators need to be based on probability distributions whenever possible to capture the natural range of variation in conditions, and we have attempted to do that whenever possible. We evaluated the indicators we chose by assigning qualitative descriptors as follows:

Condition: Good, Somewhat Concerning, Significant Concern, or Indeterminate.

Trend: Improving, Somewhat Concerning, Significant Concern, or Indeterminate.

Certainty: High, Medium, or Low.

We defined these terms in the context of each specific resource or issue we evaluated. Most indicators were assessed at the park scale, although connections to regional conditions were noted where supported by previously published analyses. The maps prepared for this assessment potentially reveal differences in resources at a finer scale, i.e., within the monument. Some of the spatial data were also compiled in tables organized by the monument's four major habitat types. Those types ("analysis units") are shown in Figure 4.

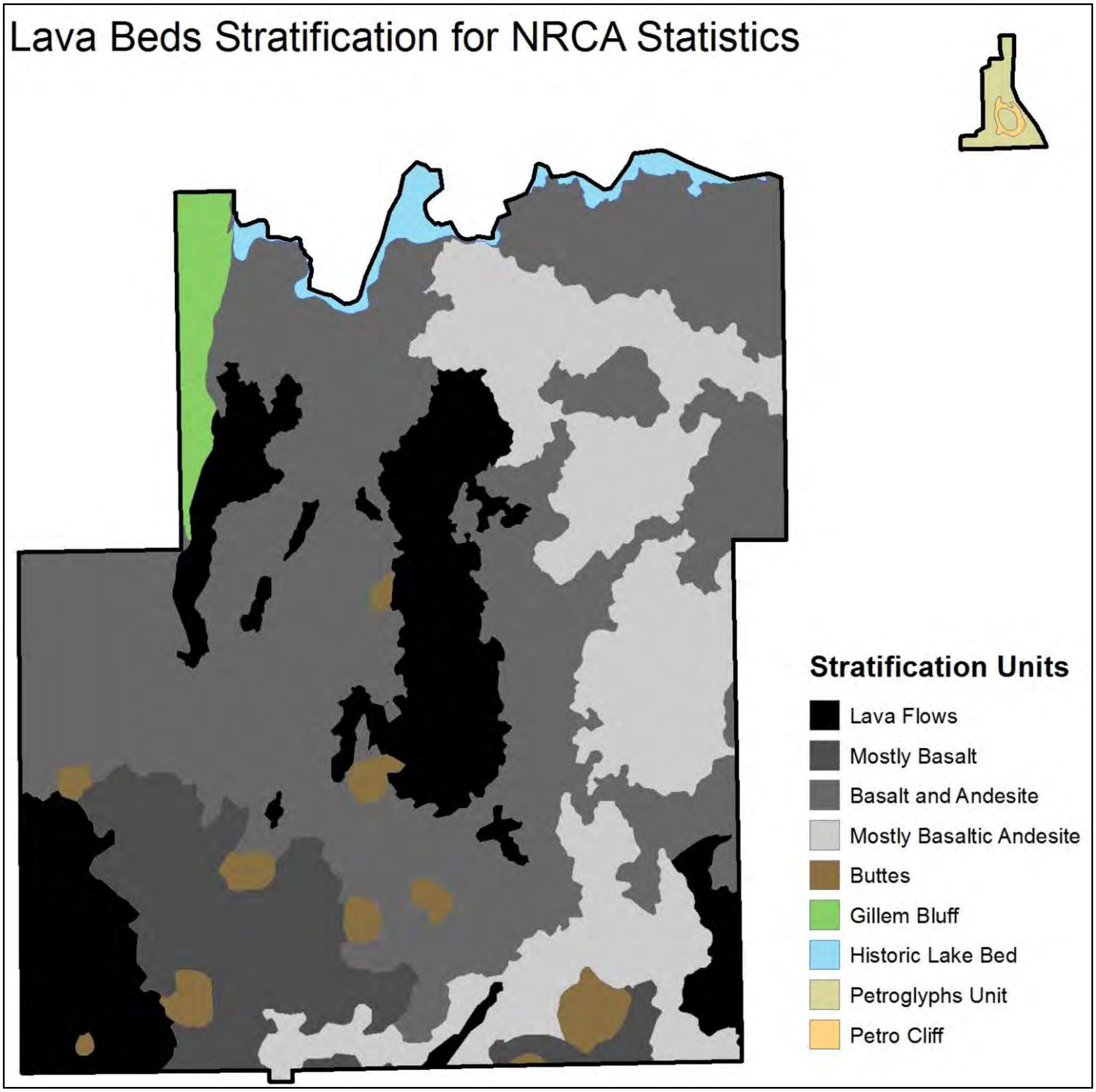

Figure 4. Analysis units used for this report.

4.0 Natural Resource Conditions

According to monument staff, the greatest concerns regarding the natural resources at Lava Beds are currently:

1. Changes in climate and microclimate
2. Changes in cave geologic features
3. Changes in cave-dependent species
4. Changes in vegetation
5. Changes in aboveground wildlife
6. Changes in air quality
7. Changes in the natural quality of the park experience

Each of these concerns is described in this chapter using the following structure:

- Background
- Regional Context
- Issue Description
- Indicators and Criteria to Evaluate Condition and Trends:
    - Criteria
    - Condition and Trends
    - Assessment Confidence and Data Gaps

Higher priority was assigned to data that were collected (a) for indicators that are anticipated to be most sensitive to the priority resource issues, and/or (b) according to a standardized protocol, and/or (c) from multiple years (the farther apart the better), and/or (d) from many locations within the monument.

4.1 Changes in Climate and Microclimate (Ice, Groundwater)

4.1.1 Background

Climate change has the potential to affect all of the monument's ecosystems, including the microclimate within its key feature, the lava caves. Microclimate refers primarily to the temperature and humidity of air, and its variation at a more localized spatial scale.

Temperature partly determines which species occur in a park, as well as controlling many biological, chemical, and physical processes such as ice formation in caves. Precipitation also influences species that are present, as well as geologic erosion, groundwater levels, and humidity within caves, pollutant transport, and fire risk.

Long-term precipitation and aboveground temperature averages for this park are shown in Appendix A. Located in the desert interior, the monument receives far less precipitation than the other Klamath Network parks. Most precipitation occurs in winter, with a secondary peak in late spring. Snowfall accumulations are usually apparent only in January and February. Within the monument, climate gradients on the land surface are gradual, with the coolest temperatures at higher elevations, and the warmest at lower elevations. Minimum temperatures in most months are lower in the northern part of the monument. The monument is located on the edge of the Tule Lake Basin, and that feature acts as a cold air pool, drawing cooler air from surrounding mountains. The southern part of the monument is slightly wetter than the rest because of the rain-intercepting effect of the Medicine Lake shield volcano.

4.1.2 Regional Context

Normally, areas closer to the ocean are at somewhat less risk of major temperature shifts because of the ocean's moderating effect on temperature. They also tend to receive more precipitation. Although this monument is relatively close to the Pacific Ocean (125 miles), its higher elevation and physiographic setting ("rain shadow" effect to the west) reduce the ocean's climate-moderating effects, thus making the monument's ecosystems more vulnerable to climate change.

4.1.3 Issue Description

4.1.3.1 Historical Climate Change

In western North America generally, during the twentieth century the winter and spring temperatures increased (Mote et al. 2005). The rate of change varied by location, but generally a warming of 1°C occurred from 1916 to 2003 (Hamlet et al. 2007). The rate of temperature increase from 1947 to 2003 was roughly double that averaged for the entire period from 1916 to 2003. This was largely attributable to the fact that much of the observed warming occurred from 1975 to 2003. Regionally averaged spring and summer temperatures for 1987 to 2003 were 0.87°C higher than those for 1970 to 1986, and spring and summer temperatures for 1987 to 2003 were the warmest since the beginning of the record in 1895 (Westerling et al. 2006). The largest warming trends have occurred in January-March (Hamlet and Lettenmaier 2007).

4.1.3.2 Future Climate Change

For the western U.S., simulations of future climate indicate that average temperatures will likely increase in both winter and summer (Giorgi et al. 2001). The average warming rate in the Pacific Northwest during the next ~50 years is expected to be in the range of 0.1-0.6°C per decade, with a best estimate of 0.3°C per decade. For comparison, observed warming in the second half of the twentieth century was approximately 0.2°C per decade (Mote et al. 2008). Less certainty is associated with projected changes in regional precipitation than those for temperature. Climate projections for the Klamath Region as a whole (Barr et al. 2010) are shown in Table 1.

Table 1. The range of projected changes to the climate (including temperature and precipitation) and ecology (dominant vegetation types, fire regime) of the Klamath Basin from three global climate models and a vegetation model. Baseline conditions are based on data from 1961-1990. Snowpack projections are based on results from supporting studies (Hayhoe et al. 2004; Goodstein and Matson 2004).

Projected Average Annual and Seasonal Temperature Increase from Baseline		
	2035 - 2045	2075 - 2085
Annual June – August December – February	+2.1 to +3.6° F (+1.1 to +2.0° C) +2.2 to +4.8° F (+1.2 to 2.7° C) +1.7 to +3.6° F (+1.0 to 2.0° C)	+4.6 to +7.2° F (+2.5 to +4.6° C) +5.8 to +11.8° F (+3.2 to +6.6° C) +3.8 to +6.5° F (+2.1 to +3.6° C)
Projected Average Annual and Seasonal Change in Precipitation from Baseline		
Annual June – August December - February	-0.27 to +0.07 inch (-9 to +2 %) -0.16 to +0.11 inch (-15 to -23 %) +0.06 to +0.57 inch (+1 to +10 %)	-0.33 to +0.74 inch (-11 to +24 %) -0.25 to +1.00 inch (-37 to -3 %) -0.28 to +1.59 inch (-5 to +27 %)
Projected Percent Change in Area Burned on Annual Basis Compared to Baseline		
Area Burned	+13 to 18%	+11 to 22%
Projected Change in Vegetation Growing Conditions from Baseline		
Vegetation Growing Conditions	Complete loss of subalpine. Partial loss of maritime conifer (Douglas-fir and spruce). Expansion of oak and madrone.	Partial to complete loss of maritime conifer Expansion of oak and madrone. Possible replacement of sagebrush and juniper with grasslands.
Projected Change in Snowpack from Baseline		
Snowpack	Loss of 37 to 65%	Loss of 73 to 90%

Estimates from Hayhoe et al. (2004) are from the Sierra Nevada range and estimates from Goodstein and Matson (2004) are for Oregon and Washington, including the Klamath region.

4.1.3.3 Ice Formation in Lava Tube Caves

Ice forms in the lava tube caves when precipitation seeps into the ground, infiltrates downward into the caves, and accumulates and freezes there. If the water did not freeze in the caves, it would likely freeze at some lower stratum or infiltrate all the way to the regional water table, at 4010 ft elevation above mean sea level (msl) (Martin 2007). Although this is several hundred feet below the lowest cave floor elevation of many of the caves (Hyatt 1965), the floors of some of the caves in the northern part of the monument are at a lower elevation, and could be within less than 100 feet of the groundwater if the water table roughly parallels the land (or cave bottom) surface. This is a potential concern because a drop in groundwater levels in the park and in some surrounding areas has been reported (see below).

Erosion or loss of perennial ice formations might also occur as a result of changing climatic conditions and could be accelerated by cave visitation. Airflow and changing ventilation patterns due to rock fall from seismic activity could have significantly affected the ice in Merrill Cave, for example (Fuhrmann

2007). Also, visitors throwing rocks at ice edges and/or otherwise dislodging ice has been observed there.

In general, factors that may influence ice formation and melting include anything that could change airflow patterns such as any structures at cave entrances or even within caves, including gates, platforms, stairs, or dirt mounds. Structures over caves may fill tiny entrances (not necessarily passable by humans) that provide airflow. Clearly climate change could impact ice levels via changes in rainfall, humidity, wind, or temperature. Heat from human visitation could increase the temperature inside a cave and lead to melting temperatures for ice. Human contact with ice such as walking on it or running a hand along it would also erode an ice deposit and cause wear and degradation.

4.1.3.4 Groundwater Levels

The monument is in the Tule Lake Groundwater Subbasin, as defined by the California Department of Water Resources. The headquarters area is the only area of the monument with a public water supply system. A water supply well located there supplies water for the visitor center, campground, park offices, and employee housing.

The USGS has monitored groundwater levels at least quarterly since 2001 at four locations within the monument as part of a regional study. The USGS reports that the water levels in wells in the monument declined an average of 1.5 to 2 feet per year from late 2001 to spring 2005. Plots of data covering the period since 2005 area were available only for the monument's Petroglyph Point monitoring well, and appear to show a declining trend since at least 2003.

Outside the monument, there was a decline of 5-10 feet in the water table in the Panhandle and Copic Bay areas adjacent to the northeast corner of the monument from 2001 to 2005 (Gannett et al. 2007). However, many of the shallow wells in the Tule Lake Groundwater Subbasin outside of the monument experienced no water level decline during this same period, perhaps because they alone were benefitting from infiltrated irrigation water. The water table declines coincided with a dramatic increase in groundwater pumping in the Tule Lake Groundwater Subbasin outside of the monument (Martin 2007). The increased pumping was initiated largely due to a negotiated agreement between various agencies and stakeholders to substitute groundwater for surface water for irrigation in the basin and to use groundwater to augment surface water supplies to meet the needs of endangered fish species in waters outside the monument. Acute water table declines have been measured in the Subbasin in direct response to pumping for a lateral distance of hundreds to thousands of feet from active well pumps, but water table recovery generally occurs soon after pumps are turned off (Gannett et al. 2010). In this Subbasin, pumping from wells within a few miles of groundwater-discharge features, such as springs and drains, can affect those features within weeks or months of the onset of pumping, and the impacts can be fully manifest in several years (Gannett et al. 2012).

Water table declines measured by the USGS began the same year (2002) as a severe local drought began, which lasted through that year and was followed by drier than normal conditions that persisted into the early part of 2005 (Gannett et al. 2010). Long-term groundwater-level data from near the town of Tulelake showed the rate of the year-to-year decline observed during the drought was about twice that observed in the most recent previous drought, which occurred from the late 1980s through mid-1990s. The total decline between 2001 and 2004 exceeded 15 feet in some parts of the region surrounding the monument, and is larger than can be attributed to drought alone. The year-to-year decline was accompanied by amplified seasonal declines. Some increase occurred thereafter; see Gannett et al.

(2010) for details. How long (if ever) it will take water levels to fully return to previous levels after wet climate conditions return and pumping stress is reduced is not known (Gannett et al. 2010).

Although the USGS studies did not focus specifically on groundwater quality, some degradation of groundwater quality has occurred in the northern part of the monument, partly as a result of infiltration of salt-laden surface water from the Tule Lake Sump, the large water body northeast of the monument (Martin 2007).

The monument is within a region of geothermal heat flow that is great enough to be of economic interest for its potential to generate power. The Glass Mountain Known Geothermal Resource Area (KGRA) is located adjacent to the monument to the south. The KGRA allows competitive lease sales for geothermal exploration. In the past there has been exploratory drilling for geothermal resources between the Medicine Lake area and the monument's southern boundary. These activities are unlikely to have directly impacted the monument's groundwater levels because of their distance from the monument as well as the depth of the wells (much deeper than the monument's caves) and the intervening geologic conditions (Martin 2007). However, future geothermal developments could impact the monument's cave microclimates indirectly if they intercept shallow groundwater for cooling or other purposes.

4.1.4 Indicators and Criteria to Evaluate Condition and Trends

Although little or nothing can be done within the monument to address the problem of global or regional climate change, improved knowledge of current conditions and anticipated changes can help resource planning efforts. Indicators that would inform this issue might include the condition and trends of the following:

1. Aboveground precipitation and temperature
2. Cave microclimate
3. Cave ice formation and persistence

Each of these is now discussed.

4.1.4.1 Aboveground Precipitation and Temperature

Aboveground precipitation and temperature influence the microclimate and ice formation within the monument's caves, as well as influencing strongly the monument's terrestrial wildlife and vegetation. Locations of various types of weather instruments in or near the monument were mapped and described in Davey et al. (2007) and Daly et al. (2009). Those with the longest consistent record are Lava Beds NM (4770 ft elevation, in the center of the monument) and Tulelake (4035 ft, about 12 miles north of the monument). The Lava Beds NM station is not entirely representative of the monument because most of the monument is at somewhat lower elevation. Most of the monument would be expected to have lower minimum temperatures due to closer connection with the Tule Lake Basin cold air pool.

Criteria

A rating of "Good" would describe a condition where the amount and seasonal timing of precipitation is at or above the average historical condition in all parts of the monument. "Somewhat Concerning" conditions would be defined as an amount and timing that are less than necessary to sustain the monument's ecosystems—directly or indirectly—close to their present state. "Significant Concern" conditions would be an amount and timing that are less than necessary to sustain the monument's ecosystems close to their historical (pre-settlement) long-term condition.

Condition and Trends
Condition: *Indeterminate*.
Trends: *Somewhat Concerning – Medium Certainty*.

Trends in precipitation and temperature are somewhat concerning. We analyzed and identified the following statistically significant trends based on data from monument headquarters (1959 through 2011) except where noted as Tulelake (1932-2011 data):

- warmer annual maximum temperatures
- warmer minimum high temperatures
- fewer days per year with extremely low maximum temperatures
- more days per year with extremely hot temperatures
- fewer days per year with extremely low minimum temperatures (Tulelake)
- fewer days where the maximum temperature was below freezing
- longer warm spells
- shorter cold spells (Tulelake)
- greater diurnal temperature range
- longer wet periods (Tulelake)

In addition, Daly et al. (2009) computed trends in temperature and precipitation at monument headquarters *for each month*, and for two periods: 1895–2007 and 1971–2007 (see Appendix A). *For annual precipitation, they found very little overall trend* over the century. Precipitation was relatively high in the early part of the century, then fell to a minimum in the 1920s and '30s. Precipitation varied little from year to year until the 1970s, when a cyclical pattern began, with maxima in the mid-1980s and late 1990s. They found *temperatures have been rising significantly, and more strongly, in the last 30 years than in the past century*. Specifically, and over the 1895–2007 period, the average maximum temperatures show significant increases in January and September and decreases in November. Over the 1971–2007 period, maximum temperatures increased significantly in March, July, and annually. Trends were generally similar between the headquarters readings and those from Tulelake, though levels of statistical significance often differed.

Assessment Confidence and Data Gaps
Medium Certainty. Consistently-measured surface temperature and precipitation data covering a relatively long period are available from only one location within the monument (headquarters). If additional weather stations were established at higher and lower elevations within the monument and spaced well apart, they could yield data essential to understanding cave ice formation and processes important to the monument's ecosystems.

4.1.4.2 Cave Microclimate

The microclimate within the monument's caves may be influenced both by the land above and the groundwater below, though the relative contribution of these influences is unmeasured in the monument. Climate in caves is distinctly different from the aboveground climate, and its uniqueness is essential to supporting similarly unique assemblages of cave-dwelling animals and plants (see section 4.3 for more on cave dependent species).

Although there is considerable variation among and within caves, humidity inside caves is often greater than on the land surface at equivalent temperatures. Direct precipitation, ultraviolet radiation, and strong winds are of course absent. Temperatures in caves are cooler in summer and warmer in winter relative to surface temperatures. Temperature and humidity vary much less than on the surface—diurnally, daily, and annually—and temporal variation is least in the most interior portions of caves. Despite being much more muted, cave temperatures follow seasonal and annual patterns that generally parallel those on the surface, with some lags. The similarity between a particular cave's microclimate and land surface conditions is generally greater the closer the cave is to the land surface. With regard to their microclimate differences, caves in this park are classified as being deeper or shallower than 30 ft (Arnold 1993).

Microclimate averages and variances change significantly according to distance into cave, depth below the subsurface, and according to the presence of features such as constrictions, multiple entrances, low spots in the passage that serve as cold traps, domes that serve as warm traps, or ice deposits. Microclimate in caves is typically measured in degrees of air temperature and percentage air humidity, but can also include speed of airflow in a given size passage or volume of airflow that passes a point per unit time, surface temperature of walls or ceilings, and water temperature. Air currents in caves are greater when there are large differences in air density in and out of the cave, and among caves that have multiple entrances on different levels. To a lesser extent, air currents within a cave may increase when outside conditions are windy or dry for long periods. In smaller, shallow caves, temperatures can be influenced by shade as determined by the north-south orientation of the entrance and perhaps by large differences in ground cover above the cave or near its entrance. Cave microclimates can be changed by natural events (e.g., rockfall blocking off internal or external passages) as well as by human activities such as building of structures in cave entrances, or by connecting or blocking internal or external passages or entrances.

Criteria

Temperature and humidity levels in caves located outside the monument cannot validly be used as a basis for setting expectations for the monument's caves because of differences in geology, morphology, and regional climate. There are no suitably analogous caves to define acceptable conditions, nor are there biological data that link cave flora and fauna to a particular humidity and temperature regime. Thus, "Good" condition would be represented by humidity and temperatures that are close to the average historical condition in each of the monument's caves. "Somewhat Concerning" and "Significant Concern" conditions would be defined by the degree of deviation from those conditions.

Condition and Trends

Condition: *Indeterminate*.
Trends: *Indeterminate – Indeterminate Certainty*.

Although humidity and temperature have been measured for varying lengths of time in some of the monument's caves, valid comparisons between years using existing data are not possible because no network of caves has been monitored consistently for many years continuously. Also, the extent to which microclimate conditions and trends in one or a few caves can be extrapolated to others in the monument is unknown. Even within a single cave, the degree to which a temperature unit's data are representative of conditions in that cave generally is unknown, and likely varies diurnally, by season, and by cave depth and morphology. Moreover, even if a good record existed of every cave's temperature and humidity, the exact conditions needed to sustain a cave's entire flora and fauna are unknown.

Assessment Confidence and Data Gaps

Low Certainty. The power to detect trends in microclimate increases with increasing numbers of temperature loggers deployed and with increasing duration of monitoring. To have 80% power to detect a 2% change in average annual temperature (of the middle zone of a cave), about 12 years of data might be needed (Krejca et al. 2010). Data from thermal loggers are less reliable at the higher humidity levels (e.g. above 95%) that sometimes are present in some of the monument's caves. Also, temperature and humidity readings tend to 'drift' with time, necessitating frequent calibration and 'resting' of the meters in a low humidity environment. Data loggers must be placed in exactly the same spot in a cave during all years (Krejca et al. 2010).

4.1.4.3 Cave Ice Formation and Persistence

The monument has documented 700+ lava tube caves with over 30 miles of known passageways. Of these caves, an estimated 35 contain ice during most years. Ice occurs in many forms, including small pockets, stalactite/stalagmite forms, and large blocks that fill entire rooms.

Caves with perennial ice have a distinctly different microclimate than those without. Ice maintains cooler summer temperatures and greater and less-variable cave humidity. Ice floors act as temperature buffers, so when ice extent declines, air temperatures within a cave fluctuate over a broader range. Compared to other caves, the caves with perennial ice have microclimates that are even more different from surface conditions than are those of other lava tube caves. This might aid the persistence of some characteristic cave-dependent species that use these caves, although among the monument's caves, the presence of bat hibernacula does not correlate with occurrence of perennial ice (Shawn Thomas, pers. comm.). Because there are no streams, ponds, springs, or wetlands in the entire monument, the ice deposits nearest the entrances of the caves are a localized source of water for a few wildlife species in this monument's semiarid landscape.

The exact mechanisms of ice formation within the monument's caves are not well understood. However, several theories are described by Hyatt (1965) and summarized here. One theory is based on air displacement: the coldest winter air sinks into downward-sloping caves and displaces any warmer air that may be present in caves, and the cold air is trapped causing the persistence of cave ice with minimal summer air circulation. Another theory is based on active air circulation: as water freezes, heat is released and flows out of the cave entrance, and this circulation would freeze ice in winter and draw cold air into the cave. A third theory proposes that cave ice is the remainder from the glacial ages. For example, ice mineral stains on the walls of Merrill Cave (and other ice caves in the monument) indicate that the lower passage was mostly filled by ice until some unknown recent time. The ice might have existed there since the last period of glacial activity in the region, 70,000 to 10,000 years ago, but this could not be determined with certainty. This theory of ice causation would apply only to caves with large bodies of permanent ice, as great mass and a tremendous potential for heat absorption would be required for ice to remain in a cave since the last glaciations in this area.

Criteria

For purposes of this assessment, "Good" conditions would be sustained ice levels at or greater than their current conditions in each cave in this monument, and within their natural range of annual variation. "Somewhat Concerning" and "Significant Concern" conditions would be defined by the degree of negative departure from those conditions. Ice levels in caves located outside the monument cannot validly be used as a basis for setting expectations for the monument's caves because they are hundreds of miles away and differ geologically.

Condition and Trends
Condition: *Indeterminate*.
Trends: *Somewhat Concerning – High Certainty* (and for at least 3 caves: *Significant Concern).*

Attempts have been made to measure ice levels systematically in several caves, beginning with eight caves in 1990 and 12-17 since 2005. In the remaining ice caves, informal visual inspections are conducted annually.

Ice levels in some caves appear to vary considerably from year to year without a well-defined trend, but in others the trend has been negative. In 1999 the ice in Merrill Ice Cave, which contained one of the larger ice resources in the monument, began to melt with the formation of a hole in the center of the ice floor. By 2001, nearly all the ice had disappeared. Analysis of ice level data revealed that from the 1960s until about 1998, ice levels in Merrill Cave increased, but around 1998 the ice decreased drastically and disappeared. However, limited evidence suggests that the ice deposit in Merrill Cave has fluctuated dramatically over several thousand years (Fuhrmann (2007). Available data on ice trends within the past 20 years are summarized in Table 2; the described trends have not been tested for statistical significance.

Table 2. Ice trends as of 2012 in the monument's monitored caves, adapted from Kern and Thomas (2012).

Cave Name	Monitored Since:	Trend in Cave Ice Level Depth
Skull	1991	no change or possibly a slight increase since 1995
Merrill	1991	increase until ~1998, then large decrease, NONE by 2006
M-470	1991	no change, then decrease 1999-2004, then NONE
C-270	1991	decrease since 2000
M-475	1991	decrease 1999-2005, then NONE
M-310	1991	decrease, then increase since 2005
M-340	1991	decrease
Crystal	1982	decrease
L-800	1991	increase, then decrease since 2003
Heppe	2005	increase, then decrease since 2007
U-200	2005	mostly stable
B-020	2009	mostly stable
L-215	2009	mostly stable

Ice caves not shown in Table 2 are nonetheless observed informally (not measured) by park staff. Those observations suggest that declines have occurred in most of those caves, with three nearing a total loss (Shawn Thomas, pers. comm.). As expected due to cooler temperatures with depth, ice disappears last in the deepest parts of most ice caves.

Another aspect of cave ice is its phenology, specifically, the time of year at which a given ice formation reaches its annual maximum and minimum. With the exception of Skull and possibly M-470, the minimum typically occurs around November. In Merrill Cave, until all its perennial ice disappeared, November had usually been the month of ice maximum rather than minimum (Kern and Thomas 2012). No correlation is apparent between the month of ice minimum or its interannual variability and the increasing or decreasing interannual trend in the ice. In a 2003-2004 study of Crystal Cave, the lag between surface temperature and cave temperature varied from 19 to 62 days, depending on depth within the cave. Visitation of caves is likely to have the greatest impact on cave temperatures (and indirectly, on ice resources) when visits are numerous and occur during winter.

Assessment Confidence and Data Gaps

Medium Certainty. Besides air temperature (which is influenced locally by elevation and aspect of a cave entrance, number of entrances, cave depth, and within-cave topography), the factors that influence annual ice extent in a particular cave might include immediate or time-lagged precipitation and seepage rates of surface and ground water (which are influenced locally by surficial geology, topography, and vegetation). These deserve further study to determine, for example, why some of the deepest caves do not retain perennial ice, whereas some shallower ones do. These differences are likely due to different regimes of temperature and moisture availability. Rain which occurs latter within the melting phase is often lost to groundwater, or may even diminish existing ice in caves. Because no well-defined aquifers are known to occur within the monument, the source, quantity and movement of groundwater in the monument, as possibly relates to cave microclimates and ice formation, requires further investigation. This need is especially important because limited evidence to date suggests that groundwater levels within the monument may also be decreasing (see section 4.1.3).

Systematic monitoring of cave ice needs to be expanded to more ice caves. Too little time has passed to identify statistically significant trends in some of the monitored caves. Measuring ice in a standardized and meaningful way is challenging. Time series photographs provide a general picture and a limited archive of photos exists, but quantification of ice volume or depth from images is not possible. Thus, the vertical level of the ice from an established benchmark is typically what is monitored, although uneven surfaces and irregularly shaped floors mean that the same magnitudes of decline among several caves are not equivalent. For this reason, in the plan for the Klamath Network's Inventory and Monitoring Program, Krejca et al. (2010) recommended also measuring the surface area of ice, referenced as well to the benchmark.

4.2 Changes in Cave Geologic Features

4.2.1 Background

The lava tube caves are of course the natural feature most visitors come to the monument to see. This highlights the importance of understanding changes to the condition of these features.

A number of cave geologic features are present. As described by Blacic (2006) they include the following. **Breakdown** consists of pieces of the lava tube wall or ceiling that have broken off and fallen to the floor during the lava's cooling phase as contraction cracks form due to shrinkage of the inner linings of the tube (Figure 5). Occasionally a **skylight** forms when the entire thickness of a lava tube ceiling collapses, creating an opening to the surface. **Tube in tube** occurs when a lava stream flows through an existing tube and the outer surface of the flow forms an insulating crust within the existing tube, leaving behind a cast of a "cave within a cave." A **pillar** is a column of hardened lava which forms when there is an obstacle in the path of the flow such as a tree or rock (Figure 6). **Contraction cracks** form in the walls of lava tubes as the lining on the inside cools and shrinkage occurs (Figure 7). **Dripstone** is a coating over a cave wall where hot lava dripped down the wall. **Pull outs** consist of sections of wall where hot lava peeled away and exposed older linings of harder lava. **Lavacicles**, also called **lava stalactites**, are drip-shaped points of hardened lava on cave ceilings which form when lava drips off a hot molten ceiling or when lava splashes up from a flow below (Figure 8). A **drip stalagmite** is a roughly conical pile of lava dripped from the ceiling. **Benches** occur when several flows of different heights move through the same lava tube and ledges of hardened lava are deposited along cave walls marking the top of prior flows (Figure 9). A **balcony** is a section of benches that spans the entire width of the cave leaving a passage below (Figure 10).

Figure 5. Ice next to breakdown in Big Painted Cave.

Figure 6. Pillar in Valentine Cave.

Figure 7. Contraction cracks in Catacombs Cave.

Figure 8. Lavacicles in Valentine Cave.

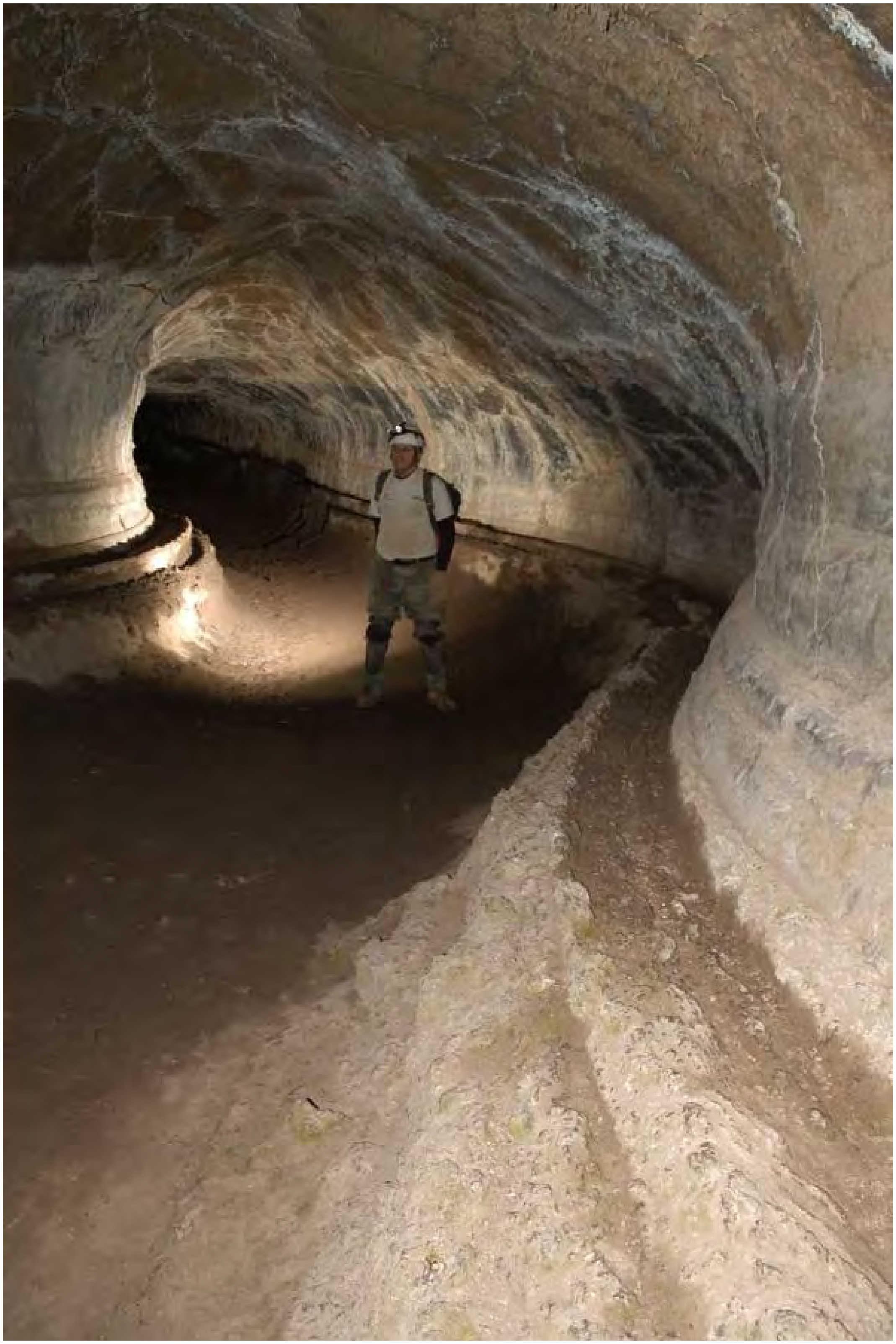

Figure 9. Benches in Valentine Cave.

Figure 10. Balcony in Caldwell Ice Cave.

Secondary mineralization is deposited by percolating groundwater on cave roof and walls to form crystals that are usually white or yellowish. This process results in formations such as *stalactites* and *stalagmites* that are familiar from non-lava caves. Sometimes the crystals form in delicate and intricate shapes called *cave coral* (Figure 11). From a limited sampling of substances in the monument's caves, the following minerals or compounds of natural origin were noted by Rogers and Rice (1992): calcite (very common), cristobalite (very common), opal-CT (very common), opal-A (moderately common), amberat (common), and uric acid (moderately common). The last two of these are of biological origin.

Figure 11. Example of cave coral.

4.2.2 Regional Context

The monument has the highest concentration of lava caves within the contiguous United States. Other significant lava caves or cave rich areas in the western contiguous U.S. include Lava River Cave in Oregon's Newberry National Volcanic Monument (225 miles), Ape Cave in Washington (390 miles), and Craters of the Moon National Monument and Preserve in Idaho (450 miles). Oregon Caves National Monument, located just 100 miles northeast, contains a different type of cave (dissolution, comprised mainly of marble).

4.2.3 Issues Description

Geologic features within the caves face several threats, including surface wear from visitor traffic, sediment deposition, erosive chemical changes, and nearby seismic and volcanic activity. These are now described.

4.2.3.1 Surface Wear and Graffiti from Visitors

Accelerated erosion or loss of geologic features occurs as a result of visitor foot traffic. As people travel through cave passages, delicate formations that formed tens of thousands of years ago are broken off, cracked, or simply worn off from repeated foot/hand/knee placement. Outside of caves this type of wear happens naturally from wind, rain, and freeze/thaw erosion, but underground where temperatures are stable and lava tube surfaces are protected from erosion, these features are commonly intact. In caves, the traffic easily impacts a high percentage of the overall lava tube interior, and the features do not rebound with disuse, as may occur on the surface with footpaths, soil, and vegetation. This inadvertent wear and tear results in worn floors, broken formations, and sediment deposition (Tinsley 1992) and is unsightly. Graffiti from recent cave visitors also degrades cave features, obscuring natural formations that provide insight into geologic processes.

4.2.3.2 Sediment Deposition

Visitors inadvertently bring into the caves small amounts of soil attached to their shoes. When shed from thousands of boots over many years, the deposited sediment cumulatively can add significantly to what is present naturally. However, in other instances moist sediment that has existed for eons within a cave is transported outside by constant foot traffic. Foot traffic also compacts the sediments in cave floors that originally were more porous. Together with sediment deposition that fills in microtopographic variations in the cave floor, the microhabitat available for cave dwelling species can be degraded.

4.2.3.3 Erosive Chemical Changes

Accelerated erosion or loss of geologic features might also occur gradually as a result of air pollution (particularly sulfate) and groundwater pollution (e.g., from road runoff). Typically this type of pollution acidifies water, causing chemical corrosion of cave surfaces, in addition to possibly creating an environment toxic to some cave species. Also, over the span of many future decades, climate change could result in more ambient carbon dioxide, and the acidifying conditions it causes are capable of accelerating chemical erosion of some cave features.

4.2.3.4 Nearby Volcanic and Seismic Activity

Although the monument's Medicine Lake shield volcano is dormant, this is a region of active volcanic and seismic activity. Nearby volcanic and/or seismic activity could have a significant impact on cave geologic features. Cave formations are often broken during earthquakes, and passages and ceilings could collapse, dramatically changing cave morphology and air currents within the cave. Air currents affect the deposition of secondary minerals in caves and have a significant effect on ice deposits. New lava flows or pyroclastic activity could completely change the landscape.

4.2.4 Indicators and Criteria to Evaluate Condition and Trends

Criteria

Some caves have particular features that are more sensitive than others, for example delicate cave coral walls as opposed to smooth lava walls. Sowers (1992) defined levels of impact for caves in the monument. A cave that is "highly impacted" would display heavily worn floors, many broken formations, and extensive graffiti. A “moderately impacted” cave would display worn floors, a few broken formations, and minor graffiti. A cave would be considered “lightly impacted” if the floors are slightly worn, almost no formations are broken, and there is only very minor graffiti. In a “pristine” cave, the floor would not be worn, no formations would be broken, and there would be no graffiti. Also, a “pristine” cave would contain only in-situ cave sediments in natural depositional environments and aeolian (wind-blown) sediments. A more quantitative indicator of cave impact is the number of cave visitors per year. However, it is a less direct means of representing impacts, and impacts sometimes depend more on visitor behavior than total number of visitors.

With regard to trends, “Good” conditions would consist of maintained or improved conditions in nearly all the caves, as the conditions are defined above. “Somewhat Concerning” would be adverse changes in condition categories (e.g., from “lightly impacted” to “moderately impacted”) in a few caves, and “Significant Concern” conditions would be adverse changes in many.

Condition and Trends
Condition: *Somewhat Concerning* – Low Certainty.
Trends: *Indeterminate*.

Staff and volunteers have inventoried caves as part of a Cave Research Foundation project, but no comprehensive dataset or analysis exists. The inventory forms include the criteria described above that are relevant for assessing formation breakage and erosion. Sowers (1992) lists examples of caves which fit each of the criteria, but updates of the descriptions she prepared 20 years ago have not been published. As of that time, Catacombs Cave and Skull Cave were highly impacted. Arch, Sentinel, and Post Office Caves were moderately impacted. Big Painted Cave, Ship Cavern, Heppe Cave, and Cox Ice Cave were lightly impacted. Copper Rock Cavern and The Bowers Cave are pristine.

Tinsley (1992) studied two impacted caves, Valentine and Skull. Valentine Cave reported a sediment plume in the entrance room which had a maximum thickness of 200 mm and thinned with distance into the cave. The sediment plume appeared to be the result of dumped construction debris. The sediment had been tracked into the cave via transport on visitors’ shoes. This sediment was the result of a one-time action, and transport of sediment out of the cave via visitors’ shoes dampened by moist cave floors was reported to be occurring at a rate exceeding the rate of input by more than an order of magnitude. The overall impact of the footgear-based removal process has not been fully determined. In Skull Cave, rock surfaces near the entrance of Skull Cave were reported to be coated and discolored with sediment transported via visitor foot traffic. Also within Skull Cave, the ice floor was degraded by reddened particles of rock and soil tracked onto the ice via visitor foot traffic. The reddened sediment originated within the cave; however, human traffic moved the sediment onto the ice.

The chemical composition of ice from 12 caves was determined in summer and fall of 2005 (Currens et al. 2006). Baseline measurements included pH, alkalinity, bicarbonate, carbonate, calcium, specific conductance, chloride, nitrate, ammonium, sulfate, sodium, potassium, and magnesium. Maximum alkalinity was 180 mg/L $CaCO_3$ and 220 mg/L HCO_3. Measurements of pH ranged from 5.26 to 9. Potentially corrosive pollutants have not been reported for any of the caves, either in the air or in runoff and groundwater that seeps in, but chemical composition of ice from several caves was measured in 2009-2010 and a report is pending.

Aboveground, levels of atmospheric sulfate deposition in this monument during 2005-2009 were rated "Good" based on data interpolated from other parts of the region (NPS-ARD 2011). Risk to the monument from acidic deposition is rated low (Sullivan et al. 2011b). The monument is in an area designated by Congress as a Class I air quality area, meaning there are increased air quality protections in place.

Assessment Confidence and Data Gaps
Low Certainty. Only a small proportion of the monument's caves have been evaluated in terms of the criteria described above, and no database or reports describe those conditions using a standardized protocol applied at annual or semi-annual intervals. Photomonitoring is useful in documenting gross change over time, and a collection of photos of major cave entrances and passages exists. Bill and Perry Frantz through the Cave Research Foundation have sustained this long term photo-monitoring project, covering 33 sites within 16 caves, but images are difficult to compare without standard reference points. The tool will likely be useful for detecting large changes, such as entrance collapse and broken stalactites, but small changes such as sedimentation, smoothing of surfaces, or breaking of delicate cave coral are not likely to be captured unless a particular spot was photographed in detail before the damage occurred.

Visitor logs and infrared counter data exist for some caves in the highly impacted Cave Loop area and are being installed in other locations as part of the I&M protocol (Krejca et al. 2010). Each method has different confidence levels associated with it. Visitor counts are likely to correlate somewhat with formation breakage and general cave erosion, and these data are collected in various ways. For gated caves with monument staff required to open the gate, visitation records are very near a perfect reflection of cave use. Very few of the monument's caves are gated so other techniques are used. Visitor logs are not likely to be filled out by every person entering the cave unless there is some type of enforcement (e.g., a monument staff member requiring it for entry), but they are cost effective and probably sufficient for remote sites with little visitation. Infrared counter data can be confounded by multiple passes of the same person into a cave entrance, by large groups entering a cave simultaneously, by vandalism, and by obstruction from natural features (e.g., windblown vegetation, animals, rockfall). Pressure plate counters have similar problems. However a combination of all of these methods, varying by site and by level of use, is useful for obtaining estimates of visitor use and subsequently correlating that with impact to the cave.

4.3 Changes in Cave-dependent Species

4.3.1 Background

When assessing the condition of cave species, it is helpful to know if its population is part of a larger, interconnected population (i.e., is a metapopulation) whose members may breed far from the monument, or if the species is essentially at an evolutionary cul-de-sac and its entire population is genetically isolated to the monument. It is also helpful to know how dependent a species is on caves. In terms of cave dependency, cave organisms are commonly classified as troglobites, troglophiles, or trogloxenes (Barr 1968).

Troglobites spend their entire existence underground and cannot survive outside of caves. They typically are characterized by eyelessness, lack of pigment, adaptation to constant temperatures and saturated humidity, attenuated appendages, and slow metabolism. Examples in this park include the millipede *Plumatyla humerosa* and the dipluran *Haplocampa* sp.

The effective conservation of a troglobite species is aided by an understanding of its evolutionary history and, specifically, how recently it evolved separately from its aboveground ancestors. Typically, troglobites evolve into separate species as a result of ancient isolating events such as glaciers, lava flows, or climate changes. In some cases those events may have extirpated their aboveground ancestors (Culver et al. 1995). Lava flow caves such as those in this park have many isolated sections, and the caves themselves are collectively distant from any other concentration of caves. These factors would seem to favor the eventual creation of a rich assemblage of troglobites (Culver and Holsinger 1992).

Troglophiles are obligated to complete some part of their entire life cycle underground, but may forage regularly outside. They are more tolerant of climactic shifts and are adapted to more nutrient-rich environments. Examples of troglophiles in the monument include most bats, arachnids (such as spiders, mites, and pseudoscorpions), grylloblattids, myriopods (such as centipedes), and many insects (Taylor and Krejca 2006).

Trogloxenes use caves, but cannot complete their entire life cycle in the cave. They typically must leave to forage or mate, and may use caves only sporadically. Nonetheless, caves are important to many of these species during critical periods, providing hibernation sites or refuge from the extremes of surface climate variation. Hibernating animals rely on consistently cold temperatures to trigger and maintain metabolic functions throughout their dormant period, without which they will expire if forced to 'awake' before sufficient food is available on the surface. Examples of trogloxenes in this monument include some birds (e.g., owls), fox, coyote, and cougar. A few of the troglophiles and trogloxenes may be modern evolutionary precursors to future troglobites, or they may be species that will never experience genetic isolation from their surface dwelling relatives. Typically the species with greater physical or physiological adaptations to cave life, such as the troglobites, occur deeper inside the caves.

4.3.2 Regional Context

The bats in this region are insectivores, and they play an important ecological role in controlling insects, including many agricultural pests. Of the monument's 14 known bat species, 7 are considered to be of greatest conservation priority due to their life history, preferred habitats, or other factors (Table 3).

Table 3. Bat species with special conservation designations documented at Lava Beds National Monument.

Scientific Name	Common Name	Special Status
Antrozous pallidus	Pallid bat	CDFW Species of Special Concern
Corynorhinus townsendii	Townsend's big-eared bat	CDFW Species of Special Concern
Myotis thysanodes	Fringed myotis	WBWG = High priority
Myotis volans	Long-legged myotis	WBWG = High priority
Lasionycteris noctivigans	Silver-haired bat	WBWG = medium priority
Myotis ciliolabrum	Western small-footed myotis	WBWG = medium priority
Myotis evotis	Long-eared myotis	WBWG = medium priority

* CDFW: California Department of Fish and Wildlife
WBWG: Western Bat Working Group

One lava tube in the monument contains the largest colony in the northern United States of the migratory Brazilian free-tailed bat (*Tadarida brasiliensis*). Most of the monument's cave-dwelling bats remain during the winter, using caves as hibernacula sites. Exceptionally large hibernacula of the Townsend's big-eared bat *(Corynorhinus townsendii)* also occur in the monument. These colonies are some of the only ones known to be stable or increasing as compared to the remainder of the state which is experiencing dramatic declines in the numbers of maternity colonies and roosts, and a dramatic decline in the total numbers of individuals counted (Pierson and Rainey 1998). The monument's caves also support the world's only known underground nesting sites of purple martin. This bird species is regionally uncommon. As well, several invertebrate species are known from no other place than from the monument's caves, as documented by Taylor and Krejca (2006) and prior researchers.

4.3.3 Issue Description

4.3.3.1 Climate and Microclimate Changes

Due to the confined nature of caves, even the simple presence of humans can increase localized temperature and humidity, especially in smaller and more confined caves. Normally, cave microclimate is influenced by surface temperature, wind, precipitation, ice formation, and cave morphology (see section 4.1). Troglobites in particular are sensitive to temperature and humidity. Most are narrowly adapted to a specific temperature range and quickly expire when exposed to small temperature variations.

Bats that hibernate locally use certain cold caves for hibernation but use different warmer caves (or warmer sections of the same cave) for breeding. In the summer, bats cluster together in domes or crevices of caves because those trap warm air. The presence of bats' bodies can increase the temperature further and that might support more favorable roosting or breeding conditions. Bats have been known to abandon cave roosts after placement of a gate at a cave entrance, and subtle alteration of cave microclimate by a gate has been suggested as a possible cause.

4.3.3.2 Effects of Aboveground Plant and Animal Communities

All changes in aboveground vegetation and animals have the potential to affect cave species positively or negatively. This includes vegetation and wildlife changes due to fuels management, grazing regime, invasive plants, air quality, and water management in surrounding areas, as well as changing climate and associated changes in patterns and rates of fire and natural succession. These can affect cave species in at least two ways: (1) changing the amount of water that infiltrates into caves and thus the cave microclimate, (2) changing the amount of nutrients that are carried into caves.

With regard to *infiltration*, some deep rooted plants are capable of penetrating cave ceilings and thus facilitating downward infiltration of water into caves, consequently providing habitat for cave invertebrates and providing water for ice formation. By shading the aboveground soil surface, other plants help maintain cooler summer temperatures at the ground surface. That in turn may help maintain belowground temperatures and thus maintain ice formations. Some aboveground shrubs effectively trap windblown snow, making more meltwater available for infiltration into caves, but on windy summer days other shrubs may transpire such large amounts of soil moisture that significantly less water is available for infiltration. Impervious surfaces such as roads and buildings can restrict or redirect infiltration that otherwise would influence cave microclimate.

Nutrients from aboveground are essential energy sources for troglobites because little or no sunlight reaches cave interiors. Thus, no plant production can occur and food must come in from external sources (some production may nonetheless occur among cave microbial communities if they are capable of using minerals directly). Potential energy sources for cave organisms are: (a) seeds and nesting material carried in by woodrats (packrats), birds, and other animals; (b) plant matter carried into cave entrances by windstorms or rare floods; (c) feces (scat, guano) and urine from bats and other wildlife that forage outside the cave; (d) plant roots that penetrate the ceilings of shallow caves; and (e) crumbs, hair, dust, and threads incidentally attached to clothing of visitors. At low light intensities, fungi grow on the decaying organic matter and this in turn feeds many species of invertebrates. Conceivably, an inorganic nutrient—atmospheric nitrogen, mainly in the form of ammonium and nitrate—could be deposited in wet or dry form on the land surface by precipitation and air currents, and then could infiltrate downward into caves. Its potentially stimulative effect on the growth of cave lichens and fungi, at the deposition rates known to be present in this park (see section 4.6), has not been studied.

The importance of nutrient inputs is recognized by a recovery plan for federally listed troglobites in central Texas (USFWS 2011), which mentions as an objective the maintenance of a natural quantity of native vertebrate and plant matter input. The recovery plan also mentions the need to maintain a healthy aboveground native plant and arthropod community and minimize threats from invasive invertebrates.

As noted before, the type and extent of the nutrient sources for some cave-dependent animals will depend on the type of aboveground vegetation, the palatability of that vegetation, and ultimately, on aboveground climate, fire, and vegetation management practices. For example, invasive plants that outcompete the native food plants of woodrats in aboveground habitats can trigger a decline in woodrats within caves, which triggers cascading effects on other cave biota due to the consequently reduced importation of nutrient-rich organic matter. Air pollution and pesticide application may reduce the food sources of bats, thereby reducing the energy that comes into the cave in the form of guano.

Both too little and too much nutrient input to a cave can be detrimental to troglobites.

Too little incoming nutrient load can reduce numbers of all cave animals, and too much input is documented to increase the abundance of trogloxenes and troglophiles at the expense of troglobites (Krejca and Myers 2005). In one study in Texas, the investigators demonstrated an association between urbanization, altered isotope ratios (an indicator of the type of nutrient source), and reduced diversity and abundance of cave invertebrates (Taylor et al. 2007).

4.3.3.3 Contaminants

In addition to affecting cave microclimates and nutrient sources, human visitors potentially introduce contamination from insect repellent and toxic trash such as batteries. Road runoff contains petrochemicals, heavy metals, and herbicides. Pesticides are used widely in the agricultural lands north of the monument (Eagles-Smith and Johnson 2012) and can potentially reach the monument, even over long distances. Herbicides are used within the monument to control invasive plants. Although herbicides are never applied near cave entrances, a potential may exist for some types of herbicides (or their inert ingredients or wetting agents) to infiltrate rapidly downward due to the monument's very porous soils.

4.3.3.4 Pathogens

In the eastern U.S., several bat species are declining due to infection with a fungus (*Geomyces destructans)* that arrived recently from Europe. Named for a distinctive fungal growth around the muzzles and on the wings of hibernating bats, white-nose syndrome (WNS) has not been confirmed among any bat populations west of the Missouri River, but that could change in the future. The mortality rate of some infected populations has been a staggering 95% in some cases. Symptoms include loss of body fat, unusual winter behavior (including flying), damage and scarring of the wing membranes, and death. Infection causes bats to rouse too frequently from torpor (temporary hibernation) and starve to death through excessive activity. The fungus can grow only in temperatures in the 4 to 15°C range (39–59°F), a range typical of many caves. It perishes at temperatures above 20°C (68°F). Recent research suggests that human anti-fungal treatments might help stem the infecting fungus in individual bats, but many questions remain. To minimize the threat of WNS reaching the monument's caves, visitors are required to state whether they have recently visited any caves or mines in the areas affected by WNS and if so, whether they have decontaminated the boots, equipment, etc. which they are bringing to the monument.

4.3.4 Indicators and Criteria to Evaluate Condition and Trends

Recently the Klamath Network of the National Park Service Inventory and Monitoring team worked closely with monument staff to create a long-term, peer-reviewed monitoring protocol for the region's cave entrance communities and cave environments (Krejca et al. 2010). The team identified and prioritized eight general factors that should be the focus of whatever indicators are routinely monitored. These factors are based on, among other things, the strength of their connection to the cave ecosystem, how feasible they are to measure given staff and resources, and the ability to track trends in sample datasets. The eight include four abiotic parameters (climate, water levels, ice levels, human visitation) and four biotic parameters (bats, visible scat and organics, entrance vegetation, invertebrates). Two specific indicators that reflect these broader factors are:

- Condition (presence and persistence) of cave-dependent species
- Condition of cave habitat for cave-dependent species

These are now discussed.

4.3.4.1 Condition (Presence and Persistence) of Cave-dependent Species

Criteria

For purposes of this assessment, "Good" conditions would be represented by sustained diversity and abundance of all cave dwelling species currently inhabiting the monument, or hypothesized to inhabit the monument prior to human impact. As with any biological system, this would ideally include sustaining relative proportions of species according to their role in the food web, and sustaining their genetic diversity in terms of healthy population size and interconnection with other populations. "Somewhat Concerning" and "Significant Concern" would represent increasingly greater reductions in the populations of cave dwelling species.

Condition and Trends

Bats

In general the condition of bat populations in the monument appears to be *Good*. However, only three of the monument's 14 species have been subject to relatively intensive long-term monitoring efforts. The remaining 11 species have been monitored opportunistically and thus have insufficient data to characterize their population condition or trend.

All or most of the Brazilian free-tailed bats, *T. brasiliensis*, occur seasonally within the monument in a single maternity colony in Bat Cave. Bat biologists have described this cave's habitat in detail, including physical and climatic characteristics of the passage (Cross and Ferrell 1984, Fuhrmann 2003). They have used photographic techniques to estimate the population size (Cross 1989, Fuhrmann 2003), thermal videography to estimate the population size (Betke et al. 2008), and dataloggers to track entrance and exit activity (Shawn Thomas, pers. comm. 2012). Acoustic activity at foraging areas surrounding Bat Cave was monitored in an effort to determine where *T. brasiliensis* bats were feeding most often (Cross and Waldien 1994). Population estimates have ranged between 50,000 and nearly 400,000 individuals when using photographic methods performed up to three times a year since 1988. But different estimation methods give different results. Numbers estimated by thermal imaging, performed only once at Bat Cave but on the same night as photographic methods, were many times lower and might be more accurate. Fuhrmann (2003) points out multiple problems with the photomonitoring method used since 1988: it is not well suited for making counts in full darkness, it is not perfectly repeatable among researchers, the historic dataset does not contain a consistent number of pre and post volancy sample events, and there are microclimate variables not accounted for that may affect flight patterns in any given night. Recently monument resource staff reviewed the historical datasets and ranked those in order of confidence so the counts could be used in future analyses. Greater confidence was assigned to evenings where researchers did not have to switch methods because of light availability.

Another species that has been the focus of some monitoring is *Corynorhinus townsendii*. A statewide survey of this species in California indicated a sharp decline, with over half of the historical colonies extirpated and with the number of bats in existing colonies in decline, with a notable exception of several caves in national parks, including Lava Beds (Pierson and Rainey 1998). This is the only bat species regularly monitored as part of the Klamath Network Inventory and Monitoring protocol. Monument staff have been tracking colony locations and estimating populations to inform decisions about which caves to close to visitors in order to minimize disturbance impacts to the species. The I&M protocol also calls for monitoring winter hibernacula in the monument (Krejca et al. in prep).

Data exist for summer and winter counts of this species using various protocols, and a report by Ted Weller that analyzes trends is in preparation. Figures 12 and 13 show a subset of the entire dataset. Based on winter hibernacula point counts performed before protocols were standardized (year?), these figures suggest stability in numbers at 12 caves which represent the majority of known hibernacula sites in the monument. Populations may have increased at two of the monument's maternity roosts in 1961 and 1970, and then again in the late 80s and early 90s (Pierson and Rainey 1998). However, no statistical analyses of trends have been published.

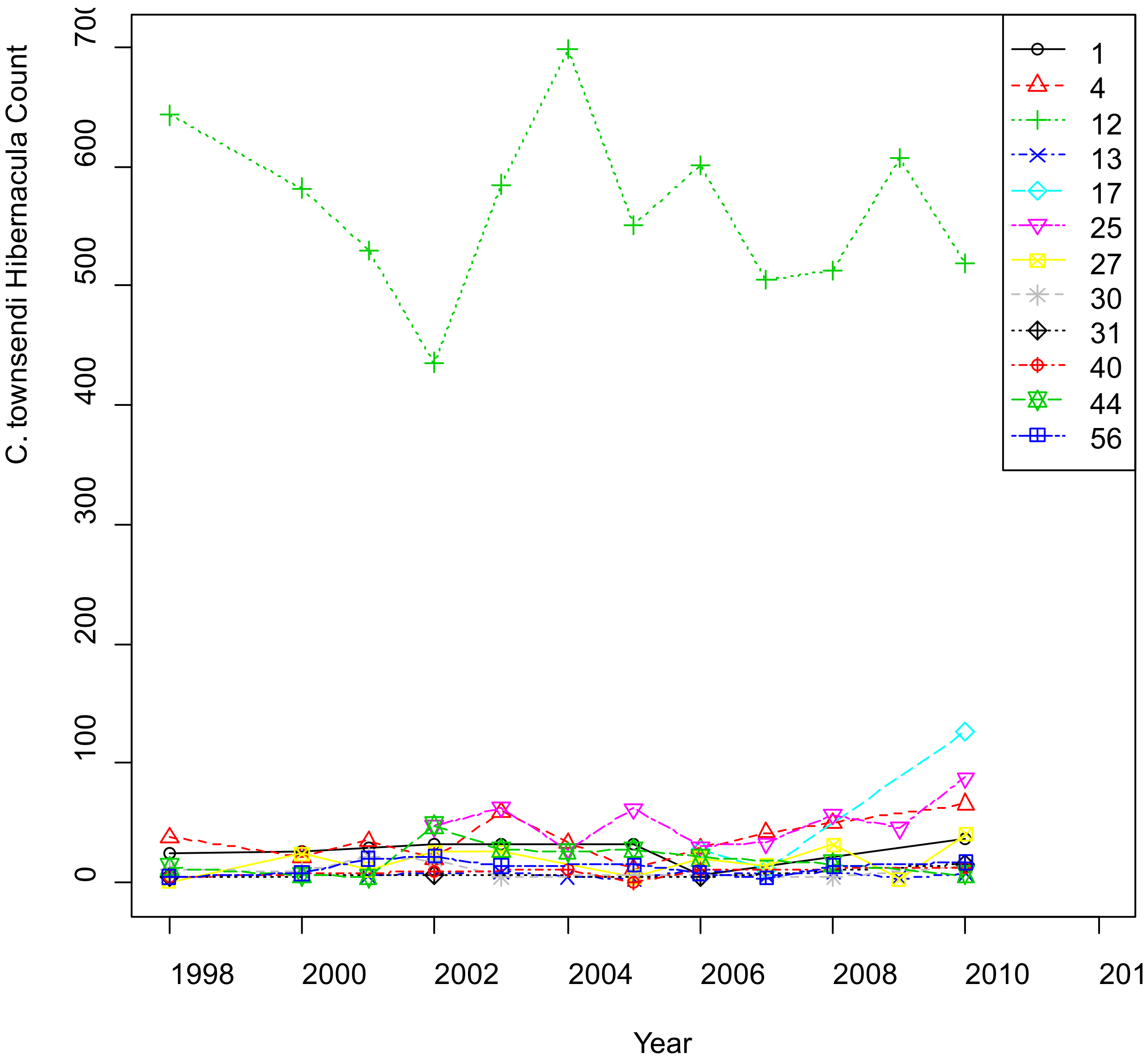

Figure 12. Winter hibernacula counts of *Corynorhinus townsendii* at 12 caves (coded to protect roost site information) from 1998 to 2010. (From Krejca et al. 2010.)

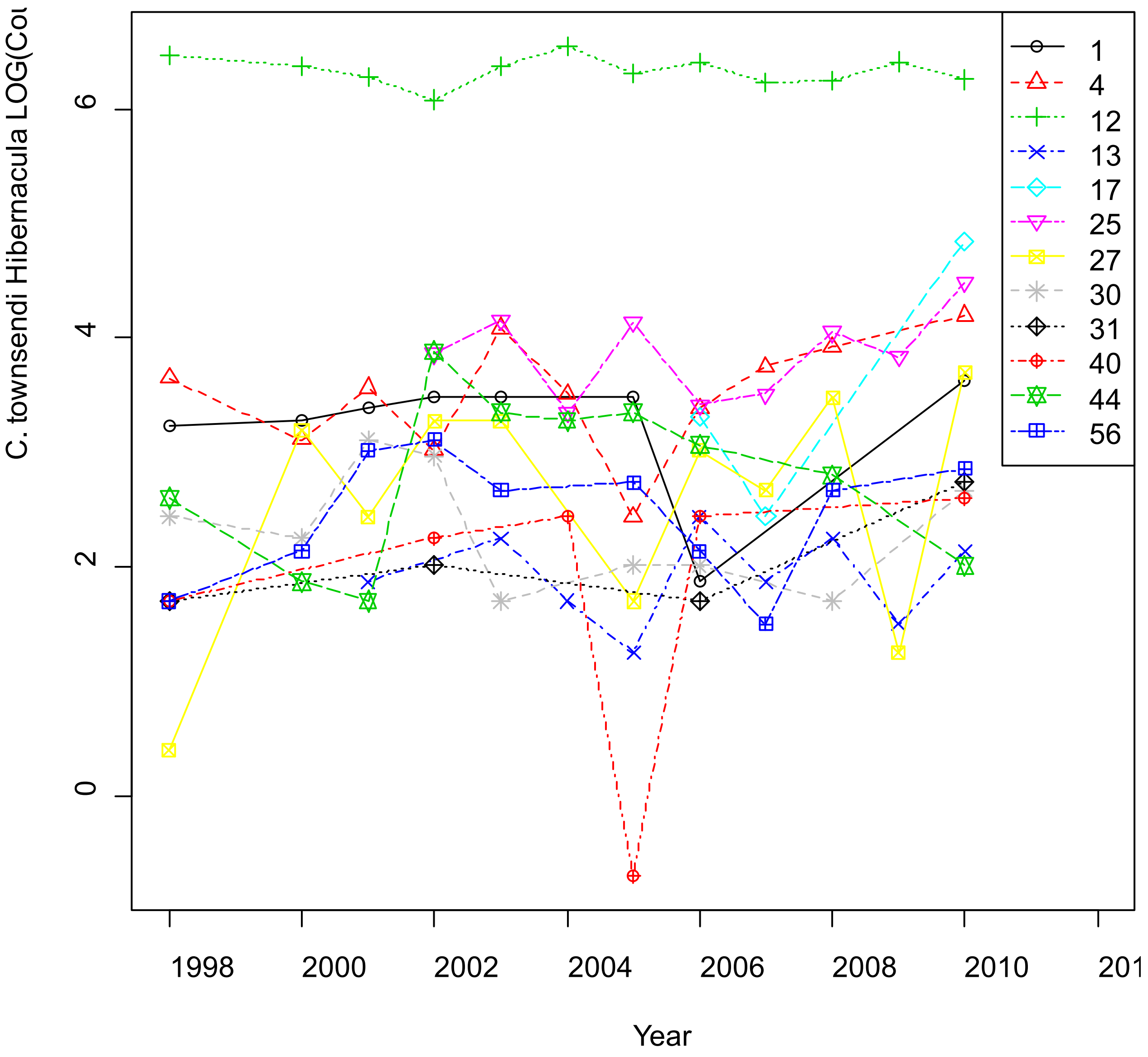

Figure 13. Log transformed winter hibernacula counts of *Corynorhinus townsendii* at 12 caves (coded to protect roost site information) from 1998 to 2010. (From Krejca et al. 2010.)

Pallid bats, *Antrozous pallidus*, were formerly known from a single colony in the monument, but in 2010 a second colony was discovered and is being loosely monitored (Shawn Thomas, pers. comm. 2012). Other species of bats are detected sporadically, by using mist nets and harp traps, for example (Tyburec 1999), but condition and population trends are unknown. No condition or trend data are available for other bat species.

In many parts of North America, bat populations are threatened by disease epidemics, loss of roosting or foraging areas due to landscape changes, and impacts from pesticide use (Rodhouse et al. 2012). Because many of the monument's bats forage outside of the monument and migrate to distant regions, it is possible they suffer from such impacts.

Other Cave-associated Mammals

The condition and population trends of the monument's cave-associated mammals, such as woodrats (*Neotoma spp.*) and deer mice (*Peromyscus spp.*), are *Unknown*. An exception is American pika (*Ochotona princeps*), a rabbit-like animal that uses cave entrances and lava flows. Recent studies in the monument have addressed pika abundance, distribution, habitat associations, management, habitat occupancy, and gene flow (Shardlow et al. 2009, Ray and Beever 2007). Those studies indicate that pika populations in the monument appear to be occupying most of the habitat considered to be suitable, although this has not been quantified. Thus, the condition for pika is rated *Good*, despite the apparent disappearance or decline of the species in many areas of the American West. However, the certainty of this estimate is *Low*, and trend is *Indeterminate*.

Cave-associated Birds

The condition and population trends of the monument's cave-associated birds are mostly *Unknown*. The main exception is purple martin, whose numbers (at the caves where they nest just inside the entrances) have been monitored irregularly since the 1960s and regularly using a standardized protocol since 2003. No long term trend is apparent, but in 2011 the numbers were markedly low (David Larson, pers. comm. 2012). This is not necessarily attributable to conditions in the monument, as they spend much of the winter in regions far to the south. Other species that occur to varying degrees just inside the monument's caves include violet-green swallow (nesting), Say's phoebe, rock wren, canyon wren, common raven, barn owl, and great horned owl. None of these is generally a cave dependent species.

Cave-associated Amphibians and Reptiles

Only one species—Pacific treefrog—regularly inhabits the cave entrances and, within the monument, may be dependent on this moist environment, although the species is not confined to caves. Rubber boas are found regularly in the monument's caves. Due to lack of standardized inventory data, the condition and population trends of these two species are *Indeterminate*.

Cave Invertebrates

Similarly, the condition and population trends of the monument's cave-dependent invertebrates are *Unknown*. Three studies to date (Crawford 1990, Ferguson 1992, Taylor and Krejca 2006) have determined which species occur in each of the major caves, but provide no context to indicate the relative condition of the monument's cave-associated invertebrate fauna. At least a dozen species may be cave obligate (troglobitic) species. Two of these (an isopod and a pseudoscorpion) may be endemic to the monument (Taylor and Krejca 2006).

Cave-associated Plants and Lichens

Lichens are diverse and abundant in the monument. While no comprehensive database exists, one study (Vanover et al. 2008) found decreased lichen and moss coverage at caves with greater visitation, although slope, elevation, and aspect were not controlled for. This suggests that some lichen species might not tolerate disturbance from human visitation, but specific thresholds and causative factors are *Unknown*. Disjunct populations of several fern species, including western swordfern (*Polystichum munitum*), dominate some of the monument's cave entrances. The condition and trend of these ferns and other plants associated with cave entrances has not been quantified, but surveys are ongoing.

Assessment Confidence and Data Gaps

Low Certainty. With the exception of two of the monument's 14 bat species, condition and trend data collected using standardized protocols is lacking for all of the monument's cave-associated fauna and flora. Recent discoveries of many new species of cave-obligate invertebrates at other western monuments (Cokendolpher and Krejca, 2010, Disney et al. 2011, Shear et al. 2009, Shear and Krejca 2007, 2011) indicate that further sampling and taxonomy effort at Lava Beds is likely to reveal more cave-obligate invertebrate species, perhaps including some that are endemic to the monument. In comparison with efforts to document invertebrates of lava tubes elsewhere in the western US (e.g., Northup and Welbourn 1997), the monument has received very little study of its cave invertebrates.

4.3.4.2 Condition of Cave Habitat

For purposes of this assessment, "*Good*" conditions would be represented by a pristine cave environment not showing effects of humans. This includes no changes to microclimate (e.g. changes to ice levels or presence of structures or alterations of entrances), no measurable effects of human visitation (e.g. sediment deposition, formation breakage), and no pollution. *"Somewhat Concerning"* and *"Significant Concern"* would represent increasingly signs of damage to the cave environment as a result of human actions. Sections 4.2.4.1 and 4.2.4.3 of this report describe in more detail the effects of human visitation (formation breakage, general cave erosion and sediment deposition). Sections 4.2.4.2 and 4.1.4.2 cover ice levels. Section 4.1.4.1 covers cave microclimate. Section 4.2.4.4 covers groundwater pollution.

4.4. Changes in Vegetation

4.4.1 Background

Vegetation is a foundation for terrestrial ecosystem composition, structure, and function. Vegetation ranked as a key vital sign for monitoring of ecological integrity in the Klamath Network Inventory and Monitoring Program. Vegetation *composition* includes an array of ecosystem components such as species, populations, genetic composition, and special habitats. Vegetation *structure* refers to the vertical and horizontal arrangement of components, such as canopy structure and corridors for species movement. Vegetation *function* refers to ecosystem processes such as cycling of nutrients, carbon, and water—which interact with disturbance processes and biological components such as interspecific competition and demographic and reproductive processes. Vegetation dominates biomass and energy pathways and defines the habitat for most other forms of life. Indicators for vegetation composition, structure, and function can therefore define the ecological integrity of terrestrial ecosystems.

Vegetation structure, function, and composition can be altered by many activities (e.g., fire management) or from extrinsic factors (e.g., off-site pollution, climate change, invasive species) (Figure 14). These affect the structure of the habitat, particularly the disturbance regimes, as well as the landscape patterns that create habitat for a wide variety of species.

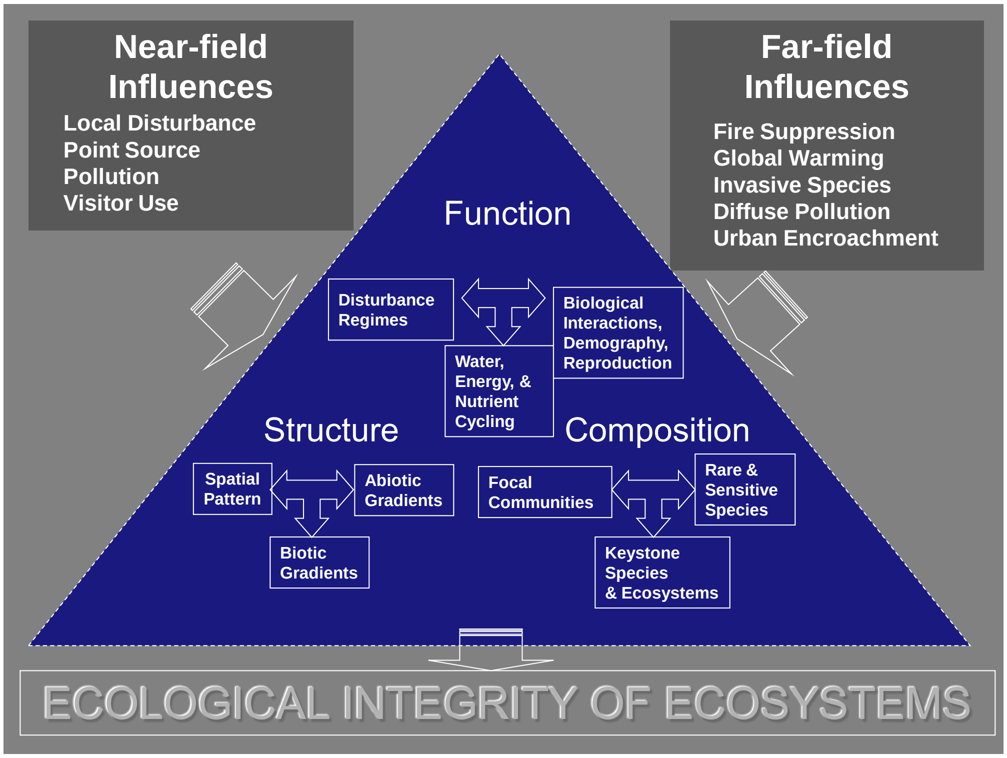

Figure 14. Human influences on the structure, function, and composition of ecosystems.

Elevation-driven changes in moisture and temperature yield marked zonation in vegetation at the monument. These factors interact with substrate age (i.e. the age of various historic lava flows) and topography to help produce the vegetation mosaic (Figure 15). Sagebrush (*Artemisia tridentata*) communities dominate the lower elevation valleys and plateaus. With increasing elevation from north to south, sagebrush decreases somewhat in frequency (though it remains abundant) while western juniper (*Juniperus occidentalis),* mountain mahogany (*Cercocarpus ledifolius* var. *intermontanus*) and vegetation height and abundance increase. At higher elevations and more mesic sites (i.e., north facing slopes), ponderosa pine (*Pinus ponderosa*) dominates. Ponderosa stands in isolated cinder cones are mainly undisturbed, but ponderosa forests along the monument's southern boundary have been profoundly altered in recent history. Railroad logging, clearing, and a major stand-replacing fire around 1915, before the monument was established, had dramatic effects. Almost all the remaining pines have regrown since these events, and the ecotone between juniper woodland and ponderosa forest has shifted south and higher in elevation. Widely scattered large-diameter stumps and snags in the southern third of the monument, particularly in the Valentine Flow and southeastern areas, now are surrounded by juniper and mountain mahogany woodlands.

4.4.1.1 Sagebrush Steppe Zone

Sagebrush steppe dominates the northern two thirds of the monument where elevations range from 1219-1524 m (4000-5000 ft). Sagebrush communities are typically co-dominated by shrubs and grasses. Grasses include both native bunchgrasses and introduced cheatgrass (*Bromus tectorum*). Fires in recent years killed most shrubs in the northernmost portion of the monument. Consequently, this area is dominated by grasses, particularly cheatgrass, and another non-native species, herb sophia (*Descurainia* *sophia*). This shift to grass domination may persist as Great Basin shrubs are slow to regenerate from seed and fire may recur before this can happen. Probability of fire recurrence is enhanced by cheatgrass, which has positive feedback relationship with fire, both promoting and being promoted by fire (D'Antonio and Vitousek 1992). Over the last several decades cheatgrass has become the most widespread and abundant plant in the monument, based on 169 vegetation mapping plots that span the range of variation in vegetation (Odion et al. in prep). Cheatgrass is common in all the main vegetation types, but is most common at the north end of the monument.

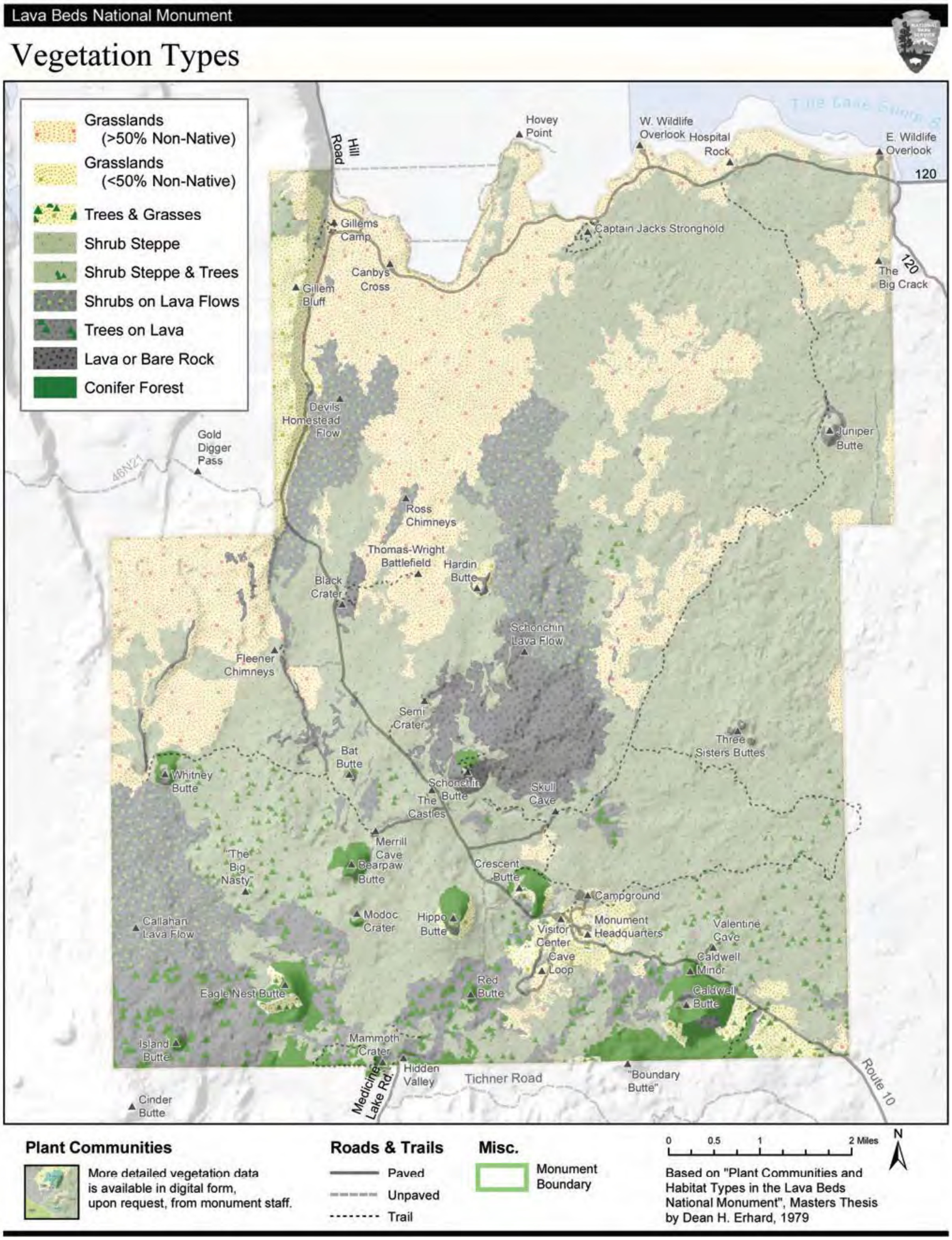

Figure 15. General vegetation map of Lava Beds National Monument. The map is reproduced from the 2010 Draft General Management Plan and Assessment (Map 15).

The unburned sagebrush steppe consists of open shrublands of Great Basin sagebrush *(Artemisia tridentata* subsp. *tridentata*), native bunchgrasses and cheatgrass. Common bunchgrasses include squirreltail grass (*Elymus elymoides)*, Thurber's needlegrass (*Achnatherum thurberianum*), bluebunch wheatgrass (*Pseudoroegneria spicata* subsp. *spicata)*, Sandberg bluegrass (*Poa secunda*), and scattered native herbs (e.g., *Agoseris* spp., *Nothocalais troximoides*, and *Astragalus* spp.). These plant communities occupy deep well-drained soils. Common woody associates include the deciduous shrubs gray rabbitbrush (*Chrysothamnus nauseosus*), and yellow rabbitbrush (*Chrysothamnus viscidiflorus).* They also occasionally include antelope bitterbrush (*Purshia tridentata),* a nitrogen-fixer and favored deer food, and the spineless horsemint (*Tetradymia canescens).* Gnarled old junipers occasionally occur in the sagebrush-steppe, most often on rocky outcrops.

A community dominated by desert gooseberry (*Ribes velutinum)* and basin wildrye (*Leymus cinereus*), a very large bunchgrass, occurs in the northeast corner of the monument at the lowest elevations (Erhard 1979, Smith 2009). Basin wildrye is an indicator of pluvial lake plains (former lakebeds) (Young et al. 2007). This seasonally moist community occurs in areas with accumulations of erosionally deposited volcanic ash (Young et al. 2007). Associated species include the shrubby to small tree willow (*Salix lasiandra* subsp. *lasiandra)*, and herbs such as water smartweed (*Persicaria amphibium* var. *emersum)*, and a stinging nettle, *Urtica dioica* var. *holosericea*. Shrublands dominated by rabbitbrush also occur in the extreme northern portion of the monument where grazing and the draining of Tule Lake have modified natural vegetation. In the northern portion of the monument, on Gillem's Bluff at sites with shallow soils, there occurs an association of the aptly named low-sage (*Artemisia arbuscula*). The tufted perennial bunch grass, *Festuca idahoensis,* occurs with the low sage. Also on Gillem's Bluff, on the north sides of volcanic outcrops, there are patchy communities of the deciduous subshrub, roundleaf snowberry (*Symphoricarpos rotundifolius* var. *rotundifolius*)*,* with an understory of Idaho fescue and the blue-flowered herb, hackelia (*Hackelia cusickii).*

4.4.1.2 Juniper and Mountain Mahogany Zone

The juniper and mountain mahogany woodland communities occupy much of the southern third of the monument, at elevations ranging from 1310-1615 m (4300-5300 ft). The woodlands represent a mid-elevation ecotone between the warmer drier lower elevation sagebrush steppe vegetation and the cooler moister higher elevation coniferous forest vegetation. In addition to western juniper and mountain mahogany (*Cercocarpus ledifolius* var. *intermontanus)*, the low-growing and deciduous antelope bitterbrush and to a lesser extent mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) are the dominant shrubs (note: the sagebrush at lower elevations is *Artemisia tridentata* subsp. *tridentata*).

Erhard (1979) noted one small community of antelope bitterbrush, and bluebunch wheatgrass on the southern slope of Hippo Butte. The boundary of this community is undefined and it grades into the surrounding sagebrush-steppe. Mountain mahogany communities in the monument occur on undulating basalt with little soil development and little forb cover (Erhard 1979, Smith 2009). Associated species include the deciduous shrubs, bitter cherry (*Prunus emarginata)* and currant (*Ribes* spp.), Sandberg's bluegrass (*Poa secunda)*, cheatgrass, and fragile fern (*Cystopteris fragilis).*

The mountain big sage communities in this zone often have antelope bitterbrush as a codominant and bunchgrasses, bluebunch wheatgrass, Idaho fescue, and junegrass (*Koeleria macrantha)* as the understory dominant. These associations are the most mesic of the sagebrush communities (Young et al. 2007). Associated species include showy herbs such as fritillary (*Fritillaria atropurpurea)*, old man's whiskers (*Geum triflorum)*, claytonia (*Claytonia rubra* subsp. *rubra)*, dwarf flax (*Hesperolinon* *micranthum)*, skullcap (*Scutellaria nana)*, fleabane (*Erigeron* spp.), groundsmoke (*Gayophytum* spp.), and flax (*Linum lewisii* var. *lewisii*).

Although some have voiced concerns about the spread of western juniper within the monument, it is rarely the most common species in any of the plant communities. One exception may be the large *Juniperus occidentalis* community on the gently rolling terrain of the Valentine flow, in the southeast corner of the monument. Associated species include mountain sagebrush, western needlegrass, bluebunch wheatgrass and the showy herbs tidy tips (*Layia glandulosa)*, penstemon (*Penstemon* spp.), and rock cress (*Arabis* spp.). Less extensive juniper communities occur on the east, west, or south slopes of cinder cones in the monument with mountain mahogany as a codominant at these sites.

4.4.1.3 Pine Forest Zone

Communities dominated by ponderosa pine occur in the southern portion of the monument, extending down to 1402 m (4600 ft) on the northern aspect of cinder cones, but mostly occurring above 1524 m (5000 ft). The shade tolerant white fir (*Abies concolor)* and incense cedar (*Calocedrus decurrens)* occur in the understory. With the absence of fire these trees may be increasing in abundance (Erhard 1979, Smith 2009). Antelope bitterbrush is a common shrub in ponderosa pine woodlands, along with montane chaparral species such as greenleaf manzanita (*Arctostaphylos patula*) and tobacco brush (*Ceanothus velutinus*), which have fire-stimulated seed germination. These shrubs occur in relatively pure stands where, historically, stand-replacing fires allowed them to establish and/or maintain their populations. Less common are two species of currant (*Ribes roezlii* var. *roezlii* and *Ribes cereum)*, and other shrubs like chokecherry (*Prunus virginiana* var. *demissa*) and goldenbush (*Haplopappus bloomeri)*. The dominant grasses include bunchgrasses from the sagebrush steppe, such as bluebunch wheatgrass and Idaho fescue.

4.4.1.4 Lava Flows, Caves, and Cinder Cones

Because the southern slopes of cinder cones are dry, harsh environments, they support assemblages of locally rare species that are specialized for those conditions. These assemblages include widely-spaced shrubs and subshrubs such as slender buckwheat (*Eriogonum microthecum*), desert purple sage (*Salvia dorrii* var. *incana*), and coyote mint *(Monardella odoratissima*), along with the distinctive Sacramento waxy dogbane (*Cycladenia humilis*). Associated species include the herbs, dwarf purple monkeyflower (*Mimulus nanus*), ballhead ipomopsis (*Ipomopsis congesta*), and the diminutive and state-listed rare plant, doublet *(Dimeresia howellii).*

The relatively recent andesite flows in the monument are sparsely vegetated. The bare, rough, and dark volcanic rock provides junipers refuge from fires, to which they are sensitive, and many grow to be fairly large. Lava flows also feature purple sage and desert sweet (*Chamaebatiaria millefolium*). Additional shrubs in this harsh habitat are large and ancient looking mountain mahogany as well as wax currant *(Ribes cereum)*, and small leaf mountain creambush *(Holodiscus microphyllus* var. *glabrescens).* The most common forbs are hot rock penstemon (*Penstemon deustus)*, lanceleaf figwort (*Scrophularia lanceolata)*, and small-leaved giant hyssop (*Agastache parviflora).*

Cave entrances within the monument support assemblages of many of these same species, especially desert sweet. Locally rare or disjunct species may be found right next to cool cave mouths, especially ferns, such as sword fern (*Polystichum munitum*) and a variety of lichens and mosses (Steven Jessup, Southern Oregon University, pers. com). The occurrence of sword fern is unusual because it is more common near the coast, with the nearest known other occurrence being about 120 km (75 miles) west of the monument. Wood fern (*Dryopteris expansa*) has a similar disjunct distribution. Ferns in the cave entrances are described in Smith et al. (1993).

4.4.2 Regional Context

Lava Beds National Monument encompasses unusual geology (young basaltic pahoehoe lava flows) and occurs in a transition zone between the Great Basin, characterized by extensive *Artemisia* sage-steppe vegetation, and the Cascades, characterized by conifer forests. As a result, the monument's vegetation blends elements of both regions: elements associated with very young geologic substrata, where primary succession is occurring, with elements associated with older geologic substrata, where regional vegetation has developed. The monument's most common shrubs — Great Basin sagebrush, antelope bitterbrush, rabbitbrush, and mountain mahogany — are Great Basin species. However, species that are not characteristic of the Great Basin are also common at the monument. For example serviceberry (*Amelanchier alnifolia* var. *semiintegrifolia)* is more commonly found along the Pacific coast to the high Sierra Nevada, and from the northern Rocky Mountains to Alaska. Two species common in the Cascades and Sierra Nevada, bitter cherry (*Prunus emarginata)* and bush chinquapin (*Castanopsis sempervirens),* occur sparsely at the monument and elsewhere on the western edge of the Great Basin (Mozingo 1987). Sierra gooseberry (*Ribes roezlii* var. *roezlii*), which normally is found in the Sierra Nevada mountains, occurs on cinder cones in the southern portion of the monument. The intermixing of sage-steppe and montane conifer communities is uncommon in the Great Basin (Young et al. 2007). Moreover, recent geologic phenomena, such as cinder cones, lava flows, and associated lava tubes, create unusual and diverse topography, varied soil conditions, and unusual microclimates. These facilitate species occurrences outside their normal ranges. Thus, the monument contains a wealth of botanical resources and anomalies within a relatively small area. These resources have been described in master's theses (Erhard 1979, Smith 2009), and a flora (Smith 2009). We use these sources in our descriptions herein.

The monument contains some of the best examples in the western Great Basin of sagebrush steppe with an abundant bunchgrass component and limited cheatgrass component (as discussed below, there are also areas, particularly at the north end of the monument, that are heavily infested with cheatgrass). Areas with relatively little cheatgrass are unusual in the Great Basin because early settlers burned and seeded much of the sagebrush-steppe to improve forage for cattle and sheep, which do not eat sagebrush and juniper. But, the rocky Lava Beds landscape appears to have provided some refugia where grazing impacts, as well as the occurrence of fire, were lower.

4.4.3 Issues Description

Non-native, invasive species are a significant threat to native plant communities in virtually all natural areas and threaten the core goals of the National Park Service. Not surprisingly, invasive plants ranked as the top vital sign for monitoring within the Klamath Network Inventory and Monitoring Program of the Park Service. In many regions, invasive species are second only to habitat loss as a threat to native biodiversity (Wilcove et al. 1998). While many invasive species are relatively benign, impacts from certain invasive species may include the replacement of native vegetation (Tilman 1999), the loss of rare species (King 1985), changes in ecosystem structure (Mack and D'Antonio 1998), alteration of nutrient cycles and soil chemistry (Ehrenfeld 2003), shifts in community productivity (Vitousek 1990), changes in water availability (D'Antonio and Mahall 1991), and, most relevant to Lava Beds, alteration of disturbance regimes and attendant consequences (Mack and D'Antonio 1998).

Across the Klamath network, the number of non-native species decline sharply from low elevations of Whiskeytown to the higher elevations at Lassen. This pattern has been well-established in the western U.S. (Mooney et al. 1986, Rejmanek and Randall 1994, Schwartz et al. 1996, Keeley et al. 2011). The monument appears to be much more threatened to be significantly degraded by invasive species than any other park in the Network because of its relatively low elevation and the presence of one exceptionally invasive, ecosystem transforming plant: cheatgrass. Although it must be noted again that Lava Beds has some of the least-cheatgrass-invaded sage-steppe anywhere. This increases the regional significance of Lava Beds and is a feature of the monument that would be valuable to preserve.

4.4.3.1 Cheatgrass

Cheatgrass (*Bromus tectorum*) is a widespread invasive from Eurasia, occurring throughout the monument and Great Basin. It is one of the world's most significant invasive species problems (Daubenmire 1940, 1968, Mack 1981). Cheatgrass invasion in the Great Basin has been described by Aldo Leopold in *A Sand County Almanac* (1949) as a particularly significant environmental disaster that has come to be remarkably well-accepted. Thus, there can be very different levels of concern associated with cheatgrass invasion. Herein, we consider cheatgrass invasion to be a serious form of degradation because it substantially alters natural conditions and perhaps functions in the monument. This is also consistent with NPS policies and with the Klamath Inventory and Monitoring Network, which considered invasive species to be one of its top vital signs of ecological integrity.

Cheatgrass and other invasive species have been monitored in 138 fire monitoring plots in the monument under the NPS fire management program. Half of the plots have been within burns and half not. These data appear to be suited to a before-after control impact assessment design (BACI: Stewart-Oaten and Bence 2001) to determine the specific effects of fire on cheatgrass, with elevation and other factors as covariates. The approach would involve analyzing changes in cheatgrass before and after fire, and comparing the difference with changes in unburned plots over the same time period to account for changes caused by variation in rainfall and other factors other than fire. The analysis would need to consider a time period of several years after fire because the first year response may be unrepresentative of longer-term levels. This type of analysis would require use of all the monitoring data and addressing a variety of complications, and was therefore considered beyond the scope of this condition assessment. Ideally a BACI assessment would be completed with fire monitoring funding. Comparisons of burned vs. unburned plots without a before-after assessment assumes that differences with unburned plots are all caused by fire and does not account for other differences that could affect cheatgrass invasion in a plot. Therefore, we did not want to rely on these kinds of assessments. In the absence of a statistically-rigorous assessment of the fire monitoring data, we rely on findings from a large literature on the general relationship between cheatgrass invasion and fire, focusing on longer-term observations in the western Great Basin by eminent ecologist W.D. Billings.

Cheatgrass can, via its flammable nature, cause conversion to grasslands from shrublands and woodlands that are not fire-adapted and which naturally burn infrequently. Cheatgrass can also dominate in ponderosa pine forests after wildfires or prescribed fires (Kerns et al. 2006). It is favored by fire (D'Antonio and Vitousek 1992) and the scale of the fires which accompanied its spread in the early 1900s in the western Great Basin has been described as unprecedented (Billings 1990, 1994). In contrast, when the herbaceous vegetation in the sagebrush-steppe was occupied mainly by bunchgrasses, there was much less fine fuel to carry fire. Early surveys in the western Great Basin mentioned no fire scars on the landscape, nor did they mention cheatgrass (Billings 1990, 1994). Cheatgrass invaded overgrazed systems and once present, it occupied much of the open space between shrubs, greatly increasing the capacity for spreading fire.

Cheatgrass is especially prevalent after fire because fires often kill the woody vegetation and release a pulse of nutrients that increase cheatgrass growth (Billings 1990, 1994, Chambers et al. 2007). In contrast, woody vegetation in Great Basin plant communities is very slow to redevelop after fire, and may be slower when competing with cheatgrass (Billings 1990, 1994). In addition, sagebrush is an obligate seeder; it does not sprout and relies on seedling regeneration (Young et al. 2007). Sagebrush accumulates no seedbank from which to germinate and grow following fire. However, following fire, at higher elevations and more mesic sites in the sagebrush-steppe, bunchgrasses (which are also fire-associated, Wright 1985, Ellsworth and Kauffman 2010) may compete better with cheatgrass and bunchgrass abundance confers some resistance to cheatgrass invasion (Chambers et al. 2007, Davies et al. 2011, Condon et al. 2011).

J. Chambers and her colleagues (e.g., Chambers et al. 2007, Mazzola et al. 2010, Condon et al. 2011) have found that susceptibility to invasion by cheatgrass varies in different environments within the sagebrush-steppe and juniper woodland environments. The susceptibility pattern mirrors the pattern of invasion at Lava Beds: that is, invasibility varies across elevation gradients. It appears that this is closely related to temperature at higher elevations and soil water availability at lower elevations (Chambers et al. 2007). At lower elevations high variability in soil water and lower average perennial herbaceous cover may increase invasion potential.

Over time, cheatgrass may give way to a variety of other noxious weeds, such as yellow starthistle (*Centaurea solstitialis*) and medusahead (*Taeniatherum caput-medusae)* (Young et al. 2007). There do not appear to be any observations of this shift occurring at the monument, although yellow starthistle is present. The non-native that is most common with cheatgrass is sophia or flix weed (*Descurainia sophia*). Its growth is luxuriant after fire when nutrients are abundant, although it may not be as persistent as cheatgrass.

Invasive species control efforts do not target cheatgrass at Lava Beds because control of this species is considered futile. However, by protecting Great Basin ecosystems from livestock grazing, which decreases bunchgrasses that help inhibit cheatgrass, at least modestly, the monument is indirectly helping control cheatgrass. In addition, efforts to suppress fire may be considered indirect cheatgrass control, whether or not that is a stated goal of fire suppression efforts. An herbicide (imazapic) with the trade name “Plateau,” which interferes with the germination process in annual grasses, is available to help control grasses like cheatgrass (Garmoe 2010). It remains uncertain whether Plateau has any long-term benefits in controlling cheatgrass, and it may harm some native grasses (Baker et al. 2009). Research to date suggests that is it likely to be ineffective in controlling cheatgrass in the long-run (Baker et al. 2009, Owen et al. 2011).

With no direct means of controlling cheatgrass, the concern is that fire will cause the monument’s sagebrush-steppe and woodlands to be displaced by cheatgrass, and the native vegetation won’t return to its former state because a new state—cheatgrass dominated grassland—will be maintained by fire. Because the shrubs regrow so slowly, even fires as infrequent as 30 to 50 years could maintain vegetation dominated by cheatgrass at the monument, in place of native shrubs. The presence of cheatgrass could also slow the regeneration of pines following fires that occur in forests. But it is more possible at Lava Beds to control fire than compared to other lands, although fires can burn into Lava Beds from adjacent lands.

4.4.3.2 Other Invasive Plants

Until 1974, much of the monument was heavily grazed, significantly impacting the native vegetation and fragile soils, and thus likely increasing the spread of invasive plants. Currently, the monument's proximity to lands disturbed by agriculture makes its flora particularly vulnerable to invasive plants. Coordination of weed control efforts with the adjoining Tule Lake National Wildlife Refuge may slow future invasions from refuge lands where those are more weed-infested.

Out of the total of 63 nonnative plant species within the monument, 23 are considered invasive. This includes cheatgrass, which has already been discussed above. Invasive plants that have been subject to control efforts at the monument include common mullein (*Verbascum thapsus*)—the efficacy of which was studied by Rickleff (2006)—as well as horehound mint (*Marrubium vulgare*), stinging nettle (*Urtica gracilis*), bull thistle (*Cirsium vulgare*), yellow sweetclover (*Melilotus officinalis*) and Canada thistle (*Cirsium canadensis*). Perennial pepperweed (*Lepidium latifolium*) has not been targeted.

In 2007, the Klamath Network prioritized the monument's invasive species based on a combination of plot sampling data and the expert opinion of Dave Hays (former Lava Beds GIS specialist), who had previously conducted invasive species monitoring through several summers in the monument. A total of 44 non-native plant species were considered for ranking. Of these, three were classified as being in the colonization phase, eight in the establishment phase, and 15 species classified as being in the spread or equilibrium phases. With relatively few colonization and establishment species, all of them were included in monument-wide monitoring for early detection (Table 4). Spread/equilibrium species are shown in Table 5.

Table 4. Prioritized invasive species list for monument-wide monitoring at Lava Beds National Monument.

Scientific Name	Common Name	Invasion Phase	Ranking Score
Lepidium latifolium	Broad-leaved pepperweed	Colonization	0.917
Centaurea solstitialis	Yellow Starthistle	Establishment	0.776
Linaria genistifolia ssp. dalmatica	Dalmatian Toadflax	Establishment	0.712
Taeniatherum caput-medusae	Medusahead	Establishment	0.696
Thlaspi arvense	Penny-Cress	Colonization	0.622
Cirsium arvense	Canada Thistle	Establishment	0.612
Melilotus officinalis (and albus)	Yellow Sweetclover	Colonization	0.591
Isatis tinctoria	Dyer’s Woad	Establishment	0.532
Torilis arvensis	Hedge Parsley	Establishment	0.530
Salsola tragus	Russian Thistle	Establishment	0.527
Kochia scoparia	Kochia	Establishment	0.461

Table 5. Equilibrium species in Lava Beds National Monument and status of which species will be monitored in the backcountry, and which will not be, for the reason given.

Scientific Name	**Common Name**	**Ranking Score**	**Monitor in Backcountry?**
Bromus tectorum	Cheatgrass	0.618	N (ubiquitous)
Descurainia sophia	Pinnate Tansymustard	0.611	Y
Cirsium vulgare	Bull Thistle	0.609	Y
Verbascum thapsus	Common Mullein	0.584	Y
Tragopogon dubius	Goat's Beard	0.582	Y
Marrubium vulgare	Horehound	0.508	Y
Poa bulbosa	Bulbous Bluegrass	0.495	N (control infeasible)
Lepidium perfoliatum	Clasping Pepperweed	0.491	Y
Lactuca serriola	Wild Lettuce	0.479	N (control infeasible)
Urtica diocia	Nettle	0.418	N (potentially native)
Vulpia bromoides	Vulpia	0.404	N (ubiquitous)
Erodium cicutarium	Filaree	0.388	N (control infeasible)
Holosteum umbellatum	Jagged Chickweed	0.341	N (control infeasible)
Sisymbrium altissimum	Tumble Mustard	0.306	N (control infeasible)
Galium aparine	Bedstraw	0.259	N (possibly native)

Ideally a Before-After-Controlled-Impact (BACI) assessment (Stewart-Oaten and Bence 2001), as described above for cheatgrass, would be completed with fire monitoring funding to assess impacts of wildfires and prescribed fires on invasives.

4.4.3.2 Juniper

Juniper is a native tree that conflicts with some management goals if it expands into grasslands and shrub steppe. There, it can block vistas and reduce the cover of native grasses and shrubs (especially those important to greater sage-grouse, see section 4.5) via shading and competition for moisture. At the same time, juniper improves habitat suitability for some wildlife species and may support a diverse array of epiphytic lichens and bryophytes. The dynamics and determinants of juniper cover expansion or contraction are complex, as addressed in a recent review (Romme et al. 2009). The following conclusions from that review are relevant to the situation at Lava Beds:

1. Historically, surface fires that were of low intensity had a limited role in juniper/piñon woodlands of the Great Basin. When they did occur, they were likely patchy and small in extent (Baker and Shinneman 2004). At Lava Beds, Miller and Heyerdahl (2008) found evidence for far more frequent fires in forests adjacent to juniper woodlands than evidence for fire in the woodlands themselves. Other researchers have recognized that findings of frequent fire in Great Basin forests cannot be extrapolated

to the shrublands and woodlands that adjoin them, at least not in their pre-cheatgrass state (Baker and Shinneman 2004, Baker 2006, 2012). Juniper woodlands generally lack the fine fuels necessary to spread surface fires and therefore may burn extensively only during the most intense fires. These would be fires that occur during high winds, particularly during droughts that reduce fuel moisture to particularly low levels.

2. Stand dynamics are often driven by factors other than fire, in particular, climatic fluctuations.

3. Historical fire rotations varied from location to location but were generally very long (measured in centuries). Most woodlands exhibit little or no evidence that they sustained widespread fires during the lifespan of the stand.

4. Recent large, stand-replacing fires in juniper and piñon woodlands are, for the most part, similar [in behavior] to fires that occurred historically. Cheatgrass invasion may increase fire frequency in woodlands and lead to loss of woodlands, but fire behavior in existing woodlands has likely not changed.

5. Tree density and canopy have increased substantially during the past 150 years in many juniper and piñon woodlands, but have not changed or have declined in others. This may occur due to more fire, as facilitated by cheatgrass invasion or climate change. This is important because juniper growth may be lessened or reversed even without juniper control efforts.

6. Mechanisms for the increasing density of juniper are not well understood in most situations and may include recovery from past disturbances, natural ongoing expansion, livestock grazing, fire exclusion, and effects of climatic variability and rising carbon dioxide (CO_2). Livestock grazing increases juniper because juniper are unpalatable to livestock, so juniper is not consumed, while competing vegetation is. Fire exclusion cannot be the principal explanation for increasing density of junipers because fires were never frequent in woodlands. And in shrublands, fire was likely as infrequent as in woodlands, although evidence is weaker.

4.4.3.3 Historical Fire and Human Influences

Fire has opposing effects on cheatgrass invasion and growth of juniper. For some management goals, this presents a conundrum: Which should take precedence—minimizing invasion of an ecosystem transforming species (cheatgrass) by limiting fire, or allow fire because it is a natural disturbance and it might sometimes limit juniper expansion? This is complicated by the fact that it usually is not possible to return Great Basin systems to their historical condition, due partly to changed climatic conditions and constraints on burning (Young et al. 2007).

It nonetheless is helpful to consider the past fire regime and the reasons why we cannot return to it. However, reconstruction of intervals of past fires at a specific site is difficult or impossible, and the pre Euroamerican settlement fire frequency specifically in the sagebrush steppe of northeast California is unknown (Young et al. 2007). At a coarse landscape scale, ecologists have recognized that some stand-replacing fires have been a normal occurrence in sagebrush dominated communities, pre-dating Euroamerican settlement. It also is apparent that many shrubland areas of the Great Basin lack of fire evidence and/or adaptation to rapid post-fire regeneration (Billings 1994). For sagebrush-steppe in general, estimates of fire frequency range from 50-240 years (Baker 2006, Mensing et al. 2006).

At the monument, historical fire occurrence in woodlands and shrublands was inferred by Miller and Heyerdahl (2008) using a succession model as well as from sampling an inferred chronosequence, and consideration of the presence of old (>140 years old) junipers. Older plots were determined in part by conditions believed to represent old plots, which were then used to define old plots (many plots could not be aged). In addition the areas sampled for each vegetation type were limited to a relatively small area of the monument. The sagebrush-steppe sampled lacked old junipers, and it was therefore inferred that the presence of younger junipers currently means that fire was frequent in the past and kept out juniper. However, this does not consider the possibility that grazing, climate, and/or $C0_2$ may have facilitated the current juniper growth in areas where it did not previously occur. The onset of juniper increases in sagebrush-steppe at the monument coincides with both grazing and the end of the Little Ice Age. This ushered a general warming trend with periods of increased precipitation. Extensive recruitment of western juniper in Oregon in the 1800s and 1900s coincided with a climatically favorable period of high winter precipitation, and this occurred on both grazed and ungrazed sites. In addition, predictions of ring growth during the past 100 years were improved in regression models that included atmospheric CO_2 concentration along with precipitation (Knapp and Soulé 2008). Elevated CO_2 decreases transpirational water loss, increasing plant water use efficiency. It may also stimulate fine root production. Thus, an absence of old junipers does not necessarily indicate that frequent fire was the cause. In addition, fires during the 1800s could have been set to increase livestock forage (i.e. bunchgrasses). There was a spike in post-settlement fire in many areas of northeastern California (Young et al. 2007).

Settlement burning, in many areas, caused a conversion of sagebrush steppe to more grass-dominated vegetation, due to the fire sensitive nature of *Artemisia*. Once this conversion occurred, overgrazing eliminated the bunchgrasses in many areas. Since the early 1900s, intentional fires have been greatly reduced and current conditions reflect successional processes from an altered system. In the mid 20th Century, overgrazing left large areas of the sagebrush steppe where shrubs were not decimated by range burning, with little plant growth other than sagebrush (Young et al. 2007). The increase in shrubs may be a response to cessation of fire, but these fires were, at least in part, intentionally set by settlers to eliminate shrubs and promote herbaceous vegetation for livestock (Young et al. 2007). With fires fueled by cheatgrass in recent decades, shrubs have again decreased dramatically.

This context of human influences helps explain why there is uncertainty about the natural state of sagebrush steppe and woodlands. Shrub growth and interrelated overgrazing may both be viewed as causes of bunchgrass decline. This is complicated by suppression of fires that favor bunchgrasses, but may have been largely anthropogenic. The relative importance of each factor and level of appropriateness in the context of NPS goals is difficult to determine. Similarly, vegetation dominated by bunchgrass may seem natural because, prior to cheatgrass invasion, fires caused conversion to bunchgrass. However, these were sometimes deliberate burns to type-convert the shrublands to grasslands for grazing. Without these burns, there would have been more time for sagebrush-steppe vegetation to redevelop and occupy more of the landscape. An additional difficulty in assessing natural conditions for fire is that the flammability and spread of fire in the sagebrush steppe is now unconstrained because there are no areas lacking cheatgrass. There are no examples of how the vegetation burned when there was less herbaceous vegetation between the shrubs (bunchgrasses are often clumped with the shrubs).

The historic fire frequencies described by Miller and Heyerdahl (2008), which may be rough estimates due to the concerns mentioned above and because only a shot-time scale was investigated, varied from a composite fire scar frequency of 8-9 years in forests[10] from 1750-1904, to 150 or more years in sagebrush steppe. These estimates illustrate the wide range of natural variability that likely occurred at the monument, and how variation in fire may have occurred at relatively fine spatial scales.

In sum, there are a multitude of factors that make the definition of a reference condition for fire extremely difficult at the monument, and restoring former conditions is not a realistic goal. This in turn makes it difficult to assess current conditions with respect to fire. Because current fires have different ecological effects than historic fires, due to the proliferation of cheatgrass, it is inappropriate to compare the influences of present and past fire. We can interpret the effects of two possibilities only: the effects of modern fires, and the effects of no fire.

4.4.3.4 Current Fire

The current fire regime at the monument is driven mainly by human ignitions. Overall, out of a total of 36,514 ha burned since 1910, 14,158 ha burned in lightning caused fires, 21,039 burned from human ignited fire, and 1,316 ha burned from unknown causes of ignition. All of the vegetation types at the monument experienced only wildfires prior to 1973 (Figures 16 a-d). There was a large amount of wildfire (almost 20,000 ha) in the 1940s, and relatively little any other time prior to the 1970s. About one-third of this wildfire resulted from human ignitions. Since 1973, most fire has been from human ignitions and deliberate burning, although wildfire in 2008, the lightning-ignited Jack fire, did burn about 2,000 ha of sagebrush steppe.

In Figures 16 a-d, recent fire at the monument is summarized for each broad vegetation type as of 1979, when the most detailed vegetation map was prepared by Erhard (1979)[11]. The distribution of some of the mapped vegetation has changed since then as a result of fires. Some areas mapped as grassland in the 1970s that burned prior to that may have been sagebrush-steppe at the time of fire, and were converted to grasslands by fire. Thus, the area of grassland that burned is likely to be considerably exaggerated and may have been mostly sagebrush-steppe. A vegetation map from the time each major fire occurred would be needed to provide an estimate of the cumulative burned acreage of each vegetation type. This is not possible.

Even with such maps, there would be inaccuracy because considerable area within the perimeter of burns, called residuals, may not burn (Gutsell and Johnson 2007). Residuals occur in most fires and may be important for wildlife and as postfire colonization sources. Residuals are especially likely in vegetation like sagebrush-steppe and woodlands, particularly in landscapes like at Lava Beds, where there are rocky areas with insufficient fuel to carry fire. Because of this, it is likely that mapped burned area may be overestimated by a considerable amount, perhaps 10-20 percent, at least in the case of wildfires. In prescribed fires, residuals may get burned with the assistance of fuel from drip torches. However, because prescribed burns may often occur in conditions less favorable to fire than wildfires,

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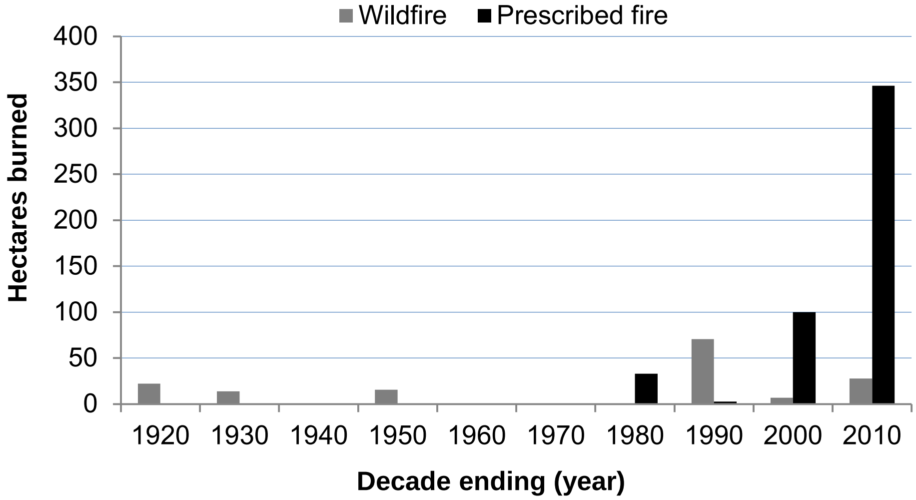
[10] The composite fire interval is a different metric than the average fire interval. It can be influenced strongly by the sampling intensity and scale. The average fire interval is captured by the fire rotation.

[11] Vegetation communities mapped were combined into the broad categories using the following criteria: Forests included all communities with ponderosa pine, the only tall conifer listed as a dominant; grasslands included all communities with no woody species listed as dominants; sagebrush-steppe included all communities having one or more shrubs listed as dominants and no juniper or mountain mahogany; woodlands included all communities in which juniper and/or mountain mahogany were dominants and ponderosa pine was not dominant.

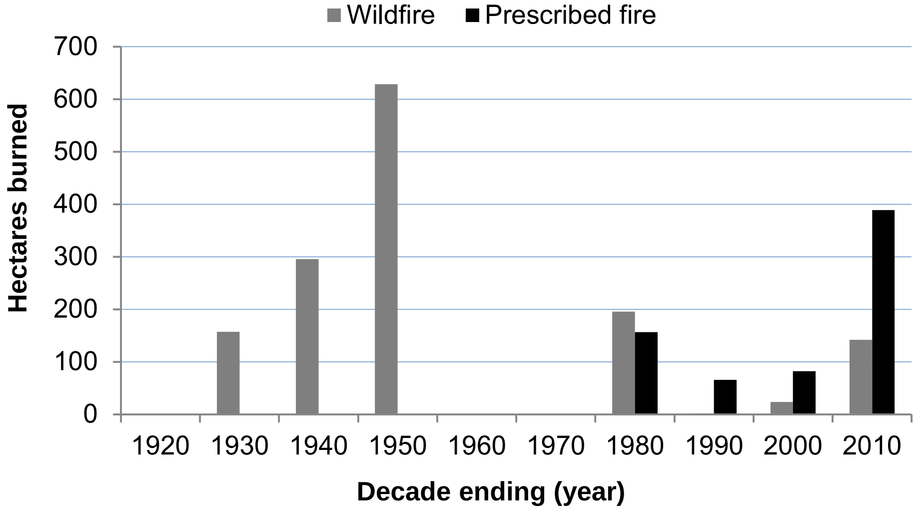
there may also be more unburned area. It is not uncommon to have areas with individual shrubs burned or partly burned with the help of drip torch fuel, and inter-shrub areas unburned.

Rotations of fire from the time period 1910-1973, in which no prescribed fires occurred, were very long for the ponderosa pine forests because these forests experienced almost no fire (Table 6). With the introduction of prescription burning in 1973, the amount of fire in these forests has increased considerably. The 63 year fire rotation since 1990 is still longer than the fire frequency (3-37 years from 1750-1904) recorded on ponderosa pines on three buttes by Miller and Heyerdahl (2008). It is not clear if areas off the buttes would have burned with the same frequency as areas on the buttes and whether some historic fires were the result of settlers.

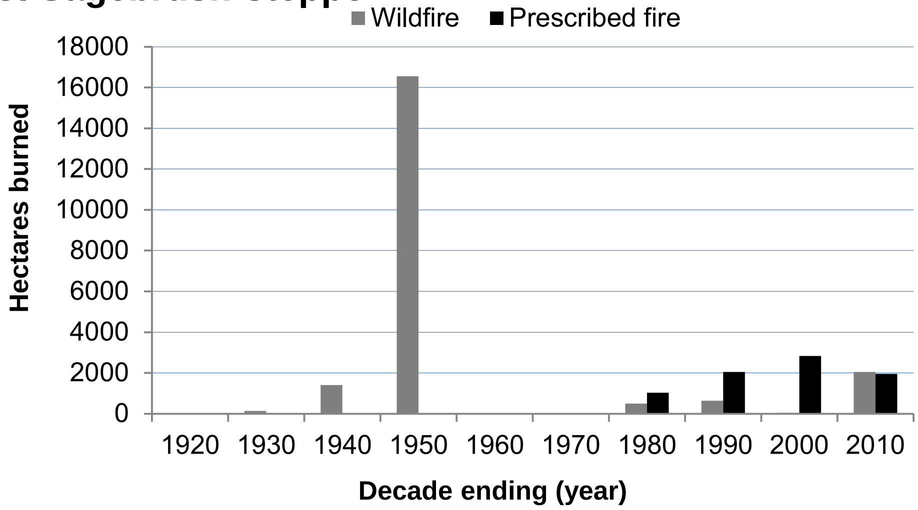
In contrast, rotations for sagebrush-steppe over the 1910-2010 time period, and for woodlands since prescription burning began in the 1970s (Table 6), were an order of magnitude shorter (i.e., more fire) than those estimated for sagebrush-steppe or woodlands in the Great Basin prior to fire suppression (Romme et al. 2009, Baker 2006). However, for Lava Beds, Miller and Heyerdahl (2008) note that absence of large live or dead junipers is an indication of sagebrush vegetation burned frequently enough, possibly <25 years, to have precluded juniper growth (Miller and Heyerdahl 2008). Alternatively, it could also be that absence of old-growth junipers in sagebrush may be due to climate that was not suitable over a long-enough time span to allow for development of such junipers in the sagebrush areas where juniper is currently encroaching (Romme et al. 2009). In the sagebrush where live or dead old-growth junipers do occur, Miller and Heyerdahl (2008) estimate that fire intervals were much longer, with >80 year fire-free periods. These periods are substantially longer than those that currently occur under the prescribed fire regime (Table 6). In woodlands, fire rotations have decreased dramatically (i.e., more fire) from 161 years during the wildfire era to only 29 years in the prescribed burning era. In the juniper woodland vegetation sampled by Miller and Heyerdahl (2008), live junipers over 250 years old may indicate that fire rotations were very long, perhaps centuries long. So, a substantial increase in fire during the prescribed burning era over historical levels appears to be occurring in most sagebrush areas and woodlands at the monument.



A. Forest



B. Grasslands


C. Sagebrush-steppe

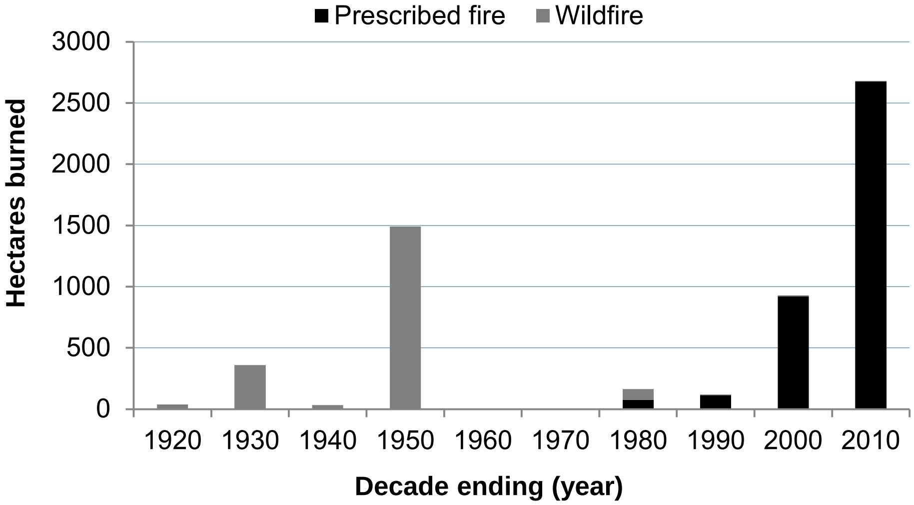

D. Woodlands

Figure 16 a-d. Fire occurrence by decade in major vegetation types at Lava Beds. Vegetation is from 1970s mapping by Erhard (1979). Some vegetation would have differed at the time fire occurred than when the vegetation was mapped.

Table 6. Fire rotations in major vegetation types at Lava Beds for different time periods since 1910.

Vegetation	Fire rotation (years)		
	1910-1970	1971-2010	1990-2010
Forest	1772	101	63
Grassland	119	79	67
Sagebrush-steppe	33	35	29
Woodlands	161	52	28.6
All	*53.1*	*44*	*32*

4.4.3.5 Climate Change and Future Fire

Fire regimes will change in the future, but exactly how is difficult to predict due to climate variations and potential modifications in fire suppression approaches. In terms of climate, fire frequency in the Pacific Northwest has been found to be correlated with the warm phase of Pacific Decadal Oscillation (PDO) (Beaty and Taylor 2008, Miller et al. 2009), which oscillates on a frequency of about 25 years (a complete cycle is about 50 years). This relationship may be enhanced by fire suppression, or alternatively, the relationship may have been weak prior to fire suppression (Morgan et al. 2008, Heyerdahl et al. 2008). From the 1970s until recently, PDO has been in the warm phase, but has recently shifted to a cool phase (Mantua 2000) particularly in the last 4-5 years. Thus, in the absence of other climate factors, fire in the Pacific Northwest should occur at lower amounts than the last 25 years.

However, this does not consider the effects of climate change. A recent analysis predicts a near doubling by the 2080s of the mean area burned between 1980 and 2006 in Washington (Littell et al. 2010). This prediction assumes decreased summer precipitation as a main driver of more fire, but data indicate a pattern of increasing, not decreasing, summer precipitation in the Pacific Northwest (Mote 2003, Hamlet et al. 2007). In terms of actual patterns in fire occurrence under changing climate, there is no ongoing trend in the proportion or amount of fire that is high in severity in the drier portions of the Cascades (Hanson et al. 2009) or Pacific Northwest. Thus, there may be factors that are mitigating the effects of warmer temperatures on fire behavior. In dry fuels, wind speed is the most important factor in determining fire behavior (Cruz et al. 2004, Cruz and Alexander 2010). Recent research indicates that with climate change, the wind speed probability distribution may be shifting towards slower winds, particularly in mid-latitudes (Pryor and Barthelmie 2010, Pryor and Ledolter 2010). Pryor and her colleagues found that wind speeds appear to be waning in most of the USA, in many locations by more than 1 percent per year. Slower winds may be disproportionately important because of the exponential relationship between wind speed and fire intensity (Byram 1959, Albini and Baughman 1979).

There also is a trend of increased summer precipitation in the Pacific Northwest (Mote 2003, Hamlet et al. 2007). In forests, this could mitigate the effects of warming temperatures on fuel moisture, a second key determinant of fire behavior. However, in shrublands and woodlands, increased precipitation may increase fire risk due to its effects in promoting more cheatgrass. Recall that Billings (1994) found a strong relationship between precipitation and fire in his study area in the western Great Basin. Another factor that will affect future fire is ignitions by humans. Human ignitions are rising in many areas due to human population growth, more roads, etc. (Syphard et al. 2009). However, these factors should have less effect at the monument, where there may be greater potential to manage human ignitions than there is on other lands in the Great Basin.

In sum, it is very difficult to predict future fire amounts, but they are most likely to increase, perhaps only slightly, unless climate change causes a reduction in cheatgrass. In that case, fire would likely decrease.

4.4.4 Indicators and Criteria to Evaluate Condition and Trends

The indicators of vegetation structure, function, and composition in Table 7 were chosen for use in this NRCA to evaluate condition and trends in the monument's vegetation.

Table 7. Vegetation indicators and the ecological conditions for which they apply.

Indicator	Conditions tracked
Cheatgrass	Vegetation conversion to cheatgrass/loss of sagebrush and woodlands
Other Invasives	Vegetation/ecosystem transformation
Juniper	Sagebrush-steppe conversion to wooded shrublands or woodlands.
Sagebrush & woodland	Loss of sagebrush and woodlands
Bunchgrass	Abundance of bunchgrass
Rare plants	Occurrence of rare species

Each of these indicators is strongly controlled by fire. Fire itself could be an indicator, but it would be necessary to describe the effects of fire separately for the indicators in Table 7. This is essentially what we have done below, so it would be redundant to also include fire as an indicator.

The effects of fire on the different vegetation indicators are shown in Figure 17 a-b. This is a general conceptual model based on literature discussed above. The specific relationships between fire frequency and dynamics of different elements of vegetation need to be determined through experiments and monitoring at the monument. Monitoring of vegetation throughout the monument by the Klamath Network will be helpful in this regard. We will refer to this figure in discussing the individual indicators next.

Figure 17a. Conceptual model of general relationships between fire frequency, as measured by the fire rotation, and the abundance of cheatgrass, sagebrush-steppe, and woodlands at lower elevations of the monument.

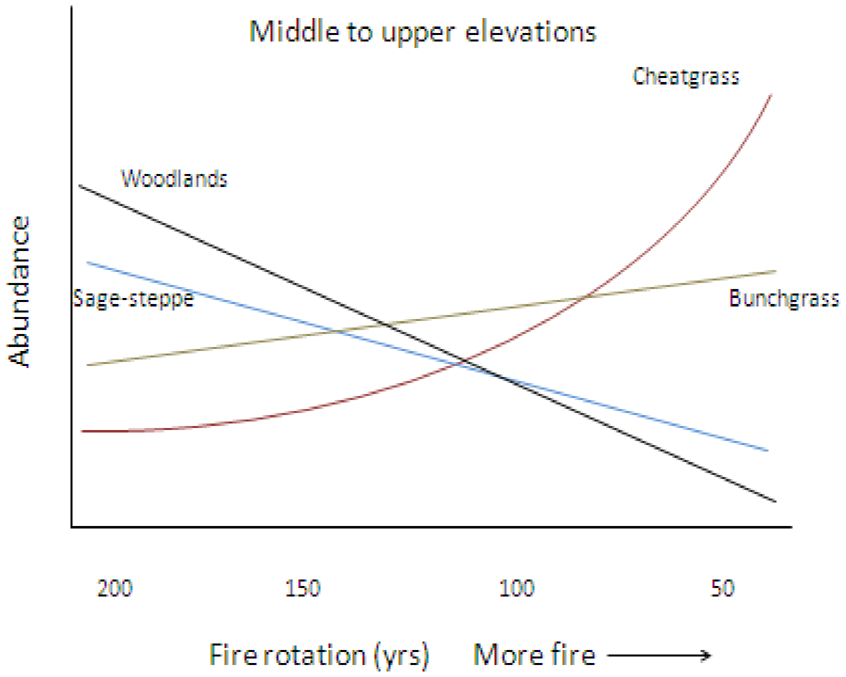


Figure 17b. Conceptual model of general relationships between fire frequency, as measured by the fire rotation, and the abundance of cheatgrass, sagebrush-steppe, and woodlands at middle and upper elevations of Lava Beds.

4.4.4.1 Cheatgrass

Criteria
"Good" condition would be a complete lack of cheatgrass invasion. "Somewhat Concerning" would be a low amount of cheatgrass, and "Significant Concern" would represent widespread cheatgrass cover with abundance in a given area increasing.

Condition and Trends
The condition and trends for this indicator are both rated *Significant Concern*. Figure 18 shows the distribution and general abundance of cheatgrass in the 169 vegetation mapping plots done at the monument. It was found in every plot and was often one of the dominant species. Cheatgrass only arrived in the western Great Basin about 100 years ago, and perhaps more recently at the monument, yet it is now found nearly everywhere in the monument where terrestrial vegetation can grow. Moreover, cheatgrass overwhelmingly dominates at the northern end of the monument and in many other areas that have burned relatively recently. The alteration may be irreversible because there is no means of controlling cheatgrass and cheatgrass invasion may ensure that fires continue to burn and favor more cheatgrass. Nonetheless, aside from recently burned areas in lower elevations of the monument, cheatgrass cover appears to be considerably less extensive at the monument than in many similar areas of the Great Basin. This may be due to a past history with less human disturbance during the settlement period (overgrazing and fire), or perhaps the volcanic substrata at the monument, climate, or other factors. The first cattle grazing in the vicinity of the monument began around 1873. In 1910, the first cheatgrass was reported at sheep bedding grounds in the area which is now Lava Beds National Monument. About 1945, some of the first attempts to re-seed perennial grasses into sites infested with cheatgrass were completed.

The trend in fire, which drives the cheatgrass invasion process, has been an increase since the onset of prescription burning in the 1970s (Table 6). This increase in fire has been particularly rapid in woodlands. All the fire in woodlands, as mapped by Erhard (1979), in recent decades has been prescribed (Figure 16d). Cheatgrass invasion may be slowed if prescription burning is reduced and fire in sagebrush-steppe and woodlands is suppressed. The current rotations of fire in both woodlands and sagebrush-steppe will lead to loss of woodlands and sagebrush-steppe in favor of cheatgrass (Figures 17a-b). This may be less severe in upper and middle elevations because species that can resprout following fire, like bitterbrush, are more common than at lower elevations.

Assessment Confidence and Data Gaps
High Certainty. Cheatgrass invasion and increasing dominance are obvious within the monument, at least at its north end.

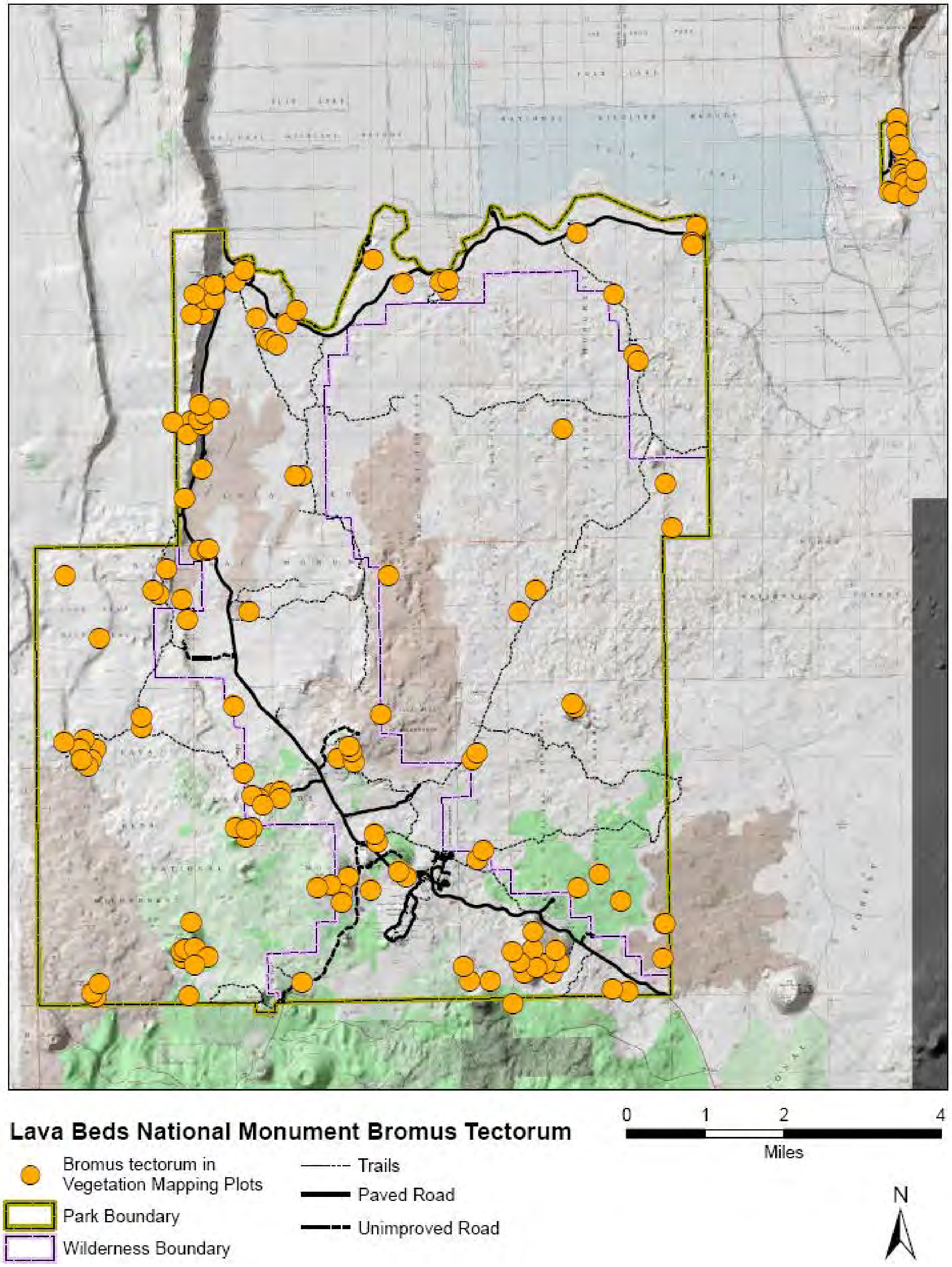


Figure 18. Location of cheatgrass in vegetation mapping plots (2009-2011) at Lava Beds National Monument. Cheatgrass occurred in every plot sampled (n=169).

4.4.4.2 Other Invasive Plant Species

Criteria

"Good" condition would be a complete lack of other invasive non-native plants. "Somewhat Concerning" would be a low amount of invasive non-native plants, and "Significant Concern" would represent extensive and rapidly increasing cover of multiple invasive plant species with consequent reductions in native plant cover.

Condition and Trends

The condition and trends for this indicator are both rated *Significant Concern*. There are at least 63 invasive plant species in the monument and control of most of these has not been achieved. There are new invasives arriving all the time from surrounding lands, which are highly disturbed. Since 2010, the monument has implemented a cyclic weed monitoring and treatment program within areas of high visitor use (roads, parking areas, trails). Roughly one-third of the monument is surveyed each year and 37 invasive species have been documented during these surveys. Treatment priorities are based on plant location, abundance, and invasive potential. The following nine species are identified as high priority for treatment: Scotch Thistle (*Onopordum acanthium*) Canada Thistle (*Cirsium arvense*), Medusahead Rye (*Taeniatherum caput-medusae*), Bull Thistle (*Cirsium vulgare*). Cereal Rye (*Secale cereale*), Tumble Mustard (*Sisymbrium altissimum*), goat's beard (*Tragopogon dubius*), prickly lettuce (*Lactuca serriola*), and common mullein (*Verbascum thapsus*). In 2011, sampling occurred between June 6 and June 13, then again on June 20 and 21—the height of the flowering season for most invasive species—and 26 segments, or 65.15 road and trail kilometers, were surveyed. By descending abundance, that effort detected goat's beard, sweet clover (*Melilotus* sp.), bull thistle, Canada thistle, and sophia (*Descurainia sophia*). Table 8 shows the percentage of segments infested by each species.

There are no comprehensive sources of information on the locations and extent of invasions by non-native plants. There are records of where control efforts have been undertaken and there are records from fire monitoring (FMH) plots. In addition, vegetation sampling for an ongoing vegetation mapping project used a relevé approach to subjectively locate plots across the range of variation in vegetation types. Figures 19 and 20 summarize the invasives found in these plots. None of these data were collected from a probability sample of the entire monument, or even of areas necessarily at highest risk of invasion by non-native plants. Where fire treatments have been done, those data need to be collected and analyzed with a Before-After Control Impact assessment (BACI: Stewart-Oaten and Bence 2001) analysis.

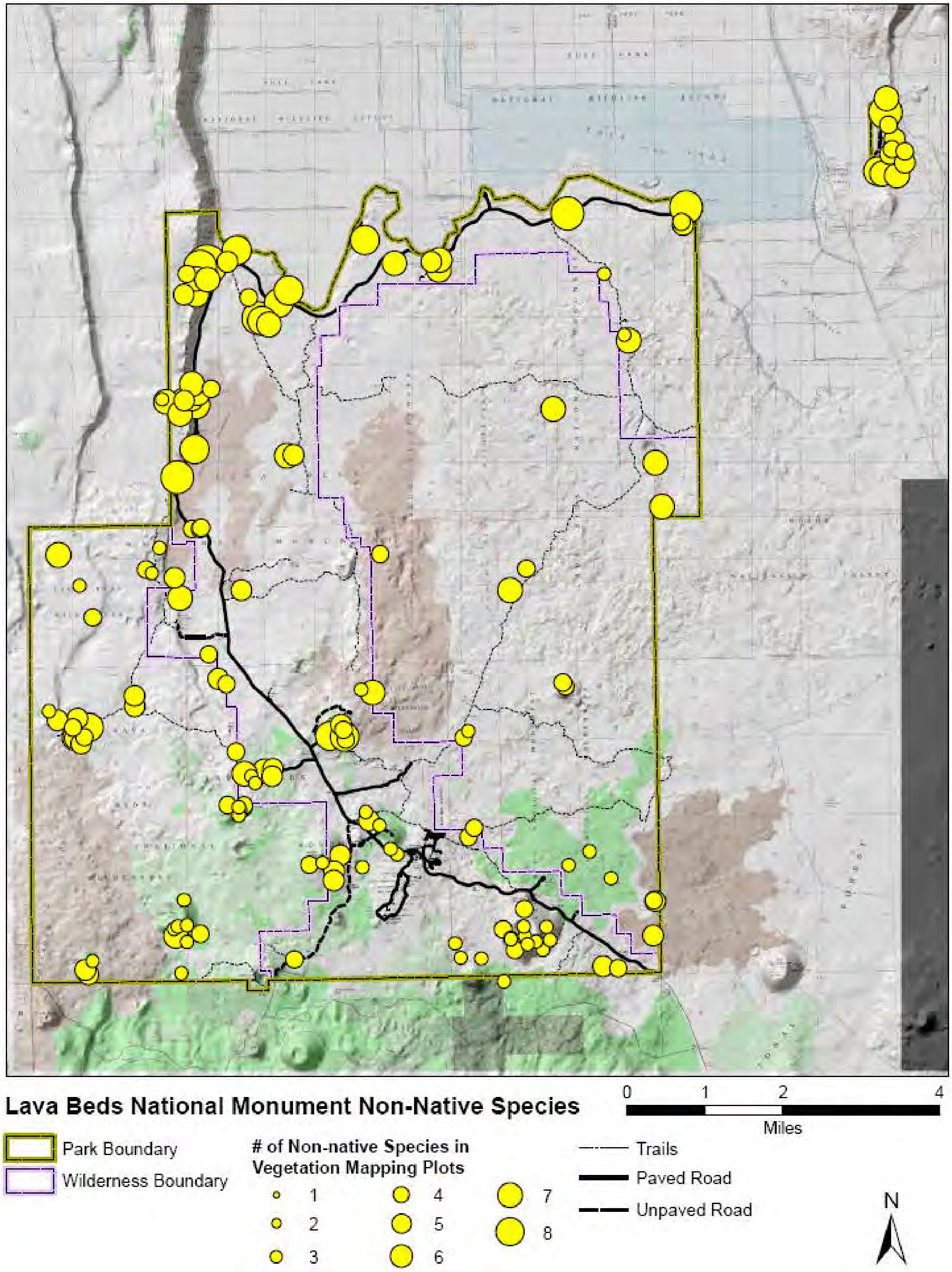


Figure 19. Locations of invasive plants documented at Lava Beds National Monument in 169 vegetation mapping plots.

Table 8. Summary of prioritized invasive species early-detection monitoring at Lava Beds NM. Note: an * indicates species surveyed only in wilderness areas.

Scientific Name	**Total # of Infestations**	**# of Segments Infested**	**% of Segments Infested**
*Descurainia sophia**	31	7	26.92
*Tragopogon dubius**	29	10	38.46
Melilotus sp.	6	3	11.54
Cirsium vulgare	2	2	7.69
Cirsium arvense	1	1	3.85

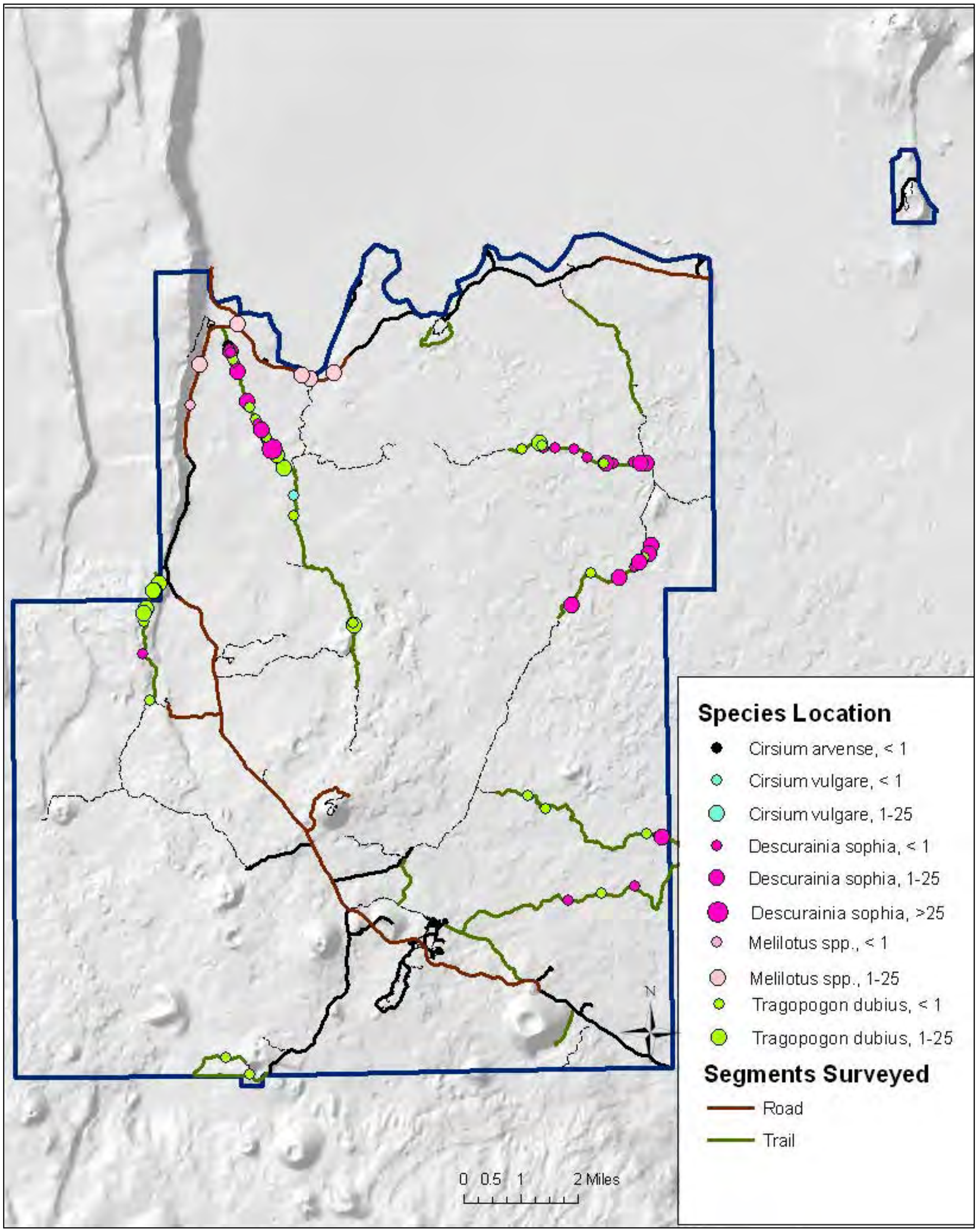


Figure 20. Locations of invasive plant species recorded in FY 2011 Invasive Species Early Detection monitoring by the Klamath Network. The circle size denotes the size of the infestation.

Invasions by sophia (*Descurainia sophia*) often coincide with locations that have been most invaded by cheatgrass. The growth of *Descurainia* may in part come at the expense of cheatgrass or vice-versa, although we are not aware of research on this. Most all other infestations are small individual locations, and it does not appear that any of these species are in the process of transforming ecosystems. Nonetheless, caution to avoid underestimating invasive plants is particularly warranted in an environment like Lava Beds. Nearby lands are managed by the US Forest Service, which conducts widespread fuel treatments; these treatments have been found to promote invasives (Stephens et al. 2012). Impacts by non-native invasives other than cheatgrass may seem subordinate in comparison to cheatgrass, but they are still potentially very significant concerns.

In general, it can be assumed there are ever increasing numbers of potential invaders. If more fire occurs due to cheatgrass growth, climate change or other factors, invasions will follow. However, these invasions are unlikely to add much to the degradation that is already being caused by cheatgrass.

Assessment Confidence and Data Gaps

Medium Certainty. More remote areas of the monument that are not traversed by trails were poorly sampled by most previous vegetation surveys. However, these areas are less likely to be invaded. There is a need for comprehensive monitoring of all burn areas and mechanically disturbed areas, if there are any, and appropriate statistical analysis of the data. Ideally, an early detection program for prioritized species that are not already well established (Table 8) could be implemented within fire management. Such a program should be designed to feed into rapid response control programs and adaptive management as shown in Figure 21. There are no specific data on invasive plant species' trends in Lava Beds National Monument.

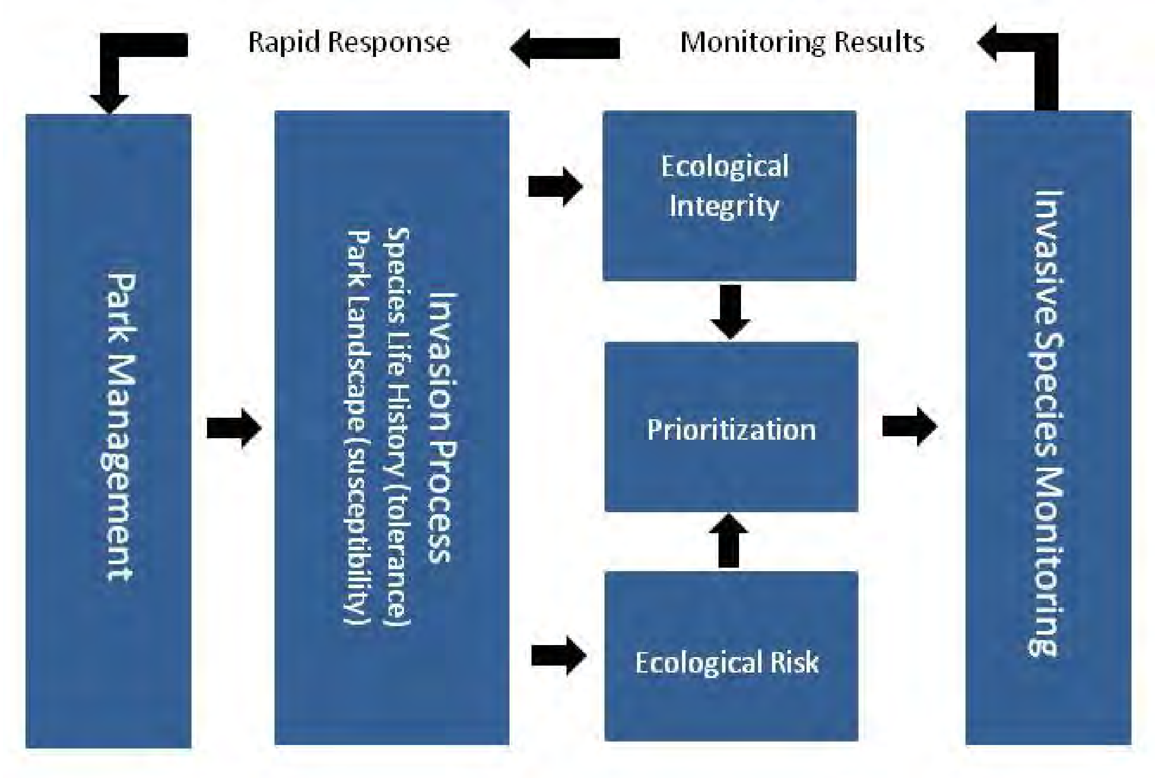


Figure 21. Conceptual model of an invasive species early detection program and the feedbacks with management (From Odion et al. 2010).

4.4.4.3 Juniper

Criteria
"Good" condition would be a complete lack of increased juniper growth where juniper conflicts with other critical resource management goals. "Somewhat Concerning" condition would be a low amount and "Significant Concern" would represent extensive and rapidly increasing juniper growth leading to substantial changes that compromise chosen ecosystem-level management goals. A specific quantitative amount of juniper growth that would constitute a significant concern is not possible to identify due to uncertainty in reference conditions and because of site-specific considerations. It is also important to note that excess juniper growth is a cultural resource management issue. The monument has a management mandate to maintain the visual abundance of juniper at levels like those at the time of the Modoc Indian war. Were this not the case, juniper growth may not be as much a cause for concern.

Condition and Trends
Somewhat Concerning. Photos show the southern end of Lava Beds National Monument to be lacking in juniper around the time of the Modoc Indian War in the 1870s or not long after. Juniper is now widely scattered in this area and visually quite apparent, but there are no recent data on trends in juniper cover throughout the monument. Such an analysis may be possible with historical aerial photography. LANDSAT imagery is of limited utility for calculating trends because it covers a relatively short time span. Juniper may also be less abundant and less ecologically impacting than it appears because it is extremely conspicuous, even at low levels of abundance.

Active management to reduce juniper cover in areas where it is increasing began in 2007 with the removal of junipers over 1200 acres at the northern end of the monument, and can slow the spread of juniper if this is desired. In the past, juniper abundance fluctuated naturally with climate in ways that are poorly understood, and its current dynamics are not necessarily related to controllable human actions (Romme et al. 2009). In addition, the amount of fire in woodlands and sagebrush-steppe (Table 6) where juniper is increasing is likely to result in future reduction in juniper.

Assessment Confidence and Data Gaps
Medium Certainty. Some expansion of juniper cover in the monument during the last century is apparent, but there is much uncertainty regarding past, present, and future dynamics of juniper. Monitoring by the Klamath Network will help considerably to fill this data gap. Future analysis and synthesis reports concerning vegetation monitoring findings will also evaluate the latest literature and ecological implications of any vegetation trends detected. This should be very helpful to monument management goals for juniper.

4.4.4.4 Sagebrush Steppe and Woodlands

Criteria
"Good" condition would be maintenance of a characteristic amount of sagebrush-steppe and woodlands. "Somewhat Concerning" and "Significant Concern" would represent increasingly greater loss of sagebrush-steppe and woodlands with consequent compromise of chosen goals for overall ecosystem management.

Condition and Trends

Significant Concern. Although quantitative data are lacking, a decline in sagebrush cover in the monument over the last century is apparent. Paralleling this decline is the documented disappearance from the monument of historical populations of the sagebrush-dependent greater sage-grouse, and possibly the decline of other sagebrush-dependent birds. Future loss of fire-sensitive sagebrush cover may be unavoidable because fires are inevitable, and fires (whether prescription or wild) are followed by invading cheatgrass, especially at lower elevations.

Assessment Confidence and Data Gaps

Medium Certainty. The cover of sagebrush has clearly diminished within the monument, but the exact areas and rate of decline are unmeasured. It is well known that sagebrush steppe and woodlands are sensitive to fire, and that fire at most locations within the monument will lead to more cheatgrass, more fire, and less sagebrush in a self-reinforcing cycle. Monitoring by the Klamath Network will help considerably to fill data gaps regarding changes in sagebrush-steppe. Future analysis and synthesis reports of vegetation monitoring findings will also evaluate the latest literature and ecological implications of any vegetation trends detected. This should be very helpful to monument management of sagebrush-steppe.

4.4.4.5 Bunchgrasses

Criteria

“Good” condition would be maintenance of a characteristic amount of bunchgrasses. “Somewhat Concerning” and “Significant Concern” would represent increasingly greater displacement of bunchgrasses by invasive non-native plants.

Condition and Trends

The condition and trends for this indicator are both rated *Somewhat Concerning*. The prohibition on grazing and the ongoing occurrence of large amounts of fire is favorable to more bunchgrass cover, particularly in the mid-elevations where bunchgrasses may be somewhat limited by shade, for example, in the understory of juniper. In fact, if amounts of fire are uncharacteristically high, fire could create amounts of bunchgrasses that are also uncharacteristically high. However, bunchgrasses in burned areas at lower elevations must coexist with potentially dense cover of cheatgrass, which will likely reduce the amount of bunchgrasses.

Assessment Confidence and Data Gaps

Medium Certainty. Trends in bunchgrasses within the monument are unmeasured, but based on limited knowledge of plant community dynamics and past fires, some decline can be assumed. Little is known about the long-term dynamics between bunchgrasses and cheatgrass, in particular, the long-term recruitment and mortality rates of the bunchgrasses and the impacts of climate change. Because bunchgrasses have been displaced much more by cheatgrass at lower elevations, it is likely that bunchgrasses will be more negatively affected in drier environments in general, which is consistent with the susceptibility of Great Basin vegetation to invasion by cheatgrass being higher at lower elevations where bunchgrasses are less common (Chambers et al. 2007). At Lava Beds, more fire also appears to be occurring at lower elevations. Monitoring by the Klamath Network will help considerably to fill data gaps regarding changes in bunchgrasses. There is also research by Eva Strand, University of Idaho, on bunchgrass abundance that may help elucidate trends. Future analysis and synthesis reports of vegetation monitoring findings will also evaluate the latest literature and ecological implications of any vegetation trends detected. This should be very helpful to monument management of bunchgrasses.

4.4.4.6 Rare Plants and Diversity of Native Plant Species

Rare plants contribute disproportionately to regional diversity. However, analyses of statistical power and other issues have shown that rare plants are impractical to use as ecological indicators (Manley 2004, Sarr et al. 2007). Thus, the policy of the Klamath Network has been to avoid focusing on just rare species and instead to sample all vegetation. Diversity patterns (i.e., composition) within communities of vegetation are a key component of this vital sign.

Criteria

"Good" condition would be represented by the sustaining of naturally-occurring turnover rates of all native plant species currently inhabiting the monument. This includes sustaining metapopulations and gene pool diversity. "Somewhat Concerning" and "Significant Concern" would represent increasingly high turnover rates of all native plant species currently inhabiting the monument.

Condition and Trends

Indeterminate. None of the monument's plants are federally listed as threatened or endangered, and no species is endemic to the monument. However, Erhard (1979) describes a distinctive plant association—purple sage and fernbush scrub (*Salvia dorrii* and *Chamaebatiaria* sp.)—which he considered to be endemic. Eight plants occurring within the monument or just outside the monument's boundary are listed by the California Native Plant Society (CNPS) as species of concern (Table 9). Two have never been collected within the monument: *Hulsea nana* was collected from Cinder Butte, just south of the monument, and *Iliamna bakeri* was collected just south of the monument. The other six have all been collected within the monument. *Penstemon cinereus* was collected long ago from the monument but it is currently considered to be a minor variant of the more widespread *Penstemon humilis* var. *humilis*. Thus, of the eight plants listed in Table 9 only five are currently found within the monument boundary. Among these species, *Salvia dorrii* might be threatened by too-frequent fire. The monument contains a single grove of quaking aspen, a tree species renowned as wildlife habitat. It is located near Heppe ice cave, and was partially burned during the Big Nasty prescribed fire of 2007. Resprouting trees are being monitored.

Trends in the monument's rare plant species are unknown. Whether some species have been extirpated from the monument is impossible to say, partly because the exact locations of many historically-reported species were not described, at least not with the precision currently available with GPS. There is no particular reason to assume that any species that occurred in the monument has been extirpated from the monument.

Assessment Confidence and Data Gaps

Although the monument's flora has been relatively well inventoried, no permanent plots or transects representing a probabilistic sample of plant communities in the monument have been monitored over time. However, the Klamath Network established 40 permanent monitoring plots in 2012 and collected the first year of data. These plots will be resampled every three years. Additional efforts will be needed to capture trends in rare plants.

Table 9. Rare plants listed by the California Native Plant Society (CNPS) from Lava Beds National Monument or the immediate vicinity (from Smith 2009).

Species Name	Global Rank1	State Rank2	CNPS List3	Vouchered from monument
Dimeresia howellii	G4?	S2.3	2.3	Y
Erigeron elegantulus	G4G5	S3.3	4.3	Y
Hackelia cusickii	G5?	S3.3	4.3	Y
Hulsea nana	G4	S2.3	2.3	N
Iliamna bakeri	G4	S3.2	4.2	N
Penstemon cinereus	G4	S3.3	4.3	Y
Rorippa columbiae	G3	S1.1	1B.2	Y
Salvia dorrii var. incana	G5T5	S1S2	3	Y

[1]Global Ranking

The global rank (G-rank) reflects the overall condition of an element throughout its global range.

Species or Community Level

G4 = Apparently secure but factors exist to cause some concern; i.e., there is some threat, or somewhat narrow habitat; G5 = Population or stand demonstrably secure to ineradicable due to being commonly found in the world.

Subspecies Level

Subspecies receive a T-rank attached to the G-rank. The T-rank reflects the global situation of just the subspecies or variety.

[2]State Ranking

The state rank (S-rank) is assigned much the same way as the global rank, except state ranks in California often also contain a threat designation attached to the S-rank.

S1 = fewer than 6 EOs *or* fewer than 1,000 individuals *or* less than 2,000 acres; S1.1 = very threatened; S1.2 = threatened; S1.3 = no current threats known; S2 = 6-20 EOs *or* 1,000-3,000 individuals *or* 2,000-10,000 acres; S2.1 = very threatened; S2.2 = threatened; S2.3 = no current threats known; S3 = 21-80 EOs *or* 3,000-10,000 individuals *or* 10,000-50,000 acres; S3.1 = very threatened; S3.2 = threatened; S3.3 = no current threats known.

[3]CNPS Ranking

1B = Rare or Endangered in CA and elsewhere; 2 = Rare and Endangered in CA, more common elsewhere; 3 = Need more information; 4 = Plants of Limited Distribution. The extension is added to the List rank following a decimal point: .1 = Seriously endangered in CA; .2 = Fairly endangered in CA; .3 = Not very endangered in CA.

4.5 Changes in Aboveground Wildlife

4.5.1 Background

As used herein, “aboveground wildlife” refers to terrestrial vertebrates and invertebrates, and excludes strongly cave-dependent species such as bats. The opportunity to observe wildlife in natural settings is an important reason why many people visit parks. Moreover, wildlife species serve vital ecological roles, such as pollinators, nutrient cyclers, and seed transporters.

The monument spans three very different habitats—ponderosa pine forest, juniper-mountain mahogany shrub, and sagebrush-bunchgrass steppe. Consequently, it supports a fair variety of aboveground wildlife species. The number of species is limited by the near-absence of surface water; as noted earlier, the monument has no permanent ponds, lakes, streams, or wetlands. However, some of the larger, more mobile, and less water-dependent birds and mammals undoubtedly move regularly between the monument and wetlands of the nearby Tule Lake National Wildlife Refuge. Only a small percentage of the monument’s hundreds of wildlife species inhabit cave environments, but many others obtain water at the mouths of caves or from melting ice a short distance within. No vertebrates are endemic to the monument. Neither the monument nor any inland areas at similar elevation and within several dozen miles comprises the northern boundary of any vertebrate’s geographic range in western North America.

4.5.2 Regional Context

As well as providing the most extensive habitat for cave-dwelling species for hundreds of miles around, the monument provides some of the most extensive ungrazed grassland and shrub steppe for dozens of miles around. Thus, it may serve as a source for colonizing individuals as they disperse into fragments of somewhat less suitable habitat in the surrounding area.

4.5.3 Issues Description

4.5.3.1 Fires and Natural Succession

Throughout much of the West, decades of active fire suppression have dramatically altered vegetation and thus wildlife species composition. However, the opposite may be the case within this monument’s boundaries. Here, the incidence of fires appears to have *increased* from historical levels in the woodland and sagebrush areas. The high incidence of relatively recent fires may have been facilitated (and caused) by the early establishment and rapid spread of highly flammable cheatgrass. This has been accompanied by a decline within the monument (and region) of sagebrush and perhaps mountain mahogany. Overall, wildlife species richness would be expected to increase with increasing cover of bunchgrasses, sagebrush, and juniper, but decrease with increasing cover of cheatgrass.

Effects of prescribed fire in ponderosa pine stands at the monument were studied by the Klamath Bird Observatory, 2002-2004. In both the spring and fall, prescribed fire did not influence the average number of bird species detected per monitoring site. More total bird species were observed on the burned area in both years following the fire than the year before the fire. A concern has been expressed that large-diameter ponderosa pines which currently provide roosts for wintering bald eagles are not being replaced rapidly enough by new growth (Stohlgren 1993, Stohlgren and Farmer 1994).

4.5.3.2 Climate Change

An analysis of the vulnerabilities of California nesting birds to climate change was published by Gardali et al. (2012). Of 128 species they identified as most vulnerable, those which are likely to have formerly or currently nested in the monument are:

- Swainson's hawk
- greater sage-grouse
- mountain quail
- ruffed grouse
- sooty (blue) grouse
- northern saw-whet owl
- common nighthawk
- common poorwill
- rufous hummingbird
- bank swallow
- juniper titmouse
- Brewer's sparrow
- red crossbill

4.5.3.3 Contaminants

Contaminants in the monument's bats have been measured but no data were made available for this report, and effects are unknown. Contaminants such as mercury and persistent pesticides are a potential concern because of aerial transport of contaminants into the monument from distant areas. Besides bats, aerial foragers likely to be at greatest risk are swallows and common nighthawk. Just outside the monument on agricultural lease lands of the Klamath National Wildlife Refuge, over 50 different pesticides are used. Hatchling success there was found to be lower in areas treated repeatedly with fungicides. Analyses of dietary items determined that nestlings were exposed to the pesticides dicamba and 2,4-D herbicides, which are approved for refuge use, and also to aldicarb, carbofuran, propazine, simazine, and dichlorprop, which are not approved for refuge use (Hawkes and Haas 2005).

Subsequently, the U.S. Fish and Wildlife Service (2007) issued a programmatic Biological Opinion that considered the risks of pesticides to suckers (fish) and bald eagles in the Klamath Basin. Based on the limited existing data on pesticide impacts and distribution, pesticide use information, benchmark toxicity values, and habitat use of the threatened and endangered species, the Biological Opinion evaluated impacts from direct exposure to the organisms, indirect effects through pesticide-induced reduction in prey populations, and pesticide-induced reductions in water quality. Although the assessment found that some level of pesticide exposure could occur to these two species, the evidence did not support a determination that the pesticide applications were likely to harm populations of these species.

4.5.3.4 Human Disturbance and Non-native Wildlife

Some wildlife species, including many avian nest predators (e.g., jays, raven, squirrels) are attracted to congregations of people such as at campgrounds, scenic pullouts, and picnic areas. Resulting increases in nest predation can have detrimental effects on local populations of other species, particularly on songbirds. Whether this is the case at Lava Beds has not been determined, but the possibility of such impacts is plausible. Christmas Bird Count data from the vicinity of the monument indicate a statistically significant 28-year increase in numbers of ravens (Table 10).

Some wildlife species are exceptionally sensitive to human presence. If humans approach too closely during critical nesting periods, they abandon nests and leave eggs exposed to predators and excessive heat. Among the more sensitive species are several uncommon raptors that nest within the monument, such as Swainson's hawk, short-eared owl, prairie and peregrine falcons, and bald and golden eagles (Dixon and Bond 1937, Bond 1939). During winter, roosts of the bald eagles that congregate in the ponderosa forest near the southern end of the monument are potentially very sensitive to disturbance (Keister and Anthony 1983; Keister et al. 1985, 1987).

In parts of the monument, illegal poaching of mule deer has been noted. The prohibition against hunting within the monument causes individual deer to acclimate to humans and makes them easy targets for poachers.

Non-native bird species reported from the monument include European starling, house sparrow, wild turkey, and a recent invader of adjoining agricultural lands: Eurasian collared dove. Small numbers of domestic sheep also range into the monument. The effects, if any, of these species on the native fauna are unknown.

4.5.3.5 Habitat Fragmentation

When the home ranges of some species are interrupted by roads and other cleared areas, the habitats are fragmented. Individuals in fragmented habitats are often subjected to greater predation, even in rangeland settings (Knick and Rotenberry 2002, Vander Haegen 2007), and feeding and reproductive attributes (e.g., genetic isolation) can be interrupted. Roads and traffic result in more road killed animals, and in extreme cases, noise associated with roads degrades reproductive success of some species. To some degree, wildlife corridors (usually, unaltered bands of natural vegetation that connect larger patches and so create "connectivity") can lessen fragmentation impacts on wildlife, as can management practices within the cleared areas that leave relicts of the original vegetation structure. Connectivity and fragmentation are perceived differently by different species. Functional connectivity of habitat for one species (e.g., deer, cougar) is not necessarily recognized by other species (snakes, plants). Connectivity can also be provided by some types of broad habitat "mosaics" (not continuous bands) over large, relatively natural areas, or as stepping stones comprised of suitable habitat patches.

4.5.4 Indicators and Criteria to Evaluate Condition and Trends

Two indicators that might be used to monitor this issue (Changes in Wildlife) are:

1. Diversity of Native Terrestrial Wildlife Species, including Rare Species
2. Extent and Connectivity of Important Terrestrial Habitats

The monument maintains a wildlife observations database, containing records from 1943 to present. Appendix D summarizes its data by species for all vertebrates. The data were not collected systematically and quality of some observations is unknown, so only limited inferences can be made.

4.5.4.1 Diversity of Native Terrestrial Wildlife Species, Including Rare Species

Meaningful criteria for evaluating this indicator would need to account for the natural range of variation in species colonization and extirpation, and the expected annual fluctuations in population levels. However, data for estimating these are not generally available from the monument or from analogous areas nearby. As well, there are no legally-based numeric criteria for evaluating the degree of "intactness" of any of the monument's wildlife communities. No agency, institution, or scientific researcher has defined minimum viable population levels, desired productivity or species richness levels, or other biological criteria relevant to any wildlife species in this particular park. Therefore, the assessment of this indicator is based mainly on professional judgment of the authors.

For purposes of this assessment, "Good" conditions would be represented by the sustaining of naturally-occurring turnover rates of all native terrestrial species currently inhabiting a park. This could include intentionally re-establishing those species which were extirpated but have the potential to become re-established. More detailed goals might be to sustain multiple representatives of each functional group in proportions characteristic of intact but dynamic ecosystems and well-functioning complex food webs, as well as sustaining metapopulations and gene pool diversity. "Somewhat Concerning" and "Significant Concern" ratings would be assigned depending on the degree to which species turnover rates and/or terrestrial biodiversity are likely to affect adversely the rates of important ecosystem functions.

Condition and Trends

These vary by species, but overall we assign a rating of *Somewhat Concerning – Low Certainty* for condition and *Indeterminate* for trends. A higher rating of "Good" is not assigned due to the decline or loss of breeding populations within the monument of greater sage-grouse and possibly other sage-associated birds. A rating of "Significant Concern" is not assigned due to the lack of any evidence of recent extirpations of native wildlife species from the monument. No systematic long term data are available on trends of any of the monument's wildlife species. For many miles around, the monument provides the only or best habitat for American pika and several species of bats.

4.5.4.1.1 Ungulates, Omnivores, and Predatory Mammals

The monument's most common ungulate is **mule deer**, and the monument provides preferred winter habitat. The only population estimate for the monument is from the 1970s, when wintering deer numbers were estimated at 1500-2000 (Schnoes 1978). During some winters, snow depth at the upper elevations of the Medicine Lake Highlands forces the deer to move down the eastern slope and into the monument (Ashcraft 1961). At that time many individuals join herds along Hill Road at the north end of the monument, attracted by the farm fields and water of the Tulelake basin. Research within the monument indicated that individual deer use the same area (home range) each winter. During at least some winters, deer distribution is affected more by availability of cover than by food. Within the monument, bitterbrush is a preferred winter food; during winter individual deer range over about 1.1 km in the southern part of the monument and 3.1 km in the northern part (Schnoes 1978).

Small numbers of **pronghorn** are also present in the grassy northern part of the monument. According to the monument's wildlife observations database, this is the third-most frequently reported mammal, with 357 sightings as of July 2012, and is exceeded only by sightings of mule deer (442) and **coyote** (403); see Appendix D. The wildlife observations database indicates that **elk** (wapiti) were reported on six occasions between June 2006 and February 2010.

Mountain bighorn sheep, which had been present in the monument historically, were re-introduced in 1971. A small population was established but all individuals succumbed to pneumonia during 1980, possibly infected by domestic sheep from adjoining areas (Foreyt and Jessup 1982).

Based on the wildlife observations database, it appears that **black bears** are rare in the monument, with only 11 sightings reported between 1985 and 2005. Far more common are records of **bobcat** (351 sightings) and **cougar** (166). Sightings of cougar within the monument seem to have increased in recent years (Horney 2008). In California, an area of at least 850 square miles (2200 sq km) may be required for a cougar population to remain stable or increase over time (Dickson and Beier 2002). The monument is only 2% of that area, so local cougars must forage as well over large areas outside the monument.

As shown in Appendix D, other predatory or omnivorous mammals reported in the monument's wildlife observations database include:

- long-tailed weasel (61 sightings)
- American badger (56)
- raccoon (33)
- striped skunk (23)
- gray fox (19)
- spotted skunk (11)
- short-tailed weasel (8)
- red fox (7)

American badger is considered a "Species of Special Concern" by the California Department of Fish and Wildlife.

4.5.4.1.2 Other Mammals

American pika is a rabbit-relative that is believed to be disappearing in many areas of the West (Beever et al. 2003). Normally a mountain-dweller, the species is also found regularly in barren lava landscapes (Rodhouse et al. 2010). Although its occurrence is influenced by many factors, it is considered an indicator species for detecting ecological effects of climate change. In the summers of 2010 and 2011, randomly-selected sites within the monument were searched for evidence of pika occupancy. Of these, 29 (29%) were considered occupied in 2011. Of the 2010 sites that were resurveyed in 2011 (n=42), five sites were colonized and seven previously occupied sites were unoccupied. Occupied sites were found on all of the major lava flows surveyed in both years, including the Callahan, Devil's Homestead, and Schonchin flows. Using techniques described in the NPS standard protocol (Jeffress et al. 2011), these sites will be monitored over time to detect trends in pika site occupancy.

As shown in Appendix D, reports from the monument's wildlife observations database of other aboveground mammals include, most often:

- porcupine (179 sightings)
- yellow-bellied marmot (132)
- mountain cottontail (83)
- black-tailed jackrabbit (81)
- California ground squirrel (53)

Excluding bats, a total of 36 mammal species are officially listed as occurring in the monument. Aboveground mammals that are included on the official monument list but have no records in the wildlife observations database are mink, muskrat, and mountain vole. Systematic surveys of small mammals are limited to one survey done for the NPS in 2002. At that time, the species caught most often was the **yellow-pine chipmunk** (52% of 164 captures in 600 trap nights).

4.5.4.1.3 Birds

The bird species that are present in the monument are a subset of all bird species in the general area, all of which are known to breed within the surrounding area/Klamath Basin. However, for many species, the monument likely provides nesting habitat of much better quality than occurs in surrounding areas. The official monument bird list includes many species that have never been recorded in the monument's wildlife observations database and are unlikely to occur within the monument; e.g., least bittern. Conversely, some birds in the observations database are not shown on the monument's official bird list. In 2006 the Klamath Bird Observatory established 25 permanent point count survey routes, each consisting of 12 survey points, and is monitoring birds every three years. Data have not yet been summarized. No annual breeding bird survey routes have been run near the monument.

The Tulelake Christmas Bird Count (CBC) has been conducted by volunteers on one day annually since 1987 and includes part of the monument in its 15-mile diameter circle (Figure 22). Trends in numbers of songbird and raptor species from the entire count circle were analyzed and are shown in Table 10. Based on statistical significance of trend as determined by the Mann-Kendall test, numbers of 14 species declined and 15 increased significantly. Many of the species that declined are raptors. Neither species richness (the number of species) nor abundance (the summed individuals of all species) showed a significant trend. CBC counts do not have a tightly standardized protocol, and the number of observers, hours spent, areas covered, and weather all vary from year to year with uncertain effects on apparent bird trends.

Table 10. Trends in selected wintering and resident songbirds and raptors in the Tulelake Christmas Bird Count, 1987-2011.

Note: Species are listed in order from most negative to most positive 28-year trend. Lava Beds National Monument comprises 18% of the Count circle (22), and the portion of each species' data that were from Lava Beds in any given year is unknown. The level of effort, expertise of observers, and exact areas surveyed within the 15-mile diameter count circle vary from year to year. This suggests caution in interpreting apparent trends. Water-associated species and species found fewer than four years were excluded.

Species Name	Maximum per Year	# of Years Reported	Trend (Z-statistic)	Statistical Significance
California Towhee	32	28	-4.49	***
American Tree Sparrow	31	21	-4.00	***
Bald Eagle	451	27	-3.95	***
Northern Harrier	627	28	-3.44	***
Ring-necked Pheasant	1192	28	-3.05	**
Sage Thrasher	28	21	-2.88	**
Rough-legged Hawk	250	28	-2.81	**
Golden Eagle	12	25	-2.81	**
Red-tailed Hawk	269	28	-2.55	*
Hairy Woodpecker	2	12	-2.47	*
House Finch	1233	28	-2.23	*
Northern Shrike	8	25	-2.20	*
Short-eared Owl	7	24	-2.08	*
Pinyon Jay	71	8	-1.97	*
California Quail	848	28	-1.64	
Ferruginous Hawk	5	16	-1.49	
Evening Grosbeak	45	11	-1.47	
Red-breasted Sapsucker	3	17	-1.06	
Bohemian Waxwing	17	4	-0.95	
Townsend's Solitaire	74	28	-0.89	
Cedar Waxwing	53	9	-0.81	
Canyon Wren	34	27	-0.78	

Table 10 (continued). Trends in selected wintering and resident songbirds and raptors in the Tulelake Christmas Bird Count, 1987-2011.

Note: Species are listed in order from most negative to most positive 28-year trend. Lava Beds National Monument comprises 18% of the Count circle (22), and the portion of each species' data that were from Lava Beds in any given year is unknown. The level of effort, expertise of observers, and exact areas surveyed within the 15-mile diameter count circle vary from year to year. This suggests caution in interpreting apparent trends. Water-associated species and species found fewer than four years were excluded.

Species Name	Maximum per Year	# of Years Reported	Trend (Z-statistic)	Statistical Significance
Lapland Longspur	290	18	-0.77	
White-crowned Sparrow	729	28	-0.73	
Downy Woodpecker	2	12	-0.72	
Mountain Bluebird	543	18	-0.67	
Prairie Falcon	15	28	-0.28	
Brown-headed Cowbird	61	19	-0.20	
Bushtit	93	20	-0.04	
American Robin	9771	28	0.00	
Loggerhead Shrike	14	28	0.06	
Mountain Chickadee	24	17	0.06	
Dark-eyed Junco	1484	28	0.12	
Titmouse sp. (prob. Juniper)	16	26	0.14	
Barn Owl	12	26	0.16	
Song Sparrow	1073	28	0.20	
Black-billed Magpie	54	28	0.26	
White-breasted Nuthatch	1	4	0.30	
Bewick's Wren	56	28	0.71	
White-throated Sparrow	2	7	0.74	
Golden-crowned Sparrow	99	28	0.87	
Horned Lark	4380	27	0.91	
Savannah Sparrow	47	18	0.91	
Ruby-crowned Kinglet	3	9	1.01	
Sharp-shinned Hawk	2	8	1.06	

Table 10 (continued). Trends in selected wintering and resident songbirds and raptors in the Tulelake Christmas Bird Count, 1987-2011.

Note: Species are listed in order from most negative to most positive 28-year trend. Lava Beds National Monument comprises 18% of the Count circle (22), and the portion of each species' data that were from Lava Beds in any given year is unknown. The level of effort, expertise of observers, and exact areas surveyed within the 15-mile diameter count circle vary from year to year. This suggests caution in interpreting apparent trends. Water-associated species and species found fewer than four years were excluded.

Species Name	Maximum per Year	# of Years Reported	Trend (Z-statistic)	Statistical Significance
American Kestrel	39	28	1.13	
Golden-crowned Kinglet	27	22	1.32	
American Pipit	25	9	1.46	
Hermit Thrush	8	13	1.50	
Great Horned Owl	22	28	1.51	
Spotted Towhee	12	28	1.64	
American Goldfinch	27	12	1.72	*
Western Bluebird	18	3	1.85	*
Western Scrub-Jay	7	22	1.85	*
Merlin	4	22	1.89	*
Northern Flicker	41	28	1.90	*
Common Raven	118	28	2.04	*
Varied Thrush	4	4	2.07	*
Western Meadowlark	1089	28	2.07	*
Rock Wren	11	19	2.23	*
Lesser Goldfinch	70	22	2.27	*
European Starling	1228	28	2.51	*
Brewer's Blackbird	3652	28	2.67	**
Mourning Dove	149	21	2.75	**
Red-shouldered Hawk	1	4	3.12	**
Eurasian Collared-Dove	249	4	3.23	**

* trend with statistical significance

** trend with high statistical significance

*** trend with very high statistical significance

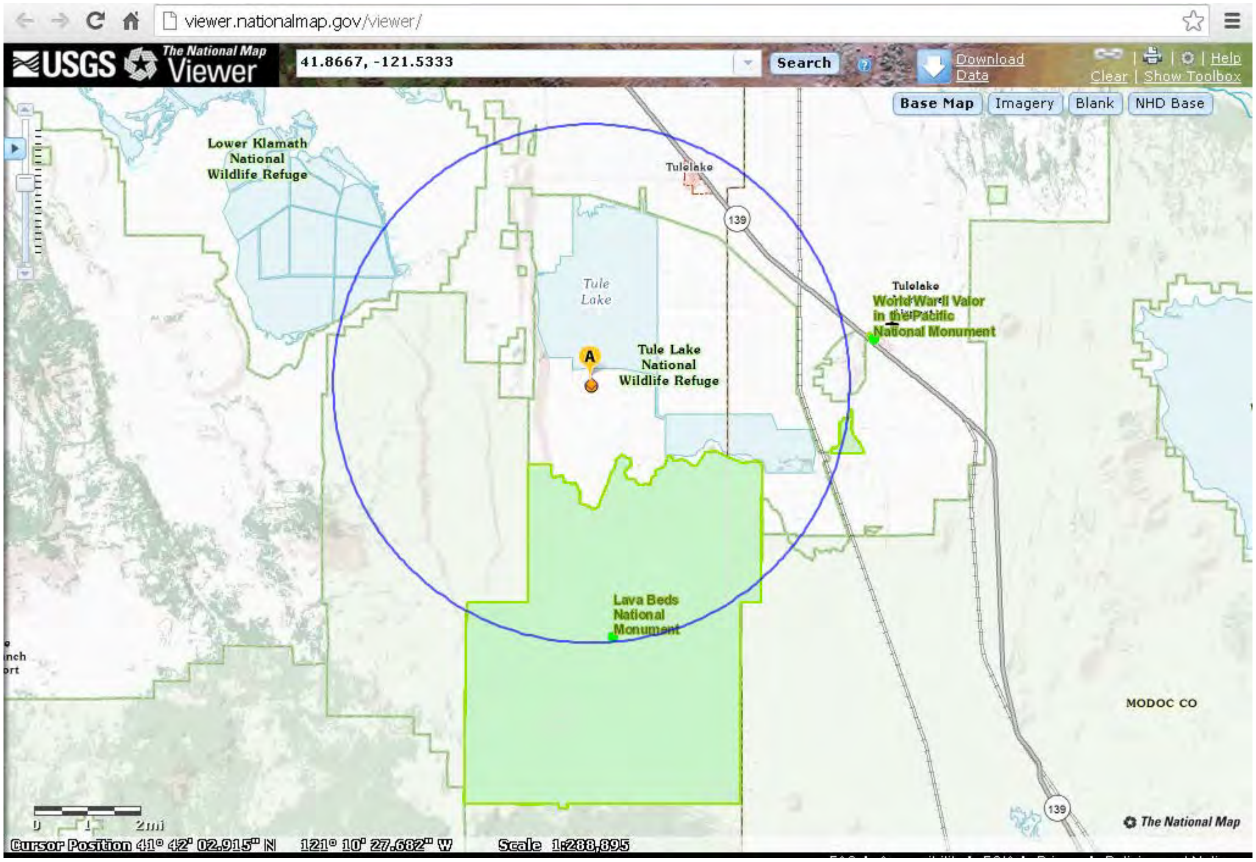


Figure 22. Boundaries of the Tulelake Christmas Bird Count circle, relative to Lava Beds National Monument.

Two raptors that nest in the monument—**bald eagle** and **peregrine falcon**—were formerly listed as federal endangered species but have since been removed from the list due to increasing populations nationwide. Both are still listed as endangered by the State of California. Stands of large conifers in the southern part of the monument (Caldwell/Cougar Butte and Eagle Nest Butte) provide key roosting habitat for bald eagles wintering throughout the Klamath Basin (Stohlgren 1993, Stohlgren and Farmer 1994). Numbers of eagles leaving the roosts annually have been counted annually since 1987 but data apparently have not been published or entered in a computer database for analysis.

The California Department of Fish and Wildlife (CDFW) has designated two other Lava Bed species—**Swainson's hawk** and **bank swallow**—as threatened statewide, and has designated **great gray owl** as endangered. Swainson's hawk forages sporadically in grasslands of the northern part and after a long absence, attempted to nest in 2011. Bank swallow has been reported only three times, the most recent in 1972, and its current nesting status in the monument is uncertain. The owl has been reported only once, in August 1992. If nesting at all, it is most likely to be found in ponderosa forest.

The CDFW has also designated several species as Species of Concern statewide due to known or suspected declining trends in populations or habitat statewide. These include the following, some of which may nest within the monument:

- greater sage-grouse (31 sightings since 1943 reported in the monument's wildlife observations database)
- northern goshawk (17 sightings)
- northern harrier (35 sightings)
- short-eared owl (32 sightings)
- long-eared owl (2 sightings)
- burrowing owl (14 sightings)
- long-billed curlew (3 sightings)
- Vaux's swift (2 sightings)
- olive-sided flycatcher (3 sightings)
- loggerhead shrike (41 sightings)
- purple martin (63 sightings)
- yellow warbler (24 sightings)

The US Fish and Wildlife Service has designated as Birds of Conservation Concern the following additional species, which may (or do) nest within the monument:

- golden eagle (89 sightings)
- prairie falcon (119 sightings)
- flammulated owl (2 sightings)
- rufous hummingbird (24 sightings)
- Allen's hummingbird (5 sightings)
- Lewis's woodpecker (57 sightings)
- white-headed woodpecker (9 sightings)
- black-chinned sparrow (2 sightings)
- Brewer's sparrow (2 sightings)

The USDA Forest Service, in the Modoc National Forest just to the south of the monument, has highlighted the following bird species—also present and possibly nesting at Lava Beds—as Management Indicator Species (MIS), with the implication that if their numbers decline, that may in some cases indicate that management practices are causing harm. In addition to sage grouse and yellow warbler already listed above, they are: **sooty/blue grouse** (35 sightings since 1943 reported in the monument's wildlife observations database), **hairy woodpecker** (9 sightings), and **mountain quail** (41 sightings).

Of the species on the monument's bird list, one that has perhaps drawn the most attention is the greater sage-grouse. That is because it has declined dramatically throughout nearly all of its continental range, and has declined dramatically in northern California since the 1950s. It is currently designated as a federal Species of Special Concern, and is being considered for federal listing as Threatened. It probably was once common at Lava Beds, but with the exception of unconfirmed sightings near Hovey Point as recently as September 2008, it has not been confirmed nesting within the monument since the late 1970s (Horney 2008). Its decline in northern California outside of the monument has been attributed directly to fragmentation and loss of sagebrush habitat, and indirectly to loss of sagebrush through fire and grazing, invasion of cheatgrass, increasing cover of shading juniper, and lowering of water tables. The nearest remaining active lek (breeding site) and known rearing areas are located around Clear Lake National Wildlife Refuge, about 15 miles east of the monument. In 2008 the grouse population there was estimated at fewer than 50 individuals and was not considered viable (Horney 2008). A recovery plan for grouse in this area and extending westward to Lava Beds and beyond was drafted by resource agencies, including the National Park Service. The monument comprises about 18% of the approximately 254,000 acres covered by the plan (Horney 2008). Re-introducing the grouse to Lava Beds is being actively considered, and monument personnel are selectively reducing juniper cover to enhance future habitat for this species.

Other bird species that regularly breed in sagebrush-juniper habitats of northern California (California Partners in Flight 2005), listed in order of their frequency of records from any time of year in the monument's wildlife observations database, include:

- loggerhead shrike (41 sightings)
- western meadowlark (17 sightings)
- sage thrasher (16 sightings, last reported in 2004)
- lark sparrow (11 sightings)
- green-tailed towhee (10 sightings)
- vesper sparrow (6 sightings)
- gray flycatcher (2 sightings)
- Brewer's sparrow (2 sightings, last reported in 1962)
- juniper titmouse (no reports in database but reported by Klamath Bird Observatory)
- sage sparrow (no reports)

Based on the KBO surveys and wildlife observations database, it appears likely that sage sparrow has been extirpated from the monument as a nesting species coincident with the fragmentation and decline of sagebrush cover in northern California generally, and there apparently has been only one (Stephens et al. 2009) recent detection of sage thrasher.

4.5.4.1.4 Reptiles and Amphibians

There are reports of 14 species of reptiles in the monument's wildlife observations database since 1943. Two of these are not on the official monument list: **western whiptail** (one report in 1993) and **racer** (27 reports).

The monument's amphibian richness is very low compared with equal-sized areas of California, but this is expected given the lack of surface water required for breeding. The only documented species are **western (boreal) toad** and **Pacific treefrog**. Pacific treefrog is found near the entrances of many of the monument's caves. In addition, the wildlife observations database lists one record each for **rough-skinned newt** and **foothill yellow-legged frog**.

4.5.4.1.5 Terrestrial Invertebrates

No systematic, monument-wide inventories of terrestrial invertebrates have been conducted. However, informal surveys of butterflies have been conducted since 2009, resulting in a list of over 50 species. Management practices intended to maintain butterfly habitat are implemented along the shoulders of the monument's roads.

Condition and Trends

Assessment Confidence and Data Gaps

Low Certainty. Although the monument maintains a wildlife observations database, those data are not systematic or comprehensively verified, so no inferences can yet be made about relative abundance or shifts in elevational or geographic ranges or productivity of any species. The wildlife camera system provides useful and standardized information, but only for a few species and covering only very limited areas. Although a preliminary herpetological inventory was conducted in the late 1960s (Ellis 1970), a comprehensive inventory of all of the monument's current reptile and amphibian species has yet to be done.

4.5.4.2 Extent and Connectivity of Important Terrestrial Habitats

What constitutes "habitat fragmentation" depends on the species and the structural characteristics of the land uses that are purported to do the fragmenting. When assessing fragmentation, conservation biologists often consider first the needs of species that have the largest home ranges. Some biologists (e.g., Harrison 1992) have proposed that the width of a typical home range of the focal species be considered the minimum for assessing the sufficiency of a habitat corridor's width. Biological thresholds for metrics relevant to fragmentation (e.g., minimum patch size, corridor width, permeability of disturbed lands to species movements) are species-specific.

Criteria

At a landscape scale, an important ecological goal is to sustain corridors or stepping-stones of relatively unaltered habitat. For purposes of this assessment, "Good" conditions would be represented by unbroken connectivity of natural vegetation on all sides of the monument. "Somewhat Concerning" would represent a measurable loss of corridors of habitat suitable for locally rare or sensitive wildlife species, as a result of temporary setbacks of succession (e.g., fires, clearcuts), and/or declining populations of threatened species known to be area-sensitive. "Significant Concern" conditions would represent widespread and irreversible losses of those corridors as a result of roads, buildings, and other newly unvegetated surfaces.

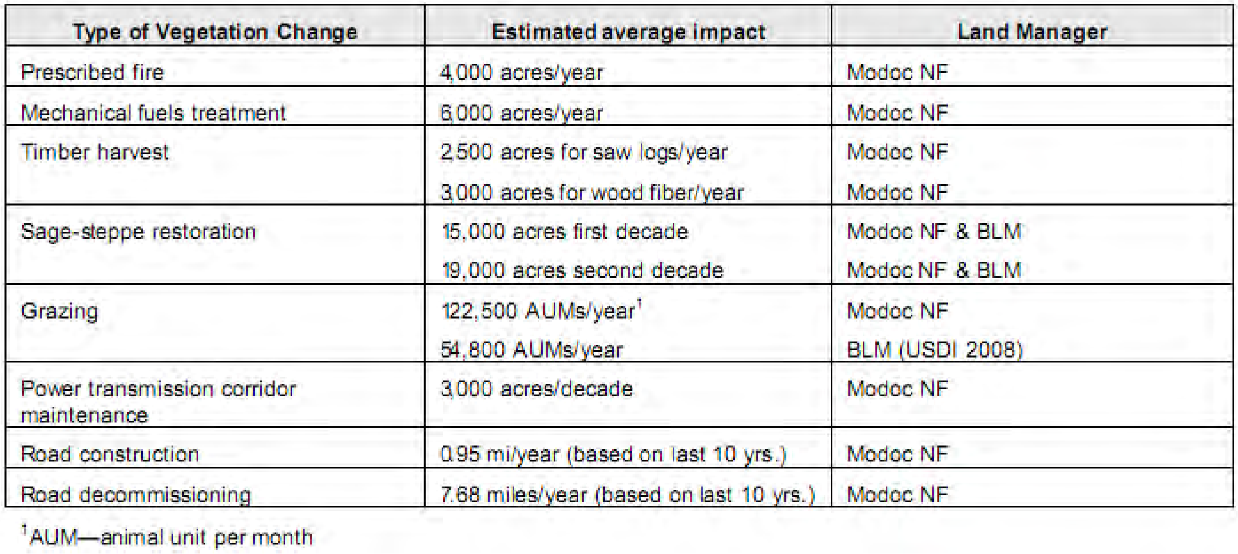
Condition and Trends

Somewhat Concerning – Medium Confidence.

Nearly all of the fragmentation of habitat that has occurred in the vicinity of the monument happened over a century ago, with the building of roads and clearing of shrubland and forests for the expansion of agriculture in the Klamath Basin (Tables 11 and 12). Currently, little or no additional loss of habitat connectivity is occurring within or near the monument. No new highways have been constructed in many years. With a locally declining human population, there has been very little new residential development. New unpaved roads for ranching, logging, or energy development are few and mostly distant from the monument boundary.

We did not rate the condition “Good” because some connectivity to undeveloped land cover has been compromised by agricultural land cover mainly to the north, and any further net loss of stands of sagebrush or large-diameter trees might, depending on location and configuration, interrupt movement corridors important to some area-sensitive species. We did not rate the condition “Significant Concern” because despite the historical loss of habitat connectivity due to agriculture, at least 70% of the monument’s perimeter is currently surrounded by large tracts of undeveloped land, and agricultural cover may be more permeable to movements of some species as compared to densely urbanized land. The monument’s generally good connectivity is recognized by maps prepared by California Department of Fish and Wildlife, which show the southern part of the monument as part of an “essential connectivity area” connecting to other natural lands in the region to the south and southeast. Coordinated actions of other agencies and private landowners could potentially re-establish some of the original habitat connectivity by restoring appropriate land cover at critical junctures.

Table 11. Summary of reasonably foreseeable vegetation-altering actions on public land in and adjacent to the Modoc National Forest. (From the Modoc National Forest Travel Management Final Environmental Impact Statement)



Type of Vegetation Change	Estimated average impact	Land Manager
Prescribed fire	4,000 acres/year	Modoc NF
Mechanical fuels treatment	6,000 acres/year	Modoc NF
Timber harvest	2,500 acres for saw logs/year 3,000 acres for wood fiber/year	Modoc NF Modoc NF
Sage-steppe restoration	15,000 acres first decade 19,000 acres second decade	Modoc NF & BLM Modoc NF & BLM
Grazing	122,500 AUMs/year[1] 54,800 AUMs/year	Modoc NF BLM (USDI 2008)
Power transmission corridor maintenance	3,000 acres/decade	Modoc NF
Road construction	0.95 mi/year (based on last 10 yrs.)	Modoc NF
Road decommissioning	7.68 miles/year (based on last 10 yrs.)	Modoc NF

[1] AUM—animal unit per month

Table 12. Road density by geographic unit within Lava Beds National Monument.

Geographic Unit (see Figure 4)	Road Sum (km)	Unit Area (sq km)	Road Density (km/sq km)
Basalt and Andesite	37.91	84.52	0.4485
Basalt	2.00	12.42	0.1606
Basaltic Andesite	6.09	36.84	0.1654
Buttes	1.34	3.81	0.3501
Gillem's Bluff	2.91	3.92	0.7428
Historic Lake Bed	5.87	2.86	2.0528
Lava Flows	0.74	7.25	0.1024
Petroglyphs Unit	1.13	0.70	1.6104
Total	*57.98*	*152.33*	*0.3806*

Assessment Confidence and Data Gaps
Medium Certainty. Connectivity is relatively simple to estimate at a coarse scale, so confidence is considered to be Medium rather than Low. Confidence in the condition and trend estimates was not considered to be High because land cover change maps for the period 1992-2001 that were generated by the NPScape project are unlikely to portray most of the fine-scale fragmentation of forested areas that may have occurred near the monument. That is because they mainly address conversions to agriculture or urban cover, which were extremely limited during that time. Moreover, thresholds at which habitat patches within the monument might become less used as a result of temporary fragmentation by wildfire are unknown for most of the monument's species, as are thresholds at which energy development or other land use conversions might harm wildlife populations by disrupting movements.

4.6 Changes in Air Quality

4.6.1 Background
Air quality is of interest aesthetically, ecologically, and for health reasons. Ozone, particulates, wet and dry deposition of nutrients, acidifying substances, pesticides, and other contaminants are monitored in many areas of North America, mainly due to concerns regarding their potentially harmful effects on biological communities and/or human health. Lava Beds began monitoring visibility in 1983 and is currently monitoring visibility and fine particles as part of the IMPROVE network.

4.6.2 Regional Context
Lava Beds is designated a Class I airshed, which is given the highest level of protection under the Clean Air Act. Air quality in this region is generally good relative to air quality in more urbanized areas or topographically confined basins. Nonetheless, the air quality in the monument is presumably degraded by widespread use of agricultural pesticides in surrounding areas,

several point sources in the Klamath Falls area, wood burning stoves, seasonal prescribed and natural fires, and other sources. Because surface waters are lacking, concerns about air quality focus mainly on visibility and ozone, as well as the effects of deposition of atmospheric nitrate, sulfate, and contaminants on the park's terrestrial ecosystems.

4.6.3 Issue Description

Fires within the monument or region have temporarily impaired air quality. But of perhaps greater concern because of their chronic nature is the deposition of airborne—and mainly particulate—nitrate (N), sulfate (S), and hydrocarbons that are carried to the monument from nearby agricultural fields and more distant developed areas. Increases in N, S, and other contaminants could alter soil biogeochemical processes and vegetation throughout the monument. Lichens and mosses are particularly sensitive to N deposition because they largely obtain their nitrogen directly from atmospheric sources (Geiser & Neitlich 2007, Jovan & McCune 2006, Geiser et al. 2010).

Ozone levels are also a potential concern. In the lower atmosphere, ozone is an air pollutant, forming when nitrogen oxides from vehicles, power plants, and other sources combine with volatile organic compounds from gasoline, solvents, and vegetation in the presence of sunlight. In addition to causing respiratory problems in people, ozone can injure plants. Ozone enters leaves through pores (stomata), where it can kill plant tissues, causing visible injury, or reduce photosynthesis, growth, and reproduction.

4.6.4 Indicators and Criteria to Evaluate Condition and Trends

Indicators that might be used to represent air quality concerns are:

- Atmospheric deposition of particulate nitrogen and sulfur
- Atmospheric deposition of pesticides and other contaminants
- Ozone

4.6.4.1 Atmospheric Nitrogen (N) and Sulfur (S) Deposition

Criteria

The NPS Air Resources Division (NPS-ARD) has suggested that, for parks with N-sensitive resources, wet nitrate deposition greater than 1 kg per hectare per year indicates a "Significant Concern." Background levels for N wet deposition in the western U.S. are about 0.13 kg/ha/yr and 0.5 kg/ha/yr for total N deposition. Thus, "Good" condition would be represented by N and S deposition rates being close to the lowest ones detected in the region. "Somewhat Concerning" would be below the NPS-ARD criteria levels but without evidence of biological effects. "Significant Concern" would be when levels are above the NPS-ARD criteria levels and/or ecological changes can be traced to excessive N or S deposition.

To protect all components of the forest ecosystem in the western Sierra Nevada, Fenn et al. (2008) recommended a critical load threshold of 3.1 kg N per hectare per year. In the Pacific Northwest, many of the most sensitive lichen species are absent from areas where mean annual wet deposition exceeds 1-4 kg N per hectare per year and mean annual dry deposition exceeds 2-6 kg N per hectare per year (Geiser et al. 2010).

Condition and Trends
Condition: *Good.* Confidence: *Medium.*
Trends: *Indeterminate.*

This monument's *risks* of experiencing either acidification effects or enrichment effects from atmospheric sulfur and nitrogen deposition were considered "very low"—the lowest of all Klamath Network parks (Sullivan et al. 2011a, b). Estimates of nitrogen deposition for the monument during the period 2004-2009 obtained via interpolation from regional measurements (NPS-ARD 2011) indicate no current need for concern (wet deposition rate was 0.5 kg/ha/yr total N, precipitation-weighted, comprised of 0.4 NH_4 and 1.0 NO_3). For comparison, background levels in the western U.S. are about 0.50 kg/ha/yr for total N deposition. Similarly, estimates of sulfur wet deposition for the monument during the period 2004-2009 obtained via interpolation from regional measurements indicate no current need for concern (0.2 kg/ha/yr total S, precipitation-weighted, comprised of 1.0 SO_4).

Trends in N or S deposition cannot be determined because comparison of spatially interpolated values between periods is not valid, and lichen N and S content has not been determined.

Assessment Confidence and Data Gaps
Medium Certainty. The interpolated estimates from NPS-ARD were calculated only for the center of the monument.

4.6.4.3 Airborne Contaminant Deposition

Toxics, including heavy metals like mercury, accumulate in the tissue of organisms. When mercury converts to methylmercury in the environment and enters the food chain, effects can include reduced reproductive success, impaired growth and development, and decreased survival. Other toxic air contaminants of concern include pesticides, industrial by-products, and flame retardants for fabrics. Some of these are known or suspected to cause cancer or other serious health effects in humans and wildlife.

Criteria
Thresholds for harm from many airborne contaminants are unknown. "Good" condition would be represented by all human-associated contaminants being below detectable levels. "Somewhat Concerning" would be levels that are detectable but below established guidelines for harm, and without evidence of ecological effects. "Significant Concern" would be levels that are both detected and found to exceed established guidelines and/or result in ecological damage.

Condition and Trends
Condition: *Indeterminate.*
Trends: *Indeterminate.*

Assessment Confidence and Data Gaps (all airborne pollutants)
Low Certainty. Too few measurements have been made to determine trends or even the existing levels of airborne contamination within the monument. Effects of airborne contaminants—especially those that tend to accumulate and persist in food webs—need to be determined with regard to the monument's most sensitive species and ecosystem processes. The monument's lichens could be analyzed for pesticides and other hydrocarbons common in the surrounding

agricultural lands, and levels compared with those already measured in western parks distant from agricultural sources. Efforts could be made to trace the infiltration pathways of herbicides and their associated ingredients in porous soils overlaying the monument's caves. The initial analyses of contaminant loads in the monument's bats could be continued and expanded.

4.6.4.4 Ozone

Criteria
The NPS-ARD (2010) guidance contains ozone criteria based on three metrics:

- 3-year average of the fourth highest daily maximum 8-hour average concentration, which should not exceed 75 ppb.
- SUM06: the running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm, expressed in cumulative ppm-hr. This should not exceed 8 ppm-hours.
- W126: cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. This should not exceed 7 ppm-hours.

The first metric pertains to protection of human health, and the other two are for evaluating risk to vegetation. In addition, summarizing the literature, Geiser & Neitlich (2007) note that ozone levels of 20 to 60 μg per m^3 may harm some lichens (Egger et al. 1994, Eversman and Sigal 1987).

Condition and Trends
Condition: *Somewhat Concerning – Low Certainty.*
Trends: *Indeterminate*.

For the metrics described above and the period 2005-2009, the following were measured:

- fourth highest daily maximum 8-hour average concentration = 70.1 ppb
- SUM06 = 15.3 ppm-hrs
- W126 = 12.0 ppm-hrs

Levels of all three are close to the NPS thresholds for "Significant Concern" so the ozone threat in this monument could best be characterized as "Somewhat Concerning" both for humans and for vegetation. An NPS risk assessment also projected that the monument's vegetation is at "moderate" risk from ozone compared with other Klamath Network parks (NPS 2004). Of the monument's many vascular plants, those most sensitive to ozone were predicted to be Jeffrey pine, ponderosa pine, quaking aspen, and Scouler's willow. None of these is widely distributed in the monument. Data are insufficient to validly determine trends in ozone concentrations or damage.

Assessment Confidence and Data Gaps
Low Certainty. Ozone levels need to be measured directly in the monument, consistently and over many years—not just interpolated from measurements elsewhere in the region. Most importantly, ozone effects on the monument's plants (especially the community composition of lichens and mosses near cave entrances) need to be determined and thresholds established.

4.7 Changes in the Natural Quality of the Park Experience

4.7.1 Background
Several attributes influence the natural quality of the park experience that is valued by most visitors. Among these attributes are long-distance visibility, a starlit night sky, quiet surroundings, and the absence of signs of human alteration. These are discussed in this section.

4.7.2 Regional Context
The monument is within a day's drive of Portland, San Francisco, and some other major cities. Each year, the monument provides thousands of visitors with opportunities for recreation and a connection with nature.

4.7.3 Issue Description
With increasing population growth projected for the Pacific Northwest generally, an opportunity exists both for broader enjoyment of the monument's resources and for increasing impairment of solitude, quiet settings, untrammeled landscapes, good visibility, and a dark night sky.

4.7.4 Indicators and Criteria to Evaluate Condition and Trends
Indicators that might be used to monitor this issue (Natural Quality of the Park Experience) include the following:

1. Visibility
2. Night Sky
3. Soundscape
4. Physical Remoteness and Solitude
5. Disturbed Area Recovery

4.7.4.1 Visibility
The 1977 amendments to the Clean Air Act declared the monument a mandatory Class I area and charged the Federal Land Manager with a responsibility to protect air quality related values, including visibility. Visibility is the clarity of the atmosphere, as typically measured by the viewable distance at a particular location and time, and the number of days annually that scenic objects at different distances can be seen. Visibility is restricted by the absorption and scattering of light that are caused by both gases and particles in the atmosphere. Natural factors that decrease visibility include relative humidity above 70 percent, fog, precipitation, blowing dust and snow, and smoke from wildland fires. Human activities reduce visibility when soil is disturbed and creates dust, as well as when fossil fuels are burned which results in soot and tiny visibility-reducing particles (aerosols). In rural areas, such as those in the vicinity of the monument, the greatest contributors to reduced visibility are carbon and, especially, sulfate. An

NPS study in the Pacific Northwest during the summer of 1990 found that sulfates accounted for over 40 percent of the visibility reduction, whereas carbon (organics and light absorbing carbon) was responsible for about 20 percent and nitrates and coarse mass for 10 percent. Measurements in the spring of 2002 noted that the majority of dust in northern California came from long-range transport across the Pacific (Cameron-Smith et al. 2005).

Criteria
The visibility criteria used by the NPS are based on the deviation of the current Group 50 visibility conditions from estimated Group 50 natural visibility conditions, where Group 50 is defined as the mean of the visibility observations falling within the range from the 40th through the 60th percentiles. Visibility is estimated from the interpolation of the five-year averages of the Group 50 visibility. Visibility in this calculation is expressed in terms of a Haze Index in deciviews (dv). As the Haze Index increases, the visibility worsens. The visibility condition is expressed as current Group 50 visibility minimums, the estimated Group 50 visibility under natural conditions.

"Good" condition is assigned to parks with a visibility condition estimate of less than 2 dv above estimated natural conditions. Parks with visibility condition estimates of 2-8 dv above natural conditions are considered to be in "Moderate" condition (we instead use the term, "Somewhat Concerning") and parks with visibility condition estimates greater than 8 dv above natural conditions are considered to be of "Significant Concern." The NPS chose the dv ranges of these categories to reflect as nearly as possible the variation in visibility conditions across the nation's visibility monitoring network.

Condition and Trends
Condition: *Somewhat Concerning – High Certainty.*
Trends: *Indeterminate.*

The most recent NPS assessment (NPS-ARD 2011), measured during 2006-2010, suggests the condition of the monument's visibility should be categorized as "moderate" because the average annual Group 50 visibility after adjustment for natural conditions was measured as 3.5 deciviews. Within the monument, visibility may be impaired by dust blowing from unpaved roads, smoke from campgrounds, occasional prescribed burns, and wildfires. From outside the monument, vehicle and wood stove emissions, agricultural dust, fall burning of agricultural lands, debris burning, and wood-fired industrial boilers contribute to hazy conditions.

Trends
The most recent NPS assessment (NPS-ARD 2011) reported a slight (but not statistically significant) improvement in visibility on the clearest days, and no statistically significant trend in the monument's visibility conditions on the haziest days during the period 1999 to 2008. Over a longer period there also does not appear to be an obvious trend (Figure 23).

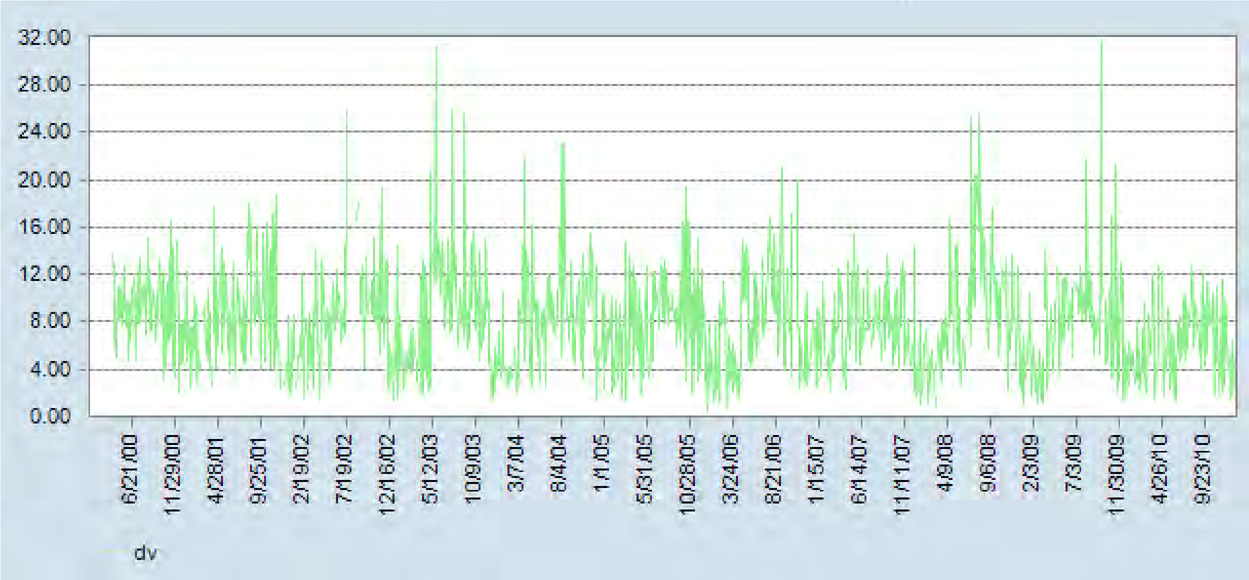


Figure 23. Visibility (in deciview units) from the monument, 1990 to 2010. (From IMPROVE web site: http://views.cira.colostate.edu/web)

Assessment Confidence and Data Gaps

High Certainty. The monument monitors particulates year-round as part of the IMPROVE[12] national monitoring network. Those data describe the visibility conditions reasonably well.

4.7.4.2 Night Sky

Natural lightscapes are critical for nighttime scenery, such as viewing a starry sky in its finest detail. They are also critical for maintaining nocturnal habitat of many wildlife species which rely on natural patterns of light and dark for navigation, to cue behaviors, or hide from predators. Human-caused light may be obtrusive in the same manner that noise can disrupt a contemplative or peaceful scene. Light that is undesirable in a natural or cultural landscape is often called "light pollution."

Criteria

The NPS has not recommended specific criteria for sky brightness, but has developed a system for measuring sky brightness to quantify the source and severity of light pollution. This system uses a research-grade digital camera to capture the entire sky with a series of images. A less precise representation of dark sky can be gained with the unaided eye using the Bortle scale, a qualitative assessment which ranges from 1 (darkest night sky) to 9 (brightest).

Condition and Trends

Condition: *Good – Moderate Certainty.*
Trend: *Indeterminate.*

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[12] Interagency Monitoring of Protected Visual Environments

The monument has been nominated as a Dark Night Sky park, and the night sky is currently rated a 2 on the 9-level Bortle scale (National Park Service 2012). Trends have not been determined. All lighting fixtures in the monument have been inventoried and all lamps have been retrofitted to meet dark sky standards. However, surrounding communities have enacted no lighting ordinances to preserve the night sky. Minor light pollution is apparent low along the Northern horizon, with a low light dome visible over Klamath Falls. There is also some light interference from developments along the State Highway 139 corridor. Agricultural operations by Petroglyph Point have extensive outdoor lighting that affects dark night skies at this location.

Assessment Confidence and Data Gaps
Confidence in the condition was not rated higher because of the qualitative nature of the Bortle assessment. More replicable measures of Night Sky conditions and trends could involve using a sky quality meter and/or digital-camera based protocol. Imagery from the Defense Military Satellite Program (DMSP) might also be helpful.

4.7.4.3 Soundscape
Since 2006, the National Park Service has required parks to identify the levels and types of unnatural sound that constitute acceptable and unacceptable impacts on park natural soundscapes. This is not only for the benefit of visitors, but is also to protect species that require often-subtle auditory cues for reproduction, predator avoidance, navigation, and communication about food locations.

Criteria
The NPS has not recommended specific criteria for soundscape integrity. "Good" condition might be represented by presence of natural sounds only and human-related sounds that travel only short distances for short periods of time. "Somewhat Concerning" and "Significant Concern" might be unnatural sounds that travel greater distances and/or are constant or noticeable for longer periods of time.

One way of quantifying human-sourced interference with natural sounds is to measure the amount of time that sound pressure levels (SPL's)—measured in decibels (dB) and weighted (dBA) to resemble the response of the human ear—exceed a given value. This can be determined with electronic acoustical monitoring systems. A common reference value range is 35-55 dBA because some studies have noted speech interference and impacts to wildlife above that range, depending also on the soundwave frequency.

Condition and Trends
Condition: *Good – Medium Certainty.*
Trends: *Indeterminate.*

The following components of the monument's soundscape are ones commonly recognized:

- *Wildlife:* During the morning and throughout the day, the vocalizations of songbirds are a dominant feature, along with the chattering of squirrels. In the evening and at night, calls of insects and owls are common.
- *Wind:* Wind blowing through the trees or across the rangeland. Trees creaking/rubbing against each other.

- The varied sounds of rainfall on vegetation and the ground.
- Occasionally some memorable thunderstorms.

The park soundscape is impacted by vehicle traffic, military and civilian over flights, generators from the monument campground, various operations and facilities, and snowmobiles from the Doorknob Snowmobile Park just outside the monument. Drilling associated with proposed geothermal development just outside the southern boundary of the monument could increase noise, vibration, and general disturbance.

Loud sounds that sometimes adversely affect the monument's soundscape:

- Vehicle traffic on monument roads. This intrusion can be heard from many places in the monument. Traffic is generated from many sources (visitors, staff, contractors) using many vehicle types; the most intrusive noises tend to be generated from motorcycles, although noise from passenger cars and RVs is persistent during the day, and sounds of snowmobiles and other off-road vehicles just outside the monument can sometimes be heard.
- Campground and day use area noise. Generators, music, doors slamming, etc. This tends to be concentrated and because the campgrounds are in well-vegetated areas, the sounds do not travel far.
- Staff housing area noise. Dogs barking from the penned area in the housing loop can be heard for well over a mile away.
- Construction and maintenance noise. Work on and around buildings and other facilities can be very noisy.
- Forestry work. This intrusion is created by chainsaws, chippers, and other powered equipment. These sounds are significant but infrequent and irregular in occurrence.
- Aircraft. This intrusion is mostly from high elevation commercial flights but is heard regularly everywhere in monument.

Assessment Confidence and Data Gaps
Medium Certainty for current condition, *Indeterminate Certainty* for trends and for the capacity to interpret the data in terms of likely impacts on people and wildlife.

4.7.4.4 Physical Remoteness and Solitude

The monument has two Wilderness units (Schonchin and Black Lava Flow) totaling 28,460 acres and covering almost two-thirds of the monument's area. Wilderness and backcountry are managed identically, to the extent possible, as stated in the 2006 Wilderness Stewardship Plan, and total approximately 45,636 acres. There are 38 miles of maintained trails and 12 miles of unmaintained trails in the backcountry and wilderness areas of the monument.

Criteria
Wilderness qualities, each of which has been defined administratively, are:

- Untrammeled

- Natural
- Undeveloped
- Solitude or primitive and unconfined recreation quality

No numeric criteria exist for assessing these.

Condition and Trends
Condition: *Good – Medium Certainty*.
Trends: *Indeterminate*.

Qualitatively, nearly the entire monument appears to have the qualities listed above. A few developments are visible from the Schonchin Wilderness, including the monument's housing and visitor center buildings, but otherwise visual intrusions are not obvious. Most monument visitors are able to find many opportunities for physical remoteness and solitude. A great majority of visitors coming to the monument come between June and September. By far the most visitors spend the bulk of their time at the lava tube caves that are open to the public. Off-road vehicles occasionally trespass from the surrounding National Forest.

Data are insufficient to detect any trend in Physical Remoteness and Solitude. The number of tourist visits, and thus automobile traffic, appears to have increased gradually. Data on visits to 11 visitor use caves during the period 1992-2008 (Figure 24) do not show an obvious trend.

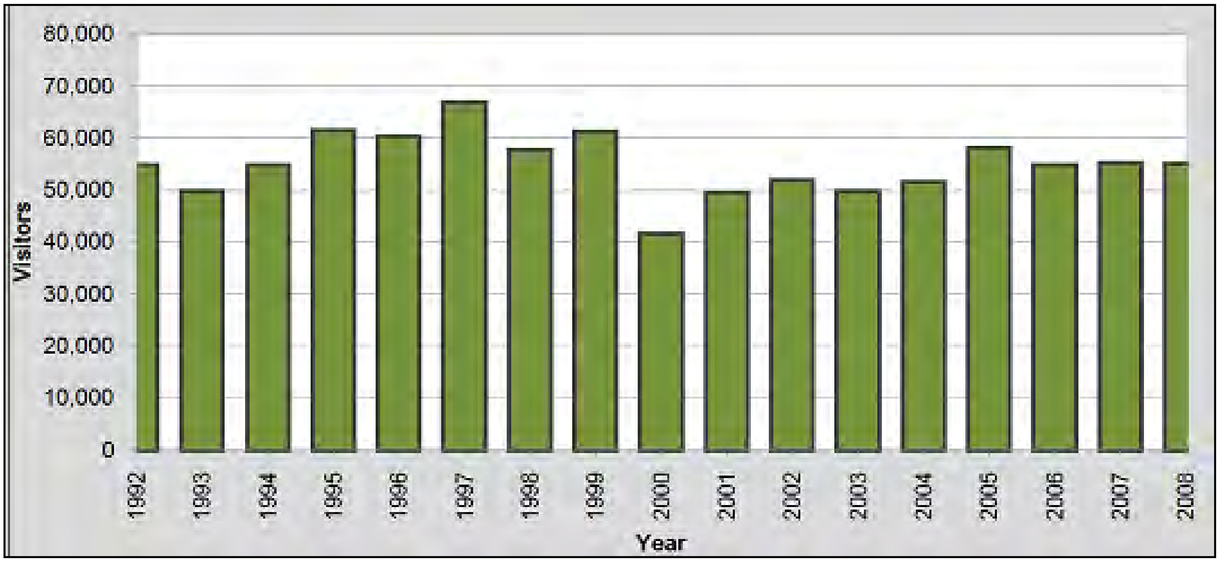

Figure 24. Total visits in 11 monitored visitor use caves during 1992-2008.

Assessment Confidence and Data Gaps
Medium Certainty. Although total visits to the monument are tallied annually, visits to various areas within the monument are not routinely tallied, nor are the disturbances potentially associated with those. Visits to half of the public use caves are not monitored, and visitation data on the other public use caves may be of limited accuracy, duration, and consistency.

Implementation of the Klamath Network's new cave entrance monitoring protocol (Krejca et al. 2010) will result in more consistent collection of such data.

4.7.4.5 Disturbed Area Recovery

While some infrastructure is obviously necessary to support the immediate safety and comfort of visitors, some artificial features—mostly ones that are hold-overs from when land uses were unrestricted before the monument was established—can be a problem. Some create a visual blight, fragment wildlife habitat, disrupt natural water flows, and provide an opportunity for the establishment of non-native plants. Actively restoring or otherwise speeding the recovery of these areas is a priority for monument staff.

Criteria

For purposes of this assessment, "Good" conditions would be represented by a park landscape with no disturbed lands except those currently vital to visitor support. It would also involve complete restoration or recovery of all artificially disturbed lands within the park that are not currently vital to visitor support. "Somewhat Concerning" and "Significant Concern" would reflect increasing extent of unrestored lands.

Condition and Trends

Condition: *Good – High Certainty*.
Trends: *Improving.*

For the monument as a whole, natural succession and planned restoration appears to be gradually leading to visual recovery in most areas historically disturbed by logging, grazing, or other disturbances. Since designation of the monument, limited development has occurred to provide for transportation, monument administration, and visitor services and access. Inevitably, development has disturbed or displaced natural vegetation and soils. Borrow pits historically excavated for road construction have mostly been stabilized. Some old roads have been abandoned and are now used as trails.

Assessment Confidence and Data Gaps

Moderate Certainty. Most of the monument's major land disturbances were systematically inventoried by Ziegenbein et al. (2006).

5.0 Discussion

Table 13 summarizes what this document has reported about the condition and trends of each of the seven major resource concerns identified at Lava Beds National Monument. Partly because lava caves are the feature most responsible for drawing visitors to Lava Beds National Monument, the greatest concerns have focused on the physical and biological condition of those caves. Physically, the risks of greatest concern are those that threaten the microclimate of the caves, particularly the caves that contain perennial ice. The cave microclimate could be placed at greater risk by increased visitation, decreasing aboveground precipitation, warming aboveground temperatures, and as perhaps by falling regional water tables. These factors are even more likely to alter the monument's aboveground vegetation and wildlife. Biologically, the feature of the lava caves receiving the most recognition to date has been their bats. Bat populations are likely to be exposed to pesticides used widely in the agricultural lands surrounding the monument. Effects of pesticides and other contaminants on bat populations within the monument have yet to be determined. Fortunately, there is no evidence that White Nose Syndrome—a recent cause of mass mortalilty among bats in eastern North America—has arrived at the monument.

Cave organisms could also be affected to an unknown degree by herbicide applications in lands that overlie the caves, as well as by changes in cave water budgets resulting from changes in aboveground vegetation cover. Vegetation shifts that have occurred have diminished—and will continue to diminish—populations of many of the monument's wildlife species that depend on habitats characterized by sagebrush, bunchgrass, or large conifers. Cheatgrass which spreads and remains indefinitely in disturbed areas slows the regeneration of shrubs and pines, and it occurs at the expense of more diverse native plant communities. Fires occur fairly often in this dry country, and both their extent and negative effects have been exacerbated by widespread post-fire establishment of cheatgrass. Even fires as infrequent as one every 30 to 50 years could maintain vegetation dominated by cheatgrass at the monument.

Understanding of condition and trends of the monument's natural resources, as essential to their sound management, could perhaps benefit the most from new or expanded research on relationships between precipitation, infiltration, groundwater levels, and cave microclimates; as well as between visitor use and cave microclimates. Also important is monitoring of: ice and microclimate in additional caves; effects of pesticides and other contaminants on cave fauna; energetics studies of bats as related to local availability of the insects upon which they forage; taxonomically intensive surveys of invertebrates in more caves; factors that may allow the bunchgrass community to persist in relationship to cheatgrass and fire; and surveys of the monument's reptiles and small mammals, especially as they may be impacted by cheatgrass invasion.

Table 13. Summary of ratings for indicators of condition and trend used in this analysis of Lava Beds National Monument. See chapter narratives for criteria and justification of each rating.

Priority Issue	Indicators	Potential Value as Indicator	Condition Rating	Certainty	Trend Rating	Certainty	Spatial Coverage	Temporal Coverage
Changes in Climate	Aboveground Temperature & Precipitation	Good	Indeterminate		Somewhat Concerning	Medium	Fair	Good
	Cave Microclimate	Good	Indeterminate		Indeterminate		Poor	Poor
	Ice Formation & Persistence	Fair	Indeterminate		Somewhat Concerning (Significant Concern for 3 caves)	High	Fair	Poor
Changes in Cave Geologic Features		Fair	Somewhat Concerning	Low	Indeterminate		Poor	Poor
Changes in Cave-dependent Species		Good	Mixed	Mixed	Indeterminate		Fair	Poor
Changes in Vegetation	Cheatgrass	Good	Significant Concern	High	Significant Concern	High	Good	Fair
	Other Invasives	Good	Significant Concern	Medium	Indeterminate		Fair	Poor
	Juniper	Fair	Somewhat Concerning	Medium	Somewhat Concerning	Medium	Good	Fair
	Sagebrush	Good	Significant Concern	Medium	Significant Concern	Medium	Good	Poor
	Bunchgrasses	Fair	Somewhat Concerning	Medium	Somewhat Concerning	Medium	Medium	Poor

Table 13. Summary of ratings for indicators of condition and trend used in this analysis of Lava Beds National Monument. See chapter narratives for criteria and justification of each rating.

Priority Issue	Indicators	Potential Value as Indicator	Condition Rating	Certainty	Trend Rating	Certainty	Spatial Coverage	Temporal Coverage
	Rare Species; Diversity of Native Plant Species	Poor	Indeterminate		Indeterminate		Poor	Poor
Changes in Aboveground Wildlife	Diversity of Native Terrestrial Wildlife Species & Rare Species	Fair	Somewhat Concerning	Low	Indeterminate		Fair	Poor
	Connectivity & Extent of Important Terrestrial Habitats	Good	Somewhat Concerning	Medium	Somewhat Concerning	Medium	Fair	Poor
Changes in Air Quality	Deposition of Atmospheric Nitrogen and Sulfur	Fair	Good	Medium	Indeterminate		N/A	Poor
	Deposition of Airborne Contaminants	Fair	Indeterminate		Indeterminate		Indeterminate	Poor
	Ozone	Fair	Somewhat Concerning	Low	Indeterminate	Low	N/A	Poor

Table 13. Summary of ratings for indicators of condition and trend used in this analysis of Lava Beds National Monument. See chapter narratives for criteria and justification of each rating.

Priority Issue	Indicators	Potential Value as Indicator	Condition Rating	Certainty	Trend Rating	Certainty	Spatial Coverage	Temporal Coverage
Changes in the Natural Quality of the Park Experience	Visibility	Fair	Somewhat Concerning	High	Indeterminate	Indeterminate	N/A	Poor
	Night Sky	Good	Good	Medium	Indeterminate	Indeterminate	N/A	Poor
	Soundscape	Good	Good	Medium	Indeterminate	Mixed	Poor	Poor
	Physical Remoteness and Solitude	Good	Good	Medium	Indeterminate	Indeterminate	Good	Poor
	Disturbed Area Recovery	Fair	Good	High	Improving	Medium	Good	Fair

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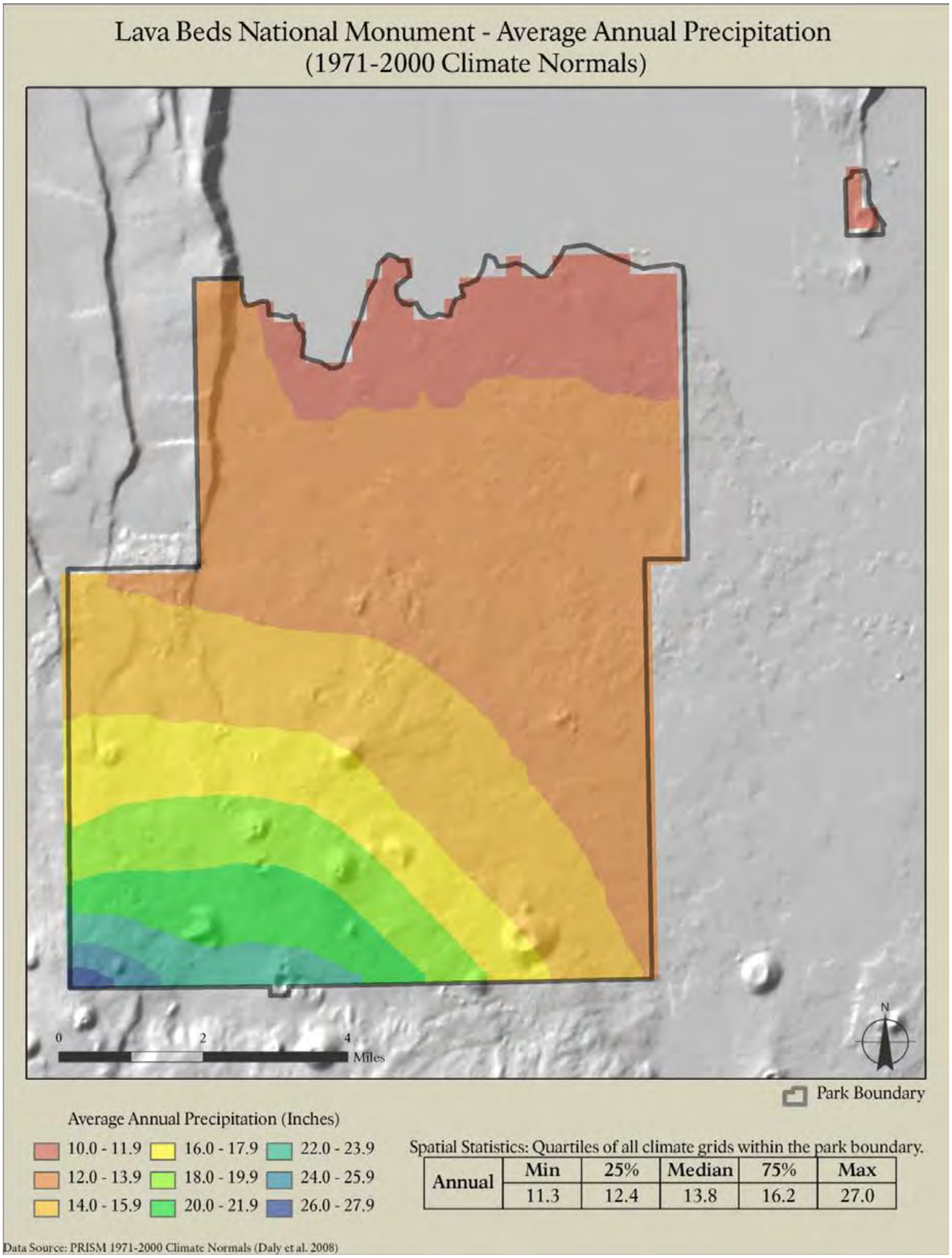
Appendix A. Climate of Lava Beds National Monument: supporting data and maps

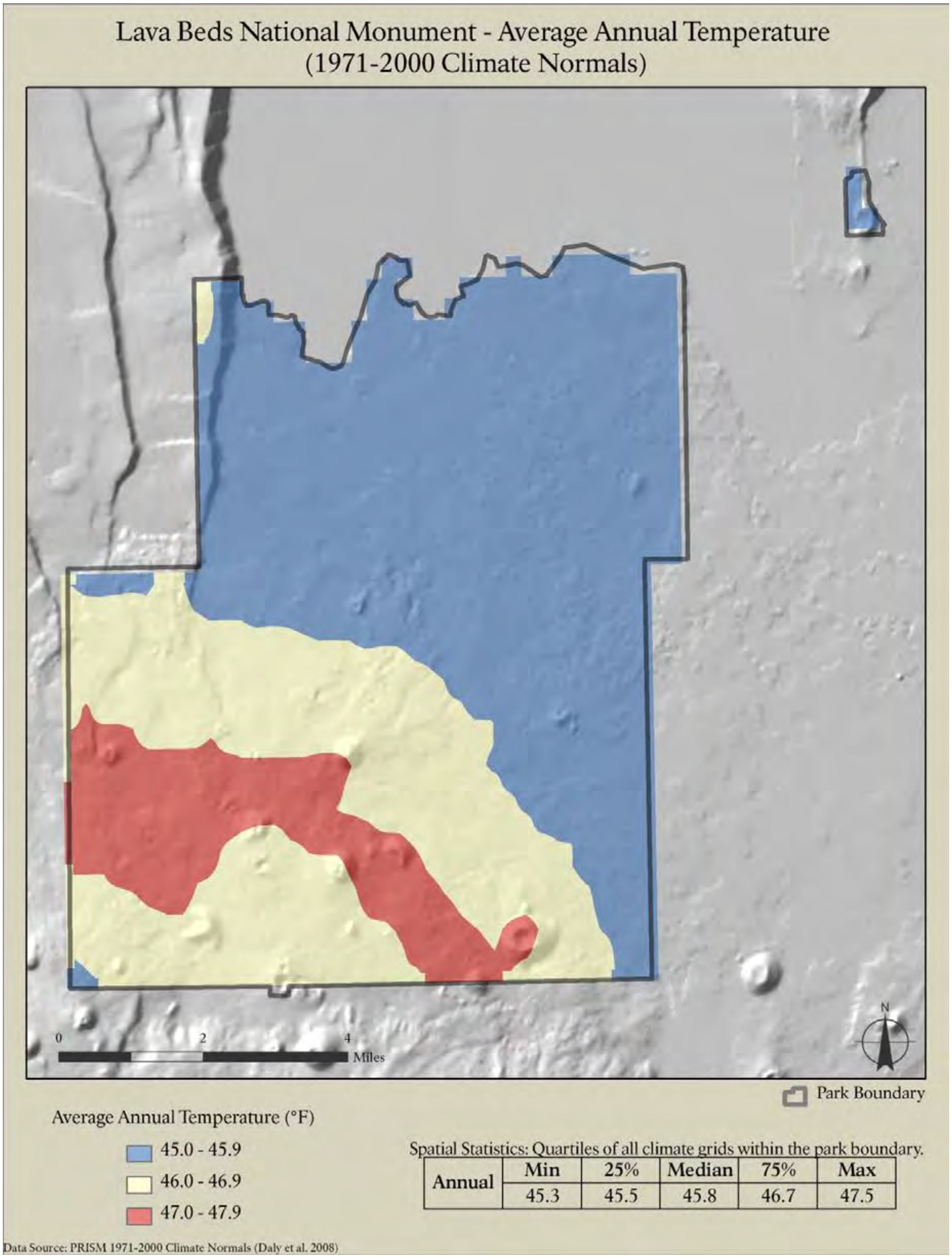


Spatial Statistics: Quartiles of all climate grids within the park boundary.

	Min	25%	Median	75%	Max
Annual	11.3	12.4	13.8	16.2	27.0

Data Source: PRISM 1971-2000 Climate Normals (Daly et al. 2008)

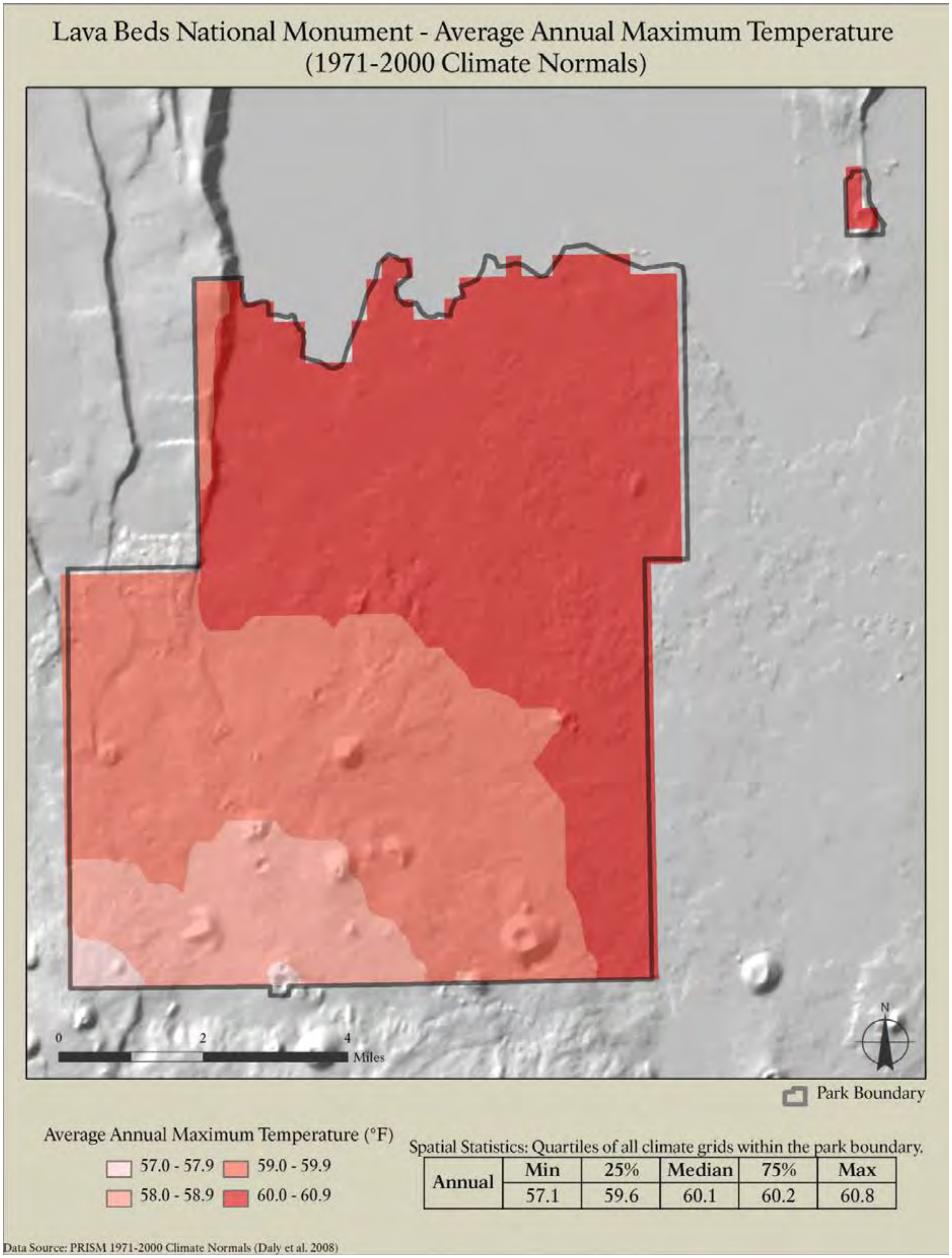
Figure A1. Annual precipitation for Lava Beds National Monument (LABE) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). This map was prepared by investigators for the LANDFIRE project who extrapolated information using Landsat Thematic Mapper and other data. The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.



Spatial Statistics: Quartiles of all climate grids within the park boundary.

	Min	25%	Median	75%	Max
Annual	45.3	45.5	45.8	46.7	47.5

Figure A2. Average annual temperatures for Lava Beds National Monument (LABE) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). This map was prepared by investigators for the LANDFIRE project who extrapolated information using Landsat Thematic Mapper and other data. The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.

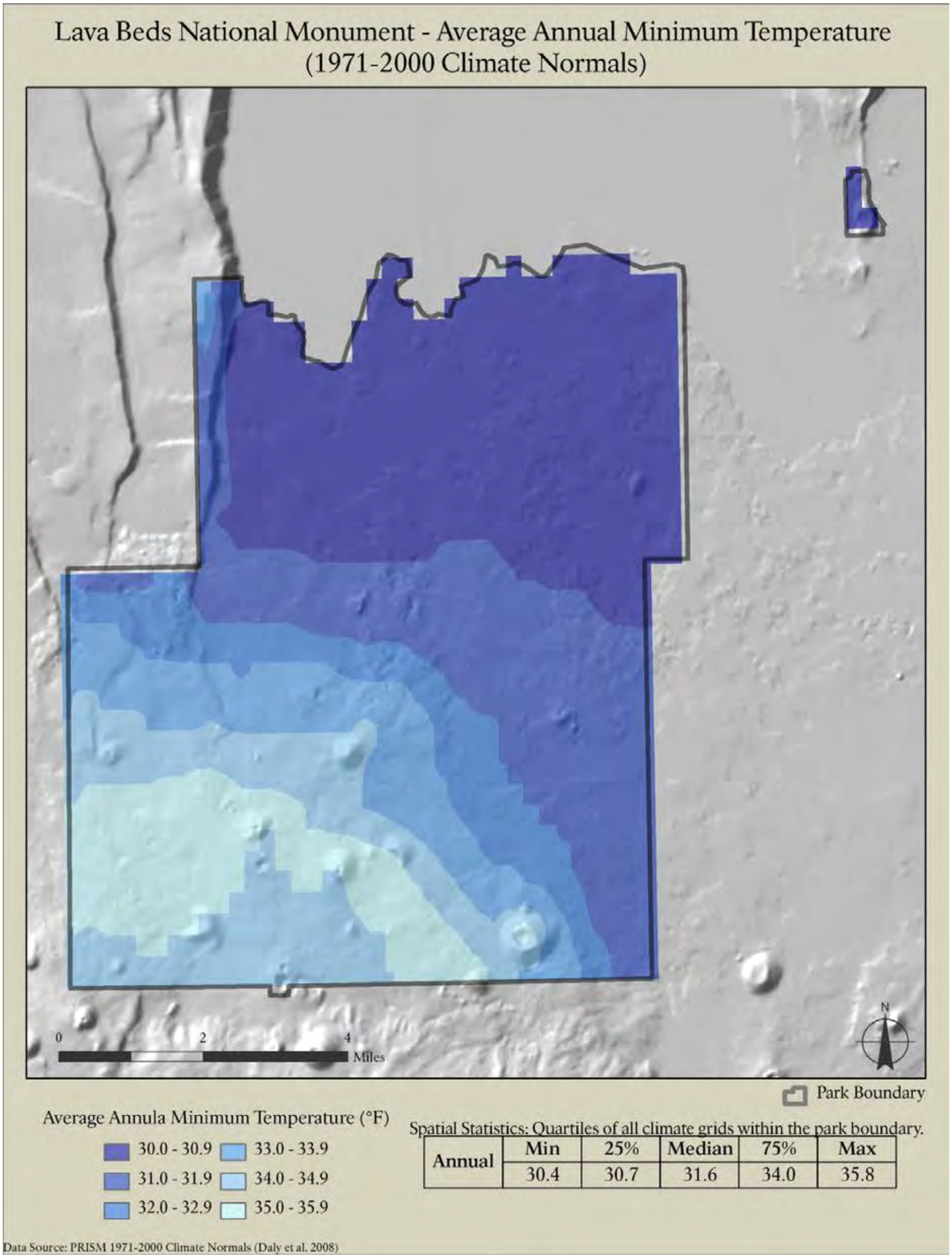


Spatial Statistics: Quartiles of all climate grids within the park boundary.

	Min	25%	Median	75%	Max
Annual	57.1	59.6	60.1	60.2	60.8

Data Source: PRISM 1971-2000 Climate Normals (Daly et al. 2008)

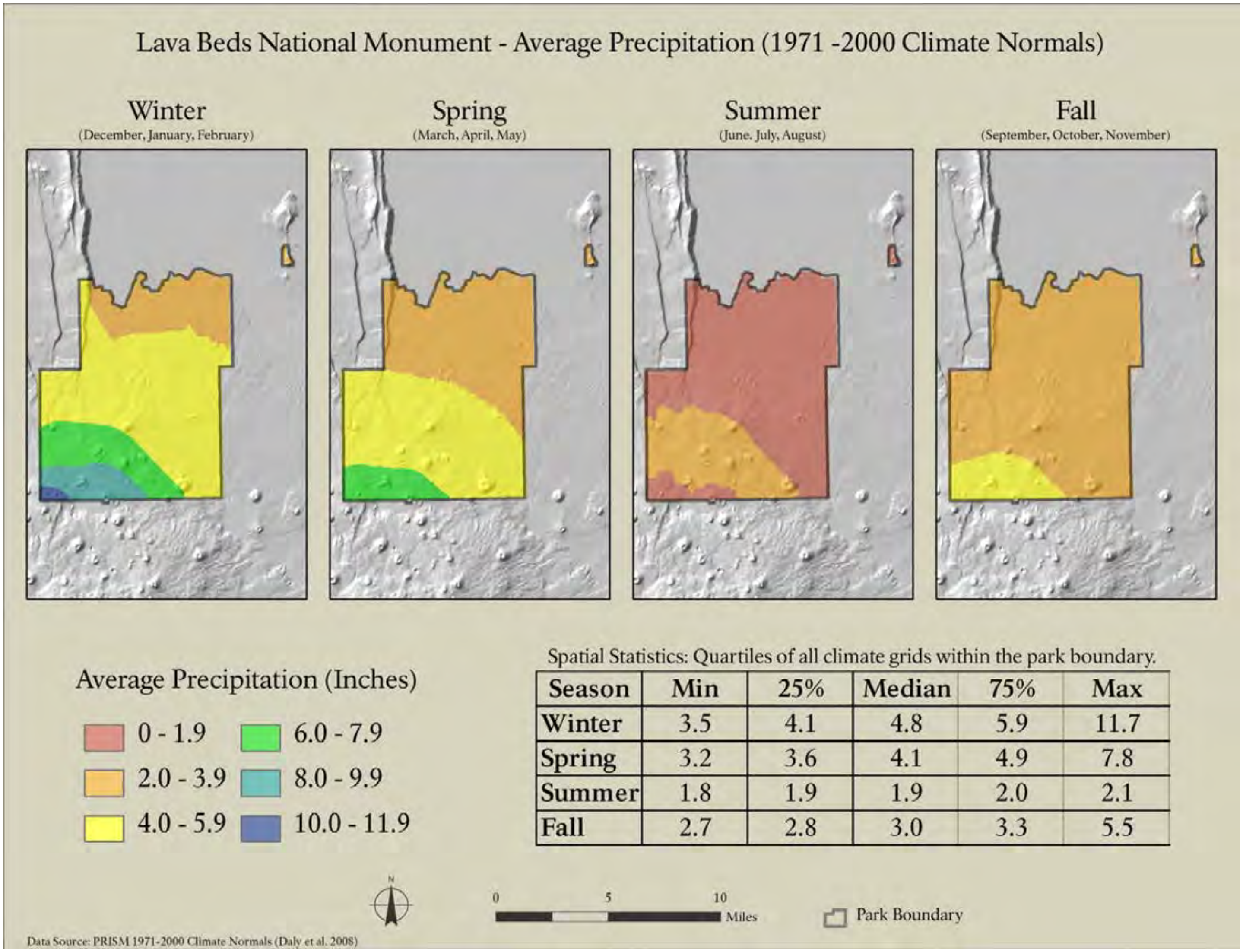
Figure A3. Average annual maximum temperatures for Lava Beds National Monument (LABE) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). This map was prepared by investigators for the LANDFIRE project who extrapolated information using Landsat Thematic Mapper and other data. The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.



	Min	25%	Median	75%	Max
Annual	30.4	30.7	31.6	34.0	35.8

Data Source: PRISM 1971-2000 Climate Normals (Daly et al. 2008)

Figure A4. Average annual minimum temperatures for Lava Beds National Monument (LABE) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). This map was prepared by investigators for the LANDFIRE project who extrapolated information using Landsat Thematic Mapper and other data. The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.



Lava Beds National Monument - Average Precipitation (1971 -2000 Climate Normals)

Winter (December, January, February)

Spring (March, April, May)

Summer (June. July, August)

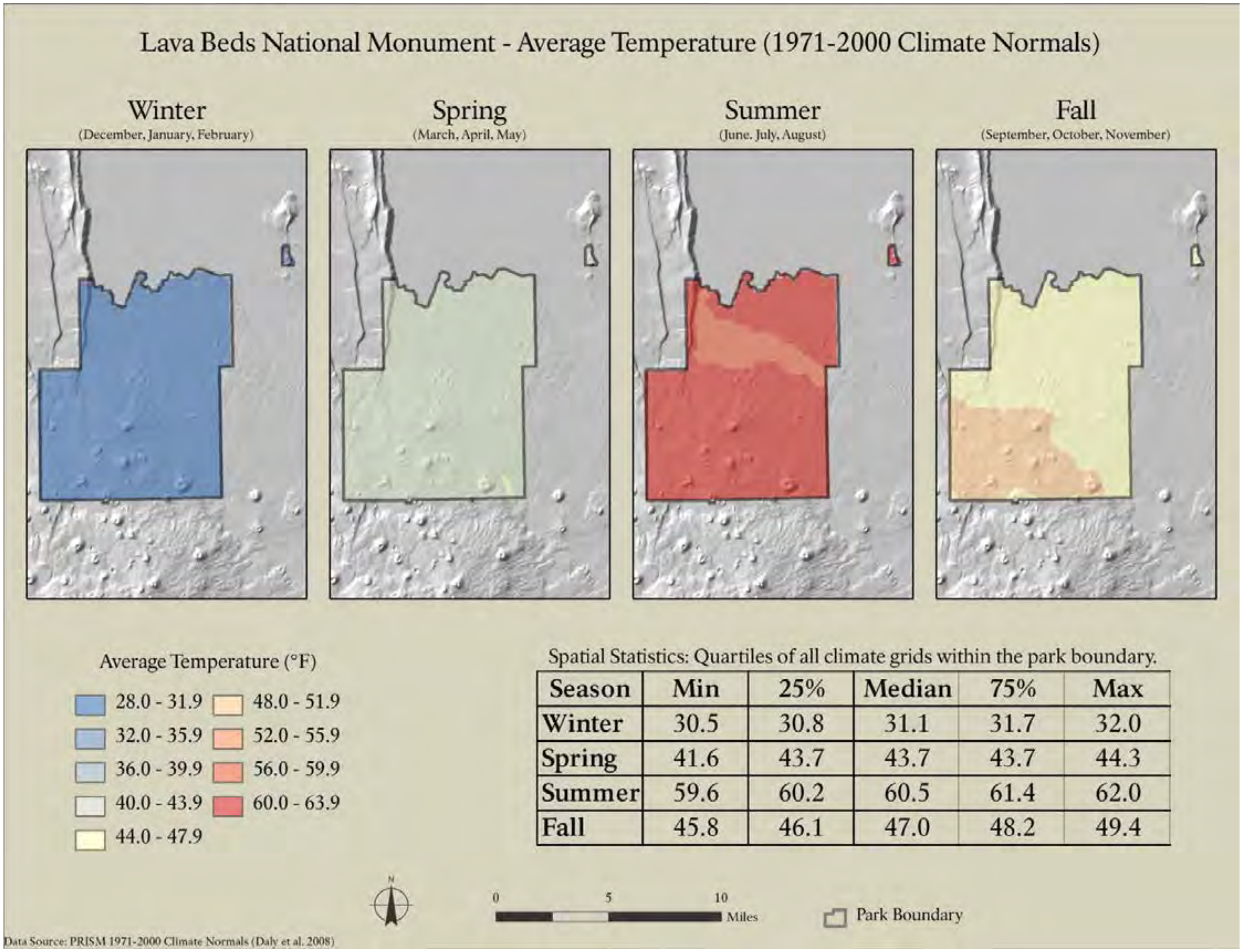
Fall (September, October, November)

Spatial Statistics: Quartiles of all climate grids within the park boundary.

Season	Min	25%	Median	75%	Max
Winter	3.5	4.1	4.8	5.9	11.7
Spring	3.2	3.6	4.1	4.9	7.8
Summer	1.8	1.9	1.9	2.0	2.1
Fall	2.7	2.8	3.0	3.3	5.5

Data Source: PRISM 1971-2000 Climate Normals (Daly et al. 2008)

Figure A5. Average precipitation for the winter (DJF), spring (MAM), summer (JJA), and fall (SON) seasons for Lava Beds National Monument (LABE) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). This map was prepared by investigators for the LANDFIRE project who extrapolated information using Landsat Thematic Mapper and other data. The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.

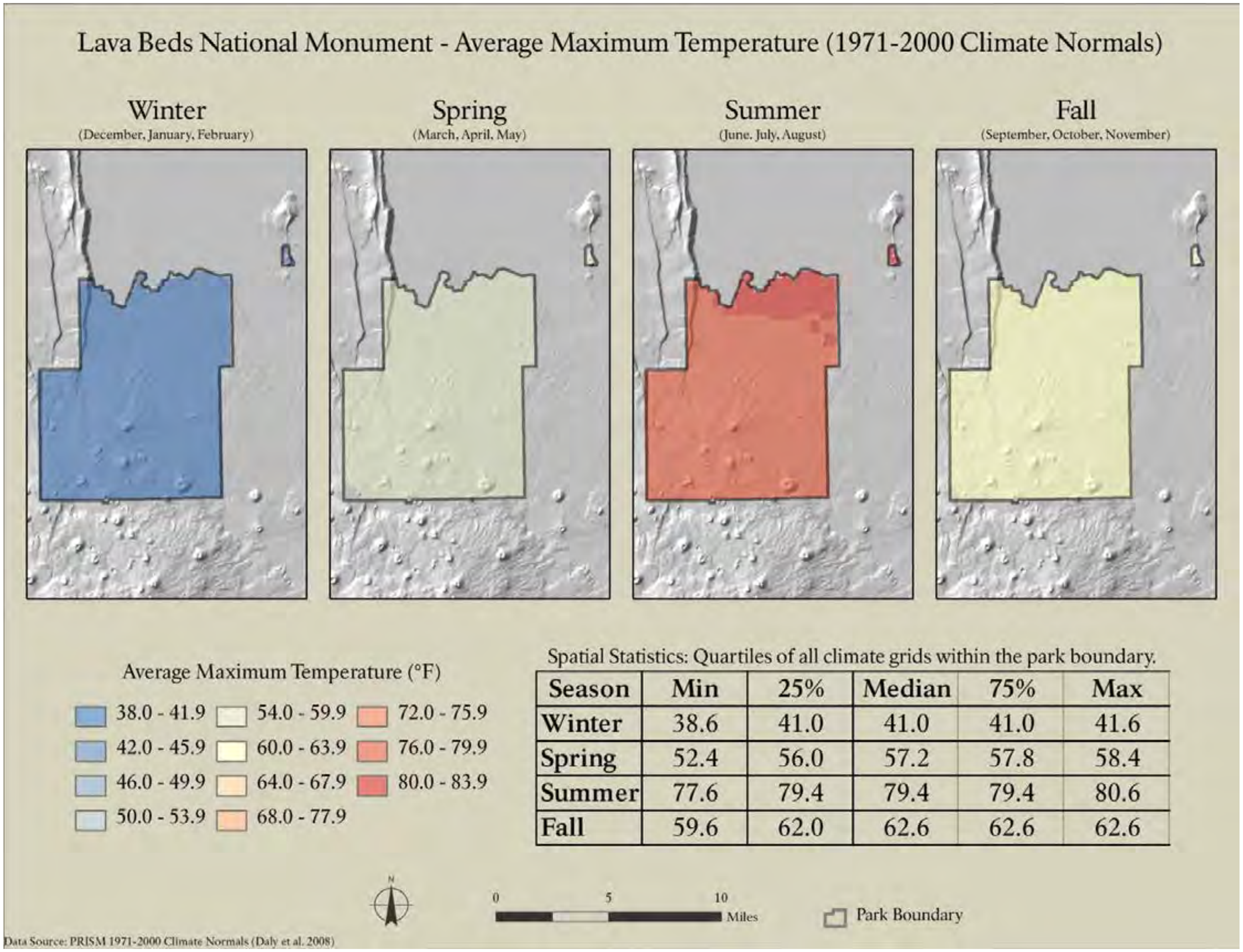


Spatial Statistics: Quartiles of all climate grids within the park boundary.

Season	Min	25%	Median	75%	Max
Winter	30.5	30.8	31.1	31.7	32.0
Spring	41.6	43.7	43.7	43.7	44.3
Summer	59.6	60.2	60.5	61.4	62.0
Fall	45.8	46.1	47.0	48.2	49.4

Data Source: PRISM 1971-2000 Climate Normals (Daly et al. 2008)

Figure A6. Average temperatures for the winter (DJF), spring (MAM), summer (JJA), and fall (SON) seasons for Lava Beds National Monument (LABE) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). This map was prepared by investigators for the LANDFIRE project who extrapolated information using Landsat Thematic Mapper and other data. The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.

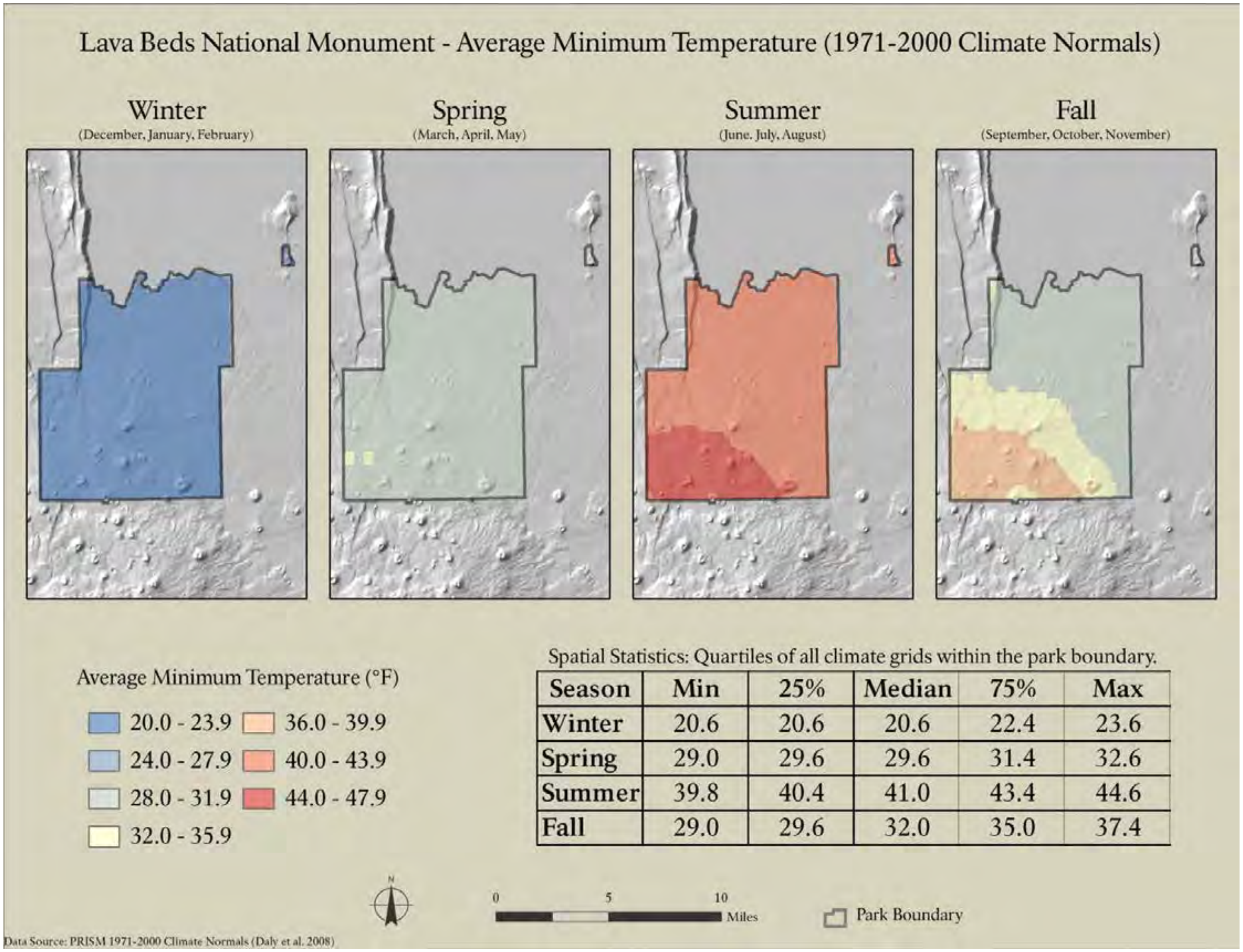


Spatial Statistics: Quartiles of all climate grids within the park boundary.

Season	Min	25%	Median	75%	Max
Winter	38.6	41.0	41.0	41.0	41.6
Spring	52.4	56.0	57.2	57.8	58.4
Summer	77.6	79.4	79.4	79.4	80.6
Fall	59.6	62.0	62.6	62.6	62.6

Data Source: PRISM 1971-2000 Climate Normals (Daly et al. 2008)

Figure A7. Average maximum temperatures for the winter (DJF), spring (MAM), summer (JJA), and fall (SON) seasons for Lava Beds National Monument (LABE) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). This map was prepared by investigators for the LANDFIRE project who extrapolated information using Landsat Thematic Mapper and other data. The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.



Spatial Statistics: Quartiles of all climate grids within the park boundary.

Season	Min	25%	Median	75%	Max
Winter	20.6	20.6	20.6	22.4	23.6
Spring	29.0	29.6	29.6	31.4	32.6
Summer	39.8	40.4	41.0	43.4	44.6
Fall	29.0	29.6	32.0	35.0	37.4

Figure A8. Average minimum temperatures for the winter (DJF), spring (MAM), summer (JJA), and fall (SON) seasons for Lava Beds National Monument (LABE) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). This map was prepared by investigators for the LANDFIRE project who extrapolated information using Landsat Thematic Mapper and other data. The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.

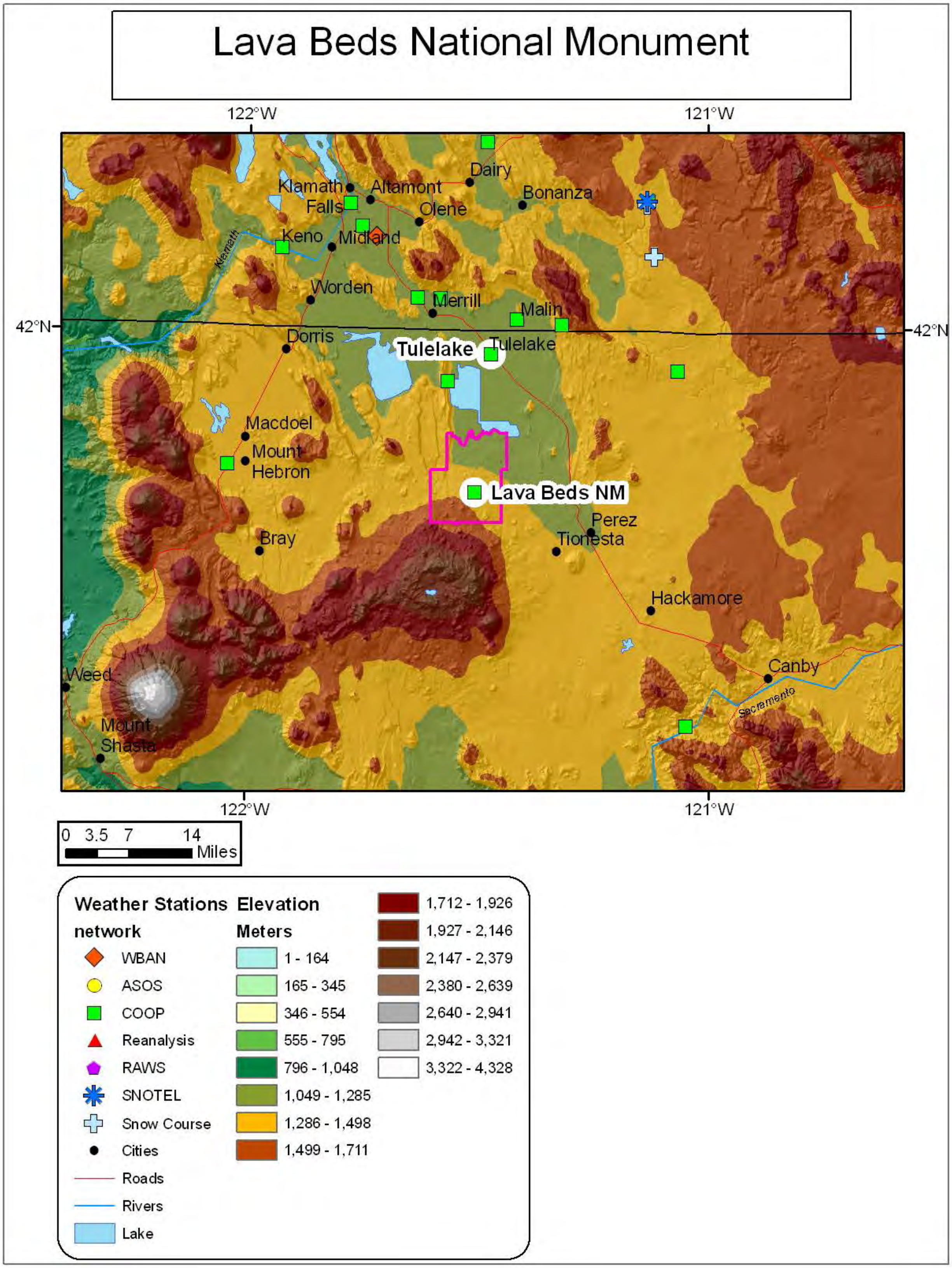


Figure A9. Climate stations in the vicinity of Lava Beds National Monument (LABE) (Daly et al. 2009). Stations highlighted in the map are further referenced in the report.

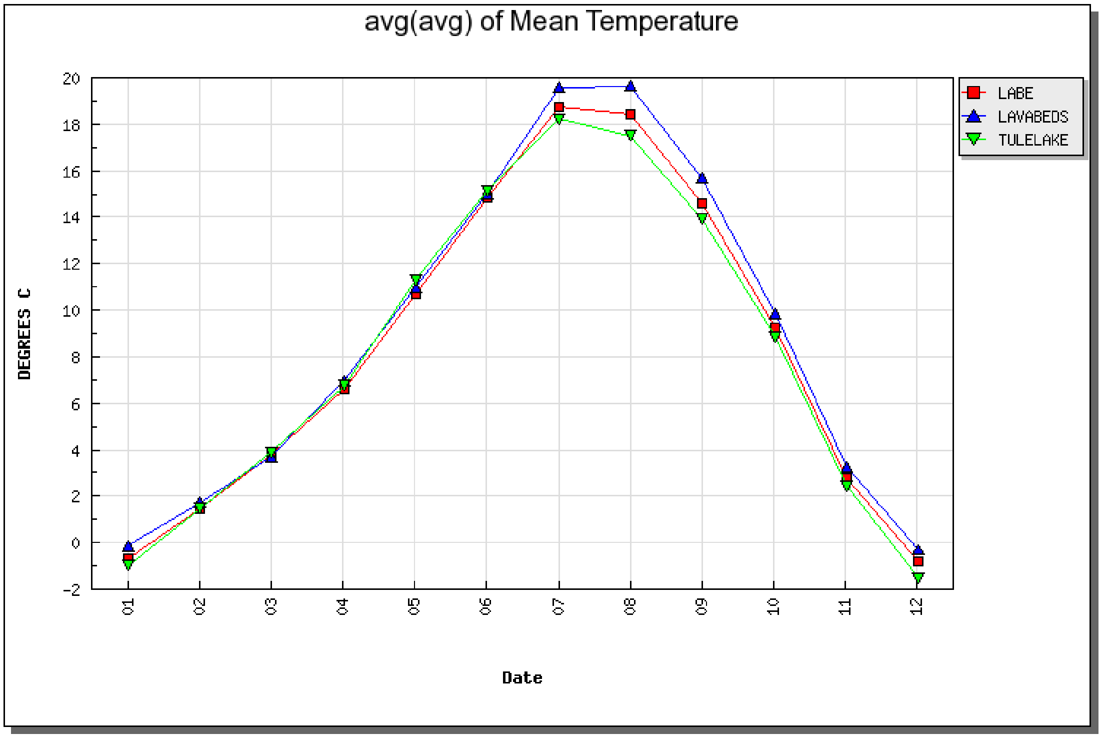


Figure A10. 1971–2000 average monthly mean temperature for the stations at Lava Beds NM, Tulelake, and the Lava Beds (LABE) park average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

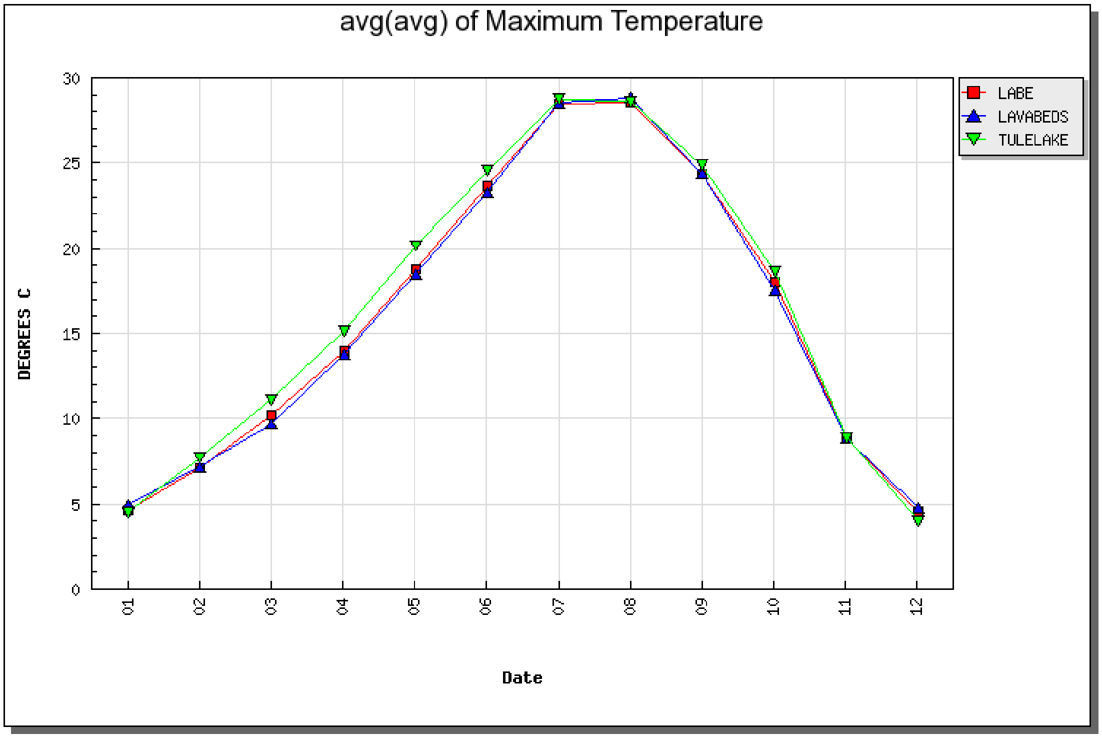


Figure A11. 1971–2000 average monthly maximum temperature for the stations at Lava Beds NM, Tulelake, and the Lava Beds (LABE) park average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

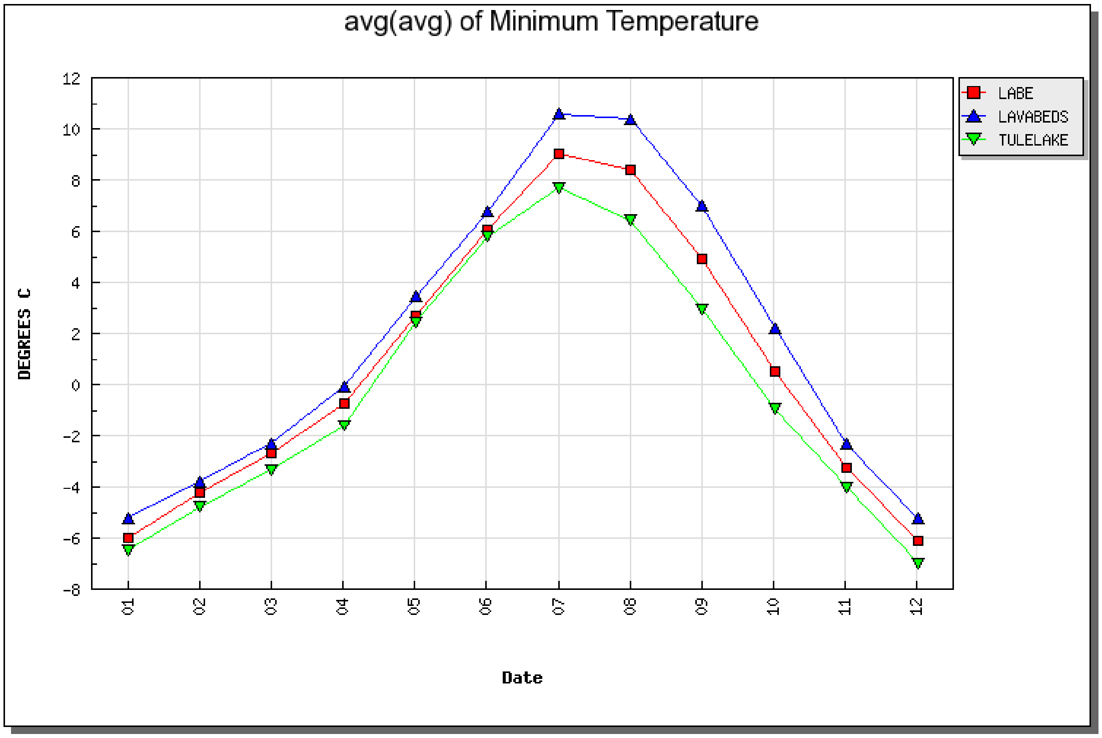


Figure A12. 1971–2000 average monthly minimum temperature for the stations at Lava Beds NM, Tulelake, and the Lava Beds (LABE) park average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

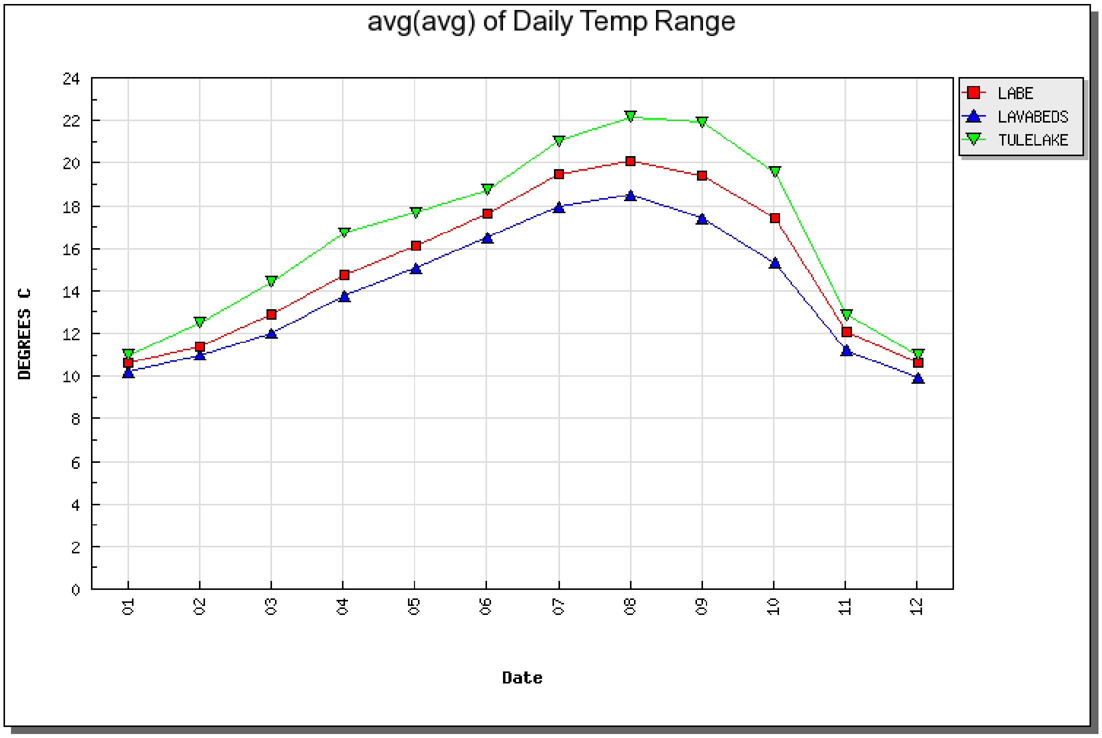


Figure A13. 1971–2000 average monthly daily temperature range for the stations at Lava Beds NM, Tulelake, and the Lava Beds (LABE) average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

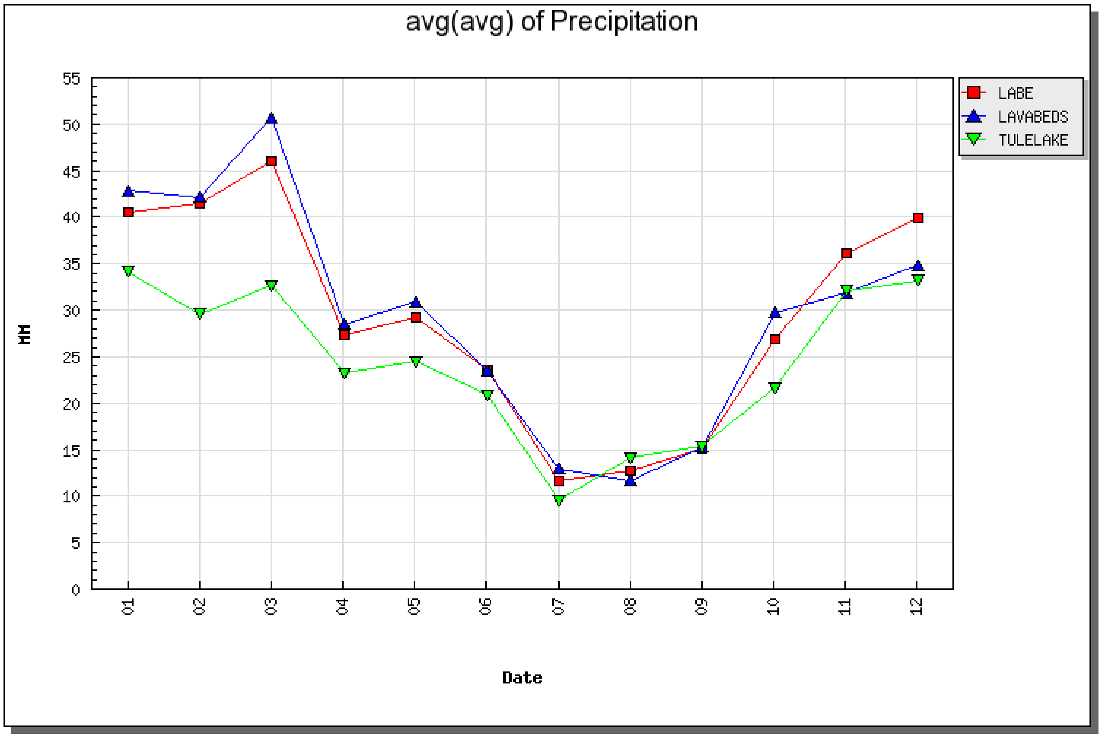


Figure A14. 1971–2000 average monthly precipitation for the stations at Lava Beds NM, Tulelake, and the Lava Beds (LABE) average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

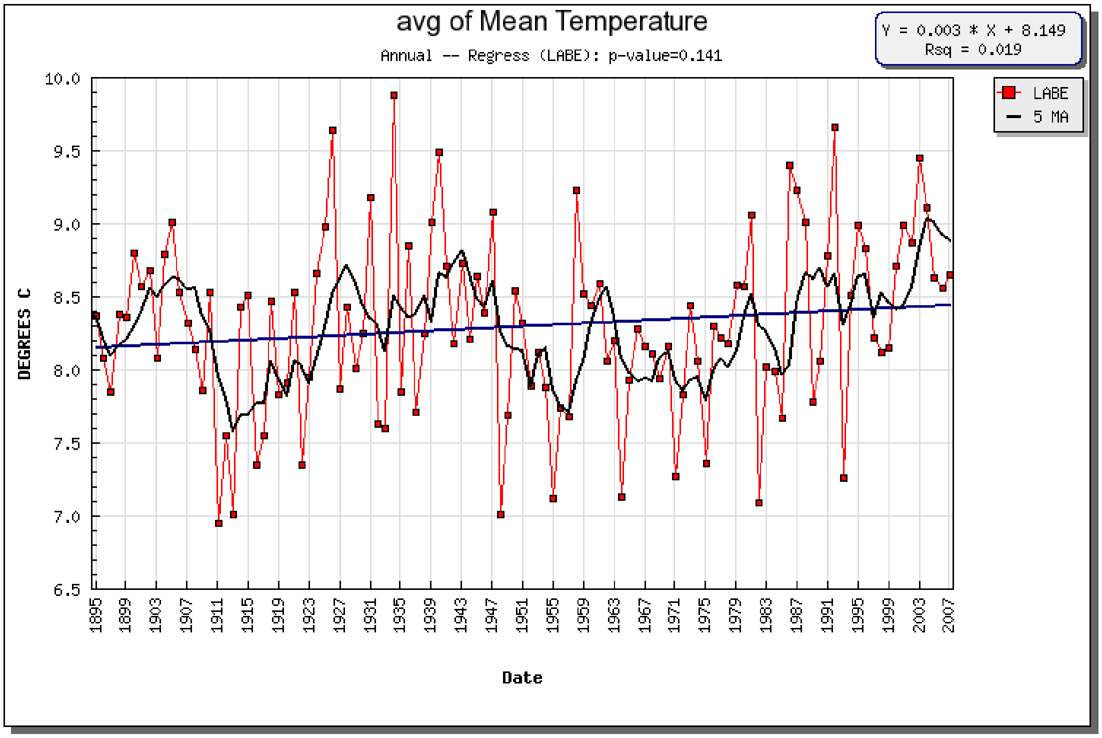


Figure A15. Time series of mean annual temperature for LABE from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

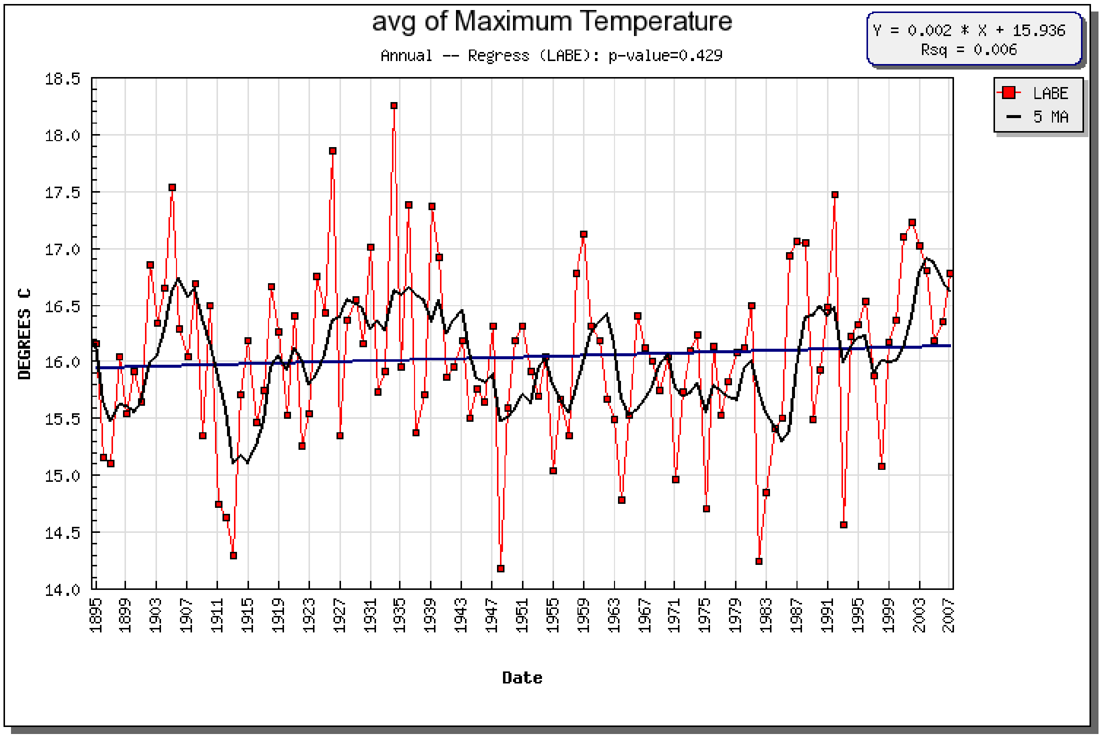


Figure A16. Time series of mean annual maximum temperature for LABE from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

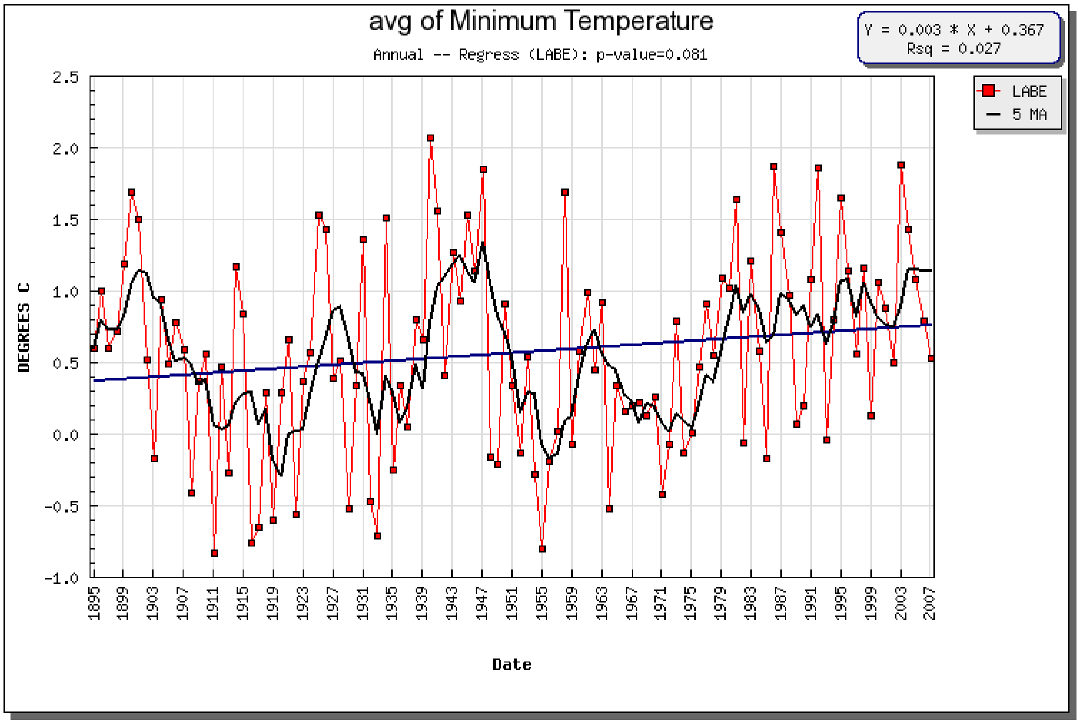


Figure A17. Time series of mean annual minimum temperature for LABE from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

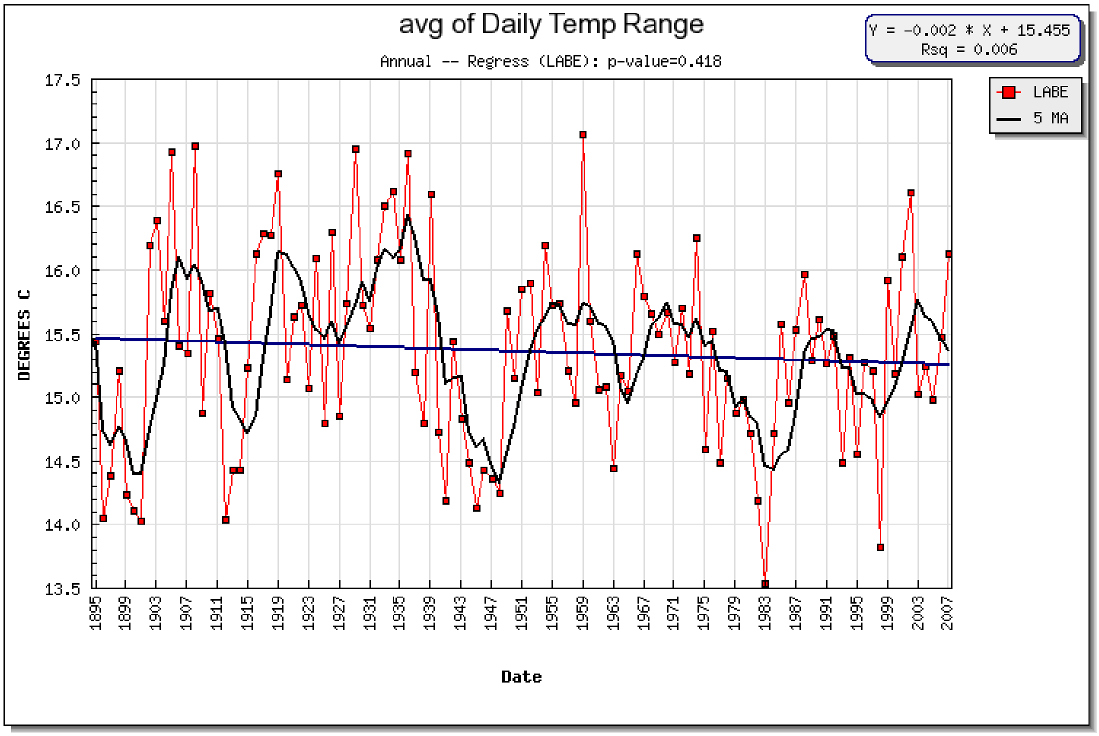


Figure A18. Time series of mean annual daily temperature range for LABE from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

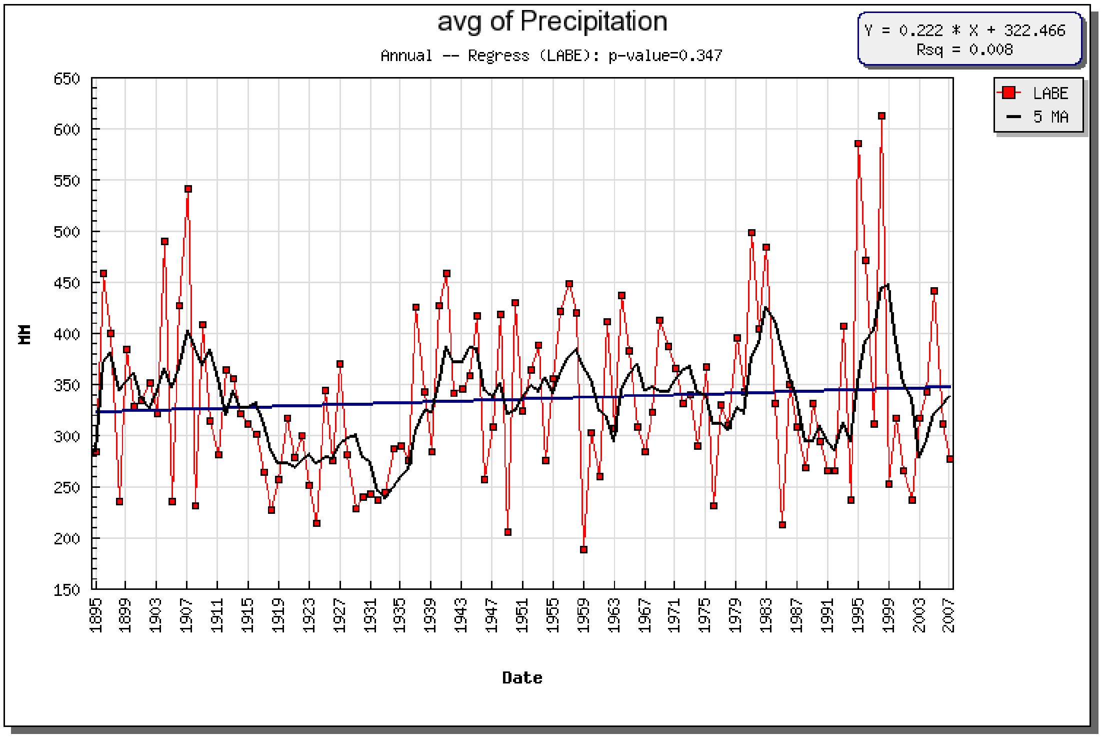


Figure A19. Time series of annual precipitation for CRLA from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

Table A1. Regression parameters and statistics for core climate elements for different time periods for Lava Beds National Monument using PRISM modeled data (Daly et al. 2009). Slope *p*-values significant at the 90% confidence level (α=0.10) are shown in bold.

	Annual Precipitation		**Annual Maximum Temperature**		**Annual Minimum Temperature**		**Annual Mean Temperature**	
Time Period (years)	**Slope (mm/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**
1895–2007	2.223	0.347	0.017	0.429	0.035	0.081	0.026	0.141
1971–2007	-0.573	0.969	0.321	0.007	0.203	0.034	0.262	0.006

Table A2. Regression parameters and statistics for core climate elements for 1895–2007 for Lava Beds National Monument using PRISM modeled data (Daly et al. 2009). Slope *p*-values significant at the 90% confidence level (α=0.10) are shown in bold.

	Precipitation		Maximum Temperature		Minimum Temperature		Mean Temperature	
Month	**Slope (mm/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**
January								
February	-0.516	0.484	0.093	0.144	0.058	0.388	0.075	0.214
March	-0.062	0.933	0.071	0.319	0.079	0.078	0.075	0.158
April	0.586	0.170	-0.097	0.178	0.005	0.906	-0.046	0.369
May	0.512	0.361	0.013	0.850	0.047	0.212	0.030	0.545
June	0.367	0.518	-0.012	0.849	0.048	0.149	0.018	0.678
July	0.171	0.554	-0.000	0.997	0.029	0.427	0.015	0.724
August	0.443	0.205	0.002	0.962	0.014	0.685	0.008	0.828
September	-0.150	0.651	0.124	0.037	0.034	0.367	0.079	0.071
October	-0.211	0.767	0.034	0.606	-0.007	0.845	0.013	0.755
November	0.810	0.303	-0.109	0.083	-0.017	0.727	-0.063	0.147
December	0.913	0.265	-0.016	0.760	0.026	0.664	0.005	0.925
Annual	2.223	0.347	0.017	0.429	0.035	0.081	0.026	0.141

Table A3. Regression parameters and statistics for core climate elements for 1971–2007 for Lava Beds National Monument using PRISM modeled data. Slope *p*-values significant at the 90% confidence level (α=0.10) are shown in bold. (Daly et al. 2009)

	Precipitation		**Maximum Temperature**		**Minimum Temperature**		**Mean Temperature**	
Month	**Slope (mm/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**
January	2.330	0.553	0.444	0.111	0.643	0.074	0.543	0.075
February	0.898	0.828	0.082	0.808	-0.012	0.969	0.035	0.906
March	-4.459	0.309	0.772	0.042	0.308	0.179	0.539	0.060
April	2.463	0.304	0.297	0.428	0.395	0.069	0.346	0.221
May	1.624	0.642	0.189	0.630	0.366	0.055	0.278	0.308
June	-0.002	0.999	0.184	0.574	0.060	0.778	0.122	0.634
July	-0.540	0.765	0.593	0.038	0.351	0.071	0.473	0.041
August	-3.083	0.214	0.417	0.126	0.071	0.676	0.245	0.225
September	-1.810	0.329	0.455	0.176	0.062	0.743	0.258	0.294
October	-2.783	0.408	0.153	0.692	-0.033	0.866	0.060	0.814
November	2.130	0.617	0.213	0.547	-0.000	1.000	0.107	0.686
December	2.659	0.600	0.046	0.875	0.235	0.467	0.140	0.618
Annual	-0.573	0.969	0.321	0.007	0.203	0.034	0.262	0.006

Table A4. Regression parameters and statistics for core climate elements for 1971–2007 at Lava Beds NM. Slope *p*-values significant at the 90% confidence level (α=0.10) are shown in bold. (Daly et al. 2009)

	Precipitation		**Maximum Temperature**		**Minimum Temperature**		**Mean Temperature**	
Month	**Slope (mm/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**
January	3.215	0.576	0.631	0.029	0.508	0.143	0.563	0.065
February	3.720	0.473	0.190	0.586	-0.060	0.847	0.063	0.841
March	-4.052	0.549	0.974	0.014	0.382	0.157	0.671	0.036
April	1.590	0.578	0.214	0.563	0.343	0.223	0.196	0.531
May	-1.175	0.774	0.361	0.413	0.224	0.333	0.288	0.364
June	-0.917	0.784	0.524	0.163	0.026	0.925	0.267	0.389
July	0.819	0.658	0.746	0.023	0.298	0.194	0.525	0.047
August	-1.871	0.499	0.473	0.136	-0.003	0.991	0.212	0.429
September	-1.107	0.550	0.537	0.114	0.018	0.945	0.274	0.334
October	-5.760	0.151	0.729	0.078	0.042	0.867	0.385	0.211
November	5.856	0.238	0.276	0.480	-0.165	0.514	0.060	0.843
December	0.811	0.884	0.158	0.622	0.210	0.523	0.207	0.513
Annual	-6.057	0.854	0.518	0.001	0.347	0.022	0.411	0.004

Table A5. Regression parameters and statistics for core climate elements for 1971–2007 at Tulelake. Slope *p*-values significant at the 90% confidence level (α=0.10) are shown in bold. (Daly et al. 2009)

	Precipitation		**Maximum Temperature**		**Minimum Temperature**		**Mean Temperature**	
Month	**Slope (mm/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**	**Slope (°C/10 yr)**	***p*-value**
January	4.341	0.171	0.186	0.623	0.562	0.274	0.386	0.367
February	1.412	0.648	-0.195	0.626	-0.246	0.490	-0.222	0.511
March	-2.897	0.360	0.263	0.530	-0.009	0.972	0.134	0.629
April	2.841	0.298	0.015	0.967	0.520	0.007	0.271	0.288
May	5.401	0.135	-0.389	0.319	0.573	0.008	0.085	0.747
June	-0.267	0.921	0.023	0.940	0.171	0.374	0.100	0.659
July	-0.439	0.827	0.134	0.641	0.356	0.096	0.250	0.301
August	-4.266	0.201	0.050	0.854	0.138	0.391	0.093	0.629
September	-2.300	0.277	0.066	0.841	0.046	0.754	0.050	0.806
October	-1.865	0.563	-0.245	0.539	0.115	0.550	-0.070	0.760
November	1.339	0.721	-0.206	0.585	0.099	0.754	-0.039	0.888
December	2.633	0.570	0.209	0.533	0.543	0.194	0.381	0.276
Annual	6.137	0.706	0.007	0.971	0.262	0.061	0.140	0.301

Table A6. Regression statistics for the 27 core climate extremes indices for the two representative climate stations for LABE. All trends statistically significant at the 0.05 level shown in bold.

Indices/Stations/Trend Statistics	Lava Beds (1960-2011)			Tulelake (1932-2011)		
	R^2	*p*-value	Slope	R^2	*p*-value	Slope
# of Days Tmax >25°C (days)	0.24	0.004	0.456	NS	0.507	0.050
# of Days Tmax <0°C (days)	0.24	0.004	-0.188	NS	0.878	0.005
# of Days Tmin >20°C (days)	NS	0.969	0.000	Not Observed		
# of Days Tmin <0°C (days)	NS	0.767	-0.053	NS	0.161	-0.167
# of Days Tmin <-10°C (days)	NS	0.093	-0.147	NS	0.064	-0.108
Growing Season Length (days)	NS	0.444	0.268	NS	0.905	0.019
Maximum Tmax (°C)	0.16	0.021	0.048	NS	0.762	0.003
Minimum Tmax (°C)	0.25	0.003	0.155	NS	0.477	0.012
Maximum Tmin (°C)	NS	0.256	0.024	NS	0.781	0.003
Minimum Tmin (°C)	NS	0.075	0.095	NS	0.191	0.031
% of Days Tmax <10th Percentile (%)	0.37	0.000	-0.130	NS	0.546	-0.010
% of Days Tmax >90th Percentile (%)	0.19	0.011	0.103	NS	0.400	-0.020
% of Days Tmin <10th Percentile (%)	NS	0.090	-0.072	0.11	0.008	-0.078
% of Days Tmin >90th Percentile (%)	NS	0.958	-0.002	NS	0.250	0.032
Warm Spell Duration Index (days)	0.23	0.004	0.177	NS	0.871	-0.006
Cold Spell Duration Index (days)	NS	0.935	0.004	0.11	0.009	-0.097
Diurnal Temperature Range (°C)	0.21	0.009	0.021	NS	0.078	-0.014

Indices/Stations/Trend Statistics	Lava Beds (1960-2011)			Tulelake (1932-2011)		
	R^2	*p*-value	Slope	R^2	*p*-value	Slope
Maximum 1-Day Precipitation (mm)	NS	0.220	-0.204	NS	0.921	0.004
Maximum 5-Day Precipitation (mm)	NS	0.363	-0.394	NS	0.861	0.016
Simple Precipitation Intensity Index (mm/day)	NS	0.545	-0.008	NS	0.338	-0.004
Annual # of Days Precipitation >10 mm (days)	NS	0.628	0.024	NS	0.857	0.003
Annual # of Days Precipitation >20 mm (days)	NS	0.746	-0.007	NS	0.701	-0.002
Maximum Length of Dry Spell (days)	NS	0.215	-0.247	NS	0.432	-0.088
Maximum Length of Wet Spell (days)	NS	0.624	-0.007	0.07	0.037	0.019
Annual # of Days with Precipitation >95 Percentile (days)	NS	0.488	-0.535	NS	0.555	-0.123
Annual # of Days with Precipitation >99 Percentile (days)	NS	0.238	-0.564	NS	0.527	-0.090
Annual Precipitation Total (mm)	NS	0.852	-0.227	NS	0.410	0.331

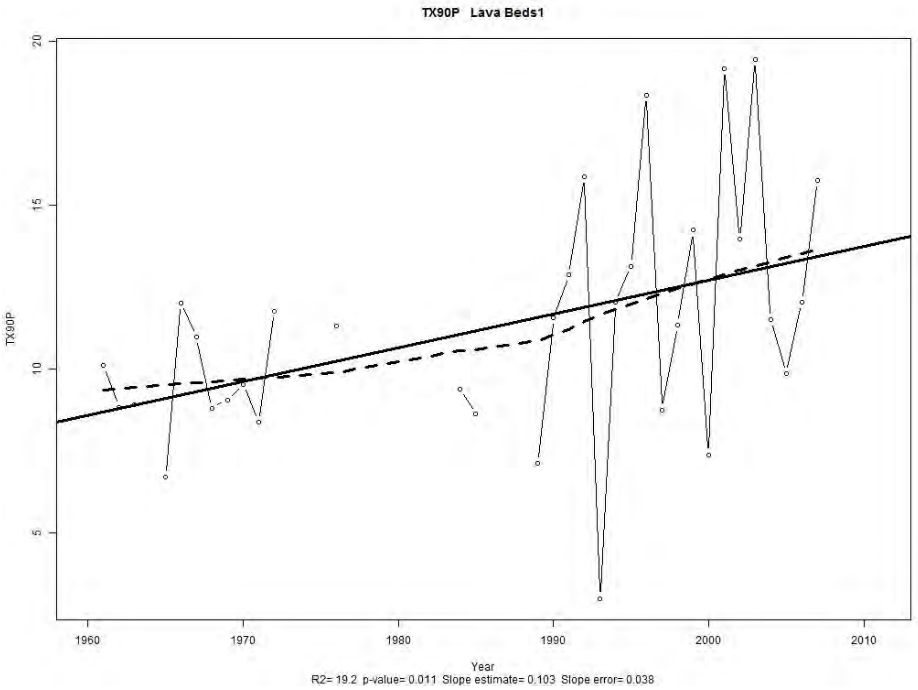


Figure A20. Example time series of the number of days when the maximum temperature is above the 90th percentile during the reference period observed each year at Lava Beds National Monument, California, during 1960-2011. Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

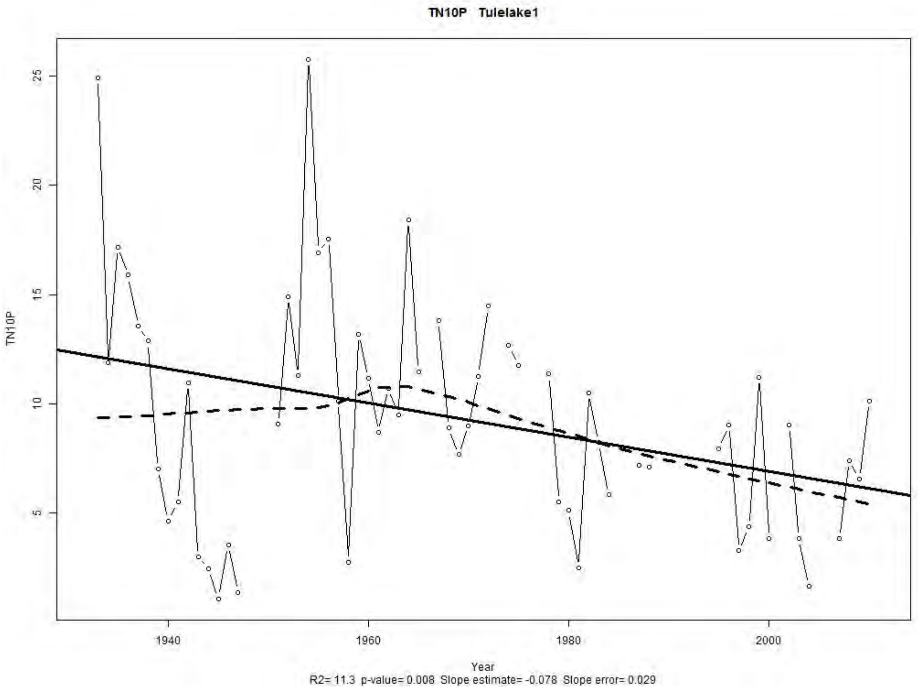


Figure A21. Example time series of the number of days when the minimum temperature is below the 10th percentile during the reference period observed each year at Tulelake, California, during 1932-2011. Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

Appendix B. Physical Characteristics of Lava Beds National Monument: supporting data and maps

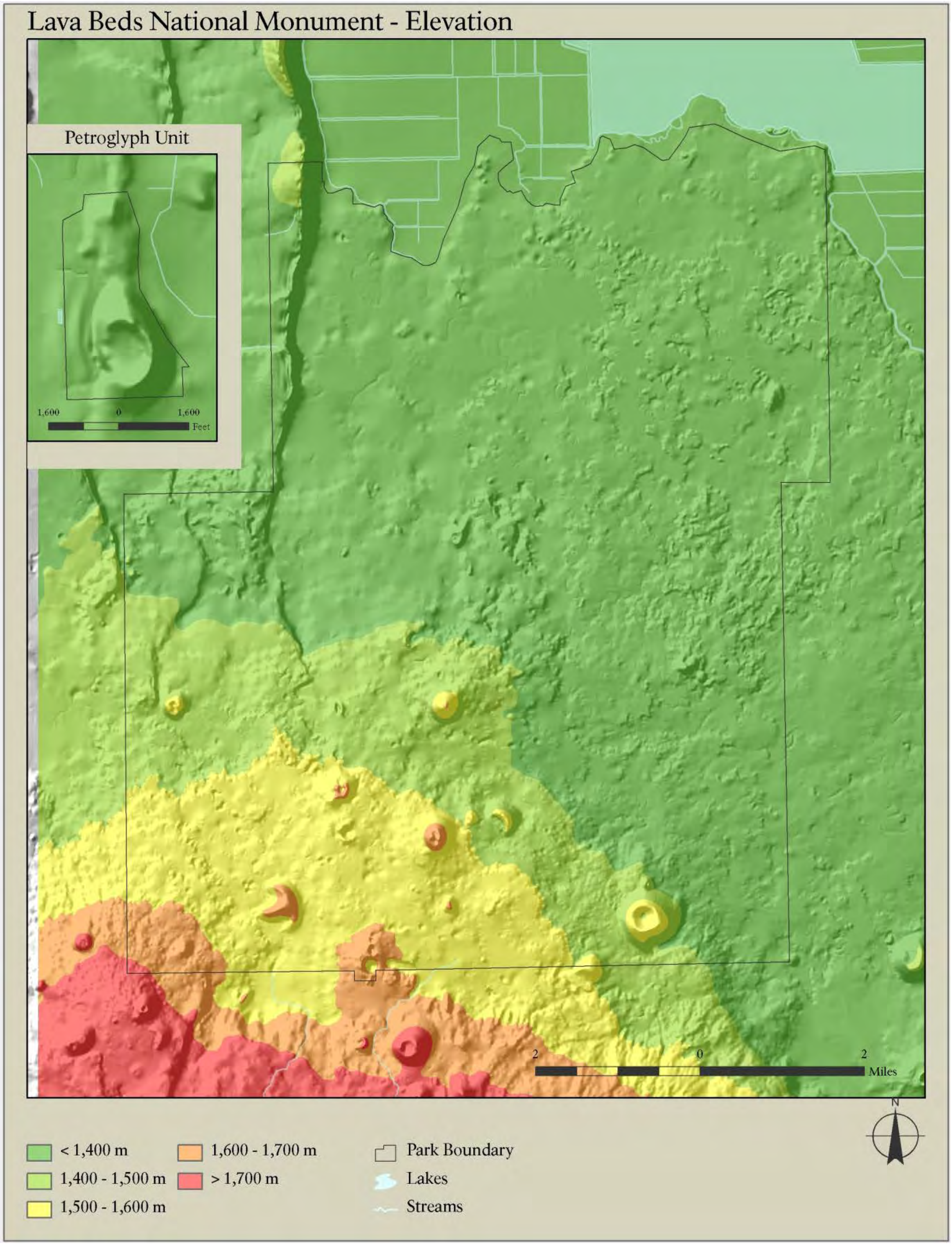


Figure B1. Mapped elevation classes in Lava Beds National Monument (USGS 2011). Scale: 10 meters.

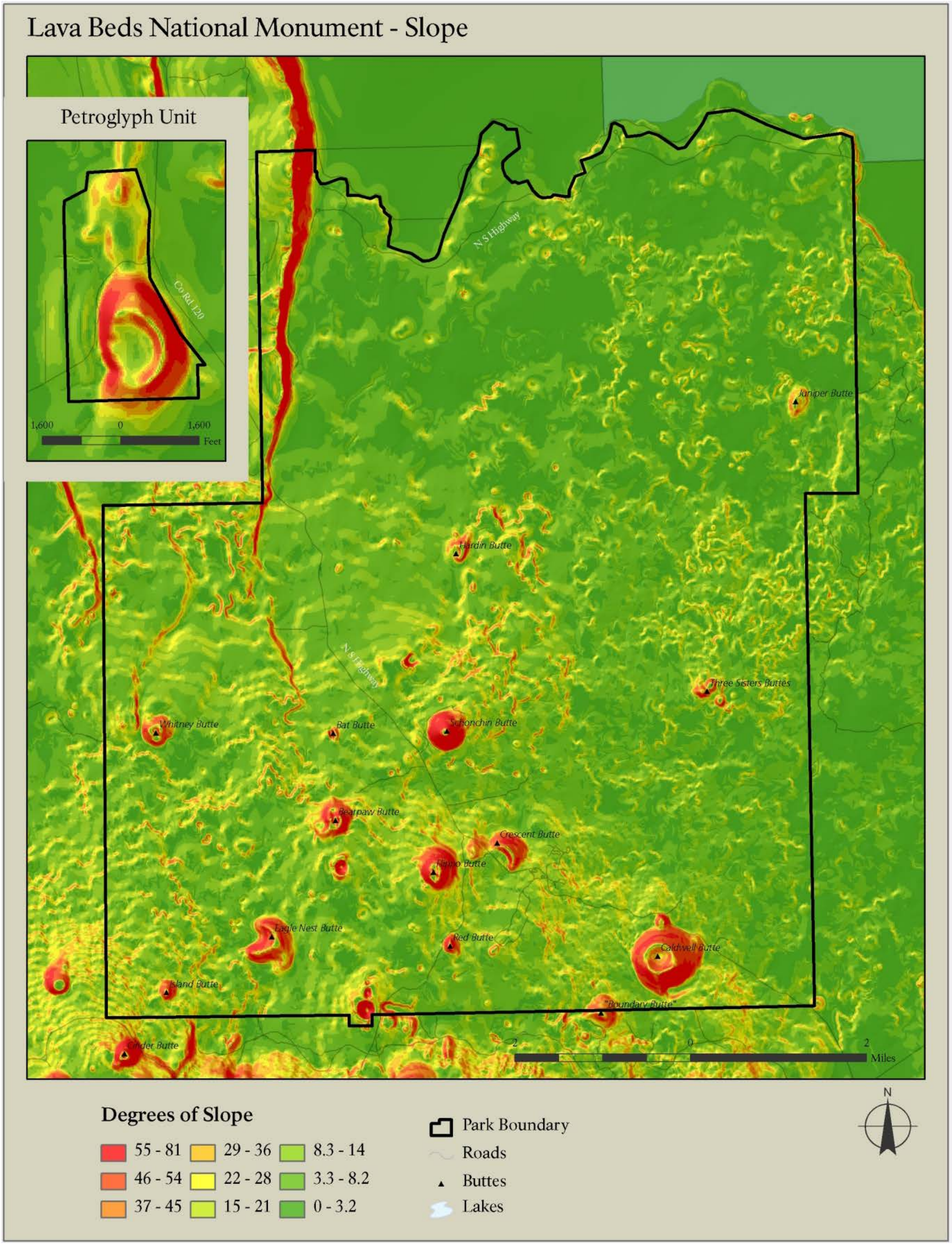


Figure B2. Mapped slope classes in Lava Beds National Monument (USGS 2011). Scale: 10 meters.

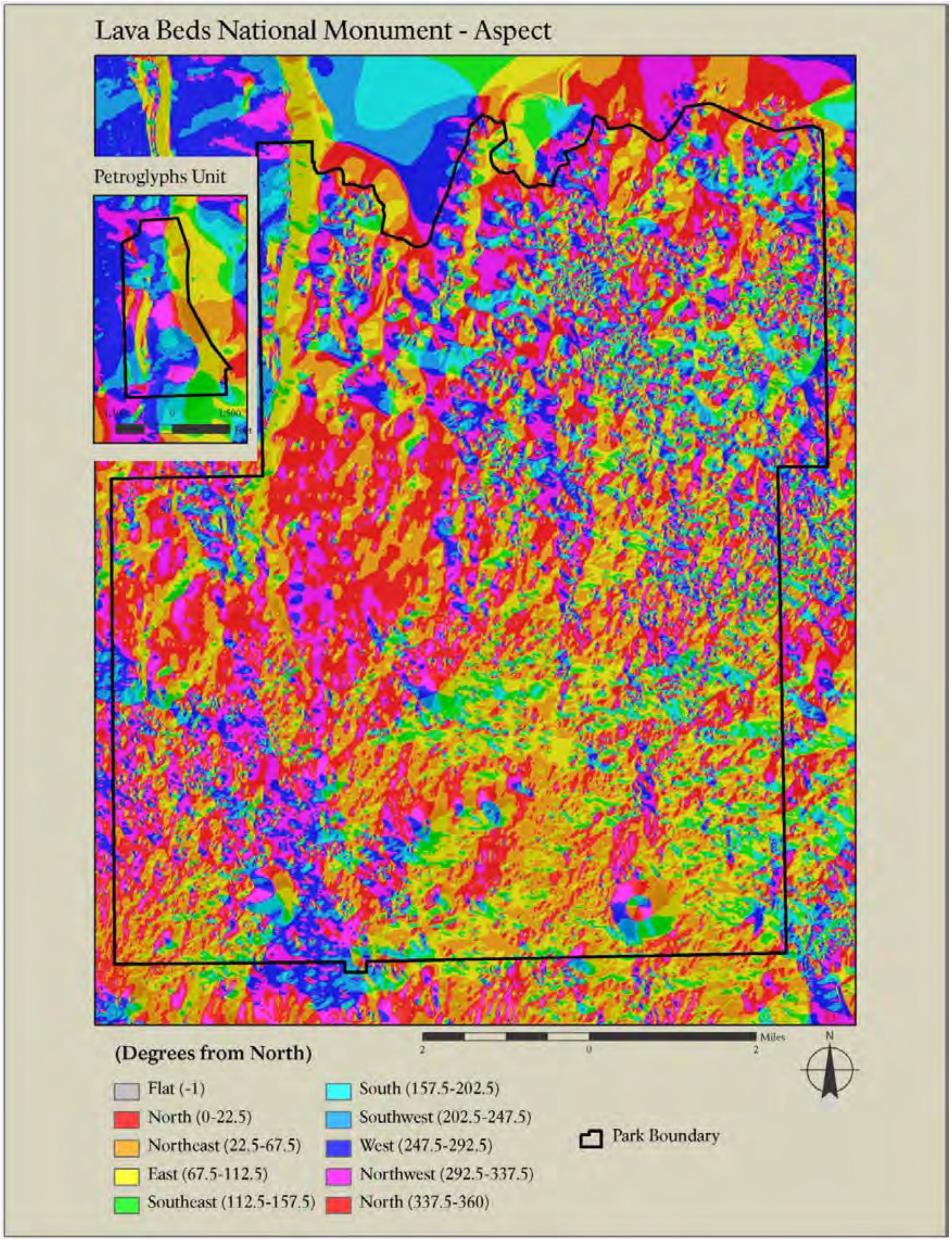


Figure B3. Mapped aspect classes in Lava Beds National Monument (USGS 2011). Scale: 10 meters. This is a raster file that identifies the orientation or direction of slope. Aspect is the down-slope direction of a cell to its neighbors. The cell values in an aspect grid are compass directions ranging from 0° to 360°; north is 0° and, in a clockwise direction, 90° is east, 180° is south, and 270° is west. Input grid cells that have 0° slope (flat areas) are assigned an aspect value of -1. This file was created from the DEM using the Aspect tool located in the Spatial Analyst toolbox provided in the ArcGIS software.

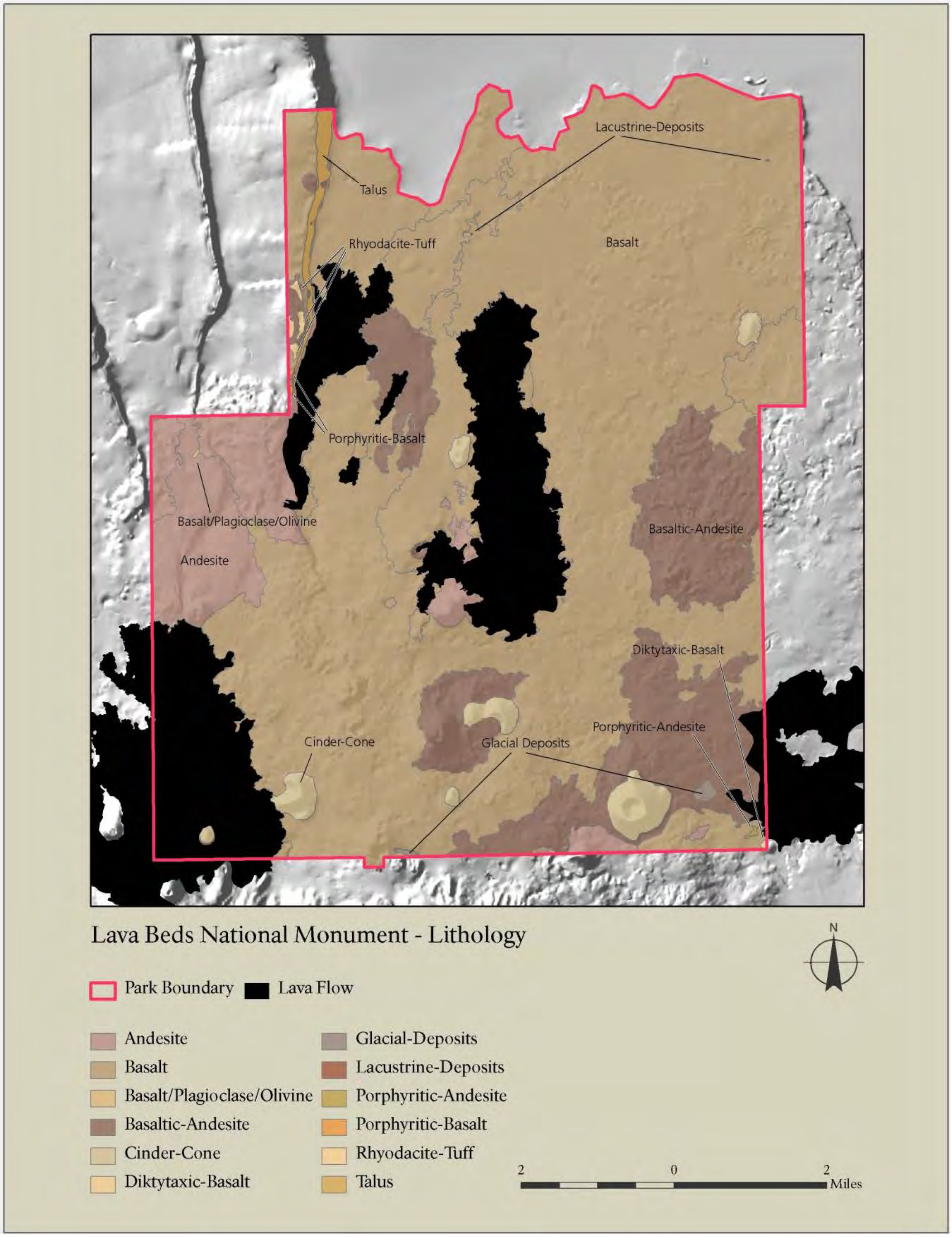


Figure B4. Mapped lithologic classes in Lava Beds National Monument (USGS 2005). Scale: 1:500,000 (Chris Wayne, NPS Klamath Network, pers. comm.)

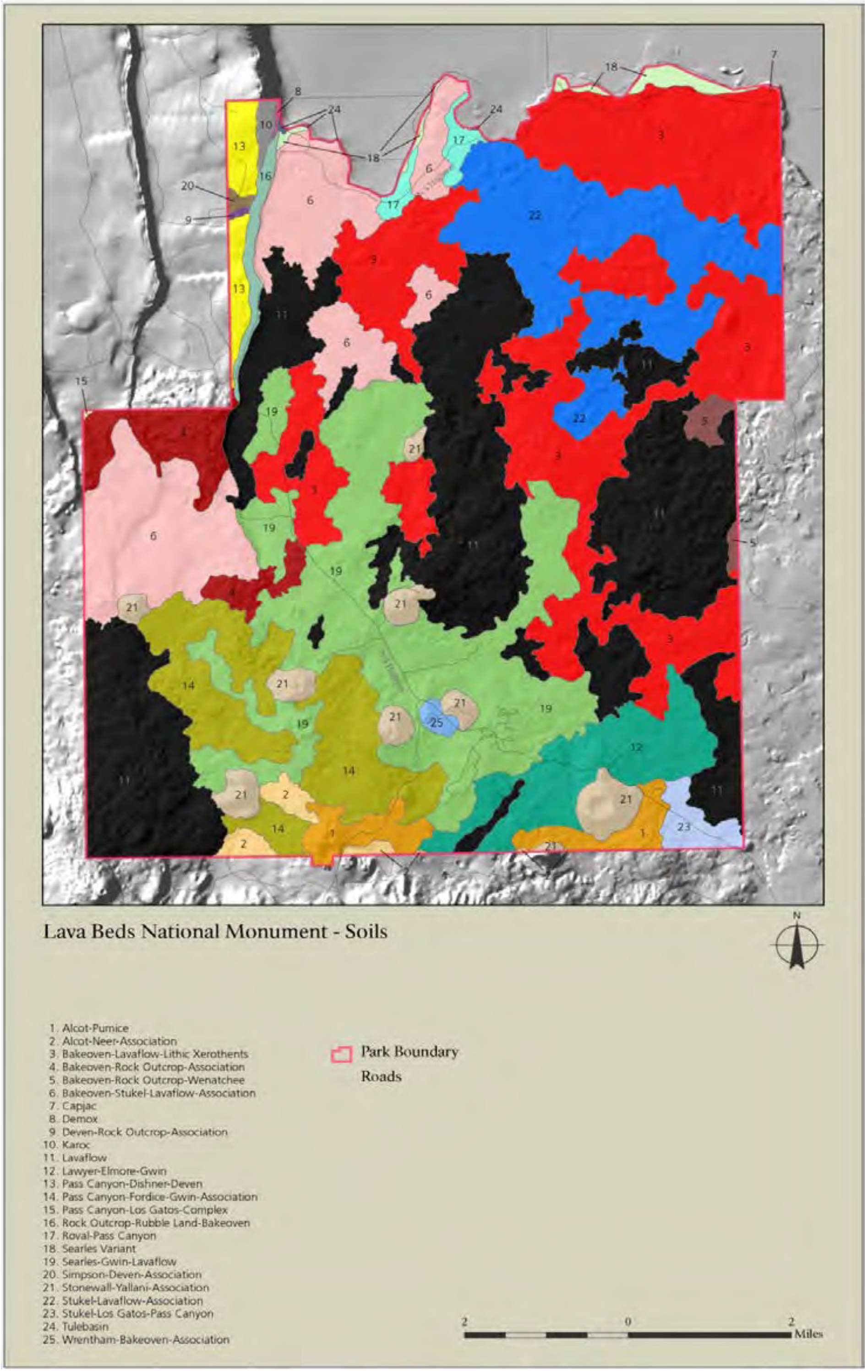


Figure B5. Mapped soil complexes in Lava Beds National Monument. Scale: 1:24,000. The SSURGO soil data map was simplified by using the dissolve tool, located in the Data Management toolbox provided in ArcGIS software, to combine multiple shapefiles of the same soil type into one single shapefile. The single shapefile was then grouped with other dissolved soil shapefiles of the same soil complex root name. The final output was single shapefiles of soil complexes, each containing multiple individual soil types from the same soil complex. The goal of 'simplifying' the data was to make the map less congested and easier to read.

Appendix C. Vegetation and Fire Characteristics of Lava Beds National Monument: supporting data and maps

Table C1. Biophysical settings: percentages by geographic unit (LANDFIRE 2008).

Table C1.	**% of Geographic Unit**									
General Biophysical Setting	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Aspen and Woodland		0.00							0.22	0
Barren	1.60	30.46	5.93	16.98	0.47	0.20	77.58	1.22	8730.58	19
Chaparral	0.00	0.21	0.01	0.00			0.00		10.64	0
Conifer Wooded Steppe		0.10							4.41	0
Desert Scrub	0.02				0.02	0.03			4.78	0
Greasewood Flat	0.65		0.01			22.73		58.89	434.42	1
Juniper Woodland and Savanna	26.66	9.81	29.37	30.13	49.80	14.79	5.42	19.60	10426.44	22
Lodgepole		0.89	0.00	0.13			0.00		42.48	0
Lodgepole and Woodland		0.15		0.13					8.52	0
Mixed Conifer Forest and Woodland	0.17	22.46	1.45	14.54	0.09	0.02	1.12		1459.56	3
Mixed Oak Woodland	0.26		0.01	0.06	0.21		0.00		60.25	0
Riparian	0.02	0.26	0.01		0.00	3.22		1.02	42.76	0
Sagebrush Shrubland	66.46	11.19	57.82	15.99	44.17	50.70	15.30	7.36	22582.73	48
Sagebrush Steppe	3.31	3.85	0.89	3.82	4.79	6.65	0.35		1137.61	2
Sparse Vegetation	0.02							7.75	21.78	0
Water		0.12	0.01				0.01		6.79	0

Table C1.

	% of Geographic Unit									
General Biophysical Setting	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
White Pine-White Fir Woodland		0.17	0.02	0.02					9.71	0
Wooded Volcanic Flowage				0.04			0.00		0.67	0
Woodland	0.45	18.63	3.26	17.18					1460.33	3
Woodland and Chaparral	0.35	0.10	1.16	0.21	0.56	1.57	0.15	3.84	232.48	0
Woodland and Savanna		0.05		0.01					2.44	0
Woodland and Shrubland	0.02	0.16	0.04	0.80			0.05		28.11	0
Grand Total	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.1%*	*99.9%*	*100.0%*	*99.7%*	*46707.69*	*98%*

Table C2. Vegetation succession classes: percentages by geographic unit (LANDFIRE 2008).

Table C2.	**% of Geographic Unit**									
Succession Class	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Succession Class A	0	17	1	4	0	1	1	0	742	2
Succession Class B	30	16	22	31	17	8	20	5	9759	26
Succession Class C	10	49	6	29	0	3	4	1	4536	12
Succession Class D	25	15	40	14	8	15	39	1	10257	27
Succession Class E	0	1	0	4			0		97	0
Uncharacteristic Native Vegetation Cover/ Structure/ Composition	0	0	0	0		0	1		41	0
Uncharacteristic Exotic Vegetation	34	1	31	17	75	73	35	93	12211	32
Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*37643*	*99%*

Table C3. Fire regime groups: percentages by geographic unit (LANDFIRE 2008).

Table C3.	**% of Geographic Unit**									
Fire Regime Groups	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Fire Regime Group I	0	34	3	34					1643	4
Fire Regime Group II	0	2	0	2					112	0
Fire Regime Group III	99	57	97	63	99	75	91	32	35284	93
Fire Regime Group IV	1	4	1	1	1	16	1	16	495	1
Fire Regime Group V	0	3	0			9	8	52	445	1
Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*37979*	*99%*

Table C4. Height classes of existing vegetation: percentages by geographic unit (LANDFIRE 2008).

Table C4.	**% of Geographic Unit**								
Existing Vegetation Height (m)	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Petroglyph Unit**	**# Acres**	**% of Total**
0-0.5 m shrubs	53.48	17.22	39.48	38.35	96.60	59.84	22.34	17024	48
0.5-1.0 m shrubs	44.60	5.78	50.94	5.03	2.82	39.88	76.35	14590	41
1.0-3.0 m shrubs	1.26	9.02	3.82	4.94	0.58	0.03	0.64	941	3
>3.0 m shrubs					0.00		0.13	0	0
0-5 m trees		0.03	0.00					1	0
5-10 m trees	0.18	17.93	0.97	5.74		0.16	0.21	733	2
10-25 m trees	0.48	50.02	4.79	45.94		0.08	0.34	2508	7
25-50 m trees		0.00		0.02				0	0
Total	*100.00%*	*100.00%*	*100.00%*	*100.00%*	*100.00%*	*100.00%*	*100.00%*	*35798*	*101%*

Table C5. Canopy classes of existing vegetation: percentages by geographic unit (LANDFIRE 2008).

Table C5.	**% of Geographic Unit**									
Existing Vegetation Canopy (%)	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
≥10 and <20 % Shrub	34	6	4	21	0	17	7	22	8157	22
≥10 and <20 % Forest	1	39	4	25		0	6		2051	5
≥20 and <30 % Herb	0								0	0
≥20 and <30 % Shrub	34	26	55	24	13	36	53	19	14502	39
≥20 and <30 % Forest	0	25	1	15		0	1	0	1060	3
≥30 and <40 % Shrub	31	0	35	3	87	46	33	58	11585	31
≥30 and <40 % Forest	0	2	0	6		0	0	0	146	0
≥40 and <50 % Shrub	0		0			0		0	5	0
≥40 and <50 % Forest		1	0	4					58	0
≥50 and <60 % Forest		0	0	2				0	27	0
≥60 and <70 % Forest	0	0		0					3	0
≥70 and <80 % Forest				0					0	0
Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*37594*	*100%*

Table C6. Canopy cover: percentages by geographic unit (LANDFIRE 2008).

Table C6.	**% of Geographic Unit**									
Canopy Cover (%)	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Non-forested vegetation	99.55	59.31	95.70	69.63	100.00	99.80	99.17	99.58	43922.12	94.09
≥ 10% and < 20%	0.42	22.61	2.91	12.20		0.11	0.76		1589.46	3.40
≥ 20% and < 30%	0.02	15.93	1.22	8.68		0.07	0.07	0.11	943.57	2.02
≥ 30% and < 40%	0.00	1.60	0.16	4.52		0.02	0.00	0.21	140.90	0.30
≥ 40% and < 50%		0.44	0.01	2.98					55.58	0.12
≥ 50% and < 60%		0.09	0.01	1.84			0.00	0.11	26.22	0.06
≥ 60% and < 70%	0.00	0.02		0.13					2.65	0.01
≥ 70% and < 80%				0.02					0.22	0.00
Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*46680.75*	*100%*

Table C7. Existing vegetation types: percentages by geographic unit (LANDFIRE 2008).

Table C7.	**% of Geographic Unit**									
Existing Vegetation Type	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Agriculture-Cultivated Crops and Irrigated Agriculture						1.23		0.36	9.78	0.02
Agriculture-Pasture/Hay	0.00			1.05		0.88	0.01	4.98	30.81	0.07
Artemisia tridentata ssp. *vaseyana* Shrubland Alliance	0.01	0.08	0.09	0.55	0.26		0.00		23.41	0.05
Barren	1.64	30.93	5.94	16.77	0.66	0.20	77.44	1.30	8721.65	18.69
California Montane Jeffrey Pine(-Ponderosa Pine) Woodland		0.04		0.43					6.85	0.01
California Montane Woodland and Chaparral	0.17	0.11	0.08	0.58	0.37	1.96	0.01	0.11	74.92	0.16
Columbia Plateau Low Sagebrush Steppe	5.02	4.65	6.94	11.85	30.66	4.33	1.48	6.79	2557.59	5.48
Columbia Plateau Western Juniper Woodland and Savanna	0.02	2.39	0.04	1.66			0.09		140.58	0.30
Developed-High Intensity	0.00								0.22	0.00
Developed-Low Intensity	0.45	0.15	0.18	0.25	0.36	1.87	0.00	2.03	144.14	0.31
Developed-Medium Intensity	0.01	0.00			0.01				2.14	0.00
Developed-Open Space	0.02	0.08	0.14	0.76		0.20	0.00		32.07	0.07
Great Basin Semi-Desert Chaparral	0.26	0.00	0.01	0.06	0.25		0.00		60.65	0.13

Table C7.	% of Geographic Unit									
Existing Vegetation Type	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Inter-Mountain Basins Big Sagebrush Shrubland	87.65	15.74	79.61	23.98	62.14	61.36	19.23	15.40	30078.51	64.47
Inter-Mountain Basins Big Sagebrush Steppe	3.04	0.22	0.01	1.53	3.66	4.55	0.18		761.66	1.63
Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	0.00	0.16	0.00	0.84			0.06		22.39	0.05
Inter-Mountain Basins Greasewood Flat	0.67		0.01			21.73		56.51	422.83	0.91
Inter-Mountain Basins Mixed Salt Desert Scrub	0.02				0.03	0.03			5.06	0.01
Inter-Mountain Basins Montane Riparian Systems	0.00	0.22	0.01			0.22		0.11	13.25	0.03
Inter-Mountain Basins Montane Sagebrush Steppe	0.05	1.44	0.52	1.14	1.00		0.01		149.99	0.32
Inter-Mountain Basins Sparsely Vegetated Systems	0.02							7.97	22.05	0.05
Introduced Upland Vegetation-Annual Grassland	0.00								0.15	0.00
Juniperus occidentalis Wooded Herbaceous Alliance				0.11					1.33	0.00
Juniperus occidentalis Woodland Alliance	0.11	2.81	0.79	7.89			0.22		335.97	0.72

Table C7.

	% of Geographic Unit									
Existing Vegetation Type	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	0.00	4.60	0.07	2.32			0.01		240.62	0.52
Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland		0.00							0.22	0.00
Mediterranean California Mesic Mixed Conifer Forest and Woodland		7.50	0.88	5.13			0.01		481.78	1.03
North Pacific Montane Riparian Woodland and Shrubland								0.32	0.67	0.00
North Pacific Wooded Volcanic Flowage		0.16	0.01	0.29			0.00		11.40	0.02
Northern and Central California Dry-Mesic Chaparral	0.34		1.08	0.11	0.53	1.48	0.14	3.96	214.82	0.46
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest		0.19	0.02	0.34			0.00		14.65	0.03
Northern Rocky Mountain Montane-Foothill Deciduous Shrubland	0.00	0.03	0.00	0.02					1.93	0.00
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	0.47	27.28	3.54	21.20		0.02	1.09		2000.59	4.29
Open Water		0.13	0.01				0.01		6.92	0.01

Table C7.	% of Geographic Unit									
Existing Vegetation Type	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Rocky Mountain Aspen Forest and Woodland		0.00							0.22	0.00
Rocky Mountain Poor-Site Lodgepole Pine Forest		0.35	0.00	0.07					16.55	0.04
Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland	0.00	0.58	0.01	0.99			0.01		39.86	0.09
Sierran-Intermontane Desert Western White Pine-White Fir Woodland		0.16	0.02	0.02					9.34	0.02
Total	*100.0%*	*100.0%*	*100.0%*	*99.9%*	*99.9%*	*100.0%*	*100.0%*	*99.8%*	*46657.58*	*99.9%*

Table C8. Environmental site potential: percentages by geographic unit (LANDFIRE 2008).

Table C8.	% of Geographic Unit									
Environmental Site Potential	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Barren-Rock/Sand/Clay	1.60	30.57	5.88	16.91	0.47	0.21	77.60	1.23	8711.93	18.65
Open Water	0.00	0.11	0.01	0.00	0.00	0.00	0.01	0.00	6.20	0.01
California Montane Jeffrey Pine(-Ponderosa Pine) Woodland	0.00	0.28	0.09	1.37	0.00	0.00	0.02	0.00	38.84	0.08
California Montane Woodland and Chaparral	0.22	0.00	0.69	0.11	0.55	0.00	0.07	0.00	127.06	0.27

Table C8.	% of Geographic Unit									
Environmental Site Potential	Basalt and Andesite	Basalt	Basaltic Andesite	Buttes	Gillem Bluff	Historic Lake Bed	Lava Flows	Petroglyph Unit	# Acres	% of Total
Columbia Plateau Low Sagebrush Steppe	0.00	1.94	0.00	0.00	0.00	0.00	0.01	0.00	88.05	0.19
Columbia Plateau Western Juniper Woodland and Savanna	26.94	17.46	33.45	30.62	57.36	14.81	6.82	19.67	11411.22	24.43
Great Basin Semi-Desert Chaparral	0.27	0.38	1.10	0.03	5.09	0.00	0.04	0.00	235.86	0.50
Inter-Mountain Basins Big Sagebrush Shrubland	65.96	5.49	53.42	15.40	31.02	50.74	14.02	7.39	21545.86	46.13
Inter-Mountain Basins Big Sagebrush Steppe	3.25	0.00	0.00	1.65	3.56	6.65	0.16	0.00	810.98	1.74
Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.00	6.66	0.01
Inter-Mountain Basins Greasewood Flat	0.65	0.00	0.01	0.00	0.00	22.75	0.00	59.07	434.40	0.93
Inter-Mountain Basins Mixed Salt Desert Scrub	0.02	0.00	0.00	0.00	0.02	0.03	0.00	0.00	4.78	0.01
Inter-Mountain Basins Montane Riparian Systems	0.02	0.26	0.01	0.00	0.00	3.22	0.00	1.03	42.73	0.09
Inter-Mountain Basins Montane Sagebrush Steppe	0.01	0.00	0.06	1.83	1.20	0.00	0.00	0.00	41.92	0.09

Table C8.

	% of Geographic Unit									
Environmental Site Potential	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Inter-Mountain Basins Semi-Desert Shrub-Steppe	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	3.90	0.01
Inter-Mountain Basins Sparsely Vegetated Systems	0.02	0.00	0.00	0.00	0.00	0.00	0.00	7.77	21.78	0.05
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	0.19	14.28	0.39	9.92	0.09	0.00	0.39	0.00	866.59	1.86
Mediterranean California Mesic Mixed Conifer Forest and Woodland	0.00	20.76	2.68	9.06	0.00	0.00	0.06	0.00	1302.40	2.79
Mediterranean California Mixed Oak Woodland	0.26	0.00	0.01	0.06	0.21	0.00	0.00	0.00	60.25	0.13
North Pacific Wooded Volcanic Flowage	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.67	0.00
Northern and Central California Dry-Mesic Chaparral	0.13	0.00	0.39	0.00	0.00	1.57	0.07	3.85	90.47	0.19
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	0.00	0.37	0.03	0.74	0.00	0.00	0.01	0.00	29.80	0.06
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	0.44	7.02	1.74	12.06	0.00	0.02	0.71	0.00	775.19	1.66
Rocky Mountain Poor-Site Lodgepole Pine Forest	0.00	0.91	0.00	0.07	0.00	0.00	0.00	0.00	41.63	0.09

Table C8.

	% of Geographic Unit									
Environmental Site Potential	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland	0.00	0.16	0.00	0.13	0.00	0.00	0.00	0.00	8.52	0.02
Grand Total	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*46707.69*	*100%*

Table C9. Estimated mean fire return intervals: percentages by geographic unit (LANDFIRE 2008).

Table C9	**% of Geographic Unit**									
Estimated Mean Fire Return Interval	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
No defined fire behavior or extremely low probabilities of fire ignition	2	31	6	17	1	0	78	10	8813	19
16-20 Years	0	0	0	2	0	0	0	0	19	0
21-25 Years	0	1	1	7	0	0	0	0	198	0
26-30 Years	0	12	1	11	0	0	0	0	762	2
31-35 Years	0	12	0	11	0	0	0	0	752	2
36-40 Years	1	10	1	9	1	0	0	0	802	2
41-45 Years	4	6	3	8	6	0	2	0	1598	3
46-50 Years	11	4	12	7	8	0	2	0	4086	9
51-60 Years	37	6	32	11	23	10	6	0	12122	26
61-70 Years	15	5	13	8	19	23	2	0	5216	11
71-80 Years	9	4	6	4	16	22	2	0	3127	7
81-90 Years	7	2	4	3	14	10	1	0	2249	5
91-100 Years	5	1	3	1	7	4	1	0	1503	3
101-125 Years	8	2	9	1	6	11	3	0	2980	6
126-150 Years	2	1	7	0	0	5	1	12	1362	3
151-200 Years	1	1	2	0	0	6	1	34	629	1
201-300 Years	0	0	0	0	0	9	1	40	256	1

Table C9

	% of Geographic Unit									
Estimated Mean Fire Return Interval	**Basalt and Andesite**	**Basalt**	**Basaltic Andesite**	**Buttes**	**Gillem Bluff**	**Historic Lake Bed**	**Lava Flows**	**Petroglyph Unit**	**# Acres**	**% of Total**
301-500 Years	0	1	0	0	0	0	0	4	63	0
501-1000 Years	0	0	0	0	0	0	0	0	51	0
>1000 Years	0	1	0	0	0	0	1	0	72	0
Most common Mean Fire Return Interval	*51-60 yr*	*None*	*51-60 yr*	*None*	*51-60 yr*	*61-70 yr*	*None*	*201-300 yr*	*46656*	*51-60 yr*

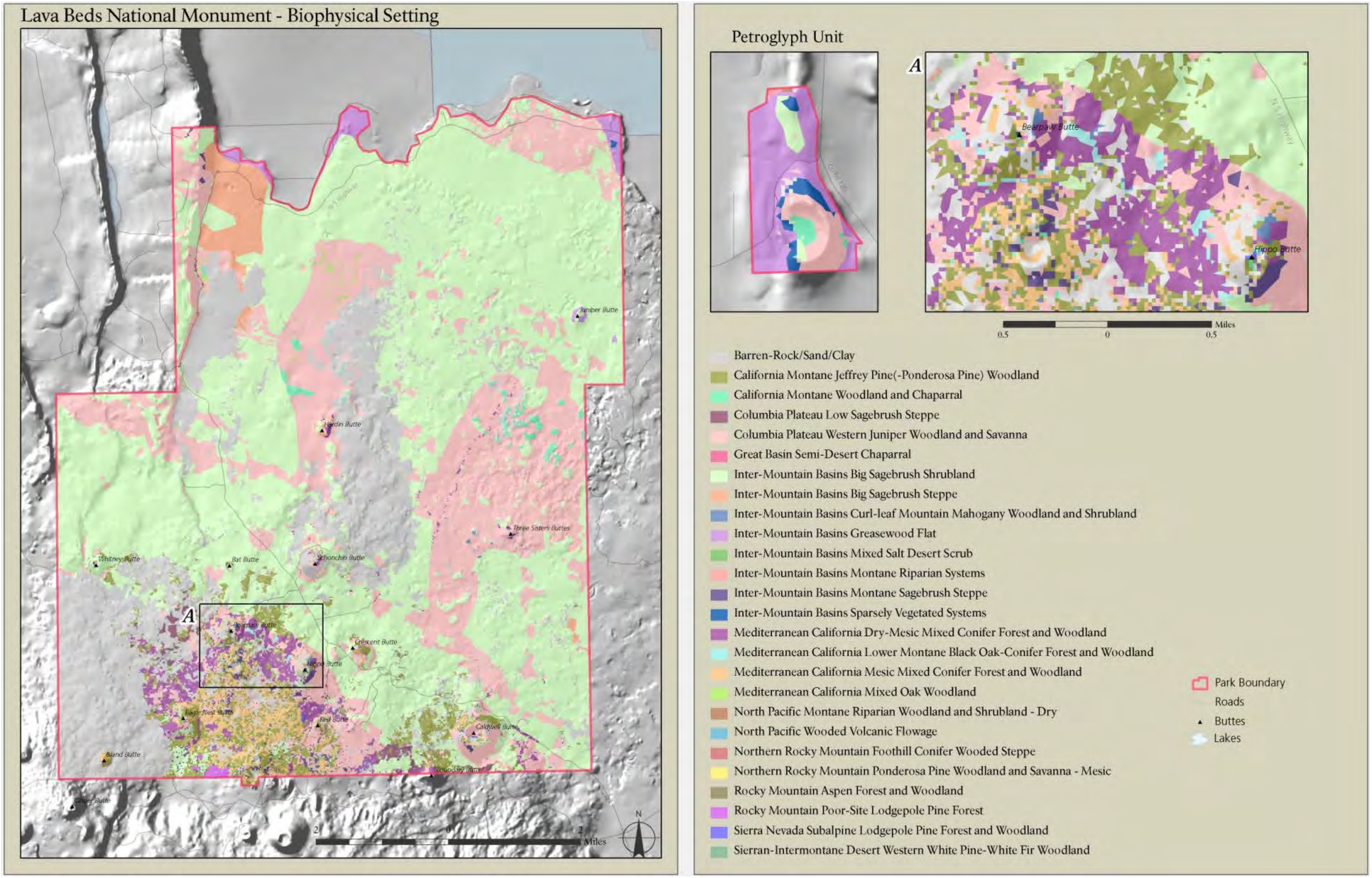


Figure C1. Mapped biophysical classes of Lava Beds National Monument (LANDFIRE 2006). Scale: 30 meters. This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The classes in this dataset represent the vegetation that may have been dominant on the landscape prior to Euro-American settlement and are based on both the current biophysical environment and an approximation of the historical disturbance regime.

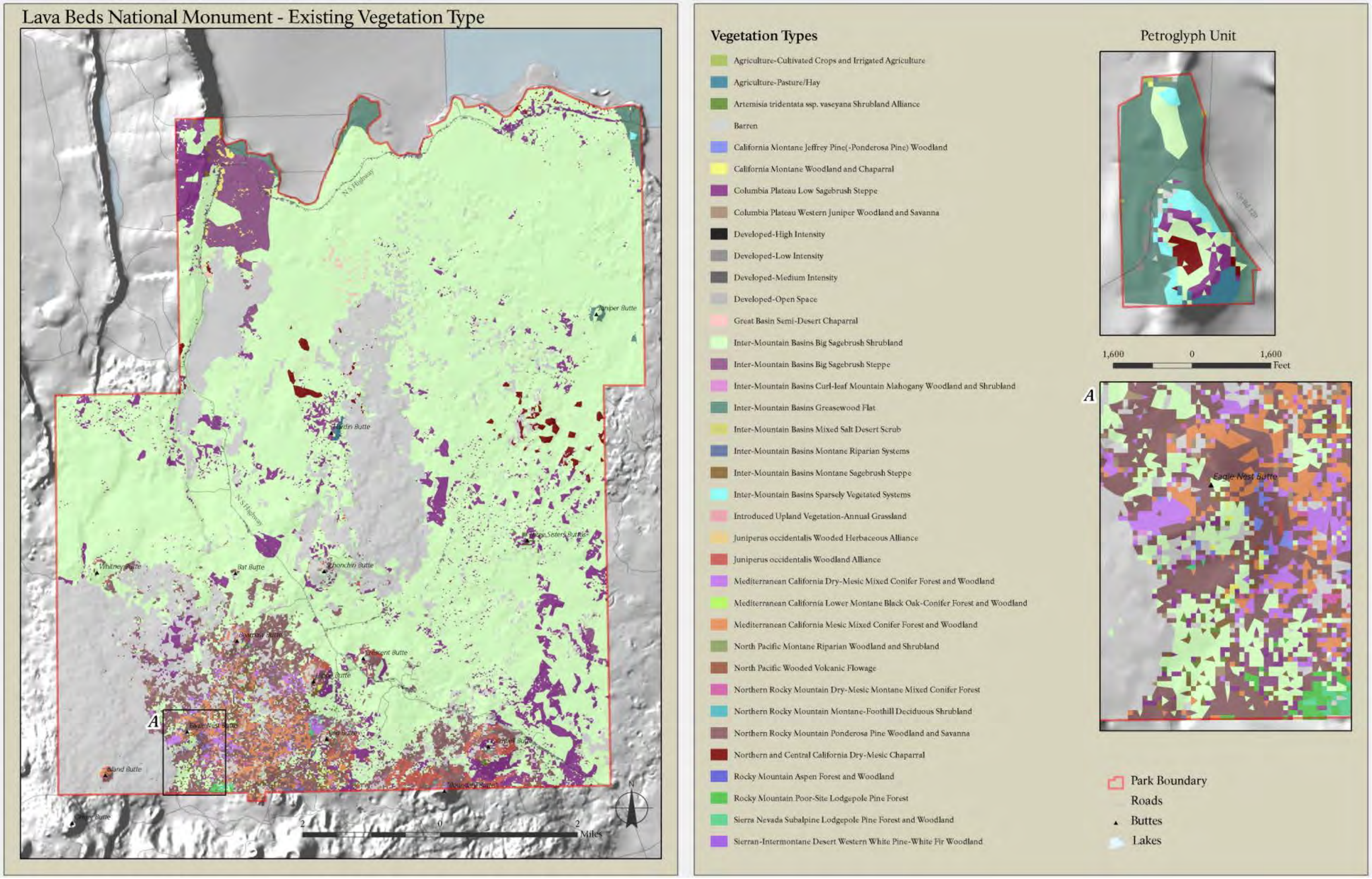


Figure C2. Mapped existing vegetation in Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

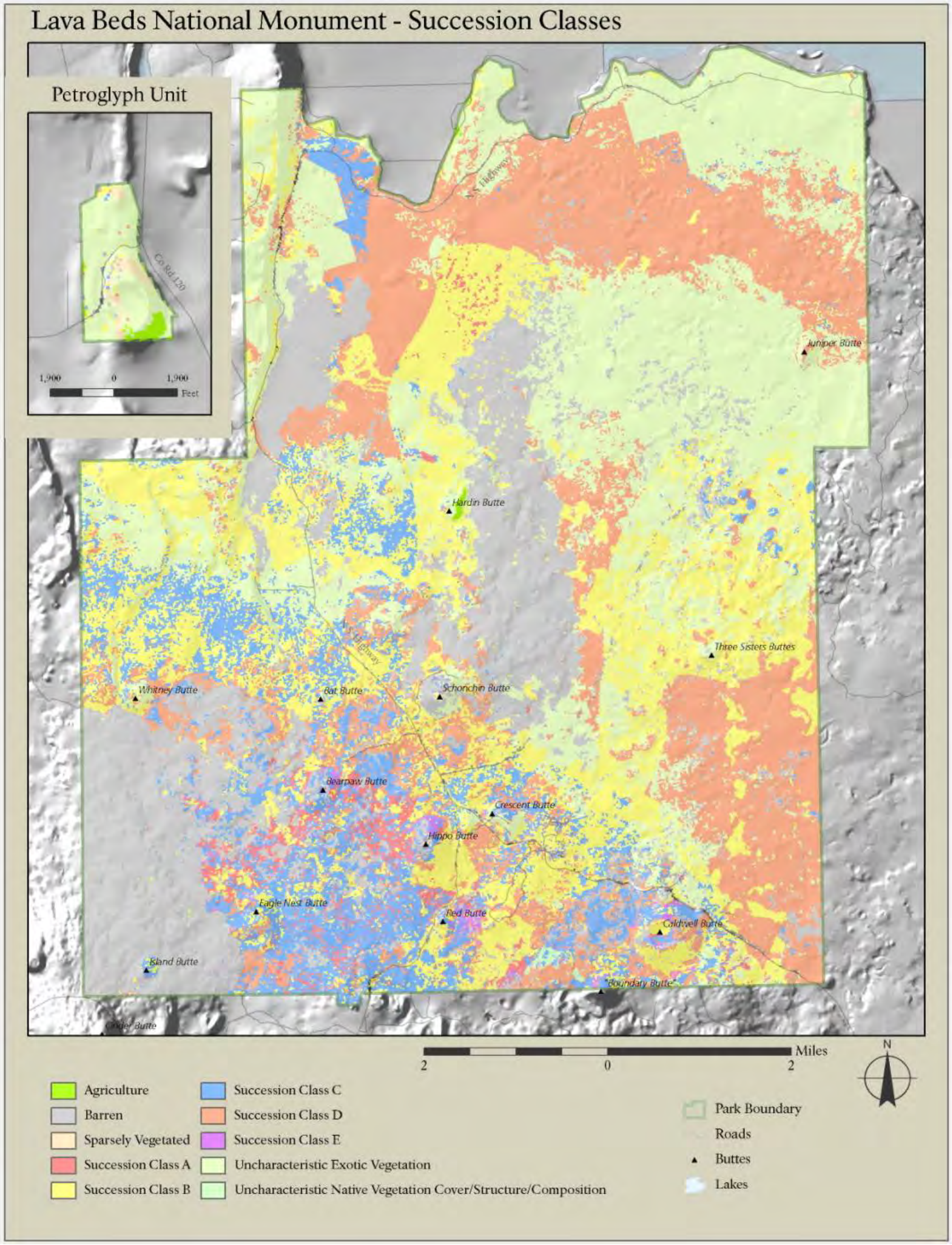


Figure C3. Mapped successional classes in Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

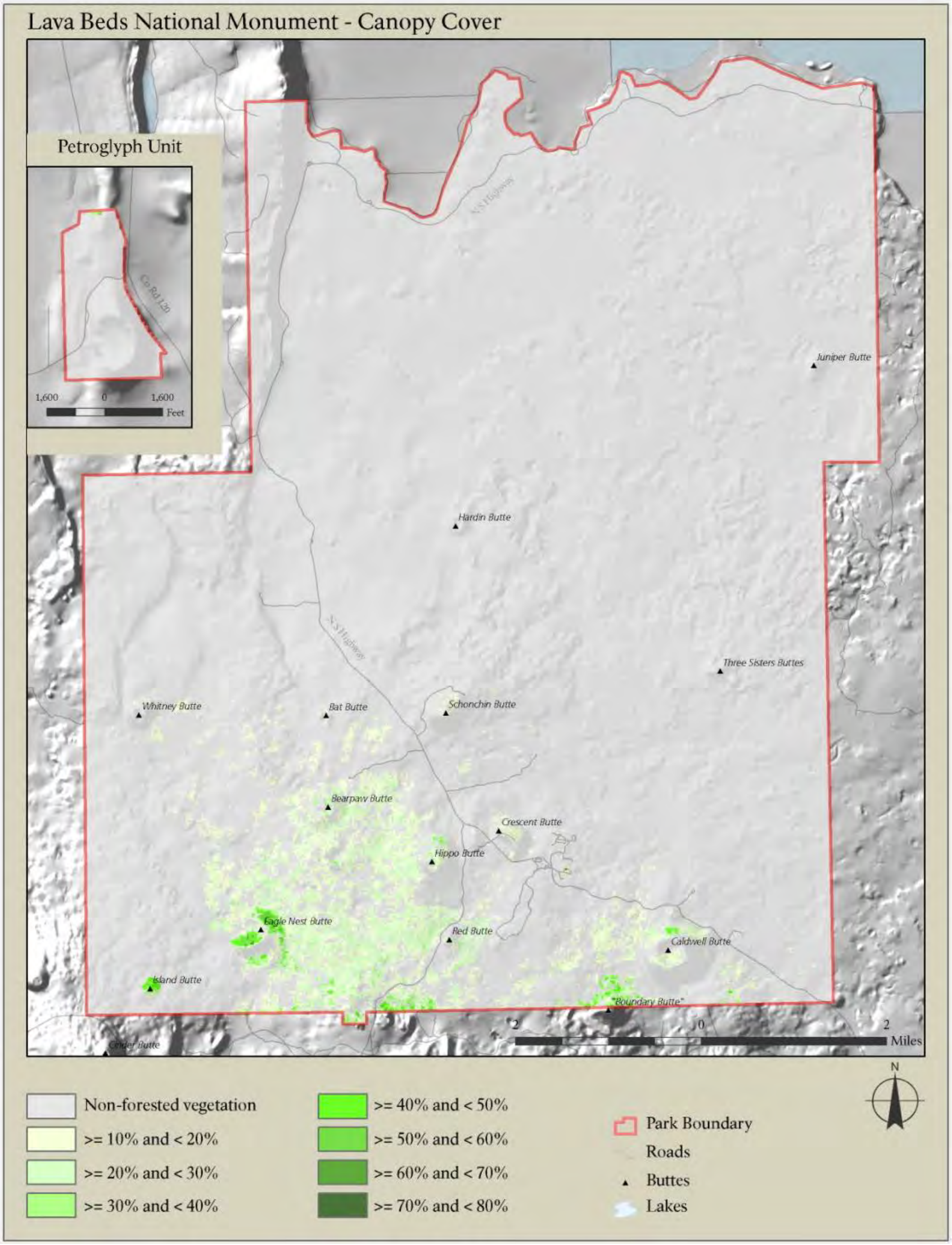


Figure C4. Mapped canopy cover of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

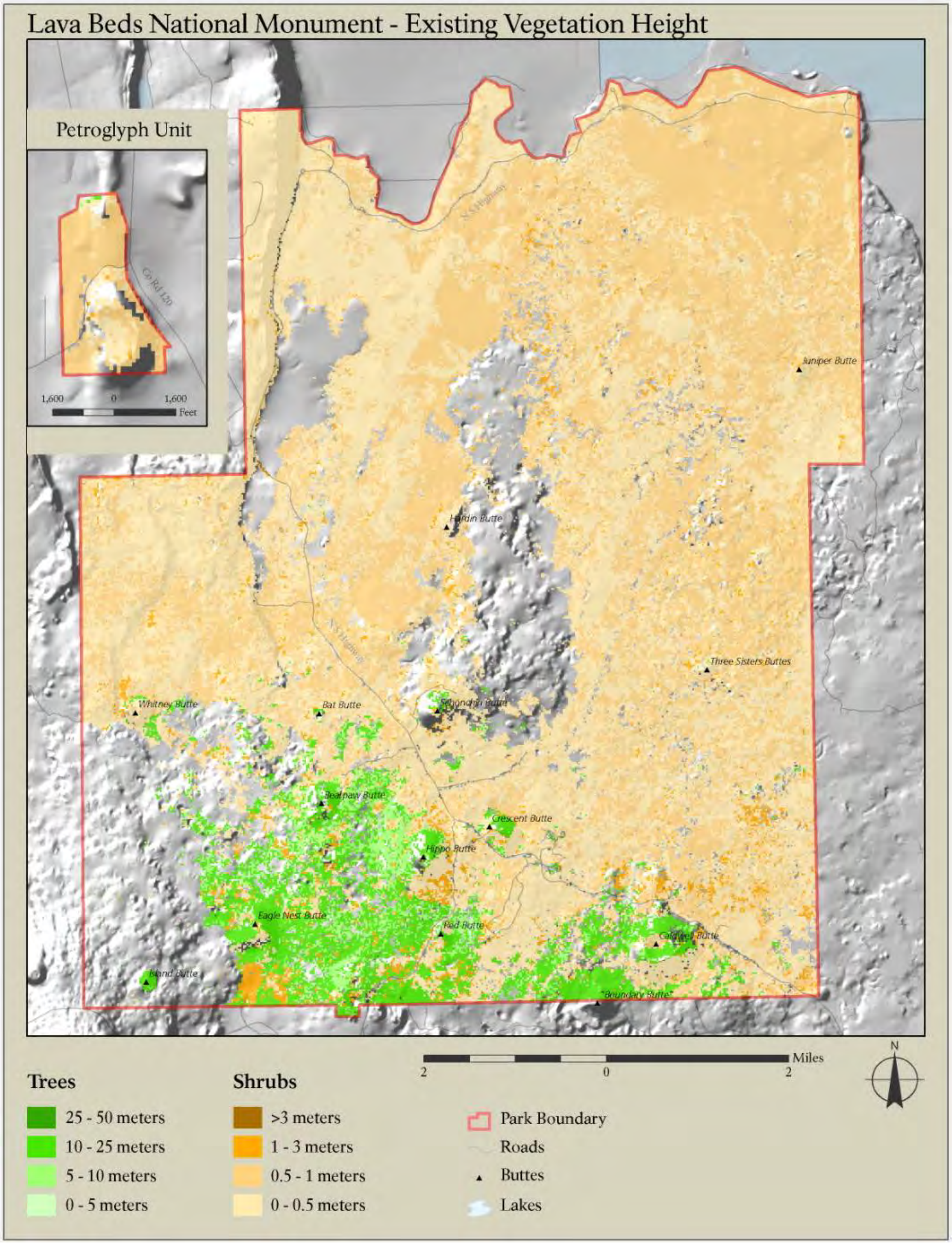


Figure C5. Mapped existing vegetation height of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

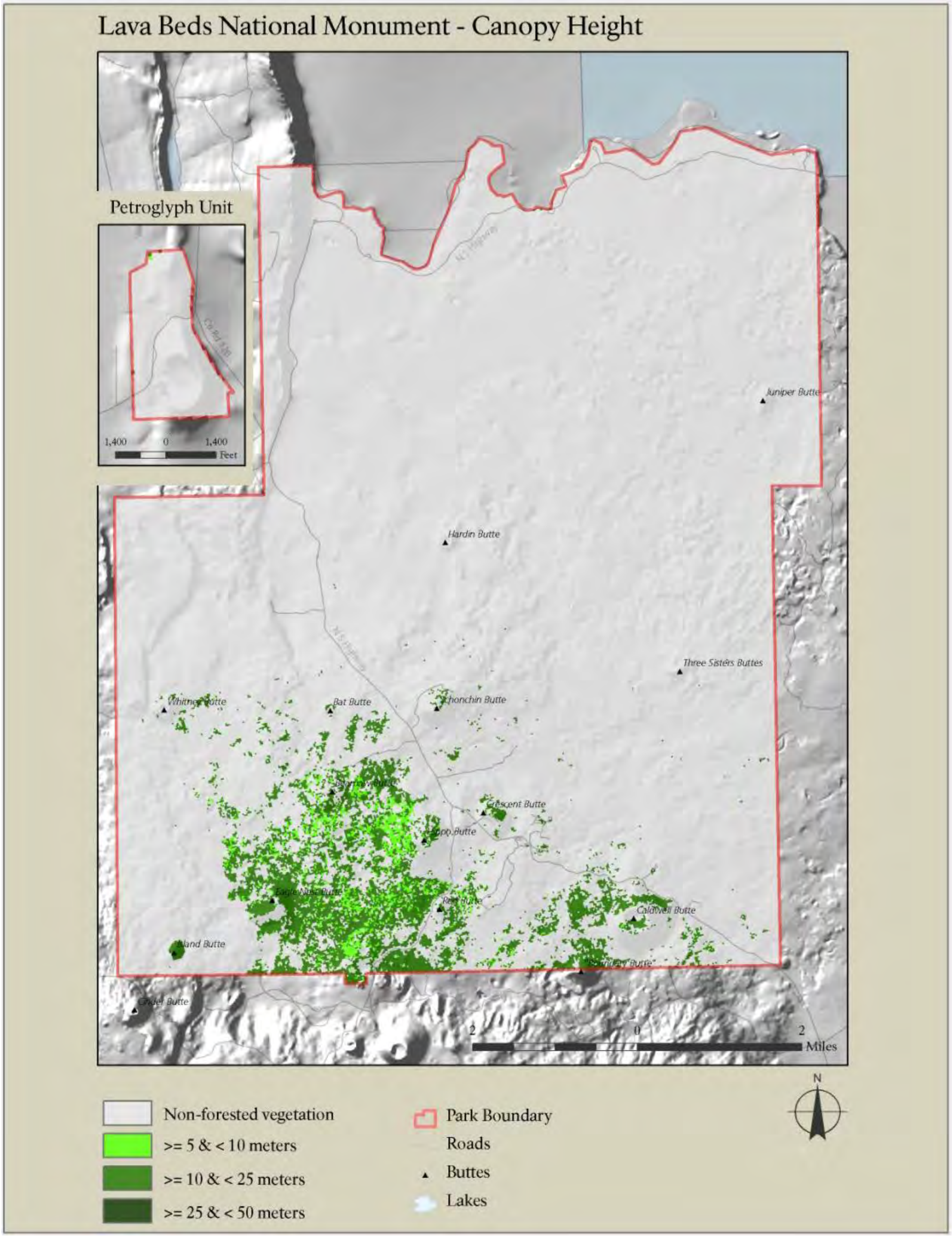


Figure C6. Mapped canopy height of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

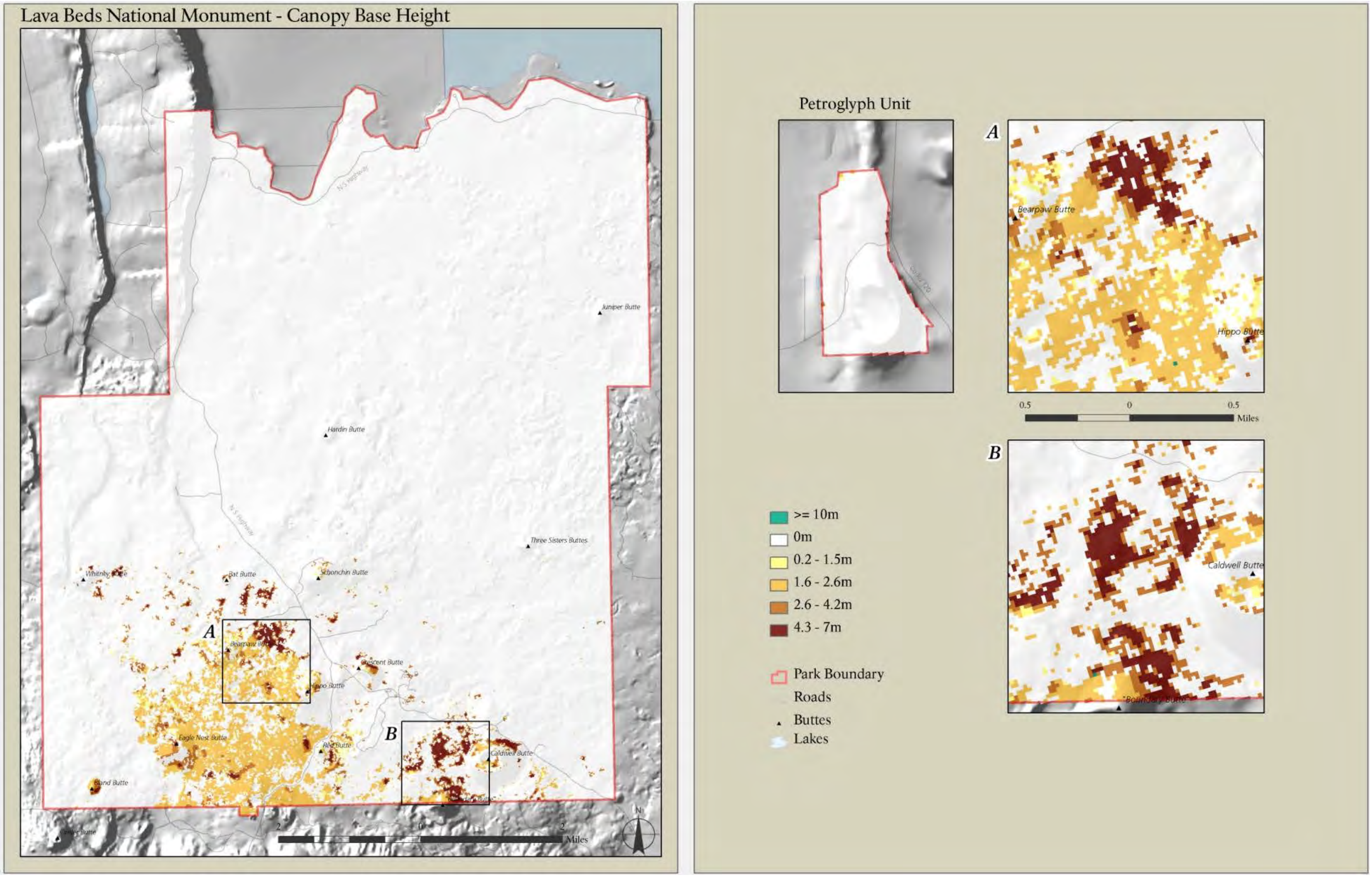


Figure C7. Mapped canopy base height of Lava Beds National Monument (LANDFIRE 2007). Scale: 30 meters. This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map describes the average height from the ground to the bottom of a forest stand's canopy; it is the lowest height at which there is a sufficient amount of forest canopy fuel to propagate fire vertically into the canopy. There is no universally accepted, empirically-derived definition of canopy base height.

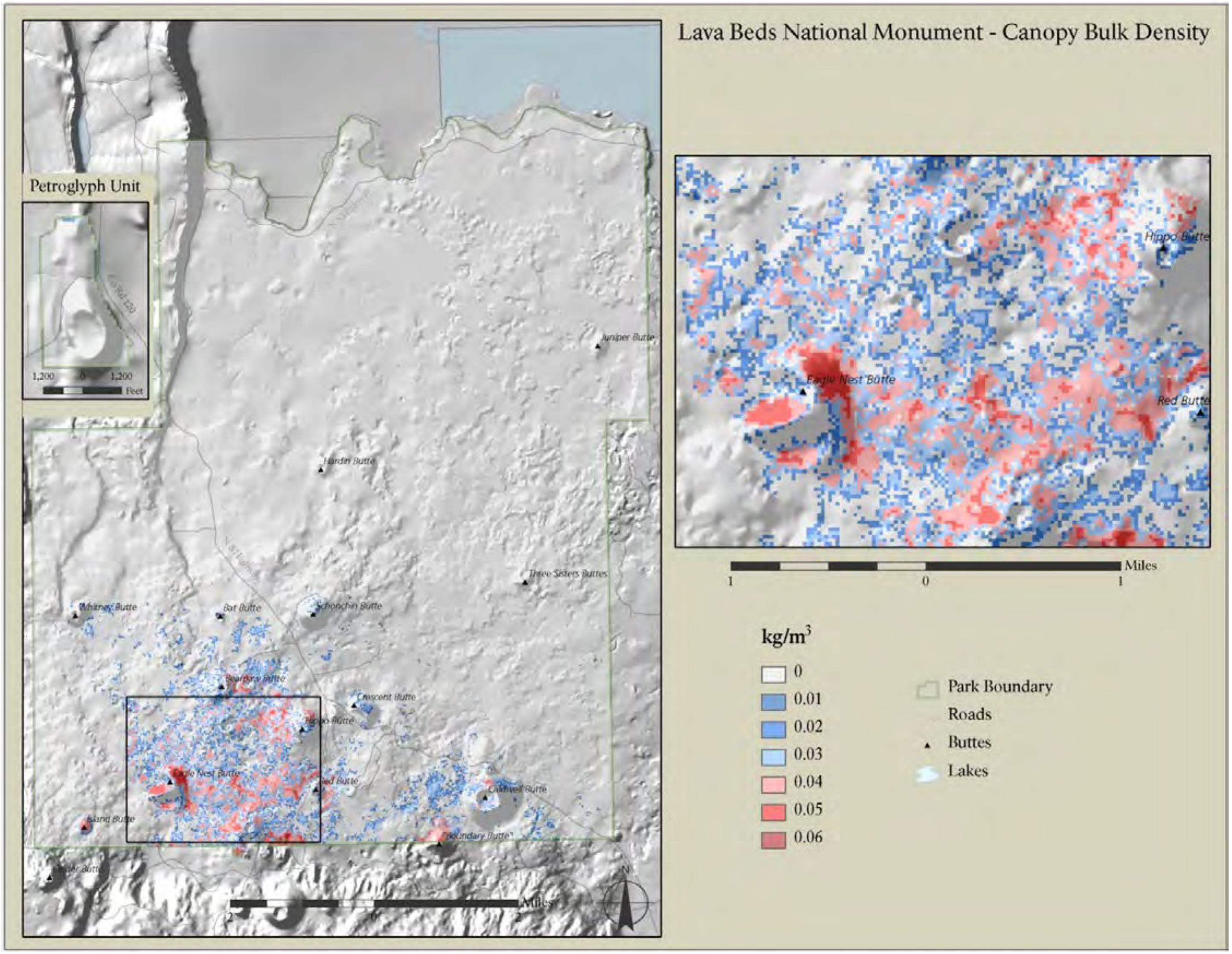


Figure C8. Mapped canopy bulk density of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

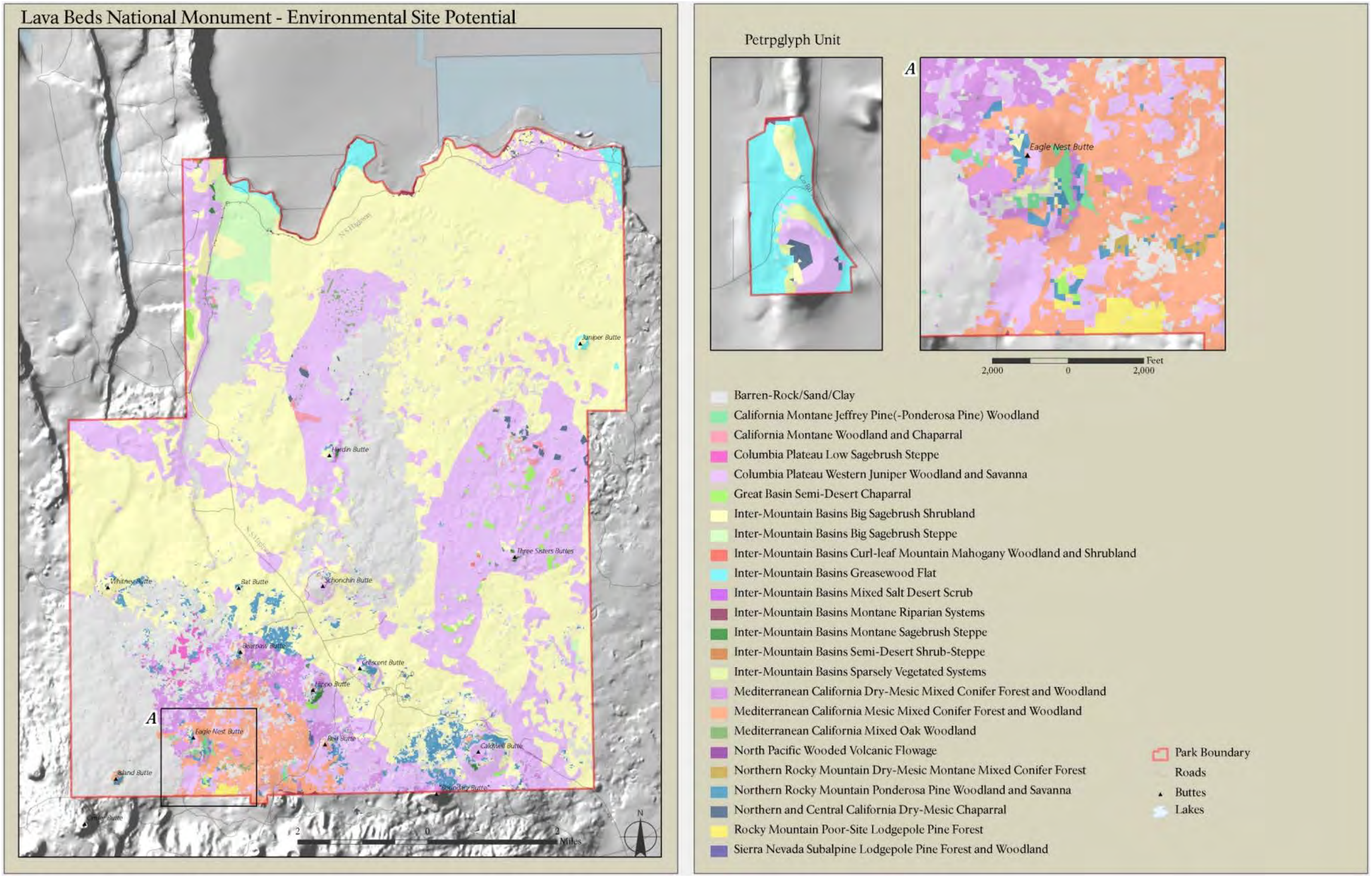


Figure C9. Mapped environmental site potential of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

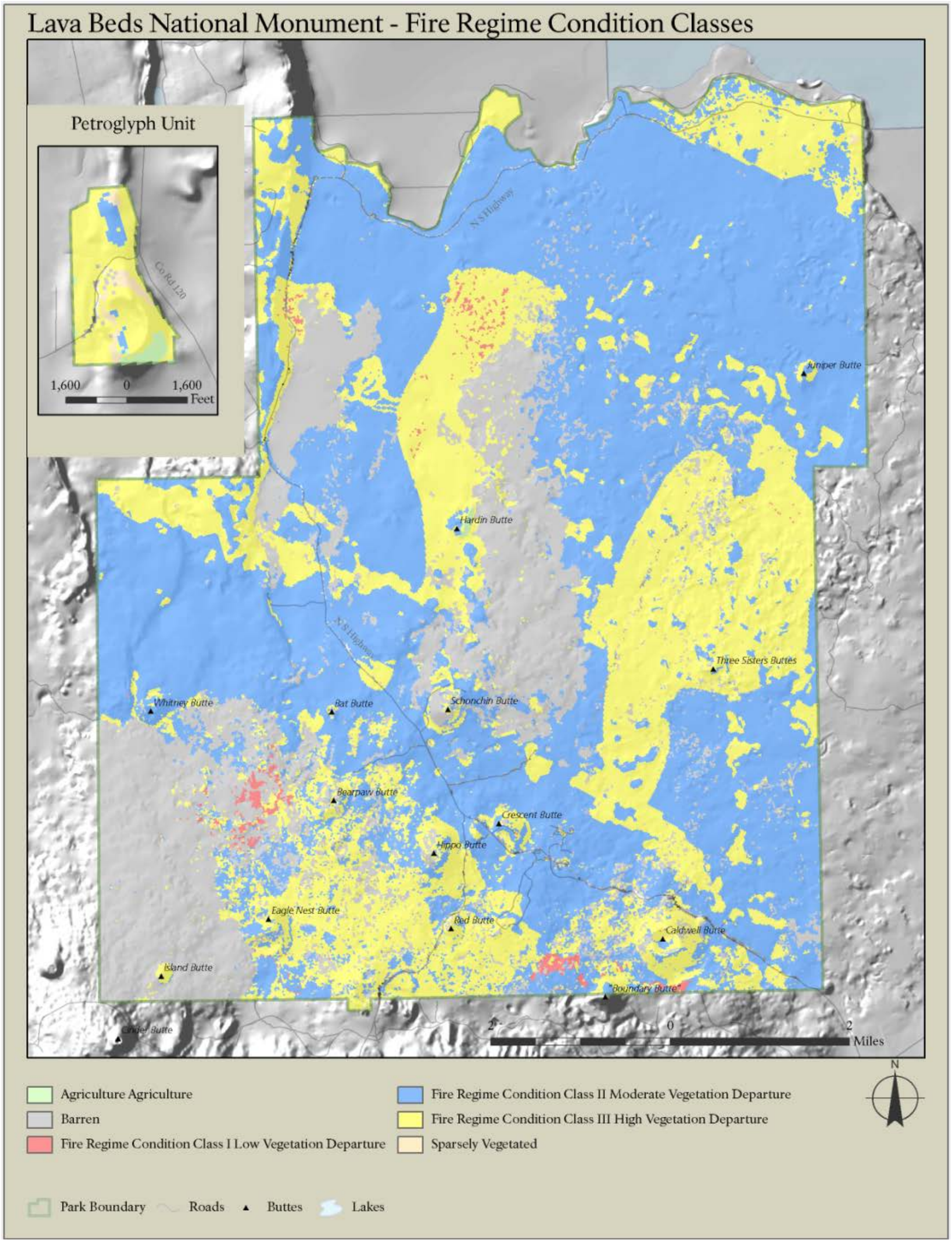


Figure C10. Mapped fire regime condition classes of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray fuel, fuel arrangement, or vegetation flammability. The map was based on rough estimates of the level to which fire frequencies have departed from “natural” fire frequencies. FRCC is also not a measure of fire risk or hazard. Increasing FRCC may lead to either more or less severe fire. Nonetheless, FRCC may be useful to identify where fire should be allowed to burn. The natural fire regime of every ecosystem falls into only five classes for determining departure, but the fire regimes of this park do not fit this classification.

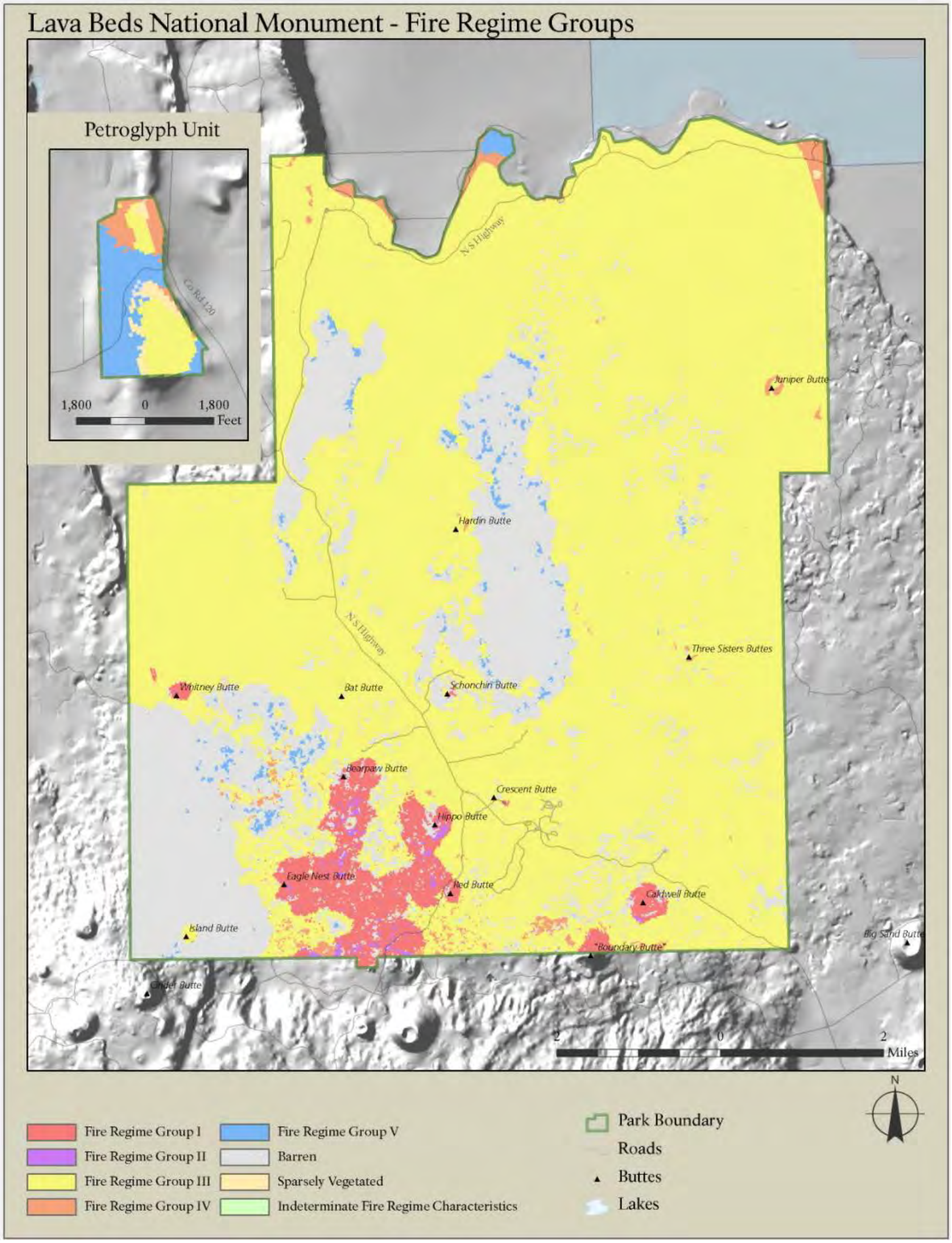


Figure C11. Mapped fire regime groups of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray fuel, fuel arrangement, or vegetation flammability.

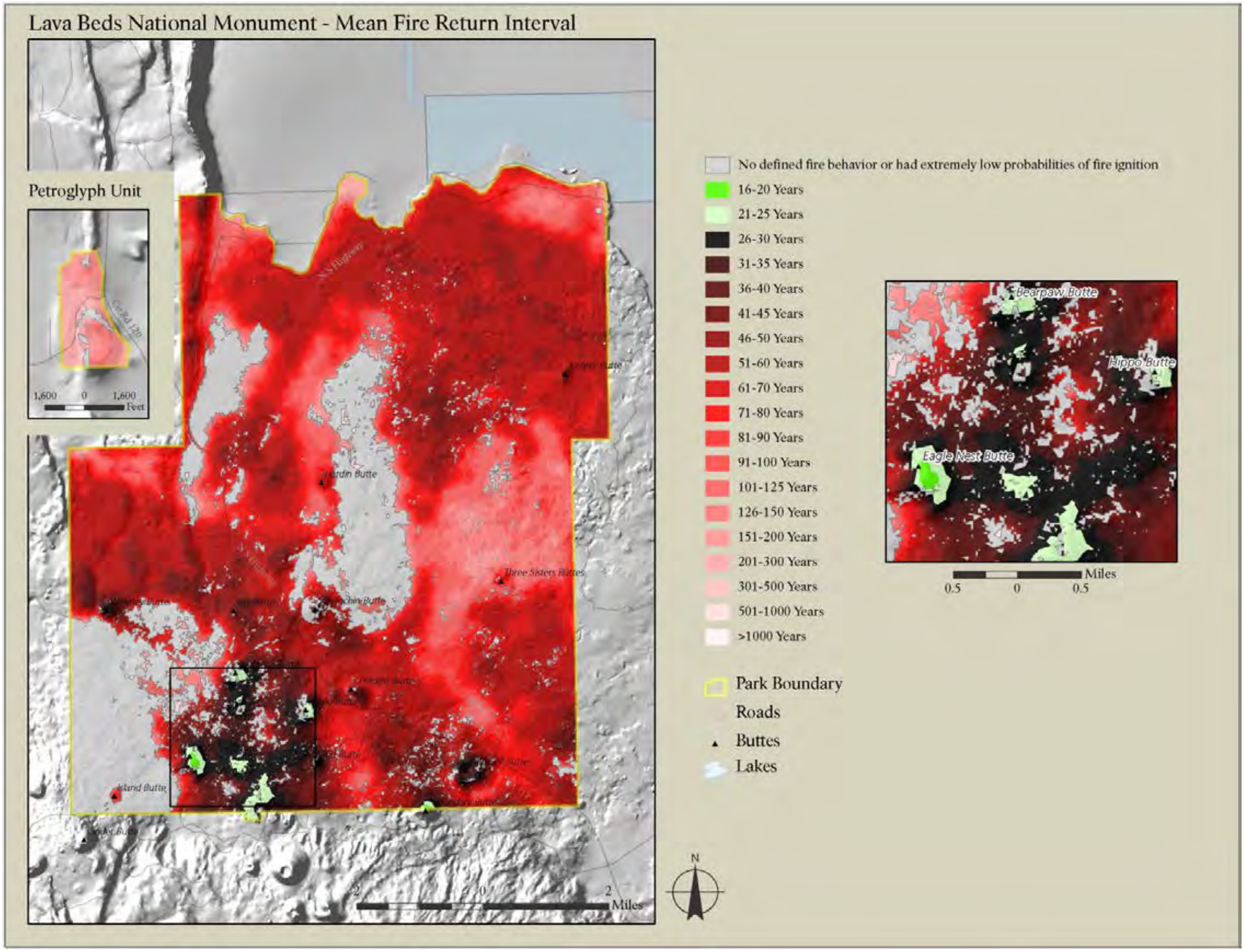


Figure C12. Mapped mean fire return interval of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray fuel, fuel arrangement, or vegetation flammability.

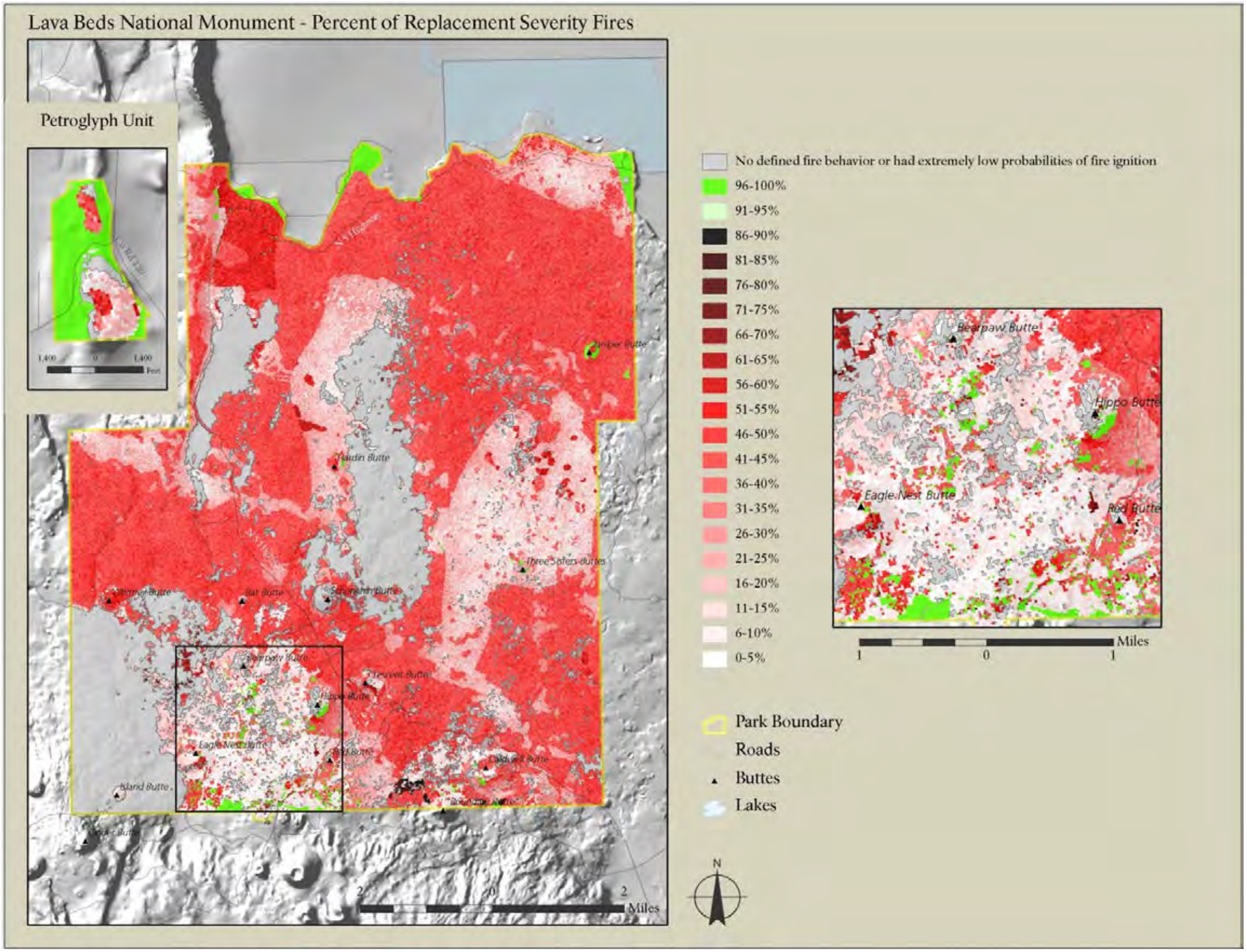


Figure C13. Mapped percent of replacement severity fires of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray fuel, fuel arrangement, or vegetation flammability.

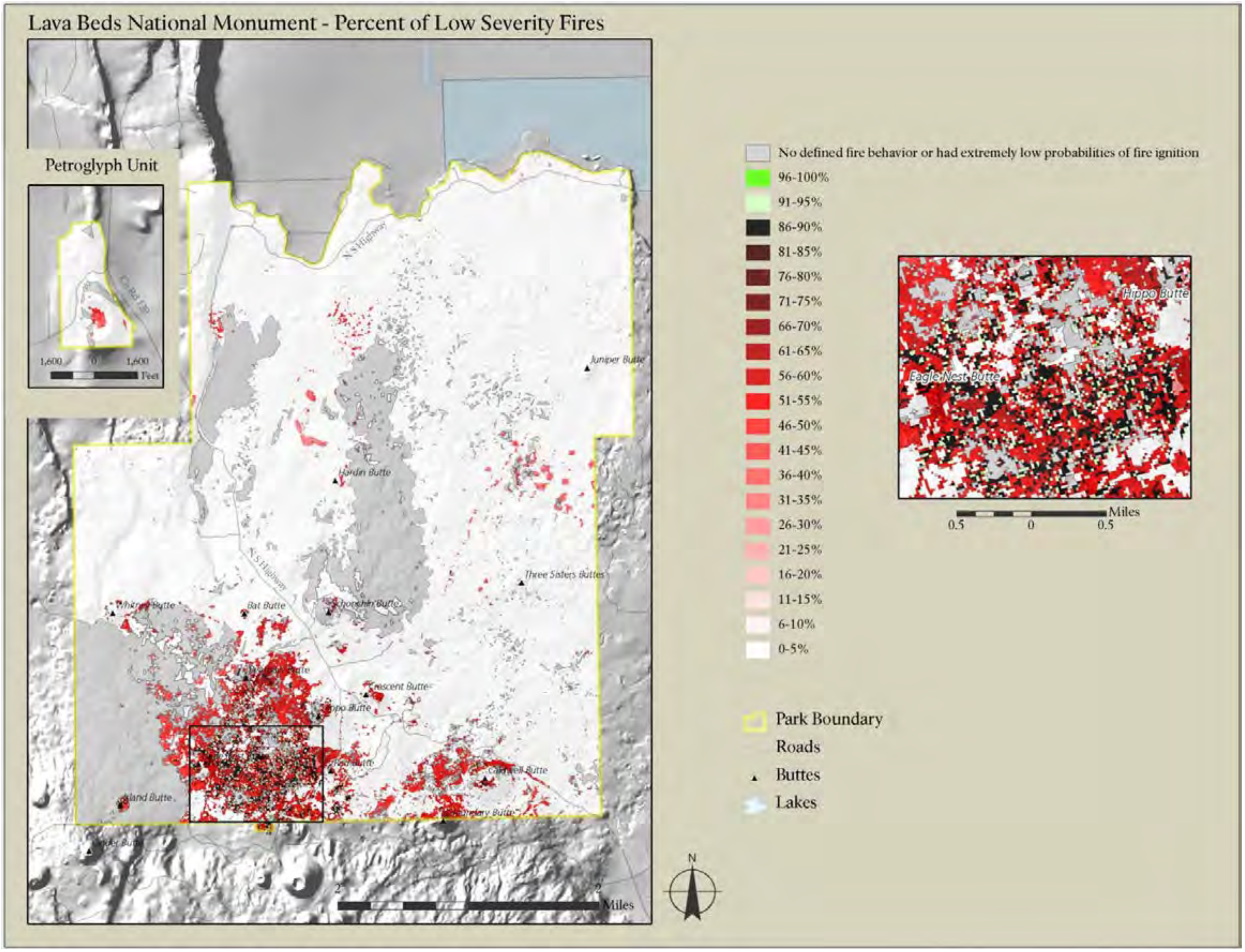


Figure C14. Mapped percent of low severity fires of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray fuel, fuel arrangement, or vegetation flammability.

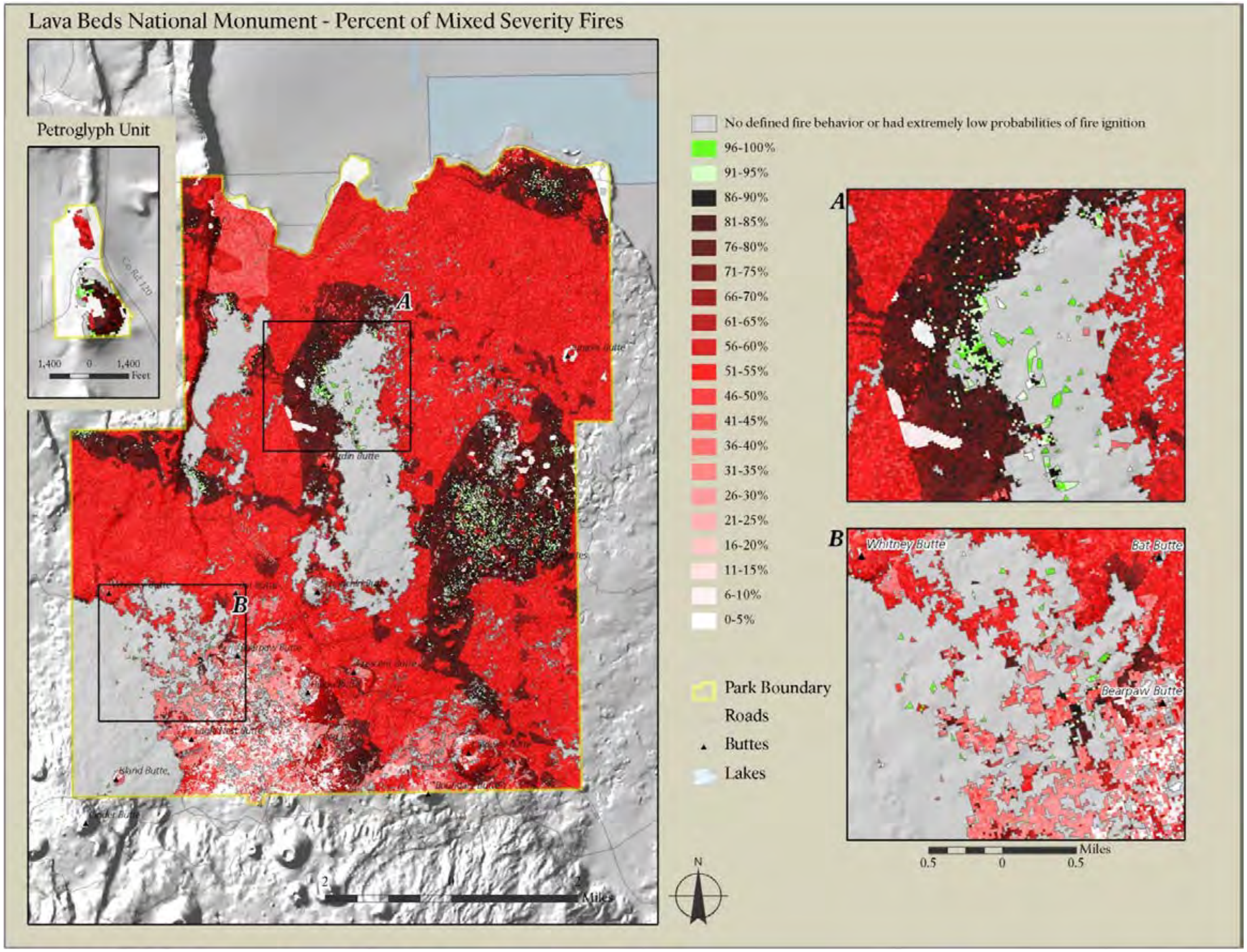


Figure C15. Mapped percent of mixed severity fires of Lava Beds National Monument (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray fuel, fuel arrangement, or vegetation flammability.

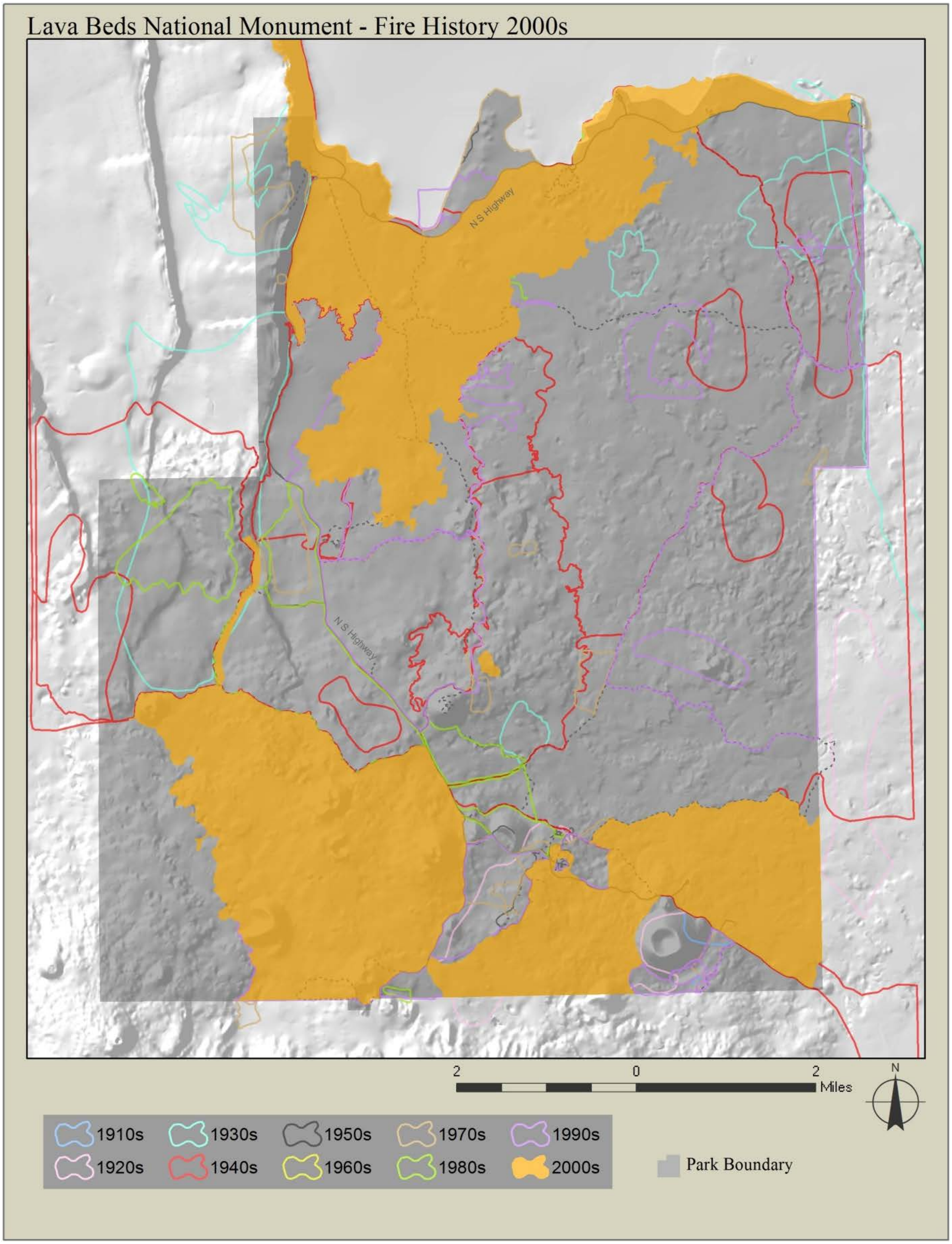


Figure C16. Mapped fire history of Lava Beds National Monument (LANDFIRE 2008).

Appendix D. Vertebrate Species Records From the Lava Beds Wildlife Observations Database

Note: The records in the following tables were not collected systematically and their accuracy has not been verified. Some records may have come from areas near but not in the monument. These lists are not comprehensive.

Table D1. Incidental observations of amphibians and reptiles, June 1960 to July 2012.

Note: The records in the following table were not collected systematically and their accuracy has not been verified. Some records may have come from areas near but not in the monument. These lists are not comprehensive.

Species	Earliest Date	Most Recent Date	# of reports	Maximum Count
AMPHIBIANS				
Foothill Yellow-legged Frog	18-Nov-92	18-Nov-92	2	1
Pacific Treefrog	15-Aug-63	1-Apr-11	17	12
Rough-skinned Newt	23-Mar-03	23-Mar-03	1	1
Western Toad	29-Jul-71	11-May-05	6	1
REPTILES				
Garter Snake	3-May-98	2-Oct-07	7	1
Gopher Snake	9-Apr-61	8-Jul-12	65	1
Night Snake	23-Jun-67	24-Jun-09	34	1
Northern Alligator Lizard	27-Jun-64	21-May-09	8	1
Northern Rubber Boa	19-Jun-60	30-Jul-09	78	1
Racer	3-Aug-60	23-May-12	27	3
Ringneck Snake	7-Sep-68	7-Sep-68	2	1
Striped Whipsnake	7-Aug-60	5-Sep-95	23	1
Western Fence Lizard	6-Aug-62	20-Aug-09	13	10
Western Rattlesnake	24-Jul-60	27-Jun-12	176	3
Western Skink	25-Aug-62	9-Jun-10	45	1
Western Whiptail	17-Jul-93	17-Jul-93	2	1
Western Yellow-bellied Racer	26-May-62	1-Oct-11	2	1

Table D2. Incidental observations of mammals, June 1943 to July 2012.

Note: The records in the following table were not collected systematically and their accuracy has not been verified. Some records may have come from areas near but not in the monument. These lists are not comprehensive.

Species	Earliest Date	Most Recent Date	# of reports	Maximum Count
American Badger	11-Oct-60	23-Jul-12	56	3
American Marten	9-Aug-65	9-Aug-65	1	1
American Pika	15-May-60	20-Jun-12	117	3
Belding's Ground Squirrel	24-May-60	5-Jun-08	32	15
Big Brown Bat	17-Jul-63	21-Jul-71	3	1
Bighorn Sheep	17-Aug-72	10-Oct-73	25	17
Black Bear	26-May-85	3-Jun-05	11	1
Black-tailed Jackrabbit	22-Sep-60	10-Oct-09	81	28
Bobcat	19-May-60	25-Jul-12	351	5
Bushy-tailed Woodrat	29-May-61	25-Aug-09	29	6
California Ground Squirrel	20-Jul-61	15-Sep-04	53	8
California Kangaroo Rat	13-Dec-07	13-Dec-07	2	1
California Mole	31-Oct-70	14-Jun-92	7	1
California Myotis	12-Jul-63	12-Jul-63	1	1
Canyon Mouse	27-Jul-81	27-Jul-81	4	4
Cougar	1-Jul-60	8-Apr-11	166	4
Coyote	25-Jun-43	23-Jul-12	403	8
Douglas Squirrel	7-Jul-61	6-May-08	14	3
Dusky-footed Woodrat	28-Oct-61	8-Jul-12	20	3
Elk (Wapiti)	25-Jun-06	19-Feb-10	6	30
Fringed myotis	25-Apr-04	25-Apr-04	1	1
Golden-mantled Ground Squirrel	11-Nov-61	22-May-94	35	7
Gray Fox	28-Aug-75	13-Jul-12	19	2
Great Basin Pocket Mouse	6-Apr-62	27-Jul-81	6	3
Heermann Kangaroo Rat	6-Feb-92	20-Aug-92	3	5
Kangaroo Rat	31-May-60	15-Mar-08	25	40

Species	Earliest Date	Most Recent Date	# of reports	Maximum Count
Kit Fox	31-May-88	29-Jun-89	3	1
Least Chipmunk	6-Apr-62	11-Jul-04	11	4
Little Brown Myotis	10-Jul-73	18-Aug-89	3	4
Long-eared Bat	7-Aug-02	27-Mar-03	2	1
Long-tailed Weasel	12-Jun-60	2-Dec-08	61	3
Mountain Cottontail	22-Sep-60	19-Dec-04	83	14
Mountain Goat	1-Jan-70	1-Jan-70	2	1
Mule Deer	2-May-60	27-Jun-12	442	52
Pallid Bat	17-Jul-63	23-Jul-70	3	300
Pinyon Mouse	5-Apr-62	27-Jul-81	6	2
Porcupine	27-Jun-60	29-Oct-97	179	7
Pronghorn (Antelope)	5-May-60	13-May-11	357	150
Raccoon	11-Sep-63	2-Aug-11	33	5
Red Fox	24-Sep-80	26-Mar-10	7	4
Ringtail	12-Aug-91	12-Aug-91	3	1
River Otter	10-Dec-91	6-Jun-06	4	3
Short-tailed Weasel	25-Aug-92	18-Jun-09	8	1
Small-footed Myotis	19-Jul-63	19-Jul-63	1	1
Spotted Skunk	11-Oct-61	2-Sep-97	11	2
Striped Skunk	18-Aug-60	16-May-10	23	1
Townsend's Big-eared Bat	22-Jun-61	1-Jul-08	21	300
Townsend's Chipmunk	5-Aug-86	6-Aug-86	4	4
Trowbridge Shrew	16-May-62	29-Jul-81	5	1
Western Gray Squirrel*	*	*	*	*
Western Harvest Mouse	27-Jul-81	28-Jul-81	4	2
White-footed Deer Mouse	16-Feb-62	3-Feb-68	4	50
Yellow Pine Chipmunk	7-Nov-61	1-Oct-04	22	13
Yellow-bellied Marmot	4-Mar-61	13-Nov-07	132	10

* recorded by remote wildlife camera

Table D3. Incidental observations of birds, February 1952 to July 2012 (209 species).

Note: The records in the following table were not collected systematically and their accuracy has not been verified. Some records may have come from areas near but not in the monument. These lists are not comprehensive.

Species	Earliest Year	Most Recent Year	# of reports	Maximum Count
Allen's Hummingbird	30-Jun-68	8-Jul-70	5	1
American Bittern	29-Jul-72	29-Jul-72	1	1
American Coot	8-Apr-62	17-Dec-72	5	4
American Kestrel	15-Jul-70	16-Jul-12	23	5
American Robin	5-Jun-61	23-Jan-07	36	20
American White Pelican	11-Apr-62	8-Jul-92	6	50
American Wigeon	31-Aug-72	20-Sep-97	4	3
Anna's Hummingbird	20-Jul-70	16-Apr-10	15	1
Ash-throated Flycatcher	25-Jun-60	22-Jun-92	26	2
Bald Eagle	9-Nov-60	13-Jun-12	233	20
Bank Swallow	31-Jul-72	31-Jul-72	3	1
Barn Owl	26-Nov-60	25-Jun-12	81	20
Barn Swallow	19-Aug-62	22-May-98	14	5
Belted Kingfisher	18-Dec-72	18-Dec-72	2	1
Bewick's Wren	8-Feb-53	23-Jan-07	17	3
Black Swift	7-Jul-72	7-Jul-72	2	1
Black Tern	19-Jul-72	1-May-98	8	200
Black-backed Woodpecker	14-Apr-98	14-Dec-07	12	2
Black-billed Magpie	5-Jun-57	7-Jan-08	50	10
Black-capped Chickadee	21-May-89	21-May-89	1	1
Black-chinned Hummingbird	6-Jun-87	6-Jun-87	1	1
Black-chinned Sparrow	31-May-91	31-May-91	2	1
Black-crowned Night Heron	27-Jun-72	17-Dec-72	2	3
Black-headed Grosbeak	7-Aug-73	23-May-09	9	3
Black-necked Stilt	27-Jul-72	31-Jul-72	6	26
Black-throated Gray Warbler	20-Aug-62	20-Aug-62	3	1

Species	Earliest Year	Most Recent Year	# of reports	Maximum Count
Black-throated Sparrow	22-Jun-68	2-Jul-07	6	2
Blue-gray Gnatcatcher	25-Sep-62	5-May-98	17	5
Blue-winged Teal	22-Jun-72	9-Jun-87	3	2
Bohemian Waxwing	25-Feb-87	17-Feb-97	4	20
Bonaparte's Gull	23-Apr-63	23-Apr-63	1	2
Brant	16-Apr-63	16-Apr-63	1	1
Brewer's Blackbird	28-Feb-52	8-Jul-92	42	60
Brewer's Sparrow	29-Jul-62	29-Jul-62	2	1
Broad-tailed Hummingbird	15-Jun-70	12-May-98	4	2
Brown Creeper	20-Oct-63	24-Mar-65	4	1
Brown-headed Cowbird	28-May-62	2-May-96	11	15
Bufflehead	29-Sep-97	20-Oct-97	4	10
Bullock's Oriole	15-May-61	20-May-12	32	6
Burrowing Owl	1-Jul-73	2-Mar-04	14	2
Bushtit	28-Jun-52	6-Apr-04	28	100
California Quail	24-May-60	1-Nov-94	154	131
California Towhee	4-Jul-85	20-Dec-02	13	1
Calliope Hummingbird	19-Jun-66	26-Jun-07	11	2
Canada Goose	14-Feb-61	22-Apr-10	14	999
Canvasback	11-Apr-62	11-Apr-62	2	0
Canyon Towhee	28-Nov-90	28-Nov-90	2	3
Canyon Wren	4-Oct-52	16-Jul-09	46	6
Caspian Tern	23-Apr-63	19-Jun-72	3	3
Cassin's Finch	4-Apr-63	17-Aug-92	16	13
Cedar Waxwing	6-Jun-59	20-Feb-09	33	100
Chipping Sparrow	22-Apr-63	10-Aug-73	8	3
Chukar	14-Apr-60	9-Jul-93	14	25
Clark's Grebe	20-Sep-97	20-Sep-97	2	2
Clark's Nutcracker	5-Jul-58	11-May-10	28	8

Species	Earliest Year	Most Recent Year	# of reports	Maximum Count
Cliff Swallow	1-Jun-62	30-Jun-04	9	300
Common Loon	21-May-63	21-May-63	2	1
Common Merganser	9-Jun-87	9-Jun-87	1	1
Common Nighthawk	7-May-60	16-Jul-09	33	8
Common Poorwill	25-Jun-60	26-May-09	19	1
Common Raven	29-Aug-52	12-Apr-06	82	9
Common Redpoll	28-Feb-89	28-Feb-89	2	2
Cooper's Hawk	22-Apr-63	1-Oct-04	13	2
Costa's Hummingbird	10-May-92	1-Jun-00	13	1
Dark-eyed Junco	24-May-60	1-Oct-04	22	40
Double-crested Cormorant	23-Apr-63	28-Apr-88	5	150
Downy Woodpecker	23-Jul-96	23-Jul-96	2	1
Dusky Flycatcher	12-Aug-72	12-Aug-72	3	1
Eurasian Collared-Dove	17-Jul-07	17-May-11	5	1
European Starling	26-Apr-65	30-Nov-66	3	10
Evening Grosbeak	10-Apr-61	19-Apr-11	18	22
Ferruginous Hawk	19-Feb-98	3-Aug-98	4	2
Flammulated Owl	22-May-03	22-May-03	2	1
Forster's Tern	25-Apr-62	19-Jul-72	5	50
Fox Sparrow	15-Oct-92	26-Sep-03	6	1
Gadwall	3-Jul-62	3-Jul-62	1	26
Golden Eagle	31-Jul-60	25-Jul-12	89	4
Golden-crowned Kinglet	23-Apr-63	18-Nov-93	3	9
Golden-crowned Sparrow	3-May-91	20-Sep-97	8	3
Gray Flycatcher	20-Aug-62	20-Aug-62	2	1
Great Blue Heron	14-Feb-61	14-Dec-92	8	7
Great Egret	7-Jul-72	20-Sep-97	5	40
Great Grey Owl	2-Aug-92	2-Aug-92	2	1
Great Horned Owl	22-Sep-60	3-Jul-12	61	5

Species	Earliest Year	Most Recent Year	# of reports	Maximum Count
Greater White-fronted Goose	30-Sep-97	20-Oct-97	4	999
Greater Yellowlegs	8-Apr-63	8-Jul-72	3	30
Green-tailed Towhee	26-Jun-72	30-Jun-96	10	3
Gyrfalcon	25-May-87	9-Nov-89	4	1
Hairy Woodpecker	25-Aug-52	6-Aug-72	9	2
Hammond's Flycatcher	20-Sep-97	20-Sep-97	2	1
Harris' Sparrow	27-Mar-95	27-Mar-95	2	1
Hermit Thrush	21-Oct-97	21-Oct-97	2	2
Hermit Warbler	20-Aug-62	12-Aug-72	6	2
Horned Grebe	15-Apr-63	15-Apr-63	1	2
Horned Lark	16-Dec-52	1-Feb-08	20	70
House Finch	23-Apr-63	8-Jul-92	7	4
House Sparrow	22-Jul-72	22-Jul-72	2	3
House Wren	24-Apr-61	24-Apr-61	3	1
Killdeer	3-Jul-62	28-Jul-73	3	5
Lark Sparrow	8-Apr-63	17-Jun-98	11	23
Lazuli Bunting	30-Jun-65	30-May-09	20	2
Least Sandpiper	19-Jul-72	22-Apr-98	4	20
Lesser Goldfinch	16-Sep-60	21-Jul-72	8	2
Lesser Scaup	17-Dec-72	17-Dec-72	2	3
Lewis's Woodpecker	11-May-62	10-Jul-07	57	3
Lincoln's Sparrow	7-Jan-04	7-Jan-04	2	1
Loggerhead Shrike	9-Apr-62	18-Nov-93	41	2
Long-billed Curlew	14-Jul-71	14-Jul-71	2	3
Long-billed Dowitcher	31-Jul-68	8-Jul-72	4	10
Long-eared Owl	2-Mar-04	2-Mar-04	2	1
MacGillivray's Warbler	3-Aug-66	17-Aug-72	8	1
Mallard	8-Apr-62	20-Oct-97	4	999
Marbled Godwit	19-Jul-72	19-Jul-72	2	50

Species	Earliest Year	Most Recent Year	# of reports	Maximum Count
Marsh Wren	20-Sep-97	20-Sep-97	2	1
Merlin	12-Aug-66	4-Nov-08	8	1
Mountain Bluebird	12-Mar-53	17-Jul-11	36	20
Mountain Chickadee	23-Apr-63	29-Apr-98	26	4
Mountain Quail	15-Aug-61	28-Aug-07	41	30
Mourning Dove	5-May-60	16-Jul-12	16	115
Nashville Warbler	5-Aug-71	17-Aug-72	12	1
Northern Flicker	1-Apr-62	15-Oct-07	25	2
Northern Goshawk	1-Oct-75	2-Feb-07	17	1
Northern Harrier	5-Sep-60	6-Oct-03	35	5
Northern Mockingbird	24-Apr-68	17-Oct-97	6	2
Northern Pygmy-owl	8-Oct-65	22-Jan-07	22	1
Northern Saw-whet Owl	15-Oct-70	14-Mar-04	22	1
Northern Shoveler	11-Apr-62	20-Oct-97	4	30
Northern Shrike	13-Nov-70	12-Feb-08	15	1
Olive-sided Flycatcher	5-Jul-58	27-Jul-62	3	1
Orange-crowned Warbler	3-Sep-68	20-Sep-97	7	5
Osprey	13-Sep-98	13-Sep-98	2	1
Pacific (Winter) Wren	14-Mar-04	14-Mar-04	2	1
Peregrine Falcon	7-Apr-62	4-Jul-08	28	2
Pied-billed Grebe	28-Jul-72	20-Sep-97	4	10
Pileated Woodpecker	3-May-05	3-May-05	2	1
Pine Grosbeak	10-Mar-89	20-May-98	4	2
Pine Siskin	7-Jun-92	26-Nov-92	6	30
Pinyon Jay	15-Jan-53	4-May-08	76	100
Plain Titmouse	17-Dec-52	13-Feb-06	29	3
Prairie Falcon	7-Jan-62	28-Mar-08	119	7
Purple Finch	27-Apr-62	29-Jul-92	10	6
Purple Martin	14-May-57	17-Apr-08	63	100

Species	Earliest Year	Most Recent Year	# of reports	Maximum Count
Pygmy Nuthatch	3-Jan-53	18-Jun-00	12	20
Red Crossbill	5-Oct-62	19-May-09	34	25
Red Knot	5-May-71	5-May-71	2	1
Red-breasted Nuthatch	7-Sep-62	20-Oct-92	16	2
Red-breasted Sapsucker	31-May-61	6-May-03	21	1
Redhead	31-Aug-72	31-Aug-72	1	1
Red-naped Sapsucker	21-Sep-97	21-Sep-97	2	4
Red-shouldered Hawk	7-Aug-93	7-Aug-93	2	1
Red-tailed Hawk	10-May-60	21-Jul-11	92	8
Red-winged Blackbird	11-Apr-62	1-Jul-92	3	40
Ring-billed Gull	28-Jul-72	15-Jun-92	6	16
Ring-necked Pheasant	27-May-60	11-Jul-12	68	308
Rock Wren	15-May-57	10-Nov-02	24	8
Rough-legged Hawk	22-Mar-61	10-Apr-08	23	6
Ruby-crowned Kinglet	21-Apr-63	21-Apr-63	3	2
Ruffed Grouse	8-Aug-67	6-Aug-69	4	8
Rufous Hummingbird	18-Aug-62	19-Apr-98	24	4
Rufous-crowned Sparrow	18-May-67	18-May-67	2	1
Sage Grouse	18-Aug-60	11-Sep-08	31	10
Sage Thrasher	3-May-63	9-Feb-04	16	6
Sandhill Crane	19-Oct-87	12-Nov-10	8	106
Savannah Sparrow	8-Apr-63	8-Apr-63	1	2
Say's Phoebe	21-Apr-62	2-Mar-10	36	7
Sharp-shinned Hawk	9-Apr-62	21-Oct-03	11	2
Short-eared Owl	25-May-62	6-Feb-08	32	39
Snow Goose	15-Dec-60	29-Oct-03	10	999
Snowy Egret	20-Jul-72	20-Jul-72	1	1
Snowy Owl	28-Nov-66	28-Nov-66	2	1
Sooty (Blue) Grouse	10-Aug-60	18-Jun-11	35	5

Species	Earliest Year	Most Recent Year	# of reports	Maximum Count
Spotted Sandpiper	16-Jul-72	20-Sep-97	4	1
Spotted Towhee	24-May-60	14-Oct-94	27	2
Steller's Jay	20-Dec-52	1-Oct-04	20	5
Swainson's Hawk	10-Aug-60	12-Sep-01	8	1
Townsend's Solitaire	25-Oct-59	1-Oct-04	32	17
Townsend’s Warbler	20-Aug-68	20-Aug-68	3	1
Tree Swallow	2-May-61	23-Jun-72	8	10
Tricolored Blackbird	23-Apr-63	23-Apr-63	1	200
Tundra Swan	15-Dec-60	29-Oct-92	8	200
Turkey Vulture	26-Apr-62	13-Mar-07	27	30
Varied Thrush	3-Nov-60	28-Oct-02	14	1
Vaux's Swift	8-Sep-70	8-Sep-70	2	6
Vesper Sparrow	9-Apr-62	17-Apr-06	6	50
Violet-green Swallow	14-May-57	29-Jun-01	17	10
Warbling Vireo	22-Aug-70	22-Aug-70	3	1
Western Bluebird	9-Apr-57	3-May-10	36	20
Western Grebe	11-Apr-62	11-Apr-62	1	10
Western Kingbird	30-Jun-52	19-Apr-09	24	3
Western Meadowlark	14-Apr-62	23-Mar-10	17	15
Western Sandpiper	20-Aug-68	19-Jul-72	4	100
Western Scrub-Jay	13-Apr-61	4-Apr-08	61	10
Western Tanager	22-May-60	18-Jun-12	33	5
Western Wood-Pewee	16-Aug-68	6-Feb-89	9	1
White-breasted Nuthatch	19-Nov-60	23-Sep-10	12	20
White-crowned Sparrow	12-Apr-62	13-Sep-07	19	25
White-headed Woodpecker	19-Jun-72	3-Nov-02	9	4
White-throated Sparrow	28-Apr-70	28-Apr-70	1	1
White-throated Swift	14-Jun-98	22-Apr-10	9	13
Wild Turkey	7-Aug-08	13-May-10	10	8

Species	Earliest Year	Most Recent Year	# of reports	Maximum Count
Willet	16-Apr-63	16-Apr-63	1	0
Williamsons Sapsucker	1-Oct-62	3-Nov-02	9	1
Wilson's Phalarope	19-Jul-72	29-Jul-72	4	75
Wilson's Warbler	3-Aug-73	9-May-07	8	2
Wood Duck	19-Apr-98	5-Apr-07	4	2
Yellow Warbler	20-Aug-62	17-Jun-08	24	2
Yellow-headed Blackbird	15-May-61	22-Jul-92	8	30
Yellow-rumped Warbler	26-Apr-62	2-Apr-08	41	8

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